# Alan Turing

Alan Mathison Turing, OBE, FRS (pronounced /ˈtjʊ(ə)rɪŋ/) (23 June 1912 – 7 June 1954) was a British mathematician, logician, cryptanalyst and computer scientist.

Turing is often considered to be the father of modern computer science. He provided an influential formalisation of the concept of the algorithm and computation with the Turing machine. In 1999 Time Magazine named Turing as one of the 100 Most Important People of the 20th Century for his role in the creation of the modern computer, stating: "The fact remains that everyone who taps at a keyboard, opening a spreadsheet or a word-processing program, is working on an incarnation of a Turing machine."[1]

With the Turing test, meanwhile, he made a significant and characteristically provocative contribution to the debate regarding artificial intelligence: whether it will ever be possible to say that a machine is conscious and can think. He later worked at the National Physical Laboratory, creating one of the first designs for a stored-program computer, the ACE, although it was never actually built in its full form. In 1948, he moved to the University of Manchester to work on the Manchester Mark 1, then emerging as one of the world's earliest true computers.

During the Second World War, Turing worked at Bletchley Park, Britain's codebreaking centre, and was for a time head of Hut 8, the section responsible for German naval cryptanalysis. He devised a number of techniques for breaking German ciphers, including the method of the bombe, an electromechanical machine that could find settings for the Enigma machine.

Near the end of his life Turing became interested in chemistry. He wrote a paper on the chemical basis of morphogenesis[2] and he predicted oscillating chemical reactions such as the Belousov–Zhabotinsky reaction, which were first observed in the 1960s.

Turing was homosexual, living in an era when homosexuality was considered a mental illness and homosexual acts were illegal. Subsequent to his being outed, he was criminally prosecuted in 1952, which essentially ended his career. He died not long after from what was officially declared self-induced cyanide poisoning, although his mother (and some others) considered the circumstances of his death to be suspicious.

## Childhood and youth

Alan Turing was conceived in Chhatrapur, Orissa, India.[3] His father, Julius Mathison Turing, was a member of the Indian Civil Service. Julius and wife Sara (née Stoney; 1881 – 1976, daughter of Edward Waller Stoney, chief engineer of the Madras Railways) wanted Alan to be brought up in England, so they returned to Maida Vale,[4] London, where Alan Turing was born on 23 June 1912, as recorded by a blue plaque on the outside of the building, now the Colonnade Hotel.[5][6] He had an elder brother, John. His father's civil service commission was still active, and during Turing's childhood years his parents travelled between Guildford, England and India, leaving their two sons to stay with friends in Hastings in England.[7] Very early in life, Turing showed signs of the genius he was to display more prominently later.[8]

His parents enrolled him at St Michael's, a day school, at the age of six. The headmistress recognised his talent early on, as did many of his subsequent educators. In 1926, at the age of 14, he went on to Sherborne School, a famous and expensive public school in Dorset. His first day of term coincided with the General Strike in Britain, but so determined was he to attend his first day that he rode his bicycle unaccompanied more than 60 miles (97 km) from Southampton to school, stopping overnight at an inn.[9]

Turing's natural inclination toward mathematics and science did not earn him respect with some of the teachers at Sherborne, whose definition of education placed more emphasis on the classics. His headmaster wrote to his parents: "I hope he will not fall between two stools. If he is to stay at Public School, he must aim at becoming educated. If he is to be solely a Scientific Specialist, he is wasting his time at a Public School".[10]

Despite this, Turing continued to show remarkable ability in the studies he loved, solving advanced problems in 1927 without having even studied elementary calculus. In 1928, aged 16, Turing encountered Albert Einstein's work; not only did he grasp it, but he extrapolated Einstein's questioning of Newton's laws of motion from a text in which this was never made explicit.[11]

Turing's hopes and ambitions at school were raised by the close friendship he developed with a slightly older fellow student, Christopher Morcom, who was Turing's first love interest. Morcom died suddenly only a few weeks into their last term at Sherborne, from complications of bovine tuberculosis, contracted after drinking infected cow's milk as a boy.[12] Turing's religious faith was shattered and he became an atheist. He adopted the conviction that all phenomena, including the workings of the human brain, must be materialistic.[13]

## University and his work on computability

Turing's unwillingness to work as hard on his classical studies as on science and mathematics meant failure to win a scholarship to Trinity College, Cambridge, and he went on to the college of his second choice, King's College, Cambridge. He was an undergraduate there from 1931 to 1934, graduating with a distinguished degree, and in 1935 was elected a fellow at King's on the strength of a dissertation on the central limit theorem.

In his momentous paper "On Computable Numbers, with an Application to the Entscheidungsproblem"[14] (submitted on 28 May 1936), Turing reformulated Kurt Gödel's 1931 results on the limits of proof and computation, replacing Gödel's universal arithmetic-based formal language with what are now called Turing machines, formal and simple devices. He proved that some such machine would be capable of performing any conceivable mathematical computation if it were representable as an algorithm.

Turing machines are to this day the central object of study in theory of computation. He went on to prove that there was no solution to the Entscheidungsproblem by first showing that the halting problem for Turing machines is undecidable: it is not possible to decide, in general, algorithmically whether a given Turing machine will ever halt. While his proof was published subsequent to Alonzo Church's equivalent proof in respect to his lambda calculus, Turing's work is considerably more accessible and intuitive. It was also novel in its notion of a 'Universal (Turing) Machine', the idea that such a machine could perform the tasks of any other machine. "Universal" in this context means what is now called programmable. The paper also introduces the notion of definable numbers.

From September 1936 to July 1938 he spent most of his time at the Institute for Advanced Study, Princeton University, studying under Alonzo Church. As well as his pure mathematical work, he studied cryptology and also built three of four stages of an electro-mechanical binary multiplier.[15] In June 1938 he obtained his Ph.D. from Princeton; his dissertation introduced the notion of relative computing, where Turing machines are augmented with so-called oracles, allowing a study of problems that cannot be solved by a Turing machine.

Back in Cambridge, he attended lectures by Ludwig Wittgenstein about the foundations of mathematics.[16] The two argued and disagreed, with Turing defending formalism and Wittgenstein arguing that mathematics does not discover any absolute truths but rather invents them.[17] He also started to work part-time with the Government Code and Cypher School (GCCS).

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## Cryptanalysis

During the Second World War, Turing was a main participant in the efforts at Bletchley Park to break German ciphers. Building on cryptanalysis work carried out in Poland by Marian Rejewski, Jerzy Różycki and Henryk Zygalski from Cipher Bureau before the war, he contributed several insights into breaking both the Enigma machine and the Lorenz SZ 40/42 (a Teletype cipher attachment codenamed "Tunny" by the British), and was, for a time, head of Hut 8, the section responsible for reading German naval signals.

Since September 1938, Turing had been working part-time for the Government Code and Cypher School (GCCS), the British code breaking organisation. He worked on the problem of the German Enigma machine, and collaborated with Dilly Knox, a senior GCCS codebreaker.[18] On 4 September 1939, the day after the UK declared war on Germany, Turing reported to Bletchley Park, the wartime station of GCCS.[19]

### Turing–Welchman bombe

Within weeks of arriving at Bletchley Park,[19] Turing had designed an electromechanical machine which could help break Enigma faster than bomba from 1932, the bombe, named after and building upon the original Polish-designed bomba. The bombe, with an enhancement suggested by mathematician Gordon Welchman, became one of the primary tools, and the major automated one, used to attack Enigma-protected message traffic.

Professor Jack Good, cryptanalyst working at the time with Turing at Bletchley Park, later said: "Turing's most important contribution, I think, was of part of the design of the bombe, the cryptanalytic machine. He had the idea that you could use, in effect, a theorem in logic which sounds to the untrained ear rather absurd; namely that from a contradiction, you can deduce everything."[20]

The bombe searched for possibly correct settings used for an Enigma message (i.e., rotor order, rotor settings, etc.), and used a suitable "crib": a fragment of probable plaintext. For each possible setting of the rotors (which had of the order of 1019 states, or 1022 for the U-boat Enigmas which eventually had four rotors, compared to the usual Enigma variant's three),[21] the bombe performed a chain of logical deductions based on the crib, implemented electrically. The bombe detected when a contradiction had occurred, and ruled out that setting, moving onto the next. Most of the possible settings would cause contradictions and be discarded, leaving only a few to be investigated in detail. Turing's bombe was first installed on 18 March 1940.[22] Over two hundred bombes were in operation by the end of the war.[23]

### Hut 8 and Naval Enigma

In December 1940, Turing solved the naval Enigma indicator system, which was more mathematically complex than the indicator systems used by the other services. Turing also invented a Bayesian statistical technique termed "Banburismus" to assist in breaking naval Enigma. Banburismus could rule out certain orders of the Enigma rotors, reducing time needed to test settings on the bombes.

In the spring of 1941, Turing proposed marriage to Hut 8 co-worker Joan Clarke, although the engagement was broken off by mutual agreement in the summer.

In July 1942, Turing devised a technique termed Turingismus or Turingery for use against the Lorenz cipher used in the Germans' new Geheimschreiber machine ("secret writer") which was one of those codenamed "Fish". He also introduced the Fish team to Tommy Flowers who, under the guidance of Max Newman, went on to build the Colossus computer, the world's first programmable digital electronic computer, which replaced simpler prior machines (including the "Heath Robinson") and whose superior speed allowed the brute-force decryption techniques to be applied usefully to the daily-changing cyphers.[24] A frequent misconception is that Turing was a key figure in the design of Colossus; this was not the case.[25]

While working at Bletchley, Turing, a talented long-distance runner, occasionally ran the 40 miles to London when he was needed for high-level meetings.[26]

Turing travelled to the United States in November 1942 and worked with U.S. Navy cryptanalysts on Naval Enigma and bombe construction in Washington, and assisted at Bell Labs with the development of secure speech devices. He returned to Bletchley Park in March 1943. During his absence, Hugh Alexander had officially assumed the position of head of Hut 8, although Alexander had been de facto head for some time—Turing having little interest in the day-to-day running of the section. Turing became a general consultant for cryptanalysis at Bletchley Park.

In the latter part of the war he moved to work at Hanslope Park, where he further developed his knowledge of electronics with the assistance of engineer Donald Bailey. Together they undertook the design and construction of a portable secure voice communications machine codenamed Delilah.[27] It was intended for different applications, lacking capability for use with long-distance radio transmissions, and in any case, Delilah was completed too late to be used during the war. Though Turing demonstrated it to officials by encrypting/decrypting a recording of a Winston Churchill speech, Delilah was not adopted for use.

In 1945, Turing was awarded the OBE for his wartime services, but his work remained secret for many years. A biography published by the Royal Society shortly after his death recorded:

Three remarkable papers written just before the war, on three diverse mathematical subjects, show the quality of the work that might have been produced if he had settled down to work on some big problem at that critical time. For his work at the Foreign Office he was awarded the OBE.

—Newman, M. H. A. (1955). Alan Mathison Turing. Biographical Memoirs of Fellows of the Royal Society, 1955, Volume 1. The Royal Society.

## Early computers and the Turing test

From 1945 to 1947 he was at the National Physical Laboratory, where he worked on the design of the ACE (Automatic Computing Engine). He presented a paper on 19 February 1946, which was the first detailed design of a stored-program computer.[28] Although ACE was a feasible design, the secrecy surrounding the wartime work at Bletchley Park led to delays in starting the project and he became disillusioned. In late 1947 he returned to Cambridge for a sabbatical year. While he was at Cambridge, the Pilot ACE was built in his absence. It executed its first program on 10 May 1950.

In 1948 he was appointed Reader in the Mathematics Department at Manchester. In 1949 he became deputy director of the computing laboratory at the University of Manchester, and worked on software for one of the earliest stored-program computers—the Manchester Mark 1. During this time he continued to do more abstract work, and in "Computing machinery and intelligence" (Mind, October 1950), Turing addressed the problem of artificial intelligence, and proposed an experiment now known as the Turing test, an attempt to define a standard for a machine to be called "intelligent". The idea was that a computer could be said to "think" if it could fool an interrogator into thinking that the conversation was with a human. In the paper, Turing suggested that rather than building a program to simulate the adult mind, it would be better rather to produce a simpler one to simulate a child's mind and then to subject it to a course of education.

In 1948, Turing, working with his former undergraduate colleague, D.G. Champernowne, began writing a chess program for a computer that did not yet exist. In 1952, lacking a computer powerful enough to execute the program, Turing played a game in which he simulated the computer, taking about half an hour per move. The game was recorded;[29] the program lost to Turing's colleague Alick Glennie, although it is said that it won a game against Champernowne's wife.

## Pattern formation and mathematical biology

Turing worked from 1952 until his death in 1954 on mathematical biology, specifically morphogenesis. He published one paper on the subject called "The Chemical Basis of Morphogenesis" in 1952, putting forth the Turing hypothesis of pattern formation.[30] His central interest in the field was understanding Fibonacci phyllotaxis, the existence of Fibonacci numbers in plant structures. He used reaction–diffusion equations which are now central to the field of pattern formation. Later papers went unpublished until 1992 when Collected Works of A.M. Turing was published.

## Conviction for gross indecency

In January 1952 Turing picked up the 19-year-old Arnold Murray outside a cinema in Manchester. After a lunch date, Turing invited Murray to spend the weekend with him at his house, an invitation which Murray accepted although he did not show up. The pair met again in Manchester the following Monday, when Murray agreed to accompany Turing to the latter's house. A few weeks later Murray visited Turing's house again, and apparently spent the night there.[31]

After Murray helped an accomplice to break into his house, Turing reported the crime to the police. During the investigation Turing acknowledged a sexual relationship with Murray. Homosexual acts were illegal in the United Kingdom at that time,[5] and so both were charged with gross indecency under Section 11 of the Criminal Law Amendment Act 1885, the same crime that Oscar Wilde had been convicted of more than fifty years earlier.[32]

Turing was given a choice between imprisonment or probation conditional on his agreement to undergo hormonal treatment designed to reduce libido. He accepted chemical castration via oestrogen hormone injections,[33] which lasted for a year. One of the known side effects of these hormone injections was the development of breasts, known as gynecomastia, something which plagued Turing for the rest of his life. Turing's conviction led to the removal of his security clearance, and barred him from continuing with his cryptographic consultancy for GCHQ. At the time, there was acute public anxiety about spies and homosexual entrapment by Soviet agents, possibly due to the recent exposure of the first two members of the Cambridge Five, Guy Burgess and Donald Maclean, as KGB double agents. Turing was never accused of espionage but, as with all who had worked at Bletchley Park, was prevented from discussing his war work.

## Death

On 8 June 1954, Turing's cleaner found him dead; the previous day, he had died of cyanide poisoning, apparently from a cyanide-laced apple he left half-eaten beside his bed. The apple itself was never tested for contamination with cyanide, but a post-mortem established that the cause of death was cyanide poisoning. Most believe that his death was intentional, and the death was ruled a suicide.

His mother, however, strenuously argued that the ingestion was accidental due to his careless storage of laboratory chemicals. Biographer Andrew Hodges suggests that Turing may have killed himself in this ambiguous way quite deliberately, to give his mother some plausible deniability.[34] Others suggest that Turing was re-enacting a scene from Snow White, his favourite fairy tale.[35]

Because Turing's homosexuality was perceived as a security risk, the possibility of assassination has also been suggested.[36] Supporters of the assassination theory[who?] point out that Turing's British passport was not revoked after his conviction, although he was denied entry to the United States. He was still free to teach mathematics and to travel to other European countries, which he did many times.

His remains were cremated at Woking crematorium on 12 June 1954.

## Posthumous recognition

Since 1966, the Turing Award has been given annually by the Association for Computing Machinery to a person for technical contributions to the computing community. It is widely considered to be the computing world's equivalent to the Nobel Prize.[37]

Breaking the Code is a 1986 play by Hugh Whitemore about Alan Turing. The play ran in London's West End beginning in November 1986 and on Broadway from November 15, 1987 to April 10, 1988. There was also a 1996 BBC television production. In all cases, Derek Jacobi had the title role. The Broadway production was nominated for three Tony Awards including Best Actor in a Play, Best Featured Actor in a Play, and Best Direction of a Play, and for two Drama Desk Awards, for Best Actor and Best Featured Actor.

Various tributes to Turing have been made in Manchester, the city where he worked towards the end of his life. In 1994 a stretch of the A6010 road (the Manchester city intermediate ring road) was named Alan Turing Way. A bridge carrying this road was widened, and carries the name Alan Turing Bridge.

A statue of Turing was unveiled in Manchester on 23 June 2001. It is in Sackville Park, between the University of Manchester building on Whitworth Street and the Canal Street 'gay village'. A celebration of Turing's life and achievements arranged by the British Logic Colloquium and the British Society for the History of Mathematics was held on 5 June 2004 at the University of Manchester; the Alan Turing Institute was initiated in the university that summer. The building housing the School of Mathematics, the Photon Science Institute and the Jodrell Bank Centre for Astrophysics is named the Alan Turing Building and was opened in July 2007.

On 23 June 1998, on what would have been Turing's 86th birthday, Andrew Hodges, his biographer, unveiled an official English Heritage Blue Plaque at his birthplace and childhood home in Warrington Crescent, London, now the Colonnade hotel.[38][39] To mark the 50th anniversary of his death, a memorial plaque was unveiled on 7 June 2004 at his former residence, Hollymeade, in Wilmslow, south of Manchester.

For his achievements in computing, various universities have honoured him. On 28 October 2004 a bronze statue of Alan Turing sculpted by John W Mills was unveiled at the University of Surrey in Guildford.[40] The statue marks the 50th anniversary of Turing's death. It portrays him carrying his books across the campus. Turing Road in the University's Research Park predates this.

A building in the School of Technology at Oxford Brookes University is called the Turing Building.

The Polytechnic University of Puerto Rico and Los Andes University in Bogotá, Colombia, both have computer laboratories named after Turing, and Aarhus University, Århus, Denmark similarly has a building named in his honour. The University of Texas at Austin has an honours computer science programme named the Turing Scholars.[41] Istanbul Bilgi University organises an annual conference on the theory of computation called Turing Days.[42] The computer room in King's College, Cambridge is named the "Turing Room" after him. Carnegie Mellon University has a granite bench, situated in The Hornbostel Mall, with the name "A. M. Turing" carved across the top, "Read" down the left leg, and "Write" down the other. The Boston GLBT pride organization named Turing their 2006 Honorary Grand Marshal.[43]

Alan Turing also appears in 2000 novel Cryptonomicon by Neal Stephenson. In the novel, Turing is depicted as his real life persona and his work at Bletchley Park is covered.

On 13 March 2000, St Vincent & The Grenadines issued a set of stamps to celebrate the greatest achievements of the twentieth century, one of which carries a recognisable portrait of Turing against a background of repeated 0s and 1s, and is captioned '1937: Alan Turing's theory of digital computing'.

A 1.5-ton, life-size statue of Turing was unveiled on 19 June 2007 at Bletchley Park. Built from approximately half a million pieces of Welsh slate, it was sculpted by Stephen Kettle, having been commissioned by the late American billionaire Sidney Frank.[44]

The Turing Relay[45] is a six-stage relay race on riverside footpaths from Ely to Cambridge and back. These paths were used for running by Turing while at Cambridge; his marathon best time was 2 hours, 46 minutes.[46] The marathon world best time in the early 1940s was in the region of 2 hours, 25 minutes.

In August 2009 a petition was started by John Graham-Cumming urging the British Government to retrospectively apologise to Alan Turing for prosecuting him as a homosexual.[47][48]

## See also

* ***Unorganized machine***
* ***Good–Turing frequency estimation***
* ***Philosophy of information***
* ***Turing Days***
* ***Turing degree***
* ***Turing switch***
* ***Alan Turing Year***

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