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Paper :
Artificial Creatures from Biological Development

Topic: Generative Robots
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References:

[1]Josh C.Bongard, Rolf pfeifer,
"Evolving Complete Agents using Artificial Ontogeny" , Morpho-functional Machines: The New Species (Designing Embodied Intelligence) Springer-Verlag,(2003) pp. 237-258.
[2] Karl Sims," Evolving Virtual Creatures", Siggraph '94, Computer Graphics1994, pp.15-22

Abstract:

This paper investigates a method of building artificial creatures in virtual environments by means of **artificial development and evolution**. Building blocks of a real creature are cells. The "cells" that our system uses are called "macrocells. They are much bigger than real cells, but much smaller than usual segments or modules used to build robots. Macrocells are simple but embody mechanisms **analogical** to those of real cells. The development procedure generates a creature body out of a single macrocell; Macrocells [simply "cells" hereafter] divide, grow, and connect to other cells to build a whole body. Cells have joints such as rigid, prismatic, rotational joints, and can connect to other cells that have matching joints. The development mechanism is specified by the genome in each cell. Each gene in the genome is designed to have specific attributes which define the behaviors of the gene products. Some gene products are control signals, which play the role of catalyst protein, and the other gene products are used to differentiate the cell into a specific cell, e.g. a neural cell and a structural cell with a rotational joint. Control signals are used to express specific genes that match them. The initial cell has predefined control signals corresponding to the maternal factors in a real fertilized cell. Neural cells, which include sensor and motor cells, connect to each other to form a neural net, which in turn connects to structural cells to move them. The physics of the environment and the creatures is simulated by means of the ODE (Open Dynamics Engine) library. Initially, genomes are generated randomly, though their attribute structure is designed. The generated creatures will be also fabricated into real robots, by using small hardware modules and electrical circuits corresponding to the structural and neural cells. Our method embodies mechanisms of reall cells quite faithfully in that **the phenotype do not correspond to the genotype one to one**, in contrast to most artificial creatures generated by genetic algorithm. Through this study, we can learn some organizing principles of life, though quite abstract from and only analogical to real life.

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Artificial Creatures By Biological Development

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Abstract

This paper investigates a method of building artificial creatures in three dimentional virtual environments by means of artificial development. Building blocks of a real creature are cells. The “cells” that our system uses are called “macrocells”. They are much bigger than real cells, but embody mechanisms analogical to those of real cells . Cells have joints such as rigid, ball, rotational joints, and can connect to other cells. The development mechanism is specified by the genome in each cell. Each gene is activated when a particular set of gene products are in the cell. When activated, each gene creates particular gene products. Some of them are used to trigger cell actions, e.g. cell division, creation of joints, necessary for the development of the creature.
The creatures are simulated by ODE (Open Dynamics Engine) library. In the future, the generated creatures will be also fabricated as real robots by small hardware modules and electrical circuits.

1. Introduction

In this work, we apply biological concepts of development to simulate artificial creatures. There are some researches that use biological concept to create artificial life. We design our algorithm within the framework of artificial development proposed by Bongard and Pfeifer [2]. This approach tries to model a gene regulatory network based on a set of genes in the genome [6,7].
The gene regulatory network is used to implement the developmental process. That is analogous to biological development. This approach contrasts to more traditional approaches to the simulation of artificial creatures, where the phenotype corresponds to the genotype almost one-to-one [1,3,4].
Section 2 describes the morphology of artificial creatures and fundamental principles

of development, e.g. gene expression, diffusion of gene products, and neural network. Section 3 discusses the implementation of these concepts. Final section provides conclusion and future work.

2. The Model

2-1. Creature Morphology and Development Mechanism

Building blocks of a real creature are cells. In this work, spheres are used to represent cells. Agents begin its development as a single cell. Each cell has sensors such as touch sensor and distance sensor. The cell can contain joints and internal neurons. The cell may grow until the radius is double. Then the cell splits into two cells, each of which has default radius and inherits the genome from the parent cell.

The development is driven by the actions of each cell at each time step. The action of the cell is divided into two kinds: gene regulatory action and structure building action. The action of the cell at each time step is determined by the current state of the cell. The state of the cell is defined by the gene products in the cell and their concentrations. The gene products that trigger structure building actions are called structural genes. The gene products that trigger gene expression to produce gene products are called regulatory genes.

When genes are expressed, the gene products are generated at specific diffusion sites. They are diffused to nearby diffusion sites as time passes by. Six peripheral sites are defined midway along the six line segments originating at the center of the sphere. We also set up the “central site” at the center of the cell.

The cell division action is triggered when the growth enhancing gene product is greater than a threshold and the difference between the growth enhancing gene product and the repression gene product is greater than a threshold at any peripheral site. The new daughter cell is attached to the parent cell at that site.

If the concentration of the joint creation gene product is greater than a threshold at the site where the cell division has occurred, a joint is created. When the joint is not created, the parent cell and the daughter cell are connected rigidly.
The joint receives a signal from the motor neuron, which receives signals from various sensors via internal neurons (Fig1). During development, at each time step, gene products get diffused to the neighbour sites in the same cell and to the neighbour site in the neighbour cell at certain rates (See Fig 2). Gene products also decay at the sites where they are created at a certain rate each time step.

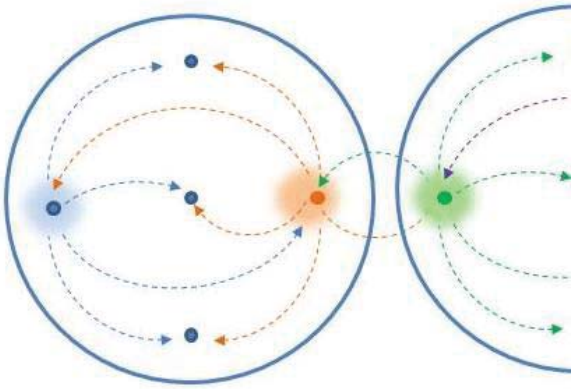

Figure 1.Diffusion of gene products

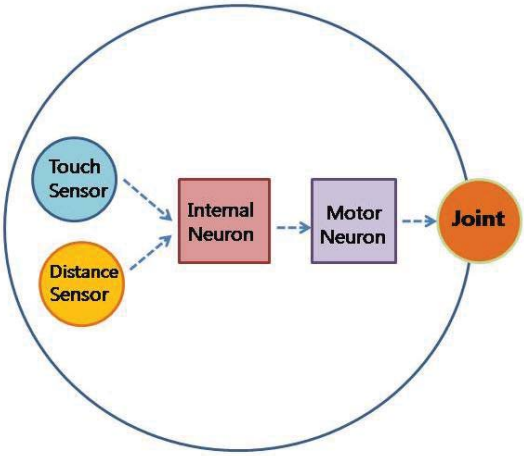

Figure2. The flow of signal transmission in the single cell

2-2. Sensors and Neurons

Sensors /Neurons	Abbreviations
Touch sensor	TS
Angle sensor	AS
Distance sensor	DS
Motor neuron	MN
Bias neuron	BN
Oscillatory neuron	OS
Internal neuron	IN

< Table 1. Sensors and Neurons>

Sensors detect signals of the environment (See Table1). Each diffusion site in the

cell can contain neurons, sensors and motors. Internal neurons receive signals from sensors and other internal neurons (Fig 3).

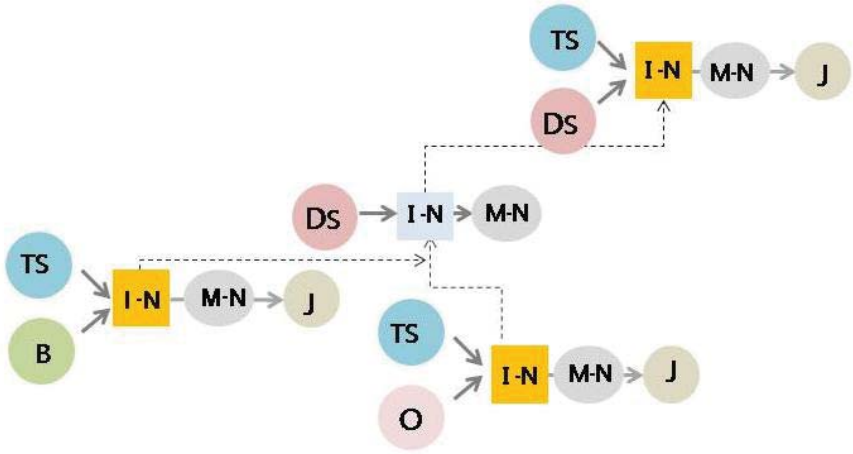

Figure3. Internal neuron nodes

The touch sensor of a cell is activated when the cell contacts either the target object or the ground. The angle sensor returns the angles of the connected joint. The distance sensor returns the distance of the cell to the target object.
The oscillatory neuron generates a sinusoidal signal and the bias sensor generates a specific constant signal. The signals from sensors propagate the motor neuron via the internal neurons. The motor neuron controls a degree of freedom of the joint.

Neurons and sensors are created in a similar manner as cells themselves. The creation of neurons and sensors are triggered by the states of the cell, which are specified by neuron creation gene products and their concentrations.
A touch sensor is created at a site when the touch sensor creation gene product has concentration greater than a threshold at that site.
Similarly for angle sensors, distance sensors, bias neurons, motor neurons and oscillatory neurons. When a motor neuron is created at a given site, it is connected to the joint at that site, if it is already there.

When the internal neuron creation gene product is available at sufficient concentration, an internal neuron is created. It is connected to the motor neuron at th e site, if it is already there. Each sensor is connected to the most recently created internal neuron that is not yet connected to any sensors.
If such internal neuron is not available, the most recently created internal neuron is used, even if it is connected to another sensor. An internal neuron can be divided when it is not connected to any sensor.
It can be divided in serial connection or in parallel connection depending on the regulatory gene product triggering the operation.

Only the non parent internal neurons can be divided. In the case of serial division, the two neurons are connected. In the case of parallel division, the two neurons are connected to their parent neuron (See Fig4).

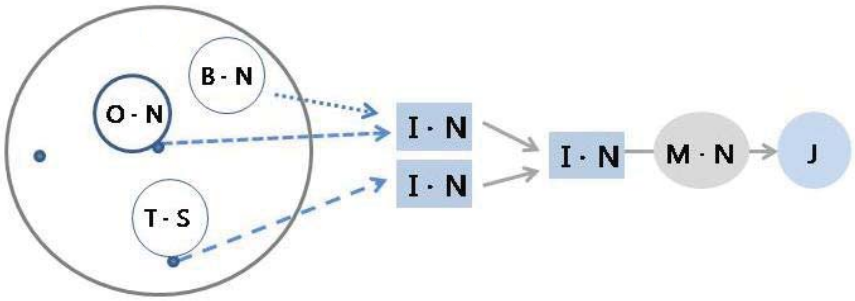

Figure 4. The parallel division of an internal neuron.

The internal neuron sums the input signals from the connected sensors or other inter nal neurons. The output signal of an internal neuron is scaled into range of (-1, 1).
The agent's motion is accomplished by the joint angles generated by the motor neurons. The above rules of neural network development does not ensure that the developed neuron network is well connected and works. It depends on the sequence of structural gene products. In turn, it depends on how the genome is defined. Since in our approach, the genome is generated randomly, only a few creatures will have working genomes and develop successfully.

2-3. Design of the Genome

The development mechanism is driven by the sets of structural gene products and their concentrations. The structural gene products are created by the genes in the genome. A gene is designed to create a regulatory gene product or a structural gene product depending on regulatory gene products currently available in the cell. We use 13 structure gene products, and 10 regulatory gene products (see Table 2, 3).

A gene has the header field and 9 parameter fields (Fig 2). The header field is the promoter. The promoter indicates the starting position of the gene along the genome.

The 9 parameters are used to regulate the gene expression. The parameter P1 (See Fig2) is the enhancer. If its value is greater than 0.5, the gene expression is enhanced by the presence of the regulatory gene products mentioned in the fields P2 and P5. Otherwise, the gene expression is repressed. Parameter P2 indicates on e of13 structure gene products. Parameter P3 and P4 define the range of P2's concentrate on in which the gene expression is enhanced or repressed. Parameter P5 indicates one of 10 regulatory gene products. Parameters P6 and P7 define the range of P5's concentration.

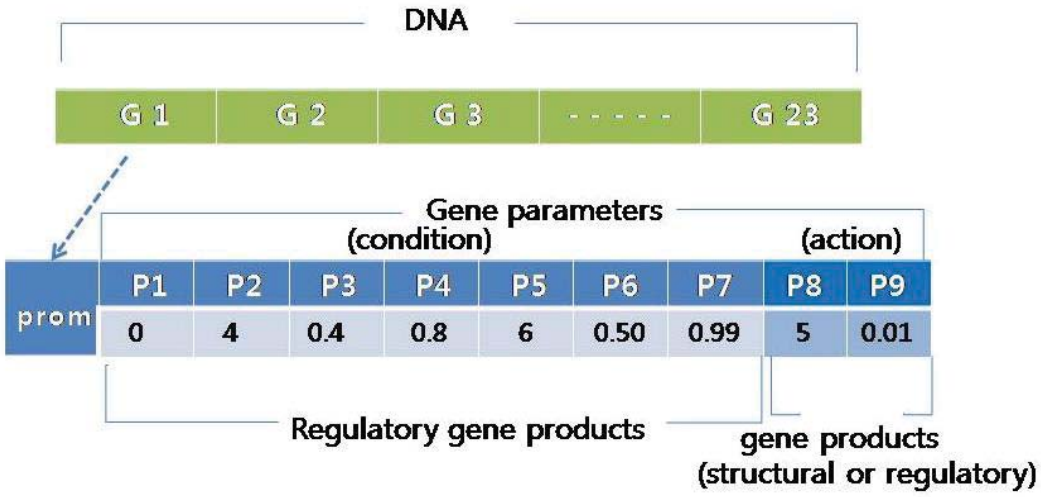

Figure5. The structure of genes

The gene expression is triggered when both regulatory gene products denoted by P2 and P5 are available in the cell and their concentrations are within the given ranges. Parameter P8 indicates one of 16 gene products which include both regulatory gene products and structural gene products. Parameter 9 defines the concentration of the generated gene product each time the gene is activated. The generated gene product is assumed to be injected at the central site of the cell.

To generate the genome the parameters of the genes are set randomly. To start development, some regulatory gene products should be injected into the initial cell. For example, the growth enhancer gene product and the growth repression gene product can be injected to opposite diffusing sites of the cell.

3. Development of Agents and their Simulation

Gene product	Description	Gene product	Description
GP1	Growth enhancer	GP 8	Create internal neuron
GP2	Growth repressor	GP 9	Create Angle Sensor
GP3	Create motor	GP10	Create joint
GP4	Create touch sensor	GP11	neuron serial division
GP5	Create distance sensor	GP12	neuron parallel division
GP6	Create oscillatory neuron	GP13	neuron division repressor
GP7	Create bias neuron		

<Table 2. Actions of the structural gene products>

Gene products	Description
RP1~RP10	Any two of the regulatory gene products are used as the triggering condition for gene activation

<Table 3. Regulatory gene products>

The development process is implemented by the following algorithm:

1) Generate a set of 23 genes by generating the values of the fields randomly. The structural gene products can range from 1 to 13 and the regulatory gene products can range from 14 to 23.
   The values of the other fields can be set randomly up to reasonable constraints. For example, in the case of range values, the lower limit cannot be greater than the up-per limit.

2) Inject the created genome into the initial cell, and inject the initial regulatory gene products into the cell.

3) For each time step until the specified steps N, do:

   3-1) Grow each cell.
   3-2) Decay and diffuse the gene products of each site by the specified rates for all cells.
   For each cell, do:
   3-3) Visit each gene.
   3-4) Check if the conditions of each gene are satisfied.
   That is, if regulatory gene products of the gene and their ranges are satisfyied by the current state of the cell.
   3-5) If so, generate the gene product of the gene by the specified amount.
   3-6) For each structural gene product, perform the action associated with it
   If the conditions for the action are satisfied by the current state of the cell, that is by the structural gene products and their concentrations.

Once the creature is generated by the developmental process, its behaviour is simulated by the ODE engine [8]. Since during the developmental process, the creature is created according to the creature data structure used by ODE, the creature can be directly simulated by implementing the simulation function so that it can access the creature data structure.
Figure 6 shows the result of artificial development of creatures which are composed of spheres.
At the present moment, the developmental process proposed by the paper is not sufficiently tested, and a full implication of this approach is not available. Also, the developed agents are supposed to be selected by testing their performances. It is because the genome used for development is created randomly, and most of them do not produce viable agents. This evolution step is not yet implemented at the moment.

4. Conclusions and Future Work

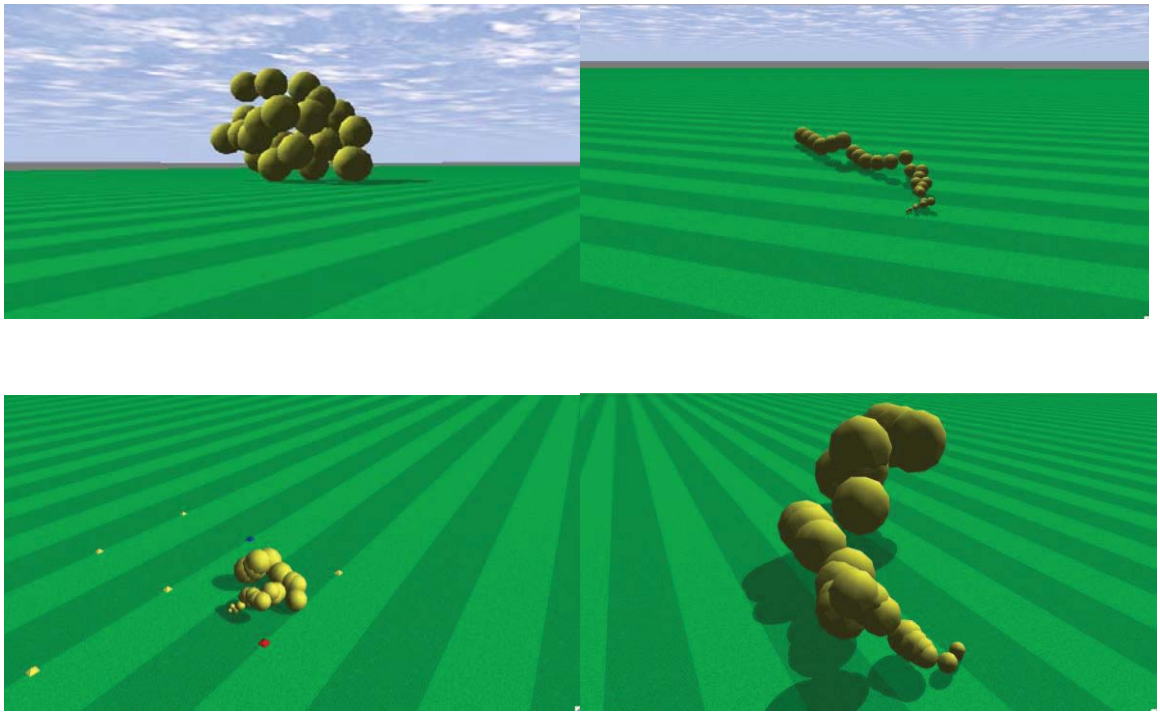

Figure 6. Developed agents

In this work we proposed a gene driven mechanism of the development as a new way of designing and simulating artificial creatures. The strong point of the approach is that the phenotype is developed via a mechanism hidden in the genome as in real creatures. Though the proposed mechanism is extremely simple compared to that of real creatures, the basic architecture of the mechanism is analogous to that of real creatures.
This approach is expected to give us some hint to the mystery and beauty of biologic al development by means of constructing artificial creatures by using biological principles.
In the future we plan to fabricate the generated creatures as real robots by small hard-ware modules and electrical circuits.

5. References

[1] A. E. Eiben & J.E. Smith, (2003) ”Introduction to Evolutionary Computing”, Springer.

[2] J. C. Bongard & R. Pfeifer (2003), “Evolving Completes using Artificial Ontogeny”, Morpho - functional machines: the new species : designing embodied intelligence, pp. 237-258.

[3] K. Sims (1994),“Evolving Virtual Creatures”, Siggraph’94, Computer Graphics, pp. 15-22.

[4] K. Sims (1994), ”Evolving 3D Morphology and Behavior by Competition”, Artificial Life IV, MIT Press, pp. 28-39.

[5] M. Komosinski & A. Rotaru -Varga (2001)”Comparison of Different Genotype Encodings for Simulated 3D Agents”, Artificial Life, Vol. 7, No. 4, pp. 395-418.

[6] P. Eggenberger (1977), “Creation of Neural Networks Based on Developmental and Evolutionary Principles”, Artificial Neural Networks , Lecture Notes in Computer Science, pp. 337-342.

[7] P. Eggenberger. (1977) ”Evolving morphologies of simulated 3D organism based on differential gene expression”, Proceedings of the Fourth European Conference on Artificial Life, Springer-Verlag, pp. 205-213.

[8] Russell Smith (2006), Open Dynamics Engine, v0.5 User Guide, http://www. ode. org/