Chapter 15

Where Do New Ideas Come From? How Do They Emerge? Epistemology as Computation (Information Processing)

Gordana Dodig-Crnkovic

Mälardalen University, Västerås, Sweden,
`gordana.dodig-crnkovic@mdh.se`

This essay presents arguments for the claim that in *the best of all possible worlds* (Leibniz) there are sources of unpredictability and creativity for us humans, even given a pancomputational stance. A suggested answer to Chaitin's questions: "*Where do new mathematical and biological ideas come from? How do they emerge?*" is that they come from the world and emerge from basic physical (computational) laws. For humans as a tiny subset of the universe, a part of the new ideas comes as the result of the re-configuration and reshaping of already existing elements and another part comes from the outside as a consequence of openness and interactivity of the system. For the universe at large it is randomness that is the source of unpredictability on the fundamental level. In order to be able to completely predict the Universe-computer we would need the Universe-computer itself to compute its next state; as Chaitin already demonstrated there are incompressible truths which means truths that cannot be computed by any other computer but the universe itself.

15.1. Introduction

The previous century had logical positivism and all that emphasis on the philosophy of language, and completely shunned speculative metaphysics, but a number of us think that it is time to start again. There is an emerging digital philosophy and digital physics, a new metaphysics associated with names like Edward Fredkin and Stephen Wolfram and a handful of like-minded individuals, among whom I include myself.

It was in June 2005 I first met Greg Chaitin at the E-CAP 2005 conference in Sweden, where he delivered the Alan Turing Lecture, and presented his book *Meta Math!* It was a remarkable lecture and a remarkable book that has left me wondering, reading and thinking since then.[1]

The overwhelming effect was a feeling of liberation: we were again allowed to think big, think *système du monde,* and the one Chaitin suggested was constructed as digital philosophy – something I as a computer scientist and physicist found extremely appealing. God is a computer programmer, Chaitin claims, and to understand the world amounts to be able to program it!

Under these premises the theory of information, specifically Chaitin's algorithmic theory of information becomes a very elegant and natural way to reconstruct epistemology, as demonstrated in Chaitin (2006). The epistemological model that is according to Chaitin central to algorithmic information theory is that a scientific or mathematical theory is a computer program for calculating the facts, and the smaller the program, the better the theory. In other words, understanding is compression of information![2]

In exploring epistemology as information theory, Chaitin addresses the question of the nature of mathematics as our most reliable knowledge, illustrated by Hilbert's program for its formalization and automatization. Based on algorithmic information theory Chaitin comes to this enlightening conclusion:

> In other words, the normal, Hilbertian view of math is that all of mathematical truth, an infinite number of truths, can be compressed into a finite number of axioms. But there are an infinity of mathematical truths that cannot be compressed at all, not one bit!

This is a very important result, which sheds a new light on epistemology. It sheds a new light on the meaning of Gödel's and Turing's negative responses to Hilbert's program. What is scientific truth today after all,[3] if not even mathematics is able to prove every true statement within its own domain? Chaitin offers a new and encouraging suggestion – mathematics may be not as monolithic and a priori as Hilbert believed.

But we have seen that the world of mathematical ideas has infinite complexity; it cannot be explained with any theory having a finite number of

[1] I had the privilege to discuss the Turing Lecture article with Chaitin, while editing the forthcoming book Dodig-Crnkovic G. and Stuart S., eds. (2007), *Computation, Information, Cognition – The Nexus and The Liminal*, Cambridge Scholars Publishing. The present paper is meant as a continuation of that dialog.

[2] For a detailed implementation of the idea of information compression, see Wolff (2006).

[3] Tasic, in his *Mathematics and the Roots of Postmodern Thought* gives an eloquent answer to this question in the context of human knowledge in general.

bits, which from a sufficiently abstract point of view seems much more like biology, the domain of the complex, than like physics, where simple equations reign supreme.

The consequence is that the ambition of having one grand unified theory of mathematics must be abandoned. The domain of mathematics is more like an archipelago consisting of islands of truths in an ocean of incomprehensible and uncompressible information. Chaitin, in an interview in September 2003 says:

> You see, you have all of mathematical truth, this ocean of mathematical truth. And this ocean has islands. An island here, algebraic truths. An island there, arithmetic truths. An island here, the calculus. And these are different fields of mathematics where all the ideas are interconnected in ways that mathematicians love; they fall into nice, interconnected patterns. But what I've discovered is all this sea around the islands.

So, it seems that apart from Leibniz bewildering question quoted by Chaitin (2006): "Why is there something rather than nothing? For nothing is simpler and easier than something." (Leibniz, Section 7 of *Principles of Nature and Grace*), there is the following, equally puzzling one:

Why is that something which exists made of parts rather than in one single piece?

For there are two significant aspects of the world which we observe: the world exists, and it appears to us as divisible, made of parts. The parts, however, are not totally unrelated universes in a perfectly empty vacuum.[4] On the contrary, physical objects constitute myriads of intricate complex structures on many different scales, and as we view them through various optics we find distinct characteristic complex structures.

Starting from the constatation that our understanding of the world is fragmented, it is easy to adopt a biological paradigm and see human knowledge as an eco-system with many sub-systems with different interacting parts that behave like organisms. Even though an organism is an autonomous individual it is not an isolated system but a part of a whole interconnected living network.

[4] Here the interesting question of the nature of a vacuum is worth mentioning. A vacuum in modern physics is anything but empty – it is simmering with continuous activity, with virtual particles popping up from it and disappearing into it. Chaitin's ocean of the unknown can be imagined as a vacuum full of the activity of virtual particles.

Contrary to the common model of a computing mechanism, in which the computer given a suitable procedure and an input, sequentially processes the data until the procedure ends (i.e. the program halts) or a model of a physical system which is assumed to be hermetically isolated with all possible conservation laws in effect, a model of a biological system must necessarily be *open. A biological system is critically reliant on its environment for survival. Separate parts of an ecological system communicate and are vitally dependent on each other.*

To sum up, extremely briefly, Chaitin's informational take on epistemology, the world is for a human effectively an infinite resource of truths, many of them incompressible and incomprehensible. Mathematics is not a monolithic, perfect, eternal crystal of the definite true essence of the world. It is rather, like other sciences, a fragmented and open structure, living and growing as a complex biological adaptive eco-system.

In the conclusion of *Epistemology as Information Theory: From Leibniz To* Ω, Chaitin leaves us with the following assignment:

> In fact, I believe that this is actually the central question in biology as well as in mathematics; it's the mystery of creation, of creativity: Where do new mathematical and biological ideas come from? How do they emerge?

Normally one equates a new biological idea with a new species, but in fact every time a child is born, that's actually a new idea incarnating; it's reinventing the notion of "human being," which changes constantly.

"I have no idea how to answer this extremely important question; I wish I could. Maybe you will be able to do it. Just try! You might have to keep it cooking on a back burner while concentrating on other things, but don't give up! All it takes is a new idea! Somebody has to come up with it. Why not you?" (Chaitin 2006)

That is where I want to start. After reading *Meta Math*! and a number of Chaitin's philosophical articles,[5] and after having written a thesis based on the philosophy of computationalism/informationalism (Dodig-Crnkovic, 2006) I dare to present my modest attempt to answer the big question above, as a part of a Socratic dialogue. My thinking is deeply rooted in pancomputationalism, characterized by Chaitin in the following way:

[5] A goldmine of articles may be found on Chaitin's web page. See especially `www.cs.auckland.ac.nz/~chaitin/g.pdf`, *Thinking About Gödel & Turing*.

> 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)

If computation is seen as information processing, pancomputationalism turns to paninformationalism. Historically, 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, 2003 and 2004) and computationalism, where the universe is seen as a computer. Chaitin (2006) mentions the cellular automata researchers and computer scientists Fredkin, Wolfram, Toffoli, and Margolus, and the physicists Wheeler, Zeilinger, 't Hooft, Smolin, Lloyd, Zizzi, Mäkelä, and Jacobson, as the most prominent computationalists. In Dodig-Crnkovic (2006) I put forward a dual-aspect info-computationalism, in which the 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 the particle and wave, or matter and energy, capture different facets of the same physical world. Computation may be either discrete or continuous[6] (digital or analogue). The present approach offers a generalization of traditional computationalism in the sense that "computation" is understood as the process governing the dynamics of the physical universe.

Digital philosophy is fundamentally neo-Pythagorean especially in its focusing on software aspects of the physical universe (either code or a process). Starting from the pancomputationalist version of digital philosophy, epistemology can be naturalized so that knowledge generation can be explained in pure computationalist terms (Dodig-Crnkovic, 2006). This will enable us to suggest a mechanism that produces meaningful behavior and knowledge in biological matter and that will also help us understand what we might need in order to be able to construct intelligent artifacts.

---

[6]The universe is a network of computing processes and its phenomena are info-computational. Both continuous as discrete, analogue as digital computing are parts of the computing universe. (Dodig-Crnkovic, 2006). For the discussion about the necessity of both computational modes on the quantum mechanical level see Lloyd (2006).

15.2. Epistemology Naturalized by Info-Computation

Naturalized epistemology is an idea that the subject matter of epistemology is not our concept of knowledge, but knowledge as a natural phenomenon (Feldman, Kornblith, Stich, Dennett). In what follows I will try to present knowledge generation as natural computation, i.e. information processing. One of the reasons to taking this approach 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 a number of others to communicate within a common framework.

In this account naturalized epistemology is based on the computational understanding of cognition and agency. This entails evolutionary understanding of cognition (Lorenz 1977, Popper 1978, Toulmin 1972 and Campbell et al. 1989, Harms 2004, Dawkins 1976, Dennett 1991). Knowledge is a result of the structuring of input data (data → information → knowledge) (Stonier, 1997) by an interactive computational process going on in the nervous system during the adaptive interplay of an agent with the environment, which increases agents' ability to cope with the world and its dynamics. The mind is seen 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 of interactive information processing which can be ascribed even to the simplest living organisms (Maturana and Varela) and likewise to artificial life.

In order to be able to comprehend 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. Among others this article addresses the question of the origin of complexity in biological organisms, including the analysis of the relationship between the parts and the whole.

15.3. Natural Computation beyond the 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 besides classical computation also includes quantum computing and molecular computation, and may be represented by either discrete or continuous models. Examples of computation occurring in nature encompass 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, and so forth. There is a considerable synergy gain in relating human-designed computing with the computing in nature. Here we can illustrate Chaitin's claim 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.

Classical ideal theoretical computers are mathematical objects and are equivalent to algorithms, abstract automata (Turing machines or "logical machines" as Turing called them), effective procedures, recursive functions, or formal languages. Contrary to traditional Turing computation, in which the computer is an isolated box provided with a suitable algorithm and an input, left alone to compute until the algorithm terminated, interactive computation (Wegner 1988, Goldin et al. 2006) presupposes interaction i.e. communication of the computing process with the environment during computation. Interaction consequently provides a new conceptualization of computational phenomena which involves communication and information processing. Compared with new emerging computing paradigms, in particular with interactive computing and natural computing, Turing machines form the proper subset of the set of information processing devices. (Dodig-Crnkovic, 2006, paper B)

The Wegner-Goldin interactive computer is conceived as an open system in communication with the environment, the boundary of which is dynamic, as in living biological systems and thus particularly suitable to model natural computation. In a computationalist view, organisms may be seen as 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) in his book explores computing beyond the Turing limit and 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 a semantic component to the information present on the web (Berners-Lee, Hendler and Lassila, 2001).

For the implementations of computationalism, interactive computing is the most appropriate general model of natural computing, as it 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 a unifying framework for the reconciliation of classical and connectionist views of cognition.

15.4. Cognitive Agents Processing Data → Information → Knowledge

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 Görzel (1994) in the following way:

> 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.

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.

Maturana and Varela (1980) presented a very interesting idea 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 and Varelas' theory as the basis for a computationalist account of evolutionary epistemology.

At the physical level, living beings are open complex computational systems in a regime on the edge of chaos,[7] 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. Living systems are "open, coherent, space-time structures maintained far from thermodynamic equilibrium by a flow of energy". (Chaisson, 2002)

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).

[7] Bertschinger N. and Natschläger T. (2004) claim "Employing a recently developed framework for analyzing real-time computations we show that only near the critical boundary such networks can perform complex computations on time series. Hence, this result strongly supports conjectures that dynamical systems which are capable of doing complex computational tasks should operate near the edge of chaos, i.e. the transition from ordered to chaotic dynamics."

Various animals are equipped with varying physical hardware, sets of sensory apparatuses goals and behaviors. For different animals, the "aboutness" concerning the same physical reality is different in terms of causes and their effects.

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)

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 match the present state with 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). Compare with Dennett's (1991) Multiple Drafts Model. 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)

Very close to the above ideas is the interactivist approach of Bickhard (2004), and Kulakov & Stojanov (2002). 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, closely related to the process metaphysics of Whitehead (1978).

15.5. Evolutionary Development of Cognition

Evolutionary development is the best known explanatory model for life on earth. If we want to understand the functional characteristics of life, it is helpful to reveal its paths of 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 the 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. However, Lloyd 2006 mentions a following, first-rate counter argument, originally due to Chaitin and Bennet. The "typing monkeys" argument does not take into account the physical laws of the universe, which dramatically limit what can be typed. The universe is not a typewriter, but a computer, so a monkey types random input into a computer.

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.

15.6. Informational Complexity of Cognitive Structures

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. (Görtzel 1994)

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

One question which 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 huge 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. 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 exceptionally effective approach to computer vision.

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. sub-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. (Görtzel 1994)

Human intelligence is indivisible from its presence in a body (Dreyfus 1972, Gärdenfors 2000, 2005, Stuart 2003). When we observe, act and reason, we relate different ideas in a way that resembles the relation of our body with various external objects. Cognitive structures of living organisms are complex systems with evolutionary history (Gell-Mann 1995) evolved in the interaction between first proto-organisms with the environment, and evolving towards more and more complex structures which is in a complete agreement with the info-computational view, and the understanding of human cognition as a part of this overall picture.

15.7. Conclusions

This essay attempts to address the question posed by Chaitin (2006) about the origin of creativity and novelty in a computational universe. For that end, an info-computationalist framework was assumed within which information is the stuff of the universe while computation is its dynamics. Based on the understanding of natural phenomena as info-computational, the computer in general is conceived as an open interactive system, and the Classical Turing machine is understood as a subset of a general interactive/adaptive/self-organizing universal natural computer. In a computationalist view, organisms are constituted by computational processes, implementing computation *in vivo*.

All cognizing beings are physical (informational) systems 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. Increasingly complex living organisms arise as a consequence of evolution. 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 an info-computationalist view for naturalizing epistemology is that it presents a unifying framework which enables research fields of philosophy, computer science, neuroscience, cognitive science, biology, artificial intelligence 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, a discussion about two seemingly incompatible views: a symbolic, explicit and static notion of representation versus implicit and dynamic (interactive, neural-network-type) one. Within info-computational framework, those classical (Turing-machine type) and connectionist views are reconciled and used to describe different levels or aspects of cognition.

So where do new mathematical and biological ideas come from? How do they emerge?

It seems to me that as a conclusion we can confidently say that they come from the world. Humans, just as other biological organisms, are just a tiny subset of the universe, and the universe has definitely an impact on us. A part of the new ideas is the consequence of the re-configuration and reshaping of already existing elements in the biosphere, like in component-based engineering. Life learns from both, from already existing elements and from something that comes from the outside of our horizon.
Even if the universe is a huge (quantum mechanical) computer for us it is an infinite reservoir of new discoveries and surprises. For even if the universe as a whole would be a totally deterministic mechanism, for humans to know its functioning and predict its behavior would take infinite time, as Chaitin already demonstrated that there are incompressible truths. In short, in order to be able to predict the Universe-computer we would need the Universe-computer itself to compute its next state.

That was my attempt to argue that in *the best of all possible worlds (*"*le meilleur des mondes possibles*" – Leibniz 1710) there are sources of creativity and unpredictability, for us humans, even given a pancomputational stance. I have done my homework.

15.8. Acknowledgements

I would like to thank Greg Chaitin for his inspiring ideas presented in his Turing Lecture on epistemology as information theory and the subsequent paper, and for his kindness in answering my numerous questions.

References

Arnellos, A., Spyrou, T. and Darzentas, J. "The Emergence of Interactive Meaning Processes in Autonomous Systems", In: Proceedings of FIS 2005: Third International Conference on the Foundations of Information Science. Paris, July 4-7, 2005.

Bates, M. J. "Information and Knowledge: An Evolutionary Framework for Information Science". Information Research 10, no. 4 (2005), `InformationR.net/ir/10-4/paper239.html`.

Bertschinger, N. and Natschläger, T. "Real-Time Computation at the Edge of Chaos in Recurrent Neural Networks", Neural Comp. 16 (2004) 1413–1436.

Berners-Lee, T., Hendler, J. and Lassila, O. "The Semantic Web". Scientific American, 284, 5, (21001), 34–43.

Bickhard, M. H. "The Dynamic Emergence of Representation". In H. Clapin, P. Staines, P. Slezak (Eds.) Representation in Mind: New Approaches to Mental Representation, (2004), 71–90. Amsterdam: Elsevier.

Burgin, M. (2005) *Super-Recursive Algorithms*, Berlin: Springer.

Campbell, D. T. and Paller, B. T. "Extending Evolutionary Epistemology to "Justifying" Scientific Beliefs (A sociological rapprochement with a fallibilist perceptual foundationalism?)." In Issues in evolutionary epistemology, edited by K. Hahlweg and C. A. Hooker, (1989) 231–257. Albany: State University of New York Press.

Chaisson, E.J. (2001) *Cosmic Evolution. The Rise of Complexity in Nature.* Harvard University Press, Cambridge.

Chaitin, G. J. (1987) *Algorithmic Information Theory*, Cambridge University Press.

Chaitin, G "Epistemology as Information Theory", Collapse, (2006) Volume I, 27–51. Alan Turing Lecture given at E-CAP 2005, `www.cs.auckland.ac.nz/~chaitin/ecap.html`.

Chaitin, G. J. (1987) *Information Randomness & Incompleteness: Papers on Algorithmic Information Theory*, World Scientific.

Chaitin, G. J. (2003) Dijon Lecture, `www.cs.auckland.ac.nz/~chaitin/dijon.html`.

Chaitin, G. J. (2005). *Meta Math!: The Quest for Omega.* Pantheon.

Coffman, A. J. "Developmental Ascendency: From Bottom-up to Top-down Control", Biological Theory Spring 1, 2 (2006), 165–178.

Dawkins, R. 1976, 1982. *The Selfish Gene.* Oxford University Press.

Dennett, D. (1995), *Darwin's Dangerous Idea*, Simon & Schuster.

Dennett, D. (1991) *Consciousness Explained.* Penguin Books.

Dodig-Crnkovic, G. (2006) *Investigations into Information Semantics and Ethics of Computing*, Mälardalen University Press.

Dreyfus, H. L. (1972) *What Computers Can't Do: A Critique of Artificial Reason.* Harper & Row.

Flake, G. W. (1998) *The Computational Beauty of Nature: Computer Explorations of Fractals, Chaos, Complex Systems, and Adaptation*, MIT Press.

Floridi, L. (2002) "What is the Philosophy of Information?", Metaphilosophy 33, 1-2, 123–145.

Floridi, L. (2003) *Blackwell Guide to the Philosophy of Computing and Information*, Oxford: Blackwell.

Floridi, L. (2004) "Open Problems in the Philosophy of Information", Metaphilosophy, 35, 4, 554–582.

Fredkin, E. (2003) "An Introduction to Digital Philosophy", International Journal of Theoretical Physics 42, 2, 189–247.

Gärdenfors, P. (2000) *Conceptual Spaces*, Bradford Books, MIT Press.

Gärdenfors, P., Zlatev, J. and Persson, T. "Bodily mimesis as 'the missing link' in human cognitive evolution", Lund University Cognitive Studies 121, Lund. 2005.

Gell-Mann, M. (1995) *The Quark and the Jaguar: Adventures in the Simple and the Complex.* Owl Books.

Görtzel, B. (1993) *The Evolving Mind.* Gordon and Breach.

Görtzel, B. (1994) *Chaotic Logic.* Plenum Press.

Goldin, D., Smolka S. and Wegner P. eds. (2006) *Interactive Computation: The New Paradigm*, to be published by Springer-Verlag

Harms, W. F. "Naturalizing Epistemology: Prospectus 2006", Biological Theory 1(1) (2006), 23–24.

Harms, W. F. *Information and Meaning in Evolutionary Processes.* Cambridge University Press, 2004.

Kornblith, H. (1999) "Knowledge in Humans and Other Animals". Noûs 33 (s13), 327.

Kornblith, H. ed. (1994) *Naturalizing Epistemology*, second edition, Cambridge: The MIT Press.

Kulakov, A. and Stojanov, G. “Structures, Inner Values, Hierarchies And Stages: Essentials For Developmental Robot Architecture”, 2nd International Workshop on Epigenetic Robotics, Edinbourgh, 2002.

Leibniz, G. W. *Philosophical Papers and Letters*, ed. Leroy E. Loemaker (Dodrecht, Reidel, 1969).

Lloyd, S (2006) Programming the Universe: A Quantum Computer Scientist Takes on the Cosmos, Alfred A. Knopf.

Lorenz, K. (1977) *Behind the Mirror.* London: Methuen.

MacLennan, B. “Natural computation and non-Turing models of computation”, Theoretical Computer Science 317 (2004) 115 – 145.

Maturana, H. (1980) Autopoiesis and Cognition: The Realization of the Living. D. Reidel.

Maturana, H. and Varela, F. (1992) *The Tree of Knowledge.* Shambala.

Popper, K. R. (1972) *Objective Knowledge: An Evolutionary Approach.* Oxford: The Clarendon Press.

Stich, S. (1993) “Naturalizing Epistemology: Quine, Simon and the Prospects for Pragmatism” in C. Hookway & D. Peterson, eds., Philosophy and Cognitive Science, Royal Inst. of Philosophy, Supplement no. 34 (Cambridge University Press) p. 1-17.

Stonier, T. (1997) *Information and Meaning. An Evolutionary Perspective*, Berlin: Springer.

Stuart, S. (2003) “The Self as an Embedded Agent”, Minds and Machines, 13 (2): 187.

Tasic, V. (2001) Mathematics and the Roots of Postmodern Thought. Oxford University Press.

Toulmin, S. (1972) *Human Understanding: The Collective Use and Evolution of Concepts.* Princeton University Press.

Wegner, P. “Interactive Foundations of Computing”, Theoretical Computer Science 192 (1998) 315-51.

Whitehead, A. N. (1978) *Process and Reality: An Essay in Cosmology.* New York: The Free Press.

Wolff, J. G. (2006) Unifying Computing and Cognition, `Cognition Research.org.uk`, `www.cognitionresearch.org.uk/books/sp_book/ISBN0955072603_e3.pdf`.

Wolfram, S. (2002) *A New Kind of Science.* Wolfram Science.