POLYWORLD: REAL LIFE IN AN ARTIFICIAL CONTEXT?

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INTRODUCTION

The subject of this talk will be Artificial Life - the study of man-made living systems. In particular, I will discuss a particular computational ecology, called PolyWorld, that represents a seemingly successful attempt to develop nonbiological life in a computer. Though itself nonbiological, PolyWorld draws heavily on biological principles: It brings together biologically motivated genetics, simple simulated physiologies and metabolisms, Hebbian learning in arbitrary neural network architectures, a visual perceptive mechanism, and a suite of primitive behaviors in artificial organisms grounded in a simple ecology. Predation, mimicry, sexual reproduction, and even communication are all supported in a straightforward fashion. The resulting survival strategies, both individual and group, are purely emergent, as are the functionalities embodied in their neural network "brains". PolyWorld is an attempt to approach artificial intelligence the same way that natural intelligence emerged: through the evolution of neural system in a complex ecology.

But are these man-made organisms really alive? Can they be? After presenting some specifics of the pseudo-physics and pseudo-biology that constitute PolyWorld's model of life, and showing videotape of some of the species and complex emergent behaviors found in the organisms of PolyWorld, I will try to address this most fundamental question of the field of Artificial Life.

I will conclude with some suggestions for future directions for this research.

OVERVIEW OF THE POLYWORLD SIMULATOR

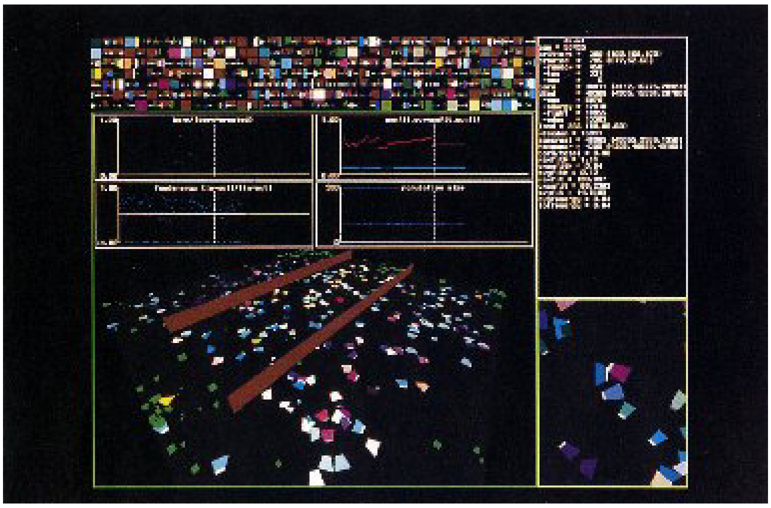
PolyWorld is an ecological simulator, consisting of a flat ground-plane, possibly divided up by a few impassable barriers, filled with randomly grown pieces of food, and inhabited by a variety of organisms. The inhabiting organisms use color vision as input to a neural network brain that employs Hebbian learning at its synapses. The outputs of this brain fully determine the organism's behaviors. These organisms and all other visible constituents of the world are represented by simple polygonal shapes. Vision is provided by rendering an image of the world from each organism's point of view, and using the resulting pixel map as input to the organism's brain, as if it were light falling on a retina. The organism's simulated physiologies — size, stength, and maximum speed — and their corresponding metabolic rates are determined from an underlying genetic code. There is also a single ID gene whose only function is to provide the green component of the organism's coloration at display time; since organisms can actually see each other, this can, in principle, support mimicry. Mutation rate, the number of cross-over points used during reproduction, and maximum lifespan are placed in the genes in order to permit a kind of meta-level genetics, and in recognition of the fact that these parameters were themselves evolved in natural systems. A final physiology gene controls the fraction of an organism's remaining energy that it will contribute to its offspring upon birth. The offspring's total available energy at birth is the sum of these contributions from the two parents.

Another group of genes control the organism's neural architecture. These genes define a number of neuronal groups or clusters, the quantities of inhibitory and/or excitatory neurons found in these clusters, and the degree and type of synaptic connections that exist between the neurons in these various clusters. This model attempts to capture the statistical nature and complexity of real neural architectures, whithout the necessity of and ontogenetic model of neural development. One result of this model of neural architectures is that it is possible for PolyWorld's simulated "Nature" to select for hardwire/instinctual behaviors, learning behaviors, or hybrids.

A small number of an organism's neurons are predetermined to activate a suite of possible primitive behaviors, including eating, mating, fighting, moving forward, turning, controlling their field of view, and controlling the brightness of a few of the polygons on their bodies. Organisms expend energy with each action, including neural activity; more actions, more neurons, or more synapses produce greater energy expenditures. They must replenish this energy in order to survive. They may do so by eating the food that grows around the environment. When an organism dies, its carcass turns into food. Because one of the possible primitive behaviors is fighting, organisms can potentially damage other organisms. So they may also replenish their energies by killing and eating each other. Predation is thus modeled quite naturally. In order to reproduce, two spatially overlapping organisms must both express their mating behavior. Reproduction then occurs by taking the genetic material from the two haploid individuals, subjecting it to crossover and mutation, and then expressing the new genome as a child organism.

Once a stable behavior strategy — one which allows the organisms to replenish their numbers (depleted by death) through reproductive mating — has emerged, PolyWorld can be run in a sort of "on-line Genetic Algorithm" mode, with an ad hoc fitness function. During this stage, a minimum number of organisms may be guaranteed to populate the world. If the number of deaths causes the number of organisms extant in the world to drop below this minimum, either another random organism may be created by the system, or the offspring of two organisms from a table of the N fittest may be created, or, rarely, the best organism ever may be returned to the world unchanged.

Minimum, maximum, and initial numbers of organisms and food may be specified, along with a food growth rate. It is possible to manage these control parameters, along with the ad hoc fitness statistics, simultaneously for a number of different independent "domains", which typically, though not necessarily, coincide with the divisions imposed on the world by the barriers. A variety of graphical displays monitor the progress of the simulation. All of the simulation control parameters and display options are defined in a single "world file" that is read at the start of the simulation. In addition, some of the display options can be invoked interactively at run-time. Current high end simulations typically involve several hundred organisms, with several hundred neurons each.



RESULTS: SPECIATION AND COMPLEX EMERGENT BEHAVIORS

Despite the variability inherent in different worlds, certain recurring "species" have occurred in the simulations run to date. Only the species from "successful" simulations are examined at any length and discussed here. A simulation is considered successful if and only if organisms emerge which are capable of sustaining the world's populations through their mating behaviors (and thus organism creations cease). These species, by definition, have evolved a stable behavior strategy. Some of these species-level and individual-level behaviors are reminiscent of behavioral strategies observed in natural organisms, and may yield insights into those natural behaviors, unencumbered as they are by prior assumptions about biological life or our usual tendency to anthropomorphize.

The first of these species to emerge, the "frenetic joggers", basically just ran straight ahead at full speed, always wanting to mate and always wanting to eat. As their particular (benign and primitive) world was set up, it turned out that they would run into pieces of food or each other often enough to sustain themselves and to reproduce. It was an adequate, if not particularly interesting solution for that world.

The second recurring species has been referred to as the "indolent cannibals". These organisms "solve" the world energy and reproduction problem by turning the world into an almost zero dimensional point. That is, they never travel far very far from either their parents or their offspring. These organisms mate with each other, fight with each other, kill each other, and eat each other when they die. It turns out that "cannibal" is somewhat of a misnomer, since the dominant reason for these slothful colonies is the ready accessibility of reproductive partners.

The third recurring species has been referred to as the "edge runners". These organisms take the next step up from the cannibals, and essentially reduce their world to an approximately one-dimensional curve. They mostly just run around and around the edge of the world. This turns out to be a fairly good strategy, since, if enough other organisms are doing it, then some will have died along the path, ensuring adequate supplies of food. And mates are easily found by simply running a little faster or a little slower, running in the opposite direction, or simply stopping at some point and waiting for other runners to arrive (all of which behaviors have been observed).

Another species known as the "dervishes" evolved in a Braitenberg-like table-top world, with world borders that represented death to organisms that stumbled over the edge. These organisms spent their entire lives turning in moderately tight circles that brought them into contact with food and mates, but carefully avoided the deadly edges of the world.

The more interesting species are not so easily classified. In worlds where a single species has become dominant, the individuals' behaviors have still been quite varied. And in many worlds, no single species becomes obviously dominant. It is in these simulations that one can observe behaviors such as:
• responding to visual stimuli by speeding up,
• responding to an attack by fighting back or running away,
grazing (slowing upon encountering food), food-seeking and food-circling,
• swarming or flocking,
• chasing or following.

BUT ARE THEY ALIVE? REALLY ALIVE?

The answer to this question is made more than a little difficult by the simple fact that there is no clear definition of just what Life really is, or what is means to be truly Alive. Farmer and Belin, in the proceedings of the second Artificial Life conference suggest that we approach the definition of life be asking, "If we voyage to another planet, how will we know whether or not life is present?" Their answer should also apply to the analogous question: If we "voyage" to an artificial world, how will we know whether or not life is present? Farmer and Belin offer a set of properties or criteria for life, including reproduction, a form of self-representation, a metabolism, interaction with the environment, interdependence of parts, stability under perturbations, and the ability to evolve. Taken at face value, the organisms of PolyWorld readily satisfy all of these criteria. So, we either need to refine our criteria, or welcome an entire new genus to the world!

It may be argued that these criteria should themselves be emergent properties of some lower level processes, and counter-argued that recursively applying this argument contradicts the fundamental tenet of Artificial Life that it is possible to examine life at various levels of organization, and may even preclude the possibility of ever unambiguously producing an example of man-made life. It may be that the best efforts to date necessarily model only aspects of life, that represent the personal biases, interests, and perspectives of the people doing the modeling. Contrast Farmer and Belin's biologically motivated definition of life with a hypothetical artificial intelligence — one that readily passed the Turning test, yet did not reproduce or evolve — which is more "alive"? Indeed, it is possible that only an appropriately staffed jury can ever adequately make such an assessment of living or not living for the scientific community. Perhaps, though, an information-based model of life may yield insights into the relation between artificial and natural biologies, and even someday permit rigorous distinctions between the living and non-living in both.

FUTURE DIRECTIONS

Besides countless behavioral ecology and evolutionary biology studies that are possible with PolyWorld, I would like to take some of the organisms that have evolved useful behavioral strategies, and begin to investigate their reactions to novel environments, perhaps even studying their response to classical conditioning experiments. In addition, making the leap from workstation (PolyWorld currently runs on a Silicon Graphics Iris) to a massively parallel processor would allow significantly larger populations and more complex neural models, thus fostering greater speciation and more complex behaviors. I would like to think that this approach to artificial life and intelligence is very open-ended, and have made the source code to PolyWorld available via anonymous ftp at ftp.apple.com, in /pub/polyworld; I may be contacted at larryy@apple.com with questions.

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