Alan Turing

"Founder of computer science"

Prof. Jonathan P. Bowen

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Birmingham City University

www.jpbowen.com

Museophile

BIRMINGHAM CITY University

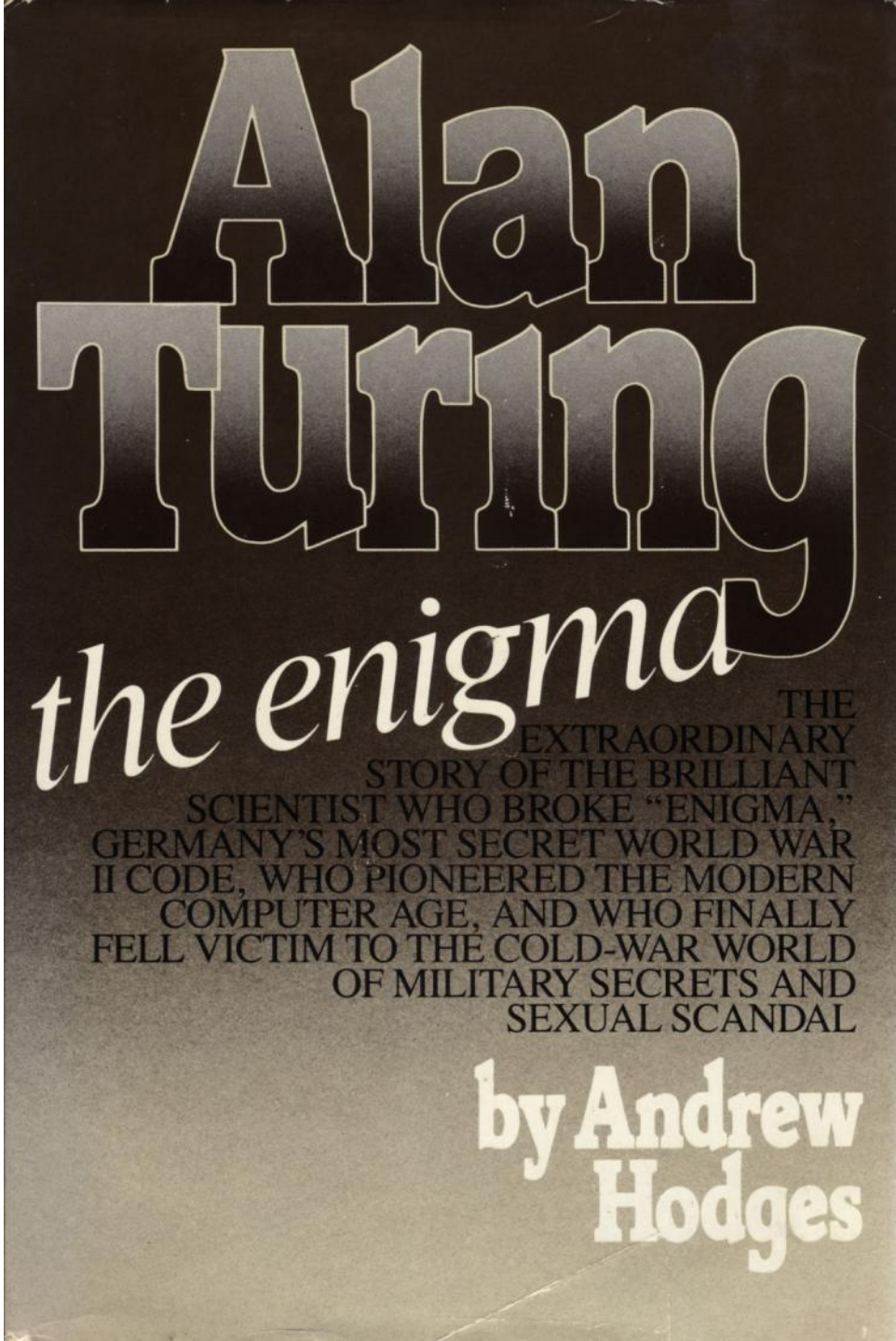
Alan Turing, *The purpose of Ordinal Logics*, 1938

"Mathematical reasoning may be regarded rather schematically as the exercise of a combination of two facilities, which we may call ***intuition*** *and* ***ingenuity****."*

Alan Turing: The Enigma

1st edition, 1983.
Centenary edition, 2012.

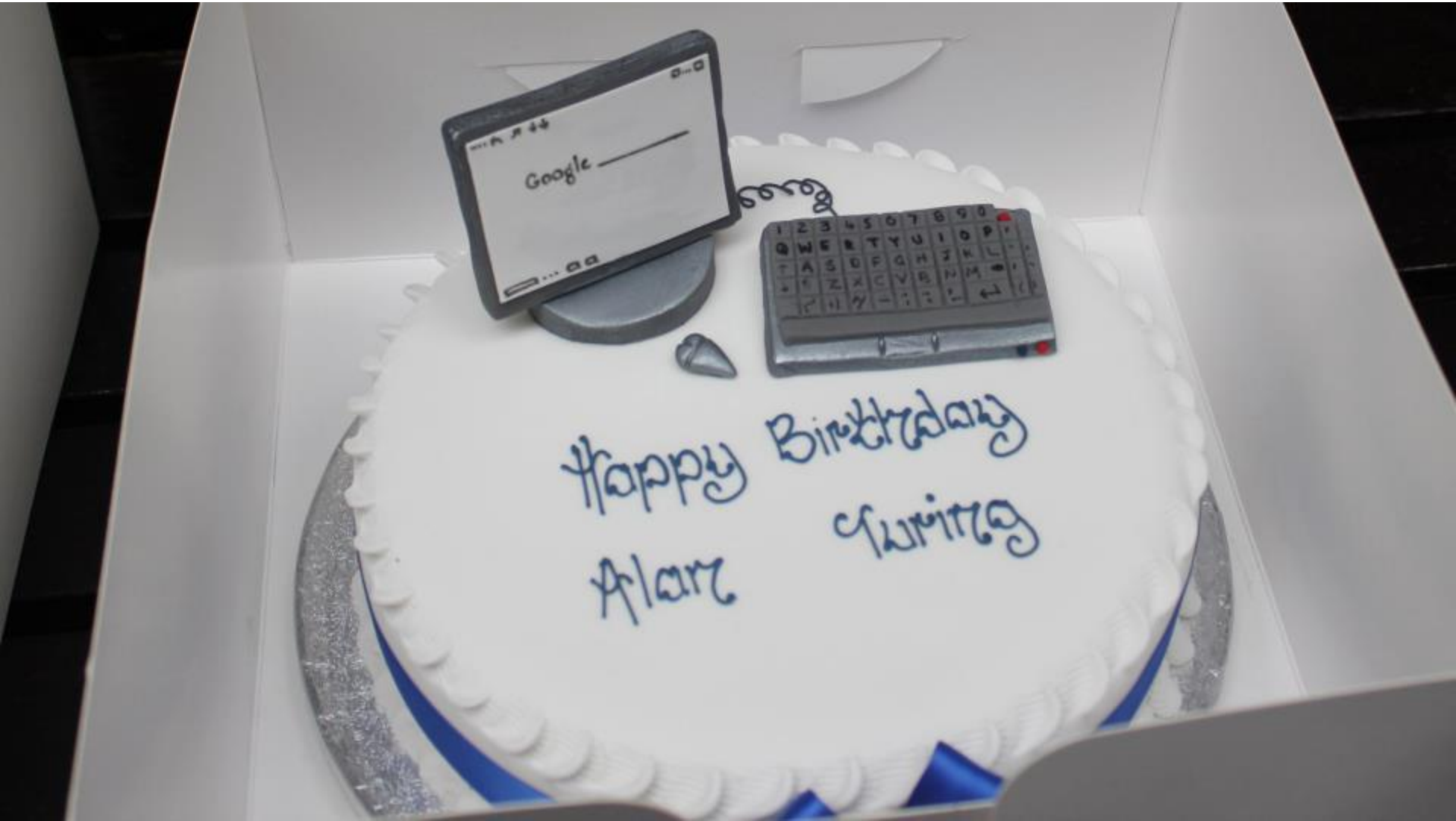
Definitive biography by Andrew Hodges, Wadham College, Oxford.



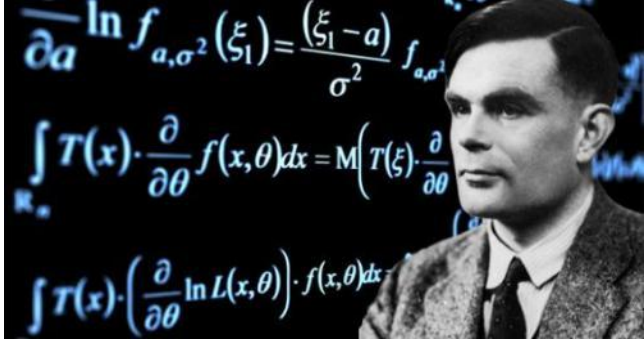
Overview

- **Alan Mathison Turing**, OBE, FRS (23 June 1912 – 7 June 1954)
- Mathematician and codebreaker
- “Founder/father of computer science”
- Centenary meetings at Bletchley Park, Cambridge, Manchester, Oxford, etc., in 2012
- Increasingly in the public consciousness

Happy Birthday Alan Turing! (2012)



Turing citations



Small number of highly influential papers
– c. 5 citations per day

Alan Turing

Reader, University of Manchester

Mathematics - Computer Science - Cryptography - Artificial Intelligence - Morphogenesis

Google Scholar

Citation indices

	All	Since 2008
Citations	24136	9113
h-index	32	20
i10-index	50	29

Turing's top 10 papers

Google Scholar

Title / Author	Cited by	Year
The chemical basis of morphogenesis AM Turing Bulletin of Mathematical Biology 52 (1), 153-197	7256	1952
On computable numbers, with an application to the Entscheidungsproblem AM Turing Proceedings of the London Mathematical Society 42 (2), 230-265	6295	1936
Computing machinery and intelligence AM Turing Mind 59 (236), 433-460	6067	1950
Systems of logic based on ordinals AM Turing Proceedings of the London Mathematical Society 2 (1), 161-228	586	1939
Intelligent machinery (1948) A Turing B. Jack Copeland, 395	491	2004
Rounding-off errors in matrix processes AM Turing The Quarterly Journal of Mechanics and Applied Mathematics 1 (1), 287-308	338	1948
with corrections from Proceedings of the London Mathematical Society AM Turing Series 2 (43), 544-546	338 *	1937
Computing machinery and intelligence AM Turing Computers & Thought, 11-35	337	1995
Computability and λ-definability AM Turing The Journal of Symbolic Logic 2 (4), 153-163	247	1937
Checking a large routine A Turing The early British computer conferences, 70-72	227	1948

Bioinformatics

Theoretical computer science

Artificial Intelligence

Contributions

- **The Universal Machine (1936)**
- **Codebreaking (WW II)**
- **Computers and computing (1946)**
- **Artificial Intelligence (1950)**
- **Morphogenesis (1952)**

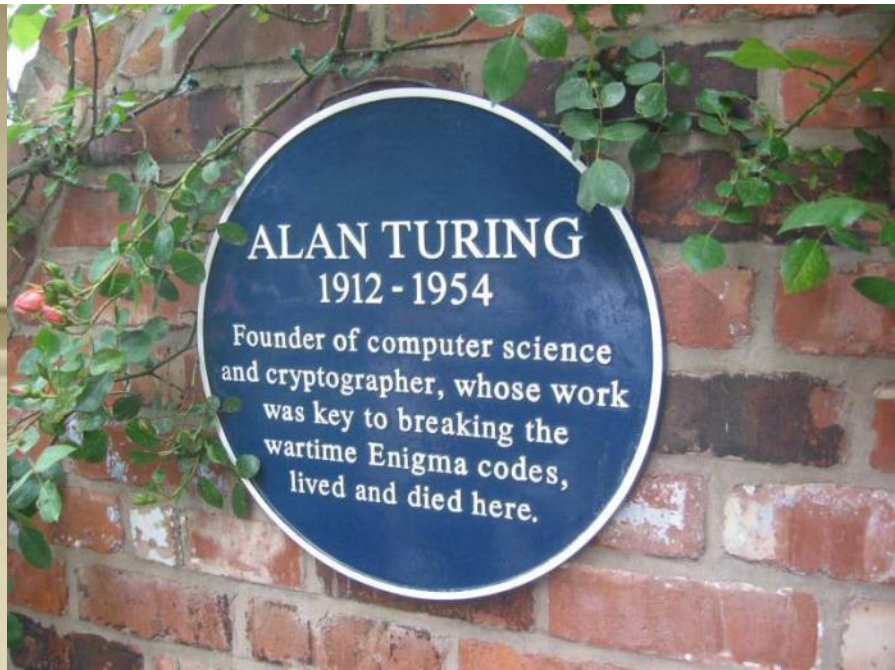
Life

- Born 1912
- Died 1954, aged 41

Alan Turing as a child

Born at Colonnade Hotel
Maida Vale, London

Died in Wilmslow, Cheshire



Southampton to Sherborne

Arrival at new school: Bicycle ride during the General Strike, 1926

Stayed at the Crown Hotel Blandford Forum

Read and understood Einstein aged 16

Max Newman – Turing's mentor

- King's College, Cambridge (1931–34), then Fellow
- Maxwell Herman Alexander **Newman**, FRS (1897–1984), mathematician and codebreaker
- Newman's 1935 lectures on the foundations of mathematics inspired Turing
- Later at Bletchley Park / Manchester
- One of Turing's few co-authors

Newman, M. H. A. (1955). "Alan Mathison Turing. 1912–1954". *Biographical Memoirs of Fellows of the Royal Society,* **1**:253–226. doi:10.1098/rsbm.1955.0019

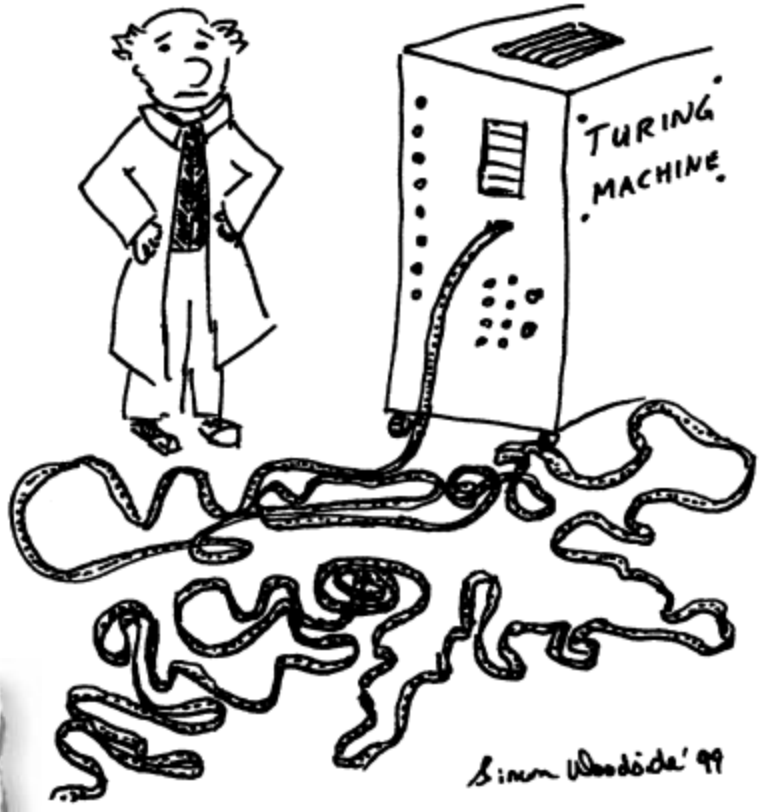
Hilbert and Gödel

- David Hilbert (1862–1943)
- Hilbert's program
- Kurt Friedrich Gödel (1906–1978)
- Completeness theorem (1929)
- Incompleteness theorems (1931)
- Turing's 1936 paper

Turing, A.M. (1936–7) On Computable Numbers with an Application to the Entscheidungsproblem. *Proceedings of the London Mathematical Society*, Series 2, **42**(1):230–265. doi:10.1112/plms/s2-42.1.230

Decidability and the Entscheidungsproblem

- Decision problem
- Turing machine – theoretical
- Halting problem
- Computability



Turing solves the halting problem, only to discover that the REAL problem with his machine is what to do with all the tape.

ON COMPUTABLE NUMBERS, WITH AN APPLICATION TO THE ENTSCHEIDUNGSPROBLEM

By A. M. TURING.

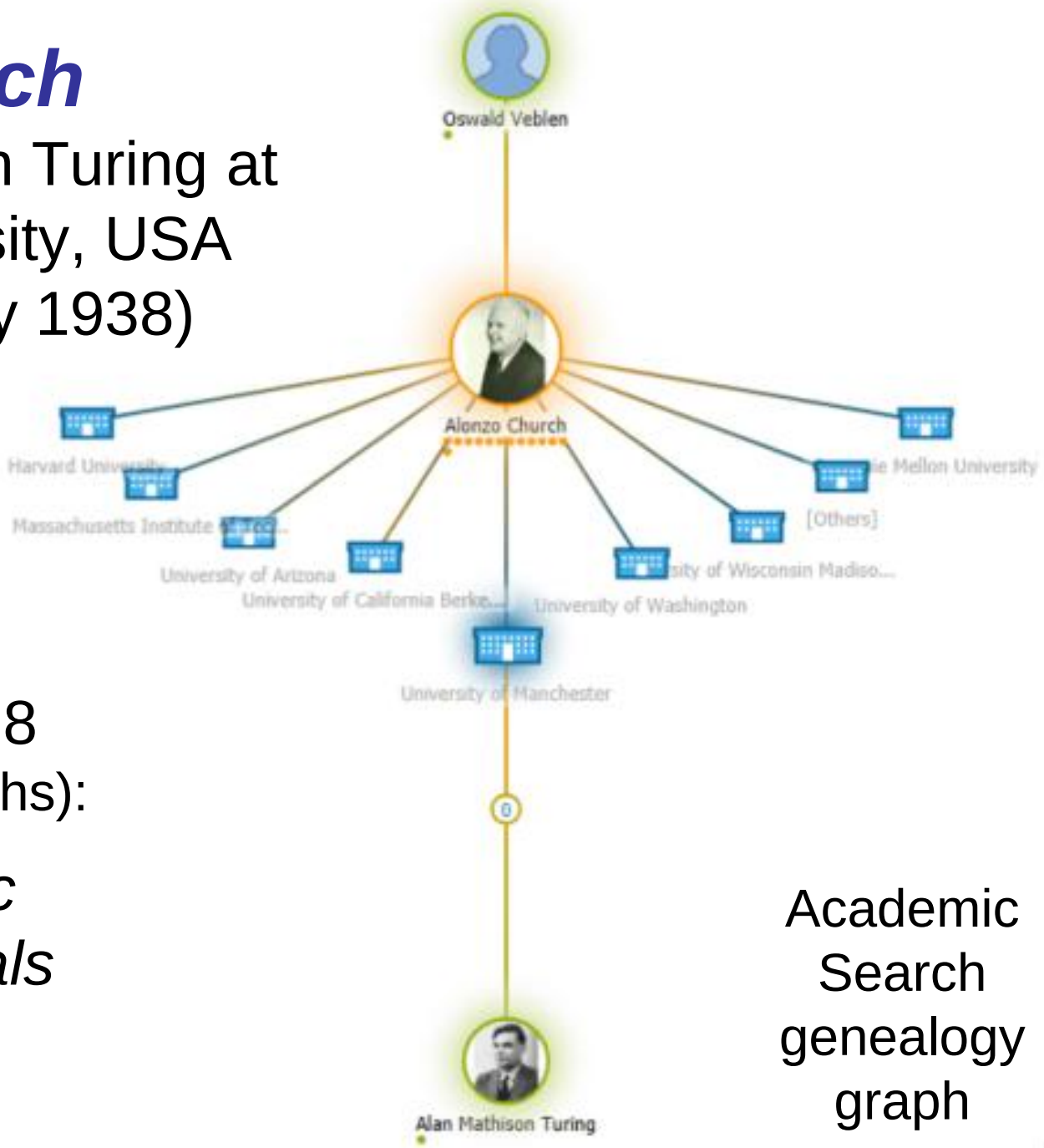
[Received 28 May, 1936.—Read 12 November, 1936.]

The Universal Turing Machine

An implementation of a Turing machine

Alonzo Church

supervisor of Alan Turing at Princeton University, USA (Sept. 1936 – July 1938)



PhD in June 1938
(only 1 year 9 months):

Systems of Logic Based on Ordinals

Academic Search genealogy graph

The Church–Turing thesis

- Alonzo Church (1903–1995)
- Undecidability of the Entscheidungsproblem
- Two independently developed approaches
- Turing could have stayed in the US, but...

Bletchley Park

- WW II codebreaking
- Enigma, etc.

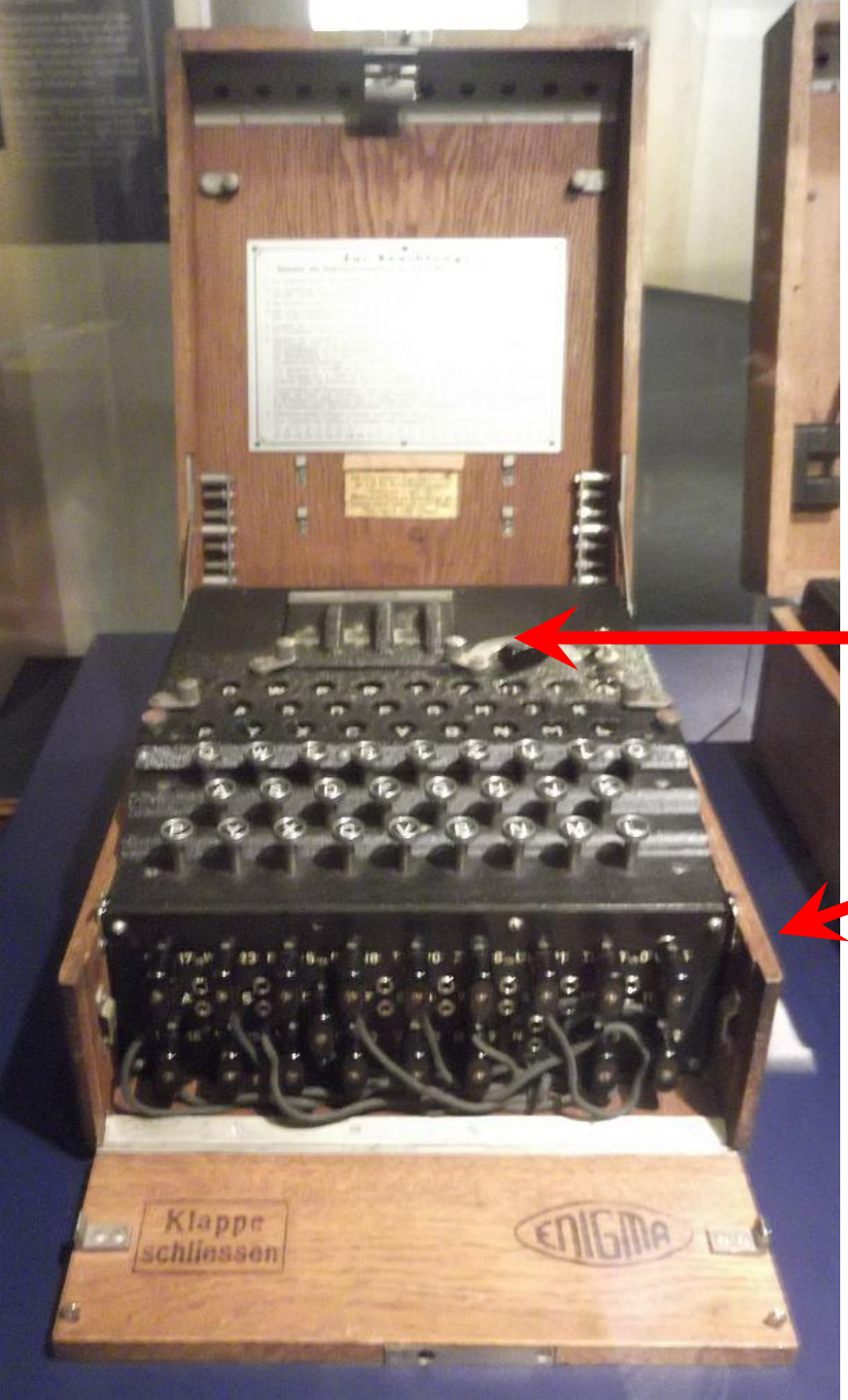
Turing's office in Hut 8

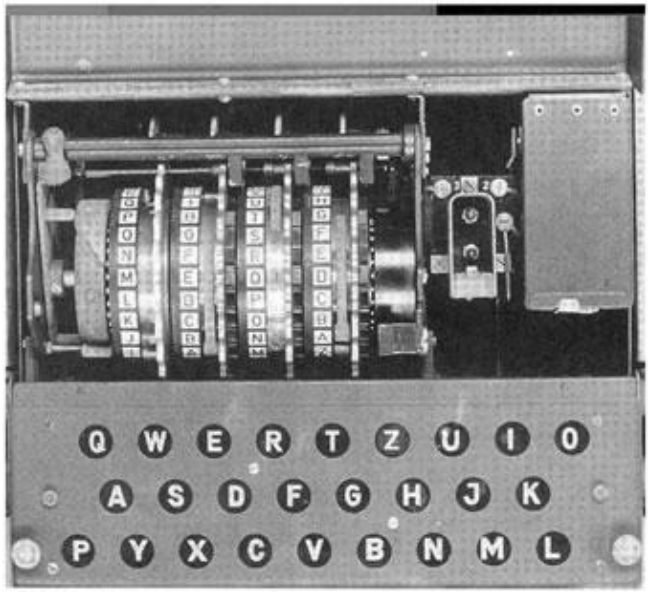
Cottages in the stableyard where Turing did early work on Enigma

Hut used by Turing

German Naval Enigma

- Electro-mechanical rotor cipher machines
- Rotors and plugboard





Bombes

- Electromechanical deciphering device
- Initial design by Turing (1939)
- Bombe reconstruction at Bletchley Park

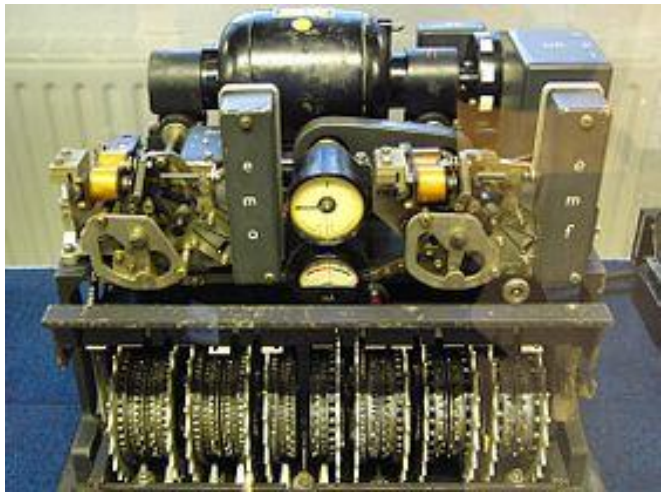
Jean Valentine, Bombe operator, now a guide at Bletchley Park

Banburismus and Turingery

- *Banburismus*: a cryptographic method developed by Turing for Enigma (Bombe pre-processing)
- Later used in *Turingery* (aka *Turing's Method* and *Turingismus*) for breaking the Lorenz cipher
- **Lorenz**: German army rotor stream cipher machines
- Nicknamed "*Tunny*" after "Fish" (non-Morse) cipher

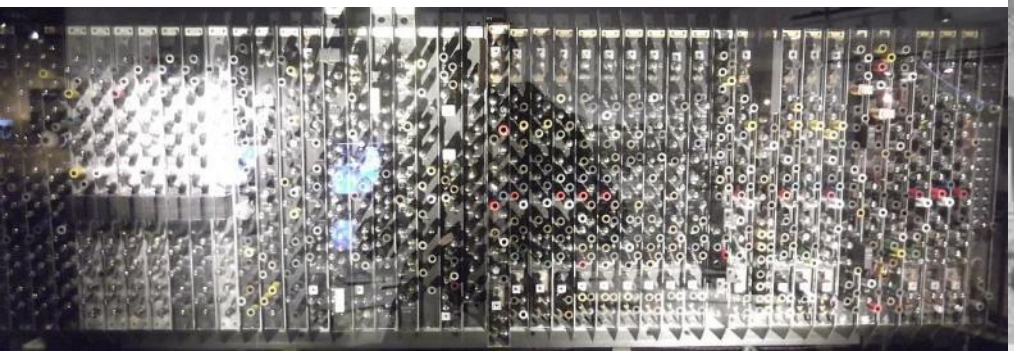
Cf.
BlackBerry
today

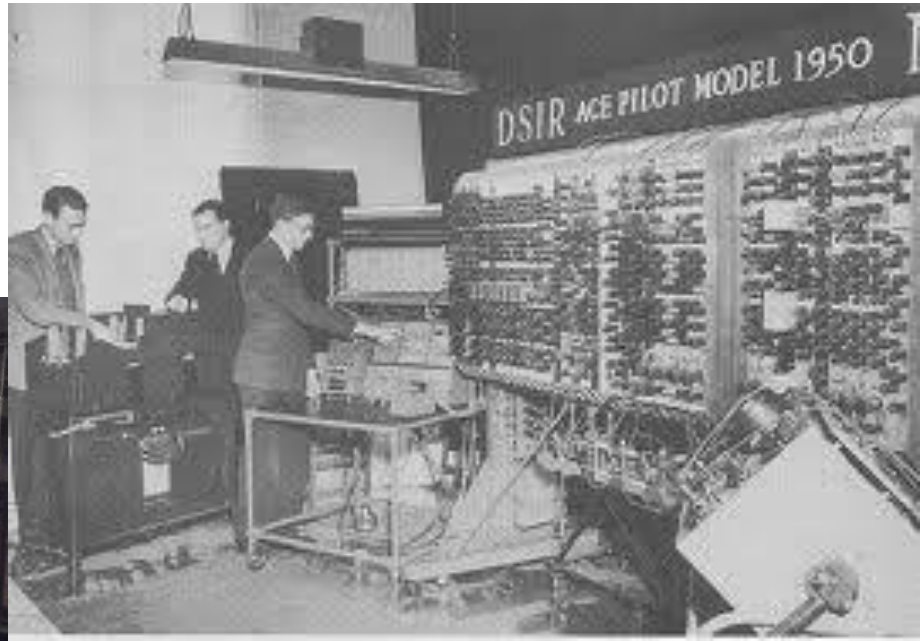
Awarded an
OBE in 1945



The ACE computer

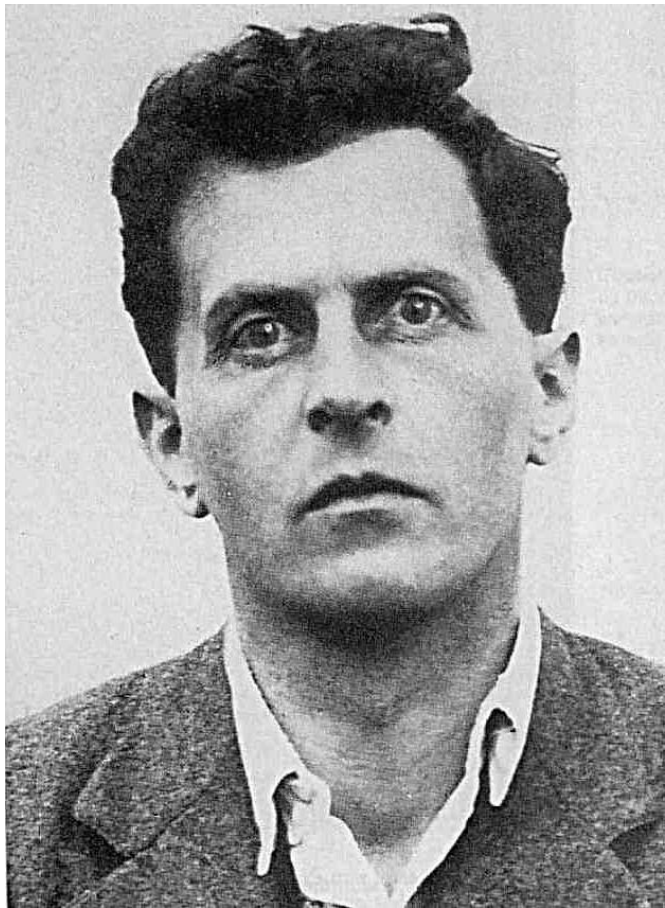
- Turing at National Physical Laboratory, 1945–47
- Automatic Computing Engine (ACE), originally designed by Turing, 1946
- Smaller Pilot ACE finally implemented, 1950
- Now in the Science Museum, London





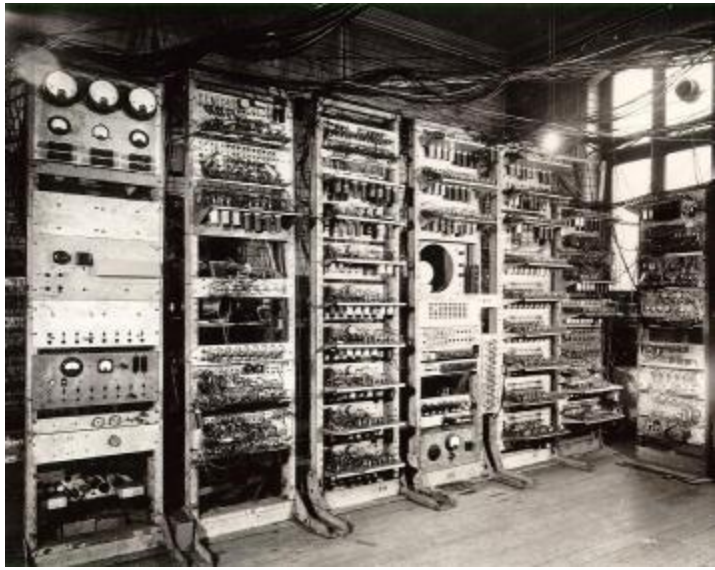
Wittgenstein and Turing

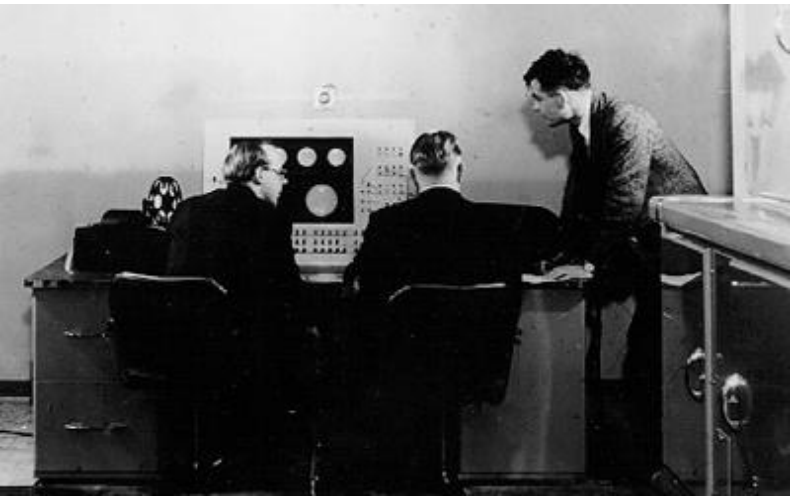
- Turing's sabbatical year in Cambridge (1947–48)
- Ludwig Wittgenstein, philosopher (1889–1951)
- Lectures at Cambridge attended (and understood!) by Turing
- Discovery vs. invention of mathematics



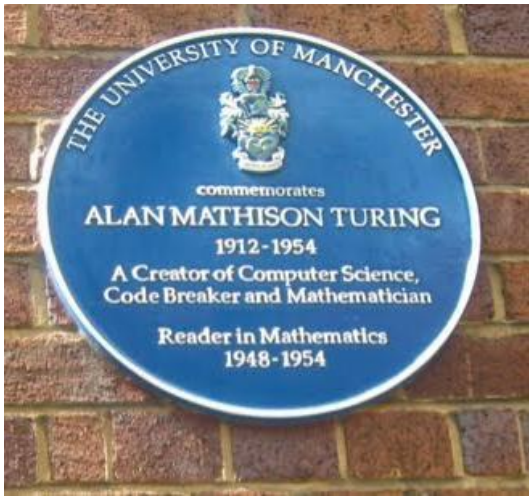
The Manchester computer

- Turing appointed 1948 (became a Reader)
- Manchester Mark I computer, June 1948
- Worked on software



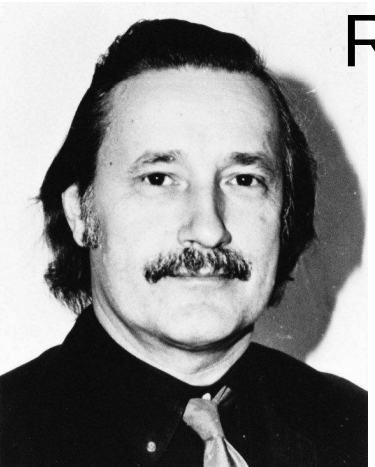


Alan Turing on the right standing at the console of the Manchester Ferranti computer.



Turing and programming

- Early meeting in Cambridge
  - "*Checking a large routine*" paper (1948)
- Turing's influence or otherwise
- Computer chess and draughts
  - Christopher Strachey (1916–75), first head of the Programming Research Group, Oxford

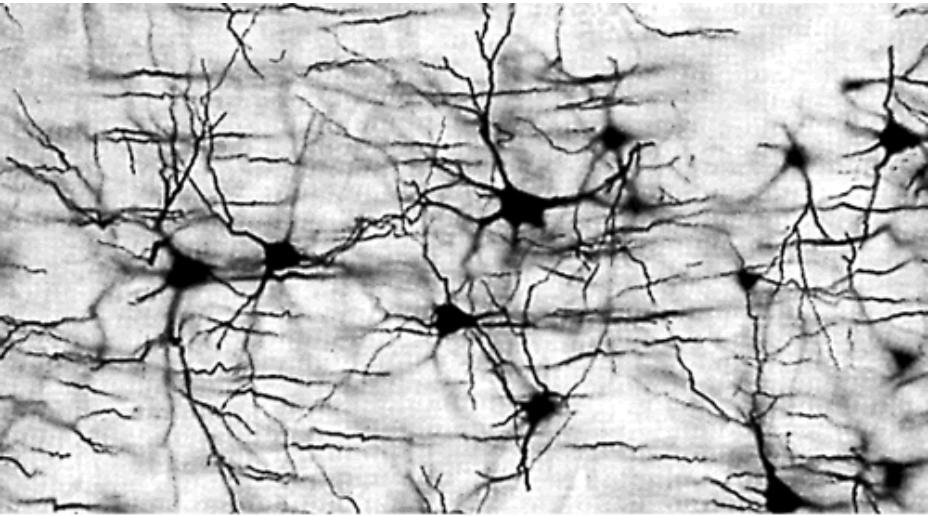


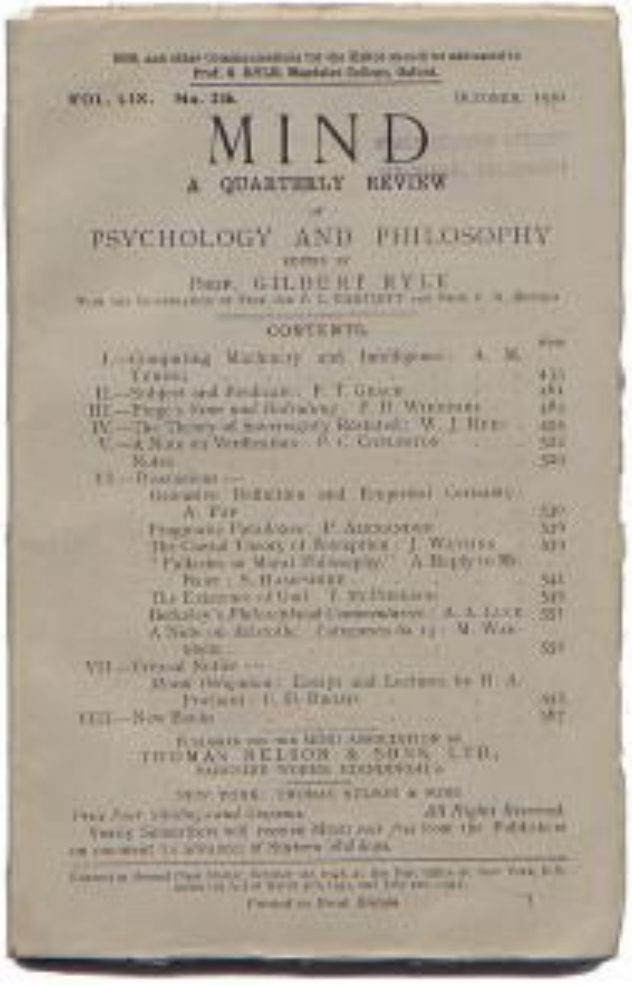
Punched cards for Pilot ACE computer

Machine intelligence

Turing foresaw *Artificial Intelligence* (AI)

Turing, A.M. (October 1950), "Computing Machinery and Intelligence", *Mind,* **LIX**(236):433–460. doi:10.1093/mind/LIX.236.433




MIND

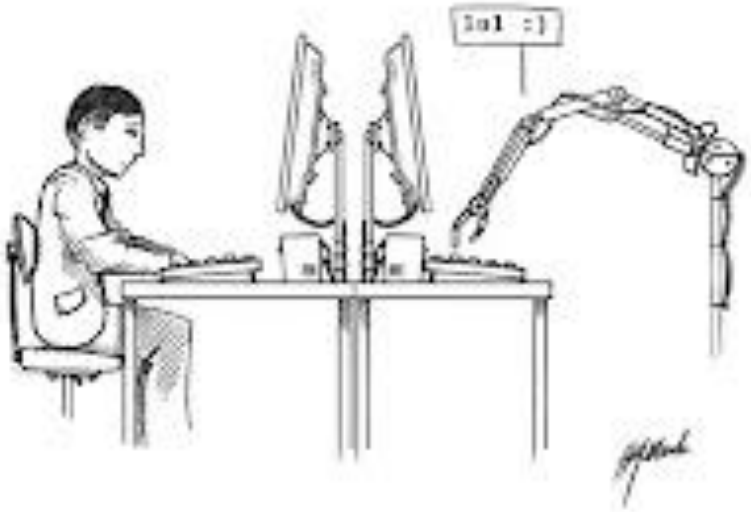
A QUARTERLY REVIEW

OF

PSYCHOLOGY AND PHILOSOPHY

The Turing Test

- The imitation game
- “Child machines” – educable
- Social communication



“On the Internet, nobody knows you’re a dog.” – New Yorker

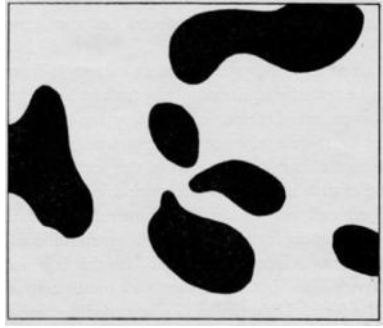
Thought

"... at the end of the [20th] century, ... one will be able to speak of machines thinking without expecting to be contradicted."

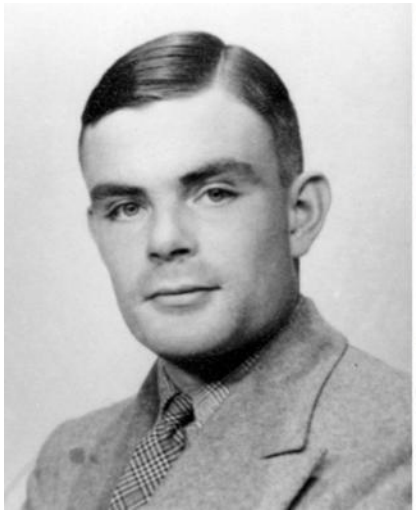
– Alan Turing

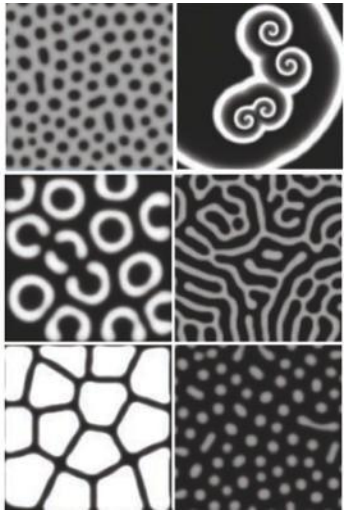
Awarded Fellowship of the Royal Society (**FRS**), 1951.

Morphogenesis



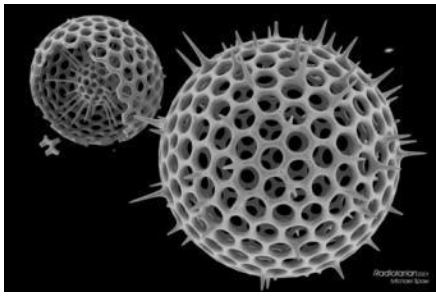
- The "beginning of the shape" – biological process, patterns
- Turing not completely correct, but close enough
- Chaos theory





Turing, A.M. (1952). "The Chemical Basis of Morphogenesis". *Philosophical Transactions of the Royal Society B: Biological Sciences,* **237**(641):37–64. doi:10.1098/rstb.1952.0012

Last student



- Bernard Richards
- Masters student under Turing at Manchester from 1953

On Alan Turing: *"The day he died felt like driving through a tunnel and the lights being switched off."*

Poem from Turing to Robin Gandy

Hyperboloids of wondrous Light;
Rolling for aye through Space and Time;
Harbour those Waves which somehow Might;
Play out God's holy pantomime.

Robin Gandy (1919–1995), student of Turing at Cambridge, later at Wolfson College, Oxford

Epitaph

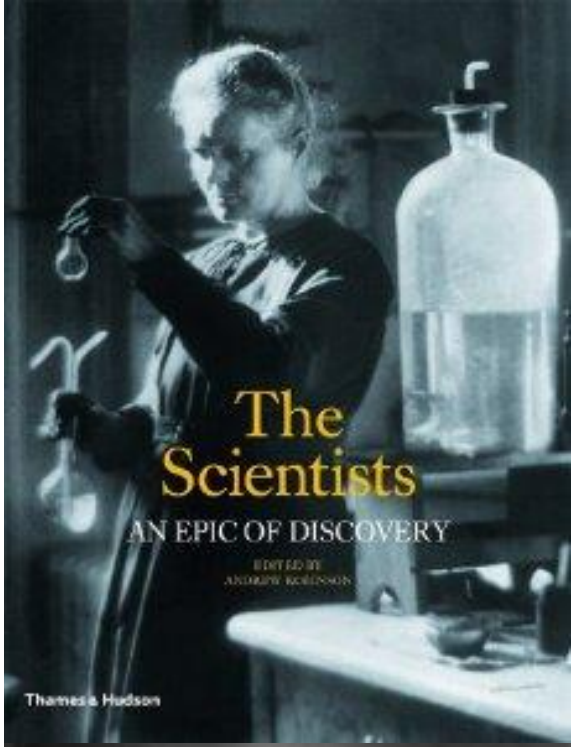
“A sort of scientific Shelley.”

– Sir Geoffrey Jefferson FRS (1886–1961)
Professor of Neurosurgery at Manchester

Shelley Memorial,
University College,
Oxford

The Scientists: An epic of discovery

- Andrew Robinson (ed.), Thames & Hudson, 2012
- 43 scientists through history
- Two computer scientists:
  - Alan Turing, “Turing Machine”
  - John von Neumann(1903–1957), “von Neumann Machine”

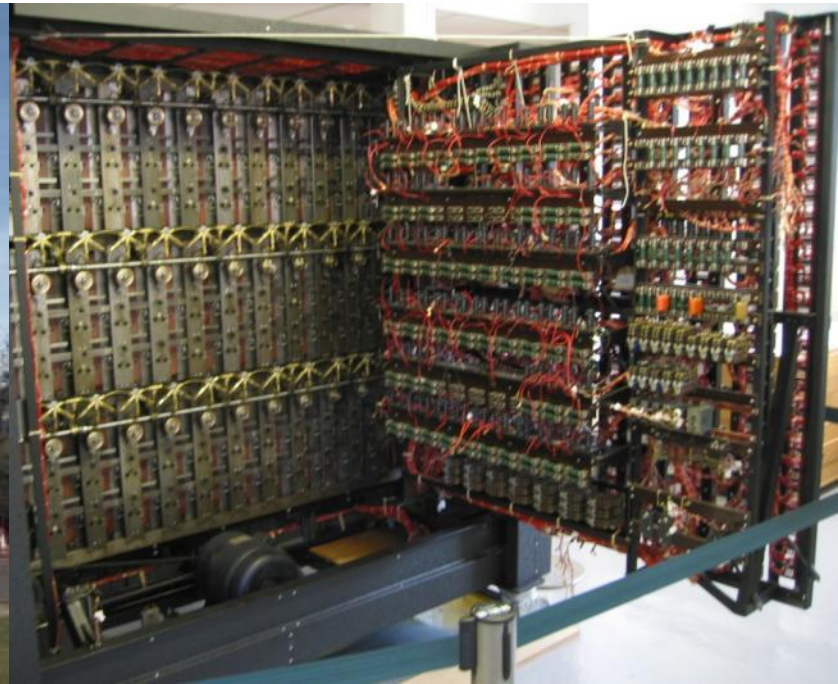


Epilogue

- ACM Turing Award, first awarded 1966
- Increasing public consciousness
- Government apology/pardon
- Turing papers: auction
- Google donation to Bletchley Park

Bletchley Park – now

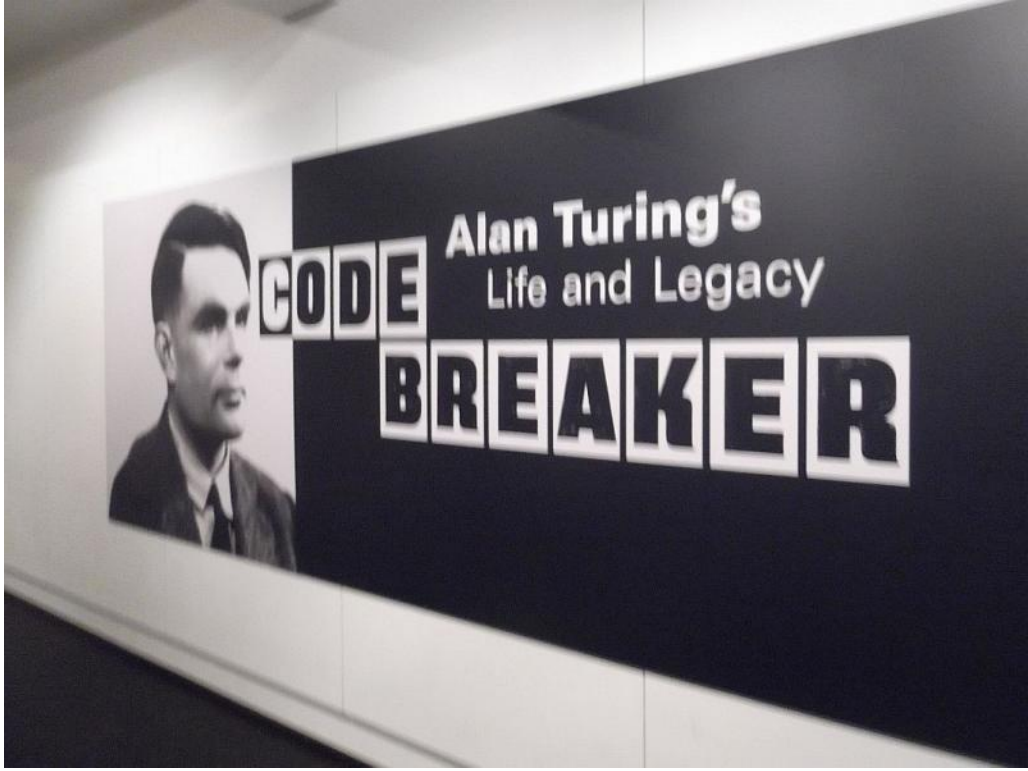
- Bombe and Colossus reconstructions
- National Museum of Computing
- Now safe, but needs further funding

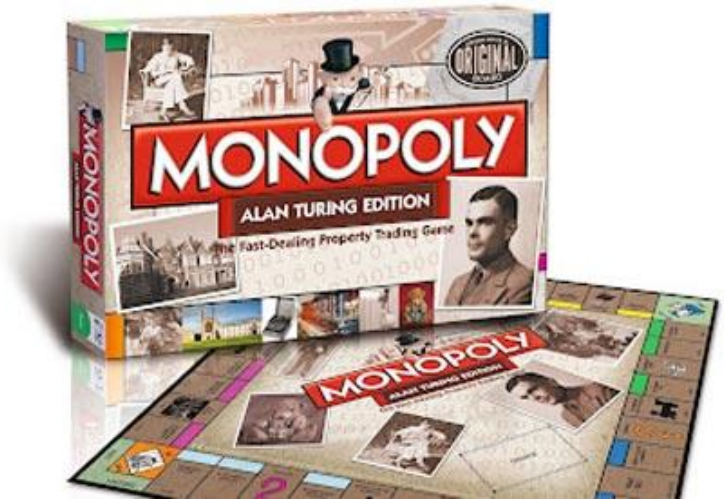


Memorials

- E.g., slate statue at Bletchley Park by Stephen Kettle
- Also statue in Manchester

Alan Turing exhibition at the Science Museum (2012)





Even Alan Turing Monopoly!
(2012 special edition)

Alan Turing – online resources

- Centenary year in 2012
  - www.turingcentenary.eu
- Andrew Hodges (Turing biographer)
  - *Alan Turing: the Enigma* (1983)
  - www.turing.org.uk
- The Turing Digital Archive (3,000 images)
  - King's College Cambridge
  - www.turingarchive.org
- Jack Copeland's *Turing Archive* (facsimiles)
  - www.alanturing.net

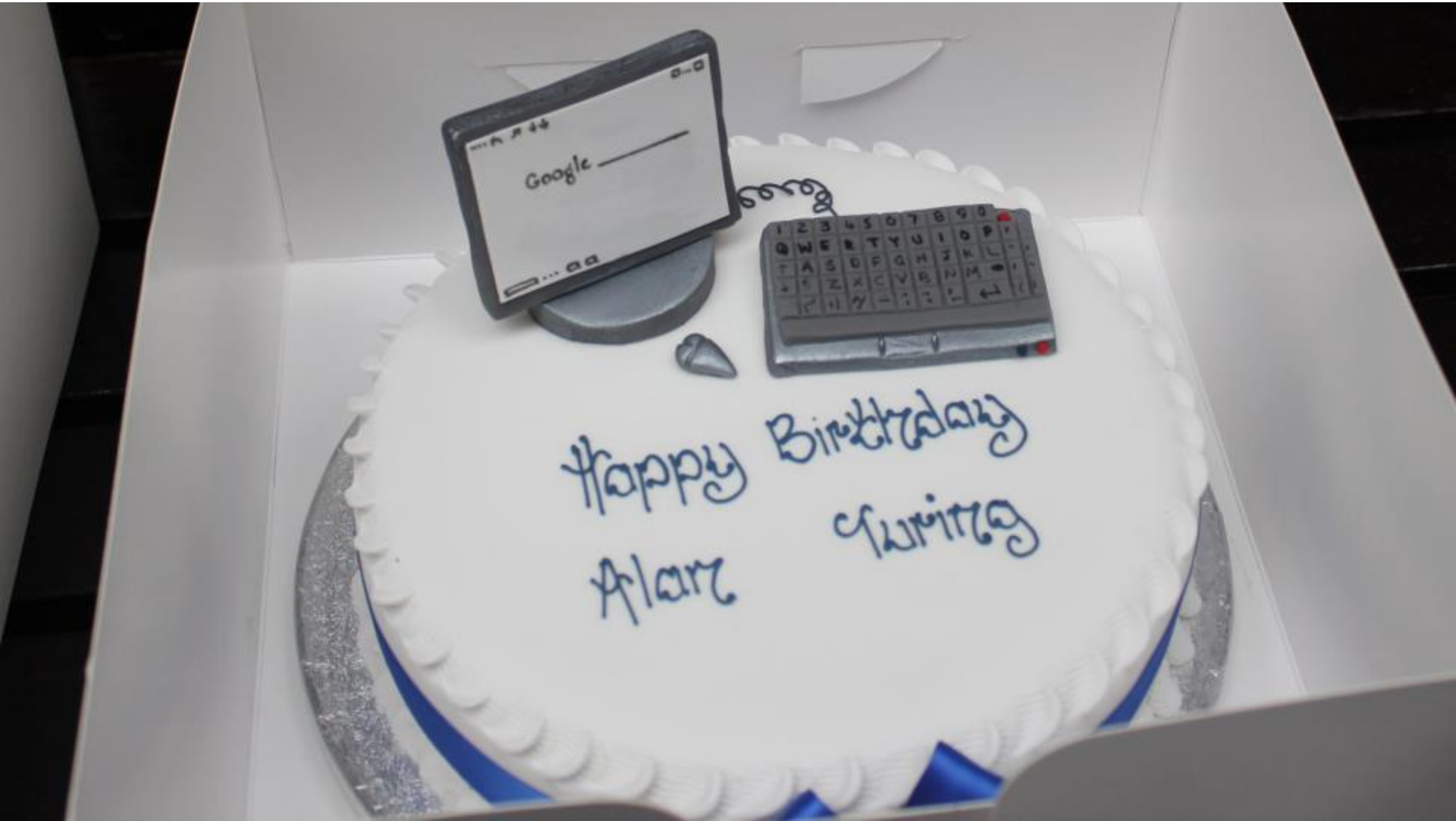
Turing's Worlds (23–24 June 2012)

Department of Continuing Education, Oxford

http://ormalmethods.wikia.com/wiki/Turing's_Worlds

Happy Birthday Alan Turing!

- Also Ivor Grattan-Guinness, historian of mathematics and logic (born 23 June 1941)



The Imitation Game (2014)

Historical drama film on the life of Alan Turing, starring Benedict Cumberbatch and Keira Knightley (based on *Alan Turing: The Enigma*).

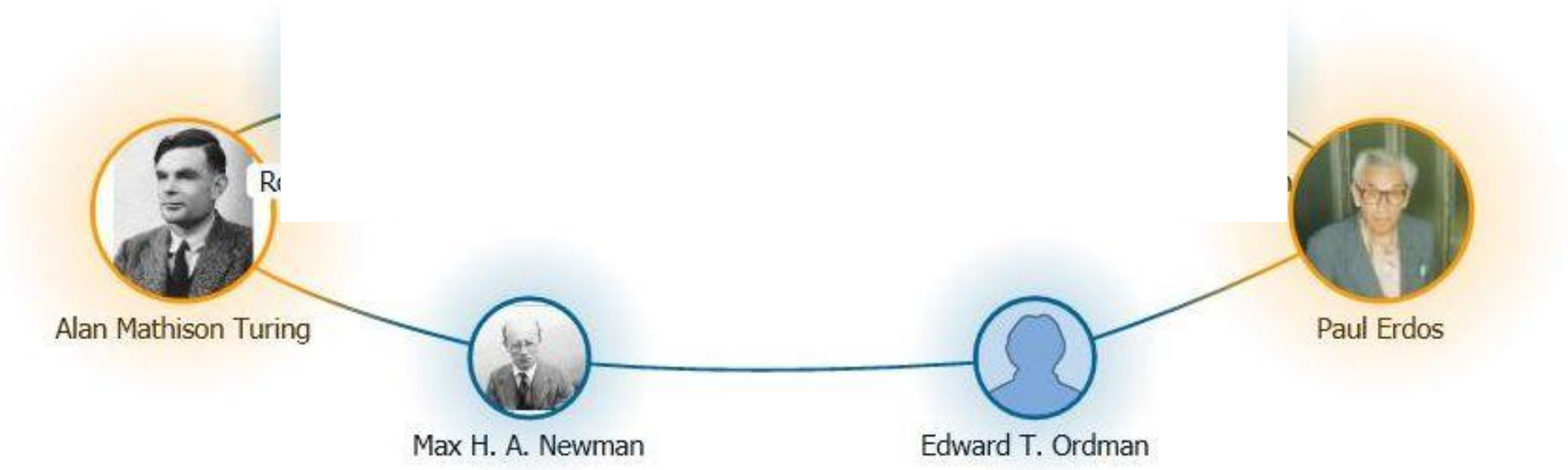
Filming at King's Cross Station, London October 2013

The Erdős number (an aside)

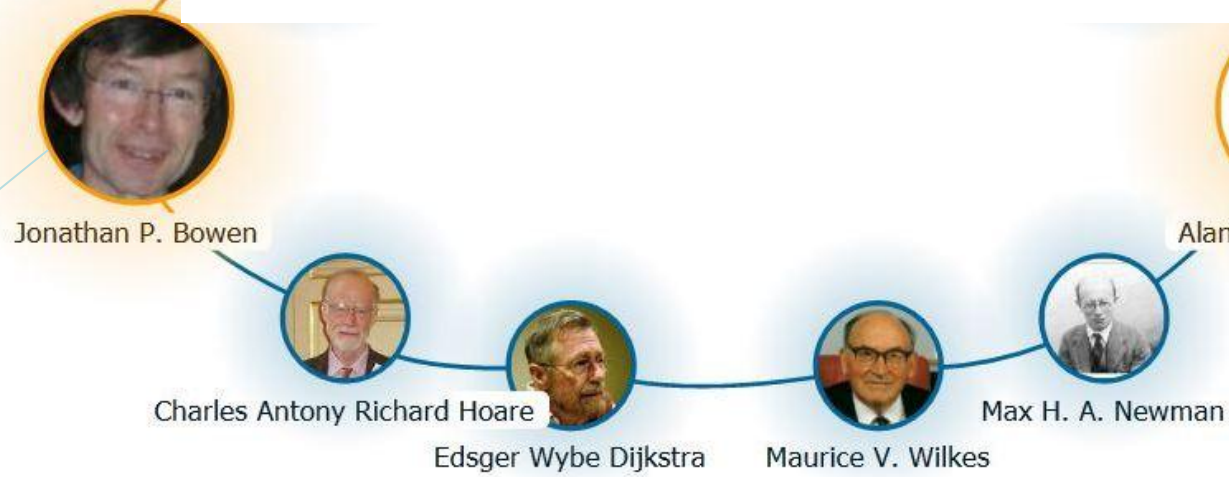
- **Paul Erdős** (1913–1996)
  - Hungarian mathematician
  - Erdős number 0
  - Co-authored over 1,000 publications
- 511 co-authors
  - Erdős number 1
  - Co-authors of Erdős co-authors
    - Erdős number 2, etc.

The “Turing number”

- Minimum distance from Turing by co-author
- Main co-author: Max Newman
- Small number of very influential papers



“Turing number”



Distance from editors!

The Turing Guide

OXFORD
UNIVERSITY PRESS

- Book due in 2015
  (2014, 60th anniversary of Turing's death)
- To be published by Oxford University Press
- Edited by Jonathan Bowen, Jack Copeland, Mark Sprevak, and Robin Wilson
- 42 chapters by contributors largely from Oxford, Cambridge, Bletchley Park meetings

The Turing Guide

Possible front cover…

warholize.me

Table of Contents

- **Preface** by the editors
- **Foreword** by Andrew Hodges
- ***Eight parts***
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OXFORD
UNIVERSITY PRESS

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   Turing's life and work
2. **Sir John Dermot Turing:**
   The man with the terrible trousers
3. **Peter Hilton: *Remembering Turing***
4. **Jack Copeland:**
   The suicide controversy

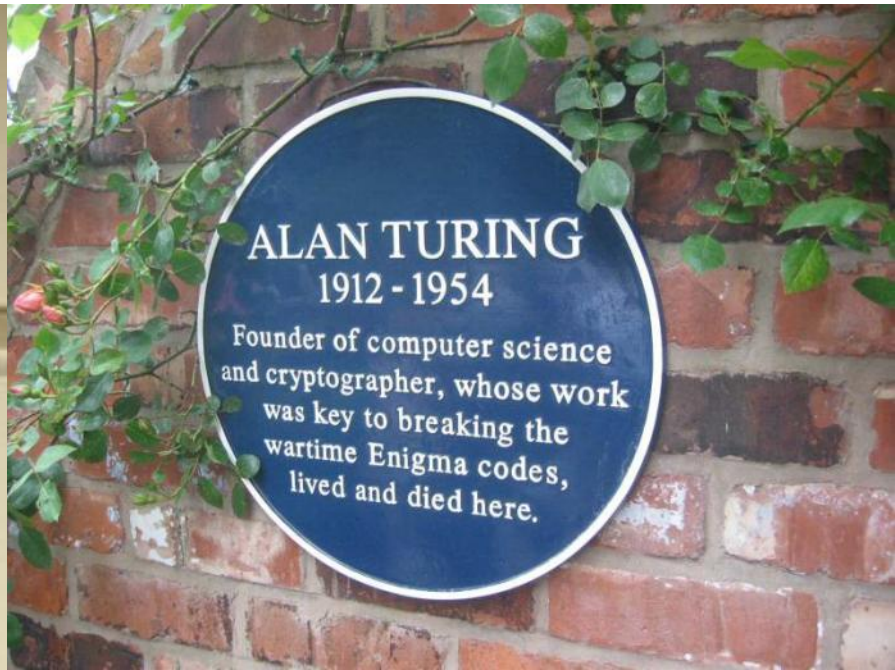
Alan Turing as a child

1. Turing's life and work

- Jonathan P. Bowen, et al.
- Biography

Born at Colonnade Hotel
Maida Vale, London

Died in Wilmslow, Cheshire



2. John Dermot Turing: The man with the terrible trousers

- Sir John Dermot Turing
  – nephew of Alan Turing
- Personal view

At an exhibition on Alan Turing at Bletchley Park, 2012

3. Remembering Turing

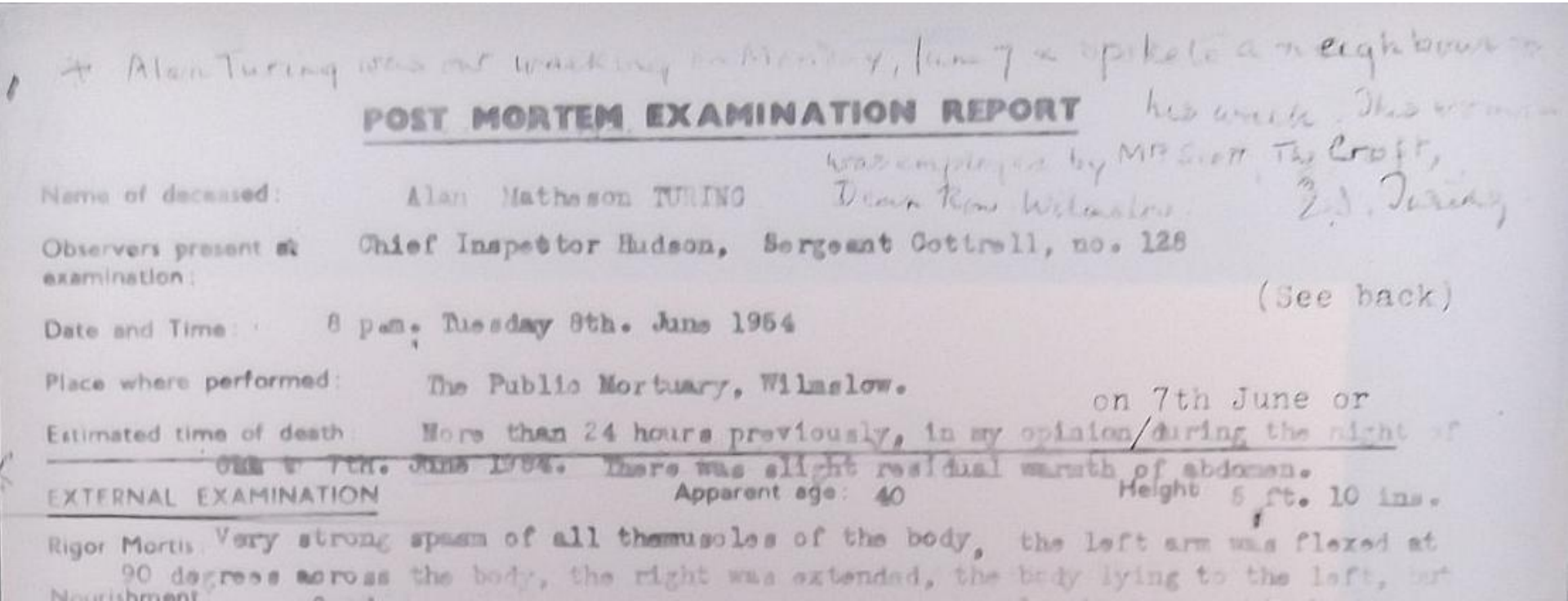
- Peter Hilton (1923–2010)
- Scholarship to Queen's College, Oxford
- Codebreaker and mathematician
- Joined Bletchley Park in 1942 (age 18)
- Worked with Turing on German naval Enigma codes (based in Hut 8)
- Subsequently an academic at Cambridge, Manchester and Birmingham

4. The suicide controversy

- Jack Copeland
- Lack of evidence
- Cyanide experiments
- Apple not tested...

*"We owe him a huge debt, especially as he **committed suicide** after being chemically castrated after being taken to court for an act of gay love."*

– Stephen Fry



POST MORTEM EXAMINATION REPORT

Name of deceased: Alan Mathison TURING

Observers present at examination: Chief Inspector Hudson, Sergeant Cottrell, no. 128

(See back)

Date and Time: 8 p.m. Tuesday 8th. June 1954

Place where performed: The Public Mortuary, Wilmslow.

Estimated time of death: More than 24 hours previously, in my opinion on 7th June or during the night of 6th & 7th. June 1954. There was slight residual warmth of abdomen.

EXTERNAL EXAMINATION — Apparent age: 40 — Height: 5 ft. 10 ins.

Rigor Mortis: Very strong spasm of all the muscles of the body, the left arm was flexed at 90 degrees across the body, the right was extended, the body lying to the left, ...

II. The Universal Machine and Beyond

5. **Stephen Wolfram:** ***A century of Turing***
6. **Jack Copeland:** ***Turing's great invention: the universal computing machine***
7. **Jack Copeland:** ***Sinking Hilbert***
8. **Brian Randell:** ***Turing and the origins of digital computers***

5. A century of Turing

- Stephen Wolfram
- Wolfram Research
- Mathematica
  – “birthday” (23 June 1988)
- Based on a blog

6. Turing's great invention:
the universal computing machine

- Jack Copeland – the "Turing machine"
- Top British inventions nomination:

  "Right, Stephen Fry here. I'm nominating Alan Turing's Universal Engine, the Universal Turing Machine."

7. Sinking Hilbert

- Jack Copeland
- David Hilbert (1862–1943)
- Hilbert's program
- Kurt Friedrich Gödel (1906–1978)
- Completeness theorem (1929)
- Incompleteness theorems (1931)
- Turing's 1936 paper

8. Turing and the origins of digital computers

- Brian Randell
  School of Computing Science
  Newcastle University
- Historian of computing
- See also Chapter 17

III. Codebreaker

9. **Jack Copeland:**
   Turing at Bletchley Park
10. **Joel Greenberg: *The Enigma machine***
11. **Mavis Batey:**
    Breaking machines with a pencil
12. **Jack Copeland, Jean Valentine, and Catherine Caughey: *Bombes***
13. **Edward Simpson:**
    Depths, Bayes, and Banburismus
14. **Jack Copeland:**
    Tunny, Hitler's biggest fish

III. Codebreaker

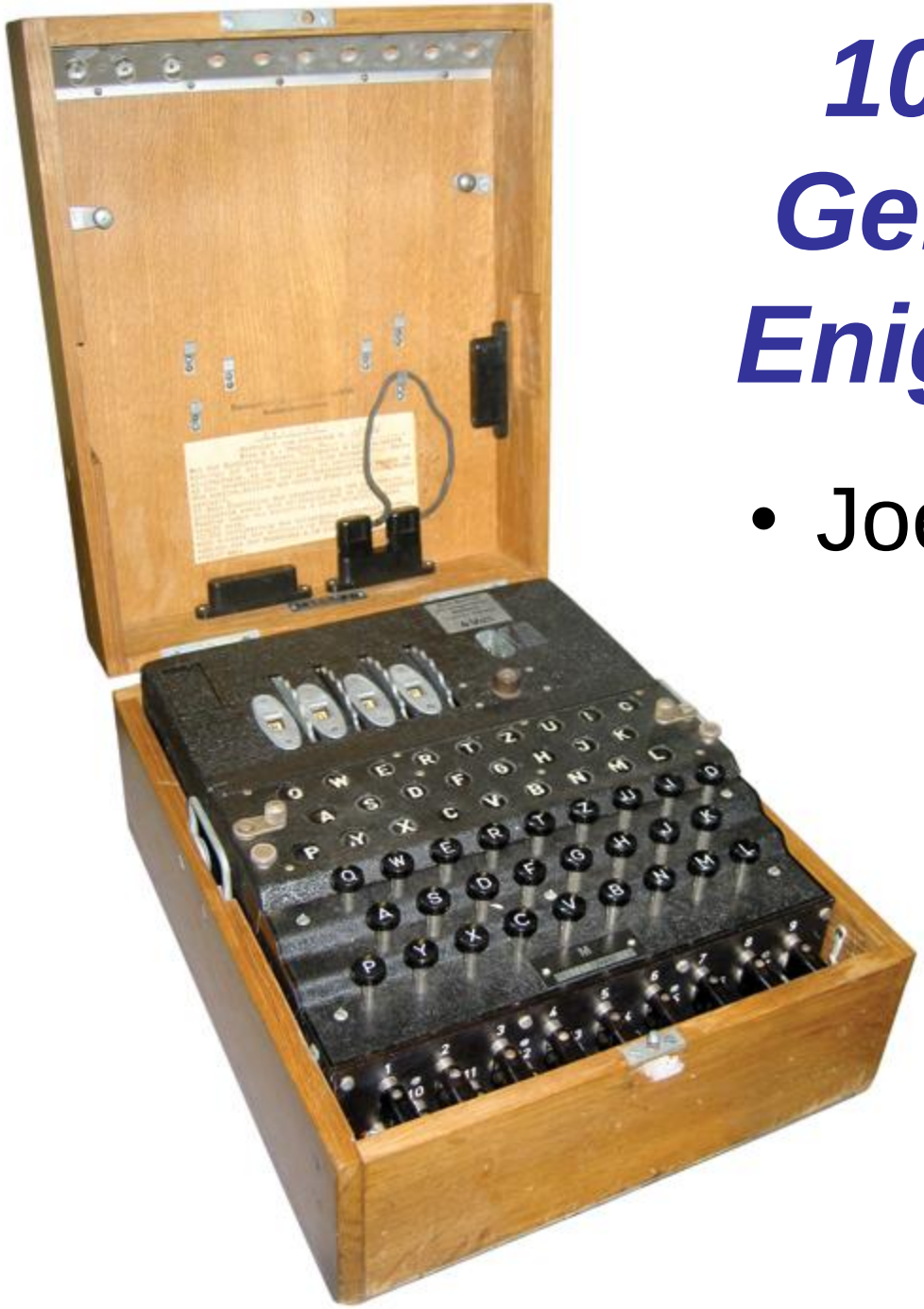
15. **Eleanor Ireland:** ***We were the world's first computer operators***
16. **Jerry Roberts:** ***The Testery: breaking Hitler's most serious code***
17. **Brian Randell:** ***Ultra revelations***
18. **Jack Copeland:** ***Delilah: encrypting speech***
19. **Simon Greenish:** ***How Bletchley Park became a national museum***

9. Turing at Bletchley Park

- Jack Copeland
- Enigma, etc.

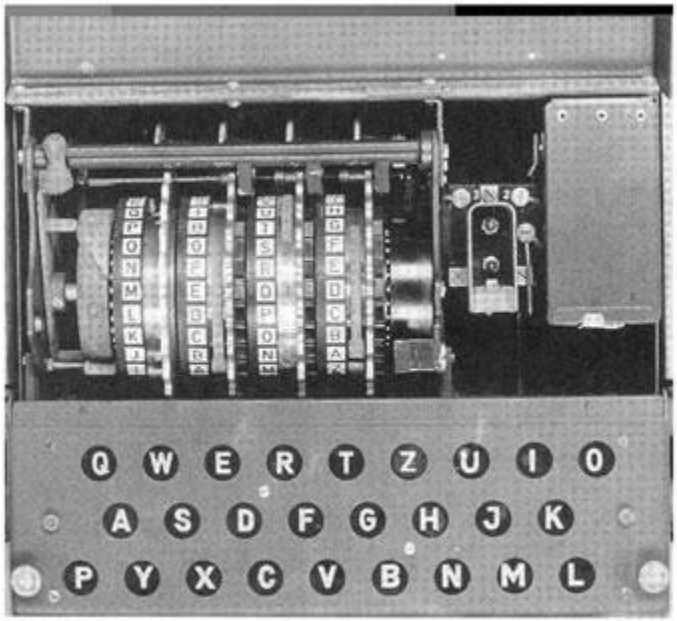
Cottages in the stableyard where Turing did early work on Enigma

Hut used by Turing



10. How the German Naval Enigma worked

- Joel Greenberg



11. Breaking machines with a pencil

- Mavis Batey, MBE (née Lever,1921–2013)
- Enigma codebreaker at Bletchley Park with her husband Keith Batey
- Later a garden historian

12. Bombes

- Jack Copeland, **Jean Valentine**, and Catherine Caughey
- Bombe operator during WW II
- Bombe reconstruction
- Guide at Bletchley Park

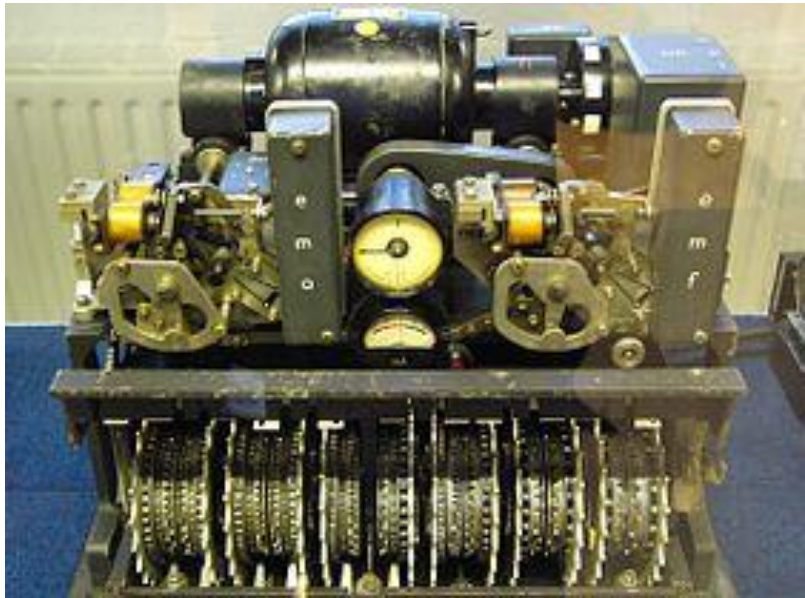
13. Depths, Bayes, and Banburismus

Edward Simpson:
Bayes at Bletchley Park

- Edward Simpson (born 1922)
- Cryptanalyst at Bletchley Park (1942–45)
- Statistician ("Simpson's paradox")
- Banburismus: a cryptographic process developed by Turing

14. Tunny: Hitler's BlackBerry

- Jack Copeland
- **Lorenz**: German army rotor stream cipher machines used during WW II
- Nicknamed "*Tunny*" after "Fish" cipher



16. The Testery: breaking Hitler's most serious code

- Captain Jerry Roberts, MBE, (1920–2014)
- Cryptanalyst & German linguist, who worked on *Tunny* at Bletchley Park, 1941–45
- "*Testery*": section at Bletchley Park, set up in October 1941 under Major *Ralph Tester*

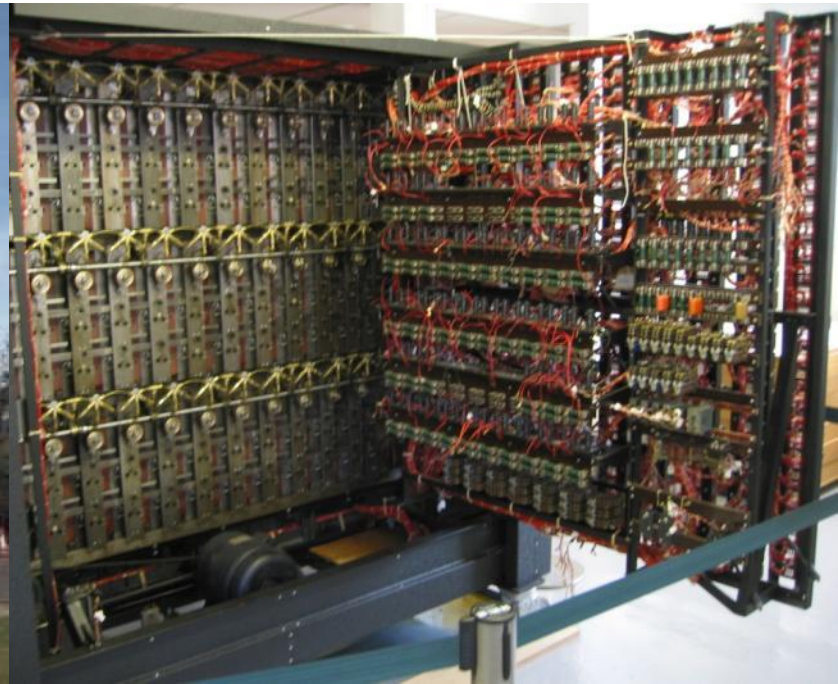
Captain Jerry Roberts

17. Ultra revelations

- Brian Randell
  School of Computing Science
  Newcastle University
- Historian of computing
- See also Chapter 8
- *"Ultra"* – designation by British military intelligence in June 1941 for WW II signals intelligence from encrypted enemy communications at Bletchley Park

19. How Bletchley Park became a national museum

- Simon Greenish, former Director
- Recent history of Bletchley Park
- Now safe



IV. The Birth of Modern Computing

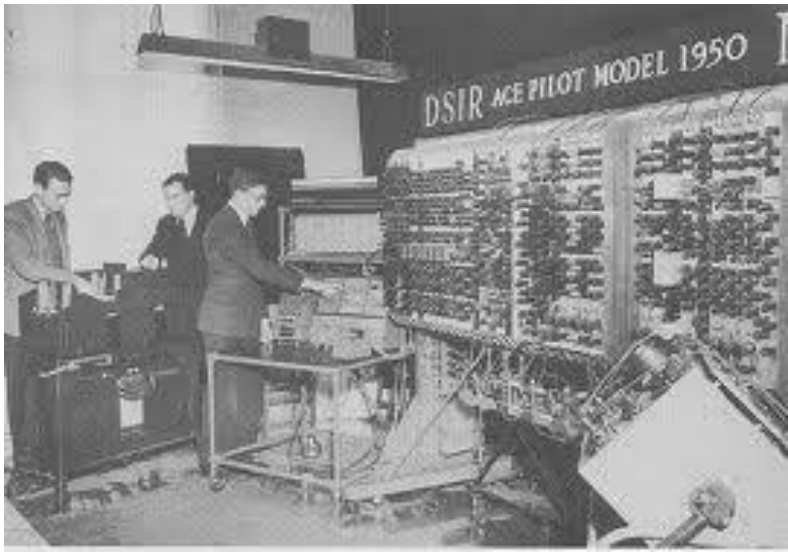
20. **Doron Swade: *Congruent worlds: Turing, Lovelace, and Babbage***
21. **Martin Campbell-Kelly: *ACE***
22. **Jack Copeland: *The Manchester computer***
23. **Mark Priestley: *Turing's approach to coding***
24. **Brian E. Carpenter and Robert W. Doran: *Turing's* Zeitgeist**

20. Congruent worlds: Turing, Lovelace, and Babbage

- Doron Swade, formerly computing curator at the Science Museum, London
- Comparing Turing's achievement with Charles Babbage and Ada Lovelace
- Difference and Analytical Engine

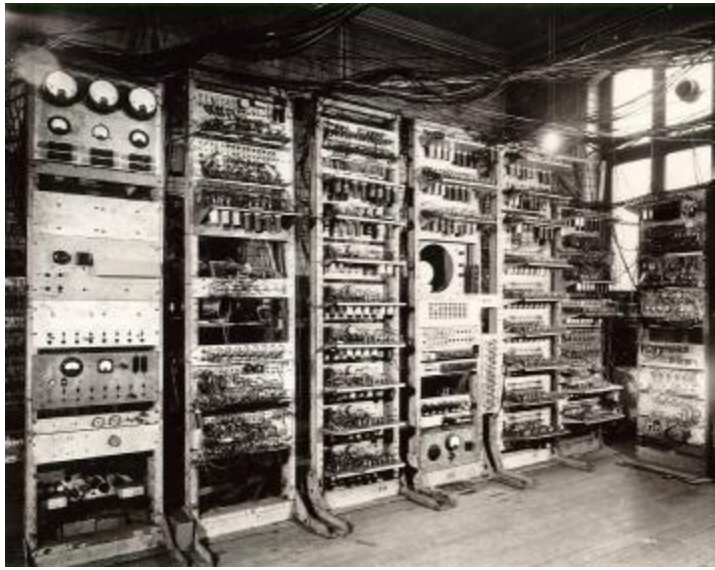
21. ACE

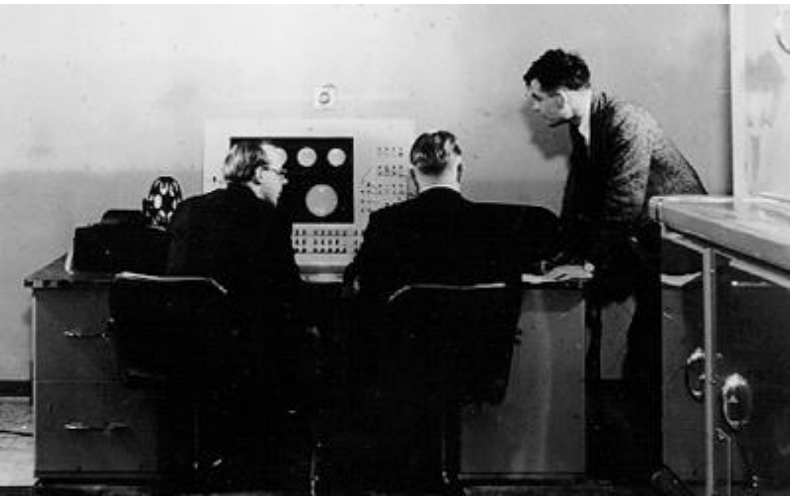
- Martin Campbell-Kelly
  (historian of computing)
  Department of Computer Science
  University of Warwick
- Automatic Computing Engine (ACE),
  National Physical Laboratory
- Pilot ACE, 1950



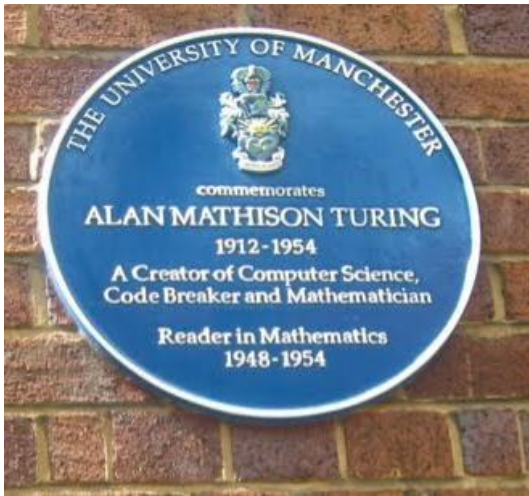
22. The Manchester computer

- Jack Copeland
- Manchester Mark I computer, June 1948
- Turing appointed Reader



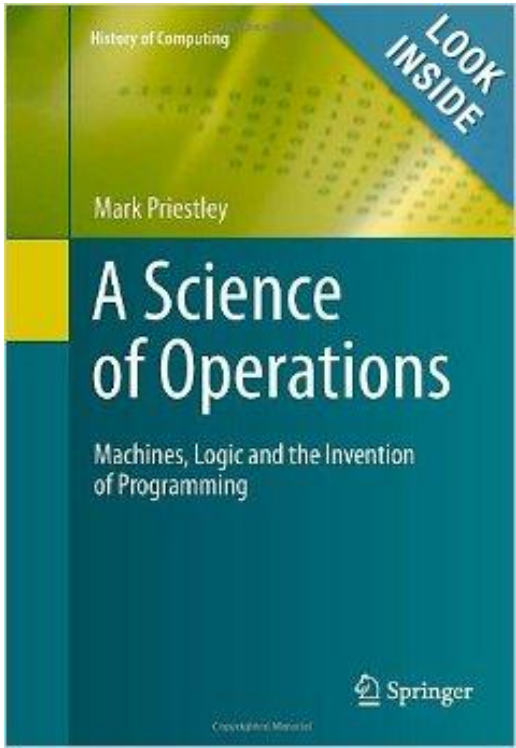


Alan Turing on the right standing at the console of the Manchester Ferranti computer.



23. Turing's approach to programming

- Mark Priestley, historian of computing
- Author of *A Science of Operations: Machines, Logic and the Invention of Programming* (Springer, 2011)



24. Turing's Zeitgeist

- Brian E. Carpenter & Robert W. Doran
  Department of Computer Science
  University of Auckland, New Zealand
- Whatever happened to the other Turing machine?

V. Artificial Intelligence and the Mind

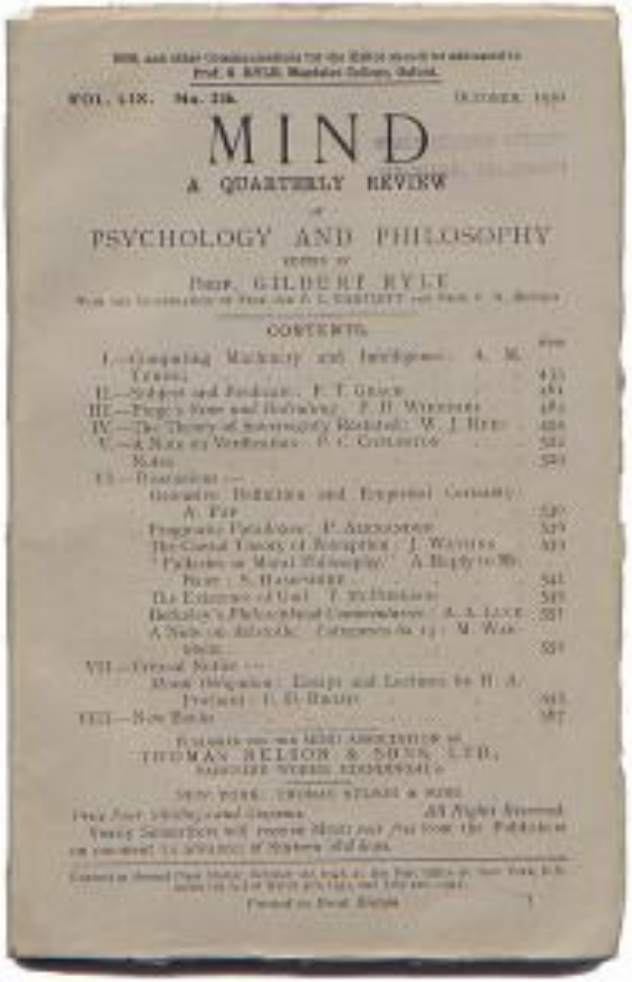
25. Jack Copeland: *Machine intelligence*
26. Mark Sprevak: *Turing's model of the mind*
27. Diane Proudfoot: *The Turing test*
28. Diane Proudfoot: *Turing's concept of intelligence*
29. Kevin Warwick and Huma Shah: *Taking the Turing test*
30. Jack Copeland and Diane Proudfoot: *Connectionism: computing with neurons*
31. Diane Proudfoot: *Turing's child machines*
32. Jack Copeland and Dani Prinz: *Computer chess: the first moments*
33. David Leavitt: *Turing and the paranormal*

25. Machine intelligence

- Jack Copeland, philosopher
- DPhil at Oxford in modal and non-classical logic, supervised by **Dana Scott**
- Many Turing books (OUP)
- Editor of the *Rutherford Journal,* history and philosophy of science and technology

26. Turing's model of the mind

- Mark Sprevak (co-editor)
  School of Philosophy, Psychology and Language Sciences
  The University of Edinburgh
- Meeting co-organizer with Jack Copeland



MIND

A QUARTERLY REVIEW

OF

PSYCHOLOGY AND PHILOSOPHY

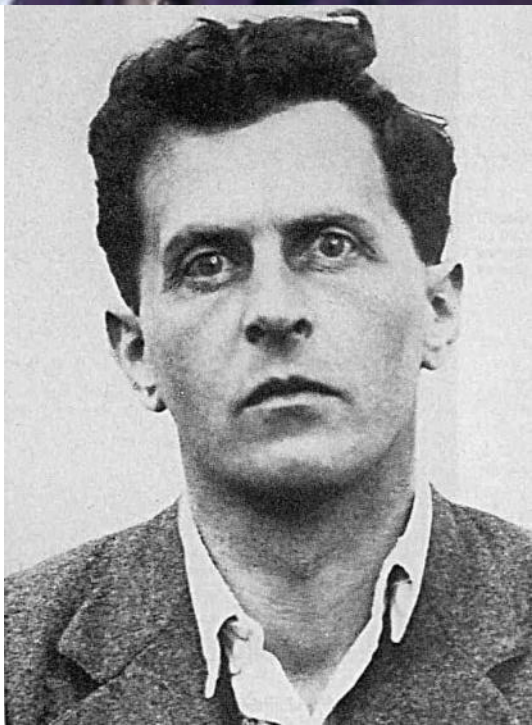
EDITED BY

PROF. GILBERT RYLE

CONTENTS

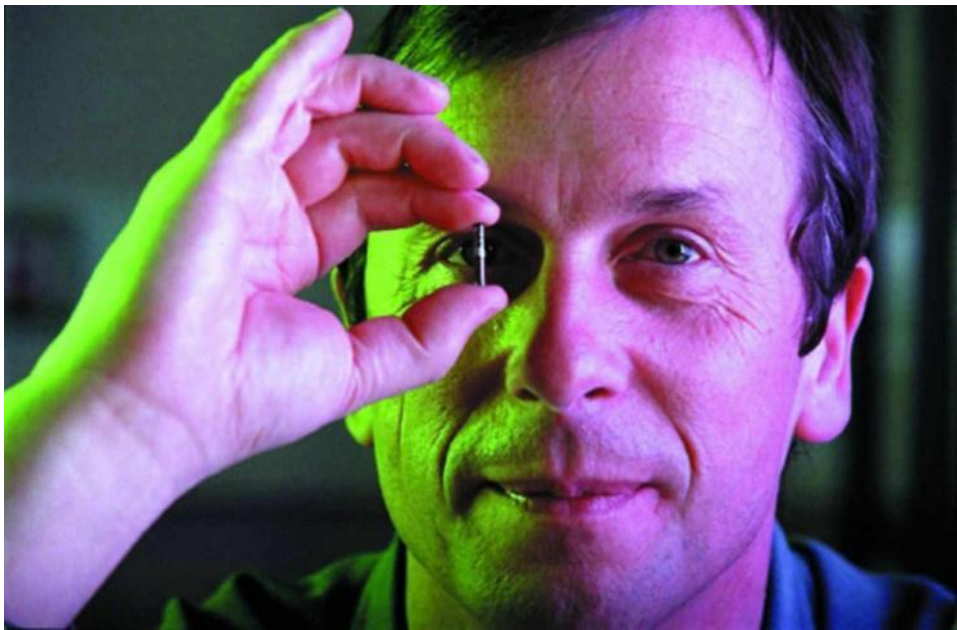
27. The Turing test
28. Turing's concept of intelligence

- Diane Proudfoot
  University of Canterbury
  New Zealand
- Ludwig Wittgenstein
  (1889–1951)
- Lectures at the
  University of Cambridge



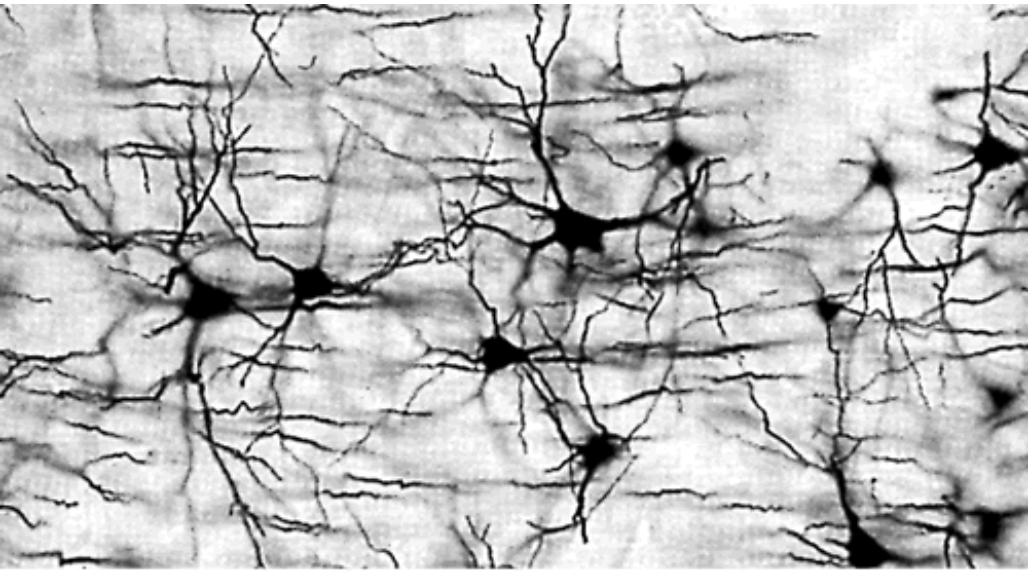
29. Taking the Turing test

- Kevin Warwick & Huma Shah
  Department of **Cybernetics**
  University of Reading
- Now at Coventry University
- The Turing test



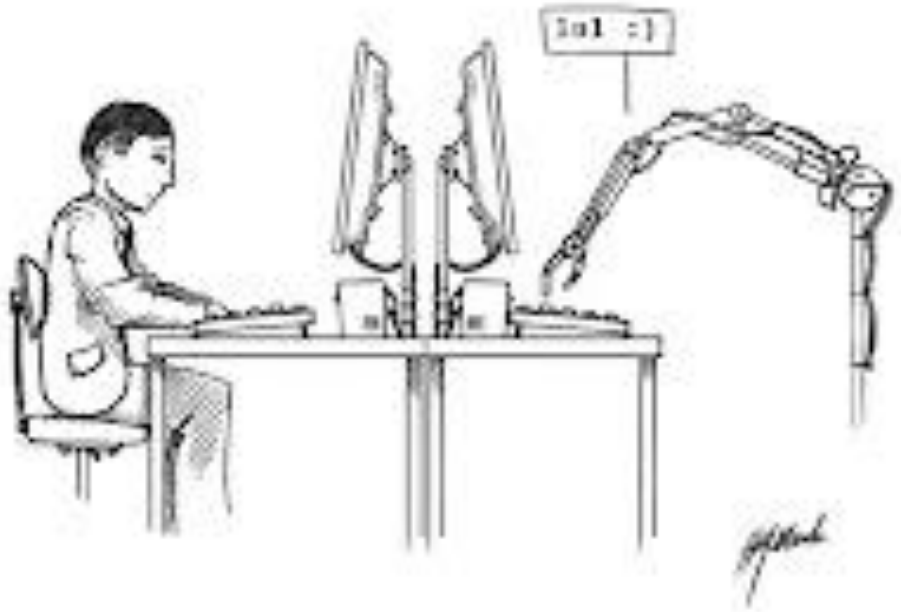
30. Connectionism: Computing with neurons

- Jack Copeland & Diane Proudfoot
  Department of Philosophy
  University of Canterbury
  Christchurch, New Zealand



31. Turing's 'child machines'

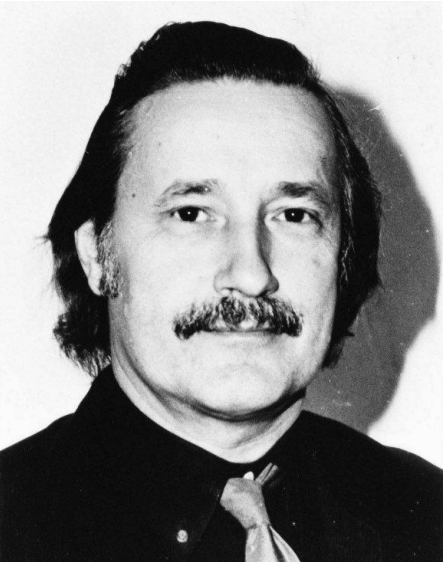
- Diane Proudfoot
- Educable machines
- Social communication



"On the Internet, nobody knows you're a dog." – New Yorker

32. Computer chess: The first moments

- Jack Copeland & Dani Prinz
- Chess – and draughts
- **Christopher Strachey** (1916–1975), first head of the Programming Research Group, Oxford

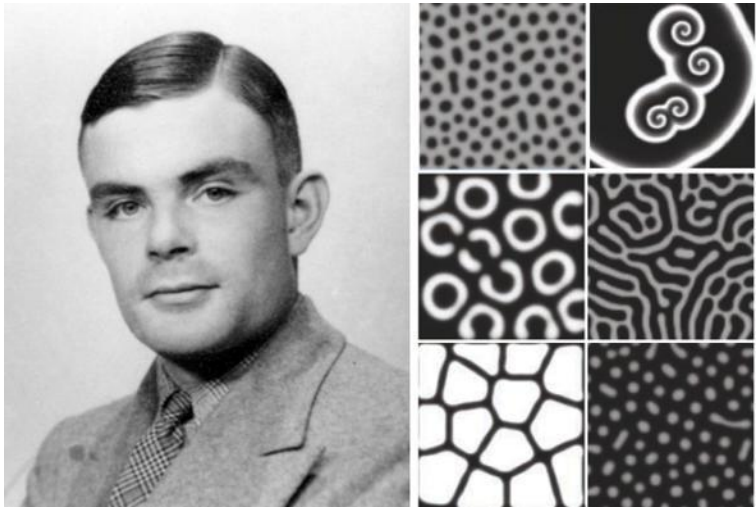


VI. Morphogenesis

34. **Margaret Boden:** ***Artificial life***

35. **Thomas E. Woolley, Ruth Baker, and Philip Maini:** ***Turing's theory of growth***

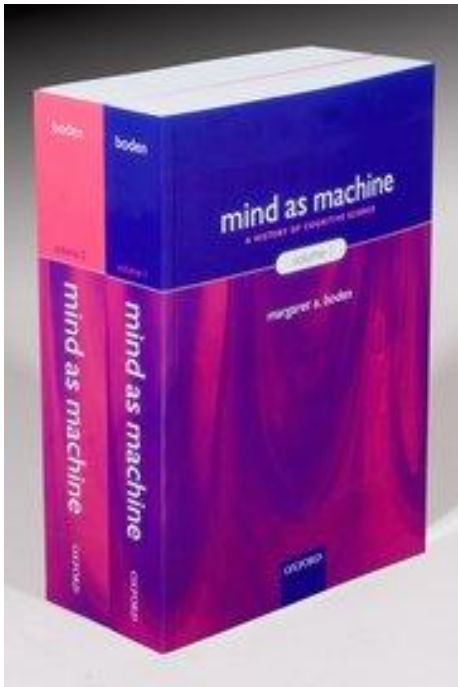
36. **Bernard Richards:** ***Radiolaria: validating the Turing theory***



34. Artificial life

- Margaret Boden, OBE
  Professor of Cognitive Science
  Department of Informatics
  University of Sussex

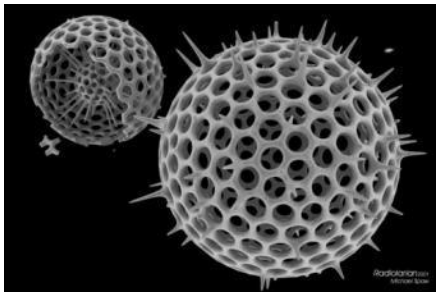
- Author of *Mind as Machine: A History of Cognitive Science* (OUP, 2006)



35. All models are wrong, but some are useful

- Thomas E. Woolley,
  Ruth Baker & Philip Maini
  Centre for Mathematical Biology
  Mathematical Institute
  University of Oxford
- Turing was not completely correct, but close enough

36. Radiolaria: Validating the Turing theory



- Bernard Richards
- Masters student under Turing at Manchester in 1953
- Protozoa with complex mineral skeletons

On Alan Turing: *"The day he died felt like driving through a tunnel and the lights being switched off."*

VII. Mathematics

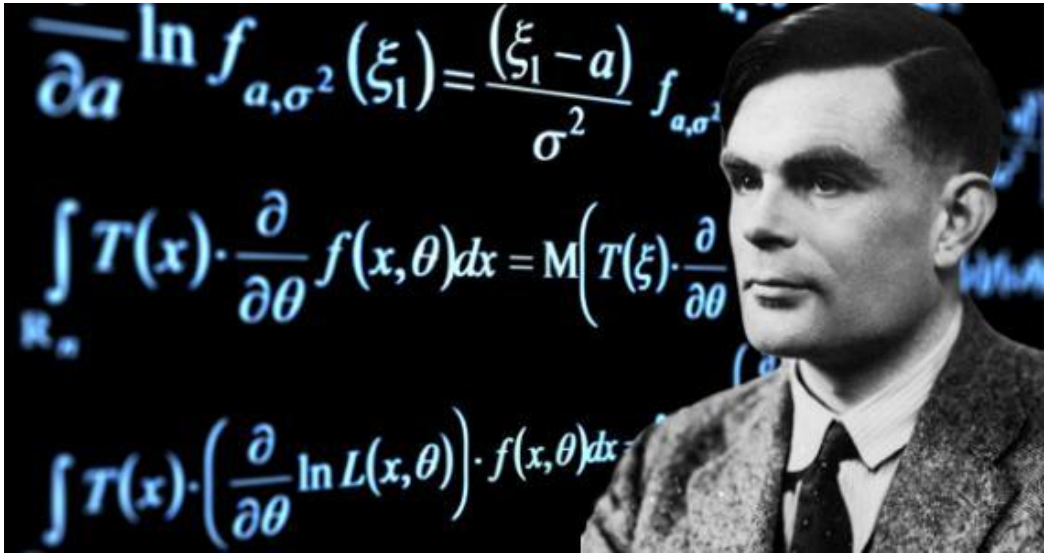
37. **Ivor Grattan-Guinness:** ***Turing's mentor, Max Newman***
38. **Robin Whitty and Robin Wilson:** ***Turing's mathematics***
39. **Robin Whitty:** ***Decidability and the*** **Entscheidungsproblem**
40. **Rod Downey:** ***Turing and randomness***

37. Turing's mentor, Max Newman

- Ivor Grattan-Guinness, historian of mathematics and logic. Middlesex University
- Maxwell Herman Alexander **"Max" Newman**, FRS (1897–1984), mathematician and codebreaker
- 1935 lectures on the Foundations of Mathematics at Cambridge inspired Turing

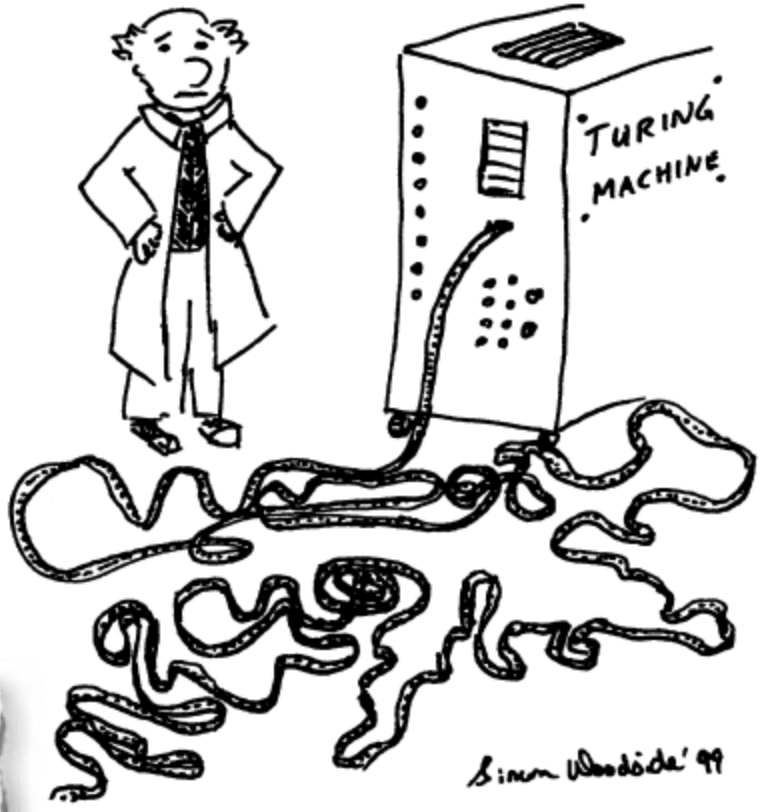
38. Turing's mathematics

- Robin Whitty & Robin Wilson (co-editor)
- *"Things like the **Poincaré conjecture**, and the **Riemann hypothesis**, and **zeta functions**, and all these rather glamorous sounding things which I course can't explain because I of course don't understand."* – Stephen Fry



39. Decidability and the Entscheidungsproblem

- Robin Whitty
- Decision problem
- Turing machine
- Halting problem



Turing solves the halting problem, only to discover that the REAL problem with his machine is what to do with all the tape.

ON COMPUTABLE NUMBERS, WITH AN APPLICATION TO THE ENTSCHEIDUNGSPROBLEM

By A. M. TURING.

[Received 28 May, 1936.—Read 12 November, 1936.]

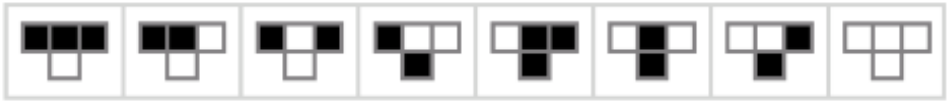
40. Turing and randomness

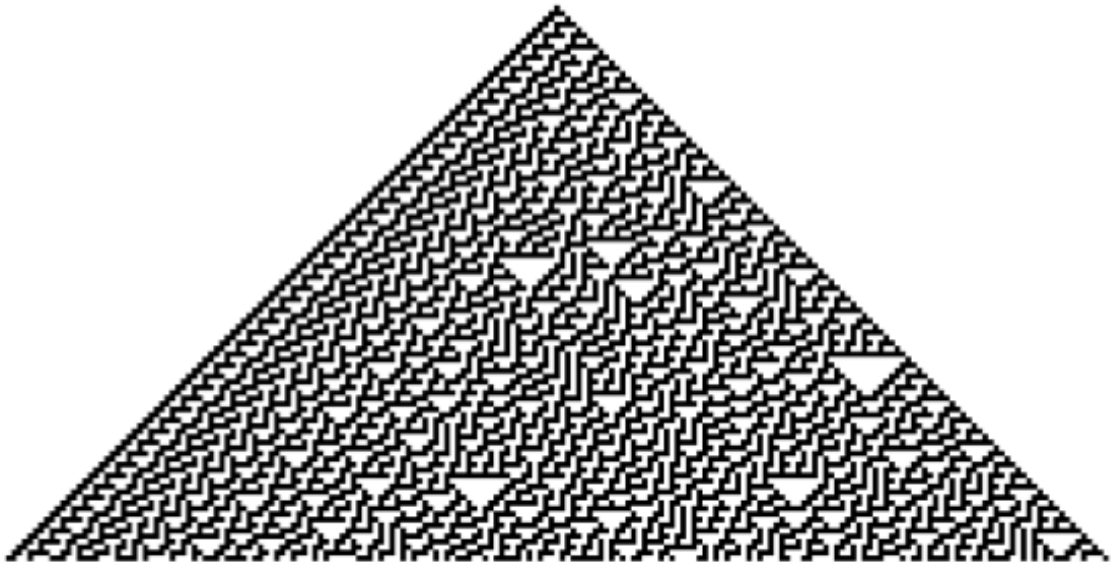
- Rod Downey
  School of Mathematics, Statistics and Operations Research
  Victoria University of Wellington
  New Zealand

VII. Aftermath

41. Is the Universe computable?

- Jack Copeland & Oron Shagrir
- “Digital philosophy”





42. Turing's legacy

- Jonathan Bowen
- Turing and modern society
- Turing papers – auction
- Government pardon
- Public consciousness
- Google donation to Bletchley Park
- ...

Stephen Fry

“Turing was a genius who helped shorten the war though his extraordinary solutions to the Enigma and Tunny code machines that the Germans were using … We owe him a huge debt.”

Thank you

Alan Turing

founder/father of computer science

The Turing Guide (OUP, 2015)

Prof. Jonathan Bowen

FBCS, FRSA

jonathan.bowen@bcu.ac.uk

www.jpbowen.com

Museophile

BIRMINGHAM CITY University

Alan Turing

warholize.me