SYNTHETIC LIFE: EVOLUTION AND ECOLOGY OF DIGITAL ORGANISMS

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Ideally, the science of biology should embrace all forms of life. However in practice, it has been restricted to the study of a single instance of life, life on earth. Because our science of biology is based on a sample size of one, we cannot know what features of life are peculiar to earth, and what features are general, characteristic of all life. A practical alternative to a truly comparative interplanetary biology, is to create synthetic life.

Synthetic organisms have been created based on a computer metaphor of organic life in which CPU time is the "energy" resource and memory is the "material" resource. Memory is organized into informational patterns that exploit CPU time for self-replication. Mutation generates new forms, and evolution proceeds by natural selection as different genotypes compete for CPU time and memory space. The creatures are self-replicating computer programs, however, they can not escape because they run exclusively on a virtual computer in its unique machine language. The virtual computer is effectively a containment facility.

Diverse ecological communities have emerged. These digital communities have been used to experimentally examine ecological and evolutionary processes: e.g., competitive exclusion and coexistence, host/parasite density dependent population regulation, the effect of parasites in enhancing community diversity, evolutionary arms race, punctuated equilibrium, and the role of chance and historical factors in evolution.

A single rudimentary ancestral "creature" has been designed; it is 80 machine instructions long and contains only the code for self-replication. This creature examines itself, determines its size and location in the memory "soup", and then copies itself, one instruction at a time, to another location in the soup. The ancestral creature does not interact directly with other individuals, although there is scrambling competition for access to memory space.

A reaper kills creatures, assuring that there is always free space into which creatures can reproduce. When creatures are born, they enter the bottom of the reaper queue, and the reaper always kills off the top, which is usually the oldest creature. However, mutant creatures often generate errors, which cause them to rise in the reaper queue and be killed.

From a single rudimentary ancestral "creature" there have evolved tens of thousands of self-replicating genotypes of many hundreds of genome size classes. Bit flipping mutations cause changes in the sequence of instructions in the genome, but they do not cause changes in the size of the genome. However, mutant genotypes make errors in their self-examination and replication, resulting in different sized genomes. As genetic change generates new genotypes, variants appear which are able to replicate more rapidly that their ancestors, and those variants increase in frequency in the soup. Very quickly there evolve parasites, which are not able to replicate in isolation because they lack a large portion of the genome. However, these parasites search for the missing information, and if they locate it in a nearby creature, they parasitize the information from the neighboring genome, thereby effecting their own replication. This informational parasitism is a commensal relationship, as it is not directly detrimental to the host. However, the parasites do compete with the hosts for space, and may be superior competitors because they can more rapidly replicate their smaller genome. However, their advantage is frequency dependent. As the parasites increase in frequency, the hosts decline, and many parasites fail to locate hosts. In ecological runs, without genetic change, hosts and parasites demonstrate Lotka-Volterra cycles.

In some runs, hosts evolve immunity to attack by parasites. One immune mechanism that has been worked out is based on the fact that the creatures only examine themselves once, and rely on retaining the information on their size and location for all subsequent replications. Immune hosts cause their parasites to loose their sense of self by failing to retain the information on size and location. Immune hosts function with this forgetful code by re-examining themselves before each replication, thus there is a metabolic cost to the immunity.

When immune hosts appear, they often increase in frequency, devastating the parasite populations. In some runs where the community comes to be dominated by immune hosts, parasites evolve that are resistant to immunity. The above mentioned immune mechanism can by circumvented by parasites which also re-examine themselves before each replication.

Hosts sometimes evolve a response to parasites that goes beyond immunity to actual hyperparasitism. Hyper-parasites allow themselves to be parasitized, letting the parasite use their code for a single replication. After the first replication, the hyper-parasite deceives the parasite by replacing the parasite's record of its size and location with the size and location of the hyper-parasite genome. Thereafter, the parasite will devote its energetic resources to replication of the hyper-parasite genome. This is a highly deleterious interaction, which drives the parasites to extinction. The hyper-parasites are facultative, getting an energy boost when the parasites are present, but not requiring them for replication.

Evolving in the absence of parasites, hyper-parasites completely dominate the community, resulting in a relatively uniform community characterized by a high degree of relationship between individuals. Under these circumstances, sociality evolves, in the sense that the creatures evolve into forms which can not replicate in isolation, but which can only replicate in aggregations. These colonial creatures cooperate in the control of the flow of execution of their algorithms.

The cooperative behavior of the social hyper-parasites makes them vulnerable to a new class of parasites. These cheaters, hyper-hyper-parasites, insert themselves between cooperating social individuals, and momentarily seize control of execution of the algorithm, just long enough to deceive the social creatures about their size and location, causing the social creatures to replicate the genomes of the cheaters.

The only kind of genetic change that the simulator imposes on the system is random bit flips in the machine code of the creatures. However, the digital organisms discover sexuality as a mechanism of genetic change, and in this way generate their own genetic changes. They cause significant recombination and rearrangement of the genomes. This spontaneous sexuality is a powerful force for evolutionary change in the system.

One of the most interesting aspects of this second instance of life is that the bulk of the evolution is based on adaptation of organisms to other organisms, rather than the physical environment. It is co-evolution that drives the system.