Chapter 3
Early Computers

Key Topics

Atanasoff-Berry Computer (ABC)
Zuse's Machines
ENIAC
EDVAC
UNIVAC
COLOSSUS
Manchester 'Baby'
Manchester Mark 1
Ferranti Mark 1
CSIRAC
EDSAC and LEO

3.1 Introduction

This chapter considers some of the early computers developed in the United States, Britain, Germany and Australia. The Second World War motivated researchers to investigate faster ways to perform calculation to solve practical problems. This led to research into the development of machines to provide faster methods of computation.

The early computers were large bulky machines consisting of several thousand vacuum tubes. A computer took up the space of a large room; it was slow and unreliable and had a fraction of the computational power of today's computers.

The early computers considered in this chapter include the Z1, Z2 and Z3 machines developed by Zuse in Germany; the ABC developed by Atanasoff and Berry in the United States; the ENIAC, EDVAC and UNIVAC computers

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developed by Eckert, Mauchly and others in the United States; the COLOSSUS machine developed as part of the Lorenz code breaking work at Bletchley Park in England during the Second World War; the Manchester 'Baby' and Manchester Mark 1 computers developed by Williams, Kilburn and others at Manchester University; the EDSAC and LEO computers developed in England; and finally the CSIRAC developed by the Australian Research and Industrial Organization (CSIR).

The early digital computers used vacuum tube technology. Later generations of computers used transistors and integrated circuits which were faster and more reliable. These are discussed in later chapters.

3.2 Zuse's Machines

Konrad Zuse was a German engineer and was born in Bonn in 1910. He is considered 'the father of the computer' in Germany as he built the world's first programmable machine (the Z3) in 1941. He initially worked as a design engineer at the Henschel aircraft factory in eastern Germany, but resigned from his job to set up a company to build a programmable machine. He returned to work with Henschel during the war. He was unaware of computer-related developments in Germany or in other countries and independently implemented the principles of modern digital computers in isolation.

He commenced work on his first machine called the Z1 in 1936, and the machine was operational by 1938. It was demonstrated to a small number of people who saw it rattle and compute the determinant of a three by three matrix. It was essentially a binary electrically driven mechanical calculator with limited programmability. It was capable of executing instructions read from the program punch cards, but the program itself was never loaded into the memory (Fig. 3.1).

It employed the binary system and metallic shafts that could slide from position 0 to position 1 and vice versa. The machine was essentially a 22-bit floating-point value adder and subtracter. A decimal keyboard was used for input, and the output was decimal digits. The machine included some control logic which allowed it to perform more complex operations such as multiplications and division. These operations were performed by repeated additions for multiplication and repeated subtractions for division. The multiplication took approximately 5 s. The computer memory contained sixty-four 22-bit words. Each word of memory could be read from and written to by the program punch cards and the control unit. It had a clock speed of 1 Hz, and two floating-point registers of 22 bits each. However, the machine was unreliable. A reconstruction of it is in the Deutsches Technikmuseum in Berlin.

His next attempt was the creation of the Z2 machine which aimed to improve on the Z1. This was a mechanical and relay computer created in 1939. It used a similar mechanical memory but replaced the arithmetic and control logic with 600 electrical relay circuits. It used 16-bit fixed point arithmetic instead of the 22-bit

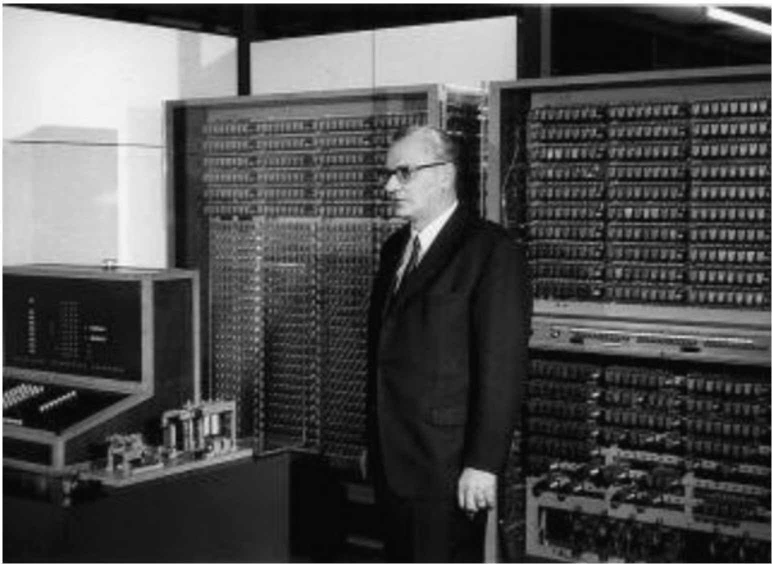

Fig. 3.1 Zuse and the reconstructed Z3 (Courtesy of Horst Zuse, Berlin)

used in the Z1. It had a 16-bit word size, and the size of its memory was 64 words. It had a clock speed of 3 Hz.

The Z3 machine was the first functional tape-stored-program-controlled computer and was created in 1941. It used 2,600 telephone relays and the binary number system and could perform floating-point arithmetic. It had a clock speed of 5 Hz, and multiplication and division took 3 s. The input to the machine was with a decimal keyboard, and the output was on lamps that could display decimal numbers. The word length was 22 bits, and the size of the memory was 64 words.

It used a punched film for storing the sequence of program instructions. It could convert decimal to binary and back again. It was the first digital computer since it predates the Atanasoff-Berry computer by 1 year. It was proven to be Turing-complete in 1998. There is a reconstruction of the Z3 computer in the Deutsches Museum in Munich.

The Z4 was almost complete before the fall of Berlin to the advancing Soviet Army. Zuse fled to Bavaria with the Z4, and this completed machine was the world's first commercial computer when it was introduced in 1950.

3.3 Atanasoff-Berry Computer (ABC)

John Atanasoff was born in New York in 1903 and studied engineering at the University of Florida. He did a Masters in Mathematics at Iowa State College and earned a Ph.D. from the University of Wisconsin. He became an assistant professor

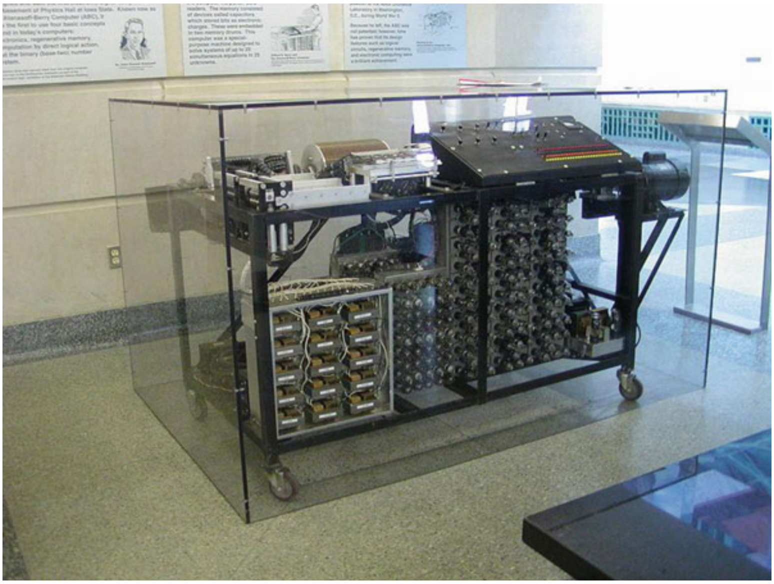

Fig. 3.2 Replica of ABC computer (Courtesy of Iowa State University)

at Iowa State College and became interested in finding faster methods of computation. He developed the concept of the ABC in the late 1930s, and using his research grant of $650 and with the assistance of his graduate student, Clifford Berry, the ABC was built from 1939 to 1942.

The Atanasoff-Berry computer was ruled to be the first electronic digital computer in a 1973 court case in the United States. The court case arose from a patent dispute, and Atanasoff was called as an expert witness in the case. The court ruled that Eckert and Mauchly did not invent the first electronic computer since the ABC existed as *prior art* at the time of their patent application. It is fundamental in patent law that an invention is novel and that there is no existing prior art. This meant that the Mauchly and Eckert patent application for ENIAC was invalid, and Atanasoff was named by the US court as the inventor of the first digital computer (Fig. 3.2).

The ABC was approximately the size of a large desk and had approximately 270 vacuum tubes. Two hundred and ten tubes controlled the arithmetic unit, 30 tubes controlled the card reader and card punch and the remaining tubes helped maintain charges in the condensers. It employed rotating drum memory with each of the two drum memory units able to hold thirty 50-bit numbers.

Atanasoff became interested in mechanising calculation from the mid-1930s, and the ABC was designed to solve linear equations. The existing computing devices were mechanical, electromechanical or analog. Atanasoff and Berry built a working prototype of the electronic digital computer, called the Atanasoff-Berry computer (ABC). However, the ABC was slow, required constant operator monitoring and was not programmable.

It used binary mathematics and Boolean logic to solve simultaneous linear equations. It used over 270 vacuum tubes for digital computation, it had no central processing unit (CPU) and it was not programmable. It was designed for a specific purpose (i.e. solving linear equations) rather than as a general-purpose computer.

It weighed over 300 kg and used 1.6 km of wiring. Data was represented by 50-bit fixed point number. It performed 30 additions or subtractions per second. The memory and arithmetic units could operate and store 60 such numbers at a time ($60 * 50 = 3{,}000$ bits). The arithmetic logic unit was unit fully electronic and implemented with vacuum tubes.

The input was in decimal format with standard IBM 80-column punch cards, and the output was decimal via a front panel display. A paper card reader was used as an intermediate storage device to store the results of operations too large to be handled entirely within electronic memory. The ABC pioneered important elements in modern computing including:

- Binary arithmetic and Boolean logic.
- All calculations were performed using electronics rather than mechanical switches.
- Computation and memory were separated.

It was tested and operational by 1942, and Atanasoff then commenced a Second World War assignment.

Controversy (Mauchly and Atanasoff)

Mauchly visited Atanasoff on several occasions and they discussed the implementation of the ABC computer. Mauchly subsequently developed the ENIAC, EDVAC and UNIVAC computers. It had been believed for many years that ENIAC was the first digital computer until a 1973 legal case ruled that the Atanasoff Berry Computer (ABC) existed as prior art at the time of the patent application. The court ruled that the ABC was the first digital computer and stated that the inventors of ENIAC had derived the subject matter of the electronic digital computer from Atanasoff.

3.4 The Bletchley Park Contribution

Bletchley Park is located near Milford Keynes in England, and it played an important role in breaking German cipher codes during the Second World War. These codes were used by the Germans for the encryption of naval messages which prevented third parties from unauthorised viewing of the messages. The plaintext (i.e. the original message) was converted by the Enigma machine into the encrypted text, and these messages were then transmitted by the Germans to their submarines in the Atlantic or their bases throughout Europe.

Fig. 3.3 The Enigma machine (Public domain)

The Enigma codes were cracked by the team of cryptanalysts in Bletchley Park using a machine called the Bombe. The Poles had done some work on code breaking prior to the war, and they passed their knowledge to the British following the German invasion of Poland. Alan Turing and Gordon Welchman built on the Polish research to develop the ‘Bombe’ machine. They used the fact that enciphered German messages often contained common words or phrases, such as general’s names or weather reports, and this enabled them to guess short parts of the original message. These guesses were called ‘cribs’.

The Enigma machine does not allow a letter to be enciphered as itself, and this also helped in reducing the potential number of settings that the Enigma machine could be in on that particular day (Fig. 3.3).

The first Bombe was installed in early 1940, and by the end of the war, there were over 200 Bombes in operation. Each Bombe weighed over a ton, and it was named after a cryptological device designed in 1938 by the Polish cryptologist, Marian Rejewski. They were over 7 ft long, 6 ft high and 2 ft deep. The Bombes were built by the British Tabulating Machine Company, and they were destroyed after the war. A replica of the British Turing Bombe machine was rebuilt at Bletchley Park by a team of volunteers and was switched on by the Duke of Kent in 2008.

The code breaking team then wired the Bombe to check the reduced set of potential settings based on the information that they had gained from the cribs. The Bombe found potential Enigma settings not by proving a particular setting, but by disproving every incorrect one in turn.

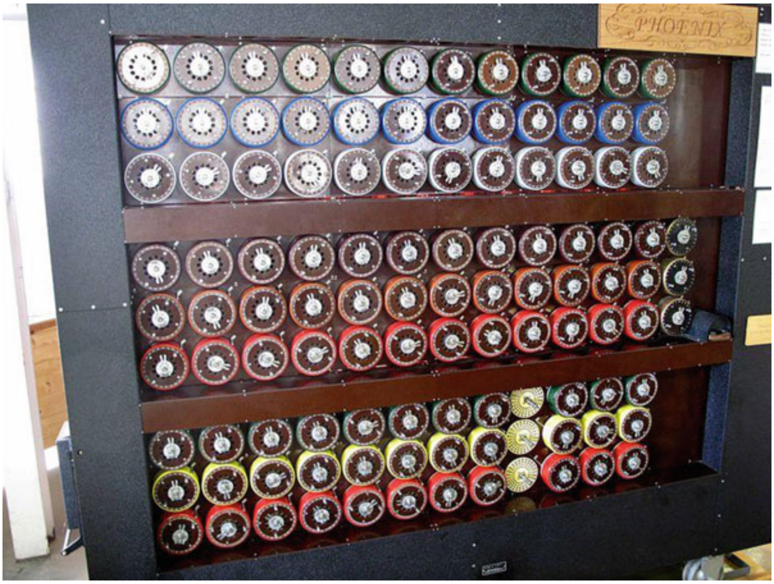

Fig. 3.4 Rebuilt Bombe (Photo public domain)

A standard Enigma machine employed a set of three rotors. Each rotor could be in any of 26 positions. The Bombe tried each possible rotor position and applied a test. The test eliminated almost all the 17,576 positions (i.e. 26^3) and left a smaller number of cases to be dealt with. The test required the cryptologist to have a suitable ‘crib’, that is a section of cipher text for which he could guess the corresponding plaintext (Fig. 3.4).

For each possible setting of the rotors, the Bombe employed the crib to perform a chain of logical deductions. The Bombe detected when a contradiction had occurred; it then ruled out that setting and moved onto the next. Most of the possible settings would lead to contradictions and could then be discarded. This would leave only a few settings to be investigated in detail.

The Lorenz codes were a more complex cipher than the Enigma codes. The enciphering was performed by the Lorenz SZ40/42 machine, and it was used exclusively for the most important messages passed between the German Army Field marshals and their Central High Command in Berlin. It was not a portable device like the Enigma machine.

The Bletchley Park code breakers called the machine ‘Tunny’ and the coded messages ‘Fish’. The code breaking was performed by carrying out complex statistical analyses on the intercepted messages. The Colossus Mark 1 machine was specifically designed for code breaking rather than as a general-purpose computer. It was semi-programmable and helped in deciphering messages encrypted using the Lorenz machine. A prototype was available in 1943, and a working version was

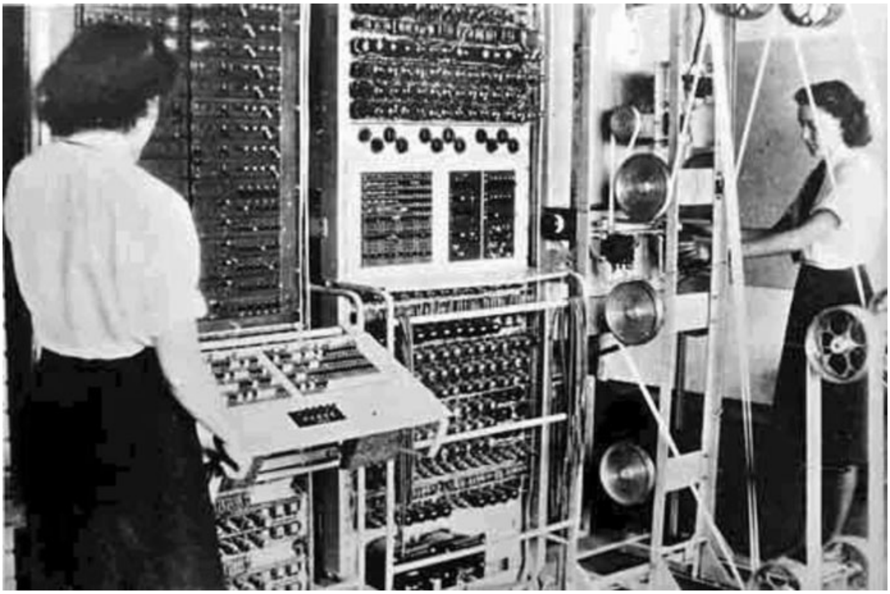

Fig. 3.5 Colossus Mark 2 (Photo courtesy of UK government)

available in early 1944 at Bletchley Park. The Colossus Mark 2 was introduced just prior to the Normandy landings in June 1944 (Fig. 3.5).

Colossus contained 1,500 vacuum tubes and used 15 kW of power. It was partially programmable and could process 5,000 characters of paper tape per second. It enabled a large amount of mathematical work to be done in hours rather than in weeks. There were ten colossi machines working at Bletchley Park by the end of the war. A replica of the Colossus was rebuilt by a team of volunteers led by Tony Sale from 1993 to 1996 and is in Bletchley Park museum.

The original machine was designed by Tommy Flowers and others at the Post Office Research Station at Dollis Hill in London. It was used to find possible key combinations for the Lorenz machines rather than decrypting an intercepted message in its entirety.

It did this by comparing two data streams to identify possible key settings for the Lorenz machines. The first data stream was the encrypted message, and it was read at high speed from a paper tape. The other stream was generated internally, and was an electronic simulation of the Lorenz machine at various trial settings. If the match count for a setting was above a certain threshold, it would be sent as output to an electric typewriter.

The contribution of Bletchley Park to the cracking of the German Enigma and Lorenz codes and to the development of computing remained clouded in secrecy until recent times. The museum at Bletchley Park provides insight to the important contribution made by this organisation during the Second World War.

3.5 ENIAC, EDVAC and UNIVAC

The Electronic Numerical Integrator and Computer (ENIAC) was one of the first large general-purpose electronic digital computers. It was used to integrate ballistic equations and to calculate the trajectories of naval shells. It was completed in 1946 and remained in use until 1955. The original cost of the machine was approximately $500,000.

The ENIAC had to be physically rewired in order to perform different tasks, and it was clear that there was a need for an architecture that would allow a machine to perform different tasks without physical rewiring each time. This eventually led to the concept of the stored program which was implemented in the successor to ENIAC. The idea of a stored program is that the program is stored in memory, and when the task to be computed needs to be changed, then all that is required is to place a new program in memory rather than rewiring the machine. EDVAC (the successor of ENIAC) implemented the concept of a stored program in 1949 just after its implementation on the Manchester Baby prototype machine in England. The concept of a stored program and von Neumann architecture is detailed in von Neumann's report on EDVAC [VN:45] (Fig. 3.6).

ENIAC was a large bulky machine and was over 100 ft long, 10 ft high and 3 ft deep. Its development commenced in 1943 at the University of Pennsylvania,

Fig. 3.6 Setting the switches on ENIAC's function tables (US Army photo)

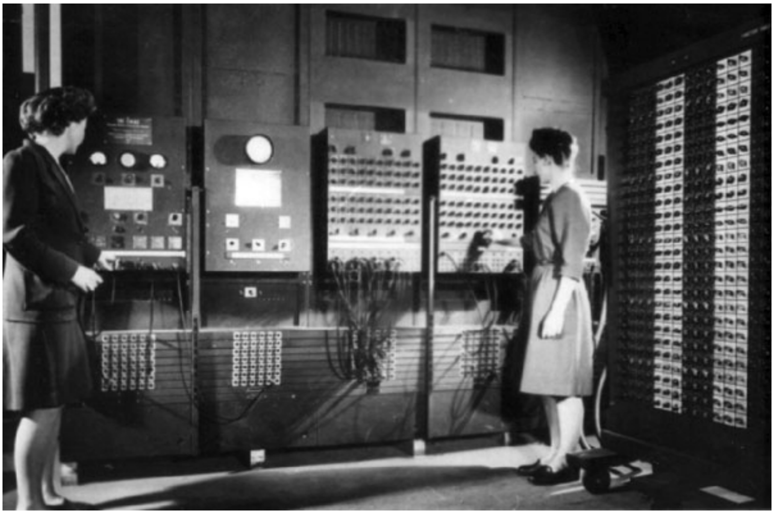

Fig. 3.7 Replacing a valve on ENIAC (US Army photo)

and it was built for the US Army's Ballistics Research Laboratory. The project team included Presper Eckert as chief engineer, John Mauchly as a consultant, von Neumann as an external advisor and several others. The machine generated a vast quantity of heat since each of the vacuum tubes generated heat like a light bulb, and there were over 18,000 tubes in the machine. The machine employed 150 kW of power, and air conditioning was employed to cool the machine. It weighed about 30 tons and employed IBM paper card readers.

It employed decimal numerals rather than binary. It could add 5,000 numbers, do 357 10-digit multiplications or thirty-five 10-digit divisions in 1 s.

It could be programmed to perform complex sequences of operations, and this included loops, branches and subroutines. However, the task of taking a problem and mapping it onto the machine was complex and usually took weeks to perform. The first step was to determine what the program was to do on paper; the second step was the process of manipulating the switches and cables to enter the program into ENIAC, and this usually took several days. The final step was verification and debugging, and this often involved single-step execution of the machine (Fig. 3.7).

There were problems initially with the reliability of ENIAC as several vacuum tubes burned out most days. This meant that the machine was often nonfunctional as high-reliability tubes were not available until the late 1940s. However, most of these problems occurred during the warm-up and cool-down periods, and therefore it was decided not to turn the machine off. This led to improvements in its reliability to the acceptable level of one tube every 2 days. The longest continuous period of operation without a failure was 5 days.

Fig. 3.8 The EDVAC computer (US Army photo)

The very first problem run on ENIAC required only 20 s and was checked against an answer obtained after 40 h of work with a mechanical calculator. One of the earliest problems solved was related to the feasibility of the hydrogen bomb. It involved the input of 500,000 punch cards, and the program ran for 6 weeks and gave an affirmative reply. ENIAC was preceded in development by the Atanasoff-Berry computer (ABC) and the Colossus computer.

The EDVAC (Electronic Discrete Variable Automatic Computer) was the successor to the ENIAC computer. It was a stored program computer, and it cost $500,000. It was proposed by Eckert and Mauchly in 1944 and design work commenced prior to the completion of ENIAC. It was delivered to the Ballistics Research Laboratory in 1949; it commenced operations in 1951 and ran until 1961.

It employed 6,000 vacuum tubes, and its power consumption was 56,000 W. It had 5.5 kB of memory (Fig. 3.8).

The ENIAC was a major milestone in the development of computing, and Eckert and Mauchly set up a company shortly afterwards called the Eckert-Mauchly Computer Corporation. They received an order from the National Bureau of Standards to develop the Universal Automatic Computer (UNIVAC) which was one of the first commercially available computers. The Univac 1 computer was delivered in late1950, and it was a machine for general processing (Fig. 3.9).

Their company was taken over by the Remington Rand Corporation in 1950, and it later became Unisys (Fig. 3.10).

Fig. 3.9 The UNIVAC operator console (Photo public domain)

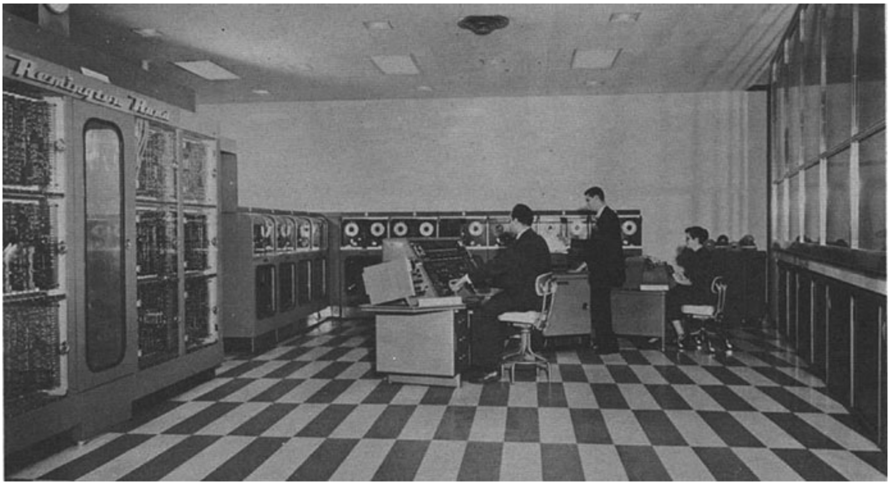

Fig. 3.10 The UNIVAC computer (Photo public domain)

3.6 The Manchester University Contribution

Sir Frederick Williams and Tom Kilburn co-invented the Williams-Kilburn Tube (also known as the Williams Tube), which was a cathode-ray tube used to store binary data. It was the first random access digital storage device and was popular in the computer data-storage field for several years until it was outdated by core memory in 1955. It provided the first large amount of random access memory (RAM), and it did not require rewiring each time the data was changed.

Williams had succeeded in storing one bit of information on a cathode-ray tube, and Kilburn began working with him in the mid-1940s to improve its digital storage ability. Kilburn devised an improved method of storing bits which increased the storage capacity to 2,048 bits. They were now ready to build a computer based on the Williams Tube.

3.6.1 Manchester Baby

The Manchester Small Scale Experimental Computer (better known by its nickname 'Baby') was developed at the University of Manchester. It was the *first stored program computer*, and it was designed and built at Manchester University in England by Frederic Williams, Tom Kilburn and others.

Kilburn was assisted by Geoff Tootill in the design and construction of the prototype machine, and the prototype machine demonstrated the ability of the Williams Tube. It was also the first stored program computer; that is the instructions to be executed were loaded into memory rather than by rewiring the computer to run a new program. That is, all that was required was to enter the new program into the computer memory. *For the first time in history, a computer used a stored program*, and Kilburn wrote and executed that short computer program in 1948 (Fig. 3.11).

The prototype machine demonstrated the feasibility and potential of the stored program. The memory of the machine consisted of thirty-two 32-bit words, and it took 1.2 ms to execute one instruction, that is 0.00083 MIPS (million instructions per second). Today's computers are rated at speeds of up to 1,000 MIPS. The team in Manchester developed the machine further, and in 1949, the Manchester Mark 1 was available.

3.6.2 Manchester Mark 1

The Manchester Automatic Digital Computer (MADC), also known as the Manchester Mark 1, was developed at the University of Manchester. It was one of the earliest stored program computers, and it was the successor to the earlier prototype computer nicknamed 'Baby'. It was designed and built by Frederic Williams, Tom Kilburn and others (Fig. 3.12).

Each word could hold one 40-bit number or two 20-bit instructions. The main memory consisted of two pages (i.e. two Williams tubes with each holding 32 × 40 bit words or 1,280 bits). The secondary backup storage was a magnetic drum consisting of 32 pages (this was updated to 128 pages in the final specification).

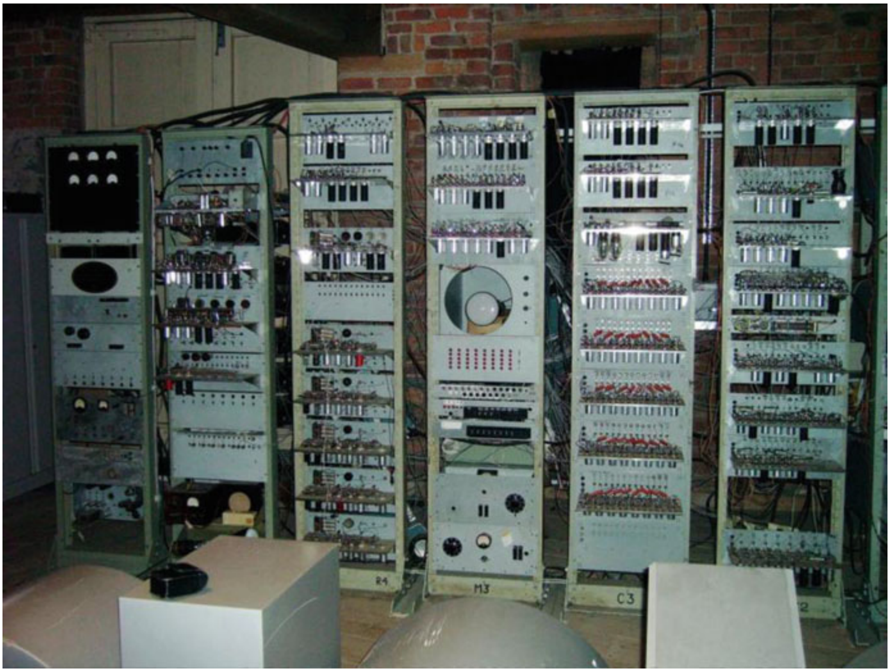

Fig. 3.11 Replica of the Manchester Baby (Photo courtesy of Tommy Thomas)

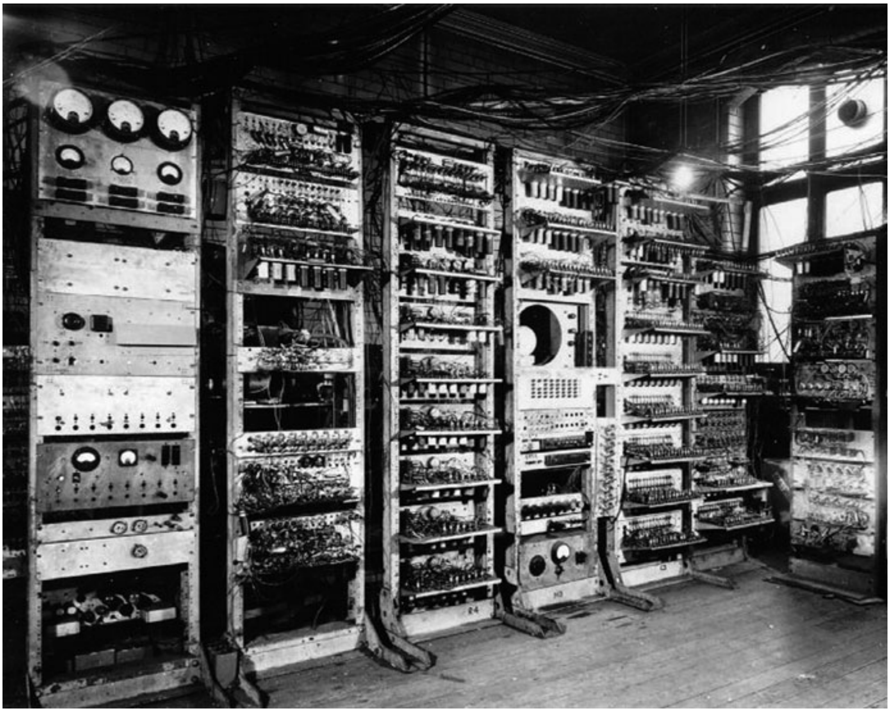

Fig. 3.12 The Manchester Mark 1 computer (Courtesy of the University of Manchester)

Each track consisted of two pages (2,560 bits). One revolution of the drum took 30 ms, and this allowed the 2,560 bits to be transferred to main memory.

It contained 4,050 vacuum tubes and had a power consumption of 25,000 W. The standard instruction cycle was 1.8 ms; however, multiplication was much slower. The machine had 26 defined instructions, and the programs were entered into the machine in binary form as assembly languages were not yet available.

It had no operating system, and its only systems software were some basic routines for input and output. Its peripheral devices included a teleprinter and a five-hole paper tape reader and punch.

A display terminal used with the Manchester Mark 1 computer mirrored what was happening within the Williams Tube. A metal detector plate placed close to the surface of the tube detected changes in electrical discharges. The metal plate obscured a clear view of the tube, but the technicians could monitor the tubes used with a video screen. Each dot on the screen represented a dot on the tube's surface; the dots on the tube's surface worked as capacitors that were either charged and bright or uncharged and dark. The information translated into binary code (0 for dark, 1 for bright) became a way to program the computer.

3.6.3 Ferranti Mark 1

Ferranti Ltd. (a British company) and Manchester University collaborated to build one of the world's first commercially available general-purpose electronic computer. This machine was the Ferranti Mark 1, and it was basically an improved version of the Manchester Mark 1. The first machine off the production line was delivered to the University of Manchester in 1951 and shortly before the release of the UNIVAC 1 electronic computer in the United States.

The Ferranti Mark 1's instruction set included a 'hoot command' which allowed auditory sounds to be produced. It also allowed variations in pitch. Christopher Strachey (who later did important work on the semantics of programming languages) programmed the Ferranti Mark 1 to play tunes such as 'God save the King', and the Ferranti Mark 1 was one of the earliest computers to play music. The earliest was the CSIRAC computer in Australia. The parents of Tim Berners-Lee (the inventor of the World Wide Web) both worked on the Ferranti Mark 1.

The main improvements of the Ferranti Mark 1 over the Manchester Mark 1 were improvements in size of primary and secondary storage, a faster multiplier and additional instructions.

It had eight pages of random access memory (i.e. eight Williams tubes each with a storage capacity of sixty-four 20-bit words or 1,280 bits). The secondary storage was provided by a 512-page magnetic drum which stored two pages per track, and its revolution time was 30 ms.

It used a 20-bit word stored as a single line of dots on the Williams tube display, with each tube storing a total of 64 lines of dots (or 64 words). Instructions were stored in a single word, while numbers were stored in two words.

The accumulator was 80 bits, and it could also be addressed as two 40-bit words. There were about 50 instructions, and the standard instruction time was 1.2 ms. Multiplication could be completed in 2.16 ms. There were 4,050 vacuum tubes employed.

3.7 EDSAC and LEO

The Electronic Display Storage Automatic Computer (EDSAC) was an early British computer developed by Maurice Wilkes and others at the University of Cambridge in England. The machine was inspired by von Neumann's report on EDVAC [VoN:45], and it was the first practical stored program computer. EDSAC ran its first program in May 1949 when it calculated a table of squares and a list of prime numbers.

It was used to support the industry needs of the university. It used mercury delay lines for memory and vacuum tubes for logic; input was via a five-hole punched tape; output was via a teleprinter. The accumulator could hold 71 bits, including the sign, and this allowed two 35-bit numbers to be multiplied.

J. Lyons & Co., a British food manufacturing and catering company, supported the project with funding of £3,000. The board of Lyon was forward thinking and realised that a computer could support its business needs. Once EDSAC was successfully completed, the board of Lyons decided to start on the construction of their own machine. This machine was christened the Lyons Electronic Office (LEO), and it was one of the earliest commercial computers. The first business application to run on LEO was Bakery Valuations which was run in 1951.

The machine was used initially for valuation jobs and extended over time to payroll, inventory and other applications. Its clock speed was 500 kHz, with most instructions taking 1.5 ms to execute.

Lyons formed LEO Computers Ltd. in 1954 following its decision to proceed with LEO II computer. The LEO III was developed in 1961, and LEO computers merged into the English Electric Company in 1963. This company merged with International Computers and Tabulators to form International Computers Ltd. in 1968.

3.8 The Australian Contribution

The CSIRAC (Council for Scientific and Industrial Research Automatic Computer) was Australia's first digital computer. It was also the fourth stored program computer in the world. It was first run in November 1949, and it is one of only a handful of first-generation computers still existing in the world. It is on permanent display at the Melbourne Museum (Fig. 3.13).

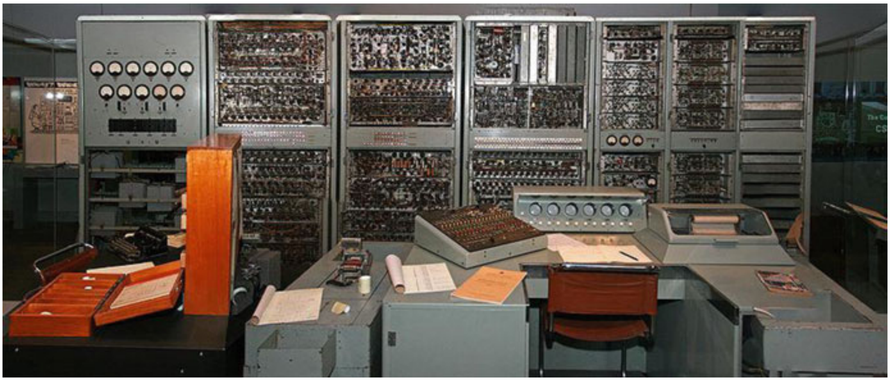

Fig. 3.13 CSIRAC (Photo courtesy of John O'Neill)

It was constructed by a team led by Trevor Pearcey and Maston Beard at the CSIR in Sydney. The machine had 2,000 vacuum valves and used 30 kW of power during operation. The input to the machine was by a punched paper tape, and output was to a teleprinter or to punched tape. The machine was controlled through a console which allowed programs to be stepped through.

The CSIRAC was the first digital computer to play music, and this took place in 1950. The machine was moved to the University of Melbourne in the mid-1950s, and today the machine is on permanent display at the Melbourne Museum.

3.9 Review Questions

1. Discuss the contribution of Zuse.
2. Discuss the contribution of Bletchley Park to cracking cipher codes and to the development of computing.
3. Discuss the contribution of Manchester University to computing.
4. Discuss the importance of the ENIAC, EDVAC and UNIVAC computers.
5. Discuss the importance of the Atanasoff-Berry computer.

3.10 Summary

This chapter considered some of the early computers developed in the United States, Britain, Germany and Australia. The Second World War motivated researchers to investigate faster ways to perform calculations to solve practical problems.

This led to an interest in the development of machines to provide faster methods of computation.

The earliest computer developed was the Z3 machine developed by Konrad Zuse in Germany in 1941. Zuse set up the first computer company, and the first commercial computer, the Z4, was delivered to the Technical University of Zurich in 1950.

The earliest computer developed in the United States was the Atanasoff-Berry computer developed by John Atanasoff and his graduate student, Clifford Berry. Mauchly met with Atanasoff on a number of occasions and Mauchly and Eckert developed ENIAC at the Moore School of Engineering at the University of Pennsylvania. This was a large bulky vacuum tube computer.

von Neumann later became involved in the design of EDVAC (the successor to the ENIAC), and he published a draft paper that describes the fundamental architecture underlying digital computers. This is known as the 'von Neumann architecture', and the names of Mauchly and Eckert were removed from the draft report as they had resigned from the Moore School to start their own computer company.

The earliest computer developed in Britain was the COLOSSUS machine developed at Bletchley Park in England as part of the code breaking work during the Second World War. The Manchester 'Baby' and Manchester Mark 1 computers were developed by Williams, Kilburn and others at Manchester University. The University of Cambridge received funding from Lyons to assist them in the development of the EDSAC Computer. This led to the development of the LEO computer for Lyons in 1951.