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The emergence of life and evolution: Towards a categorial approach

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Abstract

Among the list of proposed questions in “Open Problems in Artificial Life” (Bedau et al. 2000) the first, “how does life arise from the nonliving?” is certainly one of the most difficult to answer. The first and main challenge in the understanding of the way that life emerged from the nonliving comes from our lack of knowledge of the living organism and paradoxically, the limitations which we impose to it, so that what we call organism remains a stillborn entity at best. The second challenge is creating a formal language suited to represent the organism while taking into account all its quantitative and qualitative characteristics.
Consequently, to progress in the understanding of the organism, it is first essential to integrate two data. The first one being that both the questions “what is the living?” and “how does the living arise?” are connected. In other words, before being able to apprehend correctly the emergence of life, it would be necessary to know how to model it, almost through a theoretical biology approach. The second datum is related to finding an appropriate language which is capable of describing the organism in all its dimensions.
In this present work, we want to find answers to the first list of Bedau's questions through a more integrative definition of the living which enables us to think of its mode of emergence from the nonliving in a coextensive way. For this, we propose a categorical model of the organism. This seems to be the most suitable language at the current stage of knowledge in describing such a phenomenon.

To formalise our proposal, we use a branch of mathematics called category theory. A category is a structure that appears like a directed graph, which consists of objects and arrows between them. However, in a category, two paths from A to B may be declared equivalent in a commutative diagram. Beside, a functor is a mapping from one category to another that preserves the structures.
As far as our main purpose is to unit entities in a special bigger one, this requires encoding interfaces, functional relationships, and transfer of data, extensive and intensive properties. In short, to convert an organism appearance into the ontology of category theory, we need concepts that allow us to group and lay out things. These concepts are best captured by pushout and its dual pullback expressed in terms of diagrams of arrows, which are special types of more general constructs known as colimit and limit respectively.
In a category $\mathcal{C}$, the pushout (figure 1) for two morphisms f :A $\rightarrow$ B and g : A $\rightarrow$ C is an object D, and two morphisms j : B $\rightarrow$ D and k : C $\rightarrow$ D, such that the square commutes (f o g = j o k); and for any objet D’ and pair of morphisms j': B $\rightarrow$ D’ and k': C $\rightarrow$ D’ satisfying j' o f = k' o g, there is a unique morphism h : D $\rightarrow$ D’ such that diagram commutes. A dual is obtained by reversing the arrows. A complete presentation of category theory can be found in Lawvere and Schanuel (1997), and Ehresmann and Vanbremersch (2007).

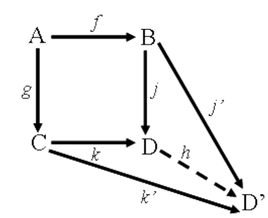

Figure 1

Pushout diagram

Three intuitions guide our approach of the living. First: a living organism transcends its material template. Second: it is a hierarchical multi-scale system within an environment (Cottam et al. 2004). Third is the idea of closure or autonomy, which was extensively analysed *inter alia* by Robert Rosen (1991). We argue that these different intuitions and characteristics of an organism are best described through the importance of colimits, functors or identity arrows. From a single cell to a complex multicellular organism such as a plant, a repetitive multi-scale hierarchical concept is found embedded, the one in the other, giving the hierarchical system a self-similarity dimension.

An organism appears with the advent of the closure of the system. From the categorical viewpoint, it happens with the instantiation of a functor called the "quale identity". The quale can be illustrated by a diagram using the categorial idea of identity arrow. Although there are other arrows with the same object for domain and co-domain, the identity arrow defines a unique relationship of the object with itself.

The dual of the quale identity is represented by the hierarchical multi-scale system. While the colimit, which is a bottom-up process, constructs the system, the quale identity is a top-down process which consolidates it. At first, the final system appears as a resulting entity of a pullback and a pushout fitting. The difference between these two characteristics is that the hierarchical system has a quantitative nature, where as the quale identity is a qualitative function.
To summarise, let (a) be a hierarchical system in its environment (A), and its identity quale (I_{qa}), an organism can be formalised as I_{qa}(a, A).

The hierarchical system and the quale identity work as two semi-categories. If we reduce the hierarchical system to a collective link (L), as the quale identity is a reduction of the top-down process, both morphisms become endofunctors. Their correlation depends on natural transformations, which are morphisms between functors. From these data, a model of the organism can be represented by the figure 2.

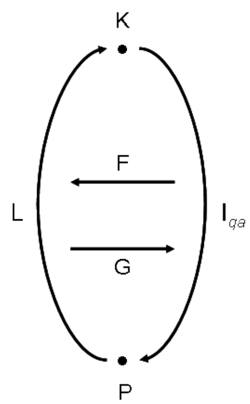

Figure 2

Formal categorial representation of an organism where (K) is the colimit of the multi-scale hierarchical system (a). (P) is the pattern of subsystems of (a). (I_{qa}) is the identity quale of (a), and (L) is a set of links from (P) to (K).The dualistic aspect of the entity is overcome by a set of natural transformations (F, G) which interplay between (I_{qa}) and (L) and by which the organism becomes an evolutionary unit (according to Cazalis, 2013).

With this model of the organism, we can better comprehend its mode of emergence from the nonliving. We propose that in a given environment, there are arguably two essential events in the advent of organisms. One is the formation of the multi-scale hierarchical system having the characteristics (C_T), and the instantiation of the quale identity within it. The second event constitutes a real heart of the system, giving it autonomy and its robustness, which are the first characteristics of the individual. It is not necessary that the hierarchical system be perfectly organised; it is actually preferable that it has certain plasticity. Indeed, the quale identity exercises a canopy function within the organism. The canopy function has two main aspects. First, it is a function which comes from the very system itself and characterises the quale. Secondly, as a functional image of the hierarchical system, it has a compensating role especially when the system has not reached its fluctuating balance; that is its coherence. On the same note, we assume that the characteristics (C_T) do not mean a full coherent system because once the quale identity is instantiated; it sustains and perfects the integration.

The interaction between the endofunctors (L) and (I_{qa}) allows the organism to be an evolutionary unit. Changes in (L) from modifications to the environment or by natural destruction of its elements entails to their replacement or substitution to preserve the feature memorized in the quale.
In the same way, the quale could be subject to positive or negative interferences with other organisms present in the environment. As long as the characteristics of the hierarchical system are protected, the maintenance of the initial quale is guaranteed.
The interactions operated by a set of natural transformations entail an internal temporality, which constitutes the second characteristic of the organism. Depending on the evolution of the organism the area of the natural transformations is subjected to a process of complexification.

Finally, how does life arise from the nonliving is suggested by the very nature of the organism according to our model. Subsequently, this work analyses the quantitative and qualitative aspects of the organism; and the notions of autonomy and internal temporality. It proposes a composition rule for the quale identity in collective organisms and discusses the problem of critical threshold (C_T) with respect to the bottom-up approach that aims to assemble artificial cells from scratch using nonliving materials.

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