Homeo Dynamics in Game of Life

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We study the emergence of homeodynamics and adaptation on top of the game of life layer with the other cellular automata layer. Homeodynamics here is defined as a space-time dynamics that maintains the state-1 density in the life game space. A genetic algorithm is used to evolve the rules of the second layer cellular space to control the pattern of the game of life which is the first layer. We discovered that pattern generators emerged in this system to control the first layer pattern. One such generator creates cloud patterns for the initial high density environment, but keeps quiet for the initial lower density environment. Homeodynamics sustained by the pattern generators is discussed by comparing with the daisy world simulations.

1. Introduction

Living systems require a stable and sustainable structure on top of unstable and highly chaotic open environments. Such a structure is called "homeostasis", it was central themes in Cybernetic studies. Several mechanisms underlying homeostasis have been proposed and they have become a guiding principle of our everyday technology. For example, positive/negative feedback loops and afferent/efferent copies are well studied and developed.

Daisy World is one of the theoretical implementation which illustrate the mechanism of homeostasis. In the Daisy world modeling, temperature should be sustained at a certain range independent of the environmental temperature[Watson 83]. More recently, the regulation mechanism in Daisy World has been applied to the designing of robot controls, for discussing adaptive and autonomous behaviors[Harvey 04, Ikegami 08].

What has been missing in these studies is the self-organizing and dynamic nature of homeostasis, especially in a very unstable world, as in the Game of Life. Here, we study the emergence of homeostasis and adaptation on top of the Game of Life with extra cellular automata rules.

2. The Model

The basic idea of the model is inspired from work by [Taylor 04]. The model consists of a 2D cellular automata running the Game of Life and extra rules which can override Life states in a certain part of the CA space. The extra rule we use is the so-called "totalistic rule" in which the gene only takes account of the number of neighboring state-1 cells, but not a specific neighboring pattern.

The extra rules are encoded in a set of genes, called genome. The gene consists of 26 bits binary string, 18 bits of which represent a state-transition rule for all the different input state. The remaining 8 bits encode the spatial position of the site where the rule is applied(4 bits for each x and y coordinate). The length of each gene is fixed and each gene specifies a particular single site in the 16×16 cell space.

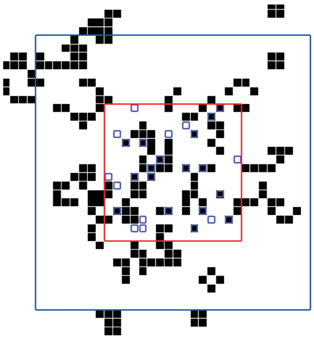

図 1: Filled squares represent Game of Life patterns. Lined squares are the site where genome specifies. The space used for the simulation. The inner square shows the area in which genes override the Life states, and the outer square depicts the target area. The dynamics is only evaluated in this target area.

The total cell space is given as a square of the size 40×40 and the intermediate area controlled by those genes is also given as a square of the size 16×16. The target area with size 32×32 is defined as a square space and all three squares share a common center. (See Fig. 1).

We examine three related but different tasks in order to observe the underlying "homeodynamics".

- **task A** Sustain the same density of the target area regardless of the initial Life pattern density.
- **task B** Control the density of the target area, making it proportional to the given initial Life pattern density
- **task C** Control the density of the target area, making it inversely proportional to the given initial Life pattern density

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3. Experiments

In order to obtain the CA rule sets that achieve the tasks A-C, the genomes could evolve to get the higher fitness. We prepared 30 genomes in a population, each of which consists of 30 genes specifying the spatial location of the intermediate area.

The GA goes through both an evolving phase and a testing phase. In the evolving phase, the 30 genomes are evolved as a unit against two different initial states with lower(0.0) and higher(0.5) density patterns. Note that we only use a fixed but random initial pattern for all evolutionary processes.

4. Result

4.1 Evolved Dynamics

In each of the three tasks, the genomes could evolve to get the higher fitness. In task A, the state-1 density almost always approaches a point independent of the initial density state.

In task B the genomes should increase the state-1 density if the target area is surrounded by the high-density pattern, but this density decreases in the sparse case. So the genome has to develop a “state-1 generator” (a spatial pattern in the Life layer that autonomously produces state-1 patterns) in the target area. A generator of this type creates cloud patterns when in the high density environment, but does not create such patterns in the lower density environment. Thus the generator observed during this task does not continually produce cloud pattern.

In task C, the densities should change inversely proportional to the initial states. So the function of the generator is opposite to that observed in task B.

4.2 Generalization

After training the genome set with these two different initial densities of 0.1 and 0.5, we have tested the evolved genome against other initial densities. Figure 2 shows histograms of the state-1 densities after 500 time steps for each task and we compare them with the original Life rule. In task A, the densities stay in a small range, independent from the initial densities. In task B and C, the histograms have two peaks according to the initial densities. It suggested that the outcome of the density in the target area can be controlled by the rate of sorting the initial cell states into two different attractors. For instance, in task B, when the initial density is low, the basin size of the attractor which does not create any cloud pattern is set bigger than that of the other attractor. But by increasing the initial state-1 density, the system changes the sorting ratio into two attractors.

5. Discussion

In this paper, we studied homeostasis and adaptability with respect to the cell states in the Game of Life.

In task A, the evolved genome can sustain the density whichever the initial Life pattern is. However no regulation happens here, because the genome just works as noise generator.

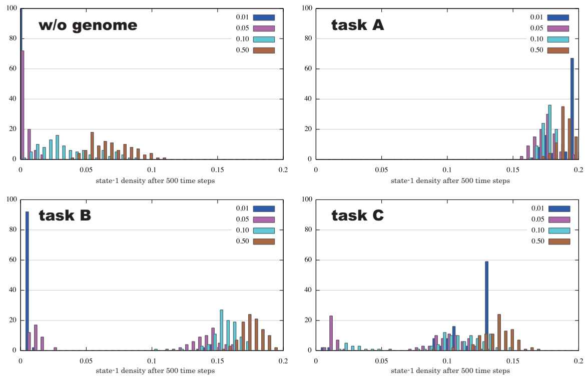

図 2: Histogram of the state-1 densities after 500 time steps observed from the task A,B,C genomes and w/o genome in 100 samples. 4 different initial densities, labeled by 4 color bars, are used to make this figure.

In task B and C, two types of attractors emerge, where it activates or inhibits the Life pattern for controlling the wanted behavior. The number of cells in state-1 is presumably regulated by changing the basin sizes of those attractors; when more initial states go to the state-1 generator, the number of cells in state-1 will be increased.

This reminds us of the Daisy world where black and white daisies can cooperatively make homeostatic states. Because black and white daisies have opposite tendencies toward the sunlight, they can self-regulate the temperature by tuning their population size. This simple scenario is certainly realized in the present Life game system.

参考文献

[Harvey 04] Harvey, I.: Homeostasis and Rein Control: From Daisyworld to Active Perception, in Pollack, J., Bedau, M., Husbands, P., Ikegami, T., and Watson, R. A. eds., *Artificial Life IX : Proceeding of the 9th International Conference on the Simulation and Synthesis of Living Systems*, pp. 309–314, Cambridge, MA: MIT Press (2004)

[Ikegami 08] Ikegami, T. and Suzuki, K.: From homeostatic to homeo dynamic self, *BioSystems*, Vol. 91, No. 2, pp. 388–400 (2008)

[Taylor 04] Taylor, T.: Redrawing the Boundary between Organism and Environment, in Pollack, J., Bedau, M., Husbands, P., Ikegami, T., and Watson, R. A. eds., *Artificial Life IX : Proceeding of the 9th International Conference on the Simulation and Synthesis of Living Systems*, pp. 268–273, Cambridge, MA: MIT Press (2004)

[Watson 83] Watson, A. J. and Lovelock, J. E.: Biological homeostasis of the global environment: the parable of Daisyworld, *Tellus*, Vol. 35B, pp. 284–289 (1983)