The Emergence of Life as a First Order Phase Transition. C. Mathis[1] (cole.mathis@asu.edu), T. Bhattacharya[2, 3] and SI Walker[4, 5, 6] [1]Department of Physics, Arizona State University, Tempe AZ USA. [2]Santa Fe Institute, Santé Fe NM USA [3]Los Alamos National Laboratory, Los Alamos NM USA, [4]School of Earth and Space Exploration, Arizona State University, Tempe AZ USA [5]Beyond Center for Fundamental Concepts in Science, Arizona State University, Tempe AZ USA, [6]Blue Marble Space Institute of Science, Seattle WA USA

Introduction: Life is a state of matter characterized by a stable pattern of non-equilibrium behavior. Replication, central to maintenance of pattern, is thought to play an important role in driving the transition from non-living to living matter [1, 2]. Using a kinetic Monte-Carlo simulation of an artificial chemistry, we demonstrate the existence of a phase transition from non-life to life (defined as non-replicating and replicating systems respectively). The transition is first order and occurs spontaneously in the absence of external tuning and has features which differ from those described previously.

In our model, the fitness of replicators is determined by two factors: (1) a trade-off between stability and replicative efficiency and (2) resource availability. There are thus are two modes of selection: a static, functional fitness landscape, which is based on the composition and information content of the replicators, and a dynamic environmentally determined fitness landscape, which occurs due to a coupling between replicators an a finite resource pool (the environment). Two equilibria are observed: non-life and life. These phases are distinguished by the length distribution of polymers, the average sequence composition, and rate of exploration of novel diversity and number of extant species. Importantly, in the non-life phase, the dynamic environmental landscape dominates selection, while in the life phase the functional fitness determines the relative abundances of species.

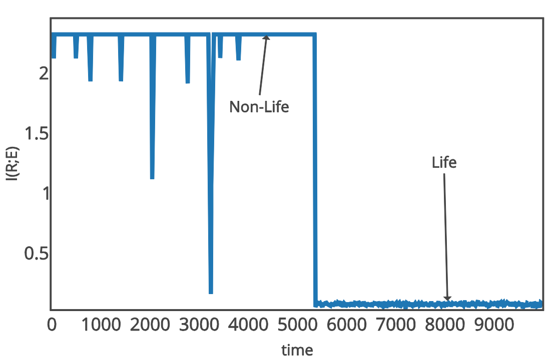

Fig. 1: The phase transition from non-life to life is tracked by the mutual information shared between replicators and environment. Many frustrated attempts can be observed before a successful transition.

The probability for the phase transition from non-life to life to occur depends on the mutual information shared between replicators and their environment (Fig. 1), where the transition is most likely to occur when the information content of replicators matches that of the environment. Interestingly, the replicators which nucleate the transition are not those that are ultimately selected. Both the replicator population and the environment are dynamically restructured during the phase transition. The system undergoes a series of symmetry breaking transitions whereby the information content of replicators becomes increasingly distinct from that of their environment (Fig. 2). During the transition, the system experiences an explosive exploration of novel diversity, with a higher diversity after the transition than before.

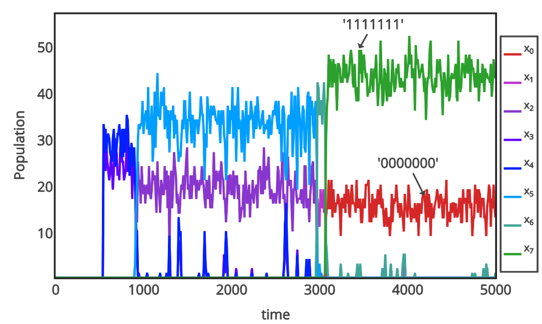

Fig 2. The population of replicators as a function of time through the transition. The functionally fit (homogeneous) sequences are ultimately selected (red and green) but they cannot nucleate the transition since they do not match the abiotic distribution of resources.

We discuss the implications of these results for understanding the emergence of life, and natural selection more broadly[3, 4].

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