



Limits of Computation

I - Intro & Motivation

Bernhard Reus

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Let's step back in time

2



This man had a dream

1646-1716



The “**s**(m)”

The brand name *Leibniz* comes from the philosopher and mathematician Gottfried Wilhelm Leibniz (1646–1716). The only connection between the man and the biscuit is that Leibniz was one of the more famous residents of Hanover, where the Bahlsen company is based. At the time when the biscuit was first made there was a fashion of naming food products after historical celebrities (compare Mozartkugel).[1]

maybe I'm the first computer scientist

The **Leibniz-Keks** is a plain butter biscuit, or *Butterkeks* as it is known in German, inspired by the French *Petit-Beurre* created in 1886 but Leibniz-Keks was originally a corruption of the English word "cake". Leibniz-Keks has since become the generic name for butter biscuits.

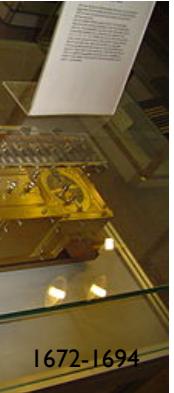
Gottfried Wilhelm Leibniz invented differential & integral calculus

Alas, I'm more chocolate than a biscuit

1672-1694

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This man had a dream too

1928



Hilbert

“The *Entscheidungsproblem* (German for “decision problem”) asks for a procedure which allows one to decide, using a finite number of operations, on the validity, respectively the satisfiability, of a given logical expression (in number theory).”

$n+0=n$
 $(n+1)m = nm + m$

decision procedure

yes
no

David Hilbert believed strongly that there exists a solution to the “*Entscheidungsproblem*”

4

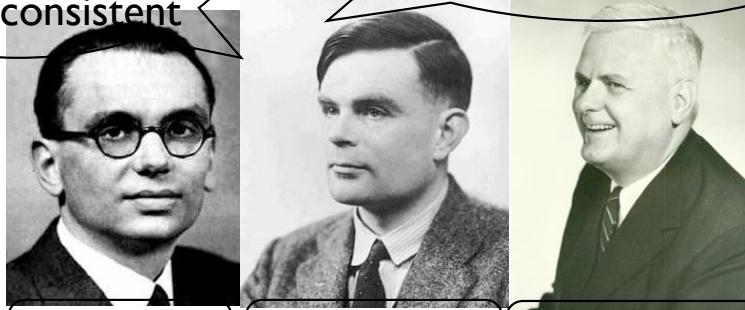


1932/1936

These guys shattered it

(formalisation
of) arithmetic
cannot be complete
and consistent

true sentences of
arithmetic cannot be
decided



Kurt Gödel

Alan M Turing

Alonzo Church

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“Entscheidungsproblem”

There is no program/machine/procedure that can decide whether any given formula in arithmetic is actually true. Sorry David Hilbert!

Alan M. Turing: ‘On computable numbers, with an application to the Entscheidungsproblem’ from *Proceedings of the London Mathematical Society*, (Ser. 2, Vol. 42, 1937);



Major Impact on Science

- not every problem (that can be clearly formalised and understood) can be solved (in this case the answer is yes/no only) by a program
- So, there are obviously limits to what programs can do!!

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Sometimes we cannot
compute it!

e.g. Hilbert's Decision Problem from earlier



Computability

Questions

- Are there problems that cannot be solved by a program on a computer?
- Does it matter which computer/language we use?
- Can one identify classes of problems that can be solved by programs or that can't be solved by programs?
- How can one see or find out that a problem can't be solved by a program?

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Sometimes we cannot
afford it!



Annoyingly...

- ... even decidable (computable) problems sometimes are problematic.
- They may take a long time to compute.
TOO LONG ACTUALLY!



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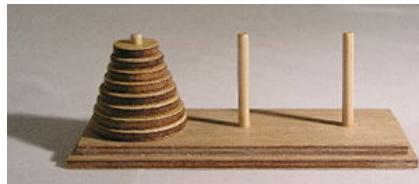
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Examples of *computable* problems that are *intractable*

12



Towers of Hanoi



- move all disks from 1st to 3rd rod
- only take/put disks from/on top of rods
- never put disk on a smaller disk.

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Towers of Hanoi (cont'd)

- for N disks it takes $2^N - 1$ moves to complete the task
- if you could move one million disks per second (!), for $N=64$ you'd still need about **585,000 years** to finish the job!

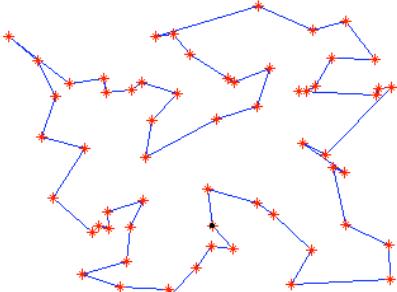
disks	moves
3	7
4	15
8	255
16	64535
32	4,294 bn
64	18,44 bn bn

Even for meditating monks this is too long!



T raveling S alesman P roblem

- Given a number of cities and the costs of travelling from any city to any other city, what is the least-cost round-trip route that visits each city exactly once and then returns to the start?



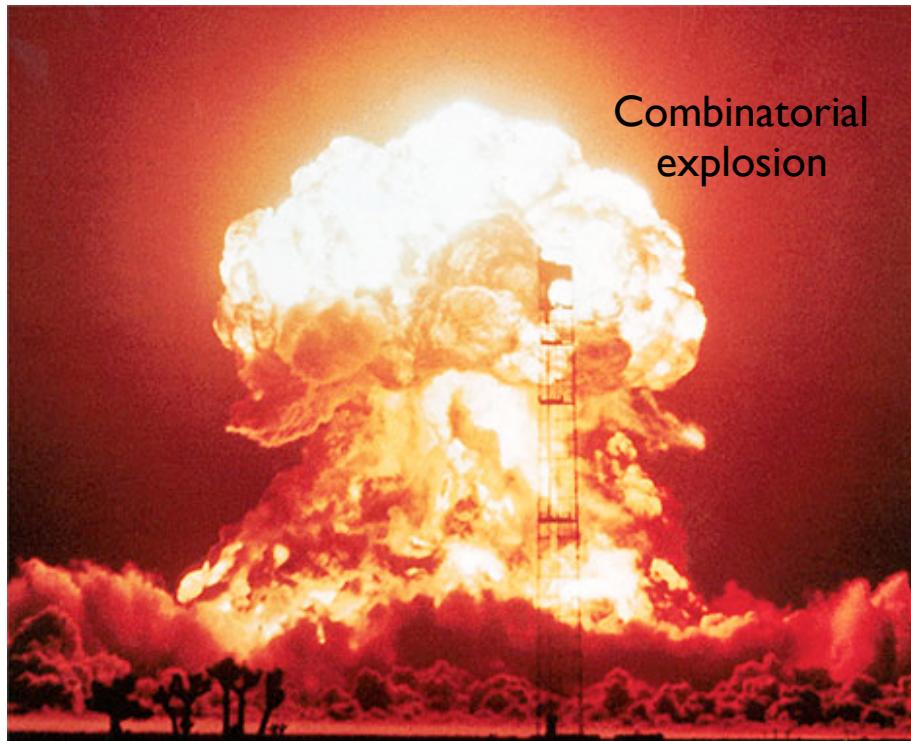
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16



Computational Complexity

Questions

- Which problems can be solved within certain limits of time (and space)?
- Are there resource limits within which certain combinatorial problems cannot be solved?
- Are intractable problems good for anything?
- Does adding resources allow one to solve more problems?
- How does one deal with intractable problems in practice?
- Can new emerging computing paradigms like *Quantum computing* and *Molecular computing* help?

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Why are these important questions?



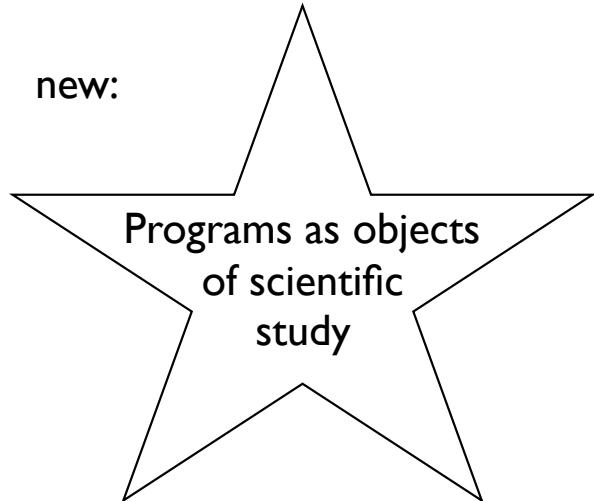
Audience Participation

18



So what is this module for?

- you know the principles of programming
 - » Programming Concepts
 - » Data Structures & Algorithms
 - » Program Analysis
- you know how to write programs



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Organisation & Overview

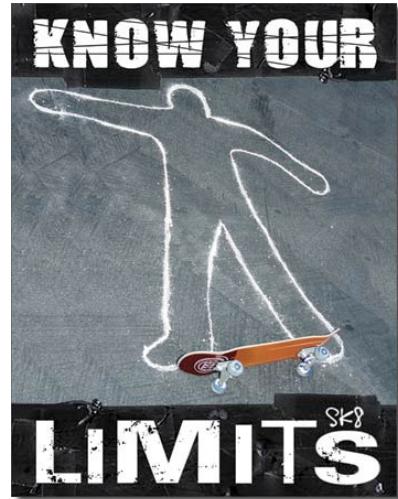
20



Scientific Questions About Programs



- What are programs? What are their limitations?
- **What** are their limits in terms of what we can achieve with programs?
- How can we spot the limits?
- How can we circumnavigate them?
- Can we exploit those limits for a benefit?



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Organisation 2021

• **Lectures**

Mon 11am, Tues 5pm (for the time being all on Zoom)

• **Classes**

Wed 10am, Fri 12am, Fri 5pm (needed?) start in teaching week 2

Sussex Direct tells you which group you're in, please stay there throughout the term (for now on Zoom)

• **Coursework**

Problem Set (60% week 6, March 4th)

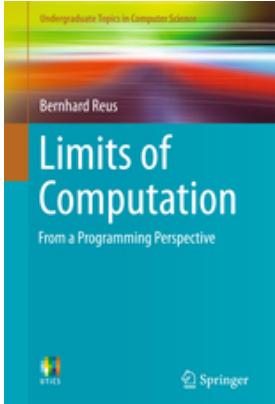
+ Test (40% week 11, April 29th online)

• **Assessment** 50% CWK + 50% UEX

• **Web** Canvas Site (with all info)

22

Course Text



There is a Reading List for this module on Canvas.

eBook
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price for United Kingdom (gross)
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a few copies in the library

condensed notes will be available for free on Canvas

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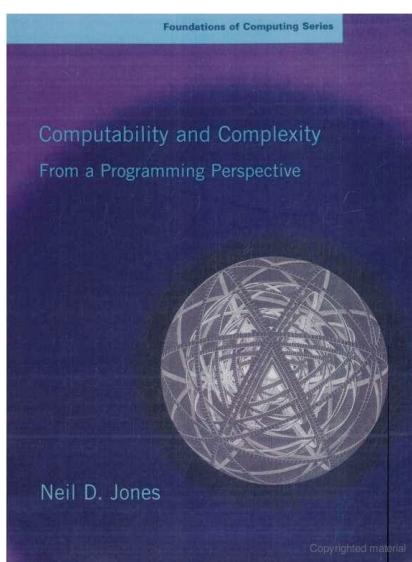
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Other literature



- Neil D Jones: *Computability and Complexity From a Programming Perspective*, MIT Press, 1997.
Online copy on Canvas Links page.
- Also useful maybe:
 Hopcroft, Motwani, Ullmann: *Introduction to Automata Theory, Languages, and Computation*, Addison Wesley

24



END

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Next time:
We define “Algorithms and
Algorithmic Problems”

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