Intelligent cell using on-line GRN policy enzyme

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Abstract

Nowadays, morphogenetic engineering (ME) [1] is inspired by biological systems (embryogenesis) to export their self-formation capabilities to engineered autonomous systems. As cells are intelligent by nature, researchers of ME are trying to recreate this intelligence in artificial systems, so that these cells know how and when to act in order to accomplish a specific function (e.g. Build an organism).

Introduction

Morphogenesis in computer science has become a topic of interest in natural systems. In their attempts to understand embryogenesis, biologists realized that the morphogens, the genes [2], chemical gradients [3], and mechanical forces between cells [4], affect the cell development, without knowing how these mechanisms work exactly.

Thus, since we still ignore the exact mechanisms of this process, that leads us to ask whether there are other mechanisms or not. Especially because scientists have not discovered everything about a cell due to its complexity.

The automatic design of complex systems, such as artificial multicellular organisms, is a considerable challenge; especially if this organism exhibits the same 'strong' characteristics of living organisms. The self-organization process results in architecture without any central planning or external drive. To achieve these properties of embryogenesis, many developmental models have been designed to simulate the growth of virtual multicellular organisms, with different levels of biological realism. In [5], the author argues that the functional requirements impose the shape development. Aligned with this idea, we propose a model of cell development that uses the function requirement at hierarchical levels to develop an organism, without using morphogens as an external driver in the environment [6] or a cell driver [7].

Due to the embryogenesis complexity, it would be very difficult for the cell to undertake the whole process of creating an organism, where some specific cells use a function to create a specific tissue not the whole organism. subsequently, we propose an *"Autopoietic Multilevel System"* to subdivide the complex shape (by function requirement).

The individuals in our model are different from a level to another. For example, cells in the 1st level, tissues in the 2nd, and so forth, until arriving at the final shape which is the organism. In this paper, we demonstrate how our GRN works in one of the levels, starting by stimulating cells that are controlled by an *"on-line GRN Policy Enzyme"*.

On-line GRN Policy Enzyme

To achieve an embryogenesis process, we must know "how the tissues and organs of the developing embryo take their miraculous forms?". We use Artificial GRN with new additions in order to obtain an on-line learning process with memory concept. Our proposed model is defined as follows:

1. A reinforcement learning realized by an Artificial GRN;
2. A policy enzyme that accelerates the activation of one of the potential actions using the memory system;
3. A memory system that is represented by two matrices: "*best action"* and "*worst action"*;
4. An evaluation module with two evaluation functions; the first one against local interest, and the second against the global interest, initialized at the birth of the individual.

Morphogens in our model are obtained from neighbors as a signal of the individual, the energy wich is fundamental to achieve an action, and proteins from the upper GRN that determine the function requirements. These morphogens can activate more than one action at the same time in the first layer. With a GRN, an individual can activate the right action in the right place using reinforcement learning. Two regulation layers are used here; the first one assures that all the necessary morphogens of the environment are present for each action. If the gene action of the first layer is active, they pass to the second layer (Policy enzyme), where it chooses between the activated actions to select the right action according to the memory. These two layers regulate the output of the GRN.

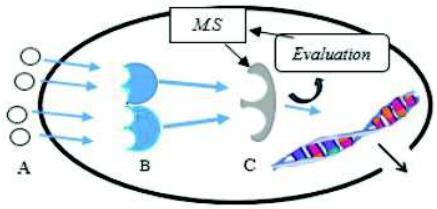

Figure 1. GRN Policy Enzyme Architecture. (A) Represents morphogens in the environment, (B) the first layer or regulation (gene action). (C) The second layer of regulation (Policy enzyme), M.S the Memory system.

Primary Results

Embryogenesis is a complex process, in which achieving some degree of morphology's complexity by a self-organization system is complicated. This task can be accomplished by using the performance of functional requirements. This function is used here to regulate the response of the GRN. Initially, just one cell is present with an unregulated *GRN Policy Enzyme*, and a function that conducts the morphogenesis process to a target shape.

Generally, a function requirement is subdivided, so each level will have a specific sub-function (eg. Obtaining a tissue shape). To achieve this function, we will demonstrate the capability of:

- Each cell to know which action to execute, where and when.
- The auto-organization process to generate a corresponding shape without external control.

To demonstrate how our GRN works, we put a stem cell in our simulation grid and we give it the task of creating an organ. Without limit geographies in the environment, morphogens in the environment have a partial effect in the cell development, but they are not defined as rules in the cell's genome. In the first generation, stem cell has no information about its memory system. Policy enzyme chooses randomly between actions that have the possibility to be executed. Each cell has its own function that it should accomplish. For example, the cell level tries to respond to the tissue function.

The figure 2 presents the obtained results of the GRN learning process with the Policy Enzyme. In the first generation (figure 2.a) just the first tissue (yellow) of the development process appears, this latter uses all the energy present in the environment. If its own function is achieved, then the cell level responds to a tissue level, which in turn will create a second sub function to cell level as creating another tissue.

Here, we observe that the second tissue doesn't appear because the energy was all used by the first tissue.

In (figure 2.b), cells in the first tissue try to use their memory differently from the previous generation; the GRN_Policy enzyme allows them to use less energy (actions chosen from the memory matrices). This will generate a competition between tissues; each tissue works on its own interest to create its shape. So, other tissues can also appear and the function to obtain an upper level (an organ) will have enough individuals (tissues) to be achieved. (Figure 2.c). When the development process generates the specific organ, each cell generates its right path, according to its function. *Policy enzyme* is regulated for each cell, in time and space. Cell modifies its *Policy enzyme* whenever the morphogens or the functions to be achieved are modified.

Conclusion and future work

In this paper, we propose a new model of an organism's development, where we try to inspire from biological systems by using a *self-organized* system that uses a new kind of GRN: *"On-line GRN Policy Enzyme"*, coupled with a hierarchical level of development using the concept of autopoietic system.

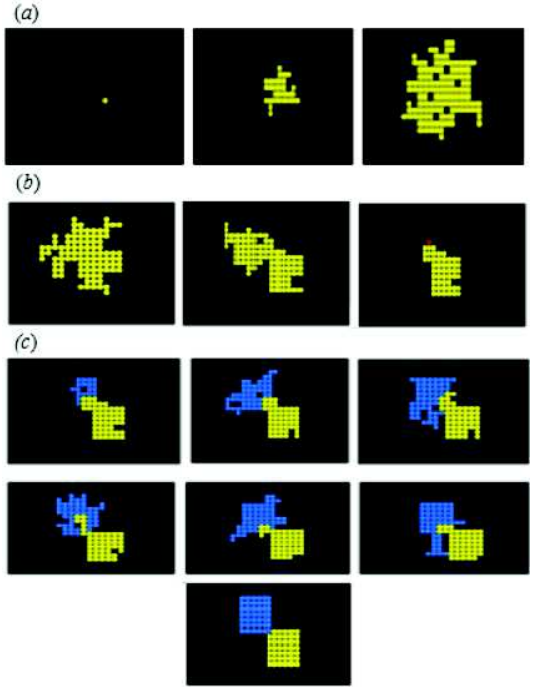

Figure 2. Development of a target shape from a single cell.

In our next work, we will detail this hierarchical development, and this by presenting how individual (cells, tissues, organs) can create itself basing on the autopoiesis concept.

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