The Life and Intelligence of Alan Turing

Denbigh Starkey

Emeritus Professor, Computer Science

MSU

Alan Mathison Turing

June 23 1912 - June 7 1954

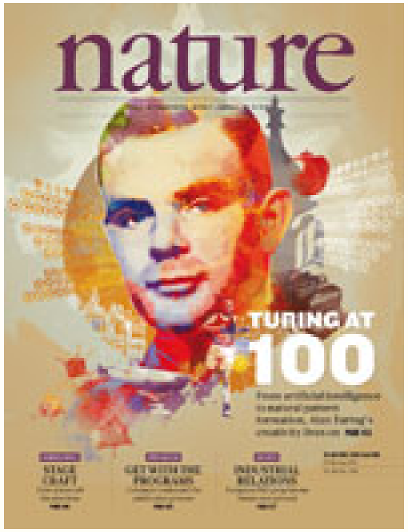
100 Year Comments & Events

- 2012, The Alan Turing Year: An international committee headed by ~100 leading researchers, organized events around the world, summarized at www.turingcentenary.eu.

- ACM: Sponsored a public meeting of 33 Turing Award winners on Turing's birthday.

100 Year Comments & Events

Nature 2/23/12 Turing at 100:



- "2012 should be named the Year of Intelligence" since Turing is "the only person to have made a world-changing contribution to human, artificial, and military intelligence."
- "The scientific world should stand together and relish the wonderful diversity of a universal mind."
- "*Nature* hailed him as one of the top scientific minds of all time."

MONTANA STATE UNIVERSITY

Mountains & Minds

Some of Turing's Honors

- ACM Annual Turing Award ("CS Nobel")
- Princeton named Turing their 2nd most distinguished alumnus (President James Madison was 1st)
- The father of Computer Science
- The father of Artificial Intelligence
- Numerous named conferences, buildings, scholarships, statues, roads, etc.
- Award winning West End and Broadway play & BBC special on Turing's life and sexuality: "Breaking the Code"

Turing's Personal Life

- Athlete

  Matching his best time would have placed him 15th in the 1948 Olympics marathon (he didn't enter due to injury).

- Gay

  At a time when being gay was illegal in Britain.

Turing's Major Achievements

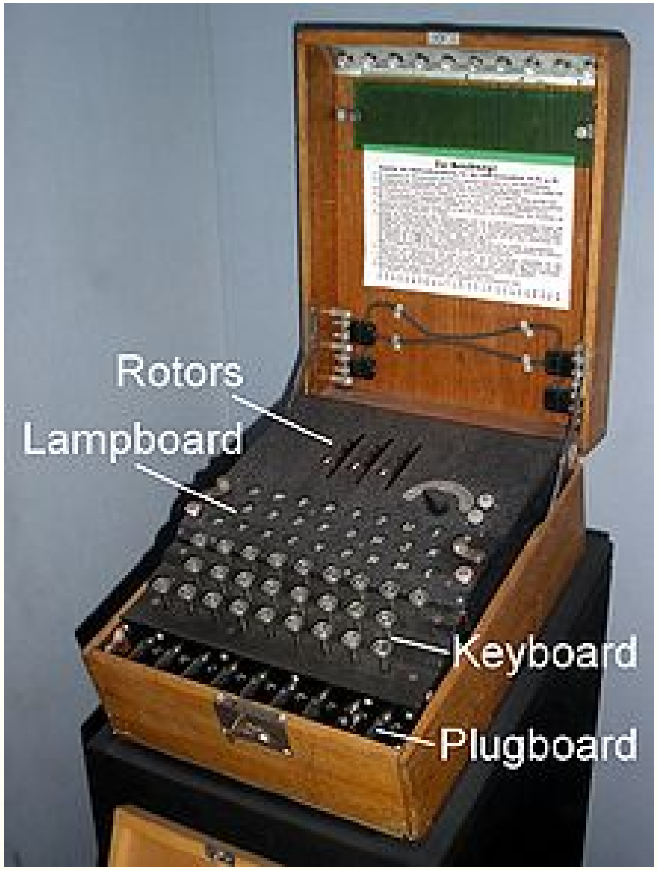
- Code breaking at Bletchley Park in WW II
- Solving Hilbert's *Entscheidungsproblem*
- Turing Machine (TM) and Universal TM
- Turing Test and Artificial Intelligence
- Designed first stored program computer
- Pioneer in Morphogenesis
- LU Decomposition (matrix inversion, etc.)

Turing's Major Achievements

- **Code breaking at Bletchley Park in WW II**
- Solving Hilbert's *Entscheidungsproblem*
- Turing Machine (TM) and Universal TM
- Turing Test and Artificial Intelligence
- Designed first stored program computer
- Pioneer in Morphogenesis
- LU Decomposition (matrix inversion, etc.)

World War II & Code Breaking

- It has been argued that Turing's work (codename Ultra) at Bletchley Park during WW II was more important to the war effort than the contributions of any other individual, and that his work shortened the war by at least two years.
- Churchill later told HRH King George that "it was thanks to Ultra that we won the war."



German Enigma Encryption Machine

Polish Intelligence gave an Enigma to Britain six weeks before the war. *HMS Petard* captured another from a sinking U-Boat, *U-559*.

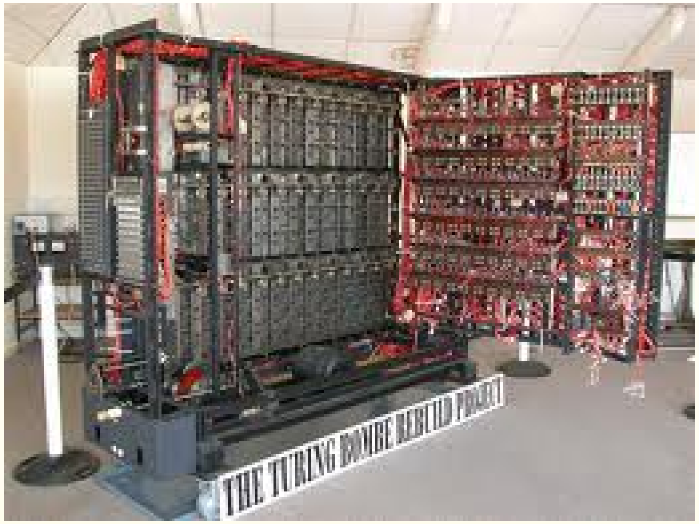
World War II & Code Breaking

There were three main components to the work at Bletchley:

- The Bombe Enigma breakers
- German Naval Enigma code breaking
- Building ten Colossus computers for code breaking, the first general purpose computers

Bombe Enigma Breakers

- Turing designed an electromechanical system called the bombe to analyze Enigma messages and determine possible rotor positions.
- Colleagues called Turing’s analyses “Turingery.”
- 224 bombes were built.



Bombe Enigma Breakers

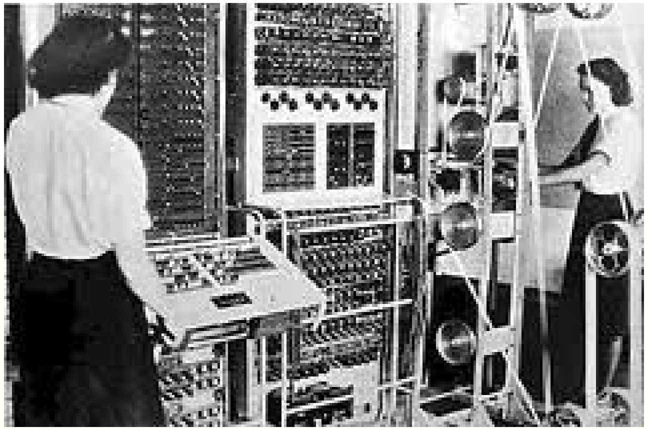
- A bombe would take a message, reject as many rotor configurations as possible, and also search for known text encodings (e.g., the message might begin with TO).
- As Enigma became more sophisticated Turing had to keep modifying bombe designs.
- Turing's bombes were the only decoding system until Colossus (1943), and continued to be used throughout the war.

Breaking Naval Codes

- Admiral Dönitz believed naval codes were being broken and added a fourth rotor to naval Enigmas in late 1941. More complexity was added later.
- Turing succeeded in breaking the more powerful Enigmas after several months.
- Successes and failures during the Atlantic War exactly match the times when German messages could be broken.

Ten Colossus Computers

- Colossus widely accepted as the first general purpose computer



- Greatly sped up Enigma decoding
- Implemented late in the war (1943)
- Turing's role in its development is disputed. Michie gives him main credit, but others give most (or all) credit to Flowers

Ultra After the War

- Much of the work at Bletchley Park was hidden by the Official Secrets Act without time limit.
- At the end of the war Churchill ordered that all ten Colossi be broken into pieces “no larger than a man’s fist.”
- In 1972, despite threat of prosecution, Michie and Randell published a history of Ultra in “On Alan Turing and the Origin of Digital Computers.”

Turing’s Major Achievements

- Code breaking at Bletchley Park in WW II
- **Solving Hilbert’s *Entscheidungsproblem***
- Turing Machine (TM) and Universal TM
- Turing Test and Artificial Intelligence
- Designed first stored program computer
- Pioneer in Morphogenesis
- LU Decomposition (matrix inversion, etc.)

Hilbert's *Entscheidungsproblem*

- David Hilbert often proposed problems to researchers. In 1928 he proposed the *Entscheidungsproblem*.
- This was to determine whether an algorithm could always decide the validity of a logical statement and output T or F in a finite number of steps.

Turing's 1936 Paper

- Turing wrote "On computable numbers with an application to the *Entscheidungsproblem*" in 1936.
- Published shortly after he began his doctoral studies at Princeton.
- Arguably the most important paper in Computer Science, and is the basis of CS Theory.
- At the time its significance was not recognized.

Turing's 1936 Paper

- The paper introduced the
  - Turing Machine
  - Universal Turing Machine
  - Proof that there were unsolvable problems
- Before the advent of the first computers, he proved that some things could never be programmed.

Turing’s Major Achievements

- Code breaking at Bletchley Park in WW II
- Solving Hilbert’s *Entscheidungsproblem*
- **Turing Machine (TM)** and Universal TM
- Turing Test and Artificial Intelligence
- Designed first stored program computer
- Pioneer in Morphogenesis
- LU Decomposition (matrix inversion, etc.)

Turing Machine (TM)

- The Turing Machine is deceptively simple, but (according to the Church-Turing Thesis) if something is computable then it is computable on a TM.

- As a computational model it is equivalent to Church's Lambda Calculus which, along with an *Entscheidungsproblem* proof based on λ-Calculus, was developed independently by Church.

Turing Machine (TM)

			1	0	0	1	1			
							⇧			
							S0			

A TM has an (infinite) tape that in this example contains five non-blank symbols, 1, 0, 0, 1, and 1, a Read/Write head that here is on the rightmost 1, and a current state, that here is S0.

Turing Machine Instructions

			1	0	0	1	1			
							⇧			
							S0			

An instruction has five parts and might be, for example (S0, 1, S0, 0, L), which means "if your current state is S0 and you are reading a 1, then stay in S0, replace the 1 with a 0, and move the R/W head left."

			1	0	1	1	0			
						⇧				
						S0				

Adding 1 to a Binary Number

I'll use adding 1 to a binary number as an example of a TM program. Three examples cover the different cases that the program must handle:

10010 + 1 is 10011

10011 + 1 is 10100

11111 + 1 is 100000

Add 1 to a Binary # on a TM

			1	0	0	1	1			
							⇧			
							S0			

(S0, 0, S1, 1, R) (S1, 0, S1, 0, R)

(S0, 1, S0, 0, L)

(S0, b, S1, 1, R) (S1, b, H, b, L)

			1	0	1	0	0			
							⇧			
							H			

Turing’s Major Achievements

- Code breaking at Bletchley Park in WW II
- Solving Hilbert’s *Entscheidungsproblem*
- **Turing Machine (TM) and Universal TM**
- Turing Test and Artificial Intelligence
- Designed first stored program computer
- Pioneer in Morphogenesis
- LU Decomposition (matrix inversion, etc.)

Universal TM

- Turing proved the existence of a "Universal Computing Machine" (now UTM) which could emulate how any TM program would run given any data on its tape.
- Given a TM program *P* and its data *d*, encode both on the UTM's tape, and then the UTM can emulate *P* running on *d*, which I'll write as *P*(*d*).

Turing’s Major Achievements

- Code breaking at Bletchley Park in WW II
- **Solving Hilbert’s *Entscheidungsproblem* (Turing Halting Problem)**
- Turing Machine (TM) and Universal TM
- Turing Test for an Artificial Antelligence
- Designed first stored program computer
- Pioneer in Morphogenesis
- LU Decomposition (matrix inversion, etc.)

Turing Halting Problem

- Turing proved that it was impossible to write a program that could decide, for any program and its data, whether or not that program would halt for that data.
- I.e., there cannot be a program *P** such that

$$P^*(P,d) = \begin{cases} T \text{ if } P(d) \text{ halts} \\ F \text{ if } P(d) \text{ does not halt} \end{cases}$$

Turing Halting Problem Proof

- The proof uses proof by contradiction where you assume that what you want to prove is false, and show that leads to a contradiction.
- I.e., we assume that there is a program *P** such that

$$P*(P,d) = \begin{cases} T \text{ if } P(d) \text{ halts} \\ F \text{ if } P(d) \text{ does not halt} \end{cases}$$

and show that leads to a contradiction.

Turing Halting Problem Proof

$$P*(P,d) = \begin{cases} T \text{ if } P(d) \text{ halts} \\ F \text{ if } P(d) \text{ does not halt} \end{cases}$$

$$P**(P) = P*(P,P) = \begin{cases} T \text{ if } P(P) \text{ halts} \\ F \text{ if } P(P) \text{ does not halt} \end{cases}$$

$$P***(P) = \begin{cases} \text{loops (does not halt) if } P(P) \text{ halts} \\ F \text{ (halts) if } P(P) \text{ does not halt} \end{cases}$$

$$P***(P***) = \begin{cases} \text{does not halt if } P***(P***) \text{ halts} \\ \text{halts if } P***(P***) \text{ does not halt} \end{cases}$$

Turing's Major Achievements

- Code breaking at Bletchley Park in WW II
- Solving Hilbert's *Entscheidungsproblem*
- Turing Machine (TM) and Universal TM
- **Turing Test and Artificial Intelligence**
- Designed first stored program computer
- Pioneer in Morphogenesis
- LU Decomposition (matrix inversion, etc.)

Artificial Intelligence

In “Computing Machinery and Intelligence” in the Philosophy journal *Mind* in 1950 Turing discussed

- why he believed that intelligent digital computers would exist
- answered possible counter-arguments.
- introduced the Turing Test/Imitation Game as a “criterion for thinking.”

Turing Test

- A human sits in a room with two teletypes, one controlled by a human and one by the computer
- The interrogator can ask any questions (e.g., write a sonnet or multiply two huge numbers)
- Uses the responses to determine which is the computer and which is the human. Both try to show that they are the human
- If the interrogator cannot decide, the computer has met the criterion for thinking
- Turing expected that by 2000 the interrogator would be correct only 70% of the time

Turing and Chess

- In 1948 Turing and Champernowne wrote Turochamp
- First chess program to attempt full games
- His 1953 paper "Chess" is an important paper on AI philosophy
- The paper includes, for the first time, a statement of the Church Turing Thesis, although he doesn't name it

Turing's Major Achievements

- Code breaking at Bletchley Park in WW II
- Solving Hilbert's *Entscheidungsproblem*
- Turing Machine (TM) and Universal TM
- Turing Test and Artificial Intelligence
- **Designed first stored program computer**
- Pioneer in Morphogenesis
- LU Decomposition (matrix inversion, etc.)

Automatic Computing Engine

- National Physical Laboratory (NPL) appointed Turing to design the ACE computer (he used the name “Engine” to honor Babbage)
- Very detailed design including cost (£11,200)
- First complete design of a von Neumann architecture (stored program)
- Restricted version, Pilot Model Ace, ran its first program in 1950

Turing and von Neumann

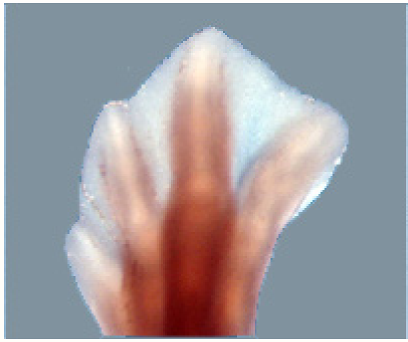
- The extent of their wartime collaboration is unknown
- Both at Princeton together for two years
- Turing spent four months in the US (11/42 to 3/43) and then Von Neumann spent five months in the UK.

Turing's Major Achievements

- Code breaking at Bletchley Park in WW II
- Solving Hilbert's *Entscheidungsproblem*
- Turing Machine (TM) and Universal TM
- Turing Test and Artificial Intelligence
- Designed first stored program computer
- **Pioneer in Morphogenesis**
- LU Decomposition (matrix inversion, etc.)

Morphogenesis

- 1952 paper "The Chemical Basis of Morphogenesis"
- Studying how embryos develop patterns from a patternless single cell
- Coined the term morphogen for a molecule capable of later inducing tissue differentiation



- Created a nonlinear system by turning on diffusion in an otherwise linear system at discrete points
- *Nature*'s review stated "*The influence of Turing's paper is difficult to overstate … What Turing should receive credit for is opening the door to a new view of developmental biology*"

Turing’s Major Achievements

- Code breaking at Bletchley Park in WW II
- Solving Hilbert’s *Entscheidungsproblem*
- Turing Machine (TM) and Universal TM
- Turing Test and Artificial Intelligence
- Designed first stored program computer
- Pioneer in Morphogenesis
- **LU Decomposition (matrix inversion, etc.)**

LU Decomposition

- Developed by Turing in 1949
- Arguably still the most important algorithm in Linear Algebra
- Used to solve systems of linear equations, invert matrices, and compute determinants.
- Works by factoring a matrix into the product of a lower triangular matrix (0's above the diagonal) and an upper triangular matrix.

Turing's Personal Life

- Athlete

  Matching his best time would have placed him 15th in the 1948 Olympics marathon (he didn't enter due to injury).

- Gay

  In 1952 he reported to the police that he had been robbed by a gay lover. Both were convicted of gross indecency. Turing chose chemical castration and probation over a prison sentence. He committed suicide two years later through cyanide poisoning (probably through eating a poisoned apple).

British Prime Minister Apology

- An international petition requested an apology from the UK government. PM Brown issued a formal apology in 2009:

  “Thousands of people have come together to demand justice for Alan Turing and recognition of the appalling way he was treated. … I am pleased to have the chance to say how deeply sorry I and we all are for what happened to him ... **So on behalf of the British government, and all those who live freely thanks to Alan's work** I am very proud to say: we're sorry, you deserved so much better.”

IEKYF ROMSI ADXUO KVKZC GUBJ

A memorial at the University of Manchester which has the text, above, on the seat. It is an Enigma encoding of "Founder of Computer Science"