THE EVOLUTION OF ANTICIPATION A SYSTEMIC HOLISTIC VIEW.

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Abstract.

The main challenge of systems science is to elaborate a general transdisciplinary language pertinent not only to describe and interpret systems of different natures, physical, chemical, biological, social, cognitive, but also to understand their dynamics over a wide time scale, from their emergence, to their evolution toward complexity and autonomy. In this paper we present the main features of a metamodel that has been proposed recently in this context. We then use this language to investigate the evolution of the anticipative behavior of natural systems through the different stages of self-organization, self-regulation, autopoiesis, self-reference and autonomy. We show that their anticipative behavior begins with the first modes of circular causality, reaches a sort of apex with the anticipation capability of cognitive systems (like human beings), and then becomes irrelevant and meaningless with strictly autonomous sytems which are identical with both their physical structure and their virtual possibles.

And so I must apologize for conducting the reader on a necessary trip to the basement.

Robert Rosen, in: Life Itself.

1. Introduction

In this contribution we shall present a general language, or metamodel, designed to represent and interpret the dynamics of natural systems, particularily of self-organizing natural systems; it will be seen that the emergence of anticipative behavior happens to be a natural by-product of the trend toward complexification and autonomization.

Let us first recall that anticipation is the capacity of a system to predict its future evolution and that of its environment, therefore to act in the present in function of some future situation. Since the replacement of Aristoteles' four causes, (causae materialis, formalis, efficiens, finalis), by the unique mechanist causality, where an event can be influenced only by past events, the interpretation of anticipative and other apparent teleonomic features has

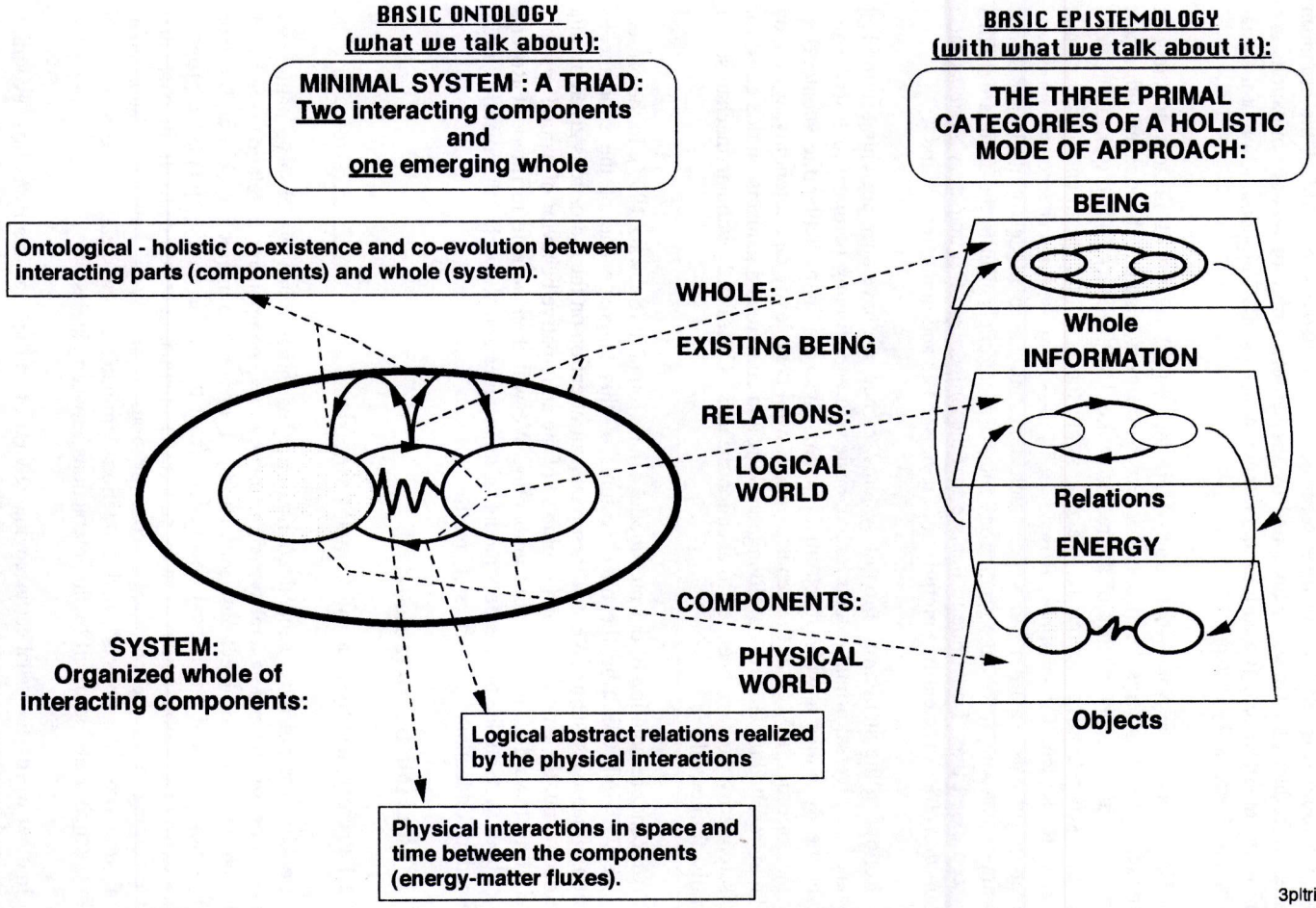


Fig.1. The basic entity at the root of the language presented here is the minimal generic system: a triad as a non-separable whole composed of two interacting elements (ontology). The corresponding epistemology has therefore three primordial categories: the physical world of objects (components), the abstract world of relations (images of interactions) and the existing world of the whole, which is what is (system, being).

become more difficult, if not taboo: "...in the worldview called mechanistic, which was born of classical physics in the nineteenth century, the aimless play of the atoms, governed by the inexorable law of causality, produced all phenomena in the world, inanimate, living and mental. No room was left for any directiveness, order or telos. The world of the organism appeared a product of chance, accumulated by the senseless play of random mutations and selection; the mental world as a curious and rather inconsequential epiphenomenon of material events" (von Bertalanffy, 1968).

The situation has somewhat improved in the last 50 years with the development of cybernetics, general systems theories, non-linear dynamics, autopoietic theories and other new notions. Several concepts, mainly of a circular nature, like feedback, self-organization, self-production, self-reference, autonomy, make possible the scientific treatment of teleonomic processes. R. Rosen, for example (Rosen, 1979), has proposed a cybernetical model of anticipative systems according to which such a system has a model of itself and of its environment enabling it to make predictions and act accordingly. But in the same article this author confessed that "I continue to believe that the properties of anticipatory systems raise new questions for the scientific enterprise of the most basic and fundamental kind."

Following the main motivation of systems science, we have been searching in the last few years for universal primal categories and basic reference frames, pertinent to describe and interpret the dynamics a wide spectrum of natural systems, in particular the spontaneous emergence of order, as well as the general trend toward complexity and autonomy, which, on this planet, resulted to what we call living, thinking and conscious organisms. In this quest for transdisciplinarity we have been led to abandon the usual Cartesian Newtonian mechanist and materialist framework.

A recent presentation of our metamodel can be found in (Schwarz 1997). In the present paper we will only describe the main features of this language and of the spontaneous evolution of natural systems. We will then focus our attention on the indications given by this metamodel about the emergence and evolution of the anticipative behavior of natural systems on their way toward complexity and autonomy. We will then be able to interpret Rosen's remark about systems having inside a model of themselves and show that this feature can be connected to fondamental properties of "reality ".

2. The Holistic Metamodel

2.1 Prototypical System and Primal Categories.

Looking for the most general configuration of things when we observe nature, we propose a most simple and general system made up of two components in relation (see fig.1). It can represent either a subject observing an object, or any two interacting objects. Drawing the epistemological and ontological conclusions from this trivial starting point, we propose that any existing situation, being given by couples of interacting components, is an existential whole emerging from the ontological confrontation, at all levels, between a substantial material structure, "the objects", and a relational immaterial organization, the network of causality, which manifests itself by the interactions between objects.

In other words, the usual cartesian dualist view of an imperial "reality" whose evolution is determined by some abstract and eternal "laws", is replaced by a holistic situation, which emerges from a kind of ontological dialogue between two inseparable and nevertheless

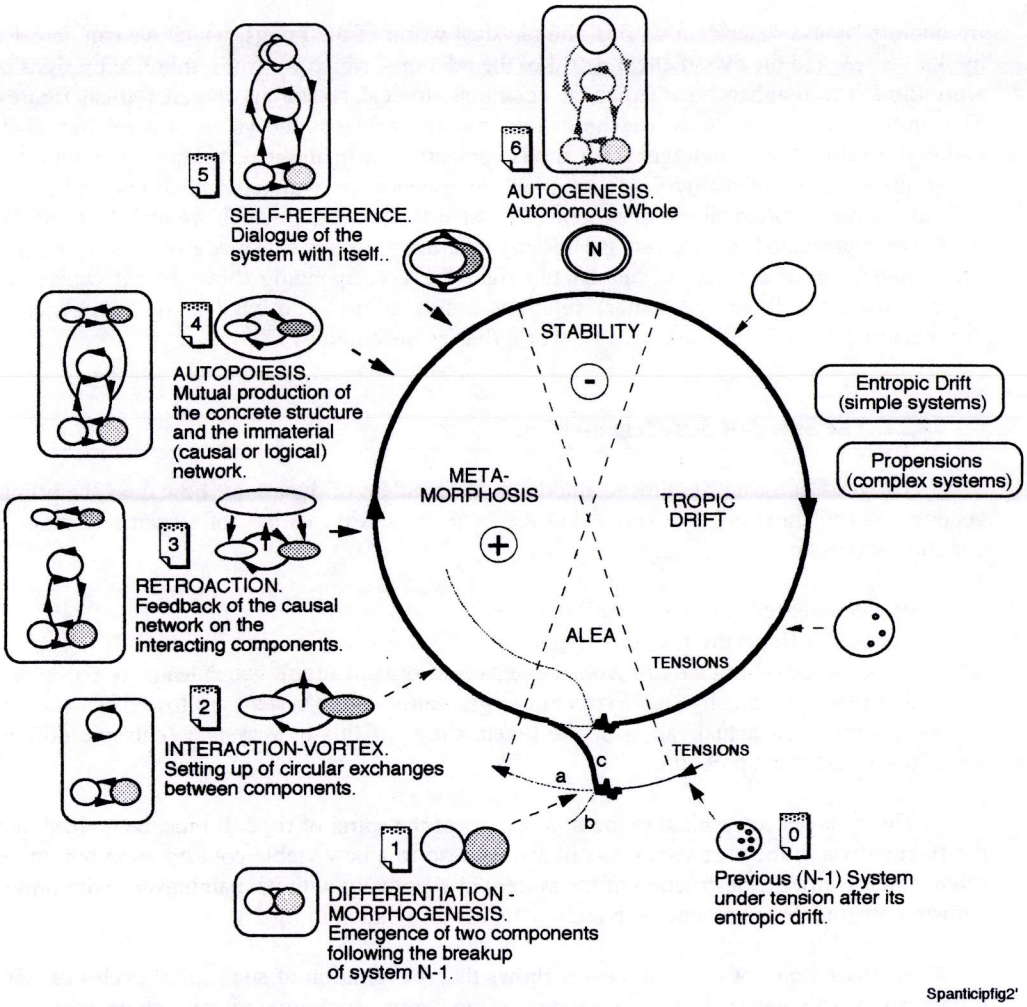


Fig. 2. The seven steps in the self-organization of viable systems.
The main recurrent steps recognized in the emergence and successful self-organization of natural systems far from equilibrium are represented on this spiral pattern. Each of the six step is drawn in two fashions. Firstly in a more or less suggestive way showing the successsive appearance of structural and relational features like components, interactions, relations, and system as a whole. The other series, in the framed figures, is more formal; it shows the successive switching on of the six basic loops which characterize viable systems. Three of these sit within the three physical, relational and existential planes; the other three connect the three planes. The successive steps of the self-organization of viable systems are the following:
0. TROPIC DRIFT. Every self-organization starts in non-linear conditions (due to conditions far from equilibrium), which often follows the entropic drift or the actualization of potentialities of some decaying parent system (N-1).
1. MORPHOGENESIS. In far from equilibrium conditions, fluctuations can be amplified and give rise to a differentiation of the medium (dissipative structures, order through fluctuations) by triggering morphogenetic local positive feedback loops.
2. VORTICES. Fluxes appear between differentiated dynamical structures giving rise to communication.
3. FEEDBACK. These physical interactions set up a network of causal relations, which influences the subsequent development of the processes (appearance of the cybernetical level).
4. AUTOPOIESIS. The dialogue between the causal network and the physical processes becomes self-productive (autopoïesis).
5. SELF-REFERENCE. The autopoïetic cycle becomes more and more self-referential: the machine (the object) and the network (the image) become more similar.
6. AUTOGENESIS. The new system reaches some level of autonomy and then drifts according its own rules (actualization of probabilities or potentialities).
Let us notice that the bifurcation (1) can also lead to the destructuration of the system, or to the recovery of the preceding stable configuration.

irreducible "phase spaces" or worlds, the physical world of the things, which we can perceive by our senses, and the cybernetical world of the relations, which we can symbolize by signs or algorithms like numbers, mathematical equations, logical reasoning or geometrical figures. The physical world of things can be called "reality", whereas the value of a relation is its validity: a valid relation emerges from and is compatible with all the rest. Thus the unique and materialistic notion of reality is replaced here by a couple of symmetric qualities: reality and validity whose ontological interplay generates what is, the whole, which we call the truth. On fig.1. are represented, on the left the prototypical simplest system, made of two interacting components (basic ontology), and on the right the corresponding three primal categories: objects (for example energy-matter), relations (information) , and wholes (systems), used in our metamodel to describe the sensible world (basic epistemology).

2.2. The Spiral of Self-Organization.

The next question in our metamodel is the problem of dynamics: how does the primal generic system emerge ? We show that the birth of a wide variety of systems displays a common succession of four stages:

0) precursor tensions source of instability,
1) noise or fluctuations (alea) triggering
2) a cascade of mutually provoked events (self-organization), which leads to
3) a new dynamically stable structure-organization of the system , followed by
4) a phase of actualization of the potentialities of this new system (entropic drift or trend toward the more probable).

These stages correspond to the four sectors of the spiral of fig.2. It must be noticed that the fluctuations in the alea sector do not always lead to a new viable configuration but, more often, end up with the destruction of the system or eventually with its maintenance with minor adjustments (the three branches a, b and c after the bifurcation in fig.2.).

A closer study of these processes shows that the iteration of such spiral cycles of self-organization and entropic drift generates a long term evolution toward complexity and autonomy, caracterized by the successive appearance of six fundamental loops of increasing abstraction (see Schwarz 1997):

1) self-organizing morphogenesis (positive feedback loops),
2) vortices (recycling of matter),
3) homeostasis (negative feedback loops),
4) autopoiesis (self-production),
5) self-reference (between physical structure and logical organization), and
6) autogenesis (leading to autonomy).

The successive switching on of the six cycles can also be seen in fig.2. in the sector of the metamorphosis, with some more explanations.

2.3. The Seven Steps in the Evolution of Viable Self-Organizing Systems.

To make the situation somewhat more explicit, we have depicted the successive appearance of the six cycles in another way in fig.3. On this picture, time increases from left

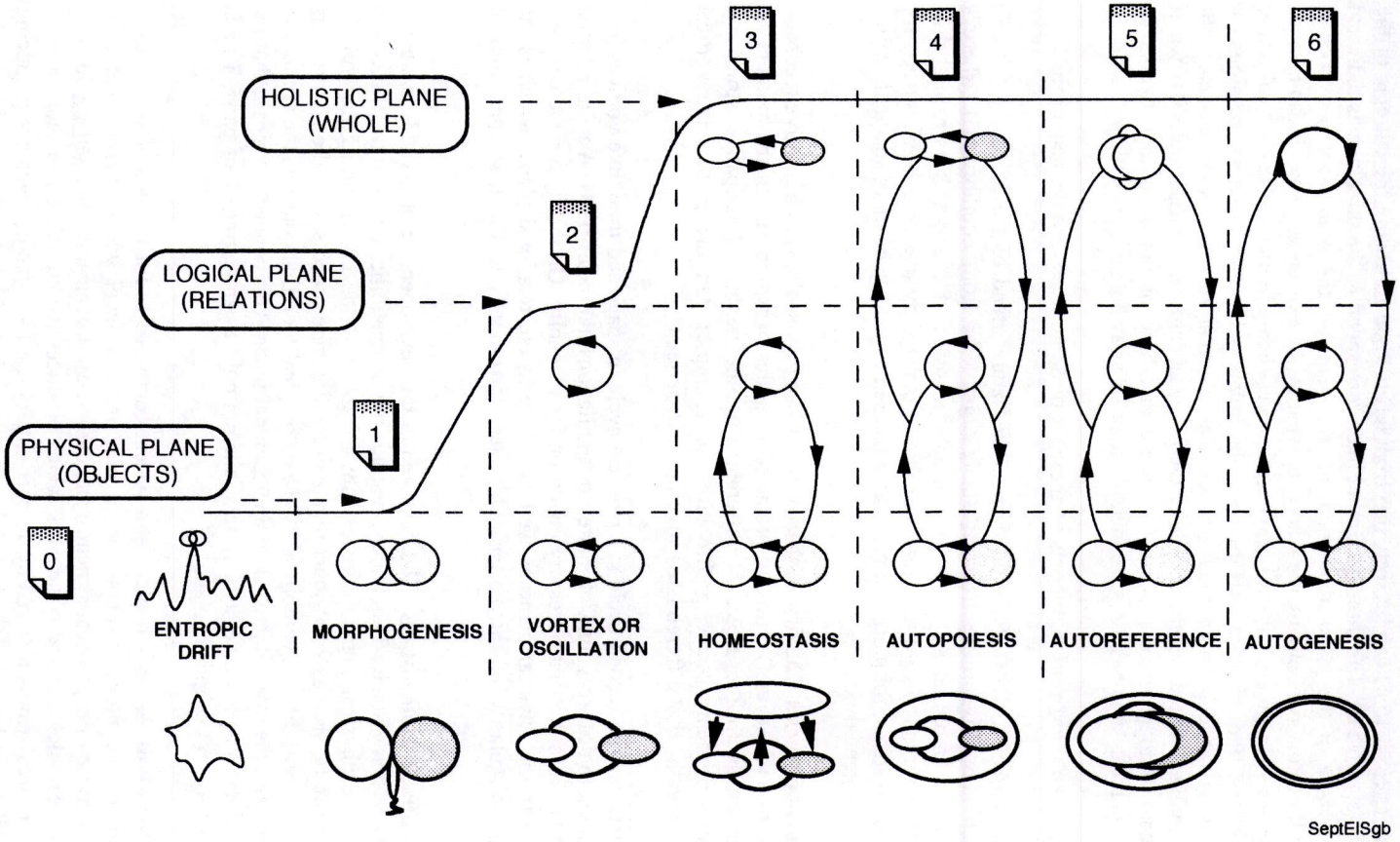


Fig.3. The seven steps of the emergence of the triad that symbolizes the prototypical system. The first step indicated here corresponds to the entropic drift, the general trend toward the more probable (0); it is followed by the successsive appearance of the six basic cycles inside and between the three ontological planes: physical plane of objects, logical plane of relations and existential plane of the whole system (1-6). The seven lower line pictures are supposed to suggest qualitatively the emergence of the triad, whereas the other pictograms are more rigorous symbols of the successive activation of the six fundamental cycles.

to right, and the six cycles of the spontaneous evolution of natural systems toward complexity and autonomy (steps 1 to 6) can be seen also from left to right following the entropic of the parent system (step No 0). The three horizontal lines correspond to the three planes indicated in fig.1.: the plane of the physical phenomena, the plane of the immaterial networks of causality and the plane symbolizing the whole, or what is, the existential plane. It can be seen that morphogenesis is a purely physical or objectal process being limited to the physical plane; with the vortices, the phenomenon reaches the relational plane, because relations or communication is made possible thanks to circular physical fluxes of the vortices; with homeostasis and beyond the system exists as a whole, as an entity with properties if its own; it cannot be reduced to physical processes in space and time or not even to networks of communication; the system has, or is, an identity; it exists as awhole with holistic properties.

Let us make some more comments on these six plus one steps with the help of fig.3.

0) The entropic drift of the medium is the natural trend of the preceding (parent) system, which may drive it far from its stable point ("far from equilibrium"), where a fluctuation can be amplified and start a catastrophic cascade of changes. This natural drift corresponds to the trend toward the more probable formalized by the increase of entropy for the most simple systems; for more complex cases this same drift can be more adequatly called actualization of potentialities.

1) Morphogenesis. The first of the six cycles can be visualized as a positive feedback loop between two (or several) mutually produced variables or parameters of the medium far from equilibrium, with the effect of differentiating the medium (dissipative structures, cancerous cells or demographic proliferation for example). On the picture the vertical feedback loop and the first differentiated structures can be seen.

2) Vortices. The second cycle is a physical cycle in space and time, like vortices in a moving fluid, ecological recycling of matter, or oscillations like heart beats. A valid relation must be circular; it is the first necessary condition for perennity. On the figure, the concrete vortex is seen in the physical plane as well as a loop in the relational plane, which is the symbol of the circularity of the vortex. This step corresponds to the first apparition of relations.

3) Feedback, Homeostasis. The next step in the developement of a viable system is the possibility of being stable. This feature requires the compatibility between the fluxes and exchanges in the physical plane (vortices, physiology) and the correponding network of causality, that can be seen as an abstract image of the concrete processes. In the picture, this inffluence or compatibility is symbolized by the ontological loop that connects the vortices in the lower plane and the logical network in the relational plane. This connection means that the system starts to exist as a whole, as a system, and not only as an aggregate of parts. This is marked by the loop in the holistic plane.

4) Autopoïesis. When a homeostatic system complexifies for billions of years like it was the case for the prebiotic evolution, it may reach a level where there is not only compatibility between the physical structure and the logical organization, but self-production: the organism incarnates a causality network which produces the organism that incarnated it. This new super-circularity is pictured by another ontological loop that connects the producing process (the dialogue between the material organism and the immaterial network) and the entity produced, the undivided individual. This step corresponds to logic of life.

5) Self-reference. Autopoïesis is the beginning of self-reference: the system is its own reference. The system is operationally closed; a completely autopoïetic system does not need any logical connection from the outside. In the picture self-reference is symbolized by the overlapping between the object and the image, the two terms in relation in the holistic plane. The object can be seen as the organism (the brain, for example) and the image as the immaterial network ("the mind" in traditional parlance). In this metamodel, the degree of self-reference of a system is interpreted as its level of self-knowledge that is of consciousness.

6) Autogenesis. The ultimate cycle represents the impact of the system as a whole on its producing dialogue; in other words autogenesis, self-creation, is what makes a system autonomous: an autonomous system is able to create its own laws. The autonomous system is pictured in fig.3. as a whole in creative dialogue with itself.

3. The Evolution of Anticipation

Let us first insist on the schematic aspect of our metamodel, which is a language for idealized situations, which are never met at this level of purity in existing situations. The fractal structure of nested systems, as found in nature, makes it often difficult to disentangle the effects of the several interlaced logics involved in any event. It is nevertheless more helpful to have a metamodel close to the basic rules at play everywhere in nature rather than a precise quantitative formalism valid only in specific conditions like in mechanics.

We will now concentrate our attention on the connection between the successive emergence of the six cycles and the corresponding gradual development of the anticipatory capacity of the evolving system. A summary of the main points of the evolution of anticipative behavior can be found on the next table, in addition to the following comments.

0) Entropic Drift.

At the thermodynamical microscopic level, all possible states are equiprobable, which corresponds to random noise or uniformity (state of maximum entropy, of maximum probability). If the macrolevel is structured, it will drift toward the most probable state (entropic, or more generally, tropicdrift). Such a system has no anticipative behavior.

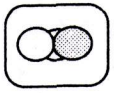
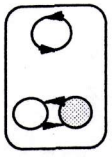
1) Morphogenesis.

The behavior of nonlinear self-organizing systems can be represented by basins of attraction in their phase space. In complex situations the form of these basins is not fixed but can change depending on the evolution of the system. This process can be seen as a primitive mode of anticipative behavior since what happens continuously determines the target state (the attractor).

2) Vortices.

Convections cells, vortices, or more generally dissipative structures also show a kind of primitive anticipative behavior: they do not predict anything but their future existence is possible because of their present existence. In other words, they make themselves, or they perpetuate themselves.

The Seven Steps in the Evolution of the Anticipative Behavior of Systems of Increasing Complexity.

STEPS	PROCESSES	LOGIC	ANTICIPATIVE BEHAVIOR	EXAMPLES
0. ENTROPIC DRIFT 	Micro-level: equiprobability of possible states (0 and 1 in the simplest case), because of absence of relations. Macro-level: Drift toward more probable: space uniformity and/or time invariance.	**No relations** therefore no logic. Only random fluctuations or noise.	No anticipative behavior.	Dissipative processes. (combustion, diffusion, etc)
1. MORPHOGENESIS 	Non-equilibrium conditions can create space and/or time structuration: growth, oscillations, chaos. Leads to complexification.	Random trigger, then **mutual causality** between parameters (positive feedbacks). Described by point attractors, limit cycles or strange (fractal) attractors, if any.	Possible **attraction** toward a self-generated stable behavior. LOGIC: self-attraction	Formation of dissipative structures, for example convection cells (displacement-force feedb. loop)
2. VORTICES 	Material (circular) fluxes.	Vortices are **vehicles of interactions** (relations).	Their present existence determines their future existence: they make themselves. LOGIC: self-execution	Functioning dissipative structures.

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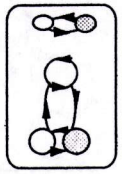
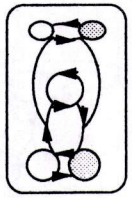
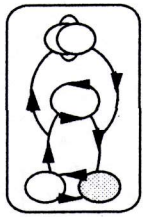
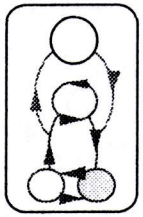
3. SELF-REGULATION 	The vortices create **a causality circuit that maintains them.** This feature is symbolized by the coming into existence of the system as a whole (see icon at left.).	The logical network built by the vortices (given the hydrodynamical constraints) is such that changes in the fluxes generate **compensating effects** (self-regulation).	Self-regulation marks the appearance of **explicit teleonomy. Homeostasis** is "selected" in the course of evolution for its stabilizing property. It functions **in the present** (instantaneous response). It has a normal causal origin but simulates a target in the future. An actual homeostatic system has a virtual end (**illusion of a purpose**). LOGIC: Stability	Natural or artificial cybernetical systems; feedback loops. Self-regulating hypercycles.
4. AUTOPOIESIS 	The (very complex) physical structures and fluxes are such that their (image) causal network produces these very same structures and fluxes.There is **reciprocal production of the immaterial network and of the meterial structures.** This feature is symbolized by the coming into existence of the ontological connection between the system as a whole and its production process (see icon).	Mutual production of the physical structure and the causal network. The system's existential organisation becomes ever more operationally closed, therefore **more autonomous.** "Information processing" or **symbolic activities** gain importance compared to energy-matter handling.	**Deeper teleonomy**: the system not only has homeostatic properties against the changes coming from its environment, but continuously produces itself. **It exists "to" produce itself.** It functions **with the present and the past**: it integrates the experience of its parent systems (wider time thickness than homeostatic system). The system **becomes.** Anticipation is only a **subfunction of becoming.** LOGIC: Life preservation: production of the production process.	Living organisms, populations, species. Terrestrial life. Social systems (?)

5. SELF-REFERENCE 	Self-reference increases within the system as **its structure refers more to its own causal network**, instead of being dependent of outside causes like in heteronomous systems (inorganic pieces of material).	The material structure (organism) and the immaterial network become more and more ontologically similar within the system as a whole. The system has (is) a holistic **identity.** It is not only a body and a "mind" (= immaterial network) it is above all **an undivisible existing entity** with holistic features.	The overlap between the material organism (brain) and the immaterial network (mind) symbolizes the fact that a very self-referential system exists as an identity **conscious** of its being. Consciousness is a manifestation of the holistic existenceof a system. As its existential dimension deepens, a system becomes **less time dependent** (not constant but outside time). **Anticipation** (as modelization of the future) therefore becomes **less relevant.** LOGIC: Self-knowing being	Self-knowing, therefore conscious systems.
6. AUTOGENESIS 	The last cycle, autogenesis or self-creation, corresponds to **self-referential ontogenesis**: the entity creates itself by itself. This is the ultimate stage of **autonomy**. It gives to itself the law which makes it such that it makes itself.	Autogenesis should not be seen so much as a state but but rather as a vector, an arrow pointing into a direction (like nirvana which can only be aimed at); or as a **timeless process**.	A strictly autonomous system is out of time, or rather includes time. It is therefore itself timeless (permanent). **Anticipation has therefore no meaning.** (Anticipation applies only to partially autonomous systems in an environment). LOGIC: Self-creation	The whole: the cosmos and the logos (the things and the laws together). And/or nothingness.

3) Homeostasis.

We see here the explicit appearance of teleonomic properties in the spontaneous evolution of self-organizing systems. Its evolutionary importance is easy to understand, given its useful stabilizing property. Homeostasis has a normal causal origin, but its real time functioning simulates a target in the future; an actual homeostatic system has a virtual end.

4) Autopoiesis.

For much more complex systems, another deeper logical closure can appear: self-production . This new circularity increases the degree of autonomy of the system, therefore its identity; it decreases its dependence from its environment and from its random variations; in other words it increases the "thickness" of its time: the system integrates or digest better the unexpected fluctuations. If a homeostatic system instantaneously compensates for the variations of the external conditions, an autopoietic system also takes advantage of the experiences made previously by its parents systems; its self-productive property is the integrated result of the whole history of all participating generations. Th ability of a system to anticipate (in the usual human cognitive sense) is a natural part of all the acquired capacities that increase its viability.

5) Self-reference.

Self-production means that the physical structures of the organism and the corresponding causal network are mutually produced: the system exists as a unitary whole emerging from the ontological dialogue between its two fundamental aspects: material structures and immaterial organization; in other words, the system is self-referential, its structure refering to its organization and its organization to its structure. It is proposed that, beyond some level, self-reference, manifests itself as consciousness, which is self-knowledge. As consciousness is outside time, when it develops, anticipation become less relevant.

6) Autogenesis.

The last cycle mentioned here is not so much a step or a state but rather a direction, an arrow pointing in a direction. Autogenesis, self-creation, is the process that leads to autonomy, the ultimate circularity of a system that creates itself its own creation laws. A strictly autonomous system is out of time, or rather includes time. At this level anticipation has therefore no meaning.

4. Concluding Remarks.

A general model, theory, language, epistemology or ontology to interpret the world around us must respect the anthropic principle: it should (if not predict), at least allow the emergence of mankind, and of some associated features like consciousness, cognition, life, organization and structures. We have proposed a general language, in the form of a set of coherent graphical patterns to interpret the spontaneous emergence of structures, the existence of stable (homeostatic) systems, of self-producing (autopoietic) living and cognitive systems, and of self-referential, possibly conscious, systems. This proposal is not a theory and even less a "theory of everything". Obviously, much more remains to be done to understand the numerous particular events of the evolution of life and society on this planet !

Our language is rather a reference frame, based on the development of cybernetics and systems science, in which the phenomena of nature, specially the long term processes, can be contextualized and make sense. The heart of our proposal is to replace the usual view of a material reality by an existential "reality", (which we call truth to differentiate it from the

usual material reality), having two non-separable aspects: a material aspect in space and time and an immaterial relational aspect in a conjunct abstract phase space. These two aspects are not only ontologically inseparable but influence each other within the existential context of the whole which they create. The dualist mechanist view of a material reality determined by eternal laws is a degenerate particular case of the general holistic view. As we have seen, this ternary representation gives rise to a very symmetric structure-organization with three cycles producing the system's stability (one cycle in each of the three planes) and three cycles producing flexibility or change (two cycles between the planes and one between the physical plane and the ground noise below).

In this paper we have investigated what this metamodel has to say about the evolution of anticipation and its rôle in the general evolution of life, cognition and consciousness. We have taken the word anticipation in a wider sense than just knowing or predicting the future; we include all processes where what happens in the present influences actively the future.

We have seen that at the thermodynamical level the system's evolution is only determined by its past and, if it is not at equilibrium, drifts in a passive way toward more probable states. Forms of anticipative behavior start in a very embryonic fashion, with steps 1 and 2, emergence and functioning of dissipative structures, which build themselves their own future: attraction toward a given state or self-maintenance. With self-regulation, teleonomy becomes more explicit: the system has a virtual purpose which is to maintain its present functioning even if the environmental conditions change (within some range).

The structure and the organization of autopoietic systems (step 4) is immensly more complex than that of the preceeding cases (steps 1 to 3); they are the result of the whole history of the system and its ascendents; such systems have accumulated and integrated the experiences of the past and have "learned" how to survive. This integration is incarnated in the physical structures of the organism, on one hand, but also and more importantly, in the immaterial causality network implicitly present in that same organism. This network, being the set of rules or laws or potentialities and constraints that connect the present state of the system to the next, can also be seen as the field of possible futures of that system. Our representation of reality with two plus one ontological planes, may help to grasp the double aspect of nature: its actual state here and now (the physical plane) and its potential states (the relational plane). What exists (the holistic existential plane) includes both the actual and the virtual. Anticipation, in the usual sense of the term, is a manifestation, in living and cognitive systems like human beings, of their network of causality or field of possible futures.

An emerging property, which intensifies with autopoiesis, is self-reference. Self-reference refers to the ontological dialogue between the physical structures of the organism (physical plane) and its conjunct organization, the corresponding immaterial network of causality (relational plane). In autopoietic systems, structures and organization are mutually produced: the structures and fluxes produce an organization whose products are these same structures and fluxes. In a system, the degree of adequation between its physical structures and its organisational network is a measure of its degree of self-reference. In a totally self-referential system, structure and organization are identical; such a system is called autonomous: its law (relational plane) originates from within itself. For a partially self-referential system, structure and organization are not identical, they are therefore distinct. Concretely, the anticipations produced by such an imperfectly self-referential system are therefore not identical to what really happens in the future, but they nevertheless contribute to the survival of the system, therefore to its autonomy with respect to the hazards of life.

The last cycle, autogenesis, which connects the self-producing dialogue (autopoiesis) to the product, the system as an existential whole, leads to autonomy. A strictly autonomous system does not need to anticipate because it is identical to what happens.

In conclusion, we have seen that anticipation is a capacity that does not exist in simple physical systems like dissipative systems; it starts and increases in sophistication with complexity and operational closure; it is most relevant in cognitive imperfectly self-referential systems like human beings. As the autonomy increases, by developing both the internal coherence of the system and its integration in its environment, anticipation becomes meaningless because of the identity between the actual and the virtual: the system exists by its structures as well as by the changing proper laws that rule the evolution of these structures. Anticipation has an ambiguous character: it is both a useful capacity for the survival of self-producing living and cognitive organisms, and a measure of its immaturity, its lack of integration within nature.

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