Exploring evolution & mutation in Artificial Life on different physical conditions
CS275 Project report

Orpaz Goldstein,[1] Taylor Caulfield,[1] Andrew Tran,[1] Carlos Sotelo,[1] and Kailun Qian[1]

Abstract— **Computer simulations of life forms are valuable, as they can provide insight into how life forms function and evolve. A popular form of simulation is the evolutionary model, which we wish to utilize to explore how a physical environment can influence a creature's locomotion. Multiple copies of a simple base creature with a base set of movement parameters are placed in a 2D environment and are mutated, randomly shifting around their movement parameters. The creatures are then given tasks in the form of a fitness function. The highest scoring creatures are kept alive and copied, while the other creatures are culled. With our method, we are able to create a creature that can move reasonably well in a variety of 2D environments.**

I. INTRODUCTION

Artificial life simulation has long been a subject of interest in fields outside of the realm of computer science, particularly biology. Simulating a life form can provide information on that life form that is difficult or impossible to obtain in the real world, such as the mechanics of its locomotion and why the life form developed the physical characteristics that it has. These simulations are also valuable in the animation sector, as they can remove the need to animate creatures by hand.

Various forms of artificial life simulation exist. In this paper, we will be focusing on evolutionary models, an iterative form of modeling that is heavily inspired by the process of biological evolution. Evolutionary models take in a base set of parameters and one or more objectives. They then repeatedly tweak the parameters in a stochastic manner and test them with the objective(s), optimizing the parameters in the process. The more iterations that are performed, the more optimized the parameters tend to become. This process, which is completely automated, is much faster than trying to find optimal parameters by hand. In the field of artificial life, evolutionary models are often used to explore the dynamics and evolution of locomotion in animals.

II. BACKGROUND INFORMATION

Evolutionary models in artificial life have been explored for over three decades. Two major developments in the field have arisen from the work of Chris Langton and Karl Sims.

A. Langton's Ant(1986)

Langton's ant is a 2D Turing Machine to kick started artificial life. It starts with an Ant moving in a grid. Each position has black or white color. The ant will turn left or right and move forward one step based on the step it was on. The trajectory pattern starts simple, symmetry like. Then the pattern becomes extremely random. But when the simulation goes to around ten thousand steps, the pattern suddenly becomes completely regular. For example, it can moving like a small circle outwards diagonally, which people like call this pattern a "highway". This is a great example shows a simple rule can lead to really complex result. Although this is not an evolutionary model in our experiment, but Langton's ant was a major influence on people's research on artificial life.

B. Karl Sims: Evolved Virtual Creatures(1994)

Karl Sims developed a system that created several hundred creatures with a "genome" that were tested on a task; each iteration, select the most fit creatures, these creatures pass their genome onto the next generation. The whole evolving process then repeat in next generation. The idea is that like evolution, better and better traits will emerge that are suited to the environment. Karl Sims' experiment inspired our team to implement our method in this project.

III. PROJECT OBJECTIVES

In this project, our first objective is to be able to reproduce some of the results from the Karl Sims' experiments. We wish to be able to evolve a creature who is able to walk in a 2D environment using Sims' guidelines for evolutionary development and evaluation using a fitness function. In addition to these, we will enhance the evolutionary method to introduce a stochastic global maximum search function, in our case we will use "Simulated Annealing", in order to allow for a wide exploration of the creature's genome. Once these methods are in place, mutation of a creature's limbs will be explored and allowed in various intensities. Lastly, We expect creatures to evolve in different ways on different physical environments. This will be tested by changing components such as the gravity in the simulation, and evolving a set of creatures that will be compared to creatures evolved on different environments. This will let us glimpse into the possible variations in creature evolution on physical conditions that differ from our own.

A. Evolutionary Computation

In this project, multiple methods and algorithms can be implemented in order to approach the objective we proposed in previous section. Different machine learning technique for example can be used as a key in this case. The general concept in this project is called Evolutionary Computation.

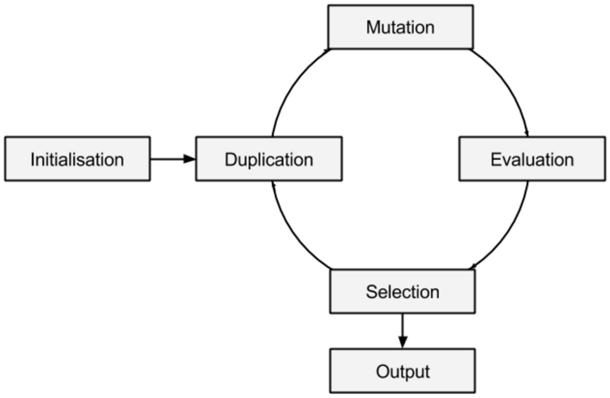

Fig. 1. evolution computation loop

It is inspired by and very similar to Darwin's evolutionary theory. In Darwin's theory, the fittest species can have the chance to produce their offspring. Therefore, they can survive the environment comparing with other species in the same environment. In evolutionary computation, our idea is very similar to evolution theory. In initialization stage, we create initial model of creatures. These creatures do not have ability to walk or run by themselves yet. In second stage, we let creatures to duplicate themselves in to hundreds of exact copies. The third stage is called mutation. In this stage, we mutate the previous copies into different creatures based on the parameters we have. Now we officially have our first generation creatures in fully developed. The fourth stage is called evaluation stage. Previous generated creatures get evaluated in this stage in a natural simulated environment, which mimic the real environment in real natural. The creatures start learn to walk by themselves in simulation. In the meantime, we keep tracking their fitness value for each individual and compare this value at the end of simulation when they stop moving forward. The fifth stage is called selection stage. In this stage, we start select the individuals performance wells in last stage based on the fitness score they achieved. For example, we had 500 creatures fully developed and evaluated. Then we only choose the first 20 creatures in the selection stage and let them have the right to evolve in the next circle according to Figure 1. This algorithm is then iteratively running for further generations. After hundreds of generations evaluated through the evolution loop, the output of our final creatures can be selected in the current selection step.

B. Mutation Computation

C. Implementation Strategy

In order to seamlessly visualize a creature model while creating control functions and defining a physical environment, we have chosen the graphics engine Unity3D to implement our project. Unity is a software that greatly simplifies the development of physics based simulation while allowing us the freedom to control every aspect of the simulation using scripts written in C$\#$. Our team focused on a single model for a base creature we would then evolve. The structure of our model contains a solid body, two eyes, four legs, four feet. The legs and feet are simple cylindrical segments joined together by springs and hinge joints. The limbs are in turn attached to the body using hinges. Each creature has a genome which contains the information that was passed down from previous generations. Each genome controls phenotype for the movement of each leg and foot(8 total). Therefore, phenotype has four parameters in our design for legs to interact differently.

D. Fitness Function Evaluation

Our fitness function scores two aspects of a walking creature. Our first parameter of evaluation is the distance a creature has passed on the X axis during our measurement time. The second parameter is the angular orientation of the creatures body. A creature who manages to stay horizontal oriented scores higher in our fitness function. The result we aimed for is a creature who is able to walk while keeping "upright" without unnecessary acrobatic maneuvers. While the X axis distance is measured easily by subtracting the starting distance from the end distance, the absolute value of angular orientation error has to be taken into account at every frame of the simulation and then divided by the number of data points taken to get a mean value for the error. In order to fine tune our fitness function, we assigned different weights to the two parameters and manually chosen the weights that gave a most balanced looking creature.

$$BodyAngle = |90.0 - body.rotation.z| \ \forall \ Frame$$

$$BodyAngleMean = \frac{BodyAngle}{\#Frames}$$

$$\begin{aligned} FitnessScore = \\ (end.position.x - initialPosition.x) * \alpha \\ - bodyAngleMean * \beta \end{aligned}$$

E. parameters

- Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as 3.5-inch disk drive.
- Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation.
- Do not mix complete spellings and abbreviations of units: Wb/m2 or webers per square meter, not webers/m2. Spell out units when they appear in text: . . . a few henries, not . . . a few H.
- Use a zero before decimal points: 0.25, not .25. Use cm3, not cc. (bullet list)

F. Equations

The equations are an exception to the prescribed specifications of this template. You will need to determine whether or not your equation should be typed using either the Times New Roman or the Symbol font (please no other font). To create multileveled equations, it may be necessary to treat the equation as a graphic and insert it into the text after your paper is styled. Number equations consecutively. Equation numbers, within parentheses, are to position flush right, as in (1), using a right tab stop. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in

$$\alpha + \beta = \chi \tag{1}$$

Note that the equation is centered using a center tab stop. Be sure that the symbols in your equation have been defined before or immediately following the equation. Use (1), not Eq. (1) or equation (1), except at the beginning of a sentence: Equation (1) is . . .

G. Some Common Mistakes

- The word data is plural, not singular.
- The subscript for the permeability of vacuum ?0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter o.
- In American English, commas, semi-/colons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
- A graph within a graph is an inset, not an insert. The word alternatively is preferred to the word alternately (unless you really mean something that alternates).
- Do not use the word essentially to mean approximately or effectively.
- In your paper title, if the words that uses can accurately replace the word using, capitalize the u; if not, keep using lower-cased.
- Be aware of the different meanings of the homophones affect and effect, complement and compliment, discreet and discrete, principal and principle.
- Do not confuse imply and infer.
- The prefix non is not a word; it should be joined to the word it modifies, usually without a hyphen.
- There is no period after the et in the Latin abbreviation et al..
- The abbreviation i.e. means that is, and the abbreviation e.g. means for example.

IV. EXPERIMENT RESULTS

In an attempt to achieve our objectives, our team performed different experiments on our creatures. In below subsections, we will present all of them to show our results. As a guiding line to all our experiments, we have attempted to evolve a natural looking creature in contrast to the Karl Sims' creatures. In addition we strive to produce a creature who will carry itself in a natural manner (i.e: head upright, fluid motion of the limbs) and constructed our fitness with that in mind.

A. Parliamentary attempt at evolving a walking creature

Our first attempt in evolving a walking creature was using a simpler version of our final creature. In constructing a creature with half the size of the genome and only two limbs connected to a body, we were able to test our theory regarding the usage of simulated annealing in "searching" for a global maximum that translated to a creature who most adequately satisfied our fitness function. The first version of fitness included only a score based on the X axis distance of a creature and nothing else. Using this basic version of a creature and fitness function, we were able to evolve a walking creature who made efficient use of it's limbs, although not in the most natural way.

Once we had a first version of a creature, we felt confident to complicate our creature design; add two more limbs, increase the genome size and adding a restriction on head/body angle orientation to induce a more naturally walking creature.

B. Fine tuning fitness

Using a fitness function that both scores both the X axis distance as well as the angle along that same axis in addition to the stochastic nature of our simulated annealing search method, allows us to play with the parameters, assign weights to either parameter and expect different results every single time. We have started by using an unweighted version of the function but quickly realized that the orientation is overtaking the distance resulting in creatures that far preferred to keep a straight head then walking a distance. In order to correct that, we introduced two weights for either parameters: α for the distance parameter and β for the head angle. By using different combinations of weights we were able to evolve creatures that were both great walkers as well as maintained a natural posture.

C. Experimentation with gravity

Once we were happy with the results of evolving a creature to walk, we approached the experiment of evolving creatures in different environments. Different values of downward acceleration were used essentially changing the value of gravity experienced by a creature, denoted here as a number representing the distance from Earth gravity (i.e: 1).

The focus of our gravity changes were to see how gravity changes in both the positive and negative direction would affect the evolution of creatures. The two gravity values that were chosen are 0.16G (lunar gravity) and 2.36G (Jupiter's gravity). As the video clips of the result show, creatures evolution have a very distinct correlation with different gravity values; while lower gravity produces creatures who are prone to walking tall and using the entire range of two or more limbs while balancing themselves, higher gravity shows creatures walk closer to the ground, using more of their limbs surface in order to efficiently walk while putting less emphasis on upright movement or stretched out limbs.

V. CONCLUSIONS

References are important to the reader; therefore, each citation must be complete and correct. If at all possible, references should be commonly available publications.

REFERENCES

[1] Karl Sims, Evolving Virtual Creatures Proceeding SIGGRAPH '94 Proceedings of the 21st annual conference on Computer graphics and interactive techniques, Pages 15-22 ACM New York, NY, USA 1994

[2] Langton, Chris G. Studying artificial life with cellular automata. Physica D: Nonlinear Phenomena. 1986