Question N. 5: What can synthetic biology offer to the study of cognition?

ON THE ROLE OF SYNTHETIC BIOLOGY IN THE INVESTIGATION OF MINIMAL COGNITION: AN ARGUMENT FROM THE POINT OF VIEW OF REGULATION

Leonardo Bich and Alvaro Moreno

IAS-Research Center for Life, Mind and Society, Department of Logic and Philosophy of Science, University of the Basque Country (EHU/UPV)
Avenida de Tolosa 70, 20018 Donostia-San Sebastián, Spain

email: leonardo.bich@ehu.es

Abstract

In this paper we argue in favor of a crucial role to be assumed by Synthetic Biology for Artificial Life in relation to the study of the origins and instances of minimal cognition. We do so by proposing a theoretical model of the emergence of specificity in the organism-environment interaction grounded in the molecular domain and originating from the minimal mechanisms of biological regulation. We distinguish between two forms of regulation - dynamical stability and active regulation - and we show how the second implies a more complex form of meaningful interaction between organism and environment and is not realizable outside the molecular domain. As consequence we argue that synthetic biology is a privileged approach to the study and modeling of these mechanisms and of the behavior of their basic instances, with substantial advantages with respect to the more traditional hardware and software methodologies.

1. Introduction: life and cognition

According to the systemic approach to the investigation of living system based on the notion of *autonomy*, the foundations of minimal cognition are to be identified in the distinctive properties of organisms: grounded in their biology. The basic idea common to the tradition of autonomy is that living systems are metabolic self-producing systems able to self-maintain and keep invariant their network organization through the continuous exchange of matter and energy with the environment (Piaget, 1967; Maturana and Varela, 1980; Rosen, 1991; Kauffman, 2000; Ganti, 2003; Ruiz-Mirazo and Moreno, 2004).

This idea is at the basis of the thesis of the equivalence between life and cognition brought forth among the others by Piaget (1967) and Maturana and Varela (1980), according to which cognition consists basically in the viable and meaningful interaction between an organism and its environment, rather than in the processing of information (for a discussion of the relationship between autonomy, agency and minimal cognition see for example Barandiaran and Moreno (2006) and Van Dujin et al. (2006)). Since these pioneering works, self-regulation - considered generally as the capability of living systems to internally compensate for perturbations - has been considered as playing a central role in the origin of cognitive processes, even if a precise definition and a detailed model of regulation has not been provided. According to the autonomy perspective, cognitive processes do not consist in representations of an independent and external reality, but in the association of internally generated operational meanings (meanings expressed in dynamical patterns of self-regulation) for environmental variations perceived as perturbations (Bich and Damiano, 2012).

In line with this theoretical framework we argue that, if considered in strict relationship with life (coextensive or not), cognition necessarily depends: (1) on its being embedded in the self-maintaining character of the metabolism and (2) on the presence of biological mechanisms of regulation. Cognition emerges when distinctions in the environment make a difference for the organism, and this occurs through their relationships to mechanisms of self-regulation.

2. Forms of regulation as the basis of minimal cognition

In our paper we will address the first two stages of the relationship between life and cognition, based on two distinct ideas of regulation, respectively: dynamical stability (and related notions, such as homeostasis and feedback) and active regulation (Bich, 2012). Stability is a general property that consists in those interactive dynamics with the environment or with other systems in which living systems respond to external *perturbations* by means of endogenous patterns of compensations (externally triggered chains of internal reciprocal adjustments). Active regulation, instead, consists in those dynamics capable of activating and modulating responses to specific features of the interactions with the environment, that are recognized as such by a dynamically decoupled subsystem of the living organism.

In the case of dynamical stability, the response of the system is directly dependent on the perturbation: it is a form of homeostasis in which the compensation of the perturbation takes place in a network through the coupling between subsystems or processes, that interact with each other by opposing the displacement of the system from a certain state triggered by the perturbation. Mechanisms of stability are too simple to account for the origins of specific, meaningful, interactions. The environment is still an indistinct background, a source of noise: the system cannot distinguish specific features of the environment, which provides just viable or non viable perturbations.

What is needed for a transition from noise towards specificity, we argue, is a qualitatively different mechanism. In opposition with the widespread idea of regulation as synonymous with feedback and homeostasis, and described in terms of stability (see, for example, Fell, 1997; Hofmeyr and Cornish Bowden, 2000; Bechtel, 2008), we define (and model) it as full-fledged (or active) of regulation: the capability of a system to mediate the effect of a perturbation by acting on its own internal dynamics through modulation or selection between distinct available internal regimes by means of a dedicated decoupled subsystem.

Unlike stability, which involves an undifferentiated network response, regulation implies that the activity of at least two distinct subsystems can be operationally identified: a constitutive one responsible of the self-production and self-maintenance of the system; and a regulatory one responsible for handling the perturbation and (reversibly) shifting between distinct available constitutive regimes, instead of allowing the perturbation to modify each time, irreversibly and unspecifically, the core organization of the system..

When a mechanism of regulation is at work, the environment is not only a source of indistinguishable perturbations, but also of specific and recognizable ones. The crucial point is that the regulated system reacts in a qualitatively new way: the *recognizable* and specific features of the interaction with the environment, do not determine directly the response of the system, but activate the regulatory subsystem which, in turn, switches the constitutive subsystem to a new modified state. able to cope with the initial trigger (the organism eats the new food, or secrets chemicals to neutralize a lethal substance).

It should be underlined that the “specific feature” becomes a “recognizable interaction” because of the nature of the relation it holds with the regulatory subsystem. The regulatory subsystem is specifically sensitive to a concrete feature in the sense that it establishes specific classes of equivalence with respect to these specific variations (Rosen 1978). Therefore we argue that, compared to the case of stability, the specificity of interaction and the association of environmental features with regulatory activation represent further steps in the origin and development of minimal cognition.

3. Conclusive remarks

On these bases, we advocate the thesis according to which minimal cognition requires mechanisms of self-regulation, and that in order for a transition from indistinct noise towards specificity and meaningful interaction to take place, full-fledged mechanisms of active regulation are necessary.

One of the main implications of this framework is that artificial (non-biochemically based) systems do not satisfy two main conditions for the mechanism of active regulation proposed. In fact, in the first place the regulatory subsystem should be produced and maintained by the system to which it belongs. In the second place, it should provide a functional (Mossio et al., 2009) contribution to the system, that is, ensuring the self-maintenance of the system in changing environmental conditions. In artificial systems, on the contrary, this task is not endogenously specified, but it is dependent on the goals of the designer.

Therefore, we argue that in order to address the issue of the origin of cognition and study its minimal instantiations synthetic biology exhibits clear advantages with respect to hardware and software investigations, as fact simplified cognitive mechanisms can be realized and studied by synthetic tools in the same domain in which they are realized in nature (Rosen, 1991; Boden, 1999), thus addressing distinctive properties not available to the others domains of artificial intelligence.

In conclusion, we sustain the thesis according to which synthetic biology can offer to the study of cognition the implementation of molecular models of basic regulatory mechanism, and of regulation based interactions with the environment, and the investigation of the range, variety and complexity of these "meaningful" interactions considered at the basis of minimal cognition.

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