Evolving Motor Techniques for Artificial Life

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Abstract

I have created a program for simulating unique creatures in a 3D environment using co-evolution of the creatures' mental and physical structures. Creature data is stored in a one-dimensional genome consisting of various nodes for each physical body segment. The brain of the creature is controlled by neuron modification of sensor inputs. There is a system for converting genomes to physical representations to allow for physical simulation in the environment, and eventual selection of prime candidates through a genetic algorithm.

Background

Related Research

Research done by Karl Sims is very similar to what I wish to accomplish. His work with evolving creatures led to a variety of organisms specialized in different areas and had very organic movements. The creatures were neuron controlled.

Yoon-Sik Shim and Chang-Hun Kim continued Sims' research and explored the possibility of flying creatures. They developed and explained a system of storing genomes as one-dimensional arrays.

Methodology

The simulation stores creatures in genomes in a way similar to Shim and Kim, however rather than being an array the structure is more like a tree. Creatures are controlled by passing joint-angle velocities received from sensors through neurons to produce joint velocity values. The data follows a circular pattern, moving between sensor, neurons, and effectors (output) each timestep (Fig. 1).

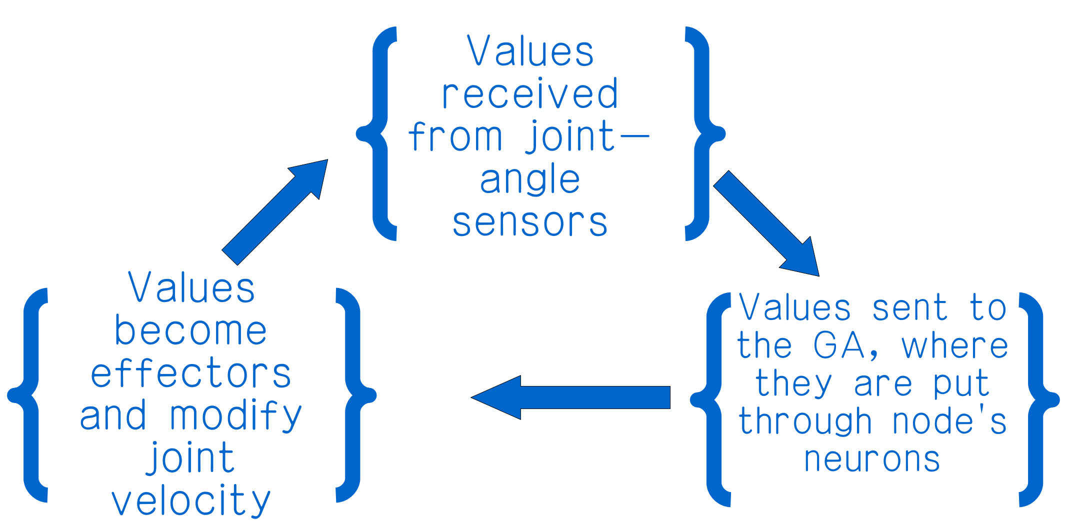


Fig. 1: Image representing the circulation of data. Data originates from sensors measuring interaction with the environment, and then is modified by neurons within each node. Finally, the modified data is passed to the joint as velocity values. The cycle starts over again when sensors receive new data after the joints move.

Development

The entire simulation will be run by the Controller object. At the beginning of each simulation the Controller will create an array of genomes, and maintain this array throughout. It also displays the creatures in the physical environment and measures their fitness levels. After the fitness levels are compared, the Controller will manage the reproduction of the creatures and update the genome array with the next generation.

Each genome is make up of several nodes, each representing a body segment in the physical creature. The nodes store physical dimensions for the limb, a list of connected limbs or children, points where the segment connects to its parent and children segments, and the neurons which will control the joints.

At each time-step the joint-angle values for each node are measured and passed to the Creature Genetic Algorithm. This algorithm passes the sensor values through the neurons for that node and produces an effector, which will be the joint velocity. Possible neuron functions are sin, cos, atan, sum-threshold,sign-of, min, max, if, mem, saw-wave, log, expt, devide, interpolate, and differentiate.

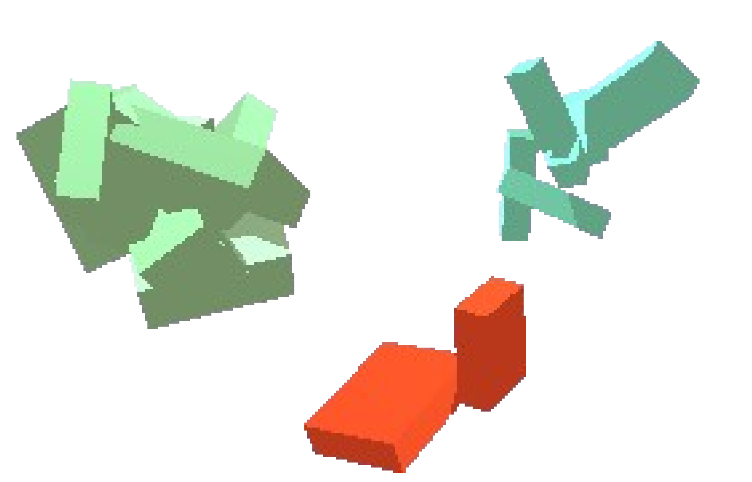


Fig. 4: Examples of creatures which used several rotating legs to roll around.

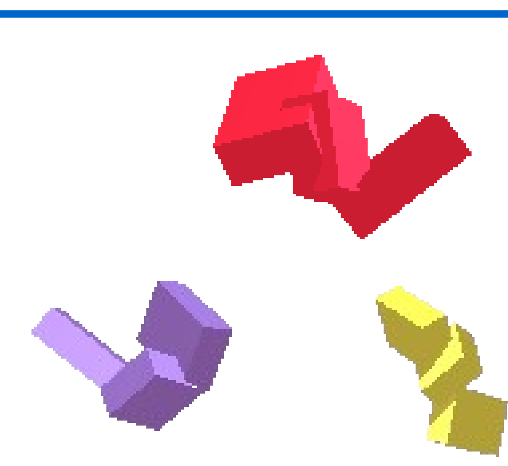


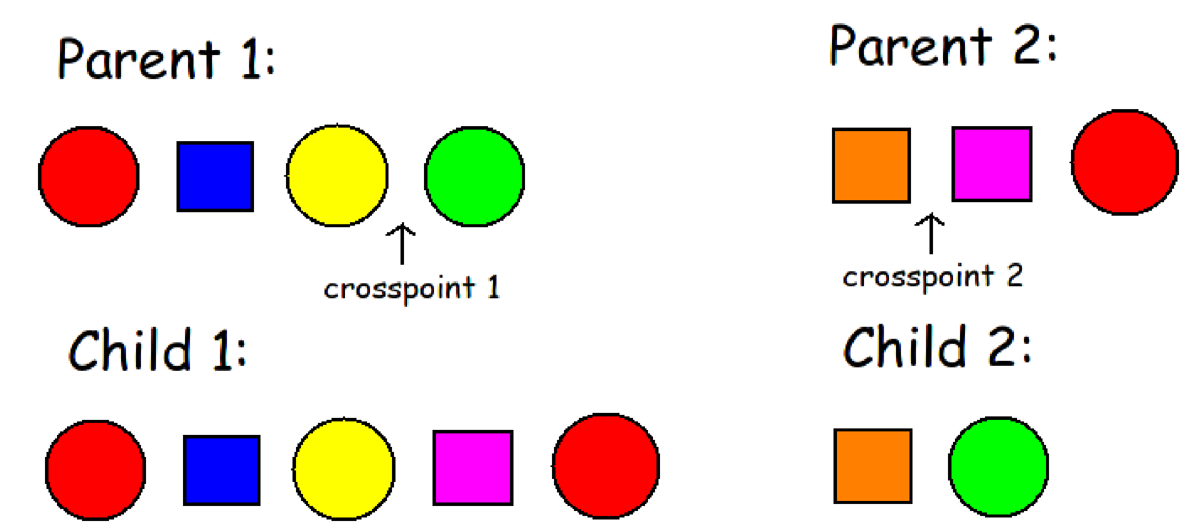
Fig. 5: Examples of creatures which used one or more limbs in a flapping motion to bounce along the ground.

Evolution

At the end of a generation, the best creatures are chosen based on their fitness value, which is how far they have moved since the start of the simulation. The top 50% of creatures are reproduced asexually (copied directly to the next generation). The remaining creatures are crossed over to produce new offspring (Fig. 2).

During this process mutation can also occur. About 10% of offspring produced through reproduction are mutated. Mutation consists of a random node being removed and replaced with a newly generated node.

Fig. 2: An example of the crossover process between two parent creatures.



Results

Results were fairly consistent over several runs of the simulation. Each generation would be three or four creatures who failed to move at all, probably due to an unfavorable combination of neurons in the nodes. Usually one to three creatures would appear as being superior, while the rest managed to move but not very efficiently. Even in later generations the motionless creatures were present.

Average fitness values increased for most simulations. Some improved only by a fitness point or two over the course of the simulation, while others increased by over twenty points (Fig. 3).

Some of the simulations with a duration longer than 100 generations started to show a leveling off or decrease in the average fitness value, although after adding mutation this result rarely occurred. This would suggest that the simulation has a maximum fitness point, after which the values begin to decrease. It could also be a sign of a bust and boom cyclical pattern.

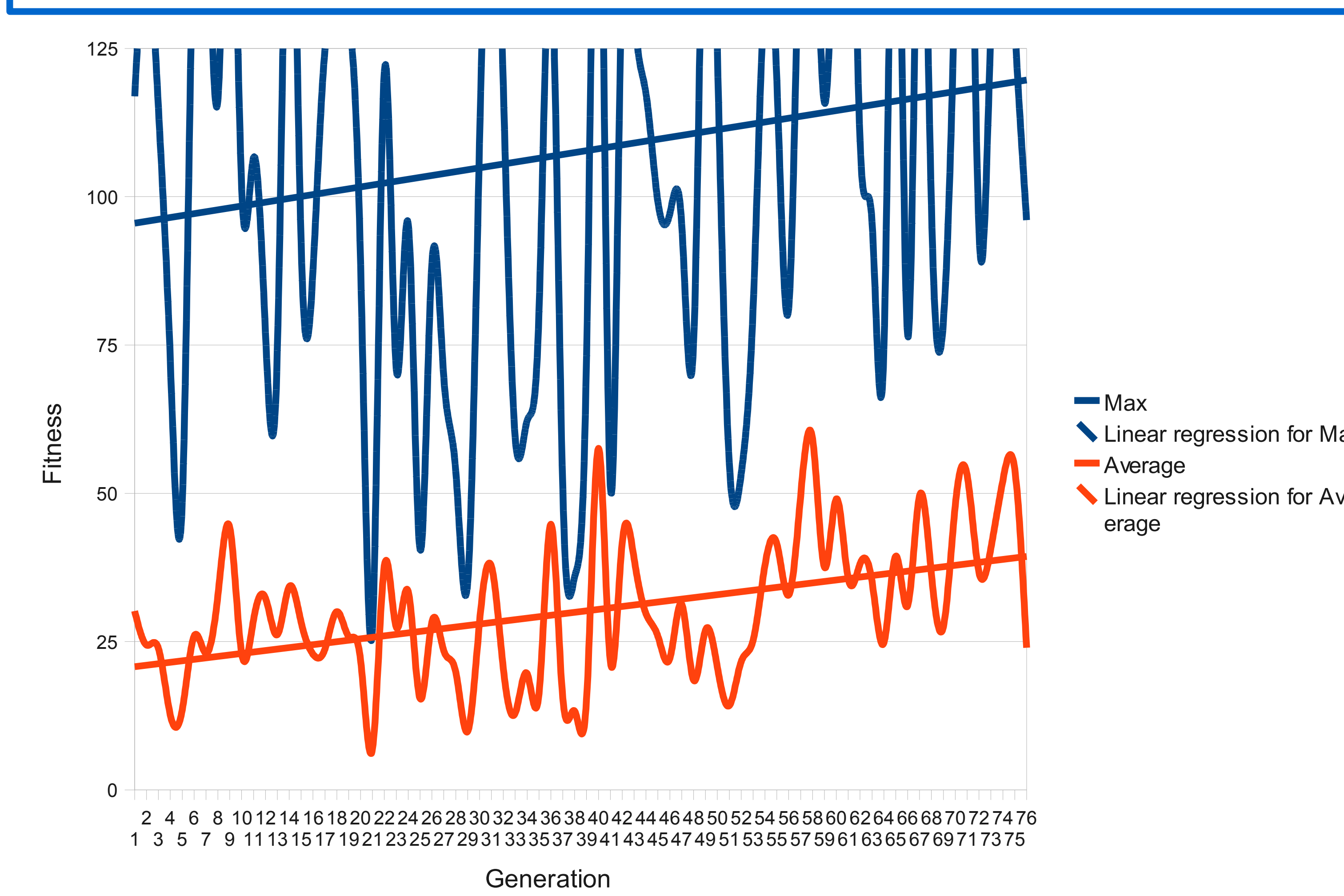


Fig. 3: A graph showing the maximum and average fitness values over time.

Potential Creatures

The number of creatures that could possible be generated is nearly limitless. The genome structure allows creatures with the same body structure to move very differently and vice versa. However, after running many simulation it seems that creatures who are lightweight with long, thin limbs usually produce the highest fitness values. Larger creatures with many boxy limbs were often unable to move.

Along with different physical structures, many different methods for movement appeared. Some creatures would rotate their legs around a central body and "roll" around (Fig. 4). Others had one or more limbs that they flapped up and down, allowing them to bounce along the ground (Fig. 5).