The Birth of the Baby

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Abstract

On June 21st 1948, in a redbrick building near the centre of a Manchester, England, a digital computer ran its first program successfully. The day was auspicious, because that was the very first time anywhere in the world that a stored program computer worked successfully.

This short note summarises the background to that momentous development and explains a little about the machine called the "The Baby".

1. Background

The need to calculate has been a driving force for innovation over the centuries. For example, Napier (1550-1617) devised a system of rods (Napier's bones) to help in doing multiplication. A lot later, Babbage (1792-1871) [1] designed his differential and analytical engines. In the first half of the twentieth century mathematicians routinely needed to tackle problems that would simply take too long to solve by manual methods or using a mechanical calculator. The need to automate calculation was clear – and well understood.

The general concepts underlying the architecture of a 'calculating machine' were also widely known. The ideas were based in many ways on the approach used by Babbage (who understood the need for input/output, for conditional control loops and for a 'mill' to do calculation). The ideas were further refined and are described in a report written in 1945 by Von Neumann [2] whose name thus became attached to 'conventional' computer architectures.

The development of digital computers benefited to a considerable extent from the pioneering work in electronics carried out during the Second World War. At that time, the best engineers and mathematicians were called up to serve in a wide variety of places supporting the war effort. In the USA, for example, considerable effort was put into ENIAC, an electronic machine for calculating ballistics information and programmed by physically re-plugging numerous connections. In Britain, among those called up was a very highly respected electronics engineer, F. C. (Freddie) Williams. He led a team of engineers at the Telecommunications Research Establishment (TRE) working, among other things, on radar and airborne systems developments, including the techniques to distinguish friend from foe. In 1942 a young Cambridge mathematics graduate, Tom Kilburn, joined him.

2. The early days

After the war, Freddie Williams and his team, including Tom Kilburn, began to investigate the use of Cathode Ray Tubes (CRTs) for uses beyond radar. They were aware of the need for improved calculating machines. They, like many others, also recognised that a major roadblock to achieving electronic calculating machines was the difficulty of storing and retrieving digital information at electronic speeds. They therefore turned their attention to using CRTs for digital data storage. They started work in July 1946 and by November 1946 could store a single bit!

In December 1946, Freddie Williams, together with Tom Kilburn, moved to the University of Manchester. Williams took up the post of Professor in the Department of Electrotechnics (later Electrical Engineering). Tom Kilburn was a

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Scientific Officer, formally seconded from TRE. They continued the investigation of CRTs as storage devices. By October 1947 they had developed a system for storing 2048 bits on a standard CRT. The mechanism used a 64×32 array of phosphor charges on the screen, planted in one of two different ways, representing a 0 or a 1. The charge would decay within 0.2 seconds, so a detector was placed in front of the CRT, and a mechanism devised so that, as an electron beam swept the array again, the type of charge at each position could be detected and refreshed before the beam moved on to the next position. With the surface of the tube being refreshed at regular intervals, before the charge could decay significantly, the CRT could hold a pattern of 0s and 1s indefinitely. Resetting of particular bits and reading values could be interleaved with the refresh mechanism. In December 1947, Kilburn wrote a report [3] that explained the mechanism in detail and described how the CRT could be used as part of a stored-program computer. This report was the foundation for the Williams-Kilburn storage system that was eventually widely adopted.

3. The Small Scale Experimental Machine (SSEM)

The problem that faced Williams and Kilburn was how to test the CRT store in order to show that it would operate effectively as a storage mechanism for an electronic computer. Tom Kilburn, who by now was leading this particular research within the Electrical Engineering Department, considered various alternatives. Eventually, he decided that the best way to test the CRT storage system was to design and build a computer. This machine was known as the Small Scale Experimental Machine – or The Baby.

The SSEM (see Figure 1) had a 32×32-bit word main store, using one CRT. It had a second CRT holding a 32-bit accumulator *A*, and a third holding the address of the current instruction *C*, and the instruction itself (*PI*). A fourth CRT, without any storage mechanism, was placed on the console and could be switched to show a copy of the current bit pattern on any of the storage tubes. This was used as the output device, and the input device was a keyboard of 32 buttons plus manual switches; these could be used to set any bit pattern in any word.

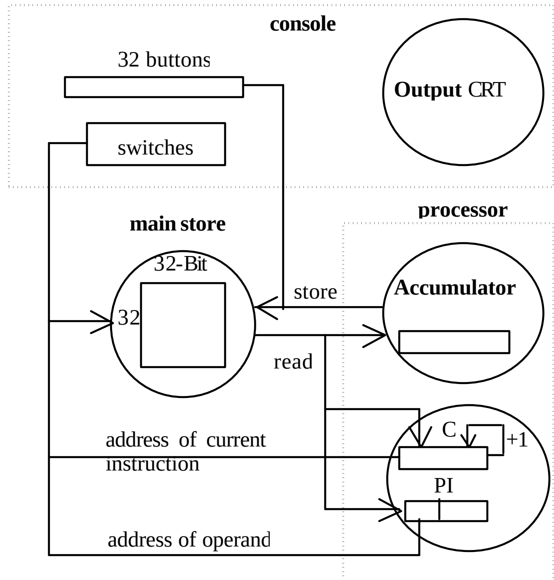

Figure 1: SSEM Architecture Diagram

The SSEM used a 32-bit word for an instruction; bits 13–15 for the function code and bits 0–12 for the store address (though as only one CRT was fitted for the main store, which could hold 32 words, only five bits were used). There were just seven instructions initially as shown below. Note *S* represents the *contents* of the given store address:

1	A = –S	Load S negated into the accumulator
2	A = A – S	Subtract S from accumulator
3	S = A	Reset S to the value in the accumulator
4	C = S	Reset C to (the address in) S
5	C = C + S	Add (the address in) S to C
6	If A < 0 then C = C + 1	Skip next instruction if accumulator < 0
7	Halt.	

Both relative (5) and absolute (4) unconditional jumps were provided; they were also indirect (the more general case) rather than direct. *C* had to be set to the instruction before the next instruction to be obeyed, since *C* was always incremented at the

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start of each instruction. The branch instruction (6) consisted of testing the accumulator and skipping an instruction if it was negative. The awkward use of negative operations (1, 2) was simply to avoid having to build a full 32-bit adder as well as a 32-bit subtractor before the SSEM could be tested – of course X + Y can be computed as X – (0 – Y). It is interesting to note that A = S, A = A+S and A= A&S were added within two months!

A 32-bit line on the main store CRT could be read, written or refreshed in just over 300 microseconds. Refreshing scans, cycling in turn through each line in the store, were interleaved with "action" scans of the same length, so that the regular rhythm of obeying an instruction was as follows:

1. Refresh the next line in turn; add 1 to the control address *C*.
2. Read the line given by *C* into *PI*.
3. Refresh the next line in turn; decode *PI*.
4. Read/write any line *S* as required and complete the instruction. (Note that any addition/subtraction involved was done serially bit by bit, and was overlapped with the serial read operation.)

Instructions were therefore executed in around 1.2 milliseconds, and the main store CRT was refreshed every 16 instructions.

In order to check that the Baby was operating correctly, Tom Kilburn needed to write suitable test programs. The first one that he chose to write was a program to find the highest proper factor of any number a; this was done by trying every integer b from a-1 downward until one was found that divided exactly into a. The necessary divisions were done by repeated subtraction of b.

The program first ran successfully on June 21st 1948. The original number used was quite small, but within a few days they had built up to trying the program on 2^{18}; here around 130,000 numbers were tested, which took about 2.1 million instructions and involved 3½ million store accesses. The correct answer was obtained in a 52 minute run. An amended version of the program is shown in Figure 2. The illustration is taken from a page in the notebook of Geoff Tootill, Tom Kilburn's assistant,

The Baby immediately proved the suitability of the CRT storage device and the effectiveness of the stored-program computer. Calculations that would otherwise have taken days to carry out were completed in minutes. Furthermore, because the program was loaded in memory without any re-configuration and physical re-plugging of the hardware, new programs could be loaded in minutes.

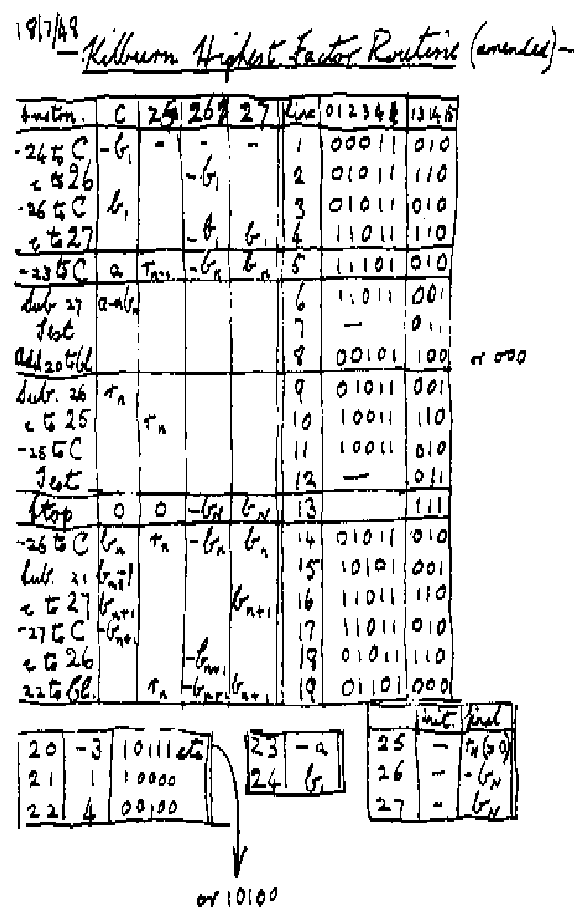

Figure 2: First Program to run on the Baby

4. Subsequent developments

Once the Baby had proved the concept of the stored program computer, expansion and further developments followed very rapidly. It was decided to expand the SSEM to a full-sized machine, the Manchester Mark 1. By October 1948 the basic design had been completed, the team had been increased from two full time engineers to five, and the government had contracted a defence company Ferranti, based in Manchester, to build a commercial version of it. The new machine evolved continuously from the SSEM, with parts being modified and added. It had a larger CRT store, a multiplier, a 26-instruction order code supporting multi-length arithmetic, and paper tape input-output. It also had two major features beyond the basic Von Neumann model; instruction modification registers and a fast random-access two-level store, achieved by adding a magnetic 'drum' store (effectively a hard disc). One reason for adding the drum store was cost. CRT stores were expensive to provide, and a more cost effective way of providing a large amount of store was needed. The left hand side of the machine, which looked just like the original SSEM, is illustrated in Figure 3.

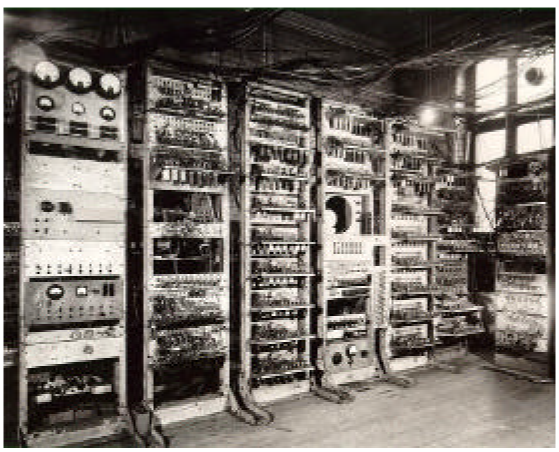

Figure 3: Manchester Mark 1

An intermediate version of the Manchester Mark 1 was available for research in April, with drum transfers only possible manually. A nine-hour overnight run was recorded in June 1949. The Manchester Mark 1 was fully operational by October 1949, by which time the design was already being transferred to Ferranti. An enhanced and re-engineered machine, the Ferranti Mark 1, was first delivered (to the University) in February 1951. This was the world's first commercially available electronic digital computer. Nine were sold.

5. In conclusion

The development of the Baby and the Mark 1 was the start of a long period in which innovative computers were designed and developed at the University of Manchester. The machine designs were commercially exploited by Ferranti, and subsequently by ICT and then ICL. More information about the Baby and the Mark 1 versions can be found in [5]. Information about subsequent machines is also available on the web at http://www.computer50.org. Another useful resource is the CD-ROM produced as part of the 50th Anniversary celebrations for the Baby [4].

The Conservation Society of the British Computer Society, under the leadership of Chris Burton, has built a full sized working replica of the Baby, using original components where possible. This replica is on permanent exhibition at the Manchester Museum of Science and Industry.

References

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[4] Department of Computer Science, University of Manchester, *The Computer that Changed the World* CD-ROM June 1998. This contains copies of early papers including the Technical Report of 1947, video interviews and explanatory material.

[5] Napper, R. B. E. "The Manchester Mark 1 Computers" in *The First Computers--History and Architectures*, eds. Raúl Rojas and Ulf Hashagen, MIT Press, July 2000