

CODE Alan Turing's
Life and Legacy
BREAKER

Large-print book

Please do not remove from the exhibition

Codebreaker

Alan Turing's Life and Legacy

The Second World War was not just fought with bombs and shells. It was a war of electronic whispers and secret radio signals snatched from the ether.

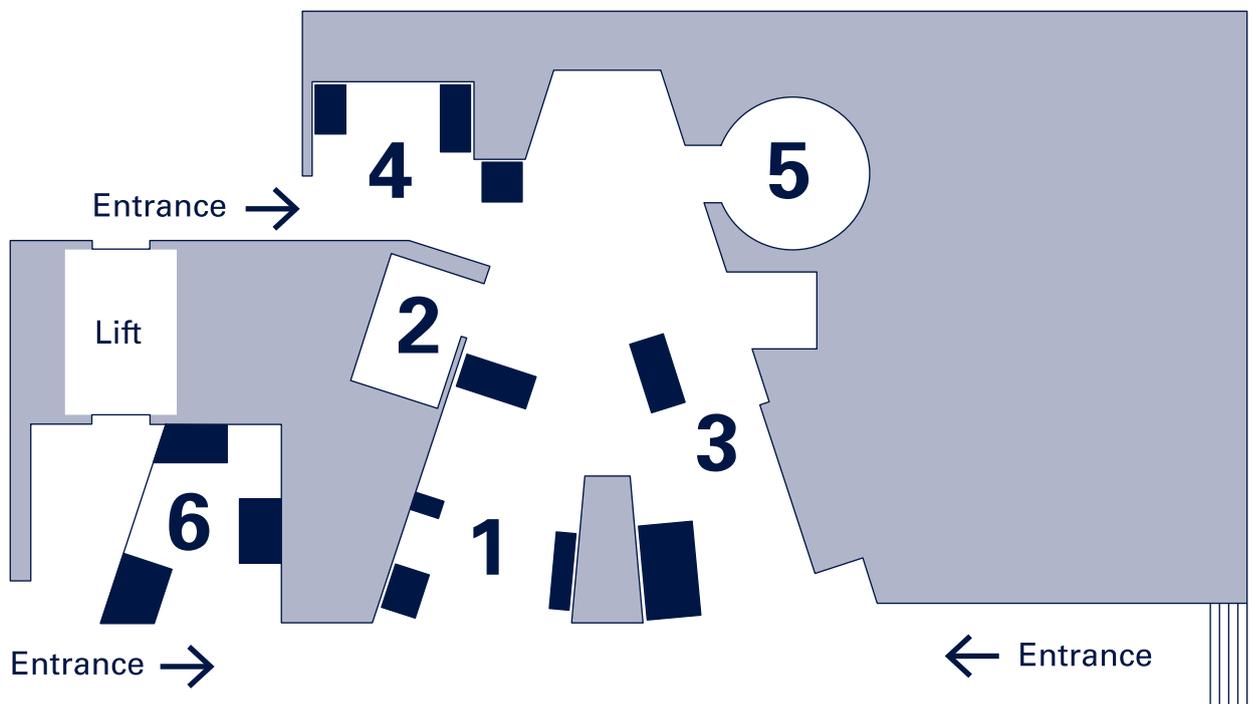
At Bletchley Park, Buckinghamshire, thousands of men and women laboured night and day to crack these coded radio messages which held Germany's most secret plans. One of these codebreakers was Alan Turing.

But Turing was not just a codebreaker. Born 100 years ago, this British mathematician was also a philosopher and computing pioneer who grappled with some of the fundamental problems of life itself. Yet his own life was cut tragically short. In 1954 he was found dead, poisoned by cyanide. He was 41.

Throughout his life, Turing broke the codes of science and society. His ideas helped shape the modern world – but it was a world he did not live to see. This is his story.

The exhibition is arranged in six sections:

- 1.** Computing before computers
- 2.** Alan Turing's war
- 3.** ACE – the Automatic Computing Engine
- 4.** Can machines think?
- 5.** A matter of life and death
- 6.** Programming computers today



1. Computing before computers

When we talk about computers today, we usually mean electronic devices that can be programmed to carry out many different tasks – so-called universal stored-program computers. The first were built in the 1940s.

But there were 'computers' before this. In some cases, the word simply meant 'person who computes', and many were women working with simple aids on repetitive calculations. In other cases, one-off devices computed specific problems, such as aiming aircraft bombs or solving certain mathematical equations.

Alan Turing wrote a seminal mathematics paper in 1936 which came to be seen as a theoretical basis for today's computers. In it he imagined a single machine that could compute any problem, effectively uniting all these early problem-specific 'computers' into one universal device.

Calculating machine used at the Scientific Computing Service, c. 1939

This calculating machine was used at the Scientific Computing Service (SCS) from about 1939 to 1965, when it was transferred to the physics and astronomy department of University College London. It was given to the Science Museum in 1981 by Beryl Waters, a computer at the SCS.

Aircraft bomb-aiming mechanical computer, c. 1942

This 'bombsight' mechanical computer was used on board Lancaster and other aircraft in the Second World War. It was used to aim the bombs, taking factors such as aircraft height and speed and weather conditions into account. Unlike electronic computers, which are programmed using software, mechanical computers carried out their computations according to the physical shape and design of the mechanism, which can be seen at the back of the machine. The gears, linkages and cams literally embodied the equations that needed to be solved.

Computing before computers

Meccano differential analyser by Douglas Hartree, rebuilt c. 1947

This is a reconstructed machine for solving complex mathematical equations, originally made in 1934 by mathematician Douglas Hartree and his student Arthur Porter from the construction toy Meccano. It was one of the first electromechanical computers. It used the movement of shafts and gears as the physical analogue of the mathematical relationships. Later digital computers electronically manipulated the numerical values themselves.

2. Alan Turing's war

In the Second World War armed forces communicated using encrypted radio messages. Britain was desperate to understand the German messages, so a codebreaking institution was set up at Bletchley Park to crack them. It was a race against the clock.

Alan Turing worked at Bletchley on a type of encryption known as 'Enigma' after the machines used to create it. He developed sophisticated decryption processes and, with colleague Gordon Welchman, devised machines called 'bombes' that could break the code on an industrial scale.

Some 200 bombes were built at a secret facility nearby. They operated around the clock at several sites including Bletchley Park itself, tended by the Women's Royal Naval Service. The intelligence gained from the Enigma messages was vital to Britain's success in the war.

Early military Enigma machine, 1937

The secret Enigma codebreaking work carried out at Bletchley Park during the Second World War became public knowledge in the 1970s, following publication of some of the details. Interest in the story grew rapidly. In the late 1970s the Science Museum began to negotiate with the Government Communications Headquarters (GCHQ), the successor to Bletchley Park, on acquiring an Enigma machine for public display. Following much consideration, this German military machine was donated to the Museum in 1980. It is believed to have been the first shown to the public.

Captured German U-boat Enigma machine, 1944

In 1942 the German navy introduced more complex Enigma machines for use by its submarine U-boats. Radio messages between command stations and the submarines contained vital intelligence about attacks on British and Allied supply ships, which carried food, armaments and fuel vital for Britain to continue the war. Germany considered this new Enigma unbreakable. For ten months the British codebreakers seemed defeated. But Enigma material seized from a German U-boat gave Turing and his team the breakthrough they needed, and soon the U-boat messages could again be read.

Alan Turing's war

Enigma machine from the 2001 film 'Enigma', 1930s

Public interest in the Enigma story grew rapidly after details started to emerge in the 1970s. Several literary, theatrical and film adaptations of the story were made. In 2001 musician and film producer Sir Michael Jagger co-produced 'Enigma', a fictionalised account of the war-winning work at Bletchley Park starring Kate Winslet and Dougray Scott. It was a critical and popular success, sharing the inspirational story with a wide audience. This Enigma machine featured in the film, and was lent by Jagger to the project.

Bletchley Park Enigma working aids, 1939–45

These devices were amongst many made by codebreakers working at Bletchley Park on the Enigma system. Their work was highly mathematical, searching for patterns and other ways to crack the coded messages. To speed up their work they devised all sorts of home-made working aids such as these. One may well have been a teaching aid for other codebreakers working on the Enigma problem. By 1944 some 10,000 people worked at the site.

Alan Turing's war

Wheels from a bombe checking machine, 1940s

The bombes were manufactured on a secret production line at the British Tabulating Machines factory in Letchworth, near Bletchley. Each one contained dozens of wheels similar to these. Different wiring configurations were tested by the bombes at high speed until a possible match to that day's Enigma settings had been found. The device would then stop, and the settings were checked on a smaller 'checking machine'. After the war ended the bombes were broken up and destroyed. However, these wheels from a checking machine survived, leaving us a tangible reminder of Turing's wartime achievements.

Punched-card machine

by British Tabulating Machines, c. 1930

Bletchley Park's work also involved industrial-scale information-handling to manage the huge number of intercepted German messages. In the 1930s commercial data-processing was the preserve of punched-card machines. Many British Tabulating Machines (BTM) devices, branded 'Hollerith' after their inventor, were installed at Bletchley Park. This identical machine was given to the Science Museum by BTM in 1932.

Alan Turing's war

3. ACE – the Automatic Computing Engine

After the Second World War, Alan Turing was asked to put his theories and experience into action by developing a ground-breaking computer at the government's National Physical Laboratory. His first specifications were written in 1945.

Following administrative delays, Turing left the project in 1948, but a trial version (known as Pilot ACE) was completed in 1950. It is now the most significant Turing artefact in existence.

Yet the Pilot ACE computer was more than just a trial. It was used for several years by a variety of external customers desperate to employ its computing power. It also became a public celebrity, referred to as Turing's 'electronic brain'.

The Pilot ACE computer, 1950

This was one of the first electronic 'universal' computers. Its fundamental design was by Alan Turing, who wrote the specification in 1945 while working at the government's National Physical Laboratory. It was completed in 1950. Turing's idea was to build a large computer, to be known as the Automatic Computing Engine or ACE. But slow progress, coupled with changes in project direction imposed on Turing, left him deeply frustrated, and he quit in 1948. This small-scale trial version, called Pilot ACE, was completed in his absence.

Demonstrating the 'electronic brain', 1950

The Pilot ACE computer, conceived by Alan Turing in 1945, was both fast and complicated. But this caused a problem. How could its operation be demonstrated to non-specialists? The answer lay in this specially made simulator, which showed how binary digits were manipulated by the computer – but at much slower speed. In January 1950 it was shown at the Royal Society's library in central London.

ACE – the Automatic Computing Engine

Wreckage from a Comet jet aircraft, 1954

Alan Turing's pioneering electronic computer immediately proved its power in a life-saving race against time, following a series of fatal air crashes. Known as Comets, the world's first jet airliners entered passenger service in 1952 to huge public acclaim. Two years later, a Comet crashed into the Mediterranean near Italy, killing all 35 on board. This is part of its fuselage. Wreckage was recovered from the seabed and sent to the Royal Aircraft Establishment in Farnborough where, along with an undamaged Comet, it was subjected to exhaustive testing. The investigation relied on a huge amount of high-speed computation provided by the Pilot ACE computer.

Model of vitamin B12 by Dorothy Hodgkin, c. 1957

By the 1950s electronic computers, including Alan Turing's Pilot ACE, were being pressed into service by scientists struggling to unlock the patterns of the body's own chemistry. Dorothy Hodgkin was a chemist who developed pioneering methods for understanding the structure of complex molecules such as vitamins and insulin, which are crucial in the functioning of the human body. This model of vitamin B12 was presented by her to the Science Museum in 1959. It represented the culmination of years of study, supported by computation carried out by the Pilot ACE and several other computers.

ACE – the Automatic Computing Engine

4. Can machines think?

In 1927, aged 14, Alan Turing began a close friendship with a boy at his school, Christopher Morcom. Three years later, Morcom died, aged 18, from tuberculosis. While grieving, Turing wrote a short essay expressing his belief that the human spirit can live outside the body.

Throughout the rest of his life, Turing grappled with ideas about human thought. As he developed electronic computers in the 1940s and 1950s, he debated whether machines could be made to think like people, and published a seminal paper on the subject.

Games such as chess formed a crucial part of this early work, with Turing and others writing computer versions. One of Turing's protégés, Dietrich Prinz, also built an electrical 'logic machine', inspired by a Victorian device made 80 years before. Others also attempted to simulate thought processes in machines resembling animals. These 'thinking machines' quickly captured public interest.

Can machines think?

Letter from Alan Turing to Mrs Morcom, 1930

Christopher Morcom, Alan Turing's teenage friend, died in February 1930 from tuberculosis. Turing was heartbroken, as he was devoted to Morcom. Shortly after, Turing wrote this letter to Morcom's mother to express his condolences. He made clear the intensity of his feelings for Morcom, and explained, 'I know I must put as much energy if not as much interest into my work as if he were alive, because that is what he would like me to do.'

'Impressions of Chris', by Alan Turing, 1930

Four months after Christopher Morcom's death in 1930, Turing sent Mrs Morcom this set of recollections about their friendship, entitled 'Impressions of Chris'. In it he admitted, 'Of course I simply worshipped the ground he trod on – a thing which I did not make much attempt to disguise, I am sorry to say.' He also revealed that he had experienced dark premonitions before Morcom died. 'Some time before Chris's death', he explained, 'I had presentiments about him that were surprising in their accuracy ... That Chris would soon die kept coming to me.'

Can machines think?

'The Nature of Spirit', by Alan Turing, 1932

Alan Turing wrote this short essay for Mrs Morcom in 1932. In it he expressed complex ideas about the human mind and his belief that it could survive after the death of the body. Certain passages offer a foretaste of the work he published some 20 years later on machine intelligence. 'Personally', he wrote, 'I think that spirit is really eternally connected with matter, but certainly not always by the same kind of body ... when the body dies the "mechanism" of the body, holding the spirit is gone and the spirit finds a new body sooner or later perhaps immediately.'

Electrical logic machine

by Dietrich Prinz and Wolfe Mays, 1949

This machine was made at Manchester University by physicist Dietrich Prinz, one of Alan Turing's protégés, and Wolfe Mays, a 36-year-old philosophy lecturer. It is an electrical device for testing logical propositions, built mostly from RAF spare parts left over from the Second World War, and was unique in Britain at the time.

Can machines think?

Mechanical logic machine **by William Stanley Jevons, 1869**

This Victorian machine profoundly influenced Dietrich Prinz and Wolfe Mays in their construction of the electrical logic machine displayed alongside. It was made in 1869 by William Stanley Jevons, professor of logic at Manchester University, and it performed logical operations mechanically.

Cybernetic tortoise **by William Grey Walter, c. 1950**

This 'tortoise' was made by neurologist William Grey Walter as an 'artificial animal' to investigate brain function. It travelled around floors, avoiding obstacles, and was attracted to light. Alan Turing knew Grey Walter well, being a fellow member of the influential 'Ratio Club' for cybernetics researchers.

Can machines think?

5. A matter of life and death

In 1948, Turing moved to Manchester University to work on a ground-breaking stored-program computer. He used subsequent versions of it to develop mathematical theories of morphogenesis – growth and patterns in plants and animals. His ideas are only today being fully appreciated.

Four years later, following a relationship with a local man, Arnold Murray, Turing was arrested under anti-homosexuality legislation and convicted of 'gross indecency'. At this time doctors were experimenting with ways to 'treat' gay people. Given a choice of imprisonment or a one-year course of female hormones, Turing opted for the latter.

Nevertheless, during his sentence and for several months afterwards Turing continued to work on his morphogenesis research. Indeed, on the day after his arrest he delivered an important lecture on the subject. Yet, in unexplained circumstances, he was found dead in his bed in 1954. The official verdict was suicide.

A matter of life and death

Programming the Turing machine

In 1948, Alan Turing moved to Manchester University to lead software development for pioneering computers being developed there. He also wrote a programmers' handbook. Turing had designed his own computer in 1945 at the National Physical Laboratory (NPL), but delays to the project, combined with changes in its management, led him to resign in 1948. In his absence, a cut-down version was only completed in 1950. With these delays, the NPL had lost out on building the world's first stored-program computer. Manchester beat the NPL to it with their first machine, completed in June 1948, followed quickly by the two larger versions that Turing worked on.

Decoding the patterns of life

In February 1952, Alan Turing gave a lecture to the influential 'Ratio Club' of academics studying cybernetics, of which he was a member. The subject of his lecture was morphogenesis – the study of pattern formation and growth in nature. The link between mathematics, chemistry and life had long interested Turing, but his access to the powerful new electronic computer at Manchester University gave him the opportunity to explore his ideas in much greater depth.

A matter of life and death

'His mind had become unbalanced'

Until the late 1960s, most homosexual acts were illegal. Many people lived in constant fear of being caught by police, prosecuted and either imprisoned or fined.

Lives were routinely destroyed in the aftermath of such humiliating events. People were often sacked from their jobs and ostracised by families, friends and the wider community. Some felt suicide was the only option. In parallel, scientists and doctors were experimenting with ways to 'cure' gay people or remove their sexual urges.

In 1952, Turing was arrested for a sexual relationship with a man, and sentenced to a one-year course of female hormone treatment. At the time he had been advising the government on secret codebreaking projects, but his security clearance was revoked and he was later placed under surveillance. Two years after his arrest, in 1954, Turing was found dead at his Wilmslow home. The official verdict was suicide from cyanide poisoning, the coroner believing 'his mind had become unbalanced'.

A matter of life and death

Bottle of oestrogen female hormone pills, c. 1950

In 1949 neuroscientist Frederick Golla published the first British results of experiments on the use of the female hormone oestrogen to reduce the libido of sexual offenders. Three years later, Alan Turing was sentenced to oestrogen treatment as an alternative to imprisonment for 'gross indecency', following a sexual relationship. He had to fight to keep his job at Manchester University.

Reproduction of Alan Turing's postmortem examination report, 1954

On 7 June 1954, Alan Turing died. The pathologist carried out an examination two days later, finding fluid in Turing's stomach he believed to be cyanide solution. A pan of the solution had been found bubbling on a stove, and by Turing's bed was a half-eaten apple. The pathologist concluded that Turing had died from cyanide poisoning, the apple being used to take away some of the taste. The coroner recorded a verdict of suicide.

A matter of life and death

6. Programming computers today

Alan Turing was fundamental in shaping the practice we now call 'programming'. In his day, there existed just a handful of computers in the world. Today there are billions, embedded into every aspect of our daily lives, and each one needs to be programmed.

A culture of computer programming now exists which involves more people than ever before. It is a rewarding activity open to anyone. This series of interactive exhibits distils down the basic principles of programming. They help reveal how computer programs work.

Looping

Programs are sets of instructions for a computer to carry out. But sometimes the same type of instruction can be repeated several times within a program. For instance, a program might need to read information or 'data' from input devices such as punched cards a certain number of times.

The same section of program might be used to look at each card in turn to see what information it holds. This is one example of 'looping'. You can explore how looping works at this exhibit.

Variables

Computer programs are all about handling information and data. The programs contain instructions on what to do with the data. The data can change but the programs will always use them in the same way. For instance, a program might be used to control the movement of a mechanical device such as a robot arm, using motors to set the arm at certain angles.

The angles will vary depending on what the user wants the arm to do. The program needs a way to handle these changing quantities. It does so using 'variables'. You can explore how variables work at this exhibit.

Programming computers today

Conditionals

Computers have to make decisions at certain points in the program. For instance, a program might be operating lights in a building. It would have to decide whether to turn each individual light on or off according to rules set by the user.

A simple rule might be, 'if the room is dark, then the light should be switched on'. Or it might be more complicated than that, with lighting being conditional on the room being occupied. These decisions are known as 'conditionals'. You can explore how conditionals work at this exhibit.

The Science Museum thanks the following people and organisations for their invaluable advice and support in the development of this exhibition:

Age UK Camden's 'Opening Doors London' project

Bletchley Park Trust

Daniela Derbyshire

GCHQ

Professor Simon Lavington and the Computer Conservation Society

National Physical Laboratory

Sir John Dermot Turing

Mike Woodger

The Museum is also most grateful to all those who have lent objects, taken part in interviews and provided historic images for display in the exhibition.

This exhibition was made possible with the support of Google.



www.sciencemuseum.org.uk/turing