Growth Control and Disease Mechanisms in Computational Embryogeny

Or Yogev
California Institute of Technology
1200 East California Blvd.
Pasadena, CA 91125 U.S.A.
or@caltech.edu

Andrew A. Shapiro
Jet Propulsion Laboratory
California Institute of Technology
1200 East California Blvd.
Pasadena, CA 91125 U.S.A.
Andrew.A.Shapiro@jpl.nasa.gov

Erik K. Antonsson
California Institute of Technology
1200 East California Blvd.
Pasadena, CA 91125 U.S.A.
erik@design.caltech.edu

ABSTRACT

This paper presents novel approach to applying growth control and diseases mechanisms in computational embryogeny. Our method, which mimics fundamental processes from biology, enables individuals to reach maturity in a controlled process through a stochastic environment. Three different mechanisms were implemented; disease mechanisms, gene suppression, and thermodynamic balancing. This approach was integrated as part of a structural evolutionary model. The model evolved continuum 3-D structures which support an external load. By using these mechanisms we were able to evolve individuals that reached a fixed size limit through the growth process. The growth process was an integral part of the complete development process. The size of the individuals was determined purely by the evolutionary process where different individuals matured to different sizes. Individuals which evolved with these characteristics have been found to be very robust for supporting a wide range of external loads.

Categories and Subject Descriptors

Categories and subject descriptors:I.2.11 Distributed Artificial Intelligence [Intelligent agents].

General Terms

Algorithms, Design

Keywords

Genetic Algorithm, Indirect Encoding, Stresses, Finite Element, Artificial Cell

1. INTRODUCTION

Natural evolution has produced systems of fantastic complexity, robustness and adaptability. Recent research has shown that it is the combination of both evolution and development processes that have produced these remarkable results [2, 3, 1]. *Embryogeny* is the process of growth by which a genotype develops into a phenotype, and is central to the emerging understanding of the relationship between evolution and development. In this case the developmental stage is artificially stopped. In this paper we will present a novel approach which mimics the fundamental processes in nature and helps an organism to reach a limited size even in a high volatility environment.

GECCO'08, July 12–16, 2008, Atlanta, Georgia, USA.
ACM 978-1-60558-130-9/08/07.

2. ARTIFICIAL MODEL

In the work reported here, an artificial embryogeny of structures has been created which is an extension of previous work done by the authors [**?**].

3.1 Metabolism and Thermodynamics

A thermodynamic energy consideration is present in the model which balances the maintaining of the organism mass with the creation of new mass [**?**]. The amount of energy E_c that each cell may consume, in a given time step Δt, is proportional to its metabolic rate B_c. Part of this energy is used for maintaining the existing phenotype while the remaining energy may be used for creation of new mass, as shown in Equation 1,

$$E_c = E_0 B_c \Delta t \tag{1}$$

.

The cell's metabolic rate is proportional to the volume of the phenotype S. Assuming that the volume of the cells has small variation in the phenotype, the metabolic rate can be determined using Kleinberg's law, given in Equation 2 where N_c represents the number of cells.

$$B_c \propto \frac{S^{3/4}}{N_c} \tag{2}$$

.

Every gene regulation consumes energy. By specifying the amount of energy, required for cell division gene, and by establishing E_0 , a thermodynamic size limit can be specified for the phenotypes, as shown in Equation 3. The specification of energy needs to be determined by the user based on his experience with the model. Our experience suggest that the model is not sensitive to these definitions,

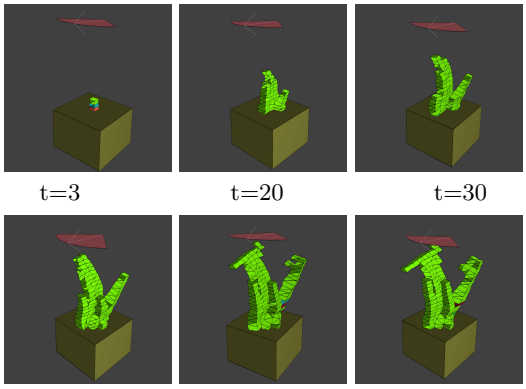

Figure 1: A growth process. The figure demonstrate a growth process of the best phenotype in the population in terms of performances. The colors in the images indicates the mechanical stress on the phenotype. Green indicates low stress while red indicate high stress. The creation of new mass was highly rated during the initial stages of development(t=3 - t=40) and was decaying close to the maturity time. The phenotype was capable of supporting all three types of loads since no cell is over stressed.

$$E_c = E_0 \frac{S^{3/4}}{N_c} \quad (3)$$

.

The advantage of using this approach is that there is no predefined upper bound or other limit on the size of the phenotype. Even when the phenotype reaches the thermodynamic limit, this approach will permit new mass to be created at the expense of removing existing mass, potentially changing the topology of the phenotype.

However, the thermodynamic balance will not prevent phenomena such as unlimited cell division or extermination of the entire phenotype. These last phenomena are addressed by evolution and disease mechanisms. Every phenotype may suffer from a disease during its developmental stage.

4. EVOLUTIONARY SCHEME

In Figure 2 the genome or the DNA of the phenotype is presented. The red and the yellow colors correspond to "veto" genes serving as control mechanism inside the genome. Although the genome itself is very complex, a large part of it is composed of control growth genes.

The evolutionary scheme is derived from a genetic algorithm. The algorithm is initialized with a set of randomly generated genomes. Starting from a single artificial cell, one individual is grown from each genome by executing the rules it contains.

4.1 Structural Growth

The approach outlined above has been applied an experiment representative of an important problem in engineering and nature. The problem was to synthesize the configuration of a structure to support a highly varied load generated by a wind. In addition, the structure needs to reach a certain height.

```
R1Z1S7bV79cFA3fDfeiA4iFC6aC9c
R1Z0B3b8b1aC7cB1h2g2gV35hV72gDdfV196hB1a5h3hF
R2Z1W115tA1iV122aB3h1b0a R1Z1W168tV73gB6b0g4bDffe
R1Z1W124tV166bFFC2aS3bA4dC10a
R1Z1V73gW158tV88cK R1Z1W50aA0iB2g5g4aC5h
R1Z1W128tV150aC6aC5hS9aS1c
R20Z1W161cV50hS1hC6hS4h R1Z1W83tV62cDiA3eB6a4h4bA1dKC9a
R3Z1C10bV79hV192gS10cKF
R2Z0W43tV67aV125gC4bDdf
R4Z1W120tV23gC4gS1aS10aC8aV43hW158tKKC5cDi
```

Figure 2: The genome of the phenotypes shown in Figure 1. The red and the yellow colors correspond to "veto" genes which control the development process of the phenotype.

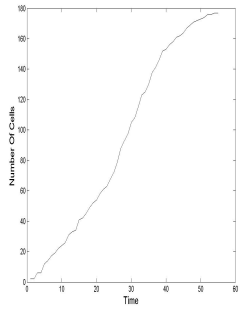

Figure 3: Growth plot - number of cells Vs. time.

The evaluation of the phenotypes was done only in their maturity stage. Figure 1 show the developmental process of phenotypes in Figure 1. which grew branches that tended to spread out. We can learn from figures 1 and 3 that new mass was created rapidly in early stages of development and decaying slowly as the phenotypes reached maturity.

5. ACKNOWLEDGMENTS

Our thanks to ACM SIGCHI for allowing us to modify templates they developed. The research described in this paper was sponsored by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration as part of the Ultra-Reliability Program

6. REFERENCES

[1] P. J. Bentley and S. Kumar. Three ways to grow designs: A comparison of embryogenies for an evolutionary design problem. In W. Banzhaf, J. Daida, A. E. Eiben, M. H. Garzon, V. Honavar, M. Jakiela, and R. E. Smith, editors, *Proceedings of the Genetic and Evolutionary Computation Conference*, pages 35–43, Orlando, FL, 1999. Morgan Kaufmann.

[2] S. B. Carroll. *Endless Forms Most Beautiful: The new science of evo devo and the making of the animal kingdom*. W. W. Norton & Co., 2005.

[3] A. R. Palmer. Symmetry breaking and the evolution of development. *Science*, 306(5697):828–833, Oct. 2004.