Question n.1 What are the possibilities and the limits of the synthetic study of the origins of life?

BEYOND THE PRINCIPLE OF CONTINUITY AT THE ORIGINS OF LIFE: SYNTHETIC BIOLOGY AND THE CHALLANGE OF PREBIOTIC TRANSITIONS

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Abstract
In this paper I will discuss the role played by Synthetic Biology in two opposing scenarios which attempt to describe the origins of life, based respectively on continuity and discontinuity. While the first one does not present, at least in principle, conceptual difficulties as past event are explained by means of forces and causes at work in the present; the second one is problematic, because it undermines this very strategy. I will provide an argument in favor of the plausibility of the discontinuous framework, based on a specific interpretation of the notion of transition, and I will point out the limits it imposes on the investigation of the origins of life. Nevertheless, I will argue, it does not imply the impossibility of testing scientifically our hypotheses, since Synthetic Biology can still enable the study of the origins of life even in this scenario, by providing 'counterfactual' experiments.

INTRODUCTION

Let us consider two possible general scenarios for reconstruction and study of the historical process that led to the origins of life. One is organized around the so called 'principle of continuity'. The other acknowledges discontinuity as one of the crucial features in pre-biotic evolution, characterized by radical transitions that involve both the context (the boundary conditions) and the (pre-biotic) actors that participate in this historical process. Synthetic Biology plays a role in both theoretical contexts (Luisi, 2006; Luisi et al., 2006; Rasmussen et al., 2009; Luisi & Stano, 2010).

The principle of continuity is the direct descendant of Lyell's principle of *actualism* in geology, one of the theoretical pillars of evolutionary gradualism. It asserts the need to explain the past by causes now at work and, consequently, it excludes the investigation of possible different forces in act in different times. As explained by Griesemer (2008), in some contemporary approaches to the issue of the origins of life, assuming the validity of this principle is considered as the only guarantee of the possibility to test scientifically our hypotheses on pre-biotic and early evolution (see for example Morowitz, 1992). The theoretical framework underlining this scenario is that of a direct entailment between past and present in the pre biotic and biological history, due to a constancy in the laws regulating it and in the general boundary conditions. It leads to the epistemological thesis according to which there is in principle a reciprocal derivability between the descriptions and models of present and past phenomena.

In this scenario, therefore, the origins of life is in principle derivable from both the properties of basic molecular components of present living systems, and from the general properties of simple life forms. The role of Synthetic Biology is, thus, to address the issue of the origins of life by investigating the steps of this derivation process through the development of bottom-up and top-down approaches, but can in principle not only be complemented, but even replaced by other forms of investigation, such as computational ones.

Nevertheless, the continuity principle is not universally shared and has already been challenged in many fields, such as for example in geology and biological evolution (Gould, 2002), in complex systems studies (Kampis, 1991; Kauffman, 2000; Bich and Bocchi, 2011; Longo et al , 2012), and even in molecular evolution (Di Giulio, 2004). And it is in the context of discontinuity, I argue, that Synthetic Biology plays a crucial role in overcoming the intrinsic limitations imposed by the thesis of different forces and entities at work in different times.

TRANSITIONS AND DISCONTINUITY: EPISTEMOLOGICAL IMPLICATIONS

The importance of discontinuity in natural processes has been acknowledged both in cosmology and in evolutionary theory (Kauffman, 2000 and 2008; Gould, 2002), but its role in questioning the principle of continuity has been pointed out by the idea of 'transition' (Maynard Smith & Szathmáry 1994), and in particular by some radical interpretations of it (Kauffman, 2000; Knoll and Bambach, 2000). The latter ascribe to transitions not just a difference in the rhythms of transformation, opposed to a gradualist view, but a redefinition of dynamics and rules of interactions, caused by the emergence of new entities and levels of organization which play an effective role in modifying the contexts in which they are involved.

The theoretical and epistemological core of this idea will be discussed, in particular its link with the notion of diachronic emergence as non-derivability of events taking place at different steps in the temporal line. The emergence of new entities triggers the redefinition of systemic unities, rules of interactions and boundary conditions that affect each transitional step (Kampis, 1991), and in so doing it leads to the generation of qualitatively new evolutionary scenarios: new functional components generate new dynamics, that is, novelty contributes to novelty on a higher systemic level (see also Maturana & Mpodozis, 2000). As Kauffman (2000) asserts, the novel laws that emerge in the historical process are similar to the introduction of new axioms and — I add — new rules of transformation, from which new consequences can be derived.

This form of change constitutes a challenge to our capability of modeling, as it imposes strong limitations in the possibility of studying past phenomena on the basis of the knowledge of present ones (and *vice versa*). In the first place it introduces a strong version of novelty that redefines its context. Secondly, if a behavior, a property or a dynamics cannot be derived from its antecedent, but requires the formulation of new models, we are not facing just a problem of choice of the right time scale for our models. We are facing, instead, some sort of "fragmentation" of the domain of temporal validity of our models in the domain under investigation that, of course, collides with the principle of continuity.

DISCONTINUITY AND THE ORIGINS OF LIFE: THE ROLE OF SYNTHETIC BIOLOGY

The idea of emergent transitions entails the radical thesis according to which at any step in pre-biotic evolution there could have been a *takeover* by new forms of proto-life, replacing older ones and thus generating new contexts by cancelling the previous ones. Coherently with the epistemological debate on complex systems, this perspective points out (a) the limits in the domain of temporal validity of models, which is divided into sub-domains by those transitions which change the rules of natural processes, and (b) the importance of developing a heuristics of discontinuity which, I propose, can be based on the logic of historical counterfactual (Hawthorn, 1991).

Surely, it is problematic to conceive the possibility of investigating the past if we cannot totally rely on the knowledge of the present. Maybe, it is still possible to think about tracing some of the characteristics of LUCA, which constitutes the first step of life as we know it. But the three of life is quite deeper and more complex. The image of a regular tree can be even misleading in this case, as it hides the possibility of takeovers. In fact, for this reason it is spreading as an alternative the use of the metaphor of the *palm-tree* of life, of which LUCA constitutes only the last segment, from which all present life evolved.

The idea of discontinuity seems to preclude the possibility of a scientific investigation of the previous segments of the trunk of the palm-tree of life, cancelled by the sequence of emergent steps and conserved only in the form of historical constraints. Nevertheless this conclusion is not totally true. Here Synthetic Biology enters the picture by attempting to create today new forms of pre-biotic evolution without necessarily claiming that they are the true antecedents of contemporary life: in doing so it can play the role of counterfactual or, better, constitute a unique case of counterfactual historical experiment.

Gould (1989) suggests that paleontology can provide counterfactual scenarios in a weak sense, and points out their importance for a deeper understanding of life. Paleontology shows specific moments and geographic areas in which alternative evolutionary lines have been experimented, and which can provide useful information about the historical constraints that evolution has imposed on living systems. But it can never provide the possibility of a real counterfactual experiment.

What Synthetic Biology can do, instead, is precisely this: to explore experimentally some of the possible pre-biological or early biological worlds which, by analogy, can provide useful information about a subset of the constraints that early evolution had to satisfy. As such, they do allow the formulation of some hypothetical scenarios about the history of life on earth.

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