Emergence in a Replicator-Parasite Automata System (R-PAS)

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How can a system of simple RNA-like replicators increase its complexity through evolution? Artificial Replicator-Parasite (R-P) systems explore the dynamics of evolution in such systems [1]. If variability in replication is allowed, parasitic entities tend to emerge which threaten to drown the replicating system. These systems have three reaction classes where R is a replicator, and P is a parasite. There are three reactions: $R : R$ which produces a new R, $R : P$ which produces a new P; and $P : P$ in which no new entities are produced.

When the rates of these reactions are allowed to evolve, the system will diminish to extinction in a well mixed situation (e.g. as implemented in ordinary differential equations), but can survive in spatial explicit systems such as 2D CA where the entities exist in cells arranged on a toroidal grid. This survival is due to the emergence of spatial patterns.

Parallel to this research, work on Automata Chemistries has also documented the emergence of parasites in replicator systems [2]. Here the replication function is encoded explicitly via a sequence of computational operators including the act of binding, the rate of which is controlled by sequence alignment between the partners. This binding system is sufficiently sophisticated to allow an R-P like model to be implemented - thus it is an R-PAS (a Replicator-Parasite Automata System). The stages of replication are encoded in the sequence and can be affected by evolution. The key advantage of this approach is that the mechanics of replication can be reconstituted through evolution and allow different functions to emerge. This leads us to ask: how does this recomposition affect the replication dynamics? Do new behaviours emerge? Is there any increase in complexity?

To explore these questions, we extended the Stringmol Automata Chemistry to run on a toroidal grid, with reactions permitted only in the Moore neighborhood of each entity. We ran 25 trials to 2 million timesteps, using five different configurations to counter effects of arena shape and initialisation. Eleven of the Twenty-Five systems went extinct before 100,000 timesteps, indicating that the parasites overwhelmed the system before the spatial patterns became established. Only three of the systems that passed this point went extinct.

The following trends were observed in all of the systems that ran to 2 million timesteps: Folowing the initilisation with the seed replicator, parasites emerge quickly, and are replicated faster than the replicators themselves because they are shorter, but the system survives due to the emergence of wave-level selection, as shown in figure 1, left. Selection for replication rate leads to shortening of the sequences, but then several mechanisms for resistance to parasites emerge, e.g. slow replication of any entity, reducing the advantage parasites have by being small. Through this complex reaction systems emerge (figure 1, right), which can take several forms:

1. *Binding wars (hypercycles)*- in whch an $R_x : R_y$ recation produces a new R_x or R_y, and parasites can only exploit one of the partners.
2. *Rate wars* replicators emerge with slower rates of replication to reduce the advantage of being shorter. This permits capacity in the replicator sequence to evolve new behaviours
3. *Diversity wars* risking the error catastrophe, some replicators are pathologically diverse, with long chains of short repeats in the sequence.
4. *Rule exploitation* although no movement is allowed in these systems, some reactions emerge where one of the parents destroys itself. This has the effect of creating a sparse distribution of replicators which is more difficult for the parasites to exploit, but at the risk of individual replicators becoming isolated and unable to reproduce.

The key result of these experiements is that despite the primary selection pressure to efficient replication, and therewith decrease in the size of the replicators, the individual replicators develop a range of strategies to exploit the capabilities and vulnerabilities of others in the system. In this way new levels of complexity arise.

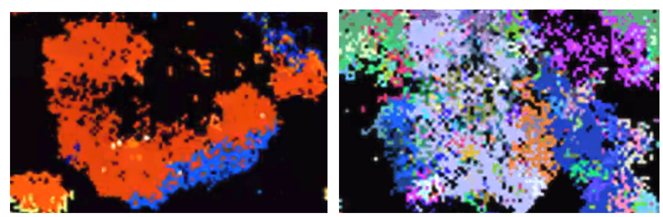

Figure 1: phase transitions in an evolving R-PAS. R-P wavepatterns (left) and diversity wars (right)

Conclusion The R-P CA models are a good description of the early phases of evolution of the AChem, where changes in mean population levels reflect the rate parameters of these models as parasites emerge.

As expected, the systems do not survive unless spatial patterns, and higher levels of selection emerge soon enough to avoid extinction. If they do survive the initial phase trends emerge towards higher population, higher diversity and increasing complexity, with associated reduction in the chance of extinction. These phenomena present an exciting result, offering new insight into the transition from selection for speed of replication to selection for a *range* of emergent, complex behaviours.

References

[1] Nobuto Takeuchi and Paulien Hogeweg. Evolutionary dynamics of rna-like replicator systems: a bioinformatic approach to the origin of life. *Physics of Life Reviews*, 9(3):219–263, 2012.

[2] Simon Hickinbotham, Edward Clark, Adam Nellis, Susan Stepney, Tim Clarke, and Peter Young. Maximizing the adjacent possible in automata chemistries. *Artificial Life*, 22(1):49–75, 2016.