The Development of Models of Computation with Advances in Technology and Natural Sciences

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The Scandal of Computation:

What is Computation?

And we can ask even more:

What Computation can be?

which is the focus of this work.
The Inevitable Development of Idea of Computing

- Ideas about matter, energy, space and time have their history.

- The same is true of the idea of number in mathematics or the idea of life in biology.

- We should not be surprised to notice the development in the theory of computation that goes along with the development of mathematical methods, new computational devices and the emergence of new domains that can be modelled computationally.
The Development of Knowledge & Hinders to Knowledge Development

**Ignorance** – white spots on the map of knowledge – what we know that we do not know (known unknowns). There are also unknown unknowns. But there is something more dangerous than ignorance – false knowledge!

**Knowledge** – what we believe we know.

A part of our knowledge are **false believes that look like knowledge** – what we believe we know, but actually we are wrong! Those beliefs are even more important and difficult to fix than things that we do not know. Those are typical hinderers to new knowledge. Questioning of the “self-evident” is necessary, but self-evident is by its nature something we seldom suspect…

Some More Scandals: Physical Universe

http://www.youtube.com/watch?v=rLmcbjLVPKc
The Dark Matter & Dark Energy (9.04)

http://www.nature.com/nature/journal/v458/n7238/fig_tab/458587a_F1.html
Dark matter and how it might be detected (Nature article)
Furthermore: Related Things That We Don’t Know Well Enough

- Biology – mechanisms of life & origins of life
- Human brain
- Complex systems in general
- ….
The human brain project has ten years to build the brain with supercomputers in collaboration between 80 research institutions in Europe. http://www.humanbrainproject.eu/
What We Miss In The Present Scientific World Picture

Is understanding of the connectedness between living and non-living world and understanding of complex phenomena.

- MECHANISTIC VS. COMPLEX
- REDUCTION VS. HOLISM (SYSTEM VIEW)
- OBSERVER DEPENDENCE VS. GOD EYE VIEW
- EMBODDIEDNESS OF ALL NATURAL PHENOMENA INCLUDING MIND
Hystory of Computation up to Electronic Computers

Traditionally, *computation* was understood as synonymous with *calculation*. The first recorded use of the word "computer" was in 1613 to denote a *person* who carried out calculations, and the word retained the same meaning until the middle of the 20th century, when the word "computer" started to assume its current meaning, describing a *machine* that performs computations.
Hystory of Computation up to Electronic Computers

- Computational machinery evolved historically from simplest tools of extended human cognition to mechanical computers (calculators) to electronic machines with vacuum tubes and then transistors, to integrated circuits and eventually to microprocessors.

- During this development of hardware technologies towards ever smaller, faster and cheaper devices, the computational principles remained similar: an isolated computing machine calculating a function, executing an algorithm that can be represented by the Turing machine model.
Hystory of Computation up to Electronic Computers

- Babbage was the first to design a *programmable mechanical computer*, the general purpose Analytical Engine. The first *electronic digital computer* was built in 1939 by Atanasoff and Berry and it marks the beginning of the *era of digital computing*.

- In 1941 Zuse designed the first *programmable computer* Z3, also the first one based on the binary system. UNIVAC was the first computer capable of running a program from memory. The first *minicomputer* PDP was built in 1960 by DEC. Since 1960s the extremely fast growth of computer use was based on the technology of *integrated circuit/microchip*, which triggered the invention of the microprocessor, by Intel in 1971. [16]
Hystory of Computation up to Electronic Computers

- The progress of computing of course depends both on the development of hardware and the corresponding development of software.

- This includes algorithms, programming languages, compilers and interpreters, operating systems, virtual machines, and so on. Yet a lot of software development was considered as advanced applications of Turing Machine model. Computability Theory is still based on Turing Machine.
Beyond Conventional Computing Machinery: Natural Computing

- One of the ideals of computing ever since the time of Turing is *intelligent computing*, which would imply machine capable of not only executing mechanical procedure, but even intelligent problem solving.

- Thus the goal is a computer able to simulate behaviour of human *mathematician*, capable of intelligent insight.

- A development of *cognitive computing* aims towards human-level abilities to process/organize/understand information.
Beyond Conventional Computing Machinery: Natural Computing

- However, natural computing has much broader scope. According to the Handbook of Natural Computing, natural computing is “the field of research that investigates both human-designed computing inspired by nature and computing taking place in nature.”
- It includes among others areas of cellular automata and neural computation, evolutionary computation, molecular computation, quantum computation, nature-inspired algorithms and alternative models of computation.
Beyond Conventional Computing Machinery: Natural Computing

● Denning argue that computing today is a natural science. Natural computation provides a basis for a unified understanding of phenomena of embodied cognition, intelligence and knowledge generation.

● "I invite readers not on a visit to an archaeological museum, but rather on an adventure in science in making” Prigogine
Computation in Closed vs. Open Systems

- Since the 1950s computational machinery has been increasingly used to exchange information and computers gradually started to connect in networks and communicate. In the 1970s computers were connected via telecommunications.

- The emergence of networking involved a rethinking of the nature of computation and boundaries of a computer. Computer operating systems and applications were modified to access the resources of other computers in the network. In 1991 CERN created the World Wide Web, which resulted in computer networking becoming a part of everyday life for common people.
Computation in Closed vs. Open Systems

- With the development of computer networks, two characteristics of computing systems have become increasingly important: parallelism/concurrency and openness – both based on communication between computational units.

- Comparing new open-system with traditional closed-system computation models, Hewitt characterizes the Turing machine model as an internal (individual) framework and his own Actor model of concurrent computation as an external (sociological) model of computing.
Computation as Interaction and Interactive Computing

The following characteristics distinguish this new, interactive notion of computation (Wegner, Goldin):

- Computational problem is defined as *performing a task*, [in a dynamical environment – my addition] rather than (algorithmically) producing an answer to a question.

- Dynamic input and output are modelled by *dynamic streams which are interleaved*; later values of the input stream may depend on earlier values in the output stream and vice versa.
Computation as Interaction and Interactive Computing

- The environment of the computation is a part of the model, playing an active role in the computation by dynamically supplying the computational system with the inputs, and consuming the output values from the system.

- Concurrency: the computing system (agent) computes in parallel with its environment, and with other agents. (Agents can consist of agents networks, recursively.)

- Effective non-computability: the environment cannot be assumed to be static or effectively computable. We cannot always pre-compute input values or predict the effect of the system's output on the environment.
The advantages of concurrency theory that is used to simulate observable natural phenomena are according to Schachter that:

- “it is possible to express much richer notions of time and space in the concurrent interactive framework than in a sequential one. In the case of time, for example, instead of a unique total order, we now have interplay between many partial orders of events--the local times of concurrent agents--with potential synchronizations, and the possibility to add global constraints on the set of possible scheduling. This requires a much more complex algebraic structure of representation if one wants to "situate" a given agent in time, i.e., relatively to the occurrence of events originated by herself or by other agents.”
Trenholme describes the relationship of analog vs. symbolic simulation:

- “Symbolic simulation is thus a two-stage affair: first the mapping of inference structure of the theory onto hardware states which defines symbolic computation; second, the mapping of inference structure of the theory onto hardware states which (under appropriate conditions) qualifies the processing as a symbolic simulation.

- Analog simulation, in contrast, is defined by a single mapping from causal relations among elements of the simulation to causal relations among elements of the simulated phenomenon.”
Symbolic vs. Sub-symbolic Computation

Douglas Hofstadter in his dialogue “Prelude…Ant fugue” in Godel, Escher, Bach.
The Unreasonable Ineffectiveness Of Mathematics In Biology And Bias Of Mathematicians

- “The unreasonable effectiveness of mathematics” observed in physics by Wigner is missing in biology.

- Mathematics is disembodied while computing is embodied in a machine that can communicate with the physical world in real time.
The Unreasonable Ineffectiveness Of Mathematics In Biology And Bias Of Mathematicians

Cooper in Turing's Titanic Machine? Limits of TM model:

- Embodiment invalidating the `machine as data' and universality paradigm.
- The organic linking of mechanics and emergent outcomes delivering a clearer model of supervenience of mentality on brain functionality, and a reconciliation of different levels of effectivity.
- A reaffirmation of experiment and evolving hardware, for both AI and extended computing generally.
- The validating of a route to creation of new information through interaction and emergence.
Logic of Computing and Para-consistency

- Open, interactive and asynchronous systems have special requirements on logic.

- Goldin & Wegner and Hewitt argue e.g. that computational logic must be able to model interactive computation, and that classical logic must be robust towards inconsistencies i.e. must be paraconsistent due to the incompleteness of interaction.
Information/ Computation And Matter/Energy

● Two concepts under current development:
  
  Information and Computation

● Epistemologically, the world for an agent is an informational structure
Info-computationalism

- Computation is information dynamics (information processing)

- Computation is constrained and governed by the laws of physics on the fundamental level.

- Rozenberg and Kari: “(O)ur 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.*”
Morphological Computing.
Meaning Generation From Raw Data To Semantic Information

- Turing proposed diffusion reaction model of morphogenesis as the explanation of the development of biological patterns such as the spots and stripes on animal skin.

- Morphogenesis is a process of morphological computing. Physical process – though not computational in the traditional sense, presents natural (unconventional), morphological computation. Essential element in this process is the interplay between the informational structure and the computational process - information self-structuring and information integration, both synchronic and diachronic, going on in different time and space scales in physical bodies.
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Morphological Computing. Meaning Generation From Raw Data To Semantic Information

- Info-computational naturalism describes nature as informational structure – a succession of levels of organization of information.

- Morphological computing on that informational structure leads to new informational structures via processes of self-organization of information.

- Evolution itself is a process of morphological computation on a long-term scale.
Conclusions & Future Work

Present account highlights several topics of importance for the development of new understanding of computation and its role in the physical world:

- Natural computation
- The relationship between the model and physical implementation
- Interactivity as fundamental for computational modelling of concurrent information processing systems such as living organisms and their networks,
- The new developments in mathematical modelling needed to support this generalized framework.
Conclusions & Future Work

- Besides the Turing machine model as well developed and generally established model of computation, variety of new ideas, still under developments are taking shape and have good prospects to extend our understanding of computation and its relationship to physical implementations.

- It will be instructive within the info-computational framework to study processes of self organization of information in physical agents (as well as in population of agents) able to re-structure themselves through interactions with the environment as a result of morphological (morphogenetic) computation.
“Our imagination is stretched to the utmost, not, as in fiction, to imagine things which are not really there, but just to comprehend those things which are there.”

Richard Feynman, The Character of Physical Law (1965)
Computation, Information, Cognition

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