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Physicists and the first computing revolution

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The noteworthy role physicists played in the computing revolutions triggered by the invention of the transistor, or the World Wide Web, is well known. But less so is their influential part in the early days of computing. This is the account of how physics and computing started a long-lasting affair — a story with unexpected parallels with the current revolution in AI.

Fig. 1 | IBM punch-card accounting machines used at Los Alamos during the Manhattan Project. At the back there are the IBM 601 multipliers with and without divide units, at the front there is the duplicating keypunch. The photograph was taken some time after November 1944. Image courtesy of Los Alamos National Laboratory.

In less than two years, calculations that had not been thought possible before became routine, the demand for computing exploded and previously essential jobs become obsolete. Although it might sound familiar, this scenario is not what you think. It's the early 1940s and the first computing revolution is underway.

Unlike later revolutions, such as the invention of the personal computer or the Internet, this one has been obscured by the shadows of the World War II. Yet, its impact on science has perhaps been most dramatic, ushering it into the computational age. The first computing revolution was also inevitable, in a similar way to the current state of affairs. And as revolutions always go, things had been brewing for a while.

Beginnings at Columbia

Pupin Hall, a red brick building with a distinctive astronomical observatory dome on top, still houses the physics and astronomy departments of Columbia University in Manhattan, New York City. An unlikely location for subversive undertakings, it is nonetheless the place where in the 1930s seemingly unrelated activities that would contribute to a computing revolution were taking place.

On his way from the Pupin Hall top-floor Rutherford Observatory, a young astronomy professor, Wallace Eckert, would often wander in to peek at the punch-card machines at the Columbia Statistical Bureau. These had been obtained a few years earlier by Benjamin D. Wood, head of Columbia University's Bureau of Collegiate Educational Research, from Thomas J. Watson Sr, president of IBM, to automate hand-scoring of examination papers[1]. Having heard of a previous successful attempt at using punch-card methods to work out astronomical tables and that IBM had new business accounting machines including a multiplying punch, Eckert convinced Watson to donate some IBM accounting machines especially modified to do direct interpolation.

The machines were delivered to the attic of Pupin Hall in 1933[1] and the next year Eckert opened a new laboratory – possibly the world's first scientific computing lab. Eckert played with the machines and came up with a control box with settings that told the different machines what they should be doing at a given time: a rudimentary form of mechanical programming. Then, for the first time, it was possible to perform general operations completely automatically and Eckert was able to solve the differential equations of planetary motion by numerical integration. Astronomers got very interested. So, in 1937, renamed the Thomas J. Watson Astronomical Computing Bureau, the lab became more broadly available to astronomers as a joint enterprise of the American Astronomical Society, the Department of Astronomy at Columbia and IBM.

Branching out

By the late 1930s, the attic of Pupin Hall was attracting all sorts of scientists, curious about the machines, who would become computing pioneers. One of the visitors was physicist Howard Aiken who was looking for a way to solve differential equations for his PhD thesis. Eckert advised him to talk to IBM, which Aiken did. The result was the development of a general-purpose electromechanical machine, the IBM Automatic Sequence Controlled Calculator, which was later renamed Harvard Mark I as it was installed at Harvard in February 1944.

While Eckert was busy with astronomical calculations, 100 miles south at the University of Pennsylvania Moore School of Electrical Engineering another physicist, John Mauchly, suggested that the calculating speed of mechanical devices would be greatly enhanced by using electronic components. He wrote a proposal in an internal memo in August 1942, and less than a year later the Moore School was approached by the Army to build such a machine. Work began promptly under the code name 'Project PX'.

Columbia physicists were also up to something in the basement of Pupin Hall, which hosted a cyclotron. That's where the first nuclear fission experiment in the United States[2] was conducted in January 1939 by Herbert Anderson and others, including Enrico Fermi, who had just arrived from Italy and taken a position at Columbia University earlier that month. That was the first step in a series of fast-paced advances that would lead to the first self-sustained nuclear reaction at the Chicago Pile-1, the world's first artificial nuclear reactor, in December 1942. Earlier that year, at the other end of Manhattan from Pupin Hall, an office was set up by the Army for a secret enterprise, the Manhattan Engineer District, or Manhattan Project for short.

Developments at Los Alamos

The Manhattan Project was formally established in the summer of 1942, but some of the groundwork had already been laid by the experimentalists at Columbia and the computational efforts (on problems in neutron diffusion, neutronics, and critical masses) had started at the Radiation Laboratory at the University of California at Berkeley, under the direction of Ernest Lawrence[3]. Among the people working with Lawrence were two postdocs, Stanley Frankel and Eldred Nelson, who were recruited to join the Manhattan Project, now relocated to a secret site in New Mexico. They were among the first to arrive at Los Alamos in March 1943 and were assigned to the Theoretical, or T Division[3]. Physicists were just starting to comprehend the new phenomena they were hoping to harness to build atomic bombs. These phenomena involved extremely high densities, pressures, and temperatures, their modelling requiring nonlinear mathematics for which no analytic techniques and solutions were available. "The only recourse was a computational approach, and the new field of experimental mathematics was entered," Nelson would recall later[4].

The computational approach meant using a computer, which at that time was a human being — usually a woman — who did computations using printed maths tables and mechanical calculating devices[5]. By late summer 1943, the hand-computing group (called the T-5 division and led by Frankel and Nelson) had 20 people including spouses of the Lab scientific staff, civilian recruits from the nearby towns and members of the Women's Army Corps. The problems they worked on took from hours to a few days to process. The human computers sitting at tables with desk calculators worked over four-hour shifts[3]. Despite its size and intense schedule, by late 1943 it was clear that the computing group was struggling to deal with the neutron diffusion calculations.

More computing power

The solution came from the Lab's procurement officer Dana Mitchell, who, before arriving at Los Alamos, had been at Columbia University and knew of Eckert's work on the IBM punch-card machines and made a case for ordering some. Frankel and Nelson agreed. The machines were ordered, but given the secrecy of the project, IBM would not be told where they were going to, hence no maintenance crew could be dispatched. Uncoincidentally, the best IBM maintenance man happened to be drafted and promptly sent to Los Alamos. However, the equipment arrived before him so Frankel and Nelson, joined by Richard Feynman, decided to unpack and assemble the machines (Fig. 1) themselves and managed to make them operate "after a fashion"[4]. The IBM man arrived, made the necessary adjustments and within a week from the arrival of the machines they were already at work doing implosion simulation calculations[4].

One of the bottlenecks of the Manhattan Project was figuring out how to achieve fission through implosion (the plutonium is squeezed by the shock wave of simultaneous detonations). The bomb design required the numerical solution of hydrodynamic differential equations, and the large volume of calculations was beyond the human computers, but not the new machines. Frankel and Nelson co-led a new T-6 computational division and were joined by Feynman and Nicholas Metropolis, who promptly organized a race between a group of human computers and the punch-card machines to calculate the first few integration steps of the implosion simulation[4]. For the first two days the hand-computing group kept the pace, but on the third day it fell behind. Humans get tired, machines don't. The race was abandoned, and the punched-card operation took over running for three shifts, 24 hours per day, 6 days per week[3].

Distributed computing

In spring 1944, John von Neumann brought news to the Los Alamos crowd of Aiken's Mark I at Harvard. Eager to benchmark their punch-card operation and hungry for potentially more computing power, they sent an unclassified form of the problem to Harvard. Another race was on. The problem took three weeks to run at Los Alamos. About two weeks later, Mark I was still halfway through. However, the comparison was unfair, noted Metropolis and Nelson, as Mark I's calculations were done with more digits and greater precision[4].

The Los Alamos physicists got so proficient at using the IBM machines that in 1945, visiting the Columbia Astronomical Computing Bureau, Feynman would teach the staff techniques "too esoteric to be in an operating manual"[5], as later recalled Herbert Grosch, an astronomer and human computer who had just been hired by Eckert. There was a reason behind the visit to Columbia from a "little group of Giant Brains at Los Alamos"[5], and Grosch ended up doing backup calculations for the Manhattan Project on the Columbia machines. The punch-card operation continued at Los Alamos and Columbia at frantic pace until summer. "Then it was August 6, and the radio and the newspapers told us about Hiroshima. We knew what we had been working on," wrote Grosch[5].

An end and a beginning

Back in February 1945, with the end of World War II in sight, reports from the battlefronts dominated the news, so the announcement of the creation of a new facility to be known as the Watson Scientific Computing Laboratory at Columbia University went almost unnoticed[1]. This was the new phase of Eckert's Astronomical Computing Bureau and was meant to "serve as a world centre for the treatment of problems in various fields of science whose solution depends on the effective use of applied mathematics and mechanical calculations"[1]. It would later become IBM Research.

Meanwhile, von Neumann learned of the near completion of Project PX, at University of Pennsylvania, or what was, in fact, the Electronic Numerical Integrator and Computer (ENIAC), the first fully electronic, general-purpose computer. A calculation that a human computer needed 20 hours to complete, the ENIAC could perform in 30 s (ref. 2). von Neumann saw great potential for the Manhattan Project, so Frankel and Metropolis were dispatched to discuss with the ENIAC team. But the ENIAC was not completed until December 1945 and by then the Trinity test had been completed, the bombs had been dropped on Hiroshima and Nagasaki, and World War II had ended. "Progress during the [Manhattan] Project was paced by the computing capabilities," later wrote Metropolis and Nelson[4]. So, it is fitting that as the world entered the atomic age and, a few months later, the electronic computing age, the first problem to be run on the ENIAC was the 'Los Alamos problem'.

Then and now

This is a brief account of a the fast-paced developments that pushed science in the computational age. It unavoidably leaves out many contributors, in particular the women human computers and first programmers, and instead focuses on the role the physicists of that era played in this revolution. But there is also a twofold moral to this story.

On the one hand, using computation was not really a choice. As Metropolis and Nelson put it "computing was exceptionally critical to the attainment of the [Manhattan] Project goals"[4] and with no analytical solutions available, numerical computation was the only option. Furthermore, due to the complexity of the problem, the volume of necessary calculations was unprecedented and with the mounting pressure of the raging war, calculations had to be done fast. Today, other types of pressure, such as intense competition, drive research in a fast-paced mode. The large volumes of scientific data put scientists in a similar position: traditional methods are no longer sufficient, and the use of AI technologies is often unavoidable. Perhaps, more broadly, when a certain point is reached, computing revolutions become inevitable.

On the other hand, "the tools we have shape the questions we ask," says Los Alamos historian Nicholas Lewis, pointing to the fact that before the war physicists were predominantly asking themselves questions that would be answered by experiments, whereas after the war the field of theoretical physics exploded, powered by increasingly complex numerical simulations. Today, in many fields research is making more and more use of AI tools. How these will shape the science questions physicists will be asking in the next decades remains to be seen.

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Related links

Frank da Cruz, *Columbia University Computing History: A Chronology of Computing at Columbia University*: http://www.columbia.edu/cu/computinghistory/