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Toward a behavior-based approach to the origins of life and the genetic system

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Abstract

In the origin of life community there has been a dispute about whether metabolism or replication came first. Yet both of these approaches are in implicit agreement that the first forms of life were basically passive. That shared assumption has begun to be challenged by a new generation of metabolism-first approaches, emphasizing that movement and adaptive behavior could have played an important role right from the start. After introducing recent research on this behavior-based approach to the origin of life, I offer a preliminary assessment of what this new approach implies for the origins of the genetic system.

Current state of the field

Metabolism- and replicator-first approaches, while differing in many respects, implicitly agree that the first forms of life were passive and encapsulated individuals. Both failed to consider the intermediate timescales between chemical self-constitution and population evolution: no mention is made of motility nor of development (Froese et al., 2011). Yet new metabolism-first approaches emphasize that motility and adaptive behavior could have played a crucial role from the start (Froese et al., 2014; Hanczyc, 2011; Egbert et al., 2012). Such a *behavior-based* approach can refresh thinking on several classic issues.

For example, it was long believed that pre-biotic evolution of a hypercycle of autocatalytic processes is unstable because it can be invaded by parasitic compounds. But later on it was realized that this is only the case in a well-mixed (non-spatial) environment, while spatial embedding can make hypercycles immune to parasites. We can push this change in perspective even further. It has been shown that it is possible to make use of the instabilities introduced by the parasites as a source of spontaneous motility, a capacity which can be adaptive under some conditions (e.g., Froese et al., 2012). Indeed, there may even have been forms of minimal cognition already at the origin of life (Hanczyc & Ikegami, 2010).

The next challenges

From the behavior-based perspective it appears likely that the origins of the genetic system were related with the origins of adaptive control of behavior during an organism's lifetime. In particular, current examples of behavior-based proto-life have a very limited set of states. Accordingly, they cannot respond differentially based on their long history of interactions. What is required is a primitive kind of memory system that permits state-based adaptive modulation of sensorimotor interactions. Could such a memory system be partially heritable and have provided the foundation for the evolution of a genetic system?

This hypothesis is consistent with the proposal that genetic evolution first began with the composite chemical phenotype serving as its own holistic genotype (Segré et al., 2000). The next milestone of this composite proto-metabolism would be the evolution of state-based adaptive behavior which enhances its survival, with some parts beginning to turn into a dedicated memory system. I speculate that aspects of this system might have eventually evolved into a relatively fixed genotype with gene sequences that 'code' for specific properties. To see how this could have happened in principle, we can draw inspiration from computer models of the origins of another compositional symbol system, language (Christiansen & Dale, 2004). Here too there is a shift from a gene-centric bias to more interactive approaches, e.g. the iterated learning model. This simplified process of cultural evolution can give rise to a syntactical communication system that 'codes' for specific features when starting from the exchange of arbitrary string-feature pairings. It still remains to be seen if such an interactive self-organizing principle could have applied to the iterative self-replication or horizontal gene transfer performed by the first proto-cells.

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