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ІНФОРМАЦІЙНА БЕЗПЕКА ТА ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ

Збірник тез доповідей
IV Міжнародної науково-практичної конференції
ІБІТ 2022

30 листопада 2022 року

Міністерство освіти і науки України
Державна служба України з надзвичайних ситуацій
Львівський державний університет безпеки життєдіяльності
Національний університет "Львівська політехніка"

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Секція 2

ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ

Напрям 15

ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ В ОСВІТІ

UDC 378.147:811.111:004.38:929

ALAN TURING: A FOUNDING FATHER OF COMPUTER SCIENCE, ARTIFICIAL INTELLIGENCE AND MODERN COGNITIVE SCIENCE

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Annotation. *This paper is devoted to British mathematician and logician Alan Turing, who created and worked in the field of computer science. Described how was created a new field of computer science (artificial intelligence), especially Turing's achievements, what steps needed to be taken to do so, and how it affected our world. Turing's design for the Automatic Computing Engine (ACE) was the first complete specification of an electronic stored-program all-purpose digital computer.*

Keywords: *Alan Turing, probability theory, artificial intelligence, letters from Turing to Churchill, The Imitation Game (USA, United Kingdom, 2014).*

Анотація. *Стаття присвячена британському математику і логіку Алану Тюрінгу, який творив і працював у галузі інформатики. Описано як було створено нову галузь інформатики (штучний інтелект), наукові досягнення Тюрінга та як це вплинуло на наш світ. Наголошено, що проєкт Тюрінга для автоматичного обчислювального двигуна (ACE) був першою повною специфікацією універсального цифрового комп'ютера із збереженими електронними програмами.*

Ключові слова: *Алан Тюрінг, теорія ймовірностей, штучний інтелект, листи Тюрінга Черчілю, фільм "Гра в імітацію" (США, Великобританія, 2014).*

When a true genius appears in the world, you may know him by this sign:
that all the dunces are in confederacy against him
Jonathan Swift

Allan Turing was a founding father of artificial intelligence and of modern cognitive science, and he was a leading early exponent of the hypothesis that the human brain is in large part a digital computing machine. He theorized that

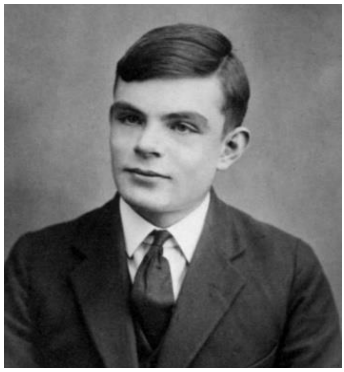


Fig. 1. Alan Turing, age 16 (1928)

the cortex at birth is an "unorganised machine" that through "training" becomes organized "into a universal machine or something like it". Turing proposed what subsequently became known as the Turing test as a criterion for whether an artificial computer is thinking (1950) [11] (Fig. 1), see the videos [4; 37].

Alan Turing, in full Alan Mathison Turing, (born June 23, 1912, London, England – died

June 7, 1954, Wilmslow, Cheshire), British mathematician and logician who made major contributions to mathematics, cryptanalysis, logic, philosophy, and mathematical biology and also to the new areas later named computer science, cognitive science, artificial intelligence, and artificial life. The son of a civil servant, Turing was educated at private Sherborne school (Fig. 2). He entered the University of Cambridge to study mathematics in 1931 (Fig. 3). After graduating in 1934, he was elected to a fellowship at King's College (his college since 1931) in recognition of his research in probability theory [11], see the video [2].



Fig. 2. Sherborne school (2022)



Fig. 3. University of Cambridge

Alan Turing was one of the most influential thinkers of the 20th century. In 1935, aged 22, he developed the mathematical theory upon which all subsequent stored-program digital computers are modeled [29], (see the video [5]).

In 1936 Turing's seminal



Fig. 4. Alonzo Church

paper "On Computable Numbers, with an Application to the Entscheidungsproblem (Decision Problem)" was recommended for publication by the American mathematical logician Alonzo Church (Fig. 4) [11]. In this paper, Turing reformulated Kurt Gödel's 1931 results (Fig. 5) on the limits of proof and computation, replacing Gödel's universal arithmetic-based formal language with the formal and simple hypothetical devices that became known as Turing machine [3, 38] (Fig. 6).



Fig. 5. Kurt Gödel (1926)

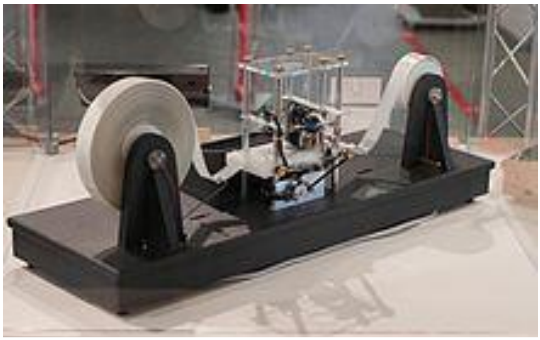


Fig. 6. The Turing machine [2]

The Entscheidungsproblem (German, "decision problem") is a famous problem in mathematics. David Hilbert (Fig. 7) formulated the problem in 1928: Is there an algorithm that will take a formal language, and a logical statement in that language, and that will output "True" or "False", depending on the truth value of the statement? The algorithm does not tell how it reaches the answer, nor prove if the answer is always correct [13].



Fig. 7. David Hilbert

Alonzo Church had himself just published a paper that reached the same conclusion as Turing's, although by a different method. Turing's method had profound significance for

the emerging science of computing. Later that year Turing moved to Princeton University to study for a Ph. D. in mathematical logic under Church's direction (completed in 1938) [11]

Turing Machine (Fig. 6) is extensively studied in *the Theory Of Automata* and was invented by Alan Turing in 1936, who called it an "a-machine" (automatic machine). It was Turing's Doctoral advisor, Alonzo Church later coined the term "Turing machine". Turing gave a brilliant demonstration that everything that can be reasonably said to be computed by a human computer using a fixed procedure can be computed by such a machine. Turing machines are similar to finite automata/finite state machines but have the advantage of unlimited memory. They are capable of simulating common computers; a problem that a common computer can solve (given enough memory) will also be solvable using a Turing machine, and vice versa. The Church-Turing thesis claims that any computable problem can be computed by a Turing machine [41].

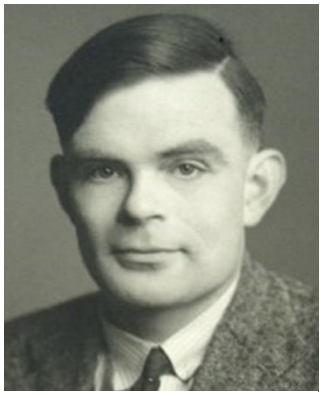


Fig. 8. Alan Turing

Alan Turing (Fig. 8) proved that his "universal computing machine" would be capable of performing any conceivable mathematical computation if it were representable as an algorithm. He went on to prove that there was no solution to the decision problem by first showing that the halting problem for Turing machines is undecidable: it is not possible to decide algorithmically whether a Turing machine will ever halt. John von Neumann (1903–1957) (Fig. 9) acknowledged that the central concept of the modern computer was due to Turing's paper. To this day, Turing machines are a central object of study in theory of computation [3].



Fig. 9. John von Neumann

After graduating from Cambridge and getting his PhD in mathematics from Princeton, Turing worked part-time for the Government Code and Cypher School, helping to decipher encrypted messages [42].

At the outbreak of hostilities with Germany in September 1939, Turing joined the



Fig. 10. Alan Turing reported to Bletchley Park, where he and a team of the best British scientists would work on breaking Enigma

Government Codebreaking team at Bletchley Park (Fig. 10), Buckinghamshire and played a crucial role in deciphering Enigma (Fig. 11), the code used by the German armed forces to protect their radio communications. Turing's work on the version of Enigma used by the German navy was vital to the battle for supremacy in the North Atlantic (the Enigma machine was used by Germans to code their military communications during World War II. British mathematician Alan Turing helped break the Enigma code), see the video [32].



Fig. 11. The Enigma machine



Fig. 12. Peter Twinn

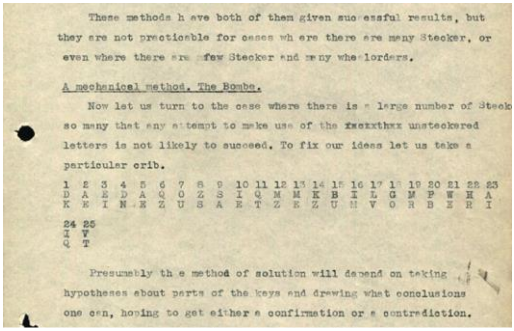
In November 1939, Turing and his colleagues Peter Twinn (1916–2004) (Fig. 12), Gordon Welchman (1906–1985) (Fig. 13) and John Jeffreys (1916–1944) were convinced that the only way to decipher Enigma naval messages

would be “the machine now being made at Letchworth, resembling, but far larg er than, the Bombe of the Poles (superbombe machine)” (HW 14/2) (Fig. 15). Luftwaffe messages were not as intricately enciphered and would only require a normal bombe Many documents connected to Turing’s work during the Second World War were destroyed for the purposes of national security, and some, such as his two papers on statistical theory, “Statistics of Repetitions” and “The Applications of Probability to Cryptography” were only released in 2012 (!). Still, The National Archives holds important documents relating to Turing, from which much can be learnt [14].



Fig. 13. Gordon Welchman

Turing also contributed to the attack on the cyphers known as “Fish”, which were used by the German High Command for the encryption of signals during the latter part of the war. His contribution helped to shorten the war in Europe by an estimated two years (see the video [5]). After the war, his theoretical work led to the development of Britain’s first computers at the National Physical Laboratory and the Royal Society Computing Machine Laboratory at Manchester University. Turing was also a founding father of modern cognitive science, theorizing that the cortex at birth is an “unorganized machine” which through “training” becomes organized “into a universal machine or something like it”. He went on to develop the use of computers to model biological growth, launching



These methods h ave both of them given suc cessful results, but they are not practicable for cases wh ere there are many Stecker, or even where there are few Stecker and many wheelorders.

A mechanical method. The Bombe.

Now let us turn to the case where there is a large number of Steck so many that any attempt to make use of the xxxxthxx unsteckered letters is not likely to succeed. To fix our ideas let us take a particular crib.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
D A E D A Q O Z S I Q M M K B I L G M P W H A
K W I N Z U S A E T Z K Z U H V O H B E R I

24 25
I V
Q T

Presumably th e method of solution will depend on taking hypotheses about parts of the keys and drawing what conclusions one can, hoping to get either a confirmation or a contradiction.

Fig. 14. A crib in Turing’s Mathematical theory of ENIGMA

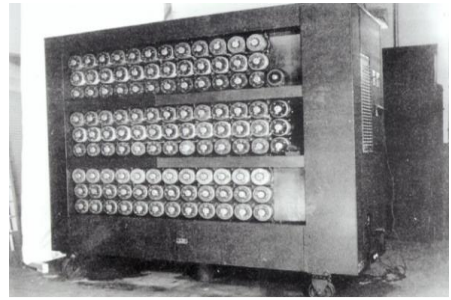


Fig. 15. The Bombe at Bletchley Park

the discipline now referred to as Artificial Life [29].

The Polish cryptologic bomb, designed by mathematician Marian Rejewski in 1938, had been built to mechanize the deciphering of German enigma-encoded messages. In 1939, the Poles had turned everything over to Britain and France, and it is their work that Turing and Welchman used to develop their own version of the machine [14] (Fig. 15), (see the video [28]).

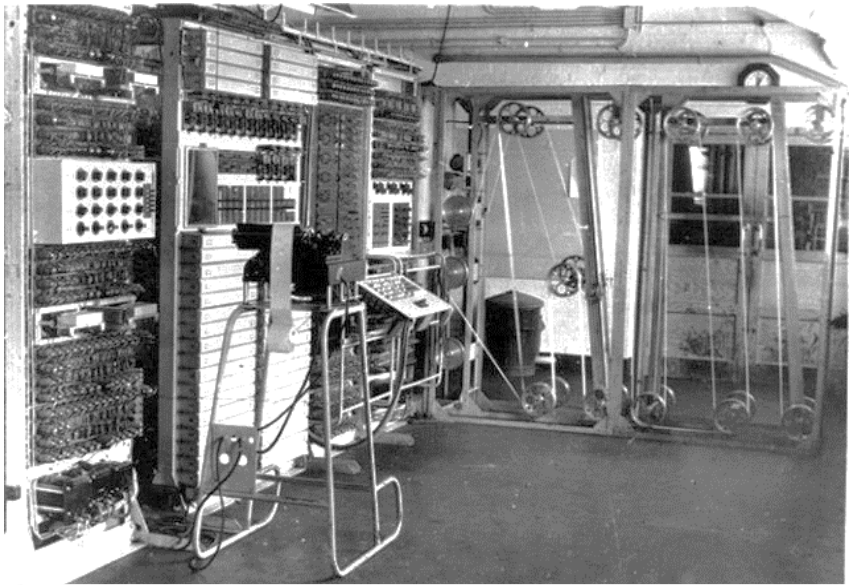


Fig. 16. The Colossus

Below an example of a crib in Turing's Mathematical theory of ENIGMA machine (Fig. 14).

Documents held at The National Archives also tell of other aspects of Turing's war. While he didn't design the Colossus (Fig. 16), the very first programmable digital computer, used to break to Lorenz cipher (codename: Tunny), his work on probability in cryptanalysis proved invaluable in the building of the machine [14], see the video [9, 16].

In July 1942, Turing developed a complex code-breaking technique he named "Turingery". This method fed into work by others at Bletchley in understanding the "Lorenz" cipher machine. Lorenz enciphered German strategic messages of high importance: the ability of Bletchley to read these contributed greatly to the Allied war effort.

Turing travelled to the United States in December 1942, to advise US military intelligence in the use of Bombe machines and to share his knowledge of Enigma. Whilst there, he also saw the latest American progress on a top secret speech enciphering system. Turing also spent some time designing codes as well as breaking them, and worked at Hanslope Park on "Delilah", a portable device that could encipher a voice message. Turing returned to Bletchley in March 1943, where he continued his work in cryptanalysis. Later in the war, he developed a speech scrambling device which he named "Delilah" [15] (Fig. 17).

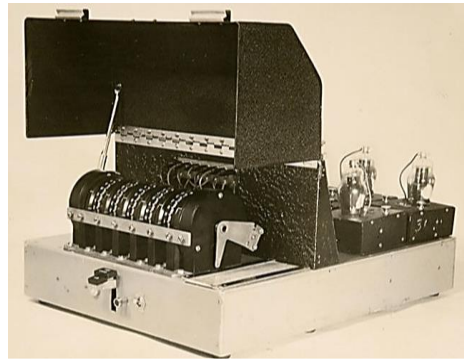
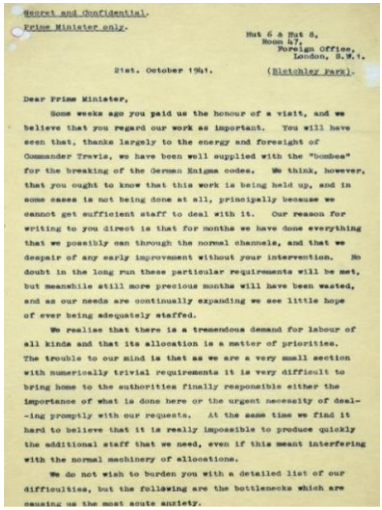


Fig. 17. Delilah code machine, 1946

In 1945, Turing was awarded an OBE for his wartime work.

Turing was a mathematical genius but, like the rest of us, he sometimes had to face more mundane problems. During 1941, codebreaking at Bletchley Park was hindered by shortages of typists and unskilled staff. These shortages could have been easily rectified, but the codebreakers urgent requests were ignored by officials in Whitehall. Going over the heads of those in command at GC & CS, Turing and his colleague Gordon Welchman (the head of Hut 6, responsible for breaking army and air force Enigma messages (Fig. 13) wrote directly to Prime Minister Winston Churchill: "*Work is being held up, and in some cases is not being done at all principally because we cannot get sufficient staff to deal with it.*" (Fig. 18).



Secret and Confidential.
Prime Minister only.

Hut 6 & Hut 8,
Room 47,
Foreign Office,
London, S.W.1.

21st. October 1941. (Bletchley Park).

Dear Prime Minister,

Some weeks ago you paid us the honour of a visit, and we believe that you regard our work as important. You will have seen that, thanks largely to the energy and foresight of Commander Travis, we have been well supplied with the "bombes" for the breaking of the German Enigma codes. We think, however, that you ought to know that this work is being held up, and in some cases is not being done at all, principally because we cannot get sufficient staff to deal with it. Our reason for writing to you direct is that for months we have done everything that we possibly can through the normal channels, and that we despair of any early improvement without your intervention. No doubt in the long run these particular requirements will be met, but meanwhile still more precious months will have been wasted, and as our needs are continually expanding we see little hope of ever being adequately staffed.

We realise that there is a tremendous demand for labour of all kinds and that its allocation is a matter of priorities. The trouble to our mind is that as we are a very small section with numerically trivial requirements it is very difficult to bring home to the authorities finally responsible either the importance of what is done here or the urgent necessity of dealing promptly with our requests. At the same time we find it hard to believe that it is really impossible to produce quickly the additional staff that we need, even if this meant interfering with the normal machinery of allocations.

We do not wish to burden you with a detailed list of our difficulties, but the following are the bottlenecks which are causing us the most acute anxiety.

Fig. 18. First page of the letter to Churchill, 21 October 1941

On receiving the letter Churchill minuted his Chief of Staff, General Ismay: "action this day Make sure they have all they want on extreme priority and

report to me that this had been done." It fell to Stuart Milner-Barry of Hut 6 to deliver the letter by hand to 10 Downing Street.

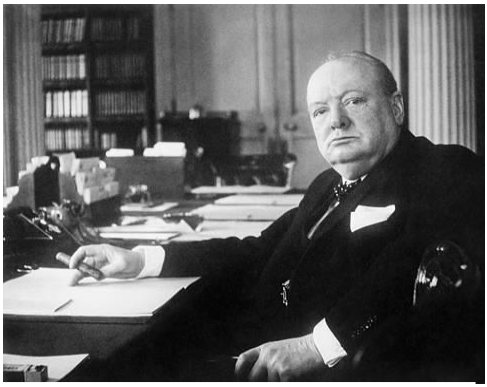


Fig. 19. Winston Churchill at his desk working at Number 10 Downing Street, 1941

Churchill's response was swift. He noted: "*Make sure they have everything they want on extreme priority and report to me that this has been done*". (Fig. 19, 20).

In 1986, Milner-Barry recalled his trip to Whitehall: "Why I was deputed to carry the letter to No. 10 I do not remember – at a guess, because I was the most readily expendable from the scene of action. What I do recall is arriving at Euston Station, hailing a taxi, and with a sense of total incredulity (can this really be happening?) inviting the driver to take me to 10 Downing Street. The taxi-driver never blinked an eyelid: without comment he directed himself to Whitehall. Arrived at the entrance to Downing Street, I was again surprised at the lack of formality: there was just a wooden barrier across the road, and one uniformed policeman who waved my driver on. At the door to No. 10 I paid off the taxi, rang the bell, was courteously ushered in, explained that I had an urgent letter which I was anxious to deliver to the Prime Minister personally, and was invited to wait. Of course I did not see the Prime Minister himself; but very shortly there appeared a dapper dark-suited figure of shortish stature whom I subsequently identified as Brigadier Harvie-Watt, Mr. Churchill's PPS from 1941 to 1945. To him I again explained my errand; and while obviously and understandably puzzled as to who I might be and what this was all about, he

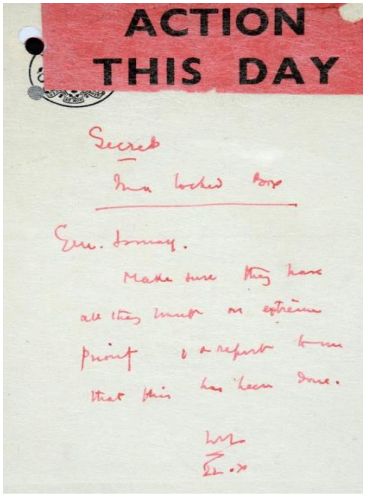


Fig. 20. Churchill's note, 22 October 1941

took me sufficiently seriously to promise that he would without fail deliver the letter to the Prime Minister and stress its urgency" [12]. (Fig. 21, 22).

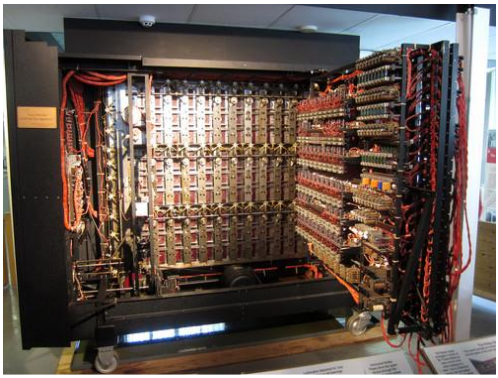


Fig. 21. The Turing machine at Bletchley Park

Let us remember the Oscar-buzzed movie "The Imitation Game" (2014) (see the film [30]) that tells the story of Alan Turing, the British cryptanalyst, who helped a great deal to solve the Enigma code used by the Germans during World War II (Fig. 22, 23, 26).

This movie is full of compelling scenes that demonstrate Turing's capacity to think on a higher level and his single-minded determination to crack the Enigma code, qualities that led to him be named the father of modern computer science. The film's message, repeated by its two main characters, is uplifting: Benedict Cumberbatch as Alan Turing.



Fig 22. The Imitation Game (2014). The Bombe

"Sometimes it is the people no one imagines anything of who do the things that no one can imagine" [14], see the video [43].

Alan Turing, who is the subject of "The Imitation Game", based on Andrew Hodges's excellent biography, "Alan Turing: The Enigma" (1983) [24].



Fig. 23. Decoded scene. Turing's team [32]

As his character points out in the film [30], it is often people's differences and peculiarities that lead them to make new discoveries, and this can be recreated with computers that "think" in a slightly different way. The movie is noteworthy for Benedict Cumberbatch's performance as Turing, which may not be completely true to life but is certainly moving, and realistically captures both the pressures of his role at

Bletchley Park and the personal pain felt because of his oppression [14] (Fig. 24, 25, 26, 27).

Turing's appearance on the big screen does give us an opportunity to discuss his extraordinary scientific and mathematical legacy, on which the movie is built (see the video [35]).

The term "imitation game" comes from a paper Turing written in 1960 called "Computing Machinery and Intelligence", where he asks "Are there imaginable digital computers which would do well in the imitation game?" Turing then goes on to describe a game that is really a test to determine if computers can actually think [40].

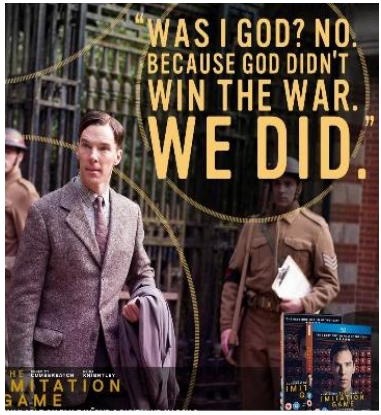


Fig. 24. Quotes from the movie



Fig. 25. Turing Turing was an atheist

On a literal level, the film's title relates to some of Turing's most important work, but it's at best peripheral to the film's plot. The term "imitation game" comes from a paper Turing wrote in 1960 called "Computing Machinery and Intelligence", where he asks "Are there imaginable digital computers which would do well in the imitation game?" Turing then goes on to describe a game that is really a test to determine if computers can actually think.



Fig. 26. The Bombe. "*The Imitation Game*" *(2014)*

Turing describes it as a simple party game involving three players. Player A is a man, player B is a woman and player C (who plays the role of the interrogator) is of either sex. Player C is unable to see either player A or player B, and can communicate with them only through written notes. By asking questions of

player A and player B, player C tries to determine which of the two is the man and which is the woman. Player A's role is to trick the interrogator into making the wrong decision, while player B attempts to assist the interrogator in making the right one.

A. Turing then argues that the game can prove the presence of (artificial) intelligence if a computer could take the role of Player A and make player C guess wrongly just as many times when an actual human being is sitting in for Player A. (Fig. 27, 28).

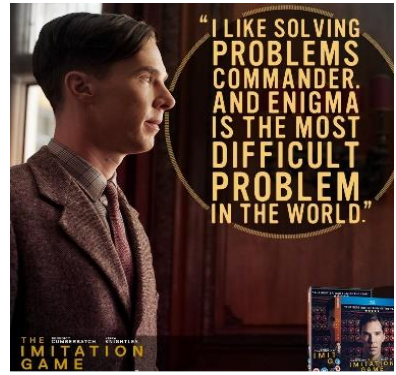


Fig. 27. Turing's motto in "The Imitation Game" (2014). in "The Imitation Game" (2014)



Fig. 28. Keira Knightley as Joan Clark

Examined more closely, one also could interpret the title as a metaphor for Turing's inability to truly understand and relate well to others. Perplexed by the tangled web of social interactions, intimations and subtext, Turing often discusses his difficulty with human interactions [40].

But in real life, the machine that cracked Enigma was called the Bombe (Fig. 15, 21, 29, 30), see the videos [7, 19]), and the first operating version of it was named Victory. The digital computer Turing invented was known as the Universal Turing Machine. Colossus (Fig. 16), the first programmable digital electronic computer, was built at Bletchley Park by engineer Tommy Flowers (see the video [16]), incorporating Turing's ideas [27].



Fig. 29. The bombe at Bletchley Park



Fig. 30. Bombe decryption machine

Manchester University's Computer Machine Laboratory.

The Manchester Mark I (Fig. 31) was built at Manchester University in 1946 under the supervision of Professor Max Newman. Alan Turing had previously been involved with the construction of the ACE (Automatic Computing Engine) at the National Physical Laboratory, and with the construction of "Colossus", the world's first electronic programmable computer, built at Bletchley Park, Buckinghamshire, during WW II.

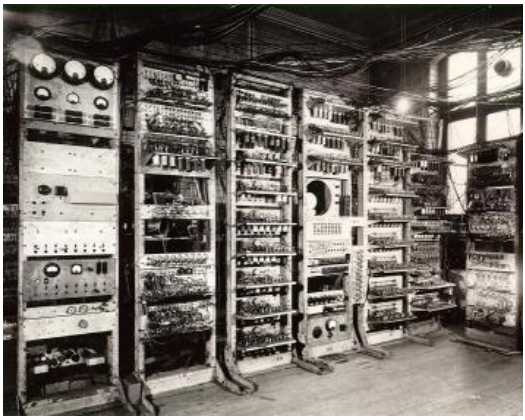


Fig. 31. The Manchester Mark 1 at working on the Ferranti Mark I Computer, 1951

After the War, Alan worked first at the National Physical Laboratory and then at Manchester University on the development of the computer from his first ideas in the early 1930s for a "Turing machine". And although the war work might have delayed Turing's academic work, it greatly accelerated progress in electronics, so that in 1945 he returned to his first love, creating a complete design for what he expected to be the world's first fully programmable computer, the National Physical Laboratory's ACE – the Automatic Computing Engine and then at Manchester University on the development of the computer from his first ideas in the early 1930s for a "Turing machine". Turing joined the Manchester team (Fig. 32), and again with remarkable prescience



Fig. 32. Alan M Turing and colleagues

started work on artificial intelligence, wondering whether electronic machines could be programmed not just to do Maths, but to think in the way human minds do – a hot topic of debate even now [37, 38].

Turing was elected a Fellow of the Royal Society in 1951. In the early 1950s he was developing a theory of morphogenesis, a mathematical theory of organic growth. The work was left incomplete when he died, on 8 June 1954, at his house in Wilmslow, Cheshire. His death at a time when official secrecy still hid his code-breaking work [17, 25], see the video [1].

Alan Turing (Fig. 33) has been identified not just as the father of computer science but as the father of the modern computer. This argument is strengthened by the fact that Turing was involved with the construction of an important computing device (the Bombe) used for decrypting the German Enigma code during World War II at Bletchley Park [18].

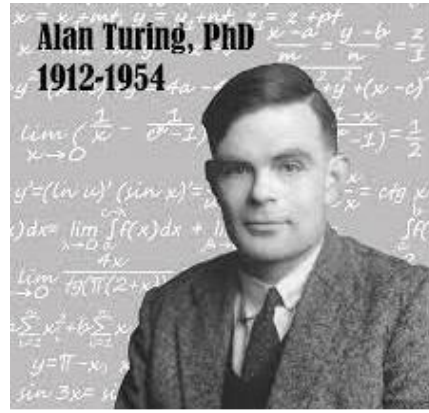


Fig. 33. Alan Turing: the man who changed history

The British genius also made key contributions to the British effort, during the Second World War, to crack the German Army's seemingly unbreakable *Enigma code*, an achievement that integrated mathematics, engineering, and a nascent effort in computer science, and which ultimately played a crucial role in shortening the war [26], see the video [34].

At last, we suggest you look the video where professor Jack Copeland discusses Alan Turing's impact on information technology. Turing is often considered to be one of the greatest minds in the 20th century, and Copeland looks at how many of Turing's ideas lie behind some of information technology's most fundamental theories [39].

Alan Turing is often remembered as the founding father of artificial intelligence. The A.M. Turing Award was created to honor his great work and is frequently referred to as the computer science equivalent of the Nobel Prize.

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