Emergence of Open-Ended Evolution in a Minimalistic Model of Interactive Cellular Automata with Global Control.

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Introduction: We propose a minimalistic model that produces open-ended evolution through emergence of novel structures. Biology is well-known to be embedded and interactive within its environment. A biological model should be able to reflect the environment's complexity [1] by allowing semi-permeable boundaries [2]. Biology is also known to utilize self-reference, which is the ability to change its behavior through global control according to the configuration of its current state [3]. To model these features, we propose a variate of Global Cellular Automata that is comprised of two spatially separate cellular automata. One of these cellular automata models an *organism* and the other models an *environment*. The boundary between the organism and the environment is semi-permiable by allowing some information about the environment influence the local update rule of the organism via a global update rule. This global update rule allows the organism to access to many possible local cellular automaton rules resulting in the emergence of highly diverse structures.

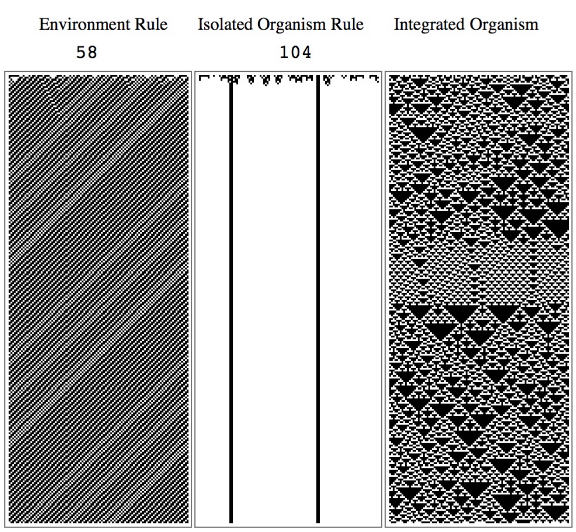

Figure 1: State evolution of the environment (left), the organism isolated from the environment by receiving no environmental input (center), and the same organism when receiving environmental input via a global rule. Time evolves from top to bottom.

Since this model assumes finite resources, the amount of complexity in a finite space is bounded. Thus, the open-ended evolution we aim to quantify is a sustained generation of diversity and high complexity once the emergence of structures arise from a deterministic system (Fig. 1). In other words, we aim to characterize open-ended complexity as a non-trivial trajectory through state space, which does not exhibit an algorithmically compressible pattern. Thus "complex" structures must exhibit novelty, generated within the context with the recent states of the system rather than randomly, distinguishing open-ended evolution from noise [4]. Interactions between every combination of environment and organism type were studied over 400 possible initial conditions. Half the initial conditions were structured and the other half were randomly generated. The evolutionary trajectories of the resulting organisms states were traced down in great detail using six standard measures of complexity, including compressibility as an approximation to Kolmogorov complexity and sensitivity in the form of estimations of a Lyapunov exponent. In order to assure open-endedness in multiple dimensions, compressibility of the rule evolution in the organisms were also measured.

Out of the 3.1×10^6 interactions sampled, 44 cases displayed all the hallmarks of open-ended evolution. We use these results to inform generalized statements about the types of initial conditions and environments needed for open-ended complexity and connect the results to the hypothesis that information as a causal driver of complexity may be an important feature of living matter [5].

References: [1] H Zenil, C Gershenson, JAR Marshall, D Rosenblueth (2012) *Entropy, 14(11),* 2173–2191. [2] K Ruiz-Mirazo, J Pereto, A Moreno (2004) *New Comp Paradigms,* 259–285. [3] T P Pavlic, A M Adams, PCW Davies, S I Walker (2014) *ALIFE 14* 522–529. [4] M A Bedau, E Snyder, N H Packard (1998) *ALIFE VI,* 189–198. [5] S I Walker, PCW Davies (2012) *J R Soc Interface 10(79),* 1–9.