a parameter of interest, and observing them for billions of years. A practical alternative to an inter-planetary or mythical biology is to create synthetic life in a computer. "Evolution in a bottle" provides a valuable tool for the experimental study of evolution and ecology.

The intent of this work is to synthesize rather than simulate life. This approach starts with hand-crafted organisms already capable of replication and open-ended evolution, and aims to generate increasing diversity and complexity in a parallel to the Cambrian explosion.

To state such a goal leads to semantic problems, because life must be defined in a way that does not restrict it to carbon-based forms. It is unlikely that there could be general agreement on such a definition, or even on the proposition that life need not be carbon based. Therefore, I will simply state my conception of life in its most general sense. I would consider a system to be living if it is self replicating, and capable of open-ended evolution. Synthetic life should self-replicate, and evolve structures or processes that were not designed in or preconceived by the creator.[43]

Core Wars programs, computer viruses, and worms[11,14,15,16,17,18,19,46,48] are capable of self-replication, but fortunately, not evolution. It is unlikely that such programs will ever become fully living, because they are not likely to be able to evolve.

Most evolutionary simulations are not open ended. Their potential is limited by the structure of the model, which generally endows each individual with a genome consisting of a set of pre-defined genes, each of which may exist in a pre-defined set of allelic forms.[1,12,13,17,27,42] The object being evolved is generally a data structure representing the genome, which the simulator program mutates and/or recombines, selects, and replicates according to criteria designed into the simulator. The data structures do not contain the mechanism for replication; they are simply copied by the simulator if they survive the selection phase.

Self-replication is critical to synthetic life because without it, the mechanisms of selection must also be pre-determined by the simulator. Such artificial selection can never be as creative as natural selection. The organisms are not free to invent their own fitness functions. Freely evolving creatures will discover means of mutual exploitation and associated implicit fitness functions that we would never think of. Simulations constrained to evolve with pre-defined genes, alleles, and fitness functions are dead ended, not alive.

The approach presented here does not have such constraints. Although the model is limited to the evolution of creatures based on sequences of machine instructions, this may have a potential comparable to evolution based on sequences of organic molecules. Sets of machine instructions similar to those used in the Tierra Simulator have been shown to be capable of "universal computation."[2,33,36] This suggests that evolving machine codes should be able to generate any level of complexity.

Other examples of the synthetic approach to life can be seen in the work of Holland,[26] Farmer et al.,[22] Langton,[31] Rasmussen et al.,[45] and Bagley et al.[3] A characteristic these efforts generally have in common is that they parallel the origin