Watson and

The Philosophy of Computation

Jan van Leeuwen

Information and Computing Sciences
Utrecht University, The Netherlands

(Leibniz image)

Leibniz's dream

- Gottfried Wilhelm Leibniz (1646-1716).
- Reduce `everything' (argumenting…) to `computation'.
- Need (a) precise symbolic languages ("*characteristica universalis*") to express `everything' e.g. in science or philosophy and (b) computational methods ("*calculus ratiocinator*") to resolve statements in these languages.
- "If controversies were to arise, there would be no more need of disputation between two philosophers than between two accountants. For it would suffice to take their pencils in their hands, and say to each other: ***Calculemus***." (Dissertatio de arte combinatoria, 1666.)
- Stimulated philosophy, mathematics, logic and (implicitly..) information technology at a very early moment.

(Turing image)

ON COMPUTABLE NUMBERS, WITH AN APPLICATION TO THE ENTSCHEIDUNGSPROBLEM

By A. M. TURING.

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

The "computable" numbers may be described briefly as the real numbers whose expressions as a decimal are calculable by finite means. Although the subject of this paper is ostensibly the computable *numbers,* it is almost equally easy to define and investigate computable functions of an integral variable or a real or computable variable, computable predicates, and so forth. The fundamental problems involved are, however, the same in each case …

In a recent paper Alonzo Church has introduced an idea of "effective calculability", which is equivalent to my "computability", but is very differently defined. Church also reaches similar conclusions about the Entscheidungsproblem. The proof of equivalence between "computability“ and "effective calculability" is outlined in an appendix to the present paper.

(Also E.L. Post, 1936)

VOL. LIX. NO. 236.] [October, 1950

M I N D

A QUARTERLY REVIEW
OF
PSYCHOLOGY AND PHILOSOPHY

I.—COMPUTING MACHINERY AND INTELLIGENCE

BY A. M. TURING

1. *The Imitation Game.*

I PROPOSE to consider the question, ' Can machines think ? ‘ This should begin with definitions of the meaning of the terms ' machine ' and' think '. The definitions might be framed so as to reflect so far as possible the normal use of the words, but this attitude is dangerous. If the meaning of the words ' machine‘ and' think ' are to be found by examining how they are commonly used it is difficult to escape the conclusion that the meaning and the answer to the question, ' Can machines think ?' is to be sought in a statistical survey such as a Gallup poll.

Instead of attempting such a definition I shall replace the question by another, which is closely related to it and is expressed in relatively unambiguous words. The new form of the problem can be described in terms of a game which we call the ' imitation game '.

(Objections…)

Bottom line: A.M. Turing (1950)

"The original question ' Can machines think' I believe to be too meaningless to deserve discussion. Nevertheless I believe that at the end of the century the use of words and general educated opinion will have altered so much that one will be able to speak of machines thinking without expecting to be contradicted."

(Ferruci / Watson image)


$1,000
KEN
$2,000
WATSON
$400
BRAD

Can Watson think…?

Jeopardy!

Imitation of quizzing: identification of `knowledge'

Examples:

- The science that got this name in Danish in 1966 and now provides the foundation for all of IT and its applications in society.
- He formulated the Singularity Hypothesis that computers will be outsmarting humans by 2030.
- The average Dutchman spends on average at least 4.5 hours per week on these creative products. (Men 5.3 hours a week, women 3.6 hours a week.)
- …

knowledge, reasoning, intelligence …?

(Humans vs Watson image)

“Watson can process 500 gigabytes, the equivalent of *a million books*, per second.

The content was stored in Watson's RAM for the game because data stored on hard drives are too slow to access. ”

Watson is a workload optimized system designed for complex analytics, made possible by integrating massively parallel POWER7 processors and the IBM DeepQA software to answer *Jeopardy* questions in under three seconds. Watson is made up of a cluster of ninety IBM Power 750 servers (plus additional I/O, network and cluster controller nodes in 10 racks) with a total of 2880 POWER7 processor cores and *16 Terabytes of RAM*. Each Power 750 server uses a 3.5 GHz POWER7 eight core processor, with four threads per core. (Cf. *IBM, Wikipedia*)

How does it do it...

- Brad Rutter (contestant) about `Watson':
  - "**They figured out algorithms in a way that they can actually do what the brain does**."
- Henry Liebermann:
  - ``It all depends on how it's done. Scientists judge by the principles and techniques, not by the contest results."
- Commentaries:
  - ``**The idea of an interface with a computer system that is capable of interpreting human language [and answering] is something that a lot of people think will be quite remarkable and pave the way for more interactive robots** in health care, help desks, defense, and maybe even education."
  - ``A next step in search engine technology..''

Watson and…

- Digitization of information..
  - Libraries, archives, newspaper repositories
  - Public records, medical records, …
  - Medicin
  - Law
  - Cultural heritage
    - *Europeana* : paintings, music, films and books from Europe's galleries, libraries, archives and museums.
    - *Library of Congress:* “preservation and access of history for future generations”
- Digitization is transformation
  - Need for `digital philosophy’

Philosophy of …??

Philosophy of Informatics

- **Historical development**
  - Centric views: logic, mathematics, programming, engineering, specific applications, etc
  - Influences: scientific, technological, social, societal, political, …
  - From `tool perspective' to `science perspective' to `innovation perspective' to….
  - Nature of the field
- **Theories of `perspectives'**
  - (1) Information-oriented, (2) Computing oriented, (3) Communication-oriented, (4) Cognition-oriented, (5) Design-oriented, (6) Behaviour-oriented, (7) Mental constructions -oriented...
- **Philosophy of**
  - Perspectives
  - Specific subareas (AI, agents, information, design methodology, risk, …)
  - Role of classical philosophy of science/technology (paradigms, research programs, …)
- **Scientific method**
  - Stepwise modelling, algorithms, languages, formal specification, design methods?
  - `Third way': theory, experiment, *program?*
- **Impact on think- and designprocesses**
  - Algorithmic (computational) thinking, design science
  - Understanding of complexity, structure of knowledge, …
  - "Can machines think, have emotions, etc" (mimicking behaviour by mass computation)
- **Impact on our values**:
  - Culture, democracy, politics, environment, ethics, ..
  - Screenagers
- **Impact on our future**
  - Control, socio-technical innovation
  - Kurzweil's `Singularity'

(to appear)

Philosophy of …

… Computation?

Computation?

- Whatever goes on `inside', from cell to laptop to brain?
- Dictionary: *to compute*
  - To reckon; to calculate (following a numeric method).
  - To determine by calculation (an answer, result, etc.).
  - The use of a computer to process data or perform calculations.
  - To be reasonable, plausible, or consistent; make sense..
- Major phenomenon (`computational processes'), together with *information.*
  - Phenomenon that exists already for ages in the societal domain, *i.e.* before the advent of computers, e.g. in the context of record keeping (in trade, astronomy and science) and in decision making (in business and government).
- Understanding computational processes/systems
  - "algorithmic processes that describe and transform information" (Denning, '85)
  - "… information processes and their interactions with the world" (Denning, '03)

General nature of computation

- *A (repetitive) transformation of information of any kind with an intent or purpose, acting on a representation of the information and according to specific rules, carried out by natural or artificial means with a fitting use of resources.*
- *The act of doing or achieving such transformations, including the handling of the information and the operation of the natural or artificial means that are deployed or used in it and any external interventions that influence it.*
- *Any process acting on information that can be understood, modeled or created as computation by the preceding clauses.*

Understanding computational processes

- **Levels of abstraction in information processing**
  - ***Understanding****:* what is processed and why,
  - ***Function****:* how is it achieved,
  - ***Design****:* the process,
  - ***Operation****:* the processor.

- **Marr** (1982)
  - ***Computational level*** **or theory**: what is the goal of the computation (what problems does it solve or handle), why is it appropriate, and what is the logic (the `why') for carrying it out in a particular way.
  - ***Algorithmic level***: how is the computation implemented *viz.* how can it do what it does, what representations does it use internally and for input and output, and what processes (algorithms) does it or should it employ to build, manipulate, and transform the representations.
  - ***Implementational level***: how can (are) the representations and the algorithms that act on them be (physically) realized?

- **Pylyshyn** (1984)
  - ***Semantic level***: knowledge, content.
  - ***Symbolic level***: form, algorithm (function) vs functional architecture (design).
  - ***Physical level***: biological or artificial medium of operation.

- **McClamrock** (Minds and Machines,1991)
  - The number of actual levels of organization in any given information-processing system (including the brain) is an entirely empirical matter about that particular system.

Evolution in concept

- A process as carried out *by* a (human) computer (Turing, 1936), respectively by symbol-manipulation (Post, 1936).
  - Algorithm
  - Turing(-Post) machine

- A process carried out *on* a computer.
  - A finite, dynamic *set of processes* …
  - … that can be programmed and carried out on a computer of a certain architecture: *sequential, parallel, distributed, self-organizing, amorphous, …*

Turing's model: *solid foundation* but *antiquated* wrt newer modes of computation?
Peaceful mathematical status quo is being stirred up..

- *Computation in nature* (cell, dna, quantum, …)
- *in interaction with external agents, in cognition* (`cognition is computation').
- *in any type of information processing* (from calculation to human thinking).
- *with an unbounded self-adjusting nature* (precision, learning, evolution,…)
- *with an unbounded horizon in time*: **computation as unbounded process.**

Computation beyond traditional boundaries

Philosophy of computation

- **Broad constructivist understanding**: `*artificial rules [*for repeated manipulation of data*] designed by humans in order to achieve specific desired effects on a corresponding artificial environment* but also, used *to [*understand and*] model the `mechanical' aspect of the [*evolution of*] natural reality*' (Goldreich 2009).

Contextual elements

- **Interaction** with `environment' (modelled as external agent, as algorithmic mechanism or otherwise), simulated behaviour, etc.
- **Non-uniformity** of program (unpredictable modification, learning, evolution, …).
- **Unbounded operation** over time (`always on', persistent).

Computation as unbounded process

- **Minsky** (1972):
  - *It would seem profitable to study the theory of machines in which the amount of machinery is not itself the limitation. But it would not be profitable […] to study machines which are really infinite either in initial endowment or in effective speed of operation. […] We must consider machines which have at each moment only a finite quantity of structure, but* which are capable of being extended indefinitely as time goes on - `*growing machines*' (p. 115-116).
- Requirement of halting in finite time abandoned
- `Hyper-computation' (not always clear).
- Motivated by `taking limits from the finite' , as in `reals vs rationals'.

Computation as unbounded process (with J. Wiedermann)

- Model: computation by finitely specified *multi-process system* progressing indefinitely
  - Observing time, space and `switches in control' (*mind changes*) over time.
  - **RED-GREEN computing.**
- Computation converges if #mind changes is bounded (stabilizes) in the limit:
  - in recognition sense (weak) or acceptance sense (strong).
  - compare (computable) reals as limits of knowable (computable) expansions.
- Ershov hierarchy of recursion theory recovered:
  - **Theorem**: hierarchy based on red-green computing with `k mind changes' vs `k+1 mind changes'.
- *Nondeterministic* red-green computing
  - Nondeterministic vs deterministic red-green computing.
  - #Mind changes may differ, also depending on further desired properties of nondeterministic red-green machines.
  - P versus NP analogue wrt mind changes in red-green computing (see later)
- Basic model for understanding (the combinatorics of) computation as unbounded process.
  - **Extended C-T thesis**: Red-green Turing machines are the general unifying model for `computation as unbounded process'.

Many alternative models of `computation as unbounded process'

- Computation `recursive' in the Halting Problem (Turing 1952, Kleene-Post 1954)
  - More generally, computation with `oracles'
- Computations with ω-automata (Büchi, 1962, Rabin, 1964)
- Trial-and-error predicates (Putnam 1965).
- Tae-computing (Hintikka and Mutanen, 1998).
- TM with display (Rovan and Steskal, 2007)
- Relativistic computing (Etesi and Nemeti, 2002)
  - Physical model of `computation recursive in the Halting Problem'
- Limiting recursion (Gold, 1965)
- Iterated limiting recursion (Schubert, 1974)
- `SAD computers' (Hogarth, 2004)
- Other…

Claim: *models are different at the conceptual and functional level, but not so at a more basic level of understanding (in accordance with the Extended C-T Thesis…)*

Levels in understanding computation rev'd

- *Conceptual level*
  - Computational notions and mechanisms …… type of unbounded operation
  - Computational objects and processes
- *Functional level*
  - Computations (models)…… concrete (hyper-)computational formalization
  - Algorithms and their properties
- *Reference level*
  - Expression formalisms …stylized formal language for expressing hyper-algorithms
  - Language frameworks
  - Programming semantics
- *Design level*
  - Process virtual machine ……abstract machine realizing the hyper-computations
  - Programs
  - Described in `realizable' abstractions
- *Operational level*
  - Application virtual machine …..…. a programmable machine in more basic terms
  - Programmed in lower layer terms

Operational level possibly grounded in lower layer.

(to appear)

Understanding `computation as unbounded process'...

- *Conceptual level*
  - Many notions in unbounded computation `in context'
  - E.g. multi-process system
- *Functional level*
  - Functional framework, e.g. process diagram, $g(x) = \lim_{t \to \infty} f(x,t)$ etc
  - Computational properties, complexity
- *Reference level*
  - **Framework**: arithmetic predicates (1st order formulas over recursive predicates)
  - **Description**: at level in Arithmetical Hierarchy (Σ–, Π–, and Δ–hierarchies) e.g.
    - Σ_1: $\exists_x$ P(w,x), standard (Turing-)computable
    - Σ_2: $\exists_x \forall_y$ P(w,x,y)
    - Σ_3: etc
- *Design level*
  - **Theorem (folklore?)**: Arithmetic Hierarchy $\equiv$ Alternating Unbounded TM's (of bounded depth)
  - **Programs**: on Alternating Unbounded TM.
  - Specialized to e.g. Σ_2-machine.
- *Operational level*
  - **Theorem**: Recursive red-green machines implement alternating unbounded TMs.
  - **Theorem**: **Red-green computing is `natural realization' of Σ_2-machine.**

Computation as unbounded process …

- Red-green computing paradigm completes the spectrum of understanding computation, as *unbounded* rather than *bounded* process (in time), while staying within Minsky's criteria.
- *Non-deterministic red-green computing*
  - **Theorem**: Nondeterministic red-green computing is no more powerful than deterministic red-green computing (thus Σ_2).
- *Mind change complexity*
  - **Theorem**: `P ≠ NP' in mind change complexity, i.e. the corresponding classes in red-green computing differ ($P^{mind} \neq NP^{mind}$).
  - **Theorem:** There is *no* recursive (computable) function *f* such that for all languages L, if L is recognized by a nondeterministic red-green TM with *k* mind changes, then L can be recognized by a deterministic red-green TM within *f(k)* mind changes.
- Unbounded computation (in time) requires only `simple' adjustment in the classical TM concept, with profound effect on concept of computation.
- *`Who's afraid of unbounded computation.'*

Summary

- Watson got *us* thinking
- (Constructivistic) *philosophy of informatics, viz. of* computation-oriented *perspective*.
- *Computation now conceived of in many more ways than in Turing's times* (interactive, non-uniform, multi-process, unbounded).
- Understanding of computation depends on *level of abstraction*.
- *Level substructure* (conceptual, functional, reference, design, implementation)
- *Computation as unbounded process well-grounded in multi-process computation*
  - *Red-green TM* basic underlying model of unbounded computation.
  - *Allows for complexity analysis of computation as unbounded process* (time-, space-functions, convergence, mind changes).
- Accepted world of Turing's Σ_1-level computability is *gradually extended* to the Σ_2 –level (with extended rules).

THE ALAN TURING YEAR
A Centenary Celebration of the Life and Work of Alan Turing

2012

- June 23, 2012, is the Centenary of Alan Turing's birth in London. During his relatively brief life, Turing made a unique impact on the history of computing, computer science, artificial intelligence, developmental biology, and the mathematical theory of computability.
- 2012 will be a celebration of Turing's life and scientific impact, with a number of major events taking place throughout the year. Most of these will be linked to places with special significance in Turing's life, such as Cambridge, Manchester and Bletchley Park.
- The Turing Year is coordinated by the Turing Centenary Advisory Committee (TCAC), representing a range of expertise and organisational involvement in the 2012 celebrations. Organisations and individuals wanting to contribute ideas or support for the Turing Year are invited to contact any of the current TCAC members.
- http://www.mathcomp.leeds.ac.uk/turing2012/


CALCULEMUS !