Semantics of Information as Interactive Computation

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A Brief, Sketchy Picture of InfoComputationalism

Semantics of information as interactive computation.
A unified picture of
- Information
- Computation
- Cognition
in a constructionist/functionalist approach
Information

A special issue of the Journal of Logic, Language and Information (Volume 12 No 4 2003) dedicated to the different facets of information.

A *Handbook on the Philosophy of Information* (Van Benthem, Adriaans) is in preparation as one volume *Handbook of the philosophy of science*. 

http://www.illc.uva.nl/HPI/

Dodig-Crnkovic G., *Ab Ovo. Information: Between the Anvil and Hammer – Orphean Theme*, oil on canvas
Information Schools

Mechanicists School
Semiotic School
Batesonian School
Logic School
Hermeneutic School
Heraclitian School
Phenomenological School
Stimulus School
Documentalism
Skeptic School

Katsushika Hokusai, *Blind Men and Elephant*
Syntactic vs. Semantic Information

1. **Syntactic** information (Chaitin-Kolmogorov, Shannon-Weaver, Wiener, Fisher) – semantics is fix (tacit), and syntax is expressed.

2. **Semantic** information (Bar-Hilel, Barwise and Perry, Dretske, Devlin) - syntax is tacit, and semantics is expressed.
Information Science

Information science (also information studies) is an interdisciplinary science primarily concerned with the collection, classification, manipulation, storage, retrieval and dissemination of information. Information science studies the application and usage of knowledge in organizations, and the interaction between people, organizations and information systems. It is incorporating not only aspects of computer science, but also mathematics, library science, cognitive science, and the social sciences.

http://www.scienceofinformationinstitute.com/about.html
The Philosophy of Information (PI)

The philosophy of information (PI) is a new area of research, which studies conceptual issues arising at the intersection of computer science, informatics, and philosophy. The research concerned with:

- the critical investigation of the conceptual nature and basic principles of information, including its dynamics, utilization and sciences
- the elaboration and application of information-theoretic and computational methodologies to philosophical problems.

(Floridi, *What is the Philosophy of Information?*, Metaphilosophy, 2002, (33), 1/2)
Open Problems of PI

Semantics
4 problems about meaning and truth

Intelligence
7 problems about cognition, intelligence and knowledge

Values
1 problem about a new ethics

Nature
3 problems about being and naturalisation

Paninformationalism

If information is to replace matter/energy as the primary stuff of the universe, as von Baeyer (2003) suggests, it will provide a new basic unifying framework for describing and predicting reality in the twenty-first century.

Computation

Computation is the process of performing a task of computing.

The definition of computation is currently widely discussed, and an entire issue of the journal *Minds and Machines* (1994, 4, 4) was devoted to the question “What is Computation?”

Computing: Computer Science, Computer Engineering, Software Engineering and Information Systems, according to ACM/IEEE (2001). The German, French and Italian languages use the respective terms "Informatik", "Informatique" and “Informatica” (Informatics in English) to denote Computing.

http://www.amsta.leeds.ac.uk/~pmt6sbc/ Barry Cooper
http://www.amsta.leeds.ac.uk/cie/ Computability in Europe Network
In 1623, Galileo in his book *The Assayer - Il Saggiatore*, claimed that the language of nature's book is mathematics and that the way to understand nature is through mathematics.

Generalizing ”mathematics” to ”computation” we may agree with Galileo – the great book of nature is an e-book!

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

Inspired by nature:
- Evolutionary computation
- Neural networks
- Artificial immune systems
- Swarm intelligence

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

Computing with natural materials:
- DNA computing
- Quantum computing

Journals: [Natural Computing](#) and [IEEE Transactions on Evolutionary Computation](#).
The Universe as a Computer - Pancomputationalism

We are all living inside a gigantic computer. No, not The Matrix: the Universe.

Every process, every change that takes place in the Universe, may be considered as a kind of computation.
E Fredkin, S Wolfram

String formation – Andrei Linde

http://physics.stanford.edu/linde
The Computing Universe: Pancomputationalism

Konrad Zuse was the first to suggest (in 1967) that the physical behavior of the entire universe is being computed on a basic level, possibly on cellular automata, by the universe itself which he referred to as "Rechnender Raum" or Computing Space/Cosmos.

Computationalists: Zuse, Wiener, Fredkin, Wolfram, Chaitin, Lloyd, Seife, ..
The Wildfire Spread of Computational Ideas

"Everyone knows that computational and information technology has spread like wildfire throughout academic and intellectual life. But the spread of computational ideas has been just as impressive. Biologists not only model life forms on computers; they treat the gene, and even whole organisms, as information systems. Philosophy, artificial intelligence, and cognitive science don't just construct computational models of mind; they take cognition to be computation, at the deepest levels."

Cantwell Smith, The Wildfire Spread of Computational Ideas, 2003
Computing Nature and Nature Inspired Computation: How Real?

If it looks like a duck, if it walks like a duck and it quacks like a duck, is it a duck?
Present Model of Computation: Turing Machine

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

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

A New paradigm:
According to George Kampis, complex biological systems must be modeled as self-referential, self-organizing systems called "component-systems" (self-generating systems), whose behavior, though computational in a generalized sense, goes far beyond Turing machine model.

“a component system is a computer which, when executing its operations (software) builds a new hardware.... [W]e have a computer that re-wires itself in a hardware-software interplay: the hardware defines the software and the software defines new hardware. Then the circle starts again.”

(Kampis, p. 223 Self-Modifying Systems in Biology and Cognitive Science)
Computation as Information Processing

With information as the primary stuff of the universe, and computation as its time-dependent behavior (dynamics), we have a Dual-aspect Universe: informational structure with computational dynamics.

Information and computation are closely related – no computation without information, and no information without dynamics.

The question is how well-motivated is this dual-aspect picture?

On TM’s limitations and computation as information processing: 
**Super-Recursive Algorithms**, Mark Burgin

Classical View: Computation vs. Nature


Computation as a form of intentionality
Computing Nature, Computationalism

The computational/informational view of the universe
Is the Computing Universe Digital or Analogue? Discrete-Continuum Dichotomy*

“In a quantum computer, however, there is no distinction between analog and digital computation. Quanta are by definition discrete, and their states can be mapped directly onto the states of qubits without approximation. But qubits are also continuous, because of their wave nature; their states can be continuous superpositions. Analog quantum computers and digital quantum computers are both made up of qubits, and analog quantum computations and digital quantum computations both proceed by arranging logic operations between those qubits. Our classical intuition tells us that analog computation is intrinsically continuous and digital computation is intrinsically discrete. As with many other classical intuitions, this one is incorrect when applied to quantum computation. Analog quantum computers and digital quantum computers are one and the same device.” (Lloyd, 2006)

* A question important when modelling mind as digital computer or a dynamic system
Cognition

The process of being aware, knowing, thinking, learning and judging. The study of cognition touches on the fields of psychology, linguistics, computer science, neuroscience, mathematics, ethology and philosophy.

(Medical Dictionary)

The internal structures and processes that are involved in the acquisition and use of knowledge, including sensation, perception, attention, learning, memory, language, thinking, and reasoning.

(Sci-Tech Encyclopedia)

It is also used in a wider sense to mean the act of knowing or knowledge, and may be interpreted in a social or cultural sense to describe the emergent development of knowledge and concepts within a group

I will use cognition to denote "making sense of the world" for a living organism

(Maturana-Varela)
Data → Information → Knowledge as Information Processing

Pragmatism suggests that *interaction* is the most appropriate framework for understanding cognition.

**Interactive explanation is future oriented**: based on the fact that the agent is concerned with anticipated future potentialities of interaction.

The actions are oriented internally to the system, which optimizes their internal outcome, while the environment in the interactive case represents primarily resources for the agent. **Correspondence (mutual influence) with the environment is a part of interactive relation.**

[One can say that living organisms are “about” the environment, that they have developed adaptive strategies to survive by internalizing environmental constraints. The interaction between an organism and its environment is realized through the exchange of physical signals that might be seen as data, or when structured, as information. Organizing and mutually relating different pieces of information results in knowledge. In that context, computationalism appears as the most suitable framework for naturalizing epistemology. ]
Molecular Networks at the Basis of Cognition

The human brain is the most complex organ in the human body. It is a network of billions of nerve cells connected at specialized junctions - synapses.

Neural synapses not only transmit but also process impulses - they translate impulses into information. This gives the synapse a vital role in information processing, behaviour, memory and diseases.

Biophysics of Computation:
Information Processing in Single Neurons
Christof Koch, 1999 http://www.klab.caltech.edu/~koch/biophysics-book/
Epistemology Naturalized

Naturalized epistemology (Feldman, Kornblith, Stich) is, in general, an idea that knowledge may be studied as a natural phenomenon -- that the subject matter of epistemology is not our concept of knowledge, but the knowledge itself.

“The stimulation of his sensory receptors is all the evidence anybody has had to go on, ultimately, in arriving at his picture of the world. Why not just see how this construction really proceeds? Why not settle for psychology?” ("Epistemology Naturalized", Quine 1969; emphasis mine)

I will re-phrase the question to be: Why not settle for computing?

See also:
Gordana Dodig-Crnkovic
Epistemology Naturalized: The Info-Computationalist Approach
APA Newsletter on Philosophy and Computers, Spring 2007 Volume 06, Number 2
Why not Settle for Computing?

Info-computationalism provides a unifying framework which makes it possible for different research fields such as philosophy, computer science, neuroscience, cognitive science, biology, and number of others to communicate.

An account of the naturalized epistemology based on the computational character of cognition and agency -- which includes evolutionary approaches to cognition.

In this framework knowledge is seen as a result of the structuring of input: data → information → knowledge by an interactive computational process going on in the nervous system during the adaptive interplay of an agent with the environment, which clearly increases its ability to cope with the dynamical changing of the world.
Naturalist Understanding of Cognition

According to Maturana and Varela (1980) even the simplest organisms possess cognition and their meaning-production apparatus is contained in their metabolism. (Of course, there are also non-metabolic interactions with the environment, such as locomotion, that also generates meaning for an organism by changing its environment and providing new input data.)

Maturana’s and Varelas’ understanding of cognition is most suitable as the basis for a computationalist account of the naturalized evolutionary epistemology.
How Does Nature Compute? Evolution

Critics of the evolutionary approach mention the impossibility of “blind chance” to produce such highly complex structures as intelligent living organisms. Proverbial monkeys typing Shakespeare are often used as illustration (an interesting account is given by Gell-Man in his *Quark and the Jaguar*.)

Chaitin and Bennet: Typing monkeys’ argument does not take into account physical laws of the universe, which dramatically limit what can be typed. Moreover, the universe is not a typewriter, but a computer, so a monkey types random input into a computer. The computer interprets the strings as programs.

Naturalist Understanding of Cognition – Evolutionary View

A great conceptual advantage of cognition as a central focus of study is that all living organisms possess some cognition, in some degree.

See also:
Gordana Dodig-Crnkovic
*Where do New Ideas Come From? How do they Emerge? Epistemology as Computation (Information Processing)*
forthcoming in *Randomness & Complexity, from Leibniz to Chaitin*, C. Calude ed. 2007
No Information Without Representation

Traditionally, there is a widely debated problem of representation of information and the role of representation in explaining and producing information, a discussion about two seemingly incompatible views: a hard, explicit and static notion of representation versus implicit and dynamic (interactive) one. The central point is that those both views are eminently info-computational.

Within info-computational framework, classical (Turing-machine type) and connectionist views are reconciled and used to describe different aspects of cognition (Arnellos et al. 2005, Dawson, 2006). The project of naturalizing epistemology through info-computationalism builds on the development of multilevel dynamical computational models and simulations of a nervous system, and has important consequences for the development of intelligent systems and artificial life.
Info-Computational Account of Knowledge Generation

Dual-aspect unification of information and computation as physical phenomena.

Natural computing as a new paradigm of computing goes beyond the Turing Machine model and applies to all physical processes including those going on in our brains.

Continuum-discrete controversy bridged by the same dual-aspect approach. This counters the argument against computational mind which claims that computational mind must be discrete. It is also an answer to the critique that the universe might not be computational as it might not be digital.
Unified Info-Computational Epistemology Naturalized

The Turing Machine model is about mechanical, syntactic symbol manipulation as implemented on the hardware level. Complexity is on the software level. Different levels of complexity have different meanings for different cognizing agents.

Semantics is essential for living organisms. Semantics defines the relationship between the mind and the world.
Info-Computational Epistemology Naturalized

Information has both declarative and non-declarative forms (e.g. biology), each of them with their own role for living systems.

Organisms solve symbol-grounding problem on a non-declarative level.

Info-computationalist approach as *agent-centered* allows for pluralism: logical, epistemological and ethical. It is supported by research results from physics, biology, neuroscience and philosophy of mind, among others.
Info-Computational Epistemology Naturalized

At the physical level, living beings are open complex computational systems in a regime on the edge of chaos, characterized by maximal informational content. Complexity is found between orderly systems with high information compressibility and low information content and random systems with low compressibility and high information content.

Crystals are static and orderly. Chaotic dynamics are similar to gases, which can be described only statistically. Periodic behavior is similar to a non-crystal solid, and complexity is like a liquid that is close to both the solid and the gaseous states. In this way, we can once again view complexity and computation as existing on the edge of chaos and simplicity. (Flake 1998)
Info-Computational Epistemology Naturalized

Artificial agents may be treated analogously with animals in terms of different degrees of complexity; they may range from software agents with no sensory inputs at all to cognitive robots with varying degrees of sophistication of sensors and varying bodily architecture.

The question: how does information acquire meaning naturally in the process of an organism’s interaction with its environment is answered via study of evolution and its impact on the cognitive, linguistic, and social structures of living beings.
An agent receives inputs from the physical environment (data) and interprets these in terms of its own earlier experiences, comparing them with stored data in a feedback loop. Through that interaction between the environmental data and the inner structure of an agent, a dynamical state is obtained in which the agent has established a representation of the situation. The next step in the loop is to compare the present state with its goals and preferences (saved in an associative memory). This process results in the anticipation of what various actions from the given state might have for consequences (Goertzel 1994).
Info-Computational Epistemology Naturalized

Based on the natural phenomena understood as info-computational, computer in general is conceived as an open interactive system (digital or analogue; discrete or continuous) in the communication with the environment. Classical Turing machine is seen as a subset of a more general interactive/adaptive/self-organizing universal natural computer. Living system is defined as "open, coherent, space-time structure maintained far from thermodynamic equilibrium by a flow of energy through it." Chaisson, 2002.

On a computationalist view, organisms are constituted by computational processes, implementing computation in vivo. In the open system of living cell an info-computational process takes place using DNA, exchanging information, matter and energy with the environment.
Cognition as Re-structuring of an Agent in Interaction with the Environment

All cognizing beings are in constant interaction with their environment. The essential feature of cognizing living organisms is their ability to manage complexity, and to handle complicated environmental conditions with a variety of responses that are results of adaptation, variation, selection, learning, and/or reasoning.

As a consequence of evolution, increasingly complex living organisms arise. They are able to register inputs (data) from the environment, to structure those into information, and, in more developed organisms, into knowledge.

The evolutionary advantage of using structured, component-based approaches (data – information – knowledge) is improving response and the computational efficiency of cognitive processes.
Cognition as Re-structuring of an Agent in Interaction with the Environment

Info-computationalist project of naturalizing epistemology by defining cognition as information processing phenomenon is closely related to the development of multilevel dynamical computational models and simulations of cognizing systems, and has important consequences for the development of artificial intelligence and artificial life.

Natural computation opens possibilities to implement embodied cognition into artificial agents, and perform experiments on simulated eco-systems.

http://bluebrain.epfl.ch/ The Blue Brain project is the first comprehensive attempt to reverse-engineer the mammalian brain, in order to understand brain function.
Semantics of Information as Interactive Computation

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http://www.amazon.co.uk/Computation-Information-Cognition-Nexus-Liminal/dp/1847180906/ref=sr_1_1?ie=UTF8&s=books&qid=1207298724&sr=1-1
A New Kind of Science

Preface
Chapter 1   The Foundations for a New Kind of Science
Chapter 2   The Crucial Experiment
Chapter 3   The World of Simple Programs
Chapter 4   Systems Based on Numbers
Chapter 5   Two Dimensions and Beyond
Chapter 6   Starting from Randomness
Chapter 7   Mechanisms in Programs and Nature
Chapter 8   Implications for Everyday Systems
Chapter 9   Fundamental Physics
Chapter 10  Processes of Perception and Analysis
Chapter 11  The Notion of Computation
Chapter 12  The Principle of Computational Equivalence

http://www.wolframscience.com
A New Paradigm of Computing: Interactive Computing

Dina Goldin, Scott Smolka, Peter Wegner, eds.

Dina Goldin, Peter Wegner
The Interactive Nature of Computing: Refuting the Strong Church - Turing Thesis Minds and Machines
Volume 18, Issue 1 (March 2008) p 17 - 38
A New Kind of Philosophy

Every Thing Must Go Metaphysics Naturalized argues that the only kind of metaphysics that can contribute to objective knowledge is one based specifically on contemporary science as it really is, and not on philosophers' a priori intuitions, common sense, or simplifications of science.

In addition to showing how recent metaphysics has drifted away from connection with all other serious scholarly inquiry, they demonstrate how to build a metaphysics compatible with current fundamental physics ("ontic structural realism"), which, when combined with their metaphysics of the special sciences ("rainforest realism"), can be used to unify physics with the other sciences without reducing these sciences to physics itself.
Consciousness Computationalist Way

What do we mean when we say "I"?

Can thought arise out of matter? Can a self, a soul, a consciousness, an "I" arise out of mere matter? If it cannot, then how can you or I be here?

I Am a Strange Loop argues that the key to understanding selves and consciousness is the "strange loop"--a special kind of abstract feedback loop inhabiting our brains. Deep down, a human brain is a chaotic seething soup of particles, on a higher level it is a jungle of neurons, and on a yet higher level it is a network of abstractions that we call "symbols." The most central and complex symbol in your brain or mine is the one we both call "I."


"In the end, we self-perceiving, self-inventing, locked-in mirages are little miracles of self-reference. Hofstadter
Randomness, Complexity and Information

On Random and Hard-to-Describe Numbers (C H Bennett)

The Implications of a Cosmological Information Bound for Complexity, Quantum Information and the Nature of Physical Law (P C W Davies)

What is a Computation? (M Davis)

The Secret Number. An Exposition of Chaitin’s Theory (G Rozenberg & A Salomaa)

Omega and the Time Evolution of the n-Body Problem (K Svozil)

God’s Number: Where Can We Find the Secret of the Universe? In a Single Number! (M Chown)

Omega Numbers (J-P Delahaye)

Some Modern Perspectives on the Quest for Ultimate Knowledge (S Wolfram)

An Enquiry Concerning Human (and Computer!) [Mathematical] Understanding (D Zeilberger)

.. and other papers

http://www.worldscibooks.com/compsci/6577.html
Making Sense by Interacting in InfoComputational Universe - Summary

- Agent-centered (information and computation makes sense is in the agent)
- Agent is a cognizing biological organism or an intelligent machine or both
- Action (interaction with the physical world & other agents) is essential for cognition
- Kind of physicalism with information as a stuff of the universe and computation as its dynamics
- Agents form different (interconnected, communicating) cognitive communities
- What is considered to exist (ontology) depends on agency
- Agency depends on what is taken for granted to exist (self reference)
Conclusions

Much like 17th century clockwork universe, huge, regulated machine operated according to natural laws where God was the Master Builder and the Prime Mover\(^1\) – todays universe is a computing machinery – a network of computational processes of dynamics changes in the informational structure\(^2\).

Present day computers are tools for data handling and communication of the networked humanity. Computers are also directly connecting to the physical world in robotics and in the envisioned Internet of things. That is why pragmatic aspects are so important, and must be taken into account together with syntax and semantics of information/computation.

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1. Similar views may be traced back machina mundi by John of Sacrobosco (1200 - 1256)
2. And of course ever since Laplace, physical laws are considered sufficient for the construction of our models of universe.
Conclusions

For present distributed, interactive, agent based and concurrent computation, the main criterion of success is *not the termination of a process*, but its *adequacy of response* – generality, speed, flexibility, tolerance to noise and robustness.

This leads us to a new paradigm of computation which is INTERACTIVE COMPUTING where Turing-Church paradigm appears as a limit case for an isolated computing process.

As a consequence of the dual-aspect info-computationalism epistemology can be naturalized: semantics of information is construed through interactive computation.

Thanks to Prof. W Neuser for the following comment: Turing's move was to propose a machine constructed to perform as a human. The InfoComputationalist move is to take the (world as a) computer and try to re-construct a human.