Changing Environments Drive the Separation of Genes and Increased Evolvability in NK-Inspired Landscapes

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Extended Abstract

Why are genes separated in complex organisms, but overlap in many simple ones? Intuitively, there seems to be an evolutionary trade-off: overlapping genes produce a smaller target for mutation, but separated genes can be modified independently (Ofria and Adami, 2002). As such, functional modularity should lead to long-term improvements to evolvability (Pepper, 2000). However, because evolution promotes immediate fitness gains rather than long-term fitness potential, modular genetic architectures will not be selected for unless they also result in more immediate fitness gains. Furthermore, modular genetic architectures that keep genes separated require more genetic material, which makes them a larger target for mutations (Gupta et al., 2016).

What environmental characteristics shift selection to favor more modular genetic architectures? Direct selection for fewer interactions between genome components has proven highly effective (Clune et al., 2013), but must be tailored to specific representations. Here, we explore the more general approach of changing environments, which facilitate the evolution of evolvability by ensuring that adaptive peaks are transitory and that the population is always undergoing active selection. We investigate this issue by modifying NK models so that genomes have variable length and the location of each gene in a genome can evolve (Kauffman and Levin, 1987). In the standard NK model, the locus of each gene influences K other genes as well. In our model, we allow genes to move and the genome to change size; we relate modularity to the extent that genes overlap with each other. If two genes overlap, mutations in one gene affect the second, often negatively. However when genes are separate, mutations can affect one gene at a time, allowing them to adapt independently, resulting in greater modularity and evolvability.

Indeed, we find that higher mutation rates create a pressure for smaller genomes with more overlap (as noted in (Gupta et al., 2016)), while changing environments create pressure for larger genomes with less overlap and more functional modularity. In turn, genes that are spread out within a genome experience more rapid adaptation to new environments. These concepts help explain genetic organization in nature, but also provide insights on producing more modular and evolvable artificial organisms in engineered systems.

We are using this system to investigate the role of changing environments in producing open-ended artificial life systems. Furthermore, genetic modularity is prevalent in multicellular organisms; the question remains whether this modularity is a necessary prerequisite for major transitions in individuality to occur (Tusscher and Hogeweg, 2011). Alternatively, is modularity selected for after such a transition occurs (*e.g.*, along with division of labor), or is it merely an unrelated side effect of such transitions? Such questions are fundamental if we want to build artificial systems that can produce the open-ended evolution of complex forms that we witness in nature.

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