Sustainable Population of Autonomous Foragers in a 3D environment with Physics

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Extended Abstract

In order to observe the dynamics of open-ended evolution and adaptation of virtual agents simulated within a 3D environment, the acquisition of energy (via foraging) is the single most important necessary capacity. Evolving this foraging behavior within an open-ended environment, however, is a difficult task because a starving population will go extinct before any agent has developed the capacity to forage. To circumvent this problem, we have evolved foraging behavior outside of the population using a standard Genetic Algorithm (GA), and placed the capable organisms into a world in which energy is limited. We observed that the resulting population is stable and can sustain itself by foraging and consuming the limited resource. Such populations can be used to study the evolution of more sophisticated foraging strategies, to adapt these strategies to resources of different types (adaptive radiation) and to respond to geographical as well as morphological variance, without the need of an external (and arbitrary) fitness function.

We understand open-ended environments as physical spaces in which organisms can live, and potentially replicate if they gathered a sufficient amount of energy. Evolution in open-ended environments is different from evolution in a GA as replication is not automatic, nor is there an explicit fitness function that assigns fitness to a genotype. In open-ended environments, fitness is implicit and can only be assessed in hindsight for those types that have been able to persist for long periods, just as for biological organisms. In such simulations, individuals accumulate energy by reaching food items, and produce a clone if their energy reaches a reproduction threshold. The forager consumes energy at a rate that is proportional to its volume (to maintain its metabolic function), and is removed if its energy level drops below a starvation threshold. The virtual organisms used in this work are inspired by Sims (1994) and similar to the blocky walkers used in Chaumont et al. (2007), but have two additional sensors: one that returns the angle and another the distance to the closest food source. In this abstract, we briefly describe the strategy we used to evolve foragers capable to sustain an population in an open-ended environment, and then present the first results for an ecology of foragers. The present system adds two features that do not exist in standard ecological simulations: first, the organism's controller and morphology are co-evolved *de novo* and second, the organisms are subject to a realistic physical environment, creating a rich adaptive landscape. Such simulations can complement other tools used in studies where the animal's motion capacity plays an important role.

The foragers used in this work were evolved with a steady-state Genetic Algorithms (SSGA), in a multi-stage method where each stage provides conditions favorable to the emergence of intermediate, increasingly elaborate skills that build upon each other to ultimately yield dependable continuous foraging. A stage consists of many replicates of SSGAs (similar to those used in Chaumont et al. 2007), identical except for the random seed. Each replicate (a population of 200 organisms evolved for a fixed number of generations) yields an evolved organism that is inspected to assess its performance against a selection criterion that is stage-dependent (Table 1). Only one individual from the current stage, called a *key organism*, is used to seed all the replicates in the next stage: this seeding is called a "transfer". The larger number of replicates in the first two stages was necessary to obtain at least five suitable candidates for transfer. New stages lead to improvements either through perfecting existing skills, or through the emergence of new ones.

The design of a fitness landscape that leads to the evolution of a desired character is often more art than science. Here, we have converged on a number of conditions necessary for the emergence of key behavioral milestones through a process of trial and error. These conditions fall into two categories: 1) GA parameters: number of generations, fitness function, selection regime, 2) Initial environmental conditions: food source position pattern, noise level. The fitness function used in the first three stages (see Table 1) favors locomotion (W_l), food source approach (W_s), and reaching targets (W_r), and is designed for roulette selection for the first two food sources. A detailed explanation of each term and their rationale is provided in Chaumont and Adami (2011). After organisms can reach two targets in sequence, the fitness in a population varies so much that

stage	replicates	generations	noise level	fitness function	selection criterion for the key organism
1	400	40	0.1%	base*	reliable steering towards at least 3 directions
2	480	50	5%	base*	reliable approach of at least 3 food sources
3	100	50	50%	base*	reach all the food sources placed on an 11x11 grid
4	120	50	100%	reach $>$ 2 targets	reach 6 food sources in sequence the most often
5	138	50	100%	# targets reached	reach 10 food sources in sequence the most often
6	144	50	100%	# targets reached	reach 10 food sources in sequence the most often

Table 1: **Parameters used at each stage.** A stage embodies a set of environmental conditions that favors the emergence of a given skill that takes the organism closer to dependable foraging. * See Chaumont and Adami (2011) for a detailed description.

diversity can be lost when roulette selection is used. Instead, starting with stage 4 we use tournament selection, while omitting the reward for reaching the first food source. Food sources are located in the four cardinal directions and placed 10 meters away to encourage steering, and organisms are scored on their ability to move in each of the four directions. For each direction, there is a chance to obtain two more food sources placed in the same direction that appear at the same distance, also sequentially. To prevent over-adaption to the direction, we add noise to each target position that we increase in later stages as the foragers become more capable (Table 1). Evolving foragers with greater amounts of noise is too challenging, and gives rise to strategies that fail to react to the target positions.

After 290 generations (across 1382 runs), the final foragers were able to reach the first and subsequent food sources about 95% of the time. To test whether our evolved foragers could form stable populations, we carried out "ecological" simulations that were seeded with an initial population of 16 identical organisms positioned uniformly randomly on a square surface of 160x160 meters. Note that this environment is very different from the one the foragers were exposed to in the GA, as in the open-ended environment foragers face for the first time other foragers that may reach and absorb food that they themselves had targeted. With a constant influx of energy and seeded with capable foragers, the environment reaches its carrying capacity and individuals compete for a limited amount of resources[1]. In the environment depicted in Figure 1 (top), the food sources decay slowly (but exponentially) and disappear if they are absorbed. To determine whether a population is stable, it is simulated for an amount of time that is two orders of magnitude longer than an organism's lifespan when starved. (Fig.1 bottom). After an initial transition period when the population is small, food accumulates in the world and triggers an exponential population growth. Eventually, the population stabilizes and maintains healthy levels throughout the simulation, as in a standard chemostat. This simulation environment provides a basic platform to study the evolution of virtual organisms in their 3D physical environment.

[1]A video is available at http://youtu.be/3eTzciBz2VY

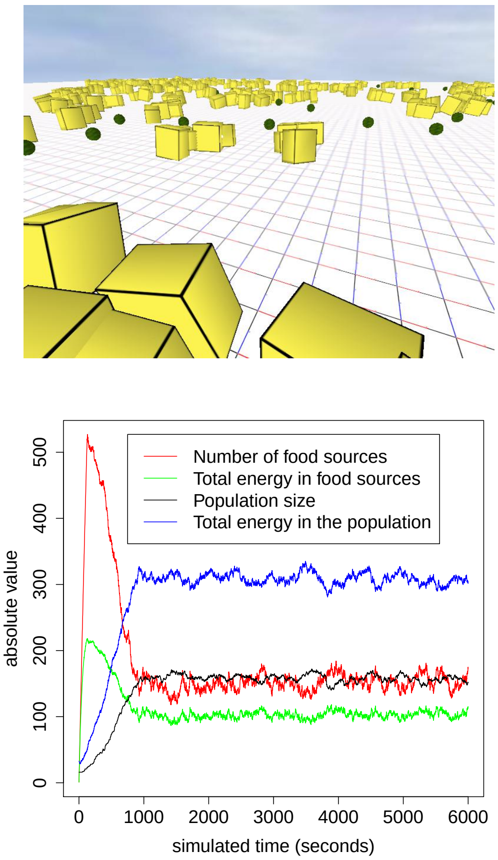

Figure 1: **A simulated ecology:** A snapshot of a population of foragers (yellow) foraging for green food sources (top). A graph showing the food source-dependent population size as well as resource abundance and internal energy (bottom).

References

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