

Order in the Nothing: Autopoiesis and the Organizational Characterization of the Living

Published in: Bich L. and Damiano L., Order in the nothing: Autopoiesis and the Organizational Characterization of the Living. In I. Licata and A. Sakaji (eds.), Physics of Emergence and Organization (pp. 343-373) World Scientific.

Leonardo Bich¹ and Luisa Damiano^{1,2}

¹ *CE.R.CO.-Center for Research on the Anthropology and Epistemology of Complexity, University of Bergamo, Piazzale S. Agostino 2, 24129 Bergamo, Italy*

² *Biology Department, University of RomaTre, V.le G. Marconi 446, 00146 Rome, Italy*

Abstract: An approach which has the purpose to catch what characterizes the specificity of a living system, pointing out what makes it different with respect to physical and artificial systems, needs to find a new point of view – new descriptive modalities. In particular it needs to be able to describe not only the single processes which can be observed in an organism, but what integrates them in a unitary system. In order to do so, it is necessary to consider a higher level of description which takes into consideration the relations between these processes, that is the *organization* rather than the *structure* of the system. Once on this level of analysis we can focus on an abstract relational order that does not belong to the individual components and does not show itself as a pattern, but is realized and maintained in the continuous flux of processes of transformation of the constituents. Using Tibor Ganti's words we call it "Order in the Nothing".

In order to explain this approach we analyse the historical path that generated the distinction between *organization* and *structure* and produced its most mature theoretical expression in the autopoietic biology of Humberto Maturana and Francisco Varela. We then briefly analyse Robert Rosen's (M,R)-Systems, a formal model conceptually built with the aim to catch the organization of living beings, and which can be considered coherent with the autopoietic theory.

In conclusion we will propose some remarks on these relational descriptions, pointing out their limits and their possible developments with respect to the structural thermodynamical description.

Keywords *Autonomy; Autopoiesis; (M,R)-Systems; Organization; Relational Biology.*

1. Introduction: epistemological remarks

"More is different" (P.W. Anderson)

In this paper we analyse, conceptually and historically, a descriptive modality which could allow to identify, even if not yet to explain at its present state of development, what is specific of a living being. It is a relational qualitative description based on the systemic thesis that what is peculiar of an organism is not the single physical processes which take place in it, but the way these are related in order to produce and maintain the integrated biological unity they belong to. The main characteristic of the descriptive approach we derive from this hypothesis is to focus on the *organization* of the system. With this term we mean *the topology of relations which allow us as scientific observers to identify a system as a unity belonging to a certain class, that is the class of living systems*.

Such a theoretical definition expresses one of the main epistemological outcomes of contemporary science: the impossibility to consider the scientific knowledge as independent from the activity of observation and categorization performed by the observer. With this acknowledgment comes the collapse of the classical idea which makes of the scientist an “absolute witness” of nature, whose cognitive point of view, neutral and external from the natural world, guarantees the power of intelligibility that able to access and represent a reality in itself. In the epistemology of modern science this amounts to capturing and representing the laws of nature, which are considered as pre-existent to the observer and discovered through an act of apprehension of a reality external to him (Prigogine and Stengers, 1979).

A first breaking of this classical epistemology was operated by quantum physics. By showing the inseparability of the activity of observing from the object observed, it caused the subsiding of the objectivistic view of modern science. This crisis of the scientific objectivity was amplified by some branches of the contemporary science, which have been led to re-orientate the traditional epistemological axis from the classic representationism into a radical constructivism. Among them we can find a twentieth century tradition of research dedicated to the study of the biological organization, and known for having given birth to the concept of self-organization (Stengers, 1985). This branch of science has the peculiarity of having developed a scientific epistemology alternative to the modern tradition (Damiano, 2007), according to which the scientific observer does not have a direct access to reality, for he has an active role in the determination of the object he investigates. He interacts with the natural world through theoretical categories which instead of representing pre-existing and pre-defined objects build reality as a set of defined objects of research. From this perspective no model or theoretical apparatus can express the reality as independent from the activity of the

scientific observer (von Foerster and Zopf, 1962; Prigogine and Stengers, 1979; Maturana, 1988; 2000). The object treated by the science is co-constructed: the observer gives it an objectual form through the categories he resorts to, while the reality, limiting the range of their applicability, defines the area in which nature can be handled as made of objects categorised by the observer.

This epistemological thesis is specifically connected to the problem of the correlations between scientific disciplines, in particular those specifically concerned by this tradition: physics and biology. It is a non-reductionistic approach oriented to the establishing of communicative circuits between these disciplines: bidirectional transfers of models, questions, theoretical structures (Morin and Piattelli-Palmarini, 1974; Domouchel and Dupuy, 1983).

The thesis of this paper, about the necessity of the construction of new kinds of models specific for biology, goes in fact in this direction, rejecting the reductionistic approaches which move from physics to biology such as the one promoted by molecular biology, which tried to find what is pertinent in order to explain the living on a different level from the one where life manifest itself, missing the crucial problem of the systemic unity, as the name itself shows. Biology instead can undergo a development that follows its own modalities, derived from the kind of problems it faces, that is the necessity of producing models able to explain the experience of the observer interacting with a living system. And also, the attention given to the problems which emerge from biological research can lead to new approaches to physics and consequently to open new lines of research.

The first to understand this opportunity was Erwin Schrödinger, a physicist that explicitly faced the main question of biology, *what is life?*, in his seminal essay on the living (Schrödinger, 1944). He tried to characterize the order proper of living systems, that he called “*order from order*” embedded in a particular rigid structure, in opposition with the statistic order of physical systems. The new descriptive modality was not supposed to be due to a new sort of force, but to the attention focused on the way living systems are built, expressed by a different concept of order. Even if he for he didn’t face the problem of the unity that constitutes the living system, he had the merit to introduce the hypothesis that looking for the laws of biology could have opened the way to the development of a new physics.

This was in fact what Ilya Prigogine did (Prigogine and Stengers, 1979). Starting from the concept of open systems proposed by von Bertalanffy’s organicistic biology in the twenties (von Bertalanffy, 1949) as one of the properties characterizing the living, he

opened the way to the development of a new branch of thermodynamics, that of dissipative structures.

Coherently with this theoretical line, and referring explicitly to Schrödinger's insight (Rosen, 2000), Robert Rosen faced the problem of the integration of the biological unity (Rosen, 1958a; 1958b, 1959, 1972), putting into evidence the epistemological consequences of his approach for scientific knowledge (Rosen, 1991). One main example is the inclusion into science of circular causal loops, considered as the characteristic peculiar to biological systems, with the purpose to widen the range of scientific explanation from the specificity of mechanistic systems to the higher generality of complex ones (Mikulecky, 2001a). Following this line of research he built new kinds of models able to deal with phenomena not explainable by the means of the physical description (Stewart 2002) and he developed new approaches to the study of complex systems also in disciplines other than biology.

2. Order in the Nothing

The distinction of a unity from its background is the primitive epistemic action which an observer performs in order to study a natural object. It is the procedure which separates, according to some criteria, the object under study from the medium with which it interacts and so specifies its domain of existence. As George Spencer Brown wrote: *"a universe comes into being when a space is severed or taken apart [...] The act is [...] our first attempt to distinguish different things in a world where, in the first place, the boundaries can be drawn anywhere we please. At this stage the universe cannot be distinguished from how we act upon it"* (Spencer Brown, 1969). The kind of unity that is distinguished depends on the observer's operation of distinction, which relies on his purpose and his point of view. Consequently it is an epistemological action, which puts some boundaries that can be topological or functional. An example is the study of thermodynamical physical systems, where the boundary can be the container used for the experiment.

What do we distinguish while interacting with a living system? The study of living systems has a particular aspect. When we interact with them we can perform distinctions according to a manifold criteria, like the production of a certain enzyme or of waste products or the identification of a certain reaction pathway inside of it. But in order to

identify them as living unities, which is the main problem faced in this work, we perform a special kind of distinction. In fact the identification of these systems operated by the observer depends on an operation of distinction that defines their identity in the same domain where they specify it through their internal operations. The organism produces itself and by so doing specifies its topology in such a way that its topological and functional boundaries coincide. In the interaction with a living system we can observe that it is characterized by the maintenance of the unity as such in a continuous process of transformation of components. A special kind of homeostasis is involved here which does not concern single processes but the whole system which is maintained stable. What makes the set of processes which occur in a living organism a unity, or better a system, needs to be found at a level different from that of the physical and chemical description. Material components indeed are continuously produced, transformed and degraded in such a way that what characterizes the identity of the system, is that what is maintained in this change, does not belong to their epistemological domain.

Starting from these remarks and following Schrödinger's insight about the necessity of characterizing the order peculiar of living systems, we pose the following question: which kind of order characterizes the continuous and intertwined flux of processes of production and transformation of components which a scientific observer sees as realizing a living being?

The difficulty in catching what makes a living system a unity of some kind consists exactly in this: we are dealing with a system which is characterised by a continuous change and nevertheless maintains itself. Unlike a machine, where the material parts are in an order visually observable, in the organism the chemical components are mixed in a continuous flux of processes that occurs at the same time in a fluid network of reactions. The order is not positional, it is not localized, as everything is dissolved in a field-like way. Also, there is a difference from some physical systems like for example a twister where there is an order in spite of the movements of components. In organisms indeed components are not pre-given but they are produced and transformed by the system itself. The first step towards a characterization of the order proper from the living is to differentiate it from purely statistical order or *order from disorder* (Schrödinger, 1944). This way of producing regularities in natural system is not absent from biology, but it is not the factor which catches what happens in a living system and that differentiates it from other natural and artificial systems. Jean Jacques Kupiec and Pierre Sonigo (Kupiec and Sonigo, 2000), in their critics of the concept of gene, refer to statistic order as the

crucial element to describe the living. They propose a sort of “molecular mechanics” which interiorizes the Darwinian selection at the molecular level together with chance. Implicitly, they develop the line of research of the tradition of Francis Galton, Wilhelm Roux, and August Weissmann who used the term “intrabiontic selection” (Pichot, 1999). Kupiec and Sonigo consider organization as an epiphenomenon, the result of the dynamics of the ontogenesis, in a way similar to the processes of pattern formation, without any sort of causal role in conserving and realizing the system. Their theoretical model is more similar to the twister referred above, and depends directly on the materiality of the parts contained in the system observed. They have the great merit to put into evidence some problems in the point of view on metabolism assumed by molecular biology, especially about instructive functional interactions operated by the genes or by the environment, which are typical of a machine-like approach. But a living system is not only a visible shape, an ordered pattern. On the contrary it shows autonomy and produces its own components. The difficulty of explaining its difference from a phenomenon like the one giving rise to a self-organizing (or more correctly a self-ordering) system as a twister or Bernard’s cells, comes out because the starting point is not the basic question “What is life”, but just a description of some chemical processes happening in the organism. The problem of the integrated unity is not taken into consideration.

Maturana and Varela instead, belong to a systemic tradition focused on the problem of the relational unity of the living, which has its origins in Claude Bernard’s concept of *milieu intérieur* (Bernard, 1865). In one of their early papers on the problem of the description proper to the living (Varela and Maturana, 1972), they propose the thesis according to which machines and organisms are different from physical systems in that they depend on how their elements are connected: “*what makes physics peculiar is the fact that the materiality per se is implied; thus, the structures described embody concepts which are derived from materiality itself, and don’t make sense without it. [...] the definitory element in the living organization [and in machines] is a certain structure independent of the materiality that embodies it; not the nature of the components but their interrelations*” (Varela and Maturana, 1972).

The problem of how things are connected in a living system is also at the core of Schrödinger’s conceptual model. But another step is needed, that is the distinction between organisms and artificial systems. Both are organized systems whose qualitative properties are generated by the way their components are interconnected: that is by their internal organization. But machine are characterized by a positional order. Hard automata

in fact are organized by geometrical spatial constraints which unlike some physical objects like crystals, are not characterized by symmetries, but have a dynamical functioning. Von Neumann's self-reproducing automata (von Neumann, 1966) constitute an example. They don't really produce themselves, but just recreate a certain spatial disposition. They are nevertheless at the basis of the metaphor of the organism as an "information processing machine" that conceptually influenced molecular biology.

The order characterizing the machine metaphor is of the same kind of the one proposed by Schrödinger as fundamental in the living. His *order from order* is in fact realized by an aperiodic solid characterized by a positional structure. The living processes are controlled by an ordered group of atoms that maintains itself and transmits his structural order to other molecular structures. Schrödinger's conceptual model is that of a clock-like system with mechanisms interconnected in a way that the positions are what is relevant (Schrödinger, 1944). He solidify the biochemical flux in a sort of chemical mechanism in which the microscopic order of the genetic code is transmitted positionally to the macroscopic order of the living. Both in organisms and in mechanisms the shape, the structure, is what is conserved and transmitted in ontogenesis and phylogenies. This idea is conceptually very close to von Neumann's one, as the aperiodic solid performs the role of the program in a computationalist view.

But living systems are not solid, they are a flux of processes and transformations in a solution that is almost homogeneous from the point of view of matter and energy. That is the reason why considering processes and especially interactions between processes is crucial. The macroscopic order is not due to the shape of the microscopic structure of components but depends on the shape of the interconnections between the processes of transformations. Their proper order differentiates itself from the other two kinds and can be found on a different level of abstractions over the flux of change. It is an epistemologically higher level of analysis where we can find a kind of order which with Tibor Ganti's words we call "*order in the nothing*" (Ganti, 2003). What is produced and maintained in the continuous change of components that we observe in living systems, and what produces and maintain this same change is the shape of the relations between the processes. Consequently, in order to understand the living as a systemic unity we need to put ourselves on a relational level of description.

	Generative mechanism	Interactions	Class of systems
Order from disorder	Statistical	Non-positional (between given components)	Physico.chemical systems
Order from order	Relational spatial (between components)	Positional (between given components)	Artificial systems (machines)
Order in the nothing	Relational abstract (between processes)	Non- positional (between components that are produced by the system itself)	Living systems

The order in the nothing is different from the first kind of order because it is independent from material parts. But it is also different from the machine kind because of its fluidity and because the geometry of relations is not spatial but abstract. It doesn't connect solid components but processes, characterizing itself as a meta level of relations which emerges when these ones assume a shape that allows self-production and self-maintenance to be instantiated.

It doesn't belong to the domain of the material structural interactions but to a relational abstract independent but complementary domain: that of organization.

3. Structure and Organization

The origin of the organizational description of the living, considered as complementary to the structural one, can be ascribed to a scientific tradition developed between the 30's and the 70's. It is a trend of research constituted by a variety of lines of the contemporary science which faced the same problem along some theoretical pathways which, although different, converged on many aspects. This crucial problem was to structurize a categorical approach pertinent to the specificity of the biological domain.

In spite of the different disciplinary origins, these lines shared the same theoretical assumption. It consists in the idea that the distinctive property of the biological domain is *autonomy: a relative independence from the environment* which cannot be referred to the physico-chemical components, but to the integrated totality in which these components

are supposed to be dynamically connected. The preliminary definition of autonomy provided by this trends of research refers to an *endogenous determination*, a self-determination, which reveals itself primarily in the scientific exploration of the biological behaviours of self-stabilization, that is, of active reaction to exogenous perturbations, consisting in compensative movements which cannot be ascribed to the individual perturbed components. Typically they appear as global regulative processes, distributed on the whole biological unities to which the components belong.

The development of the investigations performed by these branches of the scientific research is usually gathered under the denomination “scientific genealogy of the notion of self-organization” (Stengers, 1985; Ceruti, 1989; Damiano, 2007). Its characteristic is to be a theoretical movement which, although plural and differentiated, is strictly coherent and oriented. Born from the attempts to modelise the internal functional scheme which allow stability in living systems, this wide theoretical process developed up to the production of a general modelistic which has the ambition to provide a specific conceptual definition of the biological domain. It has been realized through the succession of different descriptive models, which shared some common methodological and theoretical characteristics: (a) the assumption of a qualitative and relational level of analysis, focused not on the specific physico-chemical components and processes, but rather on their *organization*, that is the functional interconnection that integrates them in the biological unities; (b) the characterization of the organizational scheme which allows the expression of the property of the biological autonomy as a relational network with a circular character. The development of this kind of modelistic has been carried out through the progressive formal specification of the concept of organizational circularity, which allowed the so-called “tradition of self-organization” to gradually approach the rigorous scientific definition of the general dynamical mechanism at the basis of the biological phenomenology. This theoretical movement, accomplished through a progressive distinction of the *organization* from the *structure* of biological systems, can be traced back to three main phases:

- 1) the production of the first theories of self-organization, performed by three independent lines of scientific research which shared a close attention to the biological level of nature: (a) the wienerian cybernetics (Wiener, 1948) and its derivations, such as second order cybernetics (von Foerster, Zopf, 1962) and French neo-connectionism (Atlan, 1972); (b) the organicistic embryology (Weiss, 1974); (c) the thermodynamics of dissipative structures (Prigogine, Stengers, 1979);

- 2) the rigorous synthesis of the first conceptualizations on self-organization, operated by Piaget (Piaget, 1967) through the elaboration of a general theory of the biological organization based on the concept of “organizational closure” (Ceruti, 1989);
- 3) the critical revision of the theories of the biological self-organization performed by Maturana and Varela, which led them to an original theoretical definition of the dynamical mechanism proper of the biological systems expressed through the concept of “autopoietic organization”.

The origins of the concept of self-organization: biological autonomy and organizational circularity

The concept of biological self-organization has its origin in the problem of the modelization of one of the most relevant and evident properties of the living. Biology at first called it *homeostasis* and defined it as the capability proper to the organisms to maintain their internal environment relatively stable against the external perturbations (Cannon, 1932). It is a biological property that the tradition of self-organization re-conceptualized as *autonomy*, conceiving it as the active control performed by the organism on its same processes: the capability to react to the external destabilizing perturbations through self-determined variations which tend to cancel the effects of the exogenous destabilizations.

This interpretation of the homeostasis of living beings is at the core of the fundamental theoretical hypothesis of the biological modelistic provided by the tradition of self-organization: the assumption which traces the autonomous behaviour of self-stabilization back to the organizational circularity.

A schematic reconstruction of the development of this axis of research can be briefly outlined showing the main contributions of the three directions of investigation that characterize the first period of the research on self-organization: (a) the model of the “feedback circuit” or “retroaction” elaborated by Norbert Wiener (Wiener, 1948); (b) the theoretical scheme of the “organized hierarchic system” produced by the embryologist Paul Weiss (Weiss, 1969; 1974); (c) the characterization of the “dissipative systems” proposed by Ilya Prigogine (Prigogine and Stengers, 1979; Nicolis and Prigogine, 1989). The first of these theoretical models already shows the methodological and theoretical definitory elements of the descriptive hypothesis which associates autonomy to a circular scheme of organization. The model of the feedback circuit was developed by Wiener coherently with the general approach of cybernetic, a discipline based on the recognition

of the convergence between the domain of the technological research and that of biology with respect to the problem of stability. The common referring by these two scientific areas to objects exhibiting the capability of self-stabilization (servo-mechanisms and organisms), led Wiener to the elaboration of cybernetics as the locus of bidirectional theoretical exchanges between technology and biology. The idea was to use the analysis of the technological mechanisms of stabilization to advance hypotheses on the functioning of biological ones and vice versa to exploit the knowledge of the latter for the implementation of the formers. Such a procedure of reciprocal exchange of knowledge has an important consequence. It requires a theorization able to set aside properties of the specific components of the two kind of objects explored. It forces the research to move to an explorative level susceptible to give an access to the general functional relations of the object investigated, focalizing not on the *structure* but on the *organization*.

This methodological option is at the origin of the model of the feedback circuit elaborated by Wiener along the axis that goes from technology to biology: defining the organizational scheme of the servomechanisms and proposing it as the hypothetical model of the general functional organization that allows the living systems to carry out self-stabilizing behaviours. As it is well known, the peculiarity of the wienerian model is to delineate a circular causal relation between a *sensor* and an *effector*, mediated by a *regulator* able to make the sensorial recording of the perturbative deviation and to act on the devices which perform compensative actions. Once applied to living systems, this scheme traces their general functional organization as a *ring*: a *functional circle* which, interconnecting the sensorial and effectorial apparatus, implies that the effects of perturbations trigger compensative activities expressed by motorial interactions which are effective in the environmental context. This model, associated by Wiener to the idea of “self-regulation” of biological systems, became the cybernetic prototype of the notion of “self-organizing system” developed in the modelization of biological autonomy by the heterodox lines of research of the Biological Computer Laboratory (Von Foerster and Zopf, 1962; von Foerster, 1980) and of the French neo-connectionism (Atlan, 1972).

The fundamental methodological and theoretical lines of Wiener’s cybernetic modelization of the autonomy of the living, were independently introduced in the context of the organicistic embryology, where they were immediately associated to the qualitative description of biological systems as “self-organizing systems”. An exemplary model of the conceptual production characteristic of this line of research is the weissian theoretical

scheme of the *hierarchical organized system* which develops the theoretical line opened by the wienerian modelistic.

This descriptive scheme was elaborated by Paul Weiss (Weiss, 1969; 1974) from the experimental investigations on the self-stabilizing behaviour of biological systems, that led him to identify their characteristic dynamics. Typically the presence of local alterations in the internal dynamics of a living system do not induce the activation of a localized and specific stabilizing centre, but triggers a series of correlated modifications in the elementary processes. If the destabilisation is lower than the stability threshold of the system, it causes a compensation.

In Weiss's exploration this remark becomes primarily a methodological option. It consists in the refusal of the approaches to the study of biological stability focalized on the individual physico-chemical components and their processes, in favour of the assumption of an explorative procedure centred on the functional relations that dynamically correlate the elements in the biological global unities constituted by the living systems.

With the adoption of this methodological perspective of an organizational character, Weiss aligned his modellistic production to the wienerian one not only from the procedural point of view but also from the theoretical one. The hypothesis he developed to modelise the organization allowing the biological stability proposes the idea of an organizational circle. From the seminal insights of the founders of the organicistic embryology¹, Weiss conceptualized it as a strict functional correlation with the shape of a "closed network": every element of the system is functionally correlated to another one so tightly that a behavioural deviation of it entails a compensative distributed reaction in the whole network.

This characterization of the biological circularity of organization distinguishes weissian modelistic from the wienerian one. It leads to the explicitation of the idea that in the living systems the compensative reaction to the perturbations is a collective action. The capability to self-stabilize does not belong to the individual components of a biological system, but to their organizational reticular correlation – to the totality.

On the basis of this remark Weiss produced a general descriptive scheme that distinguishes in the living systems two qualitatively different levels: that of the individual parts, subjected to continuous alterations, and that of the unity which

¹ The reference is to the research team which founded the organicistic embryology, that is the so called Group of Cambridge (Stengers, 1985).

comprehend them, strongly and actively conservative: *“The variability of the complete system V is much lower than the sum of variabilities v of its components.*

$$V \ll [v(a) + v(b) + v(c) + \dots + v(n)]$$

This formula contains the essential aspect of systems dynamics with respect to the composition of elements. It could not be respected if the components were free and independent.” (Weiss, 1969).

This is the model of a biological hierarchical organization. It describes a relational global unity which interconnects its subunities to one another through functional reticular links. By so doing the totality subjects its components to its own global dynamics –a collective and coordinated dynamics of its elements- and reacts to the elementary local deviations by regulating the components’ singular behaviours to achieve its own conservation. The theoretical idea of “self-organizing system” was associated by Weiss to this concept of biological system: the notion of a totality that, through the organizational reticular constraints that constitute it, produces its own constitutive dynamics, imposing it to its own elements and stabilizes itself in presence of exogenous perturbations, acting on its individual elementary processes.

By doing this, the weissian model leads to a decisive enrichment of the descriptive hypothesis that associates the autonomous behaviour to the organizational circularity. First of all it extends the meaning of the notion of living autonomy, connecting it not only to the property of self-stabilization but to a more fundamental one, that of self-production with respect to which the first is characterized as derived. Secondly, he connects the thesis of the circular organizational scheme to that of the stratification of the living systems into at least two interdependent and qualitatively different levels – the individual parts and the totality.

Both these developments are now acquired by the scientific theory of self-organization. The last one was conceptualized by Weiss through the controversial notion of “emergence”, which describes the capability of the organizational circle to generate a level of reality characterized by qualities that are not present in the lower level. It is the hypothesis of a qualitative difference between the parts and the totality, that Weiss made intelligible through an argumentation widespread today: the reticular organizational connections, constraining the components to each other in a circular way, inhibit the expression of some of the properties of the individual components and make possible the expression of global properties.

From this notion, inseparably associated to the model of the hierarchical organized system, Weiss built a complex theoretical characterization of the living. It consists in a perspective which identifies biological systems as “molecular ecologies”, describing them as structured in a plurality of levels of “molecular organization” of increasing complexity and stability – cells, groups of cells, tissues, organs, apparatus etc. It is a theoretical idea that played a decisive role in the development of the tradition of self-organization. It gave a significant contribution to the construction of the third of the explorative direction of the research on natural self-organization (Stengers, 1985).

The thermodynamics of dissipative structures was founded by Prigogine in the context of the development of a program of research finalized to deal experimentally with the crucial problem of the relation between physics and biology: the antagonism between the cosmological scenario pointed out by the principle of the entropic growth and the evidence of the biological evolution towards complexity. The ambition to provide a solution to this issue led Prigogine to develop the weissian hypothesis of the “molecular ecologies”: the idea that a molecular population with a high degree of freedom can generate a level of stable integration and able to evolve towards higher levels of complexity.

The assumption of this thesis oriented the prigoginian research program to the exploration of the behaviour of thermodynamically open molecular systems, an investigation characterized by relevant results. It put into evidence that these systems, under certain conditions (Prigogine and Stengers, 1979; Nicolis and Prigogine, 1989), are subject to phenomena of “supermolecular aggregation” which generate persistent macroscopic dynamical structures - ordered patterns.

They are irreversible physico-chemical processes that topologically organize themselves: collective coordinated movements of the molecular population which constitute active and organized global unities that self-generate and self-maintain exploiting the exogenous flux of matter and energy and by doing so producing entropy which is released in the environment. Prigogine called them “dissipative structures” to make explicit the compatibility with the second principle of thermodynamics. He provided a characterization of them in terms of self-organizing systems, taking the weissian theoretical framework of the circular and stratified organizational scheme. He explained these natural forms as emergent organized unities. He attributed to them the minimal and incomplete forms – “ancestral” (Prigogine and Stengers, 1979) – of some of the properties shown at the biological level. Among these properties he included autonomy:

the capability of these systems to self-produce their own constitutive dynamics, to stabilize against a wide range of perturbations and to exploit external perturbations to evolve –by an endogenous re-organizational control, that is by positive retroaction (Nicolis and Prigogine, 1989) – towards higher levels of complexity and stability.

Such a theoretical characterization puts the biological autonomy inside an evolutive scenario which grounds it in the physical domain. It proposes an image of the prebiotic evolution that generates more and more stable and complex molecular ecologies, which plausibly are able to develop until transcending the physico-chemical domain and proceeding into the biological one. It thus opens the possibility of a connection between the physical and biological domain, not a reductionistic, but an emergentistic one. It offers the opportunity of an exchange of knowledge between these two domains of science which is not unidirectional and reductive, but founded on a bilateral “dialogue” (Prigogine and Stengers, 1979; Stengers, 2003).

The piagetian synthesis: the notion of “organizational closure”

Besides these first lines of research, the scientific genealogy of the notions of autonomy and self-organization includes some trends of investigation definable as of first derivation. They are scientific orientations generally related to programs of research developed in the context of the human sciences and directed to bridge the cartesian cut: to overcome the theoretical gap that separates the natural and the human sciences, by producing a naturalistic notion of human being which avoids to reduce him to physical and biological aspects. The peculiarity of these lines of investigation is that they acknowledged in the evolutive scenario opened by the first research on self-organization the possibility to re-articulate the anthropo-social sphere on the biological and the physical ones, according to a non-reductionistic but emergentistic theoretical approach. The aim of this operation was realized through the investigation of the first research on self-organization, in order to perform theoretical syntheses able to produce a complex and multidimensional notion of the human being. (Morin, 1973; Morin and Piattelli-Palmarini, 1974; Jantchsh, 1980; Dumouchel and Dupuy, 1983).

Among these programs of research the piagetian genetic epistemology assumes a particular relevance, due to its decisive contribution to the scientific characterization of the biological organization (Ceruti, 1989). This line of the contemporary epistemology was directed by Jean Piaget towards the construction of a natural science of cognition based on a specific interpretation of the general assumption of cognitive sciences that

identify life with cognition. It consists in a minority theoretical option that refuses the computationalist modelization of living systems in favour of the identification of autonomy as their definitory property.

The piagetian work of exploration and integration of the scientific production on the natural self-organization led the genetic epistemology to the elaboration of an innovative theoretical element, quickly acquired by the scientific research and still at the core of the investigations on biological autonomy. It is a concept that rigorizes the previous achievements on the organizational circularity of living systems: the notion of “*organizational closure*”, proposed by Piaget in *Biologie et Connaissance* as a concept complementary to that of thermodynamical openness, earlier emphasized by von Bertalanffy’s systemic biology (Piaget, 1969).

“The central ambiguity is that of the ‘open system’, for, if system exist, then something like a closure intervenes, which has to be reconciled with the ‘opening’. The opening is certainly justified and is founded on the basic idea that ‘in biology there is not rigid organic form carrying out vital processes but a stream of processes which are revealed as forms of a seemly persistent kind’ (von Bertalanffy). The opening then is the system of exchanges with environment, but this in no way excludes a closure, in the sense of a cyclic rather than a linear order. This cyclic closure and the opening of exchanges are, therefore, not on the same plan, and they are reconciled in the following way, which may be entirely abstract but will suffice for a analysis of a very general kind.

(AxA’)→(BxB’)→(CxC’)→...→(ZxZ’)→(AxA’)→ ecc.

A,B,C: the material or dynamic elements of a structure with cyclical order

A’, B’, C’...: the material or dynamic elements necessary for their maintenance: the interaction of the terms of the first range with those of the second

→: the end points of these interactions

In a case like this we are confronted by a closed cycle, which expresses the permanent reconstitutions of the elements A,B,C ... Z, A, and which is characteristic of the organism; but each interaction (AxA’), (BxB’), etc., at the same time represents an opening into the environment as a source of aliment.” (Piaget, 1967).

The piagetian notion of closure can be considered as a development of the weissian formulation of the theoretical assumption that associates the biological autonomy to the organizational circularity. The concept formulated by Piaget presents biological autonomy as an endogenous determination of the living systems that has the character of

the self-production and correlates it to the idea of an organizational scheme realized by the circular functional interconnection of the components. The specific contribution of the piagetian notion of closure consists in the idea that the organizational circularity corresponds to a concatenation of processes which continuously re-constitute the components of the living systems. The theoretical picture is that of a closed chain of elementary transformative operations which, by realizing themselves, trigger each other, giving rise to a self-determined recursive and cyclical process that, producing the components, produces the organism itself.

Piaget associated this conceptualization to the theoretical explicitation of the difference between *organization* and *structure* (Ceruti, 1989). He defines the first as the general relational scheme of all the living systems and the second as its materialization in specific processes and components. Piaget underlined that the two aspects are distinct because, as the idea of organizational closure points out, the peculiarity of the living systems is that their materialization keeps changing: what persists in them are the functional relations that integrates the components in the global unity, while the specific components are permanently in flux.

By this theoretical distinction Piaget laid the basis for what can be considered the most mature development of the genealogy of self-organization: the formulation of the autopoietic biology, oriented by Maturana and Varela towards the definition of the dynamical mechanism of living systems.

3.3 The autopoietic biology: the duality of structure and organization in the scientific general definition of living systems

The basic theoretical project of the autopoietic biology was to provide a new kind of solution to the problem of the identification of the living. Maturana and Varela wanted to develop a criterion of identification which does not consist in the classical enumeration of properties we can recognise in the living from our external point of view. Instead of undertaking an analytic descriptive procedure, doomed to go on indefinitely, Maturana and Varela conceived a criterion which identify the living by specifying a mechanism able to produce these properties, or, more accurately, a mechanism able to produce all the living phenomenology.

“Our aim is to proceed scientifically: if it is not possible to produce an inventory which characterizes a living being, why not conceiving a system which, while operating, produces all its phenomenology ? ” (Maturana and Varela, 1987)

This can be considered the main aim of the autopoietic biology: defining the living from the inside, by specifying its deep “dynamical mechanism”, the inner mechanism able to generate the living phenomenology.

The development of the theory of autopoiesis relies on two fundamental thesis:

- 1) the most basic property of the living is *autonomy*, understood as the capability that such natural systems have to produce and maintain, all by themselves, their own identity, by a triple endogenous action: a) self-production; b) permanent topological self-distinction in an environment; c) self-stabilisation against endogenous and exogenous perturbations;
- 2) autonomy is a property which does not belong to the individual physico-chemical components of the living, but to their organizational correlation, that is the functional “organization” which integrates them in the relational unities usually called “organisms” (Maturana and Varela, 1973).

The adoption of these hypotheses coincided with the alignment of the autopoietic biology with the tradition of self-organization, a connection which remained implicit and offered the ground for a transformative development of the production of this tradition. Here is what allows us to consider autopoietic biology as a critical reform of the first research on self-organization: although it shared with the latter some theoretical presuppositions and some conceptual elements, this biological school spent more time stressing the flaws of the tradition of self-organization than acknowledging its theoretical debts towards it.

The main shortcoming that autopoietic biology attribute to this tradition of research consists in a *insufficiency*. The genealogy of self-organization has postulated that the biological level of reality is populated by relational unities of elements whose primarily property is autonomy. It has postulated biological self-organization, but it didn't try to scientifically explain it, that is to define the mechanism able to generate these unities and their phenomenology (Maturana and Varela 1973).

In order to do it, one essential consideration, substantially missed by the research on self-organization, has to be taken in account. It consists in the idea that the organization which functionally supports the biological autonomy constitutes the invariant of the biological phenomenology – both at the ontogenetic and at the phylogenetic levels. The relational unity of components is what maintain itself in the permanent flux of physico-chemical

elements peculiar to the organism's life. This unity is what is permanent within the strong transformations that can make the individual living being un-recognisable from one observation to another. The relational unity is the biological element which is transmitted through reproduction: it is the feature of the living that remains unchanged generation after generation. The global unity is what is constant in the evolutive differentiation, to such an extent it constitutes the feature shared by all the living: being a relational unity of components.

It is from this consideration that Maturana and Varela infer the generative hypothesis of the theoretical conceptual structure of their autopoietic biology, according to which the organization is the identity that the living permanently produces and keeps, thanks to a permanent and self-determined change the physico-chemical components (Maturana and Varela, 1973).

It is a thesis that implies the refuse of the term "self-organization", which can seem to express the idea of a self-determined change of the living organization. It can seem to miss the specificity of the dynamics of the living, namely, the conservation of the organizational invariance coupled with the permanent flux of physico-chemical elements. Here relies the need for a new term, namely, "autopoiesis", which can avoid the confusion between the invariant and the variant aspects of the living dynamics.

This term expresses the acknowledgment that biological systems constitute dynamical systems in which the relation between invariance and change has a peculiar aspect: in these systems what is conserved is the relational unity of components, which, in themselves and in their specific functional relations, permanently change.

Maturana e Varela elaborated this point through the implicit recovering and strict scientific treatment of the conceptual dyad introduced a few years before by Piaget: the duality of *organization* and *structure*, which within the autopoietic biology coincides with the duality between the invariant element of biological phenomenology and the variant one. Here "organization" refers to the stable and permanent relations which define a biological individual as a unity, while "structure" refers to the particular and transient materializations of a living unity. These two notions are distinct but inseparable for they express two complementary aspects of the living. In this kind of systems the relational unity of the components –the *organization*- cannot be without a concrete and transient realization into specific elements and relations between them –a *structure*. Conversely there cannot be a concrete and transient unity of elements in flux –a *structure*- without the stable relations – *the organization*- which integrates them into a persistent unity.

The formulation of such a conceptual complementarity has constituted the core of the development of autopoietic biology's program, aiming at defining the dynamical mechanisms of living systems through the individuation of the interplay between the invariant element of their dynamics and the variant one. Maturana and Varela carried out this theoretical operation on the basis of a specific hypothesis concerning the relation between *organization* and *structure*: the continuous structural change, due to the transformative interactions of the components, produces and maintains the organization which, in turns, enables the structural change.

This thesis allowed autopoietic biology to provide the definition of a plausible mechanism for the living dynamics, elaborated by Maturana and Varela in relation to the minimal and "fundamental" living system: the cellular system, present in all living forms, evolutively antecedent to them, and therefore able to generate them.

The dynamical mechanism of the cellular unity has been explained by Maturana and Varela through the definition of cellular organization, called by them "autopoietic organization". It is a theoretical elaboration that implicitly recovers the piagetian concept of *organizational closure*. It corresponds to the notion of a circular dynamic mechanism: a close chain of operations of elements transformations in which the realization of one operation triggers and integrates another one, in such a way that the global cyclical process that emerges is essentially characterized by the property to determinate and regenerate itself. It is easy to recognize the influence of the piagetian idea in the definition of autopoietic organization, according to which:

" [The autopoietic organization] (...) is a network of production processes (transformation and destruction) of components which produces the components which :

1- Through their interactions and transformations, permanently regenerate and realise the network of processes (relations) which produces the components ; and

2- Constitute a concrete unity in space, within which they (the components) exist by specifying the topological domain of its realisation in that network. " (Maturana and Varela, 1973)

The more relevant aspect of the autopoietic model is that this theoretical scheme considers relations between processes that involve components. It opens a large range of possible materializations of the autopoietic organization. It does not impose conditions on the specific basic elementary constitution of autopoietic systems (Bich and Damiano, 2007). It points out the crucial aspect of elements not in their intrinsic properties, but in they

interactive specificity: the relational properties that define the forms of functional correlation that the elements can develop (Bich, 2005).

The constitution of the elementary level is allowed to change, but within in a well defined range of variability: the space of all the elementary compositions able to generate a recursive chain of functional relations of reciprocal production. It is by imposing this only relational constraint onto the level of components that the descriptive scheme is able to generate the two dimensions that constitute the dynamics of the living unity: it poses the organization as the invariant element and the structure as the variable one. In doing so it succeeds in expressing theoretically the idea that in this kind of system the conservation of organization is obtained *through* the continuous structural variation.

4. Relational Biology and Rosen's (M,R)-Systems

A parallel line of thought that goes in the same direction inaugurated by the studies of cybernetic and continued by genetic epistemology and autopoiesis is the one opened by Nicholas Rashevsky and carried on by Robert Rosen. It has the merit not only to focus on the integrated organization of the living systemic unity but also to develop specific formal tools in order to describe it.

Rashevsky developed mathematical biology since the early 30's (Abraham, 2004), giving a great contribution to the mathematical study of the biological processes of self-organization which led to Alan Turing's and Ilya Prigogine's models of pattern generation. His first approaches dealt with separate biological phenomena from a physical point of view.

In his seminal paper "*Topology and Life*" in 1954 Rashevsky shifted his approach to the study of living systems from the construction of structural models of the biological processes to the modelization of the relational properties of organism, that is, to the study or their organization. His purpose was to develop a mathematical theory able to treat the integrated activity of the organism as a whole: "*we must look for a principle which connects the different physical phenomena involved and express the biological unity of the organism and of the organic world as a whole*" (Rashevsky, 1954).

Following this idea, he reflected upon the difference between physical and biological phenomena which, according to him, consist in that that formers are characterized by metrical aspects, the latter by relations. Also, while the structural physical description

focuses on the differences between systems, the relational one considers their similarity, embedded in the common minimal organization that defines their class, in this case the organization of the minimal living system, shared by all the other more complex organisms. The identity is the starting point of his research. The differences are secondary to the theoretical characterization of the organisms, which is primary with regards to the investigation of the variety of their phenomenology. In looking for what makes biology special we notice in fact not only quantitative aspects but, above all, the presence of complex relations. These ones, according to Rashevsky, do not concern shape, like in the approaches *a la* D'Arcy Thompson, but consist in relations between processes or properties.

His new line of research, called *relational biology*, focused on the abstract description of the relations that connect the fundamental properties of organisms up to letting us recognize that network of relations as characteristic of the minimal living being. He opened the way to the development of a mathematical theory able to treat not the metric aspect of these systems but the integrated properties realizing the organism.

His work in *relational biology* thus, was based on two related theoretical assumptions:

- 1) the first concerns the importance of relations in identifying and characterizing the living: “*we postulate that the highly complex biological structures are due to relational forces, that is, that they are formed because as a result of this formation certain qualitative relations appear, relations which make us recognise the structure as a living organism*” (Rashevsky, 1972).
- 2) The second concerns the possibility to study living systems starting from their common organization. It is the *Principle of Bio-topological mapping*, according to which “*all organisms can be mapped on each other in such a manner that certain basic relations are preserved in this mapping*” (Rashevsky, 1960).

Rashevsky's approach, nevertheless, was characterized by the attempt to connect the different structural processes and properties observed in living systems. It was an additive procedure which had the purpose to build the relational schemes of biological functions of different organisms. What was conserved in the transformation from one scheme to the other was the hypothetical relational structure of the minimal organization common to all living systems.

Rosen started from Rashevsky's insights but followed a different path. On a higher level of abstraction, he extended the approach of relational biology to the form that the fundamental relations should assume to express the basic autonomy of living beings. He

was looking for the mechanism that causes the biological properties to be instantiated. In doing so, he conceptually started from the integrated unity of the living organism, characterised by the capability to self-produce and self-maintain.

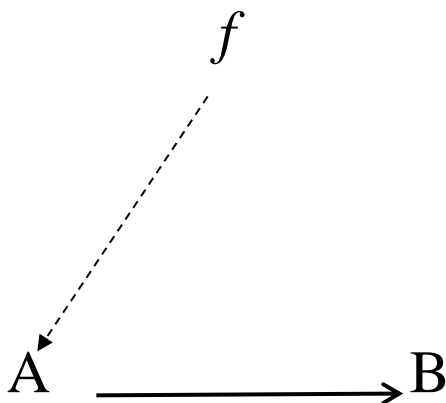
In the late 50's Rosen proposed a formal model based on the mathematic of Category Theory, the (M,R)-System, which described the organization of the living as the integration of the functioning and the fabrication of the system (Rosen, 1958a; 1958b; 1959). His early works are quite obscure and he clarified some of their mathematical aspects after many years (Rosen, 1972), but he fully understood the theoretical meaning of his model only later (Rosen, 1991). A recent and clear explanation of the mathematical formulation of (M,R)-Systems together with some attempts to relate it to biochemical processes, was provided by some researchers belonging to the autopoietic school (Letelier et al, 2006).

Rosen's basic assumption in the construction of his model is that every component must be produced, or replaced after its degradation, inside the system. He uses some instrument of Control Theory, considering every process like an input-output one, but in the end he realizes a formal structure very different from those characteristic of machines.

The first step is to consider the "*metabolic*" process that usually takes place in a cell, where some catalysts transform into components the substrates coming from outside the system. It is expressed formally by a set of mappings $H(A,B)$ which transform a set of substrates A into a set of components B .

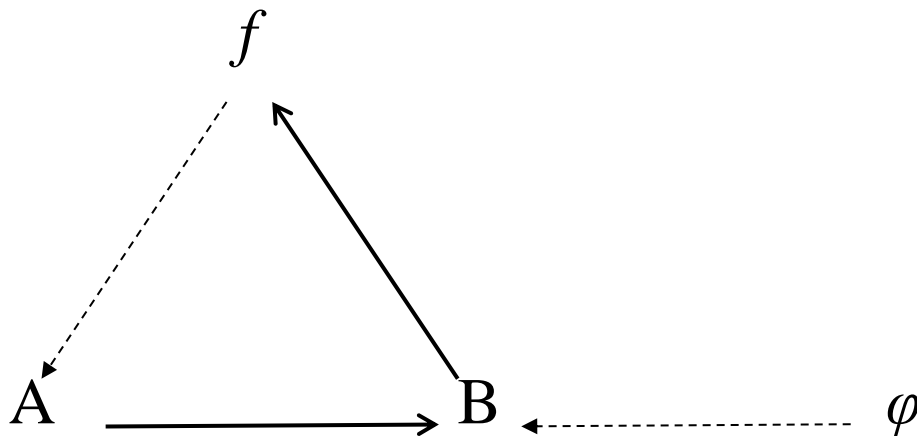
$$f: A \rightarrow B$$

$$f(a) = b \text{ with } f \in H(A,B) \tag{1}$$



The catalyst f , which has a limited lifespan, must also be produced or replaced by some processes inside the system. Living organism in fact, unlike machines, are characterized by a continuous turnover of components. So Rosen introduces another process, called “*repair*” in his original papers (or “*replacement*” in Letelier et al., 2006), that produces the metabolic catalyst f out of the components belonging to the set B.

$$\begin{aligned} \varphi: B &\rightarrow H(A, B) \\ \varphi(b) &= f \text{ with } \varphi \in H(B, H(A, B)) \end{aligned} \quad (2)$$



Now we have the concatenation of two processes:

$$\begin{aligned} A &\rightarrow B \rightarrow H(A, B) \\ \text{Where:} \\ f(a) &= b \\ \varphi(b) &= f \end{aligned} \quad (3)$$

But again the mapping φ , which plays the role of catalyst in the production of f is not produced inside the system. So another process, another mapping, is needed. It has to be placed inside the system too, but this procedure can lead to an infinite regress. In order to avoid it, Rosen introduces the mapping that makes its model interesting. In fact he looks for it in the components inside the system, in such a way that the models folds onto itself and every mapping becomes the output of another mapping of the system. He calls this

third process “*replication*”, but Letelier et al. prefer to call it “*organizational invariance*” because it is the process that closes the model onto itself and makes it a self-producing and self-maintaining system under the continuous turnover of components, while replication reminds more of biological reproduction (Letelier et al., 2006).

The third mapping is β that produces φ out of f :

$$\begin{aligned} \beta: H(A, B) &\rightarrow H(B, H(A, B)) \\ \beta(f) = \varphi &\text{ with } \beta \in H(H(A, B), H(B, H(A, B))) \end{aligned} \quad (4)$$

How can we obtain it from inside the system itself? The answer is to identify β with $b \in B$. The procedure in order to achieve this result is to consider an evaluation map $Ev_b: H(B, H(A, B)) \rightarrow H(A, B)$ that evaluates all the possible choices of φ at b . It is the mapping that correspond to an element $b \in B$.

$$\begin{aligned} Ev_b: H(B, H(A, B)) &\rightarrow H(A, B) \\ Ev_b(\varphi) = \varphi(b) &\text{ with } Ev_b \in H(H(B, H(A, B)), H(A, B)) \end{aligned} \quad (5)$$

In order to obtain β from b , the evaluation map must be invertible, that is, it must be injective.

$$\begin{aligned} \text{with } Ev_b(\varphi) &= \varphi(b) \\ Ev_b(\varphi) = Ev_b(\varphi') &\text{ implies } \varphi = \varphi' \end{aligned} \quad (6)$$

By the definition of evaluation maps $Ev_b(\varphi) = \varphi(b)$ means also that

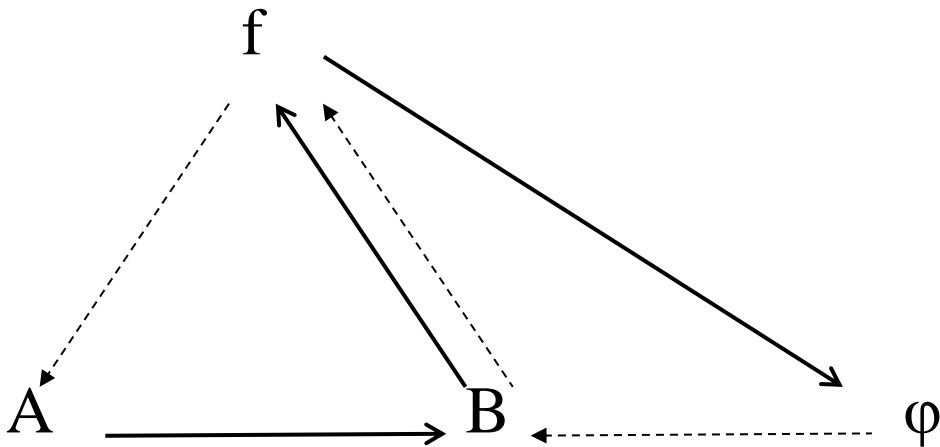
$$\varphi(b) = \varphi'(b) \text{ implies } \varphi = \varphi' \quad (7)$$

Consequently we can obtain (4), that is $\beta: H(A, B) \rightarrow H(B, H(A, B))$, as the inverse evaluation map Ev_b^{-1} corresponding to b , such that the system closes onto itself. It gives rise to a hierarchical folded chain of processes:

$$A \rightarrow B \rightarrow H(A, B) \rightarrow H(B, H(A, B))$$

Where:

$$\begin{aligned}
f(a) &= b \\
\varphi(b) &= f \\
\beta(f) &= \varphi \text{ with } \beta \text{ corresponding to } b.
\end{aligned}
\tag{8}$$



By this procedure Rosen achieved a circularity inside its model, a closure very similar to the organizational one proposed by autopoietic theory. He called it “*closure under efficient causation*” to mean that all the mappings are entailed by other mappings in the system itself. In fact f entails b , that corresponds to β which entails φ which entails f so realizing a causal loop. The only element that comes from the environment is the substrate A , coherently with the physical hypothesis of thermodynamical openness. This model expresses the basic circularity of the organization that characterizes the continuous flux of processes of production of components inside the living systems, together with its maintenance made possible by the organizational invariance embedded by the mapping β .

This model has a particular characteristic, in that its formalism allows mappings acting on other mappings, and thus self-referential functions. And also, it assumes the shape of a closed loop. This introduction of circularity into a formal model of a minimal living system is of extreme interest because it has usually been avoided in mathematics and in natural sciences. Instead Rosen, who starts from the biological point of view on the organismic unity, puts it at the core of Biology. This kind of model marks a deep differentiation from the study of artificial machines. Even if Rosen starts from mappings that remind of input-output functions, its (M,R)-Systems are characterized by a

qualitatively different approach. In fact as already pointed out above, the mappings which represent the active components, can be entailed by other mappings. On the contrary, in artificial systems the mechanic components are not produced inside the system, and consequently their functions are not entailed in the same way as it happens here. In the homeostatic models of the retroaction mechanisms, the loops concern only the variables, which re-enter the functions. In this model instead, the same functions act on each other, so that the system acts not only on some of its own parameters but on its same production rules.

The (M/R)-System is also very different from physical models, because of its formal characterization that opens the way to the study of circularity. Also it is placed on a different epistemological level, that of organization. Biology has always lacked an integrated mathematical approach similar to that characteristic of physics (Bailly and Longo, 2006). The reason is in the complexity of its phenomenology, that allows only the construction of structural models with a limited range of application. The purpose of Relational Biology is to find a top-down approach that focuses on the relational character of the organizational order proper of the living, that makes us as observers to identify its unitary identity in spite of its continuous turnover of components and of the variety of its different realizations. Along this line of research , Rosen's (M,R)-Systems are an interesting attempt to catch formally the *order in the nothing*, on the abstract level of relations between processes. The purpose in fact is explicitly to answer to Schrödinger's question on its proper level of analysis. *"The graph looks very much like an aperiodic solid, and indeed it possesses many of the properties Schrödinger ascribed to that concept. The novel thing is that it is not a "real" solid. It is, rather, a pattern of causal organization; it is a prototype of a relational model"* (Rosen, 2000).

The limit of this approach consists in its abstractness, which makes problematic to connect these formal mappings to the biochemical processes observed in the cell, even if it can provide conceptual tools in order to develop a theory of the cell. In fact the mappings, which represent the production rules in the metabolism of the living system, can be conceptually equated with enzymes, that determine the reactions that the metabolic components can undergo. Interpreted along this way, the closure under efficient causation means that all the catalysts necessary for an organism to be alive, are produced by the organisms itself (Cornish-Bowden, 2006).

(M,R)-Systems can be considered an explicitation of the concept of organizational closure proposed by the autopoietic theory, especially of the first part of the definition of the

living provided by Maturana and Varela (Maturana and Varela, 1973). Thanks to its formal nature it can be very useful in order to understand the epistemological and theoretical consequences of closure. An effort in the direction of an integration of the two theories has already been started (Letelier et al., 2003).

5. Conclusive Remarks

Starting from the theoretical perspective we tried to present here in order to deal with the complex domain of biological systems, we can assert that science needs something more than physical structural models. Understanding what makes a living being to be alive and different from physical systems and machines has thus significant consequences for scientific explanation. In fact it can widen the range of the possible descriptions, forcing us to assume different points of view and develop new tools along a path which can lead to the construction of a new class of models.

To briefly summarize the conceptual scheme we introduced here, we showed how physical, artificial and living systems can be classified according to three different kinds of order, due to the properties of the different domains where their specific properties are realized. The third kind, the *order in the nothing*, was shown to require a specific modellistic to be developed, which is the result of a long tradition of transdisciplinary scientific research. The constructivist concept of organization in fact requires a modelization placed on a level of abstraction detached from the properties of material components and characterized by the acknowledgment the circularity between the processes that realize the living. The paramount importance of this basic circularity is shown in Rosen's proto-relational model whose analysis is still only in an initial phase.

As a consequence of the remarks expressed in this paper, we can point out that the concept of organization as it has been developed by the line of research that we outlined here, can be put in the middle between two different positions. The first considers organization as an epiphenomenon, as a merely phenomenal consequence of the statistical behaviour of the material component of the system observed. This is the case of the theoretical approach developed by Kupiec and Sonigo presented above under the class of the *order from disorder* (Kupiec and Sonigo, 2000). The second position considers organization as self-sufficient in itself and puts it on an independent level. This theoretical position gives

rise to a strong duality between structure and organization, that could lead to an ontological contraposition.

The approach whose most rigorous expression is achieved by the autopoietic theory considers the relation between organization and structure as a descriptive complementarity: “*the [organization] of living systems and their actual (material) components are complementary yet distinct aspects of any biological explanation: they complement each other reciprocally*” (Varela and Maturana, 1972; see also Varela, 1979). They are mutually defining concepts, because *structure* is what changes while *organization* remains invariant. The distinction thus, is an epistemological operation, a useful tool in order to focus on different aspects of the same system. It is also important to underline again that the organizational scheme characterizing a system has important consequences as it allows to make sense of the presence of global processes in the system considered. The basic example is the self-stabilization achieved when a circular relation is realized, like in homeostatic machine. At an higher level of complexity typical of living system the role of organization is crucial in order to understand not only self-stabilization but also self-production.

A new step in the development of a Relational Biology that recognizes the mutual interaction between the structural and organizational description can be the attempt to an integration of the thermodynamical and relational description. The line of development that goes from the insight and issues coming from biology to the development of physics is characterized by the attempt to widen thermodynamics in order to make sense of the peculiarity of the living systems (Prigogine and Stengers, 1979; Kauffmann, 2000). A possible line of research, coherent with the approach that we outlined here, is that of a relational thermodynamics (Mikulecky, 2001b). An interesting result in this direction, if we assume the point of view of autopoietic theory, is Tellegen’s theorem, based on the circular scheme of closure in electronic circuits (Tellegen, 1952; for the possible connections with the autopoietic theory see Letelier et al., 2005). This approach is still related to the description of artificial machines, based on a positional relational order, but it can be a starting point towards the understanding of the consequences of the relational circularity in the thermodynamics of living systems.

References

Abraham T. H., 2004, *Nicholas Rashevsky's Mathematical Biophysics*, Journal of the History of Biology, v. 37, pp. 333-385.

Atlan H., 1972, *L'organisation biologique et la théorie de l'information*, Hermann, Paris.

Bailly F. & Longo G., 2006, *Mathématiques at sciences de la nature. La singularité physique du vivant*, Hermann Éditeurs, Paris.

Bernard C., 1865, *Introduction à l'étude de la médecine expérimentale*, Baillière, Paris.

Bich L., 2005, *Autopoiesis and Emergence*, in Minati G., Pessa E. and Abram M. (eds.), *Systemics of Emergence, Research and Development*, Springer, USA, pp. 281-292.

Bich L. and Damiano L., 2007, *Theoretical and Artificial Construction of the Living: Redefining the Approach from an Autopoietic Point of View*, Origins of Life and Evolution of the Biosphere (in press).

Cannon W., 1932, *The Wisdom of the Body*, Norton, New York.

Ceruti M., 1989, *La danza che crea*, Feltrinelli, Milano.

Cornish-Bowden A., 2006, *Putting the Systems back into Systems Biology*, Perspectives in Biology and Medicine, vol. 49, pp. 475–489.

Damiano L., 2007, *Unità in dialogo*, Bruno Mondadori, Milano (forthcoming).

Dumouchel P. and Dupuy J. P. (eds), 1983, *L'auto-organization. De la physique au politique*, Seuil Paris.

Ganti T., 2003, *The Principles of Life*, Oxford University Press, Oxford.

Jantcsh E., 1980, *The Self-organizing Universe*, Pergamom, New York.

Kauffman S., 2000, *Investigations*, Oxford University Press, Oxford.

Kupiec J. and Sonigo P., 2000, *Ni Dieu ni gene. Pour une autre théorie de l'hérédité*, Éditions du Seuil, Paris.

Letelier J.C., Marìn G. and Mpodozis J., 2003, *Autopoietic and (M,R) systems*, Journal of Theoretical Biology, n. 222, 2003, pp. 261-272.

Letelier C., Kuboyama T., Yasuda H., Cárdenas M. L. Cornish-Bowden A., 2005, *A self-referential equation, $f(f) = f$, obtained using the theory of (M,R) systems: overview and applications*, in H. Anai and K. Horimoto (eds.), *Algebraic Biology 2005*, Universal Academy Press, Tokyo, pp. 115–126.

Letelier J-C., Soto-Andrade J., Guinez-Abarzua F., Cardenas M-L., Cornish-Bowden A., 2006, *Organizational Invariance and metabolic closure: analisis in terms of (M,R) systems*, Journal of Theoretical Biology, v.238, pp. 949-961.

Maturana, H., 1988, *Reality: the search for objectivity or the quest for a compelling argument*, Irish Journal of Psychology, 9 (1): 25-85.

Maturana H., 2000, *The Nature of the Laws of Nature*, Systems Research, 17, 2000, pp. 459-468.

Maturana H. and Varela F., 1973, *De Máquinas y Seres Vivos: Una teoría sobre la organización biológica*, Editorial Universitaria, Santiago.

Maturana H. and Varela F., 1987, *The Three of Knowledge*, Shimbhala, Boston.

Mikulecky D., 2001a, *Robert Rosen (1934-1998): a snapshot of biology's Newton*, Computers and Chemistry, vol. 25, pp. 317-327.

Mikulecky D., 2001b, *Network Thermodynamics and Complexity: a transition to relational system theory*, Computers & Chemistry, v.25, pp. 369-391.

Morin E., 1973; *Le paradigme perdue*, Seuil, Paris.

Morin E. and Piattelli-Palmarini M.(eds), 1974, *L'unité de l'homme*, Seuil, Paris.

Nicolis G. and Prigogine I., 1989, *Exploring complexity*, Freeman, New York.

Piaget J., 1967, *Biologie et connaissance*, Gallimard, Paris.

Pichot André, 1999, *Histoire de la notion de gene*, Flammarion, Paris.

Prigogine I. and Stengers I., 1979, *La Nouvelle Alliance. Métamorphose de la science*, Gallimard, Paris.

Rashevsky N., 1954, *Topology and Life: in Search of General Mathematical Principles in Biology and Sociology*, Bulletin of Mathematical Biophysics, v.13, pp. 317-348.

Rashevsky N., 1960, *Mathematical Biophysics. Physico-Mathematical Foundations of Biology*, Dover, New York.

Rashevsky N., 1972, *A Unified Approach to Physics, Biology and Sociology*, in Rosen (ed.), *Foundations of Mathematical Biology*, Academic Press, New York, vol. III, pp. 177-190.

Rosen Robert, 1958a, *A relational theory of biological systems*, Bulletin of Mathematical Biophysics, v. 20, pp. 245-260

Rosen Robert, 1958b, *The Representation of Biological Systems from the Standpoint of the Category Theory*, Bulletin of Mathematical Biophysics, v. 20, pp. 317-345.

Rosen Robert. 1959, *A relational theory of biological systems II*, Bulletin of Mathematical Biophysics, v. 21, pp. 109-128

- Rosen R., 1972, *Some Relational Cell Models: The Metabolism-Repair Systems*, in Rosen (ed.), *Foundations of Mathematical Biology*, Academic Press, New York, vol. II, pp. 217-253.
- Rosen R., 1991, *Life Itself: a Comprehensive Inquiry into the Nature, Origin, and Fabrication of Life*, Columbia University Press, New York.
- Rosen R., 2000, *Essays on Life Itself*, Columbia University Press, New York.
- Schrödinger E., 1944, *What's Life? The Physical Aspect of the Living Cell*, Cambridge University Press, Cambridge.
- Spencer Brown G., 1969, *Laws of Form*, George Allen and Unwin Ltd, London.
- Stengers I., 1985, *Genealogies de l'auto-organization*, Cahiers du CREA, 8.
- Stengers I., 2003, *Cosmopolitiques*, 6, *La Découverte*, Paris.
- Stewart J., 2002, *La modélisation en biologie*, in Nouvel P. (a cura di), *Enquête sur le concept de modèle*, Press Universitaires de France, Paris, pp. 43-66.
- Tellegen B., 1952, *A general network theorem with applications*, Phillips Research Report, 7, pp. 259-269.
- Varela F., 1979, *Principles of Biological Autonomy*, North-Holland, New York.
- Varela F. and Maturana H., 1972, *Mechanism and Biological Explanation*, Philosophy of Science, v.39, n.3, pp. 378-382.
- Varela F., Maturana H. and Uribe R., 1974, *Autopoiesis: the Organization of Living Systems. Its Characterization and a Model*, Biosystems, 5, pp. 187-196
- von Bertalanffy, L., 1949, *Das Biologische Weltbild: Die Stellung des Lebens in Natur und Wissenschaft*, Francke, Bern.
- von Foerster H., 1980, *Observing Systems, Selected Papers of Heinz von Foerster*, Intersystems, Seaside.
- von Foerster H., Zopf G (eds), 1962, *Principles of Self-organization*, Pergamon, London.
- von Neumann J., 1966, *Theory of Self-Reproducing Automata*, University of Illinois Press, Urbana.
- Weiss P., 1969, *The Living System: Determinism Stratified*, in Koestler A. and Smythies J. (eds.), *Beyond Reductionism: The Alpbach Symposium*, Hutchinson & Co, London, pp. 3-55.
- Weiss P., 1974, *L'archipel scientifique*, Maloine, Paris.

Wiener N, 1948, *Cybernetics, or Control and Communication in the Animal and in the Machine*, MIT, Cambridge MA.