SELF-MODIFYING SYSTEMS IN BIOLOGY AND COGNITIVE SCIENCE: A NEW FRAMEWORK FOR DYNAMICS, INFORMATION, AND COMPLEXITY by George Kampis. Pergamon Press, 1991, xix + 543 pages.[1]

Self-Modifying Systems is not only a radical and (in my opinion) fundamentally correct critique of modern science and systems theory, it is also an illuminating and insightful suggestion for the potential foundations of the future of the sciences of life and mind. The book is an advance in the movement, begun by quantum physics and continued by modern information theory (e.g. chaos and complexity theory), away from the centuries of Western scientific tradition in and prejudice towards deterministic, formal models. The impossibility of computational models to predict evolutionary events is starkly revealed, and the fundamental limits on scientific knowledge reinforced. While Kampis is somewhat less clear about how we can move forward in the face of these limits, after finishing this long book the reader is left with a much enhanced view of the true nature of evolutionary and emergent processes. Kampis' sense of wit and irony helps to clear away the recent plethora of ultimately confusing fashions such as computational emergence, artificial life, and artificial intelligence.

The book provides both an excellent summary and continuation of the previous work of Kampis and his colleague Vilmos Csànyi (Csànyi 1982, Csànyi and Kampis 1985, Kampis and Csànyi 1991). Yet it also continues a thread of cybernetics and systems science which has built a strong theory of modeling and theory formation (Klir 1985; Pattee 1973, 1977; Rosen 1985, 1991; Löfgren 1977, 1990). It not only synthesizes existing ideas, but introduces many novel ideas covering a huge laundry list of contemporary issues: from philosophy of science, mathematics, and language; through systems, information, complexity, automata, and computer theory; and on to cognitive science; theoretical biology and the origins of life; biological and physical semiotics; chaotic dynamics, catastrophe theory and bifurcations; and self-reference, self-reproduction, and autopoiesis.

The material is balanced between philosophical exposition and mathematical treatment and examples. The mathematical level is high conceptually but formally simple. Kampis draws from the latest results from the complete spectrum of the sciences, and is further able to relate and synthesize them together in terms of their implications. The content of the book extends across the whole spectrum of contemporary systems science as well, including extensive references. Therefore it may also be useful as a survey in systems science for advanced graduate students.

There are, unfortunately, some significant problems in the text, which suffers from a lack of professional copy-editing and typesetting, and the primitive mathematical notation available from the camera-ready copy provided by the author. There are some typographical and mathematical errors (e.g. on p. 15, we should have $W(E) = \hat{g}(q)$, not $E = \hat{g}(q)$), and in other places the adopted notation is less the adequate (e.g. the various relative complexity measures in sections 6.4-6.7). A good English editor would help the flow of the reading (but not the ideas), and there are some errors in references. Ultimately these are trivial complaints, properly the responsibility of the publisher, not the author. The development of the ideas and substance of the book is not seriously affected.

THE PRIMARY ARGUMENT

Kampis' philosophical outlook is constructivist without being "radically" constructivist (as is currently fashionable among some cyberneticians). Epistemology is held to be primary to ontology in the sense of Kant, where the "categories of perception" are provided by inherent neural structures,

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and knowledge of the world is a model constructed by the subject in terms of those categories. Thus systems as knowledge-objects are constructed, consciously or unconsciously, as delimiters or boundaries of parts of the universe. Further, all models are *relative*, dependent on an external interpreting system, or "descriptive frame", which is not accessible from within the model itself.

This kind of constructivism cannot regard existence as a *property*, since lacking an entity, there is nothing of which to say it does not exist. Instead, real things are seen as historically bound, only understandable in the context of the complete history of their construction.

Kampis' fundamental purpose is to understand the nature of systems which *evolve*. The hallmark of evolution is *emergence*, or the development of new phenomena. Thus the primary problem is to explain *novelty*, and how (or if) the appearance of *qualitatively* new things can be captured by theory. From this all issues of emergence and evolution flow.

> I shall try to show that it is possible for systems to change their identity in the mathematical sense, to increase their information content and to use it to change their own constitution by introducing new elements in an irreducible and unforeseeable way. This is what in my view constitutes creation (or creativity): a **mode of process** [p. 1].
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> The organization of the world is continually self-creating; this process is at any given stage incomplete. Information about the future is not only inaccessible but does not exist in any form. Creation is a basic and general phenomenon that cannot be explained logically [p. 258].

A primary result is that scientists and natural philosophers tend to commit referential fallacies when they use models. In particular, Kampis attacks the reigning paradigm of dynamical models of mechanistic systems. Although these models have been hugely successful, especially given the recent developments in chaos and self-organization theory, nevertheless the assumptions of these models (state-determinism and fixed state spaces, among others) should never be mistaken for logically or empirically necessary properties of the object systems which they model. Furthermore, it must always be recognized that formal models require an embedding interpretive mechanism in which they are implemented and by which they are made manifest.

Component Systems

This argument begins with a distinction between what Kampis calls "component systems" and general "mechanisms". Mechanisms are at the foundation of classical cybernetics (Ashby 1956), and are endemic in science and systems science. They consist of those deterministic systems which have nominalist, dynamical models with *a priori* fixed universes of discourse, or state spaces. Mechanisms with dynamic models can be seen as performing *computation*. In computation there can be new *appearances* of states, but never any new states *themselves*.

We can attempt to generate *actual* novelty in mechanistic models by modifying the rules to reflexively act on the universe of discourse itself, and thus change it, or add elements. But then the problem is only begged to the meta-level, and meta-states are postulated to serve the same role as the states of the lower level system.

Component systems, on the other hand, are systems in which *construction*, not computation, goes on; where "molecular" components are created from the combinations of "atomic" fundamental units. When components in turn combine to create meta-components, complex hierarchical structures can result. Component systems do not *appear* to be mechanisms, because their state spaces do not appear to be fixed. New components can be created and destroyed, adding or removing properties from the universe, and growing or shrinking the state space. Such changes in the state space are not predictable given any amount of system history.

While in a computational system, the interpreting structure itself is given *a priori*, in a component system it is also a product of and changes with the system. Components only exist relative to their embedding component systems, which have the form of *process networks*.

> Components do not exist absolutely and are only definable relative to the process which creates them. It is no more possible to consider the components as *things*. It is only the *system*, integrating the components, that starts to have 'thing-ness' ... for unlike its parts it is closed for its defining information content [p. 266].

Component systems are typified by the kind of "organized complexity" described by Weaver (1968). Indeed, Kampis claims that all "organized complex" systems in Weaver's sense are component systems.

Component systems encompass a vast variety of all interesting systems, including chemical molecular systems, genetics, and natural languages. While the idea of component systems is implicit in much current work, and specific component systems are extensively studied, the distinction and the resulting *general* theory of component systems is a welcome addition to systems theory.

Meta-State Models

The natural argument against this view is that mechanistic models of component systems are indeed possible. They require only the recoding of the component state space in terms of meta-states similar to those generated from the self-application of dynamical rules mentioned above. After all, new components are created in accordance with some fixed laws which govern the combinations of components and elements.

This approach leads us to "universal libraries" of possible components, and concepts like "the set of all possible genomes" or "the set of all possible sentences". Then of course "in principle" it would be possible to work out "property generators" at the meta-level, so that creation of new phenomena is understood as simply "filling out" a sparsely populated meta-state space through some algorithmic search process. We could then consider theories which would predict the appearance of new properties in the universe, for example life and mind. Indeed, there is a great deal of active research which takes exactly this approach (e.g. various "evolution simulators" (Kauffman 1989)).

Kampis addresses this objection head on, arguing very strongly that such meta-level mechanistic models of component systems are untenable, and fundamentally incorrect. This is because component systems are characterized by a high degree of algorithmic complexity (in the sense of Chaitin (1987)) in that the quantity of information required to describe or compute a component in a model is on the same order as that required to actually produce or construct the component "in reality". Thus without some further simplification methods there is generally no efficiency gained in even modeling such systems: rather they must be "played out" in order to explore their productions and those productions' properties. Further, since this quantity of information increases exponentially with the number and size of components, models of component systems are not only inefficient or ineffective tools for understanding, they are also *very* quickly yielded intractable in a very deep sense, and thus useless to the theoretician.

Even if tractable meta-state models are available at one level, the movement multiple further levels quickly becomes futile. Furthermore, any attempt to actually construct a valid meta-state space, that is to foresee and list *all* the properties that might arise from the combinations of components, is necessarily incomplete:

> Every action, physical or logical, brings forward new potentialities as a side product. When combining building blocks into some component, not only do the foreseen properties emerge but a number of others as well. A realization theory (or a universal library)

> deals with some of these only. What in the combination of two elements happens always involves *emergence* in the arch-naive sense of the word [p. 382].

The unconstrucability and intractability of formal models of component systems thus results in necessary uncertainty as to their behavior. But as turbulence and chaotic systems exemplify, this uncertainty does *not* entail a lack of causality or determinism of the underlying system. A complex system will always do the *same* thing, despite the fact that we cannot predict, before seeing it for the first time, what that thing is. Thus our knowledge of complex systems is embodied in *material* implications — just a recording that e.g. a always results in b, in which b is not used, only mentioned; rather than *formal* implications — a mathematical model e.g. $f\colon A \mapsto B$, with $a \in A$ and $b \in B$, where both A and B must be specified, such that $f(a) = b$.

In my opinion, Kampis' view is correct but his counter-arguments are not as clear as they should be. A stronger approach would be to actually accede "in principle" to the *possibility* of formal models at the meta-level, and then to argue about the nature and value of the principle. A deep consideration of this issue would yield the understanding that large component systems are indeed *effectively* unpredictable and uncomputable, even if such meta-models are *conceivable.*

The key to this understanding lies exactly, as Kampis has described, in the immensity of the required meta-model, and its *absolute* non-realizability as a matter of *fact*, or as a matter of *physical* or *effective* impossibility. We can *imagine* a computer the size of the solar system which takes 10^{1000} years to calculate a function, but can gain no understanding in even attempting to approach such a Laplacian fantasy. Only absolutely fundamental changes to our understanding of the laws of nature and the physical limitations on computation would allow the possibility of even beginning such a thing. Those who prefer facts to principles gleefully watch as artificial life (as did artificial intelligence before it) falters on the actual impossibility of their promises.

Along with the general development of the argument outlined above, *Self-Modifying Systems* puts forth a host of new ideas and concepts related to the major issues of systems science. Only some of the other ideas in the book can be dealt with very briefly in this review.

SYNTHESES

Most impressively Kampis demonstrates how a clear and consistent analysis of scientific theories in the context of their modeling languages (almost always dynamical systems) can clarify seeming contradictions and paradoxes both among the scientific specialties and within the systems sciences.

For example, he is (humbly) able to reconcile neo-Darwinism and coevolution as two different focuses of attention, two different choices of dependent and independent variables, on one formal model. Or the difference between cognitivism and behaviorism is understood simply as a different balance between the complexity of states and transfer functions respectively. And he is able to demystify and put the host of special methods from the so-called "complex systems theory" school (including synergetics, catastrophe theory, connectionism, etc.) in their proper context of seeking scale-dependencies and simplified patterns in the trajectories of dynamical systems.

INFORMATION SETS

Kampis' constructivist modeling theory begins with the concept of the "information set". Formally, an information set is a set of pairs $\{\langle\, name, value \,\rangle\}$, where $name$ is the name of some measured quantity or quantities, and $value$ is the corresponding measured value or values. Typically the set contains some standard "backdrop" variable, for example space or time. Information sets have correlates in other systems theories (e.g. "data system" for Klir (1985)), but again, the introduction of the specific concept and the development of its implications are significant.

Information sets are crucial to a constructive modeling approach to component systems. Unlike simple "data streams", the semantic relation to the measured quantities is captured by the inclusion of their "labels". In dynamical systems the labels form an invariant, static backdrop against which formal predictions can be made: the labels are *calculated* within the formal model. But in component systems the labels come under the action of the *system*, not its model.

> In a computable system the system operates *with* but not *upon* its variable. In a component system, it is the other way around. It is the operation upon variables that opens a door to *operation on existence*, and through that, to a creative Universe [p. 277].

Both the great value and detriment of dynamical models is their simplification of time and history: it is reduced to a formal parameter along which predictions can be made anywhere. Kampis describes this "shuttle principle" as requiring the "anticipation" of the identity of future state spaces. But information sets can only *increase* in size and complexity, reflecting the irreversible historicity of real things and the concreteness of time; time becomes a reflection of *events*.

COMPLEXITY ANALYSIS AND CONSERVATION

Kampis provides an exceptionally complete analysis of the various concepts of "complexity" and "randomness" currently in use. He begins by reiterating that, as with all formal models, measures of complexity must always be understood *relative* to an "interpretational framework". Any discussion of complexity must consider not just the complexity of the object under consideration, but also the complexity of this interpretive "support". In formal complexity theory the latter are aggregated into a constant and ignored in the limit, but in *real* systems we deal with *finite* strings, and therefore this "overhead" cannot be ignored.

What results is a distinction (first offered by Löfgren (1977, 1990)) between "descriptive" complexities (d-complexities) measured on symbolic *objects* (e.g. algorithmic complexities, entropies); and "interpretational" complexities (i-complexities) measured on the *processes* which result from the interpretation of such objects (e.g. computational and proof complexities, logical depth).

The resulting unified view should go a long way to disambiguate the current crowded field of unrelated complexity measures. For example, we understand that chaotic systems and other prizes of so-called "complex systems theory" can never actually *generate* complexity: rather the interpretational complexity of the generated forms is only a conversion of the high descriptive complexity of the information content required by the initial conditions.

Indeed, Kampis asserts that in *all* formal systems complexity can only be *converted* between these forms, and thus is actually *conserved*: the d-complexity represents "potential" i-complexity, and vice versa. Transference is achieved through the complementary encoding and interpretation processes. This heretical conclusion has significant consequences for virtually every currently fashionable method in systems theory, and destroys such concepts as "computational emergence" or "self-" or "re-production" in formal systems. It is only in component systems that complexity can (and must) actually increase.

It is also revealing that while component systems are complex, and do not yield to dynamical models, nevertheless they do not display *random* behavior either. Indeed, Kampis asserts that the Chaitin definition of randomness as complexity is actually quite poor, since complexity is only a necessary, not a sufficient, condition for something having a random origin.

REFERENTIAL INFORMATION

The distinction between object- and process-complexity naturally generates another between object- and process-information. Object-based information is *about* something. Kampis calls it *non-referential*, which characterizes the kind of formal, passive, syntactic information (knowledge) available to observers. It is *structural*, and derived from *measurement.*

Process-based information, on the other hand, is *for* something. Kampis calls it *referential.* It is active, characterized by unobservable actions realizable only in material implications. This is thus the elusive *semantic* information of semiotics and information theory. It is manifested in causal processes, not symbolic representations. It is *functional*, and not derived from measurement, but rather from the self-generated, real complexities of component systems.

Referential information is a kind of "potential information" which is converted into non-referential information through system behavior, in particular the construction of *boundary conditions.* It is this idea of referential information which can (and must) be *created* in truly complex systems, and whose understanding is crucial to any serious study of life and mind.

As the hallmark of evolution is the origins of life and mind, so the fundamental problem of evolution is the origin of semiotic systems, and of semantic relations distinct from the strictly syntactic (or "meta-syntactic", e.g. "denotationally semantic") descriptions available from formal models. Thus meaningfulness is identified with the "creative" capacities of component systems, which in turn make possible the denotations of formalisms (and not vice versa): "Symbols operate at the expense of other non-symbolic systems that integrate them [p. 421]".

OTHER CONCEPTS

I can only mention in passing some final thoughts that Kampis gives us:

Hierarchy: Every hierarchical system produces "forms", which result from the aggregation of unobservable microscopic states into observable macroscopic states. Level independence and irreducibility can be achieved even in dynamical systems determined by high-order derivatives (e.g. non-holonomic constraints operating in activation-inhibition networks).

Recursion: Recursion is the reflexive self-application of laws to the system which implements them. But formal recursion can always be represented by a corresponding iteration, and is merely an efficient programming technique. This is "trivial" recursion, while nontrivial recursion is manifested in the multi-level, mutual change in structure and physical laws resulting from the action of component system.

Von-Neumann Numbering: This idea is similar to Gödel numbering, but instead the enumeration is done on the mathematical support of some automata model, enabling the arbitrary creation of meta-state automata.

WHITHER SYSTEMS SCIENCE?

We leave *Self-Modifying Systems* with an understanding that complex systems (including component systems) may be causal (an ontological category) but not deterministic (an epistemic category). This is true of the now celebrated chaotic systems, since in their behavior we see complex results (in Chaitin's sense, exponentially growing information content). When approaching a chaotic system, we may know that this complexity is just a translation through a dynamical process of the d-complexity of some initial condition, that it *could* yield to a deterministic model *in principle.* Yet we simultaneously treat it as though it acts with random variables. Such a complementary approach is not inconsistent, since the two descriptions are at two distinct levels of analysis. The lower level (dynamics) is abandoned for the upper level (stochastics) out of *necessity.*

Conversely, when approaching a component system, at one level we can postulate an ontological determinism in a fixed meta-state space, while simultaneously entertaining the novelty of the systems' productions at the *lower* level of analysis. We are thus led to understand how the Church-Turing thesis fails: because the state-spaces of complex systems cannot be formally *defined*, only *discovered.* They are indeed *self-modifying*, and our necessary ignorance of the nature of that modification is reflected in the freedom of evolving systems.

Finally we are left wondering what we can do except to yield to the inevitability of a very deep ignorance about the nature and change of the living world. Of course we recognize what Kampis calls "rational irrationality", the fact that we know that there are some things that we cannot know. The history of philosophy of science in this century is partly the story of the discovery of inherent and necessary limits on knowledge, just as simultaneously knowledge vastly increases.

Yet this is not necessarily a cause for dismay: just as knowing that we do not know something does not entail that it is not true, so the knowledge that knowledge is itself limited does not entail that we know what those limits themselves are, or even if they are great or small in any specific domain. No doubt formal theory building will progress, to a certain extent. No one can predict when and where "islands of predictability" will emerge, nor their size, shape, or significance of the understanding they will bring.

REFERENCES

R. Ashby, *Introduction to Cybernetics.* Methuen, London, 1956.

G.J. Chaitin ed., *Information, Randomness, and Incompleteness.* World Scientific, 1987.

V. Csányi, *General Theory of Evolution.* Akademia Kiado, Budapest, 1982.

V. Csányi and G. Kampis, "Autogenesis: The Evolution of Replicative Systems." *J. Theoretical Biology*, **114**, 1985, pp. 303-323.

G. Kampis and V. Csányi, "Life, Self-Reproduction and Information: Beyond the Machine Metaphor." *J. Theoretical Biology*, **148**, 1991, pp. 17-32.

S.A. Kauffman, "Adaptation on Rugged Fitness Landscapes." In: *Lectures in the Science of Complexity*, edited by D.L. Stein, Addison-Wesley, Redwood City, 1989, pp. 527-618.

G. Klir, "Emergence of Two Dimensional Science in the Information Society." *Systems Research*, **2**, No. 1, 1985, pp. 33-41.

L. Löfgren, "Complexity of Descriptions of Systems: A Foundational Study." *Int. J. Gen. Sys.*, **3**, No. 4, 1977, pp. 197-214.

L. Löfgren, "On the Partiality of Self-Reference: Towards a New Cybernetics." In: *Self-Steering and Cognition in Complex Systems*, edited by F. Heylighen *et al.*, Gordon and Breach, New York, 1990, pp. 47-64.

H.H. Pattee, "Physical Problems of the Origin of Natural Control." In: *Biogenesis, Evolution, Homeostasis*, ed. A. Locker, Springer-Verlag, New York, 1973.

H.H. Pattee, "Dynamic and Linguistic Modes of Complex Systems." *Int. J. Gen. Sys.*, **3**, 1977.

R. Rosen, *Anticipatory Systems.* Pergamon Press, Oxford, 1985.

R. Rosen, *Life Itself.* Columbia U. Press, New York, 1991.

W. Weaver, "Science and Complexity". *American Scientist*, **36**, 1968, pp. 536-544.

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