Axiomathes (2006) 16:137–154
DOI 10.1007/s10516-005-6001-0

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THE MEMORY EVOLUTIVE SYSTEMS AS A MODEL OF ROSEN'S ORGANISMS – (METABOLIC, REPLICATION) SYSTEMS★

ABSTRACT. Robert Rosen has proposed several characteristics to distinguish "simple" physical systems (or "mechanisms") from "complex" systems, such as living systems, which he calls "organisms". The Memory Evolutive Systems (MES) introduced by the authors in preceding papers are shown to provide a mathematical model, based on category theory, which satisfies his characteristics of organisms, in particular the merger of the Aristotelian causes. Moreover they identify the condition for the emergence of objects and systems of increasing complexity. As an application, the cognitive system of an animal is modeled by the "MES of cat-neurons" obtained by successive complexifications of his neural system, in which the emergence of higher order cognitive processes gives support to Mario Bunge's "emergentist monism."

KEY WORDS: category, cognition, complexity, emergence, hierarchy, organism

Robert Rosen has stressed the difference between "simple" physical systems (or those controlled through "mechanisms") and the "complex," natural systems, such as living systems, which one calls "organisms." The Newtonian model is well adapted for the simple systems as it represents a system by observables in the phase space satisfying certain (partial) differential equations representing Newton's laws of motion. Organisms are, however, not amenable to this type of model: at best they could be approximated by several incommensurable, partial descriptions through simple systems; each such simple model will be then valid only "locally and temporarily" (Rosen 1985a, 1986). Another difference between these two very distinct types of system is that the mechanisms operating in simple systems and the life processes occurring in organisms have differing causality attributions, with Aristotelian causes

★ Dedicated to the memory of Robert Rosen who kindly accepted to come to Amiens while he was very ill.

being intermingled in the latter case. Last-but-not-least, organisms act as *anticipatory* systems.

The aim of this paper is to show how these characteristics of organisms can be specified precisely in the framework of Memory Evolutive Systems (MES) which we have introduced and developed over the last 20 years in a series of papers (e.g., Ehresmann and Vanbremeersch 1987, 1990, 1996, 2002, 2005 – where an animation representation of MES was also provided). MES represents a model-based on category theory – for evolutionary autonomous systems with a hierarchy of components that have organized exchanges with their sustaining environment, and are therefore able to adapt to changing conditions through learning. This model also brings to light the property which allows for the emergence of increasingly complex objects and systems during the course of evolution.

1. WHY CATEGORY THEORY?

Category theory is a recent domain of mathematics, introduced by Eilenberg and Mac Lane in 1945. It is at the border between mathematics and meta-mathematics as it provides a unified setting for the study of different structures and operations that are being employed in mathematics. Its particular status offers a framework for a "mathematical structuralism," thus capturing the thinking process of the "working mathematician" (in terms of the book of Mac Lane 1971), as for example when the mathematician develops models to fit the reality that one observes and thereby gains predictive power through such models.

Categories have been used in various scientific domains and, in particular, in computer science (Barr and Wells 1984; Gray 1989), in physics (Lawvere and Schanuel 1980), and also more recently to give a new interpretation of quantum physics (Abramsky and Coecke 2005). Robert Rosen was the first to propose – as early as 1958 – to employ categories in biology, in the frame of a "relational biology" as supported by Rashevsky (1967), in particular with his notion of (**M,R**)-systems. Subsequently, Baianu (1971), Baianu and Marinescu (1968, 1974), and Kainen (1990) have used limits and colimits to represent organisms and (**M,R**)-systems. Let us recall here that a category can be defined by data determined by objects and arrows between them (the morphisms), thus forming a graph on which there is given an internal law associating to two successive arrows – let us say from A to B and from B to C – a composite from A to C; this composition law is *associative* and has an *identity* defined for each object. Our contention is that categories are an adequate tool to study complex systems, and in particular *cognitive systems*, because they mirror the main brain capacities which evolution has so far endowed man with (or possibly later an even higher developed animal). Such capacities allow man to recognize certain regularities in the environment and develop adapted behaviors, namely:

= to distinguish different objects A, B,... (considered as objects of a category) and how they interact; this may be alternatively in the form of an action of A on B, or an information received by B from A (represented by the arrows from A to B which are the morphisms of this category);
= to compose such interactions and differentiate sequences of interactions that are functionally equivalent (composition law and its associativity);
= to take account of changes by comparing an earlier with a later state (functor);
= to identify patterns of interacting objects and their collective actions and extract some invariant in their action (defined here as a *colimit operation*), or conversely, to decompose a complex object in more elementary components in order to improve its analysis;
= to bind together objects already recognized or learned processes to form more complex ones than the initial ones (*a complexification process*), and then to search for optimal solutions (to *universal problems*).

2. THE BINDING PROBLEM HIERARCHICAL EVOLUTIVE SYSTEMS

A natural complex system, such as a biological or social system, has interacting components which may vary over time. To account for such change with time these systems will not be modeled by a unique category but by a family of categories.

2.1. *Evolutive systems (ES)*

An evolutive system (ES) is a family *of categories indexed by time*, with *partial functors*, called *transitions* between them. The category

Kt at the time t models the state of the system at t; its objects and morphisms (which we call *links*) model, respectively all the (states at t of the) components of the system and their interactions existing around this time. The transition from Kt to Kt' models the change from t to t'; it is only a partial functor in order to account for the possible loss of components. Furthermore, there is a transitivity property for such transitions. A *component* A of the system is modeled by the family of its successive states At from its 'birth' to its 'death.' Formally, this is defined by a maximal family of objects in successive state categories having a first state (corresponding to its birth) and later, derived states from the preceding ones through transitions. The state At of A will often be simply denoted by A and will be called a component at t.

2.2. *The binding problem*

A complex system has components of various complexity levels (e.g., for a cell these are: its atoms, molecules, macromolecules, organelles, etc.). A component at a given level has its own internal organization in the form of '*more elementary*' components which it binds. How can one determine this situation internally in an ES by using only the properties of the links between its components? Our idea is to model the internal organization of a complex component A as a pattern of linked objects such that the actions of A on any other component are entirely determined by the collective actions of this pattern. This 'universal' property characterizes A as the *colimit* (or *inductive limit*, Kan 1958) of the pattern in the category.

In a category, a *pattern of linked objects* P is a family of objects P_i with some distinguished links between them. A collective link from P to an object B is a family of links f_i from the various P_i to B which are compatible with the distinguished links (thus forming a cone with basis P and vertex B). The pattern admits a *colimit* A if there is a collective link from P to A such that any other collective link from P to any object B has a unique factorization through A (universal property). In the state category at t of an ES, we can think of the colimit A of a pattern P as a more complex object integrating the pattern by binding the different P_i along their distinguished links. Conversely, moving from the top to the bottom, P can be thought of as a *decomposition* of A into '*more elementary*' components. Note that the colimit entails both local and global properties. Locally, if it exists, the colimit is well determined by the data of the pattern which it binds; globally, it is 'functionally' determined by all the possible collective links of the pattern (*a universal property*). Moreover, collective links model the operations which can be performed by the components of the pattern acting collectively through their distinguished links, whereas the colimit models a more complex component performing by itself these same operations; thus, the latter represents an invariant for the class of patterns which perform the same actions. While the colimit of a pattern is unique (up to an isomorphism), two different patterns may have the same colimit. This is an important property which, refined in the frame of hierarchical systems, will be the key to the emergence problem.

2.3. *Hierarchical evolutive systems*

A category is *hierarchical* if its objects are partitioned into different levels 'of complexity,' with an object A of level $n+1$ being the colimit of at least one pattern of linked objects of strictly lower levels. A *hierarchical ES* (HES) is an ES in which the state category at each t is hierarchical and the transitions preserve the levels. In an HES the internal organization of a component has some plasticity and may gradually change without affecting the identity of the component itself. For example, the different molecules of a cell vary while maintaining the integrity of the cell. Indeed, if the state At of a component A is the colimit of a pattern of lower level objects, then a successive state At' of A is not necessarily the colimit of the image of the pattern formed by the transition from t to t'. On the other hand, we suppose that there is a largest interval, dt, called the *stability span* of A at t, during which there exists a decomposition of At whose successive states remain the colimit of the successive states of A. Roughly, the internal organization of A varies, but sufficiently slowly to preserve the identity of A at its own level.

3. CHARACTERISTICS OF COMPLEXITY: THE MULTIPLICITY PRINCIPLE

In an HES a component at a higher level has a decomposition into 'more elementary' components. Does this mean that all the information is contained in the lowest level, so that higher levels can be directly 'reduced' to this level? (The *reductionist hypothesis*, or *reductionism* answers this question in the affirmative.) Alternatively, is there some new information emerging at each level? Then, how would that emergence come about ? (If answered positively, the latter lead to the *non-reductionist* view supported by Robert Rosen). In natural, complex systems there is the emergence of increasingly complex objects and processes that are not 'locally' deducible from lower ones, but that are 'globally' relying on their whole structure. We are going to state next the characteristics lying at the root of such an emergence.

3.1. *Simple and complex links*

In an HES we distinguish two kinds of links between level $n+1$ components: the *n-simple links*, are directly deducible from lower level decompositions of these components; the *n-complex links* are not, though they reflect global properties of the lower levels. If A and B are 2 objects of level $n+1$ in a hierarchical category K, the n-simple links from A to B just sum up information contained in lower level decompositions P of A and Q of B. To define them, we first define the 'good' links between patterns: a *cluster* G from the pattern P to Q is a maximal set of links which, for each i contains at least one link from P_i to a Q_j and if it contains 2 such links they are connected by a zig-zag of distinguished links of Q; moreover the cluster is closed by composition on the left by a distinguished link of P, and on the right by a distinguished link of Q. Note that if Q is reduced to an object, a cluster reduces to a collective link. The patterns are the objects of the category IndK (generalizing Duskin 1966) having the clusters for morphisms. If P has a colimit A and Q a colimit B, a cluster G binds into a unique link g from A to B, called a (P,Q)-*simple link*. A link from A to B is *n-simple* if there exist decompositions P of A and Q of B such that g is (P,Q)-simple.

The composite of a (P,Q)-simple link with a (Q,Q′)-simple link is (P,Q′)-simple. However, there may exist composites of n-simple links binding non-adjacent clusters which are not simple, they are called *n-complex links*. The existence of such 'emerging' links depends on a characteristic of complex systems we have identified in Ehresmann and Vanbremeersch (1996), namely the existence of components C which have two different decompositions with no observable links between their own components at their level. Such a C is simultaneously the colimit of 2 lower level patterns, say R and R′, between which there is no cluster so that the identity of C is not *n*-simple; in this case, C is called a *multifold object* and the passage from R to R′ a complex switch. Note that this property cannot be locally verified through the components of R and R′, but appears at the level of C as a global property of the lower levels. For such a C, the composite of a (P,R)-simple link from A to C with a (R′,Q)-simple link from C to B is a link from A to B which may not be *n*-simple.

3.2. *The multiplicity principle emergentist reductionism*

We say that a HES satisfies the *multiplicity principle* (MP) if some of its components are multifold. This principle is a kind of degeneracy (generalizing the degeneracy condition emphasized for neural systems by Edelman in 1989, and which he has later generalized to biological systems with Gally (Edelman and Gally 2001)). The MP is a characteristics of complex systems that implies the existence of both simple and complex links between its components. While the *n*-simple links from A to B model properties that just reflect local properties of their lower level organizations, the *n*-complex links represent information or properties not locally deducible from lower level decompositions, which emerge at the level $n+1$ as a trace of the global structure of the lower levels.

3.3. *The problem of reductionism*

If an HES satisfies the MP, it will not be possible to reduce a component of level $n+1$ to a level strictly lower than n in 1 step (as a "pure reductionism" would require); however, the reduction is possible in several steps, and the number of steps will measure the order of complexity of A.

Indeed, let us say that a component A of level $n+1$ is *reducible* to the level k if A is the colimit of at least one pattern of levels lower than or equal to k. We define the *order of complexity* of A as the lowest level to which A is reducible. As a component of the HES, A is the colimit of at least one pattern P of lower levels, hence is reducible to the level n. Now each component P_i of P is itself the colimit of at least one pattern P^i of linked objects of levels lower than n, so that A admits the *ramification* $(P,(P^i))$ down to levels lower than $n-1$, from which it can be re-constructed in

2 steps by unfolding the ramification; and so on down to still lower levels. But is it possible to construct a 'large' pattern connecting the different P^i's of which A is directly the colimit? We have proved (Ehresmann and Vanbremeersch 1996) that it is possible if all the distinguished links of P are simple, but it is generally not possible if some of the links of P are complex. Hence the result

THEOREM 3.1. *If an HES satisfies the MP, it has components of increasing complexity orders, meaning that they can be re-constructed from lower levels only by the unfolding of a ramification requiring several steps with emerging properties at each step.*

This situation gives a mathematical model of the "emergentist reductionism" advocated by Mario Bunge (1967). How can it be realized in the course of evolution?

4. EMERGENCE VIA COMPLEXIFICATION

In an ES, we have spoken of change, but not elaborated on its form and advent. For natural complex systems, change is the result of the 4 processes singled out by Thom (1974): "birth, death, scission, collusion".

4.1. *The complexification process*

In a category K, these processes correspond to the addition or suppression of some objects (modeling exchanges with the environment), decomposition of some higher order components while others remain bound, binding together of patterns of interacting components to form new complex components. Their realization leads to a new category K′, the *complexification* of K *with respect to the strategy* having these objectives. In a *mixed* complexification, the strategy has also for objective to add to some patterns a (projective) limit (the 'dual' of colimits, obtained by inversing the arrows).

We refer to our former papers (e.g., Ehresmann and Vanbremeersch 1987) for the explicit description of the complexification K′ of category K with respect to a strategy; let us just say that its objects are: the objects to be added, those of K except those to be suppressed, and, for each pattern P to bind, an object cP which becomes its colimit. Among the links from a cP to a cQ, there are (P,Q)-simple links but, if the category satisfies the MP, there are also complex links obtained as composites of simple links binding non-adjacent clusters. The complexification process can be iterated, and it leads to a hierarchical category, if the new objects cP added at each step to bind a pattern P are taken as being of a higher level than its P_i's. Then a main theorem is the following one (Ehresmann and Vanbremeersch 1996):

THEOREM 4.1. *If a category K satisfies the MP, successive complexifications of it also satisfy the MP, and they lead to the emergence of objects of strictly increasing complexity orders, so that a sequence of complexifications is not always reducible to a unique complexification of K with respect to a strategy subsuming the successive strategies.*

4.2. *Emergence of higher order objects*

In an HES, we assume that an elementary transition, say from t to a near-by time t', corresponds to the passage from the category Kt to a complexification Kt' of Kt with respect to a strategy on Kt, and that any transition is a sequence of such elementary transitions. If the HES satisfies the MP, the successive complexifications lead to the emergence of components of *strictly increasing* complexity orders which have both: robustness, since they remain invariant while their lower level components vary; and plasticity, due to the fact that a multifold component can be unfolded through different ramifications, with complex switches at each step. This can explain the emergence of more and more complex objects and systems through evolution, from the particles to atoms, molecules, and so on up to more and more complex systems, up to cognitive systems and to societies. These systems have evolved through iterated complexification processes from the category Atm of particles, ions and atoms with their interactions as defined in quantum physics. The quantum laws imply that an atom is a multifold object admitting non-connected decompositions in its various electronic configurations; thus Atm satisfies the MP. From the above theorem, it follows that successive complexifications of Atm or of its sub-categories lead to the emergence of multifold objects of increasing complexity orders, able to switch between various internal ramifications down to the lower levels, and connected by complex links which correspond to emerging higher processes.

4.3. *Application to cognitive systems*

We can apply this to the evolution of higher cognitive processes. The brain of an animal can be modeled by the ES of its neurons Neur, which has for components at t the neurons existing at t and for links classes of synaptic paths functionally equivalent (i.e., which transmit in the same way the neural activity of the first neuron to the last one). As proposed by Hebb (1949), neuroscientists have shown that mental operations are carried out by the activity of synchronous assemblies of neurons. Such an assembly is modeled by a pattern in Neur. The formation of a corresponding mental object (in the sense of Changeux 1983) will be represented by the binding of this pattern in a complexification of Neur, in which the colimit so added takes its own identity as a higher order component, called a *cat-neuron* which models a class of synchronous assemblies of neurons; the construction of the complexification determines what are the 'good' links between cat-neurons, thus clarifying the binding problem evoked in neuroscience (von der Malsburg and Bienenstock 1986; von der Malsburg 1995). The cognitive system of the animal will be modeled by the *MES of cat-neurons* obtained by successive complexifications of Neur. Its components are more and more complex cat-neurons, which are conceptual but functional units modeling mental objects, concepts or cognitive processes of increasing complexity. A higher order cat-neuron has several ramifications down to the level of neurons with possible complex switches between them (to be thought of as the choice of various parameters depending on the context); its later recall requires the activation of one of these ramifications through the step by step unfolding of *a synchronous assembly of synchronous assemblies of ... synchronous assemblies of neurons*.

This model shows how higher cognitive processes (up to consciousness, cf. Ehresmann and Vanbremeersch 2002) can emerge from the neuronal level as a consequence of the quantum laws (which ensure that the MP is satisfied, cf. the above), but their unfolding requires several steps, each taking into account the whole structure of the lower levels. This may relate somehow to the quantum-based and holographic theories of Pribram (1971, 2000); it also proposes a solution to the brain-mind problem in agreement with the emergentist monism defended by Mario Bunge (1967).

5. MEMORY EVOLUTIVE SYSTEMS

To model an autonomous system such as a biological, cognitive or social system, we have yet to introduce its *anticipatory* properties and its *mode of internal regulation*.

5.1. *Memory allows for later anticipation*

In an organism modeled by an ES, one of the objectives of its successive (mixed) complexification processes is the long-term storage of information, procedures and their result. We assume that they form a hierarchical sub-system of the ES, called its *Memory*, from which they can be later recalled. A component of this memory, called a *record*, can be thought of as an internal representation of an object or a situation formerly encountered by the system, or of a procedure formerly performed. The links in the memory model interactions between them, such as *activator* links from a situation to an appropriate procedure to respond to it. It is easily accessed through its links to other parts of the system (cf. below). Let us emphasize here that despite its name a record is *not* a rigid unit, as any component of an ES its internal organization can be gradually modified to adapt to the environment constraints. Thus the memory has some *plasticity*. Moreover, a record can be a *multifold object*, thus having different ramifications down to lower levels, and can be recalled through anyone of them, hence with the parameters most adapted to the present context.

We distinguish a *sub-ES* of the memory, called the *procedural memory*; its components Pr are called *procedures* and are equipped with a *pattern of commands* OPr indexed by links from Pr to effectors (its 'commands'). The procedural memory develops from an innate part through the formation of limits of already stored procedures, through a sequence of mixed complexification processes.

An ES with such a memory can be qualified as an *anticipatory system* in the sense of Rosen (1985b). Indeed, the memory, with its innate – or formerly learnt records – constitutes an internal representation of the system in its environment. The recall of a record, e.g., a procedure, in a given situation should have the result anticipated by former similar experiences, the anticipation relying on past performance.

5.2. *The coregulators*

An autonomous system must have a kind of internal regulation which cannot consist in a central executive organ, because of the various temporalities at different levels. We assume it has a modular organization in a web of coordinated and possibly conflicting local regulation organs, which gives rise to a coherent global dynamics through an equilibration process. In an ES these local regulation organs are modeled by sub-ES called *coregulators* (CR) which collectively participate to the selection of the successive strategies at the base of the transitions. Thus, we define a *Memory Evolutive System* (MES) as an ES, with a hierarchical sub-ES called the *memory* satisfying the MP, and a net of sub-ES called *coregulators* (CR). Each CR has its own discrete time-scale; it consists of a small number of components of the system, its *actors*, which belong to a particular complexity level and act cooperatively through their distinguished links; its function is defined by the data of a set of '*admissible procedures*' Pr (in the procedural memory) that have links to its actors, and whose commands it can (either directly or not) trigger. Lower CRs may have only one admissible procedure developing a cyclic process, for higher CRs, there may exist a large number of admissible procedures allowing for more flexibility, and possibly new ones can be formed over time. The CRs contribute to the development of the memory at their own level by storing the new information received, and the result of their procedures. To account for the duration of material operations, we associate to each link of the system a *propagation delay* depending on its level of complexity, such that the propagation delay of a composite is the sum of the propagation delays of the factors.

6. MES DYNAMICS

We successively analyze in this section the operation of a particular CR and the global dynamics of the system.

6.1. *One step of a CR*

A CR operates as a stepwise process; at each step of its time-scale, it first gathers the partial information it can receive from the system and the environment, it selects an admissible procedure to respond, sends its commands to effectors, and finally evaluates its results. The information received by the CR around a time t is modeled by a category Lt, its *landscape at t*: the objects, called *perspectives*, are clusters G from a component B of the system in a near level to the CR taken as a pattern, the links are such that there is a *difference* functor from Lt to the state category Kt associating B to G; this functor measures the difference between the internal representation the CR may have of the system and the system itself; in particular Lt contains perspectives of the admissible procedures of the CR. So it is in this landscape that the CR selects such a procedure Pr depending on the information received and on the anticipated memorized result of the procedure. The commands of Pr are translated into the objectives of a strategy on the landscape, and the next landscape should be the complexification L′t of Lt with respect to this strategy. The evaluation consists in comparing L′t to the next landscape. If they differ, we speak of a *fracture* for the CR.

6.2. *Global dynamics*

The procedure selected by a CR may not have the expected result because the CR has only partial information which it proceeds at its own timescale, and it competes with the other CRs, since all depend on the same resources. At each time, all the commands of the procedures selected by the various CRs are relayed to the system (through their difference functors), and there is need for an equilibration process between them, which we call the *interplay among the procedures*. This interplay is facilitated by the robustness and plasticity of higher order components and procedures, which can be realized through the unfolding of any of their ramifications. It leads to a strategy on the system, called the *operative strategy*, with respect to which a complexification of the system is effected, possibly leading to the emergence of higher order components and of new procedures. This strategy may discard the commands of the procedure of some CRs, thus causing a fracture to these CRs and imposing a change of procedure to repair it.

Temporal constraints play an essential role. Indeed, each CR operates at its own time-scale, but its operations rely on information or procedures coming from other CRs with differing temporalities. The accuracy of the information used to select the procedure and send its commands depends on the propagation delays of the links which convey them to the actors, and on the stability spans of the components used in these operations. In (Ehresmann and Vanbremeersch 1996), we have determined the *structural temporal constraints* which must be respected by such operations; these connect the propagation delays and stability spans to the *period* of the CR, defined as the *mean length of its steps*. Though the constraints leave some flexibility (they are expressed under the form of inequalities), there is a limit to the discrepancies which are tolerable without disruption of the process. In particular we have shown that the global dynamics is modulated by a *dialectics* between heterogeneous CRs with differing period and complexity, say a higher 'macro' CR and a lower 'micro' CR with a much shorter period; the successive changes coming from the micro CR are not transmitted in real time to the macro CR, but only all together and much later, with a possibility of a macro fracture.

7. MES AS MODELS OF AN ORGANISM

Robert Rosen has proposed different ways to distinguish "mechanisms" and "organisms," and in particular through their causality properties. Mechanisms correspond to simple physical systems which can be fitted into the frame of the Newtonian paradigm and modeled by dynamic systems. For them, Aristotelian material causation can be split-off from efficient or formal causation, and final causation is rejected. In organisms, the causal categories are mingled, and some anticipation is possible. How can his analysis be applied in MES?

7.1. *Causes of the emergence of higher order components*

For an external observer, the causes of the emergence of a new component in a single complexification process could be assigned to: the initial state as its material cause, the operative strategy as its formal cause, the realization of the strategy (through effectors) as its efficient cause, and possibly to the actors selecting the strategy as its final cause. The situation is different if, in a MES, we consider the transition from an initial state K_t to a later state $K_{t'}$ necessitating a sequence of complexifications. As we have seen above in Section 4 (Theorem 4.1.), a sequence of complexifications satisfying the MP *cannot* be reduced to a single complexification, and the formation of a higher order object cannot be done in one step. It means that we cannot directly select a strategy on the initial category K*t* leading by complexification to K*t′*, but we must construct the first complexification, then choose a strategy on it leading to the second one, and so on up to the last one. In terms of causality, it follows that the material, formal and efficient causes have to be "updated" at each step, thus are completely untangled in the global transition from K*t* to K*t′*. Thus, the Aristotelian causes intermingle, because the progressive unfolding of the material cause must be taken into account in the formation of the successive formal and efficient causes.

7.2. *The case of one CR*

If we consider the situation in a MES during one regular step of a CR (without fracture), the dynamics of its landscape once the procedure has been chosen and up to the end of the step can be modeled by a simple physical system (e.g., by systems of differential equations satisfied by appropriate observables). The material cause is the initial landscape, its formal cause the chosen procedure and the efficient cause the commands of the procedure. If the step is interrupted by a fracture, the fracture may just correspond to the introduction of a singularity (bifurcation or chaotic behavior), or impose a change of procedure, so that the representation as a simple system has to be modified.

Now the choice of the procedure and the equilibration process between the different CRs rely on several factors depending on the system as a whole and not only on the information accessible to the CR. If we consider the situation during several successive steps of the CR not interrupted by fractures, the dynamics of the landscape evolves by a sequence of complexifications, which generally cannot be replaced by a unique complexification of the first landscape. so that the CR does no more function as a simple system. In particular, the emergence of new components increasing the dimensionality of the system may require the introduction of new observables. Thus the *long-term* behavior of the landscape, even restricted at its level, is no more simple and may reveal an apparent a-causality.

7.3. *Global dynamics of the MES*

If the system is considered as a whole, the causal interactions between all the levels are continuously merged into the dynamic flow, so that the 4 causes are completely intermingled. As suggested by Rosen (1986), the system can be approximated by a simple system only valid "locally and temporarily," more precisely during one step of a particular CR. However, we can say that a MES is closed under efficient causality, in the sense that the choice of the procedures in response to external constraints, and the equilibration between them, are internal processes, essentially controlled by temporal conditions. And we can attribute some "finality" to the choice of already known procedures, since their result can be anticipated from the memory. Hence, *a MES can be qualified as an "organism" in Rosen's terminology*, with both local and temporal anticipatory behavior due to the presence of memory, and its complexity ultimately resulting from the Multiplicity Principle which requires one to take into account the whole structure of lower levels when constructing the higher ones.

8. CONCLUSIONS

We have seen that MES are well qualified to model the organisms in the sense of Rosen:

= They are approximated by simple systems locally (in a CR's landscape) and temporarily (during one step of the CR), these different descriptions being incommensurable.
= The central memory, which develops in time, allows for a choice of local operations based on *anticipation* of their results.
= The Aristotelian causes are intermingled.

Moreover, there is an emergence of objects of increasing complexity, the property at the root of this emergence being the MP which, for natural complex systems, is deduced as a long-term consequence of the quantum level laws at the micro-level. Thus there is no need of a new science to study "organisms," only a more thorough reflection on the nature of time and organization. This result may be, indeed, surprising: we say that the MES offer *a relational model* that incorporates time, and in which final causation and function are present. On the other hand, Robert Rosen previously said that there cannot be such a model. Is there a contradiction? We think not, because in MES the time is not just a parameter (as it is in physics), but intervenes as a complex multifold dynamical process: each CR operates on its own timescale; the equilibration process plays on the differences and constraints introduced by such time-scales. Finally, memory, in some sense, subsumes the past and the present, allowing for some anticipation of the future (based on the past) that may influence the present.

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