Epistemology Naturalized: The Info-Computationalist Approach

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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.

In his "Epistemology Naturalized", Quine claims the following:

> 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? (Quine 1969)

This essay will re-phrase the question to be: Why not settle for computing? The main reason is that 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.

We will give an account of the naturalized epistemology based on the computational character of cognition and agency -- which includes evolutionary approaches to cognition (Lorenz 1977, Popper 1978, Toulmin 1972 and Campbell et al. 1989, Harms 2004). In this framework knowledge is seen as a result of the structuring of input data (data $\rightarrow$ information $\rightarrow$ 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 dynamics of the world.

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, those 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.

1. Dual Aspect Info-Computational Framework

Within the field of computing and philosophy, two distinct branches have been established: informationalism (in which the focus is on information as the stuff of the universe; Floridi 2002) and computationalism (where the universe is seen as a computer). Chaitin (2006) mentions cellular automata[1] researchers-- and computer scientists Fredkin, Wolfram, Toffoli, and Margolus, and physicists Wheeler, Zeilinger, 't Hooft, Smolin, Lloyd, Zizzi, Mäkelä, and Jacobson, as prominent computationalists.

Recently, a synthetic approach has been proposed in the form of dual-aspect info-computationalism (Dodig-Crnkovic 2006), in which universe is viewed as a structure (information) in a permanent process of change (computation). According to this view, information and computation constitute two aspects of reality, and like particle and wave, or matter and energy, capture different facets of the same physical world.

Computation may be either discrete or continuous (digital or analogue). The present approach offers a generalization of traditional computationalism in the sense that "computation" is understood as the process governing dynamics of the universe, or in the words of Chaitin:

> And how about the entire universe, can it be considered to be a computer? Yes, it certainly can, it is constantly computing its future state from its current state, it's constantly computing its own time-evolution! And as I believe Tom Toffoli pointed out, actual computers like your PC just hitch a ride on this universal computation! (Chaitin 2006)

Mind is seen in this dual-aspect framework as a computational process on an informational structure that, both in its digital and analogue forms, occurs through changes in the structures of our brains and bodies as a consequence of interaction with the physical universe. This approach leads to a naturalized, evolutionary epistemology that understands cognition as a phenomenon that can be ascribed, in the spirit of Maturana and Varela, even to simplest living organisms, and in the same vein to artificial life.

In order to be able to comprehend and eventually construct artificial cognitive systems we can learn from the historical development of biological cognitive functions and structures from the simple ones upward. A very interesting account of developmental ascendancy, from bottom-up to top-down control, is given by Coffman 2006.

1.1 Natural Computation Beyond Turing Limit

As a direct consequence of the computationalist view that every natural process is computation in a computing universe, "computation" must be generalized to mean *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 may be represented by either discrete or continuous models. Examples of computation occurring in nature include information processing in evolution by natural selection, in the brain, in the immune system, in the self-organized collective behavior of groups of animals such as ant colonies, and in particle swarms. Computation inspired by nature includes genetic algorithms, artificial neural nets, simulated immune systems, ant colony optimization, particle swarm optimization, and so forth. There is a considerable synergy gain in relating human-designed computing with the computing in nature. Chaitin claims that "we only understand something if we can program it". In the iterative course of modeling and computationally simulating (programming) natural processes, we learn to reproduce and predict more and more of the characteristic features of the natural systems.

Ideal, classical theoretical computers are mathematical objects and are equivalent to algorithms, abstract automata (Turing machines), effective procedures, recursive functions, or formal languages. Compared with new emerging computing paradigms, particularly interactive computing and natural computing, Turing machines form the proper subset of the set of information processing devices.

An interesting new situation (Wegner, 1998) arises when the computer is conceived as an open system in communication with the environment, the boundary of which is dynamic, as in biological systems. Chaisson (2002) e.g. defines life as an "open, coherent, space- time structure maintained far from thermodynamic equilibrium by a flow of energy through it." On a computationalist view, organisms are constituted by computational processes; they are “living computers”. In the living cell an info-computational process takes place using DNA, in an open system exchanging information, matter and energy with the environment.

Burgin (2005) identifies three distinct components of information processing systems: hardware (physical devices), software (programs that regulate its functioning and sometimes can be identical with hardware, as in biological computing), and infoware (information processed by the system). Infoware is a shell built around the software-hardware core, which is the traditional domain of automata and algorithm theory. Semantic Web is an example of infoware that is adding semantic component to the information present on the web (Berners-Lee, Hendler and Lassila, 2001).

For implementations of computationalism, interactive computing is the most appropriate general model, as it naturally suits the purpose of modeling a network of mutually communicating processes (Dodig-Crnkovic 2006). It will be of particular interest to computational accounts of epistemology, as a cognizing agent interacts with the environment in order to gain experience and knowledge. It also provides the natural unifying framework for reconciliation of classical and connectionist views of cognition.

2. Epistemology Naturalized

> Indeed, cognitive ethologists find the only way to make sense of the cognitive equipment in animal is to treat it as an information processing system, including equipment for perception, as well as the storage and integration of information; that is, after all, the point of calling it cognitive equipment. That equipment which can play such a role confers selective advantage over animals lacking such equipment no longer requires any argument. (Kornblith 1999)

Our specific interest is in how the structuring from data to information and knowledge develops on a phenomenological level in a cognitive agent (biological or artificial) in its interaction with the environment. The central role of interaction is expressed by Goerzel (1994):

> Today, more and more biologists are waking up to the sensitive environment-dependence of fitness, to the fact that the properties which make an organism fit may not even be present in the organism, but may be emergent between the organism and its environment.[2]

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.

A very interesting idea presented by Maturana and Varela (1980) is that even the simplest organisms possess cognition and that 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. We will take Maturana’s and Varelas’ theory as the basis for a computationalist account of the evolutionary epistemology.

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.

> Langton has compared these different regions to the different states of matter. Fixed points are like crystals in that they are for the most part 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)

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 is: how does information acquire meaning naturally in the process of an organism’s interaction with its environment? A straightforward approach to naturalized epistemology attempts to answer this question via study of evolution and its impact on the cognitive, linguistic, and social structures of living beings, from the simplest ones to those at highest levels of organizational complexity (Bates 2005).[3]

Various animals are equipped with varying physical hardware, sets of sensory apparatuses (compare an amoeba with a mammal), and goals and behaviors. For different animals, the “aboutness” concerning the same physical reality is different in terms of causes and their effects.

Thus the problematic aspect of any correspondence theory (including spectator models of representation) is the difficulty of deciding whose reality is to be considered “the true one”. However, Harms, 2004 claims that “We now have a fairly satisfactory account of correspondence truth for simple signals like animal warning cries, a rather surprising triumph for naturalism. Essentially, a signal in an environmental tracking system is true when it gets its timing right vis-`a-vis its adaptive design (Millikan 1984; Skyrms 1996)." The correspondence is in this case about the existence of the phenomenon ("there is a cat") and not about the "true nature of the phenomenon" (its interpretation).

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.[4] 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). Here is an alternative formulation:

> This approach is not a hybrid dynamic/symbolic one, but interplay between analogue and digital information spaces, in an attempt to model the representational behavior of a system. The focus on the explicitly referential covariation of information between system and environment is shifted towards the interactive modulation of implicit internal content and therefore, the resulting pragmatic adaptation of the system via its interaction with the environment. The basic components of the framework, its nodal points and their dynamic relations are analyzed, aiming at providing a functional framework for the complex realm of autonomous information systems (Arnellos et al. 2005).

2.1 Interactive Naturalism and Computational Process

Interactivism[5] (Birkhard 2004, Kulakov & Stojanov 2002) is a philosophical approach especially suited to the analysis of agency. On the ontological level, it involves naturalism, which means that the physical world (matter) and mind are integrated, mind being an emergent property of a physical process. It is closely related to process metaphysics (Whitehead 1978), in which the fundamental nature of the universe is understood as organization of processes.

Interactivism has been applied to a range of phenomena, including perception, consciousness, learning, language, memory, emotions, development, personality, rationality, biological functionality, and evolution. The approach is inspired by, among others, Piaget's interactionism and constructivism (Piaget, 1987), but it differs from Piaget in that it gives a central role to variational construction and selection.

The interactive model is pragmatist in its process and action approach, and in its focus on the consequences of interaction it resembles Peirce's model of meaning. The essential difference between the interactivist concept of perception and Peirce's concept is the emphasis in the former on the process (interactive) nature of perception (data) and information (representation).

2.2 Evolutionary Development

> One cannot account for the functional architecture, reliability, and goals of a nervous system without understanding its adaptive history.

> Consequently, a successful science of knowledge must include standard techniques for modeling the interaction between evolution and learning. (Harms, 2005)

A central question is thus what the mechanism is of evolutionary development of cognitive abilities in organisms. 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 an illustration (an interesting account is given by Gell-Man in his *Quark and the Jaguar*). However, Lloyd 2006 mentions a following, very good counter argument, originally due to Chaitin and Bennet. The "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.

> Quantum mechanics supplies the universe with "monkeys" in the form of random fluctuations, such as those that seeded the locations of galaxies. The computer into which they type is the universe itself. From a simple initial state, obeying simple physical laws, the universe has systematically processed and amplified the bits of information embodied in those quantum fluctuations. The result of this information processing is the diverse, information-packed universe we see around us: programmed by quanta, physics give rise first to chemistry and then to life; programmed by mutation and recombination, life gave rise to Shakespeare; programmed by experience and imagination, Shakespeare gave rise to Hamlet. You might say that the difference between a monkey at a typewriter and a monkey at a computer is all the difference in the world. (Lloyd 2006)

Allow me to add one comment on Lloyd's computationalist claim. The universe/ computer on which a monkey types is at the same time the hardware and the program, in a way similar to the Turing machine. (An example from biological computing is the DNA where the hardware (the molecule) is at the same time the software (the program, the code). In general, each new input restructures the computational universe and changes the preconditions for future inputs. Those processes are interactive and self-organizing. That makes the essential speed-up for the process of getting more and more complex structures.

2.3 Info-Computational Complexity of Cognition

> Dynamics lead to statics, statics leads to dynamics, and the simultaneous analysis of the two provides the beginning of an understanding of that mysterious process called mind. (Goertzel 1994)

In the info-computationalist vocabulary, "statics" (structure) corresponds to "information" and "dynamics" corresponds to "computation".

One question which now may be asked is: Why doesn't an organism exclusively react to data as it is received from the world/ environment? Why is information used as building blocks, and why is knowledge constructed? In principle, one could imagine a reactive agent that responds directly to input data without building an informational structure out of raw input.

The reason may be found in the computational efficiency of the computation concerned. Storage of data that are constant or are often reused saves enormous amounts of time. So, for instance, if instead of dealing with each individual pixel in a picture, we can make use of symbols or patterns that can be identified with similar memorized symbols or patterns, the picture can be handled much more quickly.

Studies of vision show that cognition focuses on that part of the scene which is variable and dynamic, and uses memorized data for the rest that is static (this is the notorious frame problem of AI). Based on the same mechanism, we use ideas already existing to recognize, classify, and characterize phenomena. Our cognition is thus an emergent phenomenon, resulting from both memorized (static) and observed (dynamic) streams. Forming chunks of structured data into building blocks, instead of performing time-consuming computations on those data sets in real time, is an enormously powerful acceleration mechanism. With each higher level of organization, the computing capacity of an organism's cognitive apparatus is further increased. The efficiency of meta-levels is becoming evident in computational implementations.

Cognition as the multilevel control network in Goertzel's model is "pyramidal" in the sense that each process is connected to more processes below it in the hierarchy than above it in the hierarchy. In order to achieve rapid reaction, not every input that comes into the lower levels can be passed along to the higher levels. Only the most important inputs are passed.

Goertzel illustrates this multilevel control structure by means of the three-level "pyramidal" vision processing parallel computer developed by Levitan and his colleagues at the University of Massachusetts. The bottom level deals with sensory data and with low-level processing such as segmentation into components. The intermediate level handles grouping, shape detection, and such; and the top level processes this information "symbolically", constructing an overall interpretation of the scene. This three-level perceptual hierarchy appears to be an extremely effective approach to computer vision.

> That orders are passed down the perceptual hierarchy was one of the biggest insights of the Gestalt psychologists. Their experiments (Kohler, 1975) showed that we look for certain configurations in our visual input. We look for those objects that we expect to see and we look for those shapes that we are used to seeing. If a level 5 process corresponds to an expected object, then it will tell its children [i. e., processes] to look for the parts corresponding to that object, and its children will tell their children to look for the complex geometrical forms making up the parts to which they refer, et cetera. (Goertzel 1994)

In his book *What Computers Can't Do*, Dreyfus points out that human intelligence is indivisible from the sense of presence in a body (see also Stuart 2003, Gärdenfors 2000, 2005). When we reason, we relate different ideas in a way that resembles the interrelations of parts of our body and the relation of our body with various external objects, which is in a complete agreement with the info-computational view, and the understanding of human cognition as a part of this overall picture.

3. Summary

In conclusion, let us sum up the proposed view of naturalized epistemology, based on the info-computationalist view of the universe.

Within the info-computationalist framework, information is the stuff of the universe while computation is its dynamics. The universe is a network of computing processes and its phenomena are fundamentally info-computational in nature: as well continuous as discrete, analogue as digital computing are parts of the computing universe. On the level of quantum computing those aspects are inextricably intertwined, Dodig-Crnkovic, 2006.

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.

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 time and the computational efficiency of cognitive processes.

The main reason for choosing info-computationalist view for naturalizing epistemology is that it 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, exchange their results and build a common knowledge.

It also provides the natural solution to the old problem of the role of representation in explaining and producing information, a discussion about two seemingly incompatible views: a symbolic, explicit and static notion of representation versus implicit and dynamic (interactive) one. Within info-computational framework, those classical (Turing-machine type) and connectionist views are reconciled and used to describe different aspects of cognition.

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

Notes

1. Cellular automaton <algorithm, parallel> A regular spatial lattice of "cells", each of which can have any one of a finite number of states. The state of all cells in the lattice are updated simultaneously and the state of the entire lattice advances in discrete time steps. The state of each cell in the lattice is updated according to a local rule which may depend on the state of the cell and its neighbors at the previous time step. Each cell in a cellular automaton could be considered to be a finite state machine which takes its neighbours' states as input and outputs its own state. The best known example is J.H. Conway's game of Life. (http://foldoc.org/ Free On Line Dictionary of Computing). For applications, see Wolfram, 2002.

2. For an illustrative example, see http://dir.salon.com/story/tech/feature/2004/08/12/evolvable_hardware/index.html as quoted in Kurzweil (2005).

3. Normally this takes time, but there are obvious exceptions. Situations where the agent is in mortal danger are usually hard-coded and connected via a short-cut to activate an immediate, automatic, unconscious reaction. For a living organism, the efficiency of the computational process is presumably critical for its survival:

   "Over the billions of years of life on this planet, it has been evolutionarily advantageous for living organisms to be able to discern distinctions and patterns in their environment and then interact knowingly with that environment, based on the patterns perceived and formed. In the process of natural selection, those animals survive that are able to feed and reproduce successfully to the next generation. Being able to sense prey or predators and to develop strategies that protect one and promote the life success of one's offspring, these capabilities rest on a variety of forms of pattern detection, creation and storage. Consequently, organisms, particularly the higher animals, develop large brains and the skills to discern, cognitively process and operationally exploit information in the daily stream of matter and energy in which they find themselves … In the broadest sense then, brains are buffers against environmental variability" (Bates 2005).

4. Here a typical approach is Connectionism, with the basic principle that mental phenomena are the emergent processes of interconnected networks of simple units. The most common forms of Connectionism use neural network models. Learning is a basic feature of connectionist models. One of the dominant connectionist approaches today is Parallel Distributed Processing (PDP) that emphasizes the parallelism of neural processing, and the distributed character of neural representations. It should be added that both connectionist and classical cognitive models are information processing and they both belong to the info-computationalist framework.

5. The name interactivism derives from the model for representation developed within this framework. Roughly, representation emerges in the presuppositions of anticipatory interactive processes in (natural or artificial) agents. The first dubbing of the model was by Rita Vuyk who called it “Radical Interactivism”. (Interactivism: A Manifesto, Bickhard, http://www.lehigh.edu/~mhb0/InteractivismManifesto.pdf)

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