Alan Turing — a short biography

by Andrew Hodges

This short biography, based on the entry for the written in 1995 for the Oxford *Dictionary of Scientific Biography*, gives an overview of Alan Turing's life and work. It can be read as s summary of my book *Alan Turing: The Enigma*.

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1. The Origins of Alan Turing

Alan Mathison Turing was born on 23 June 1912, the second and last child (after his brother John) of Julius Mathison and Ethel Sara Turing. The unusual name of Turing placed him in a distinctive family tree of English gentry, far from rich but determinedly upper-middle-class in the peculiar sense of the English class system. His father Julius had entered the Indian Civil Service, serving in the Madras Presidency, and had there met and married Ethel Sara Stoney. She was the daughter of the chief engineer of the Madras railways, who came from an Anglo-Irish family of somewhat similar social status. Although conceived in British India, most likely in the town of Chatrapur, Alan Turing was born in a nursing home in Paddington, London.

In four inadequate words Alan Turing appears now as the founder of computer science, the originator of the dominant technology of the late twentieth century, but these words were not spoken in his own lifetime, and he may yet be seen in a different light in the future. They are also words very remote from the circumstances of his birth and infancy.

The name of Turing was best known for the work of Julius' brother H. D. Turing on fly fishing, and had no connection with the scientific or academic worlds. The name of Stoney however was notable for a remote relative, the Irish physicist George Johnstone Stoney (1826-1911), today best known for his identification of the natural units of physical quantities. Possibly the engineering base of his mother's family, with its respect for applied science, had some influence, but if so it was subordinated to the demands of class, church and Empire. Certainly the elder brother John F. Turing, who became a London solicitor, showed no sign of it. Alan Turing's story was not one of family or tradition but of an isolated and autonomous mind.

Alan Turing shared with his brother a childhood rigidly determined by the demands of class and the exile in India of his parents. Until his father's retirement from India in 1926, Alan Turing and his elder brother John were fostered in various English homes where nothing encouraged expression, originality, or discovery. Science for him was an extra-curricular passion, first shown in primitive chemistry experiments. But he was given, and read, later commenting on its seminal influence, a popular book called *Natural Wonders Every Child Should Know.*

His boyhood scientific interests were a trial to his mother whose perpetual terror was that he would not be acceptable to the English Public School. At twelve he expressed his conscious fascination with using 'the thing that is commonest in nature and with the least waste of energy,' presentiment of a life seeking freshly minted answers to fundamental questions. Despite this, he was successfully entered for Sherborne School. The headmaster soon reported: "If he is to be solely a Scientific Specialist, he is wasting his time at a Public School." The assessment of his establishment was almost correct.

2. Matter and Spirit

Turing's private notes on the theory of relativity showed a degree-level appreciation, yet he was almost prevented from taking the School Certificate lest he shame the school with failure. But it appears that the stimulus for effective communication and competition came only from contact with another very able youth, a year ahead of him at Sherborne, to whom Alan Turing found himself powerfully attracted in 1928. He, Christopher Morcom, gave Turing a vital period of intellectual companionship — which ended with Morcom's sudden death in February 1930.

Turing's conviction that he must now do what Morcom could not, apparently sustained him through a long crisis. For three years at least, as we know from his letters to Morcom's mother, his thoughts turned to the question of how the human mind, and Christopher's mind in particular, was embodied in matter; and whether accordingly it could be released from matter by death.

This question led him deeper into the area of twentieth century physics, first helped by A. S. Eddington's book *The Nature of the Physical World,* wondering whether quantum-mechanical theory affected the traditional problem of mind and matter.

As an undergraduate at King's College, Cambridge from 1931, he entered a world more encouraging to free-ranging thought. His 1932 reading of the then new work of von Neumann on the logical foundations of quantum mechanics, helped the transition from emotional to rigorous intellectual enquiry. At the same time, this was when his homosexuality became a definitive part of his identity. The special ambience of King's College gave him a first real home. His association with the so-called anti-War movement of 1933 did not develop into Marxism, nor into the pacifism of his friend and occasional lover James Atkins, then a fellow undergraduate mathematician, later musician. He was closer in thought to the liberal-left economists J. M. Keynes and A. C. Pigou. His relaxations were found not in the literary circles generally associated with the King's College homosexual milieu, but in rowing, running, and later in sailing a small boat.

Turing's progress seemed assured, A distinguished degree in 1934 followed by a Fellowship of King's College in 1935 and a Smith's Prize in 1936 for work on probability theory, and he might then have seemed on course for a successful career as a mildly eccentric King's don engaged in pure mathematics. His uniqueness of mind, however, drove him in a direction none could have foreseen.

By 1933 Turing had already introduced himself to Russell and Whitehead's *Principia Mathematica* and so to the then arcane area of mathematical logic. Bertrand Russell had thought of logic as a solid foundation for mathematical truth, but many questions had since been raised about how truth could be captured by any formalism. In particular, in 1931 Gödel had shattered Russell's picture by showing the incompleteness of mathematics: the existence of true statements about numbers which could not be proved by the formal application of set rules of deduction. In 1935, Turing learnt from the lecture course of the Cambridge topologist M. H. A. Newman that a further question, posed by Hilbert, still lay open. It was the question of Decidability, the *Entscheidungsproblem.* Could there exist, at least in principle, a definite method or process by which it could be decided whether any given mathematical assertion was provable?

To answer such a question needed a definition of 'method' which would be not only precise but compelling. This is what Turing supplied. He analysed what could be achieved by a person performing a methodical process, and seizing on the idea of something done 'mechanically', expressed the analysis in terms of a theoretical machine able to perform certain precisely defined elementary operations on symbols on paper tape. He presented convincing arguments that the scope of such a machine was sufficient to encompass everything that would count as a 'definite method.' Daringly he included an argument based on the transitions between 'states of mind' of a human being performing a mental process.

3. The Turing machine

This triple correspondence between logical instructions, the action of the mind, and a machine which could in principle be embodied in a practical physical form, was Turing's definitive contribution. Having made this novel definition of what should count as a 'definite method' — in modern language, an algorithm — it was not too hard to answer Hilbert's question in the negative: no such decision procedure exists.

In April 1936 he showed his result to Newman; but at the same moment the parallel conclusion of the American logician Alonzo Church became known, and Turing was robbed of the full reward for his originality. His paper, *On Computable Numbers with an application to the Entscheidungsproblem,* had to refer to Church's work, and was delayed until August 1936. However it was seen at the time that Turing's approach was original and different; Church relied upon an assumption internal to mathematics, rather than appealing to operations that could actually be done by real things or people in the physical world. Subsequently, the concept of the **Turing machine** has become the foundation of the modern theory of computation and computability.

Turing worked in isolation from the powerful school of logical theory centred on Church at Princeton University, and his work emerged as that of a complete outsider. One can only speculate, but it looks as if Turing found in the concept of the Turing machine something that would satisfy the fascination with the problem of Mind that Christopher Morcom had sparked; his total originality lay in seeing the relevance of mathematical logic to a problem originally seen as one of physics. In this paper, as in so many aspects of his life, Turing made a bridge between the logical and the physical worlds, thought and action, which crossed conventional boundaries.

His work introduced a concept of immense practical significance: the idea of the Universal Turing Machine. The concept of 'the Turing machine' is like that of 'the formula' or 'the equation'; there is an infinity of possible Turing machines, each corresponding to a different 'definite method' or algorithm. But imagine, as Turing did, each particular algorithm written out as a set of instructions in a standard form. Then the work of interpreting the instructions and carrying them out is *itself* a mechanical process, and so can *itself* be embodied in a particular Turing machine, namely the *Universal* Turing machine. A Universal Turing machine can be made do what any other particular Turing machine would do, by supplying it with the standard form describing that Turing machine. One machine, for all possible tasks.

It is hard now not to think of a Turing machine as a computer program, and the mechanical task of interpreting and obeying the program as what the computer itself does. Thus, the Universal Turing Machine embodies the essential principle of the computer: a single machine which can be turned to any well-defined task by being supplied with the appropriate program.

Additionally, the abstract Universal Turing Machine naturally exploits what was later seen as the 'stored program' concept essential to the modern computer: it embodies the crucial twentieth-century insight that symbols representing instructions are no different in kind from symbols representing numbers. But computers, in this modern sense, did not exist in 1936. Turing created these concepts out of his mathematical imagination. Only nine years later would electronic technology be tried and tested sufficiently to make it practical to transfer the logic of his ideas into actual engineering. In the meanwhile the idea lived only in his mind.

In common with other outstanding young scientists, Turing spent two years at Princeton University enrolled as a graduate student. He arrived in September 1936. *On Computable Numbers...* was published at the very end of 1936 and attracted some attention; by the time he left, the idea had come to the attention of the leading Hungarian-American mathematician John von Neumann. But Turing certainly did not shoot to fame. He worked on on algebra and number theory; on showing that his definition of computability coincided with that of Church; and on an extension of his ideas (Ordinal Logics) which provided a Ph.D. thesis.

The work on 'ordinal logics', probably his most difficult and deepest mathematical work, was an attempt to bring some kind of order to the realm of the *uncomputable.* This also was connected to the question of the nature of mind, as Turing's interpretation of his ideas suggested that human 'intuition' could correspond to uncomputable steps in an argument. But Turing never pursued this line of development after 1938. Instead, he was increasingly preoccupied with more immediate problems which demanded logical skills.

True to the concreteness of the Turing machine, he also spent time at Princeton making a cipher machine based on using electromagnetic relays to multiply binary numbers. Even then he saw a link from 'useless' logic to practical computation. Although not one of the political intellectuals of the 1930s, Turing followed current events and was influenced in studying ciphers by the prospect of war with Germany.

4. The Second World War

In 1938 Turing was offered a temporary post at Princeton by von Neumann but instead returned to Cambridge. He had no University lectureship; in the year 1938-9 he lived on his King's College fellowship, as logician and number theorist. Unusually for a mathematician, he joined in Wittgenstein's classes on the philosophy of mathematics; unusually again, he engineered gear-wheel parts for a special machine to calculate the Riemann Zeta-function.

Publicly, he sponsored the entry into Britain of a young German Jewish refugee. Secretly, he worked part-time for the British cryptanalytic department, the so-called Government Code and Cypher School. His appointment marked the first scientific input into a hitherto arts-based department. That revolution was caused by the failure of pre-scientific methods to penetrate the mechanical Enigma cipher used by Germany. No significant progress was made, however, until the gift of vital ideas and information in July 1939 from Poland, where mathematicians had been employed on the problem much earlier.

Upon British declaration of war on 3 September, Turing took up full-time work at the wartime cryptanalytic headquarters, Bletchley Park. The Polish work was limited as it depended upon the very particular way the Germans had been using the Enigma. One of their ideas was embodied in a machine called a Bomba. The way forward lay in Turing's generalisation of the Polish Bombe into a far more powerful device, capable of breaking any Enigma message where a small portion of plaintext could be guessed correctly. Another Cambridge mathematican, W. G. Welchman, made an important contribution, but the critical factor was Turing's brilliant mechanisation of subtle logical deductions.

From late 1940 onwards, the Turing-Welchman Bombe made reading of Luftwaffe signals routine. In contrast, the more complex Enigma methods used in German Naval communications were generally regarded as unbreakable. Happy to work alone on a problem that defeated others, Turing cracked the system at the end of 1939, but it required the capture of further material by the Navy, and the development of sophisticated statistical processes, before regular decryption could begin in mid-1941. Turing's section 'Hut 8', which deciphered Naval and in particular U-boat messages, then became a key unit at Bletchley Park. By the end of 1941, as the United States entered the war, the battle of the Atlantic was moving towards Allied advantage. On 1 February 1942, the Atlantic U-boat Enigma machine was given an extra complication and this advantage was suddenly wiped out: nothing could be decoded and catastrophe loomed.

Besides illustrating the always razor-edge state of the war of wits, this crisis brought about a new ingredient in Alan Turing's experience: electronic technology made its first appearance at Bletchley Park as telephone engineers were pressed into an effort to gain ever higher speeds of mechanical working. As it turned out, however, the electronic engineers found themselves called upon to mechanize the breaking of the 'Fish' material: messages enciphered on the quite different system used for Hitler's strategic communications. Here again Turing's statistical ideas underlay the methods employed, though it was M. H. A. Newman who played the organising role. The conjunction of Turing's thoughts with the practicality of large-scale electronic machinery, arising from this technical U-boat Enigma change, came to have momentous consequences.

5. Emergence of the Computer

By 1942 Alan Turing was the *genius loci* at Bletchley Park, famous as 'Prof', shabby, nail-bitten, tie-less, sometimes halting in speech and awkward of manner, the source of many hilarious anecdotes about bicycles, gas masks, and the Home Guard; the foe of charlatans and status-seekers, relentless in long shift work with his colleagues, mostly of student age. To one of these, Joan Clarke, he proposed marriage, and was gladly accepted. But then he retracted, telling her of his homosexuality.

Turing crossed the Atlantic in November 1942, for highest-level liaison not only on the desperate U-boat Enigma crisis, but on the electronic encipherment of speech signals between Roosevelt and Churchill. Before his return in March 1943, logical weaknesses in the changed U-boat system had been brilliantly detected, and U-boat Enigma decryption was effectively restored for the rest of the war. With the battle of the Atlantic regained for the Allies, crisis resolved, chess champion C. H. O'D. Alexander, hitherto Turing's deputy, took charge of Hut 8.

Turing became an all-purpose consultant to the by now vast Bletchley Park operation. As such he saw the 'Fish' material cracked by the Colossus machines, brought into operation just before D-Day, demonstrating the feasibility of large-scale digital electronic technology. Turing himself devoted much time to learning electronics: ostensibly for creating his own, elegant speech secrecy system, which he effected with the aid of one assistant, Donald Bayley, at nearby Hanslope Park. But he had another and more ambitious end in view: in the last stage of the war (for his part in which he was awarded an OBE) he planned the embodiment of the Universal Turing Machine in electronic form, or in effect, invented the digital computer.

In 1944, at the invasion of Normandy that Allied control of the Atlantic allowed, Alan Turing was almost uniquely in possession of three key ideas:

- his own 1936 concept of the universal machine
- the potential speed and reliability of electronic technology
- the inefficiency in designing different machines for different logical processes.

Combined, these ideas provided the principle, the practical means, and the motivation for the modern computer, a single machine capable of handling any programmed task. He himself was as eager as anyone in the world to bring them together, and was spurred even more by a fourth idea: that the universal machine should be able to acquire and exhibit the faculties of the human mind. Even in 1944 he spoke to Donald Bayley of 'building a brain'.

Turing was captivated by the potential of the computer he had conceived. Although his 1936 work had shown the absolute limitations of the computable, he had become fascinated by what Turing machines could do, rather than by what they could not. He had long abandoned his youthful expectations of finding free will or free spirits through quantum mechanics. His later thought was strongly determinist and atheistic in character. And by the end of the Second World War he had turned against the tentative idea that there were steps of 'intuition' in human thought corresponding to uncomputable operations. Instead, he held that the computer would offer unlimited scope for practical progress towards embodying intelligence in an artificial form.

For the second time, he experienced being pre-empted by a parallel American publication, in this case the EDVAC plan for an electronic computer, with Von Neumann's name attached. Nonetheless, this publication when it appeared in June 1945 worked in practice to Turing's advantage, American competition stimulating the National Physical Laboratory to plan a rival project, to which he was appointed a Senior Principal Scientific Officer. Turing despised his nominal superior J. Womersley, but at least initially this applied mathematician showed a rapid appreciation of the scope of Turing's ideas, and with a eye for acronyms steered Turing's design towards formal approval in early 1946 as the Automatic Computing Engine, or ACE.

6. Building a Brain

Turing's detailed computer scheme was drawn up in a continuation of wartime spirit: as a plan that could be effected immediately with the memory storage (cumbersome acoustic delay lines, as used in radar) that was to hand. Turing knew that superior technology would soon transform design: his emphasis was on speed in every sense, and in the exploitation of the universal machine concept. This meant, in particular, implementing arithmetical functions by programming rather than by building in electronic components, a concept different from that of the American-derived designs.

The hardware design was short-term; but his prospectus for the use of the machine was visionary. Turing projected a computer able to switch at will from numerical work to algebra, codebreaking, file handling, or chess-playing. Methods for handling subroutines included a suggestion that the machine could expand its own programs from an abbreviated form, ideas well ahead of contemporary American plans. A later talk (February 1947) depicted a national computer centre with remote terminals, and the prospect of the machine taking over more and more of its own programming work. In 1947 his Abbreviated Code Instructions marked the beginning of programming languages. But not a single component of the ACE was assembled, and Turing found himself without any influence in the engineering of the project. The lack of cooperation, very different from the wartime spirit, he found deeply frustrating.

From October 1947, the NPL allowed, or perhaps preferred, that he should spend the academic year at Cambridge. Rather than publish these fundamental principles of computing, he spent his time on new study amidst the post-war renaissance of science, not in mathematics or technology but in neurology and physiology. Out of this came a pioneering paper on what would now be called neural nets, written to amplify his earlier suggestions that a sufficiently complex mechanical system could exhibit learning ability. This was submitted to the NPL as an internal report, and never published in his lifetime. Meanwhile the NPL made no advance with the construction of the ACE, and as Turing's position fell back, other computer projects at Cambridge and Manchester took the lead.

Indeed it was Newman, who had been the first reader of *On computable numbers,* and in charge of the electronic breaking of the 'Fish' ciphers, who was partly responsible for this. On his 1945 appointment to the chair of pure mathematics at Manchester University, he had negotiated a large Royal Society grant for the construction of a computer. Newman strongly promoted Turing's principle of the stored-program computer, but unlike Turing, intended no personal involvement with engineering. He conveyed the basic principles to the leading radar engineer F. C. Williams, who had been attracted to Manchester, and the latter's brilliant innovation made possible a rapid success: Manchester in June 1948 had the world's first practical demonstration of Turing's computer principle.

Although losing in the race to implement a universal machine, and slow to communicate or compete in the game of scientific priority, Turing ran very competitively in a literal sense. After the war he developed his strength in cross-country running with frequent long-distance training and top-rank competition in amateur athletics. He would amaze his colleagues by running to scientific meetings, beating the travellers by public transport, and only an injury prevented his serious consideration for the British team in the 1948 Olympic Games.

The return to Cambridge helped Alan Turing form an agreeable circle of lasting friendships, particularly with Robin Gandy, who began at this period to develop under Turing's influence and would later inherit his mantle as a mathematical logician. Although never secretive about his sexuality, he now became more deliberately outspoken and exuberant, and all thoughts of comfort or conformity were now left behind. A mathematics student at King's College, Neville Johnson, became a lover.

7. Turing at Manchester

In May 1948, Newman offered Turing the post as Deputy Director of the computing laboratory at Manchester University. Turing accepted, resigned from the NPL, and moved in October 1948. The meaningless title reflected Turing's uncertain status. He had no control over the project whose fate was in fact determined by its sudden necessity for the British atomic bomb project. F. C. Williams had in any case built his own empire, and Newman's original plans were largely swept aside. But Turing did have a clear role to play: as the organiser of programming for the engineers' electronics.

Turing at Manchester could perhaps have led the world in software development. His partly explored ideas included the use of mathematical logic for program checking, implementing Church's logical calculus on the machine, and other ideas which, combined with his massive knowledge of combinatorial and statistical methods, could have set the agenda in computer science for years ahead. This, however, he failed to do; his work on machine-code programming at Manchester, produced only as a working manual, was limited in scope.

Instead, there followed a confused period, in which Turing hovered between new topics and old. He revisited his 1939 calculation of the Riemann zeta-function with the use of the prototype computer; he pursued the question of computability within the algebra of group theory. Out of this confused era arose, however, the most lucid and far-reaching expression of Turing's philosophy of machine and Mind, the paper *Computing Machinery and Intelligence* which appeared in the philosophical journal *Mind* in 1950.

This, besides summarising the view he had developed since 1936, absorbed his first-hand experience and experiment with machinery. The wit and drama of the Turing Test has proved a lasting stimulus to later thinkers, and the paper a classic contribution to the philosophy and practice of Artificial Intelligence research. But this was essentially the end of his investigation, and despite this model of communication, supported by his radio talks, he had apparently no influence on the American foundation of Artificial Intelligence later in the 1950s.

At the same time, in 1950, there emerged a clear direction for new thought. Rather than return to classical mathematics, the novel potential of the computer still held his attention, and he became a pioneer of its personal use. For, as he settled in Manchester, buying his own first house at outlying Wilmslow, he had an entirely fresh field in view. It was what he described as the mathematical theory of morphogenesis: the theory of growth and form in biology.

Outwardly an extraordinary change of direction, for him it was a return to a fundamental problem; even in childhood he had been spotted and sketched 'watching the daisies grow'; from childhood *Natural Wonders* to D'Arcy Thompson's *On Growth and Form* to a more recent interest in how brains grow new connections, he had sustained an interest in the biological structures so easily taken for granted, yet so complex and bizarre from the viewpoint of physics. Out of all the phenomena of life he fixed on the way asymmetry can arise out of initially symmetric conditions as first thing requiring explanation, and his answer, given without apparent reference to anyone else's work, was that it could arise from the nonlinearity of the chemical equations of reaction and diffusion. He modelled hypothetical chemical reactions on the circle and the plane, and for the repetitive numerical simulation required to test his ideas, became the first serious user of an electronic computer for mathematical research.

He was elected to Fellowship of the Royal Society in July 1951, for the work done fifteen years before, but equal originality was on the way: his first successful work on *The Chemical Basis of Morphogenesis* was submitted as a paper that November. Long overlooked, it was a founding paper of modern non-linear dynamical theory.

8. Alan Turing's Crisis

Alan Turing was arrested and came to trial on 31 March 1952, after the police learned of his sexual relationship with a young Manchester man. He made no serious denial or defence, instead telling everyone that he saw no wrong with his actions. He was particularly concerned to be open about his sexuality even in the hard and unsympathetic atmosphere of Manchester engineering. Rather than go to prison he accepted, for the period of a year, injections of oestrogen intended to neutralise his libido.

His work on the morphogenetic theory continued. He developed his theory of pattern formation out of instability into the realm of spherical objects, such as the Radiolaria, and also on the cylinder, as a model of plant stems. He set as a particular goal the explanation for the appearance of the Fibonacci numbers in the leaf patterns of plants — most noticeable in the close-packed spirals of sunflower heads and fir cones.

Besides this he refreshed his youthful interest in quantum physics, studying the problem of wave-function reduction in quantum mechanics, with a hint that he was considering a non-linear mechanism for it. He took a new interest in the representation of elementary particles by spinors, and in relativity theory.

A factor in his life unknown to most around him was that he had also continued to work for GCHQ, the post-war successor to Bletchley Park, on the basis of a personal connection with Alexander, now its director. But since 1948, the conditions of the Cold War, and the alliance with the United States, meant that known homosexuals had become ineligible for security clearance. Turing, now therefore excluded, spoke bitterly of this to his onetime wartime colleague, now MI6 engineer Donald Bayley, but to no other personal friends. State security also seems the likely cause of what he described as another intense crisis in March 1953, involving police searching for a visiting Norwegian who had come to see him. Concern over the foreign contacts of one acquainted with state secrets was understandable, and his holiday in Greece in 1953 could not have been calculated to calm the nerves of security officers.

Although unable to tell his friends about questions of official secrecy, in other ways he actively sought much greater intimacy of expression with them and with a Jungian therapist. Eccentric, solitary, gloomy, vivacious, resigned, angry, eager, dissatisfied — these had always been his ever-varying characteristics, and despite the strength that he showed the world in coping with outrageous fortune, no-one could safely have predicted his future course.

He was found by his cleaner when she came in on 8 June 1954. He had died the day before of cyanide poisoning, a half-eaten apple beside his bed. His mother believed he had accidentally ingested cyanide from his fingers after an amateur chemistry experiment, but it is more credible that he had successfully contrived his death to allow her alone to believe this. The coroner's verdict was suicide.

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