Theoretical and Artificial Construction of the Living: Redefining the Approach from an Autopoietic Point of View

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Abstract In this article, we would like to discuss some aspects of a theoretical framework for Artificial Life, focusing on the problem of an explicit definition of living systems useful for an effective artificial construction of them. The limits of a descriptive approach will be critically discussed, and a constructive (synthetic) approach will be proposed on the basis of the autopoietic theory of Maturana and Varela.

Keywords *Self-organization – Autopoiesis - Biological autonomy - Artificial life – Constructivism.*

> "*If you want to explain lightning, you must provide a mechanism that generates it.*" (H. Maturana)

We would like to actually counteract the statement according to which there are no forms of life simpler than 'ours', but not by bringing new data. We would rather shift the attention from the applicative level to that of the theoretical foundations of Artificial Life[*], focusing in particular on the problem of an explicit definition of the living systems useful for an effective artificial construction of them. Therefore we present some epistemological and theoretical arguments which lead us to assert, at a general level, that life may be possible -at least in principle- with different chemical systems. This thesis is developed in three steps: (a) we point out the limits for artificial life of a merely

[*] Historically Artificial Life was born as a computationalist approach characterized by the attempt to simulate the properties of living systems. Recently a new approach emerged from the chemical area, called Synthetic Life, that has become a well established line of research in the scientific community. In fact it is one of the main topics of the conferences in this area (cfr. for example Tenth International Conference on the Simulation and Synthesis of Life, www.ALIFEX.org). Proposing a theoretical framework for Artificial Life we mainly refer to the latter approach, expressing some critical remarks on the former. Our purpose here is to study the theoretical foundations of this discipline, which often implicitly refers to ideas that are similar to those expressed by autopoietic theory, whose importance is nevertheless underestimated.

descriptive (analytic) *approach* to the definition of the living; (b) we propose a *constructive* (synthetic) *approach*, namely the autopoietic one; (c) we derive from this a theoretical guide-line for artificial life, constituted by a principle that disengages the material realization of living systems from the chemical composition of 'our' life.

§1- The problem of the definition of the living

Our approach is based on a very simple epistemological remark, consisting in the idea that every attempt to construct alternative forms of life is doomed to fail if it does not face one of the main theoretical problems of biology: what is the individual living being- that is, *how it is organized.*

This assertion corresponds to a strong criticism of the traditional theoretical definitions of the biological phenomenon: the refusal of the definitory procedures based on lists of properties, as they show two deep limits -a logical and an applicative one. The first consists in a vicious definitory circularity, for the identification of the relevant properties and the possibility to know when the list is complete require *a-priori* the knowledge necessary to the recognition of an organism. The second is the risk to identify with a living being a system that simulates some of the behaviours of life, even if its nature is very different from a biological one. In fact this procedure misses the peculiarity of the internal processes that produce these behaviours and that continuously turn a disordered manifold of physico-chemical elements into the active and integrated totality of the organism.

Such a criticism does indeed challenge the definition of life implicit in the question, which displays a list of biological properties that includes "metabolism", "self-reproduction" and "evolvability". The main failing of this formulation is that it puts the defining operation on two levels of description, the *molecular level* (*metabolism*) and the *level of species* (*reproduction*, *evolutive variability*), which miss the organization of the individual biological unity, so that a consistent definition of it cannot be produced. The categories of "*self-reproduction*" and "*evolvability*" do not provide but presuppose -on the *logical*, *operational* and *phenomenological* levels – the concept of biological individual, for the individual is what reproduces itself and, by so doing, moves ahead the evolutive process: the first organism has to be alive before reproduction and evolution can arise. A satisfying definition of the biological unity is not either provided by the general theoretical category of "metabolism". If it remains on the level of elaboration typical of molecular biology it does not succeed in expressing the specific conditions -

that we will show are organizational - under which the metabolic transformations give rise and are integrated into an individual unity.

And yet this is the task of a definition of the living that aims to open an effective solution space to the main question of Artificial Life: not to produce a list of biological properties, but to define the individual living being: to give rise, at a theoretical level, to the metabolic mechanism capable of producing a biological unity.

§2-Autopoiesis: a possible framework for Artificial Life

A biological theory able to satisfy this definitional criterion is autopoiesis (Maturana and Varela, 1973), the theoretical framework that we propose here for Artificial Life.

This theory does not want to answer the question of the artificial life, nor that of the origins of the living, but to provide a general definition of life, referred to the whole biological domain. The specificity of autopoietic theory consists in furnishing a new solution to this classical problem, which corresponds to a new concept of life science. It is the idea of a *synthetic biology*, () characterized by an epistemological attitude which doesn't condemn the observer to an endless analysis of all the variety of biological forms, but requires him to conceptually construct a biological mechanism capable to produce all the living phenomenology. It is a way of conceiving *theoretical biology* which is particularly suitable for artificial life, for it proposes to develop a *constructive biology*: a dimension of the theoretical research where the *scientific explanation* coincides with the *conceptual construction of the mechanisms* able to generate the object studied.

The autopoietic constructive definition of life is developed in few simple steps, marking a pathway which can efficaciously lead scientific rationality from the *theoretical* to the *artificial construction* of the living.

The *first* of these steps consists in the individuation of the object that is phenomenically primary in life science. The autopoietic theory finds it through the assumption of a methodological principle fundamental in the systemic biology of the 20th century: the idea that the object pertaining to the inquiry on life consists not in the physico-chemical components, but in the complex individual unities in which they are dynamically integrated (Ceruti, 1989).

It is a methodological option that allows autopoietic biology to face the problem of providing a constructive definition of life, for it focuses the theoretical research on the minimal living unity. As Maturana and Varela acknowledge, the cell is the biological unity that not only composes all the living organisms, but also generated them all through

the evolutive differentiation. To produce the whole domain of the living it is necessary to build the generative mechanism of the cellular system.

This specification of the object of the constructive definition of life constitutes the *second* step in the development of autopoietic biology. The *third* provides a crucial hypothesis for this definitional construction. It consists in the idea that the cellular system is able to perform a creative activity on itself, being not the product of exogenous forces, but of an internal action of self-production.

This thesis too is the development of an intuition belonging to the systemic biology, particularly to the lines of research responsible of the introduction of the notion of "*self-organization*" (Damiano, 2006). These are explorative directions characterized by the qualification of biological systems as "*autonomous*", relatively independent from environmental perturbations thanks to the capability to regulate their own internal processes and maintain their stability (*homeostasis*). This property of the organism to act on itself is what is strongly empathised by autopoietic theory, which re-conceptualizes it starting from simple remarks about the way cellular unities work:

a) the cell is continuously produced by a set of interconnected processes that involves its chemical components, transforming them continuously;
b) the membrane that separates the cellular system from its environment, individualizing the cell, is produced not by external actions, but by metabolic internal transformations;
c) through this boundary the cellular unity actively exchanges energy and matter with the environment (*thermodynamical openness*), supplying its internal processes.

It is not a simple re-definition of the previous idea of biological autonomy. The theoretical shift from the notion of *self-regulation* to that of *self-production* – better: "*autopoiesis*" – informs in a decisive way the development of the autopoietic biology. It leads to the identification of the *generative mechanism of the cell* – to be produced in order to define the biological domain – with the *mechanism of cellular self-production*.

The procedural solution adopted by autopoietic theory in this direction follows the classical canons of the scientific description of natural dynamics: to distinguish the invariant aspect from the variable and define their relations. The singularity the theory has to face is the specificity of the dynamical systems to be modelised: an object that is permanently generated and maintained by the continuous transformation of its components.

The conceptual formalization of this particular dynamics is the *fifth* step of the path, which consists in the following description of the cellular dynamics of self-production:

- *The variant aspect* is the "*structure*" of the cell, given by its materialization at any instant, namely the transient aggregation of physico-chemical elements functionally and structurally correlated;
- *the invariant aspect* is the "*organization*" of the cellular system, consisting in the relational unity in which the components are connected, namely the set of all structural and functional elementary relations that define the cell as an individual persistent unity;
- the *interplay* between variant and invariant is such that the continuous structural change, due to the transformative interactions of the components, produces and maintains the organization, which, in turns, enables the structural change.*

The *sixth* step provides the definition of a plausible mechanism for this dynamics. It is a theoretical elaboration that, once again, develops the insights of systemic tradition, implicitly recovering the piagetian concept of *organizational closure* (Piaget, 1967). It corresponds to the notion of a circular dynamic mechanism: a close chain of operations of elements transformation 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 this piagetian idea in the definition of autopoietic organization, conceived by Maturana and Varela as the net of processes of production, transformation and destruction of components, that:

1. through their interactions and transformations recursively realize and regenerate the same network that produces them; and
2. constitute the system as a concrete unity in the space in which they exist, by establishing its boundary and thus specifying the topological domain of its realization.

It is a definition of the living cell organization that provides a theoretical principle which suggests an answer to the question about artificial life we are dealing with. In order to artificially construct the living it is necessary to set aside the *structural (intrinsic) properties* of the elemental components, focusing on their *relational properties*. The only

* The autopoietic theory affirms the generality of this definition of biological dynamics, and not only because it characterizes the fundamental unity of every organism. Maturana and Varela think that all the biological transformations – ontogenetic and filogenetic- show the conservation of a unity through structural variation.

condition imposed to the constituents is to have the capability of realizing a process that has the characteristics of the autopoietic one. In this perspective, life in general does not depend on the presence of some particular chemical component typical of terrestrial life, for example DNA, but rather on the way the elements are related.

With this principle, the autopoietic theory opens a solution space for the artificial construction of life which is defined along two directions, a theoretical and a methodological one:

(a) the realization of the living can be manifold, i.e. in principle there are not limits to the chemical composition of life;

(b) the artificial production of life has to adopt, instead of a bottom-up approach, a top-down one, which goes from the integrated unity towards the constituents.

§3- Remarks on the artificial construction of the living

This solution space to the problem of Artificial Life has strong and deep consequences with regard to the application of the most common paradigm in this field, namely the computationalist one, refusing computers as the proper model or medium for the production of alternative forms of life.

The autopoietic approach, which describes the relations between metabolic processes as circular and recursive, is in fact in strong contrast with the metaphors of the genetic "program" and of the organism as an "information processing machine", which have their paradigmatic origin in von Neumann's work (von Neumann, 1966). The notion of *organizational closure* characterizing the living, formalized by Rosen in his theory of M/R-Systems (Rosen, 1958,1991; Letelier et al., 2006), makes to collapse the distinction between hardware and software that characterizes the machine-metaphor, because the same components can be considered as playing the role of both hardware and software at the same time. In this theoretical perspective the computationalist approach is not able to deal with the intertwining of roles that characterizes the biological processes. In addition, the circularity of organization requires a top-down approach from the integrated unity to the processes involving the components (Bich, 2005). So it excludes those computational attempts to modelise the biological process of autopoiesis, characterized by a bottom-up approach of pattern formation, which aim to simulate only the formation or the repairing of a boundary. These models consider only the second part of the definition of autopoiesis, and can reach only a topological "closeness".

The limits of the computationalist approach demand and bring out the importance of alternative studies and experimentations based on different assumptions. A relevant example is the research line of Luisi's synthetic life (Luisi, 2006), that tries to realize the minimal cell in the same molecular medium in which they can be observed. It is the realization of the generative autopoietic approach in the domain of Artificial Life, coherently with the space of solution opened by autopoietic theory. In fact it moves from organization to structure, from the properties of the whole to those of components. Certainly it also requires an analysis of the results obtained in order to evaluate if the auto-producing synthetic systems respect the definition of autopoiesis, that is fundamentally the capability to produce a closure that is not only topological but also organizational.

This is one of the challenges that nowadays stand out in the emergent domain of the autopoietic studies on life. It consists in the necessity of an integration of the efforts concerning the two fundamental conditions provided in the autopoietic definition: the production of a topological boundary and the organizational closure from which it originates.

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