FEEDBACK CONTROL IN THE EVOLUTION OF GENERATIVE LINDENMAYER SYSTEMS

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Abstract: This paper discusses the incorporation of feedback and feedback control in the modeling of biological and robotic systems via Lindenmayer representations. Context-free, context-sensitive, parametric, context-sensitive parametric and context-sensitive parametric Lindenmayer systems under feedback control are discussed. Proposals are made on how to modify generative context-sensitive parametric L systems to place them under feedback control. This has implications for biological modeling, robot design and genomics.

Keywords: Bio control biocybernetics biomedical control system robotics physiological models

1. INTRODUCTION

L-systems (Lindenmayer, 1968) were introduced by Aristid Lindenmayer to describe the growth of plants. Cell division and the changing identities of cells are catalogued, so that the fate of cells and cell lines can be traced and reduced to algorithms. The system has been extended to animals. In the case of the Nematode worm (C. elegans), for example, the fate of all 959 cells that make up the adult worm has been traced. In the turtle graphics interpretation of L-systems they have been extended to model the generation of 3D robots (Hornby, 2003). This is especially relevant for robots or robot swarms that are made up of similar units. The robotic models generated by such L systems have been successfully manufactured by various workers (Funes, 2001). It is suggested in this paper that biological growth involves extensive feedback in the creation of shapes during embryogenesis and wound healing, and that the application of feedback in L-systems will generate better robots and deepen our understanding of biological organisms. In addition, biological systems have internal set points, which could denote limits to growth (growth set points). By applying such set points to Lindenmayer systems they could be enhanced.

In addition, it may be that the genome is a complex generative Lindenmayer system, with interesting consequences for biology.

2. CONTEXT-FREE DETERMINISTIC L SYSTEMS

It is known that plant structures can be generated by simple Lindenmayer systems like

Angle 16
Axiom ++++F
F=FF-[-F+F+F]+[+F-F-F] (1)

With the application of turtle graphics and 5 generations we get the following structure:

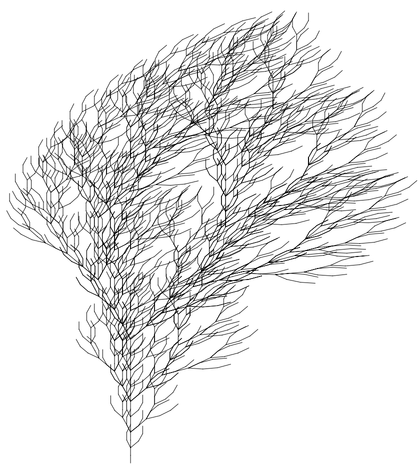

Fig. 1. Graph of Lindenmayer “tree”.

This is an example of a context free deterministic L-system (D0L system). These are static structures, with infinite growth.

3. PARAMETRIC L-SYSTEMS

Parametric generative L systems were also described by Aristid Lindenmayer. In Parametric L-Systems the production rules have parameters. These parameters are used to decide which production rules to apply. For example, a production rule with predecessor $P0(n)$, condition n and successor $P1(n)$ may be written as:

$$P0(n): n > 1 \rightarrow [P1(n*1.5)]a(1)b(3)c(1)P0(n-1)$$

$$P1(n): n > 1 \rightarrow \{[b(n)]d(1)\}(4)$$

Starting with $P(3)$ the production rule evolves as follows:

1. $P0(3)$

2. $[P1(4.5)]a(1)b(3)c(1)P0(2)$

3. $[\{[P1(3)]a(1)b(3)c(1)P0(1)$

4. $[\{[b(4.5)]d(1)\}(4)]a(1)b(3)c(1)[P1(1.5)]a(1)b(3)c(1)$

5. $[\{[b(4.5)]d(1)\}(4)]a(1)b(3)c(1)\{[b(1)]d(1)\}(4)a(1)b(3)c(1)$

The letters a, b, c and d can now be replaced by production rules for the turtle like "move forward", "make neuron", "make muscle" etc.

It may also be desired to harmonize the growth cycles with the Monod growth equation, if such a simulation is needed.

4. CONTEXT-SENSITIVE PARAMETRIC L-SYSTEMS

If we have more than one component growing at the same time we could make the growth of the one system conditional on the state of another L system or on environmental variables like temperature. For example, if temperature was a function $T(t)$ the production rules could be modified as follows:

$$P0(n): n > 1 \rightarrow [P1(n*T(t))]a(1)b(3)c(1)P0(n-1)$$

$$P1(n): n > 1 \rightarrow \{[b(n)]d(1)\}(4)$$

There will now be a different growth pattern depending on the environmental temperature. This happens for e.g. with some reptiles where the sex is determined by the temperature of the egg.

The number of generations to be generated (n) could also be made be made dependent on environmental functions. This would e.g. affect the size of the organism or robot.

5. CONTEXT-SENSITIVE PARAMETRIC L-SYSTEMS UNDER FEEDBACK CONTROL

By cycling the production rules (switching them on and off as environmental conditions dictate) we would have true growth under feedback control. By applying a feedback rule with a set point to the system or to its components we could stop the growth at a predetermined point or density. The size or density of the tissue would then be maintained via the feedback rule. An environmental matrix would have to be accessed to check whether a production rule should be run. If any cells died we could make the generation of new cells dependant on the same feedback rule. The grammar of Lindenmayer systems would have to be modified with if-then-else statements to implement feedback, but in this way the concept of context-sensitive Lindenmayer systems could be extended. To get repair a new generation has to be called, hence we need an if-then-else on the calling of the rules themselves. Such systems could be described as context-sensitive parametric L systems under feedback control.

If Structure[x,y,z] dies

Then

$$P0(n): n > 1 \rightarrow [P1(n*T(t))]a(1)b(3)c(1)P0(n-1)$$

$$P1(n): n > 1 \rightarrow \{[b(n)]d(1)\}(4)$$

else…

Detailed description of such a system would depend on the particular components involved.

In this case the system is still sensitive to temperature, so that e.g. wounds would heal differently depending on the environmental temperature.

6. CONCLUSION

Lindenmayer systems have been used successfully to model biological organisms and to design and generate robots. The application of automatic control theory has been absent in these representations. The concept of if-then-else statements to introduce feedback into Lindenmayer systems is presented. Combined with the representation of variable maxima dependent on external factors or internal set points, an enhancement in the utility of Lindenmanyer systems could be achieved.

It should also be noted that there is feedback on the evolution of the shape of the individual organisms, but that feedback occurs through a process of elimination, i.e. the genetic algorithm itself.

These ideas have relevance for the modeling of biological systems as well as the design of modular and swarm robots.

It is also suggested that the genome could be represented as a complex generative parametric L system with feedback elements.

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