In Pursuit of the Computable

- **Newton** - mathematics rules science
- we look for computable natural laws ... 
- theories which computably predict ...

When we say that we understand a group of natural phenomena, we mean that we have found a constructive theory which embraces them

Albert Einstein: P.54, `Out of My Later Years', 1950
1936 - Turing's machines

Hardware trivial

Actions simple

But compute 'anything'
computable

All the computing power lies in the program ...

Computation Disembodied

reading head which is in internal state $q$ and obeys Turing program $P$

tape, infinitely extendable in each direction
Computation Disembodied

A familiar picture:

reading head which is in internal state $q$ and obeys Turing program $P$

- tape, infinitely extendable in each direction

Computation Disembodied
Universality, and Programs as Data

- Turing, 1936: Build a **UNIVERSAL TURING MACHINE**, which can simulate **ANY** other machine

- An anticipation of the **stored program** computer

- A concept immediately understood by **John von Neumann** - as in his 1945 EDVAC report

- And ‘**program as data**’ key to the first computer ...
Universality, and Programs as Data

First Draft of a Report on the EDVAC, 1945

The General and Logical Theory of Automata, based on talk at the Hixon Symposium, Pasadena, September 1948

John von Neumann
A New Computing Paradigm ...

The omnipotent computer - I am building a brain

Functionalism and AI - stress what a computer does as something realisable in different hardware -
Hilary Putnam: “Minds and Machines”, 1960

Virtual Machine (IBM, 1965) - software implementation of a programmable machine -
JAVA, Unix
Articles

UBIQUITY SYMPOSIUM 'WHAT IS COMPUTATION?'
COMPUTATION IS PROCESS

November 2010 | BY DENNIS J. FRAILEY

Full text also available in the ACM Digital Library as PDF | HTML

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Various authors define forms of computation as specialized types of processes. As the scope of computation widens, the range of such specialties increases. Dennis J. Frailey posits that the essence of computation can be found in any form of process, hence the title and the thesis of this paper in the Ubiquity symposium discussion what is computation. --Editor

The concept of computation is arguably the most dramatic advance in mathematical thinking of the past century. Denning [2010], in his opening statement, describes how computation was originally defined in the 1930s and how that definition has progressed through the ensuing decades. Church, Gödel, and Turing defined it in terms of mathematical functions, which they divided into the decidable (can be evaluated by algorithms) and the un-
“What Is Computation?”

- ACM UBIQUITY SYMPOSIUM: Computation Is Process by Dennis J Frailey:

- The concept of computation is the most dramatic advance in mathematical thinking of past century

- Church, Gödel, and Turing defined it in terms of mathematical functions ...

I'll call this the "mathematician's bias" - I believe it limits our thinking and prevent us from fully appreciating the power of computation
“Giving a program + data logically implies the output (leaving aside non-determinism or randomness), so why bother computing the result!

... Can information increase in computation? Information theory and thermodynamics seem to tell us that it can't, yet intuitively, this is surely exactly why we compute - to get information we didn't have before.”
The first electronic digital computer - John Atanasoff (1937-42)?

First stored program computer that worked - Manchester ‘Baby’ (1948)

First commercial computer - EDSAC in Cambridge (Maurice Wilkes, 1949), or Eckert and Mauchly’s UNIVAC (1951)

If ‘Program as data’ key to the first computer ... out go Babbage; Zuse, 1930s; Colossus, 1944; ENIAC, 1946
Programs as Data Embodied

Pilot ACE, May 10, 1950 - small version of plan contained in Turing’s ACE Report of 1945

Turing Bombe Rebuild at Bletchley Park
Programs as Data Embodied

Turing and the Ferranti Mark 1

See: http://www.turing.org.uk/bio/oration.html

Dietrich Prinz and Computer Chess
The Discovery of ‘Incomputability’

Hilbert’s Programme:

“For the mathematician there is no Ignorabimus, and, in my opinion, not at all for natural science either. ... The true reason why [no one] has succeeded in finding an unsolvable problem is, in my opinion, that there is no unsolvable problem.

In contrast to the foolish Ignorabimus, our credo avers:

We must know,
We shall know. “

- David Hilbert’s opening address to the Society of German Scientists and Physicians, Königsberg, September 1930
The Discovery of ‘Incomputability’

☐ **Turing (1936):** Take a Universal Turing machine $U$:

**Unsolvability of the Halting Problem for $U$:**
No computer can tell us, for each given input $x$, whether $U$ will compute - where, remember - we allow an input to include a coded program!

**‘Church’s Theorem’:**
No computer can tell us, for each given sentence, whether it is logically valid or not.
Turing’s observation: Things we cannot compute can often be approximated - as closely as we want!

Maybe, using human ingenuity, we can use this to compute beyond the Turing (machine) Barrier?
Now we witnessed ...

a certain extraordinarily complicated looking set, namely the Mandelbrot set.

Although the rules which provide its definition are surprisingly simple, the set itself exhibits an endless variety of highly elaborate structures.

Roger Penrose

in “The Emperor’s New mind”, Oxford Univ. Press, 1994

**OPEN PROBLEM:**

Is the Mandelbrot set computable?
Mathematical creativity observed

“Having reached Coutances, we entered an omnibus to go some place or other. At the moment when I put my foot on the step, the idea came to me, without anything in my former thoughts seeming to have paved the way for it ... I did not verify the idea ... I went on with a conversation already commenced, but I felt a perfect certainty. On my return to Caen, for conscience sake, I verified the result at my leisure.’

from Jacques Hadamard [1945], “The Psychology of Invention in the Mathematical Field”, Princeton Univ. Press
The Brain as Computer?

Supervenience 'represents the idea that mentality is at bottom physically based, and that there is no free-floating mentality unanchored in the physical nature of objects and events in which it is manifested'.


“A set of properties A supervenes upon another set B just in case no two things can differ with respect to A-properties without also differing with respect to their B-properties.”

Stanford Encyclopedia of Philosophy
How can mentality have a computational role in a world that is fundamentally physical?

And what about ‘overdetermination’ - the problem of phenomena having both mental and physical causes?

... the problem of mental causation is solvable only if mentality is physically reducible; however, phenomenal consciousness resists physical reduction, putting its causal efficacy in peril.

-Jaegwon Kim: *Physicalism, or Something Near Enough*, Princeton, 2005
So get Challenge ...

... to Standard Model ...

... from Information and ...

... embodied Incomputability
Pointing to ...  

... the computational significance of ... 

... information
Computability and Information

- Turing, 1939 - Oracle Turing Machines ...

- Provide a model of how we compute using data given to us from unknown sources

- A model within which Newtonian computability etc comfortably fit ...

reading head which is in internal state q and obeys Turing program P
1950s - Alan Turing proposes a simple reaction-diffusion system describing chemical reactions and diffusion to account for morphogenesis, i.e., the development of form and shape in biological systems.

See http://www.swintons.net/jonathan/turing.htm
How Nature Computes
Notice - It is often possible to get descriptions of emergent properties in terms of the elementary actions.

E.g., this is what Turing did for the role of Fibonacci numbers in relation to the sunflower etc.

In mathematics, it is well-known that complicated descriptions may entail incomputable phenomena.

A potential source of surprise in emergence...
Physical Computation, Turing Landscape and Emergence ...

- Can describe global relations in terms of local structure ...
- ... so capturing the computation of large-scale formations

Mathematically - formalise as definability over structure based on oracle computations

More generally - as invariance under automorphisms
Morphogenesis - in the same world as ... 

... the Mandelbrot set
Morphogenesis - in same world as ...

... the Halting Problem
Morphogenesis - in same world as ...

... Mental Supervenience
Morphogenesis - in the same world as...
Simple Rules ...

... Complex Outcomes ...

... Emergent Forms ...

... at the Edge of Computability
Intelligent Machines?


“Turing, as is well known, had a mechanistic conception of mind, and that conviction led him to have faith in the possibility of machines exhibiting intelligent behavior.”
‘Deep Blue’ and other successes ...

- Garry Kasparov - youngest undisputed world chess champion
- ... became arguably world’s greatest ever chess champion
- Beaten on May 11, 1997 by IBM chess playing computer ‘Deep Blue’
- And IBM’s Watson wins Jeopardy ...
Marvin Minsky at Boston University, May 2003:

AI has been brain-dead since the 1970s
... neither AI nor Alife has produced artifacts that could be confused with a living organism for more than an instant.
How do we judge whether a machine can "think" at approximately human-level?

The Turing Test (1950): A human examiner ‘converses’ with another human, and with the machine (an advanced computer), without knowing which is which.

If the examiner fails to correctly identify which is the machine, then the machine passes the test.
Questions

Can a machine be conscious?

Is the brain computing differently from a universal Turing machine? And if so, how?

Can we really build brain-like computers?

☐ And do we want to?

Intelligent machines - evolve? or be designed?
Turing Centenary Books -

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Centenary Edition
SARA TURING

THE CENTENARY EDITION
With a foreword by Douglas Hofstadter and a new preface by the author
ALAN TURING
THE ENIGMA
ANDREW HODGES

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—Ray Monk, author of Wittgenstein:
The Duty of Genius

ALAN TURING:
HIS WORK AND IMPACT
S. Barry Cooper • Jan van Leeuwen
Thank you!