Cognition and Learning: A Primary Determinant and Seed of Life

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Introduction: Given the primacy of learning and information processing as a defining feature of the living state, we believe that exploring the emergence of learning in scenarios relevant to the origin of life could yield deep new insights in astrobiology. Despite the fact that life does not violate the laws of thermodynamics, the concentration of information and computational dynamics that are a fundamental characteristic of the biological world, are in sharp contrast to most driven systems, which in general do not spontaneously exhibit behaviour that is reminiscent of an autonomous Maxwell demon (driving gradients of free energy uphill, at the expense of others falling downhill). Thus we would like to propose a new, parallel programme of research in the origin of life field, that explores the emergence of learning in (geo)chemical scenarios relevant to astrobiology.

Context: The study of cognition has traditionally resided within the domains of neurology, artificial intelligence and systems biology. Those fields have made astounding progress in understanding how brains, neural networks, gene regulatory networks, and many other networked systems are capable of storing and processing information, predicting future events, and making decisions. Concepts from learning theory are also being used to enhance and re-write our understanding of evolution [1]. It is now clear that lower level biological systems or subsystems, including gene and protein networks, colonies of simple microorganisms [2] and subsets of cells (e.g. the immune system [3]) are capable of learning. There have also been significant advances in a rather more abstract, but we believe deeply connected realm: stochastic thermodynamics and molecular machines. Theoretical progress in this field now allows the calculation of upper limits for the efficiency with which molecules can make use of a given driving signal or free energy gradient [4,5].

Proposal: We believe that there lies a deep intersect and relationship between all the aforementioned works, and the origin of life. Alongside the search for abiotic synthesis of biomolecules and the exploration of proto-genetic systems, we would like to suggest an additional line of origins enquiry: the emergence of elementary learning systems. We believe that fundamental new insights would be gained from understanding the origin of computation, wherein the outputs of those computations feed back positively on the emergent computational architecture, making it more viable in its environment. The origin of life may well have been concomitant with the origin of cognition: the origin of a system capable of learning but also open-endedly expanding its learning capabilities. To understand that event or events, we must first understand where learning comes from in simple chemical systems, and eventually map that to early Earth conditions and potentially, exoplanetary environments.

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