Evolving Signal-driven Digital Organisms with SignalGP

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Abstract

Together, carefully designed laboratory experiments, mathematically rigorous simulations, and studies of natural evolutionary dynamics in digital organisms are beginning to yield insight into the evolution of complex traits and behaviors. Digital organisms balance the speed and transparency of simulations with the open-ended realism of laboratory experimental systems. Here, we present Signal-driven Genetic Programs (SignalGP), a new class of digital organism that emphasizes dynamic interactions among organisms and between organisms and their environment. SignalGP allows digital methods to realize a broader and richer spectrum of evolutionary dynamics that more closely rivals that of biological evolution.

In digital evolution, self-replicating computer programs (digital organisms) mutate, compete, and evolve *in silico*. Digital evolution systems enable perfect data tracking, and modern compute power allows experimenters to observe many generations of evolution at tractable time-scales (thousands of generations in minutes as opposed to months or years). In laboratory settings, the types of biological organisms we choose to work with can influence our repertoire of experimental possibilities; the same is true in digital evolution. Different types of digital organisms have different genetic program representations that impose different sensory interfaces and mechanisms for processing sensory information.

SignalGP is a genetic program representation that allows digital organisms to dynamically react to signals from the environment or other agents. In traditional digital evolution systems (*e.g.*, Avida), genetic programs are expressed procedurally: actions are performed one at a time in a single chain of execution and must explicitly check for new sensory information. These traditional digital organisms must generate explicit queries in order to identify (and react to) any changes in their environment. In SignalGP, program expression is signal-driven: genetic programs are segmented, and each segment can be independently expressed in response to a signal. For example, if a SignalGP organism senses a nearby predator, any evolved predator-response code in the organism is automatically expressed (in parallel with existing expression patterns). The mechanism

by which signals specify and trigger segments of code is inspired by transduction of chemical signals in natural cells. The specific signals used and the actions taken in response to those signals remain under the purview of evolution.

We have verified the functionality of SignalGP digital organisms, demonstrating their ability evolve solutions to a variety of computational problems that require frequent organism-organism or organism-environment interactions, such as phenotypic plasticity in a changing environment and distributed consensus. Our next steps are to investigate a range of challenging questions in evolutionary biology, focused primarily on watershed events such as group formation, division of labor, or the evolution of complex regulatory networks. We are developing open-source research software for this work with web-based interfaces to encourage the scrutiny, replication, reuse, and extension of our methods within the scientific community.