Konrad Zuse and Heinrich Billing: Masterminds of early German digital computers

This column has been quite US-centric, primarily because of the provincial experience of the editor. We did highlight the Englishman Alan Turing (1), the Hungarian/American Johnny von Neumann (2), and the German/American Erich Bloch (3), and this column will further our international reach by highlighting Konrad Zuse (zoo-suh) and Heinrich Billing, two German pioneers of digital computers. Zuse (1910-1995) used telephone relays as opposed to vacuum tubes as the active computing elements in his early Z-series computers and the programs were executed from an external tape, however the Z3 was arguably the first implementation of a Universal Turing Machine (1). Billing (1914-2017) was awarded the Konrad Zuse Medal for creating the first magnetic drum storage (but also see 4), and he developed the first stored program computer in Germany (the G2 in his G-series of computers, also known as the Göttingen computers).

I’ll briefly review Zuse’s and Billing’s lives, their series of computers, Zuse’s high level programming language and Billing’s storage drum. I’ll conclude with Zuse’s speculations about the computational nature of the universe and Billing’s contributions to gravity wave astronomy.

Personal lives

Zuse was born in 1910 in Berlin. His parents moved to several other German towns when he was young, but he returned to Berlin for college, enrolling in what is now the Technical University of Berlin. He considered architecture and engineering and settled on civil engineering as a major. After graduation, he worked for Ford Motor Company designing advertisements and then worked for Henschel Aircraft as a design engineer. He did not complete his Ph.D. due to the war (and failure to pay a required fee!), but his intended dissertation described the first high-level programming language. As with the other computer pioneers, he found the extensive calculations required for his job at Henschel mind-numbing and began seeking a better way, which resulted in the Z computers described below. (5,6)

Billing was born in 1914 in Salzwedel, Germany. He studied mathematics and physics at the University of Göttingen and received his Ph.D. in 1938 in Munich. Billing worked at the Aerodynamic Research Institute in Göttingen, where he developed a magnetic drum memory. He was lured to Australia in 1950 by the promise of better funding, then lured back to Germany by even better funding at the Max Planck Institute for Physics in 1951. He remained there for the rest of his career, first developing the G computers from 1952 to 1961, then returning to physics as the development of computers became entirely industrialized. (7)

Zuse’s Z computers

The first computer Zuse was designed and built (1936-38) in his parents apartment and was paid for with private funding. He called it the V1, but after the war he changed its name to the Z1 to avoid confusion with the V1 flying bomb. This was a mechanical computer whose action was driven by an electric motor. It utilized binary, floating point numbers and was “externally” programmable (that is, instructions were read from punched celluloid film). The Z1 never worked well because the mechanical tolerances were not good. Both the Z1 and its plans were destroyed in the war. (8)

Zuse completed his second machine, the Z2, in 1940. It was similar to the Z1 except that the arithmetic was changed to fixed point, and the mechanical computing element was changed to one based on telephone relays. The Z2 plans were destroyed in the war. But the Z2 was demonstrated to colleagues and Zuse gained funding for its successor, the Z3. (9)

The Z3 was completed in 1941. It was substantially more reliable and faster than its predecessors and contained 2600 relays. The program was still external and read from a tape, but it included looping instructions and was (theoretically but not practically) a universal Turing machine. It was not deemed militarily significant, and so failed to get additional war-time support. As with the Z1, it was destroyed during the war. (10)

As the war was ending, Zuse was designing the Z4. He had formed a company to sell computers, starting with the Z4, which was an improvement of the Z3. A 32-bit floating point number replaced the 22-bit floating point of the Z3, and the external program was improved, but still not a stored program. It was under construction as the fall of Berlin was imminent and it was trucked out of the area. Work was suspended on the Z4 until 1949 due to the post-war privations, and it was purchased in 1950 by ETH Zurich. It remained in operation until 1959 (first at ETH then at the French Franco-German Institute of Research). The Z4 may have been the first successful computer sale, beating the first Univac sale by a few months. (11)

Additional models followed. The Z5 was ordered in 1950 and delivered in 1954, still with relays not vacuum tubes. The Z11 in 1955, the Z22 (with vacuum tubes!) in the late 1950s, and the Z23 (with transistors!) in 1961. In 1963, the Z25 was built and was very much like other 1960s computers, including a stored program. By 1967, the *Zuse KG* had sold a total of 251 computers. Owing to financial problems, the company was sold to Siemens in 1969. (12,13)

Billing’s Magnetic Storage Drum and G Computers

In 1947, a small group of British computer scientists (which may have included Alan Turing) met in Göttingen with an equally small group of German computer scientists, which did include Zuse and Billing. As a result of this meeting, the University of Göttingen embarked on a computer-building project with Billing in charge.

Perhaps at this meeting, Billing learned that the British were storing numbers during calculations in “mercury delay lines,” that is, a number was represented as a sequence of impulses continuously circulating in a circular tube of mercury. This idea led Billing to develop the magnetic storage drum. He had been aware of magnetic tape storage since 1943. By 1948 he had successfully wrapped strips of such tape around a drum and the computer magnetic storage drum was born.

The Göttingen computer project was delayed because funds were not available. Billing accepted an offer from Australia where project money was available. As he arrived there, Marshall Plan money from the US started to arrive in war-torn Europe, and he was lured back to Göttingen in 1950 with the promise of adequate funding. By 1952, the G1 had been constructed. It had his drum as primary memory and utilized vacuum tubes, but it still had an external program on paper tape. Next, the G2 was completed in 1955. It continued to have a drum as primary memory, but now used that drum to hold the program as well as the data. Therefore it was the first stored program German computer. (The IBM 650, first delivered in 1954, known as the first mass-produced computer (14), also used a drum as primary memory for both program and data.) The G1a completed in 1958 was a “bit-serial” machine like the G1 and G2, but represented numbers in floating point, not fixed point like the two previous machines. Finally, the G3, which was completed in 1961, was a “thoroughly modern” computer. It had a bit-parallel architecture and a core memory, and these improvements produced dramatic speed improvement to 5 kips (five thousand floating point instructions per second). (15)

Zuse’s Plankalkul

*Plan Calculus* (in English) was Zuse’s effort to build a high-level programming language for the Z computers. His notes indicate that he started to think about it in the late 30s and had pursued its development far enough by 1944 that he intended to submit it as a Ph.D. dissertation. The collapse of Germany prevented this academic goal but in the immediate post-war years it wasn’t possible to resume work on the Z computers so he continued to refine his ideas about it.

As the Wikipedia article on Plankalkul states, “In 1945, Zuse wrote an unpublished book about the Plankalkül and in 1948 he published a paper in the "Archiv der Mathematik" and introduced his programming language at the Annual Meeting of the German Society of Applied Mathematics and Mechanics. His work did not attract much attention, and for a long time to come programming a computer would only be thought of as using machine code.”(16)

In more recent times, Plankalkül has been both written about and implemented. The general consensus is that it was far ahead of its time and has many modern language features. Zuse was disappointed that the developers of Algol 58 didn’t reference his work on Plankalkül, of which they were aware.

Billing’s Oversight of Max Planck Computers

By the early 1960s, Billing (and most other university researchers) could see that the future of computer creation belonged to the now-emerging computer industry (including Zuse’s company). One of his new responsibilities at Max Planck was to set up and chair a new IT committee that had to approve all requests for research computers and to give directions. In 1976, a newly-hired young investigator representing the recently established Institute for Psycholinguistics came to his committee with a request for a DEC PDP-11/55. In a very courtly and polite manner, Billing started the interview, “And why do linguists need a computer?” One of the two researchers representing the linguists, who was actually an engineer who had been hired to give the linguists computer literacy, responded that they needed to perform FFTs on human speech recordings. (FFT, the fast Fourier transform, was only ten years old at the time and not yet widely known as one the the most important scientific algorithms of all time.) Billing and the committee were sufficiently impressed that “the linguists” knew what the FFT was so that after a few more serious questions the committee approved the request, which at that time was unusual (17).

Zuse’s Speculations about a Cellular automata world

As the Wikipedia article on Zuse says, “In 1967, Zuse suggested that the universe itself is running on a cellular automaton or similar computational structure; in 1969, he published the book *Rechnender Raum* (translated into English as *Calculating Space*). This idea has attracted a lot of attention, since there is no physical evidence against Zuse's thesis. Edward Fredkin (in the 1980s), Jürgen Schmidhuber (in the 1990s), and others have expanded on it.”(18)

Some of the others who have pursued this idea of “digital physics” include the mathematician-physicist-philosopher A. N. Whitehead who formulated a “process philosophy” in the 1920s, which is a speculative system closely related to cellular automata, John von Neumann who created the first self-reproducing cellular automaton in the 1950s (2), and Steven Wolfram who elaborated on these ideas in his 2002 book entitled *A New Kind of Science*. (19)

Billing’s Contribution to LIGO

In the 1970s, Billing returned to his first love, physics, and focused on gravity as described by Einstein’s general theory of relativity. He spent time considering how to measure “gravity waves” in space-time, which were predicted by general relativity. As stated in the Wikipedia article on Billing,

“In 1975, Billing acted on a proposal by Rainer Weiss from the Massachusetts Institute of technology (MIT) to use laser interferometry to detect gravitational waves. He and colleagues built a 3m prototype Michelson interferometer using optical delay lines. From 1980 onward Billing commissioned the development and construction of a laser interferometer with an arm length of 30m. Without the knowledge gained from this prototype, the LIGO project would not have been started when it did.”(20)

As followers of physics know, the NSF-supported LIGO experiment detected gravity waves in 2016, thus proving that they exist. After a rocky start, the LIGO project was approved in 1994 for NSF funding of almost half a billion dollars, making it the largest NSF grant to this day. Even more recently (in April 2019), another NSF-supported project announced that it had taken a picture of “the shadow” of a black hole (since a black hole can’t be seen directly), thus proving that black holes exist. It took a *year* of high performance computer processing of the raw data to create that picture. (21)

Conclusion

As this series of articles has shown, computers were “in the air” by the 1930s. At least six researchers in at least three countries (and probably more researchers in more countries ) were at work trying to automate the onerous task of mathematical computation. In itself, that was not new: machines that added and then multiplied had been developed centuries earlier. However, to define theoretically what could be automatically computed (Turing), to create a machine that would at least theoretically compute anything that was computable (Zuse), and to create a machine using high speed electronics (Atanasoff) launched the world into the Information Age.

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