On the interplay of self-replication and self-reproduction in protocells

Roberto Serra
Department of Physics, Informatics and Mathematics, University of Modena and Reggio Emilia
European Centre for Living Technology (ECLT), Venice
Institute for Advanced Study (IAS), University of Amsterdam
rserra@unimore.it

Abstract

Modern biological cells are endowed with effective mechanisms which control their division, ensuring that it does not take place before the duplication of the genetic material has been completed. It is unlikely that similar sophisticated mechanisms were in place in primitive protocells, which were much simpler than their present-day descendants. So a major question concerns the way in which reproduction of the whole protocell might take place together with replication of its genetic molecules, absent any kind of high-level control.

This might happen if the rate of duplication of the genetic material and that of fission of the protocell are the same, i.e. if the two processes are synchronized. This possibility can be studied using simplified models of reaction networks (among replicators), assuming that one or more replicators can affect the growth and fission rates of their lipid container. Surprisingly enough, such synchronization does not necessarily require a careful assembly of reactions with very specific reaction rates. On the contrary, it turns out to be a property which emerges spontaneously in a broad set of models, with different parameters, different reaction networks and even different protocell architectures. Note that synchronization, while being a widespread property, is not always achieved for all the models and reaction types. The conditions for emergent synchronization will be discussed, reviewing previous work and showing some new results.

These results are based upon dynamical models which assume that the reactions are known a priori. On the other hand, in models of the origin of life it is often assumed that not all the important chemicals are there since the very beginning, but that some of them are synthesized at later stages. The appearance of new chemicals makes new reactions possible, which may in turn lead to the synthesis of new chemicals, etc. Dealing with this kind of problems requires the choice of a particular model of the replicators and of their interactions; in this paper the random binary polymer model proposed by S. Kauffman, where the replicators are polymers which can undergo cleavage or condensation, will be considered. This model allows, in principle, the appearance in time of polymers of increasing length. Another aspect which has to be taken into account, in order to properly model these phenomena, is that new chemical species may be initially present in very low concentrations, which require a stochastic treatment like the one allowed by the well-known Gillespie algorithm.

The random binary polymer model can give rise in time to collectively autocatalytic sets, which are able to self-replicate; if some chemicals which belong to the core or to the periphery of these sets are coupled to the growth of the lipid container, this may lead to emergent synchronization. However, the interactions can be quite complicated and the overall behaviour can be counterintuitive. Some examples of dynamical behaviours which have been observed in simulations will be presented and discussed, with particular emphasis on features which are always, or frequently, observed. It will be argued that studying the dynamical interaction of autocatalytic sets with the growth and splitting dynamics of the lipid container is crucial to understand the possibility that a population of protocells undergo sustainable growth and evolution.