

# Alan Turing: 80 Years of Computing

#### Josef Urban

#### Czech Technical University in Prague

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#### Hilbert's Entscheidungsproblem



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#### Others Even Earlier – Russel, Leibniz: Calculemus!



#### Enters the Hero: Alan Turing (1912 – 1954)



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## Alan Turing 1936 - Turing Machines and Undecidability

- "On Computable Numbers, with an Application to the Entscheidungsproblem"
- Introduced Computing (Turing) machines
- Universal computing (Turing) machines (stored-program computers)
- Showed that halting of a Turing machine is *undecidable*:
- There is no terminating algorithm that will tell the answer
- Shows that the Entscheidungsproblem is unsolvable:
- By encoding the halting problem in first-order logic
- Showed equivalence to parallel Alonzo Church's results with lambda calculus

#### Aftermath: Undecidability and Computers

- Setback for Hilbert/Leibniz-style optimists:
  - "It is not possible to have a decision procedure for math, therefore attempting to do math automatically is futile"
  - For many theoretical computer scientists Turing's work ends in 1936
- Bust also the most important invention of 20th century:
  - Computers designed and built by von Neumann, Zuse, Turing and others (all preceded by Babbage)
  - Exponential growth of our computing power (Moore's law)
  - Basis of the fastest development of technology, science and engineering in human's history

### Turing's Later Work

- Cryptoanalysis in WW 2: Statistical code breaking
  - Statistical inference methods using custom machines
  - Estimated to have shortened WW2 by 2–4 years
- Helped to build the first computers in the UK
- Wrote the first chess program Turbochamp
- Introduced Artificial Intelligence
  - "Computing Machinery and Intelligence" (1950)
  - Can machine's think? Imitation Game (Turing test)
  - Discussion of possible counter-arguments
  - Proposed Learning machines (machine learning)

#### Turing 1950, AI and Learning Machines:

- "We may hope that machines will eventually compete with men in all purely intellectual fields."
- Which intellectual fields to use for building AI?
- "But which are the best ones [fields] to start [learning on] with?"
- "... Even this is a difficult decision. Many people think that a very abstract activity, like the playing of chess, would be best."

### Turing 1950, AI and Mathematics/Logic – Round 2:

- "Opinions may vary as to the complexity which is suitable in the child machine. One might try to make it as simple as possible consistently with the general principles. Alternatively one might have a complete system of logical inference 'built in'."
- "The processes of inference used by the machine need not be such as would satisfy the most exacting logicians. There might for instance be no hierarchy of types."
- "For at each stage when one is using a logical system, there is a very large number of alternative steps, any of which one is permitted to apply, so far as obedience to the rules of the logical system is concerned. These choices make the difference between a brilliant and a footling reasoner, not the difference between a sound and a fallacious one."

#### Where Are We with Thinking Machines Today?

- DeepBlue vs. Kasparov: 1996 (brute-force search, some learning)
- AlphaGo vs. Sedol: 2016 (deep learning, Monte-Carlo tree search)
- IBM Watson 2011: question answering, statistical and symbolic reasoning
- Many others: Google Translate, self-driving cars, image recognition, bioinformatics, ...

# Where Are We with Thinking Machines Today – Mathematics?

- Four color theorem proof found by a computer in 1976 by Appel and Hakken
- Completely verified in the Coq system in 2005 by Georges
  Gonthier
- Robbins conjecture proof found automatically with EQP by McCune
- Kepler conjecture computer-assisted proof by Hales (1998)
- Completely verified in 2015 in HOL Light by Hales et al.
- *Hammer* systems: combining learning and proof search over large databases of mathematics

### Resources and Credits

- Alan Turing: On computable numbers, with an application to the Entscheidungsproblem
- Alan Turing: Computing Machinery and Intelligence
- The Alan Turing Centenary Conference: http: //curation.cs.manchester.ac.uk/Turing100/ www.turing100.manchester.ac.uk/?man=true
- Martin Davis: The Universal Computer: The Road from Leibniz to Turing
- Andrew Hodges: Alan Turing The Enigma http://www.turing.org.uk/
- Apostolos Doxiadis, Christos H. Papadimitriou: Logicomix
  An Epic Search for Truth

https://www.logicomix.com/en/index.html