Symmetry Breaking of Sequence Information and Emergence of Hypercycles in information-polymer soup

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The first life form has presumably developed in the soup of information polymers such as RNA, DNA, peptides, and their analogues. For developing into a highly complex life form, the emergence of molecular species sustaining genetic information is a crucial step. However, no scenario has clearly addressed how information polymers can self-organize into a stable self-replicating species without lapsing into an error catastrophe lacking any order nor a frozen state dominated by the species with the fastest growth rate. Here, we explore the templated ligation of DNA strands by DNA ligase, which simulates the simplest and most primitive reaction of information polymers. We find that, by repeated templated ligations, DNA strands inevitably form a precursor of species, a stable and complex nonequilibrium structure replicating its genetic information, under nonequilibrium driving force of temperature cycling, feeding, and diluting. The key concept behind is the cooperative hyper-exponential growth of sequence information caused by the general property of templated ligation that longer strands hybridize more stably than shorter strands. The hyper-exponential growth leads to a frequency-dependent selection that suppresses the error catastrophe while provides a rich complexity to the sequences by preventing the most stable sequence from dominating the sequence space. As the direct consequences of the frequency-dependent selection, we demonstrate the spontaneous symmetry breaking of sequence information and the coexistence of different species in spatially resolved systems.