The Complexity Ratchet: Stronger than selection

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A recurrent question in evolutionary biology is the question of the arrow of complexity: is there a trend in evolution toward more complexity? At a macroscopic level, when looking globally at the "tree of life", this trend may seem undeniable [1]. However, when looking more specifically at some particular organisms and lineages, streamlining is clearly also at work, *e.g.*, in endosymbionts or in some cyanobacteria [2]. At the molecular level, biological systems have evolved toward strikingly complex structures as exemplified by the size of the genetic and metabolic networks or by the intertwining of the metabolic and signalization pathways.

Understanding the roots of this possible trend is difficult because it requires deciphering the complex interactions between the many forces that drive evolution, including selective, neutral and non-selective ones. In that context, Artificial Life is a valuable addition to the classical evolutionary toolbox (population genetics, phylogeny, fossil records...) as it enables to populate environments which complexity is perfectly mastered with artificial organisms and observe in which conditions these organisms will grow in complexity or, conversely, follow a streamlining route [3].

With this idea in mind, we used the Aevol platform [4][5], to design an *in silico* experiment able to support – or disprove – the existence of an arrow of complexity. More specifically, we used the platform to let evolve for a very long time (100,000 generations) populations of organisms in an environment designed to enable survival of the simplest possible organism, *i.e.*, in Aevol, an organism whose genome encodes a single gene. By repeatedly evolving organisms in this experimental design, we observed two very different outcomes: some lineages were able to quickly find the optimal genotype – one single gene – typically before 1,000 generations. These lineages were then stable for the remaining 99,000 generations. On the opposite, lineages that were not able to quickly find the optimal genotype showed a very different dynamics with a slow acquisition of genes all along the 100,000 generations of the experiment. Importantly, the two kinds of dynamics were also characterized by very different outcomes in terms of fitness value: single-gene genotypes ended up with a very high fitness (equal or close to 1, the maximum possible value in Aevol) while complex genotypes ended up with fitness values typically 10 to 100 times lower.

Our results show that, even in a simple constant environment, evolution leads to a "complexity ratchet" [6]: each event of gene acquisition creates the potential for the acquisition of further genes, ultimately pushing evolution towards complex solutions even when the problem at stake is simple. Moreover, in our experiments, organisms engaged in this process were never able to outcompete those that found simple solutions, showing the selection is not able to invert the complexity ratchet.

References

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