CHAPTER x

DOES COMPUTING EMBRACE SELF-ORGANISATION?

Wolfgang Hofkirchner

Unified Theory of Information Research Group
c/o Institute of Design and Technology Assessment, Vienna University of Technology
Favoritenstraße 9, A-1040 Vienna, Austria
E-mail: wolfgang.hofkirchner@tuwien.ac.at

It is a widely held assumption that computers process information. When finding out that natural systems manifest information processes, it is hypothesised that natural systems too are computers. This can be called the quintessence of the "computational turn", however, it is a *non sequitur*. This chapter draws upon the ontological distinction of strict determinism and less-than-strict determinism. It contends that artificial devices like computers work on the basis of strict determinism, while natural systems to the extent as they self-organise work on the basis of less-than-strict determinism. Strict determinism is a derivative of less-than-strict determinism. Thus the chapter concludes that concerning computers and natural, self-organising systems the assumption of the computational turn is wrong. It is the other way round: computers play a restricted, though essential and indispensable, part within self-organising (natural and social) contexts.

1. Introduction

The rise of the computer as man-made machine for processing information, the spread of PCs, the diffusion of ICTs and the penetration of social life including the natural environmment as well as human bodies with "intelligent" devices on our way to pervasive computing all seem to justify a "computational turn" – the assumption that the nature of social and natural information processes is identical to the nature of information processing in artifacts and a research programme that aims at devising smooth tools that connect to persons better because of the convergence of social and natural information processes with artificial information processing. Often, e.g., in fields like "emergent computing" and "organic computing", it is asserted that the new paradigm of the computational turn is different from preceding paradigms like, e.g., cognitivism. This assertion, however, was heard already when connectionism tried to overcome cognitivism. It might be doubted whether connectionism was a replacement of technically oriented, mechanistic thinking (which might become clear in the course of the argumentation below).

In order to be able to contrast the new assumption against those which it is set out to replace it is necessary to enter the field of ontological considerations and deliberations – assumptions on how the world is, how it functions, how things, properties and relations populate it. The most decisive question in that context is how causal relations are viewed. Do causes determine effects and, if so, to which extent?

This question is important to answer because

(1) the understanding of computing and information processing depends on the answer;
(2) it serves as litmus test indicating whether or not this understanding amounts to a really new paradigm.

2. Determinism

Determinism is the view of determinacy and indeterminacy in real-world causal relationships. The mechanistic view is associated with the names of Newton and Laplace. Another view that is emerging goes hand in hand with research in self-organisation.

It is worth noting that the notion of "determinism" used here might differ from the commonly used term. It seems a common habit not to distinguish between "determinism" and the "principle of causality" and thus to conflate both. The principle of causality tells us that there is no event that is not caused, that is, every event is held to be an effect of a cause. Thus it is assumed there exists a closed chain of causes and effects. However, "causality" signifies the direct interaction between events. "Determinism", on the other hand, is about interaction between events, be it a direct one or an "indirect" one. So-called "indirect" interaction refers to laws that regards that part of interaction that is universal and necessary and to chance that regards that part of interaction that is not universal but particular and not necessary but random. If you cut free chance from the principle of causality, then you get indeterminism. Otherwise you can talk about random events that are nevertheless caused (see Hörz 1962, Hörz 1971, 208, Fuchs-Kittowski 1976, 178-187).

Hence determinism is, primarily, about how entities are related to each other in an ontological sense. It's only in a second sense about predictability. Unpredictability might be due to lack of intelligibility (then it is an epistemological issue) or to fortuitous factors (then it is an ontological issue).

2.1. *The Clockwork View*

Newton's mechanical perception of the world was based on three principles (see Gerthsen et al. 1995, 13, Fleissner et al. 1997):

(1) The principle of inertia: a body on which no forces are exerted moves constantly in a straight line.
(2) The principle of action: If a force F is exerted on a body of mass m and velocity v, the impulse of the body, mv, is changed, such that $d/dt\,(mv) = F$.
(3) The principle of reaction: If the force F which is acting on a body has its origin in another body, exactly the opposite force $-F$ is acting on the latter.

Newton's classical mechanics used the concept of causality in an elementary way. If a force is acting on a body, by the principle of action the velocity of the body is changed in a unique way. The body is accelerated proportionately to the force exerted.

These principles imply the unique determination of the effect on the basis of a known cause.

This mechanistic worldview was made explicit by the well-known idea of Laplace that a demon who knew the world formula plus all data describing a certain state of the universe would be capable of predicting and retrodicting any state of the universe, and which in Popper's terms may be called the clockwork view of the universe (Popper 1966).

The thesis of strict determinism, in terms of systems, can be characterised as follows (see Heylighen 1990, Weingartner 1996, 187–189):

(1) Given a system, inputs and outputs are related in such a way that each input is related to one, and only one, output. The system transforms the input into the output by way of a mechanism which can be conceived of as a bijection. If you call the input "cause", and the output "effect", you may state that equal causes have equal effects and distinct causes have distinct effects.
(2) Little changes in the causes lead to little changes in the effects.
(3) There are only repetitions. Each state of a system will return in the future.

In this sense *causa aequat effectum*, or – as Newton's dictum was interpreted elsewhere (Fleissner et al. 1997) – *actio est reactio*. Due to the mathematical function, a tool is provided by which calculable results seem to be guaranteed.

2.2. *Less-Than-Strict Determinism*

Now there is a paradigm shift from classical physics towards self-organisation theories, and from the mechanistic world view which originally laid the foundations for classical physics, towards a view which allows for processes that produce emergent properties, relations and entities (see Kanitscheider 1993, Coveney et al. 1990, Goerner 1994). It is worth recalling the remarkable words of Sir James Lighthill (1986), who regretted that so many scientists had for so many centuries trailed what, in the sixties of the twentieth century, was proven definitely false. He felt obliged to apologise publicly for this.

As science has unravelled the natural world, mechanical relations and strict determinism which are prevalent in the clockwork view of the universe hold for systems at or near at thermodynamic/chemical equilibrium only. But they do not hold for systems exposed to fields in which the uneven distribution of energy density exceeds a critical level. Such field potentials force energy to flow in non-linear and interdependent ways. And here the systems are showing self-organisation, that is the build-up of order out of fluctuations via dissipation of entropy.

In case of less-than-strict determinism and emergentism causality, in terms of system-theoretical considerations, in contradistinction to the description of a mechanical universe, must be described as follows (Hofkirchner 1998):

(1) Inputs and outputs are not related in a way which can be plotted as bijective mapping. There are no transformation mechanisms which unambiguously turn the causes into the effects; causes and effects are coupled in a way that allows different causes to have the same effect and the same cause to have different effects.
(2) Little changes in the causes may lead to big changes in the effects.
(3) The more complex a system, the less probable the return of a certain state in the future.

This is what ensues ontologically from findings in self-organisation research. Thus *causa non aequat effectum*, *actio non est reactio*. Due to mathematical short cuts not being applicable, emergent phenomena cannot be predicted in detail. There is no mechanistic transformation which turns the cause into the effect. There is an activity of the system itself which selects one of the several possible ways of reacting. There remains a gap in quality between cause and effect which cannot be bridged in a mechanical way.

Hence, standing on the base of the concept of emergence, we have on the one hand the opportunity to stick to the principle of causality, which means that there is nothing which was created out of nothing (let's leave the question of the coming into being of the universe out), and on the other hand there remains enough openness to let novelties arise which did not exist before.

Less-than-strict determinism is not to say that there is no determinism at all or that the clockwork view has to be replaced with a clouds view. It does not mean that anything goes. It only admits that nature itself is capable of spontaneously producing events which are not describable in a mechanistic way and that besides and beyond clear-cut one-to-one cause-effect-relations there are more flexible causal connections in the real world, too, which seem to be more important and more in number. These connections are due to the fact that self-organising systems have the freedom to choose between several alternatives which make up a non-devoid space of possibilities, compared with mechanical systems where there is only one possibility. Seen this way, strict determinacy is but a special case of causality. It applies if, and only if, the system is deprived of the freedom to choose between several alternatives and the space of possibilities is narrowed down to one trajectory only.

In that way the thesis of less-than-strict determinism not only opposes the thesis of strict determinism but also leads to a new understanding of determinism which includes strictness as correct under certain conditions only.

The common feature of all non-mechanical causation is that the cause is an event which plays the role of a mere trigger of processes, which themselves depend on the nature of the system, at least inasmuch as they are dependent on the influence from the system's environment, and that the effect is an event in which this very self-organisation process finally ends up.

3. Information processing, computation

Let's apply now the mechanistic worldview and the thesis of less-than-strict determinism to the case of information generation.

A clockwork universe offers no room for information. If we presume that information has something to do with novelty, information is not possible in a mechanistic universe because there is nothing new to this universe. There is also no need for a concept of information. Everything can be explained in terms of matter. Specific conditions of matter instantiate universal laws of matter. The only place where information could enter the stage is the case of human knowledge about these laws. Science would then be the historical process by which absolute truth is revealed – an idea definitely out-of-date.

This is in sharp contrast to what findings in self-organisation research render obvious.

Self-organisation may be looked upon as the way evolutionary systems come into existence or change their structure, state or behaviour and the way they maintain themselves (their structure, state or behaviour). In either case it is a process in which a difference is produced or reproduced, in that a quality, which differs from the qualities that existed before a certain point of time is made to appear or, from that point on, is sustained vís-a-vís and by virtue of co-existing qualities from which it differs. Hence, in either case emergence is the underlying process.

Thus a philosophy of emergence seems the proper background theory of evolutionary systems thinking. Emergentist philosophy, as developed for instance by Lewis Morgan and summed up by David Blitz (1992) in a book on Emergent Evolution, holds that effects which do not "result" from causes, that is, which are not "resultant" but "emergent", cannot be "reduced" to their causes. In this case causation is only a necessary constraint, but not a sufficient one as it is in mechanistic causation.

By that, self-organisation inheres a touch of spontaneity, that is, a touch of indeterminacy, since the order that is built up is not fully determined. Bifurcations mark possibilities for the system to go one way or another in building up its order. But there is no condition outside the system that compels the system to go this way or that way. It is, so to say, up to the system itself. Determined is that the system has to go one way or another, but it is not determined which way to go.

Actually, with the paradigm shift from the mechanistic worldview cognisant of objects only towards a more inclusive view of a less-than-strict, emergent, and even creative universe inhabited by subjects too, we have got everything required to connect the notion of information to the idea of self-organisation; it is the very idea of systems intervening between input/cause and output/effect and thus breaking up the direct cause-effect-relationships of the mechanistic worldview that facilitates, if not demands, the notion of information, for information is bound to the precondition of subjects and their subjective agency. Self-organising systems that transform the input into an output in a non-mechanical way, that is, in the context of an amount of degrees of freedom undeniably greater than that of a one-option only, are subjects. And each activity in such a context, each acting vís-a-vís undeniable degrees of freedom, is nothing less than the generation of information because the act to discriminate, to distinguish, to differentiate, is information.

Self-organisation stands therefore at the beginning of all information, insofar as the system selects one of a number of possible responses to a causal event in its environment, as it shows preference for the particular option it chooses to realise over a number of other options, as it "decides" to discriminate.

Information is involved in self-organisation. Every system acts and reacts in a network of systems, elements and networks, and is exposed to influences mediated by matter and/or energy relations. If the effects on the system are fully derivable from, and fully reducible to, the causes outside the system, no informational aspects can be separated from matter/energy cause-effect relations. However, as soon as the effects become dependent on the system as well (because the system itself contributes to them), as soon as the influences play the role of mere triggers for effects being self-organised by the system, as soon as degrees of freedom intervene and the reaction of the system is unequal to the action it undergoes, the system produces information (see Haken 1988). Information is created, if there is a surplus of effects exceeding causes in a system. Information occurs during the process in which the system exhibits changes in its structure, or in its state, or in its behaviour (Fenzl et al. 1996), i.e., changes which are due to the system. Information is created by a system, if it is organising itself at any level. Information is that part of the process of self-organisation that is responsible for generating new features in the system's structure, state, or behaviour. In a figurative sense, information can be looked upon as the result of this process, as what is new in the structure, state, or behaviour. And insofar as this new feature in system A may serve to stimulate self-organising (and therefore informational) processes to produce new features in system B, we can speak of information in a metaphoric sense as if it were something to be sent from one system to another.

Summing up, we can speak of information in the following situations: where the deterministic connection between cause and effect is broken up; where a system‘s own activity comes into play, and the cause becomes the mere trigger of self-determined processes in the system, which finally lead to the effect; where the system makes a decision and a possibility is realised by an irreducible choice.

Since information generation is a process that allows novelty to emerge, it is worth noting that information generation is not a mechanical process and thus defies being formalised, expressed by a mathematical function, or carried out by a computer. It is only in the case of a mechanical process, that methods of mental transformation apply so as to unequivocally lead from a model of the cause to the model of the effect. These intellectual methods are provided by formal sciences like formal logic, mathematics, or computer science; they involve the deduction of a conclusion from its premises or the calculation of a result or a computer operation (Krämer 1988). Mechanical processes can be mapped onto algorithmic procedures that employ clear-cut and unambiguous instructions capable of carrying out by the help of computers as universal machines. But the generation of information escapes algorithmisation, in principle.

Having said this, it follows that a claim of algorithmic information theory to study information based upon algorithmic and computational approaches is, according to the definition of information given above, to be considered a too ambitious one. For this approach does not cover the whole range of what the phenomenon of information embraces. In particular, it must fail to reflect novelty as essential quality of information. Deductions, by definition, don't yield novelties, algorithms, by definition, can't do it either, nor can computation, by definition, do it.

The distinction between the property "deterministic" and the property "probabilistic" concerning automata is, in this context, misleading. Also probabilistic machines rely completely on strict deterministic mechanisms in the sense defined above and are thus mechanistic despite their inclusion of, e.g., "random numbers" which are, in fact, pseudo-random numbers produced by strict deterministic mechanisms (Fuchs-Kittowski 1976, 193). Machines don't choose. To claim this would blur the distinction between the way mechanical devices work and the way systems endowed with subjectiveness (evolutionary systems, i.e., self-organising systems) act. At best we can say that probabilistic computing is a way to simulate less-than-strict deterministic processes of real-world systems but it is not exactly the way these processes work in real world.

This holds for evolutionary computing too. Apart from using the same computer mechanisms, there seems to be a mechanistic misinterpretation of Darwinian theory (see e.g. Peter Corning 2003 who is one of the critics) underlying the computation of evolutionary processes that makes it, at best, a simulation of real-world evolutionary processes but not identical to them or an evolution itself. As Mario Bunge (2003, 152) puts it, "things are not the same as their artificial simulates. In particular, a computer simulation of a physical, chemical, biological, or social process is not equivalent to the original process: at most, it is similar to some aspects of it." Susan Oyama (2000) collected a many literature dealing with that problem with regard to biology.

The argument here that stresses novelty and thus emergence is an ontological one but not an epistemological one (Hofkirchner 2001). It is worth noting that Heinz von Foerster who is known as the first who at the end of the fifties of the last century introduced the notion of self-organising systems to the scientific community (see v. Foerster 1960 and v. Foerster et al. 1962) and who is known for his distinction between trivial and nontrivial systems himself used an epistemological argument. According to von Foerster, a nontrivial system is nontrivial, finally, because the observer is faced with a nontrivial problem when trying to find out how the system works. A nontrivial system differs from a trivial one in that "a response once observed for a given stimulus may *not* be the same for the same stimulus given later," due to the fact that it has at least one internal state *z* "whose values co-determine its input-output relation (x,y). Moreover, the relationship between the present and subsequent internal states (z, z') is co-determined by the inputs (x)" (v. Foerster 1984, 10). Ontologically, however, there is no difference between trivial and nontrivial systems. Both kinds of systems can behave strictly deterministically. Once the mechanism of the function f_y and f_z of a nontrivial system is fixed, its output *y*, given an input *x*, is unambiguously determined (Hügin 1996, 128). Thus, Foerster's hidden ontology turns out to be mechanistic.

The same holds for the case of deterministic (*sic*!) chaos. You can't predict the next state of a chaotic system since there is no formula that helps you compute whatever step you like, while the next step the real-world system in question will take is strictly determined. This means there are restraints in epistemology, while ontologically there is no difference in determination.

4. Paradigms

There is an intricate relation between the ontic and the epistemic, between reality and method. Furthermore, we have to add a "praxic" dimension, that is, praxis, to this relationship which altogether yield a praxio-onto-epistemological perspective (Hofkirchner et al. 2005).

Thus a paradigm can be looked upon as a body of interrelated praxiological, ontological and epistemological assumptions formed along a particular way of thinking.

The mechanistic paradigm is made up of praxiological, ontological and epistemological assumptions shaped according to the reductionist way of thinking. The new paradigm, if it is to deserve the attribute "new", has to be shaped according to a different way of thinking that is set up to confront complexity.

Let's first deal with the relationship of praxis, reality and method, then explain ways of thinking and, finally, employ these findings to the paradigms in question.

4.1. *Praxis, Reality, Method*

Praxio-onto-epistemology is a stance that builds upon onto-epistemology as coined by Hans Jörg Sandkühler (1990, 1991, 34-37, 353-369) and shaped by Rainer E. Zimmermann (e.g. 2002, 147-167). Onto-epistemology tries to reconcile realism with constructivism. Praxio-onto-epistemology tries to complement the interrelationship of ontology and epistemology by the relation to ethics, aesthetics and axiology all of which we propose to include in so-called praxiology (Hofkirchner et al. 2005).

In terms of subjects and objects, praxis is the totality of the human subject-object-dialectic, reality is what is, so to say, objecting to becoming subject to humans, and method is the subjective way of casting objects and making them subject to humans. It becomes clear from that order of definitions that praxis builds upon reality and that reality builds upon method. Anyway, there is relative autonomy of each of the domains (praxis may shape reality but reality gives the scope of possible practices, while reality may shape method but method gives the scope of possible realities).

The rationale for defining subject matters in such a concatenated way is to give an appropriate sketch of the following: particular interests (that reflect particular practices) define the sphere of intervention (that is made up of objects in which subjects are interested and is characterised by a boundary beyond which there are no real objects since there is no subject interested in them) and particular spheres of intervention (that reflect particular realities) define the scope of instruments (that is made up of means which are useful for intervention and is characterised by a boundary beyond which there are no real means since they do not fit the object); and, in turn, particular instruments (that reflect particular methods) can help construct a particular sphere of intervention that excludes different realities and particular spheres of intervention can meet a particular bunch of interests that exclude different interests.

4.2. *Ways of Thinking*

A way of thinking is the way how identity and difference are thought to relate to each other. Relating identity and difference may be presumed to be the most basic function of thinking. That is, practical problems that come to thought, entities that are investigated, phenomena that have to be cognised, may be identical in certain respects but may differ from each other in other respects..

Regarding identity and difference, given complexity, that is, provided that which differs is more complex than that from which it differs, but, by the same token, instaurates an integrated whole, the question arises as to how the simple does relate to the complex, that is, how less complex problems or objects or phenomena do relate to more complex ones.

The first way of thinking, in terms of ideal types, establishes identity by eliminating the difference for the benefit of the less complex side of the difference and at the cost of the more complex side; it reduces "higher complexity" to "lower complexity"; this is known as reductionism. Reductionism is manifested by the main stream of natural and engineering science.

The counterpart of the reductive way of thinking is what might be called projective. Projective thinking too establishes identity by eliminating the difference, albeit for the benefit of the more complex side of the difference and at the cost of the less complex side; it takes the "higher" level of complexity as its point of departure and extrapolates or projects from there to the "lower" level of complexity. It overestimates the role of the whole and belittles the role of the parts. This is one trait of many humanities.

Both the reductive and the projective way of thinking yield unity without diversity.

To go on, there is a third way opposed to both reductionism and projectivism in that it eliminates identity by establishing the difference for the sake of each manifestation of complexity in its own right; it abandons all relationships between all of them by treating them as disjunctive; it dissociates one from the other, it dichotomises and yields dualism (or pluralism) in the sense of diversity without unity. Let's call it disjunctivism. In fact, this is a description of the state of the scientific adventure as a multiplicity of monodisciplinary approaches that are alien and deaf towards each other.

Eventually, there is a fourth way of thinking that negates all three ways together. This is a way of thinking that establishes identity as well as difference favouring neither of the manifestations of complexity; it establishes identity in line with the difference; it integrates both sides of the difference (yielding unity) and it differentiates identity (yielding diversity); it is a way of thinking that is based upon integration and differentiation; it is opposed to both dissociation and unification and yields unity and diversity in one. It integrates "lower" and "higher complexity" by establishing a dialectical relationship between them.

4.3. ***Mechanicism vs. Emergentism***

Let us distinguish between objects of praxis (the praxic dimesnion), objects of reality (the ontic dimension) and objects of method (the epistemic dimension) (Hofkirchner 2004). Objects of praxis O_p are the ones which are acted upon. Objects of reality O_o are the ones existing as such. And objects of method O_e are the ones in our heads. According to the way we (assume to) act on objects O_p, we assume how they exist independently of our actions as O_o. And according to the way (we assume) the objects O_o exist, we assume methods of investigation and representation by which we manipulate the objects O_e in our heads. And according to the way we (assume to) link objects O_p in praxis, (we assume) they are able to be linked as objects O_o in reality, and it is according to the latter that (we assume) they have to be linked by our method as objects O_e.

Let O_x^{t1} and O_x^{t2} indicate the same object O_x at the point of time t_1 and t_2 respectively whereby $x = \{p, o, e\}$ and let the arrow $\rightarrow$ indicate an unambiguous transformation while the sign $\underline{\uparrow}$ shall signify a transformation that involves ambiguity.

Then we can describe the mechanistic paradigm as follows:

(1) on the praxic level we have $O_p^{t1} \rightarrow O_p^{t2}$; that is, the action applicable is a "brute force" operation which leads unambiguously from the object in an initial state to the object in a well-determined final state;

humans can apply this operation only when functionalising cause-effect-relationships that rest upon the ontic level;

(2) thus on the ontic level we have $O_o^{t1} \rightarrow O_o^{t2}$; that is, the object at t_1 is causally transformable into the object at t_2 by pure necessity; this is the case with strict determinism; objects transform in this manner only when embodying on the ontic level deductive logic or computable functions or algorithmic precriptions that are located on the epistemic level;

(3) thus on the epistemic level we have $O_e^{t1} \rightarrow O_e^{t2}$; that is, the object at time t_2 is derivable from the object at time t_1, given particular conditions; the outcome is necessitated in a compelling way: a conclusion is drawn from premises in an inference and there is no way to evade that, a mathematical solution results from inputs in formulae and there is no way to evade that, and data is processed by algorithmic computer programmes and there is no way to evade that.

That is to say, first, the mechanistic paradigm is reductionistic, since the output, be it praxic, ontic, or epistemic, to which higher complexity is ascribed is leveled down to the respective input to which lower complexity is ascribed, and, second, information processing within the confines of this paradigm cannot generate information, since the transformations under consideration are by definition devoid of self-organisation, emergence and novelty. In deductive transformations the truth value is transferred from the input to the output and cannot give room to leaps in quality, in algebraic transformations the output explicates what is implicit in the input and cannot give room to leaps in quality, in algorithmic transformations each step is determined by the preceding step and cannot give room to leaps in quality.

The mechanistic paradigm must fail, if applied to processes other than mechanistic. The generation of information is not a mechanistic process. It is bound to self-organisation which is open for leaps in quality. Thus another paradigm has to be cast to fit information processes. We have to replace transformations of that rigid, fixed character with another kind of transformations that are open for openness so as to yield:

(1) on the praxic level $O_p^{t1} \underline{\nearrow} O_p^{t2}$; according to evolutionary systems design, human intervention is a mere nudge that when intelligently

deployed may trigger a transformation by which the desired outcome may emerge; evolutionary systems design takes advantage of the self-organisation capacity of the objects of reality in that it aims at facilitating or dampening those processes and not at constructing them *ab novo* nor getting rid of them;

(2) on the ontic level $O_o^{t1} \underline{\uparrow} O_o^{t2}$; according to evolutionary systems modeling, the starting point of the transformation builds the base upon which a contingent reality will emerge; the transformation may inhere bifurcations and thus not "obey natural laws" as viewed in a mechanicist concept but rather adhere to propensities our cosmos is displaying (see late Popper 1977);

(3) on the epistemic level $O_e^{t1} \underline{\uparrow} O_e^{t2}$; according to evolutionary systems methodology, the base from wich the transformation on the ontic level starts has to be codified on the epistemic level as necessary condition only but not as sufficient one (as is the case with the mechanistic paradigm) in order to do justice to the emergent character of the "result" of the transformation which represents a new quality; dialectical logic with its sublation scheme is a good candidate for grasping this relationship.

Having said all this, the question remains whether or not, in the computationalist perspective, computation equals information-processing equals transformations in the mechanistic, reductionistic, deterministic sense. Only if computation is meant as a self-organising process involving emergence in a non-epistemological sense, it can do justice to the generation of information.

Actually, computers compute according to the mechanistic paradigm and thus cannot bring about new information. But this is not to say that they are expandable. Though they are bound to algorithmic procedures they are of advantage to and a needful link in human information generation. Inmidst the overarching cycles of human information processes, including cognition, communication and cooperation, they play their role and carry out the task that is distributed to them and is not *per se* generation of information. The situation can be compared to the field of logic. We certainly make use of deductive logic but are aware of the power of the unformalisable.

5. Conclusion

The computational turn resulting eventually in pan-computationalism equates computation and information-processing. If information-processing as it is done in computers is considered to be the role-model for information processes going on in the universe, then information generation is impossible, since information generation involves the phenomenon of emergence on the ontic level. Hence the need for the paradigm of self-organising real-world systems. Current computations find their *raison d'etre* in assisting, augmenting, supporting human information generation.

References

Blitz, D. (1992). *Emergent evolution: qualitative novelty and the levels of reality* (Kluwer, Dordrecht)

Bunge, M. (2003). *Emergence and Convergence* (University of Toronto Press, Toronto).

Corning, P. (2003). *Nature's Magic* (Cambridge University Press, Cambridge).

Coveney, P., and Highfield, R. (1990). *The Arrow of Time* (Allen, London).

Fenzl, N., and Hofkirchner, W. (1997). Information Processing in Evolutionary Systems. An Outline Conceptual Framework for a Unified Information Theory. In: *Self-Organization of Complex Structures: From Individual to Collective Dynamics*, Schweitzer, F., ed., Foreword by Hermann Haken (Gordon & Breach, London), pp. 59-70.

Fleissner, P., and Hofkirchner, W. (1997). Actio non est reactio. An Extension of the Concept of Causality towards Phenomena of Information. *World Futures*, 3–4(49) & 1–4(50)/1997, pp. 409–427.

Foerster, H. v. (1960). On Self-Organizing Systems and Their Environments. In: *Cybernetics of Cybernetics,* Foerster, H. v., ed. (Future Systems, Minneapolis), pp. 220-230.

Foerster, H. v. (1984). Principles of Self-Organization – In a Socio-Managerial Context. In: *Self-Organization and Management of Social Systems*, Ulrich, H. and Probst, G. J. B., eds. (Springer, Berlin), pp. 2–24.

Foerster, H., and Zopf, G. W., eds. (1962). *Principles of Self-Organization* (Pergamon Press, Oxford).

Fuchs-Kittowski, K. (1976). *Probleme des Determinismus und der Kybernetik in der molekularen Biologie* (Gustav Fischer Verlag, Jena).

Gerthsen, C., Kneser, H. O., and Vogel, H. (1995). *Physik* (Springer, Berlin).

Goerner, S. J. (1994). *Chaos and the Evolving Ecological Universe* (Gordon & Breach, Amsterdam).

Haken, H. (1988). *Information and self-organization*. (Springer, Berlin).

Heylighen, F. (1990). Autonomy and Cognition as the Maintenance and Processing of Distinctions. In *Self-Steering and Cognition in Complex Systems, Toward a New Cybernetics*, Heylighen, F., Rosseel, E., and Demeyere, F., eds. (Gordon & Breach, New York), pp. 89-106.

Hofkirchner, W. (1998). Emergence and the Logic of Explanation – An Argument for the Unity of Science. *Acta Polytechnica Scandinavica, Mathematics, Computing and Management in Engineering Series*, 91, pp. 23–30.

Hofkirchner, W. (2001). The Hidden Ontology: Real World Evolutionary Systems Concept as Key to Information Science. *Emergence* 3/3, pp. 22-41.

Hofkirchner, W. (2004). A New Way of Thinking and a New World View: On the Philosophy of Self-Organisation I. *Cybernetics & Human Knowing*, Vol. 11, No. 1, pp. 63–78

Hofkirchner, W., Fuchs, C., and Klauninger, B. (2005). Informational Universe. A praxeo-onto-epistemological Approach. In *Human Approaches to the Universe, Interdisciplinary Studies,* Martikainen, E., ed. (Academic Bookstore, Helsinki), pp. 75-94.

Hörz, H. (1962). *Der dialektische Determinismus in Natur und Gesellschaft* (Deutscher Verlag der Wissenschaften, Berlin).

Hörz, H. (1971) *Materiestruktur* (Deutscher Verlag der Wissenschaften, Berlin).

Hügin, U. (1996). *Individuum, Gemeinschaft, Umwelt. Konzeption einer Theorie der Dynamik anthropogener Systeme* (Peter Lang, Bern).

Kanitscheider, B. (1993). *Von der mechanistischen Welt zum kreativen Universum. Zu einem neuen philosophischen Verständnis der Natur* (Wissenschaftliche Buchgesellschaft, Darmstadt).

Krämer, S. (1988). *Symbolische Maschinen*. (Wissenschaftliche Buchgesellschaft, Darmstadt).

Lighthill, J. (1986). The Recently Recognized Failure of Predictability in Newtonian Dynamics. *Proc. R. Soc.* A 407, p. 38.

Oyama, S. (2000). *The Ontogeny of Information. Developmental Systems and Evolution* (Duke University Press, Durham NC).

Popper, K. R. (1966). *Of clouds and clocks: An approach to the problem of rationality and the freedom of man. The Arthur Holly Compton memorial lecture* (Washington University, Washington).

Popper, K. R. (1997). *A World of Propensities* (Thoemmes Press, Bristol).

Sandkühler, H. J. (1990). Onto-Epistemologie. *Europäische Enzyklopädie zu Philosophie und Wissenschaften* (Meiner, Hamburg), pp. 608-615.

Sandkühler, H. J. (1991). *Die Wirklichkeit des Wissens, Geschichtliche Einführung in die Epistemologie und Theorie der Erkenntnis* (Suhrkamp, Frankfurt).

Weingartner, P. (1996). Müssen wir unseren Gesetzesbegriff revidieren? In *Gesetz und Vorhersage*, Weingartner, P. , ed. (Alber, Freiburg im Breisgau), pp. 179-222.

Zimmermann, R. (2002), *Kritik der interkulturellen Vernunft* (mentis, Paderborn).