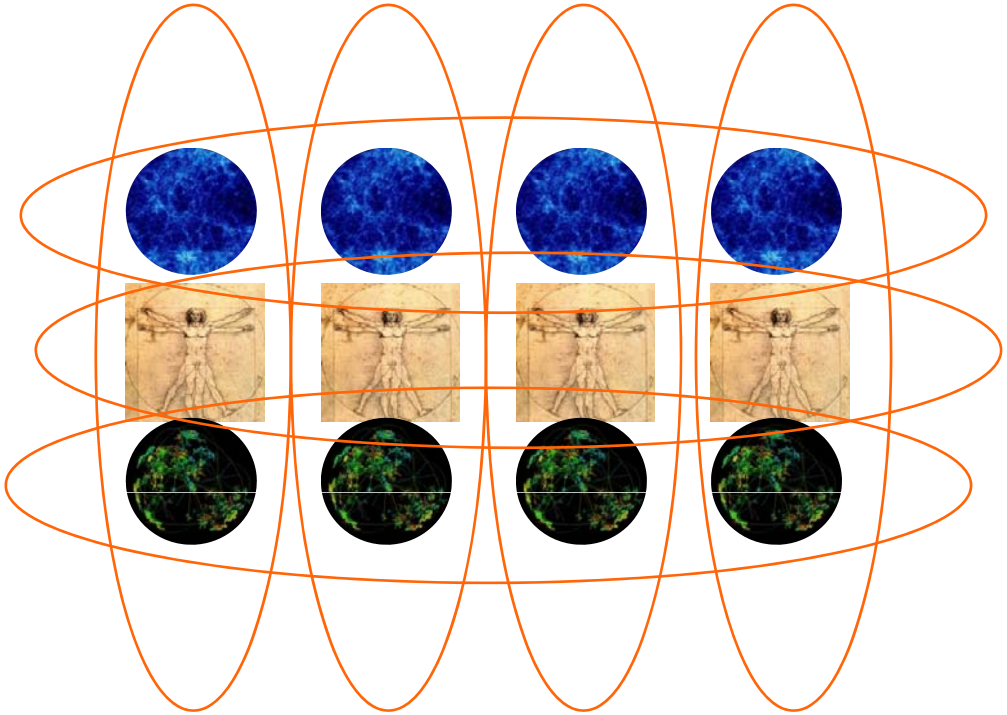
COMPUTING BEYOND TURING MACHINE MODEL



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European conference on Computing and Philosophy, E-CAP 2009
The Universitat Autònoma de Barcelona http://ia-cap.org/e-cap09/

The Necessity of Considering Computation Beyond Turing Machine Model

New research results from computer science, physics, logics, cognitive science, bioinformatics and related research fields provide strong reasons for us to try to generalize the idea of computing.

Generalization of Turing concept of computation in essentially two ways:

1. *Generalization of the model*, extending the idea of algorithm to a non-halting process (Wegner, Burgin, Rice).

2. *Generalization of the physical realization of computation process* (MacLennan, Lloyd, Cooper, Hogarth).

Computation

The Computing Universe: Pancomputationalism

The definition of computation is widely debated, and an entire issue of the journal **Minds and Machines** (1994, 4, 4) was devoted to the question **“What is Computation?”** See even: Theoretical Computer Science 317 (2004)

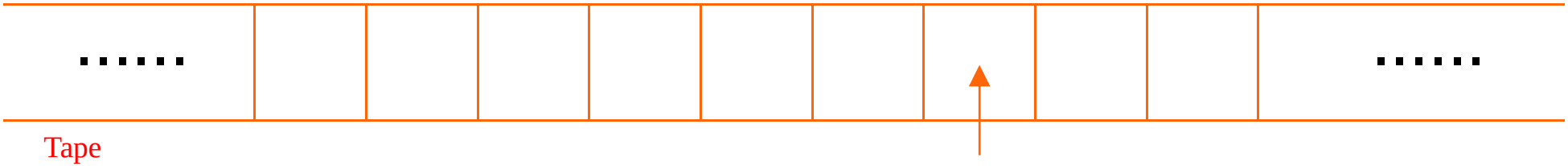
However, currently, computation is generally defined as information processing.

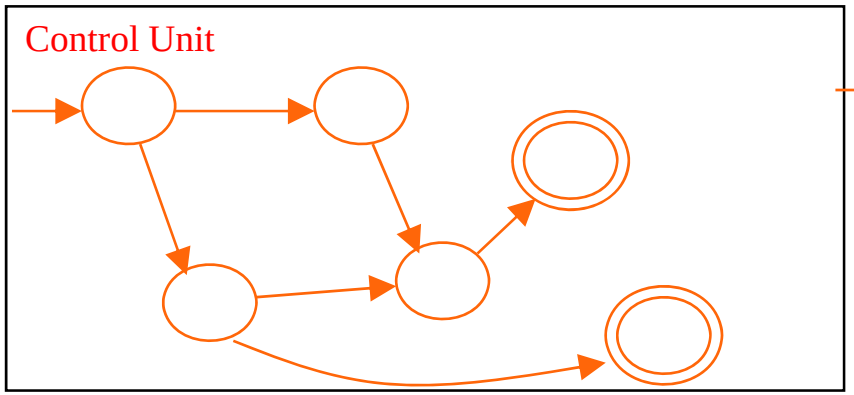
(See Burgin, M., Super-Recursive Algorithms, Springer Monographs in Computer Science, 2005)

For different views see e.g.

http://people.pwf.cam.ac.uk/mds26/cogsci/program.html Computation and Cognitive Science 7–8 July 2008, King's College Cambridge

Turing Machine





Read-Write head

1. Reads a symbol
2. Writes a symbol
3. Moves Left or Right

http://plato.stanford.edu/entries/turing-machine/

A New paradigm:
http://www.cse.uconn.edu/~dgg/inter_book.html Interactive Computation: the New Paradigm. Published by Springer-Verlag in September 2006 (co-edited with Dina Goldin, Scott Smolka)

Turing Machine

Turing pointed out in 1947*:

“the intention in constructing (computers) in the first instance, is to treat them as slaves, giving them only jobs which have been thought out in detail. Up till the present machines have only been used in this way.” Then he asked

“But is it necessary that they should always be used in such a manner?”

Peter Kugel It’s Time To Think Outside The Computational Box, Communications Of The Acm November 2005/Vol. 48, No. 11

****Turing, A. Lecture to the London Mathematical Society on 20 February 1947.***
In A.M. Turing’s ACE Report and Other Papers, B. Carpenter and R. Doran, Eds. MIT Press, Cambridge, MA, 1986.

The Necessity of Considering Computation Beyond Turing Machine Model

The model and implementation are necessarily linked. As soon as a new kind of physical process is identified as computation we will need an adequate theoretical model. Likewise, a new model will necessarily be linked with its implementations.

The Necessity of Considering Computation Beyond Turing Machine Model

In search for a new generalized model of computation, we specifically address interactive computation (Wegner, Goldin) which unlike Turing machine (basically an isolated box processing an algorithm that must halt) implies communication of the computing process with the external world during the ongoing process of computation.

The Necessity of Considering Computation Beyond Turing Machine Model

The search for new physical computation processes aims at enrichment of the conventional computing repertoire. Present-day computers have developed from the tools for mechanizing calculations into adaptive devices interacting with the physical world, which itself may be conceived of as a computer (Zuse, Fredkin, Wolfram, Chaitin, Lloyd). In that sense Natural computing represents the extension of the domain of physical phenomena which are understood as computational processes and goes beyond Turing model of computation.

Computation as Information Processing

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Computation as Information Processing

The essential conceptual novelty that interactive computing brings about is its articulation of the difference between an open and a closed system, the distinction being equally relevant for physics, axiomatic systems, biology as for computing itself. The conventional theories are about closed isolated systems with the environment represented by some average behavior, and treated as a perturbation. An observer is external to the system. In the interactive framework the system is in general communicating with the explicitly expressed environment which also allows for the integration of the observer into the model.

Computation as Information Processing

Goldin and Wegner (2002) argue that computational logic must be able to model interactive computation, that classical logic does not suffice and that logic must be paraconsistent due to the incompleteness of interaction. Interesting research is currently going on in the field of paraconsistent logics with relevant applications within computing. “And it is semantics that establishes that ultimate real-life meaning of logic.” (Japaridze 2006)

Computation as Information Processing

In pancomputational view the whole physical universe is represented as a network of computing processes at different levels of organization. For an info-computationalist, information constitutes physical structure (static) of the universe with (natural) computation (information processing) as its dynamics. (Dodig-Crnkovic 2006)

Complexity, Computing, Algorithms And Hypercomputation

In order not only to describe, but also to interact with the universe, computation must be compatible with its environment, which, according to Ashby (1964) means to match the complexity of the environment. Ashby's "law of requisite variety" states namely, that to control a state, the variety of system responses must at least match the variety of disturbances. This amounts to the claim that in order for a computer to achieve adequate control of a complex system, the complexity of the repertoire of its responses must correspond the complexity of the environment.

Complexity, Computing, Algorithms And Hypercomputation

If we compare Turing machines with the physical universe (including quantum physics and biological organisms) the latter exhibit a much higher degree of complexity. That would imply that we need more powerful machines than what is represented by Turing model in order to be able to control by computers the real world phenomena on those levels of organization.

Computation as Interaction

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Computation as Interaction

The paradigm shift from Turing algorithms to interactive computation follows the technology shift from mainframes to networks, and intelligent systems, from calculating to communicating, distributed and mobile devices. A majority of computers today are embedded in other systems and they are continuously communicating with each other and with the environment. Use in communication and control have definitely outweighed the original use of a computer as an isolated calculating machine.

Computation as Interaction

Computational logic is a tool that both supports computation modeling and reasoning about computation. Goldin and Wegner argue that classical logic does not suffice and that logic must be paraconsistent, able to model both a fact and its negation, due to the role of the environment and incompleteness of interaction (different stages in the “update” of the system undergoing change). Two important related topics will be addressed in the article: logical pluralism and logical games as used in modeling of computing.

Natural Computation

MacLennan (2004) defines natural computation as ”computation occurring in nature or inspired by that in nature”, which includes quantum computing and molecular computation, and might be represented by either discrete or continuous models. Examples of computation occurring in nature comprise information processing in natural evolution, in the brain, in the immune system, in the self-organized collective behaviour of groups of animals such as ant colonies and insect swarms.

Natural Computation

Computation inspired by nature cover genetic algorithms, artificial neural nets, simulated immune systems, ant colony optimization, particle swarm optimization, and similar. Natural computational models are most relevant in applications that resemble natural systems, as for example real-time control systems, autonomous robots, and distributed intelligent systems in general. There is an interesting synergy gain in the relating of human designed computing with the computing going on in nature.

Computing Nature and Nature Inspired Computation

Natural computation includes computation that occurs in nature or is inspired by nature.

Computing Inspired by nature: Evolutionary computation, Neural networks, Artificial immune systems, Swarm intelligence, Organic computing

Simulation and emulation of nature: Fractal geometry, Artificial life,

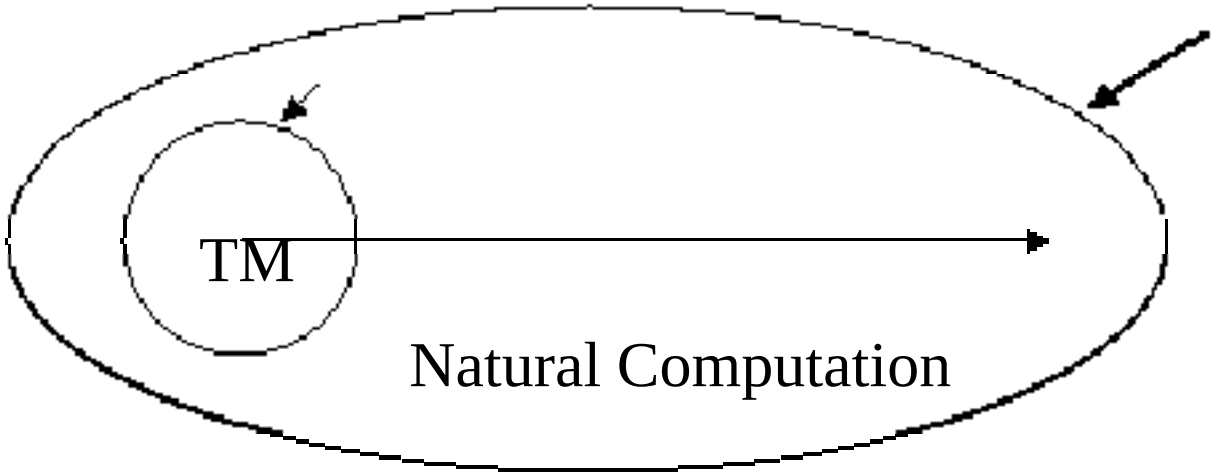
Computing with natural materials: DNA computing, Organic computing, Quantum computing

Beyond Turing Machines

The challenge to deal with *computability in the real world* (such as computing on continuous data, biological computing/organic computing, quantum computing, or generally *natural computing*) has brought new understanding of computation.

Natural computing has different criteria for success of a computation, halting problem is not a central issue, but instead the adequacy of the computational response in a network of interacting computational processes/devices. In many areas, we have to computationally model *emergence* not being clearly algorithmic. (Barry Cooper)

Correspondence Principle



picture after Stuart A. Umpleby

http://www.gwu.edu/~umpleby/recent_papers/2004_what_i_learned_from_heinz_von_foerster_figures_by_umpleby.htm

A New, Broader, Notion of Computation

"In these times brimming with excitement, our task is nothing less than to discover a new, broader, notion of computation, and to understand the world around us in terms of information processing." (Rozenberg and Kari 2008)

Rozenberg, G. and Kari, L. (2008), 'The many facets of natural computing', *Communications of the ACM,* 51.

Summary

Increasingly results from number of disciplines call for a new generalized concept of computing for which Turing machine is a special case. This generalization has significant philosophical and scientific consequences.

The following two approaches are discussed:

- Search for new models of computation process able of generalizing Turing model (non-halting algorithms, interactive computing) and

- Search for new kinds of (physical) computing in a sense of natural computation.

INFORMATION AND COMPUTATION

Forthcoming Book by World Scientific Publishing Co.
Dr. Gordana Dodig-Crnkovic (Mälardalen University, Sweden) and
Dr. Mark Burgin (UCLA, USA), Editors

Greg Chaitin - Mathematics as biological process

Jean-Paul Delahaye & Hector Zenil - On the algorithmic nature of the world

Barry Cooper - From Descartes to Turing: The computational Content of Supervenience

Søren Brier - Cybersemiotics and the question of knowledge

Christophe Menant - Computation on Information, Meaning and Representations. An Evolutionary Approach

Oron Shagrir - A Sketch of a Modeling View of Computing

John Collier - Information, computation, measurement and irreversibility

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Darko Roglic - Super-recursive features of natural evolvability processes and the models for computational evolution

C.N.J. de Vey Mestdagh & J.H. Hoepman - Inconsistent information as a natural phenomenon

Gordana Dodig Crnkovic and Vincent Mueller - A Dialogue Concerning Two Possible World Systems

Wolfgang Hofkirchner - Does Computing Embrace Self-Organisation?

Bruce J. MacLennan - Bodies — Both Informed and Transformed

Mark Burgin - Information Dynamics in a Categorical Setting

Marvin Minsky - Interior Grounding, Reflection, and Self-Consciousness

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Gordana Dodig-Crnkovic

Where do New Ideas Come From? How do They Emerge? Epistemology as Computation (Information Processing)
Chapter for a book celebrating the work of Gregory Chaitin, Randomness & Complexity, from Leibniz to Chaitin, C. Calude ed., World Scientific, Singapore, 2007 Book Cover

Gordana Dodig-Crnkovic

Epistemology Naturalized: The Info-Computationalist Approach
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