Adaptability and Homeostasis in the Game of Life Interacting with the Evolved Cellular Automata

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ABSTRACT

In this paper, the authors study the emergence of homeostasis in a two-layer system of the Game of Life, in which the Game of Life in the first layer couples with another system of cellular automata in the second layer. Homeostasis is defined as a space-time dynamic that regulates the number of cells in state-1 in the Game of Life layer. A genetic algorithm is used to evolve the rules of the second layer to control the pattern of the Game of Life. The authors found that two antagonistic attractors control the numbers of cells in state-1 in the first layer. The homeostasis sustained by these attractors is compared with the homeostatic dynamics observed in Daisy World.

Keywords: *Adaptation, Cellular Automata, Daisy World, Game of Life, Homeostasis,*

INTRODUCTION

Living systems require a stable and sustainable structure to survive in unstable and open environments. The maintenance of such a structure is called "homeostasis". This term was coined by Cannon (1932) and Bernard (1957), and has become one of the central themes in cybernetic studies (Wiener, 1948). Several mechanisms underlying homeostasis have been proposed and these have become a guiding principle of our everyday technology. For example, the idea of positive/negative feedback loops came from the cybernetics field.

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The controlling mechanisms of homeostasis have been revealed, but very few studies have been done on the self-organization aspect of homeostasis. Exceptions can be found in ecological homeostasis. Many people have studied ecological homeostasis, in particular after Lovelock (1972) proposed his Gaia hypothesis. The Gaia hypothesis posits that the complex and global network of living/nonliving systems self-organizes to achieve homeostasis. The Gaia hypothesis has been theoretically examined by Watson and Lovelock (1983) by developing the Daisy World model, a simple implementation of the Gaia theory. In the Daisy World, temperature is sustained at a certain range independent of the environmental temperature. This is done by complex interaction of two kinds of daises which have different albedos. Harvey (2004) calls the mechanism underlying the Daisy World a "rein control", a controlling mechanism that serves to pull the temperature toward the viability zone.

With respect to the adaptability of homeo-systems, Ashby (1960) proposed an interesting design principle for the brain and for life forms in general that was mainly driven by homeostasis. He posited that the adaptive behavior of life is only an outcome of homeostatic properties, and proposed a different type of homeostatic system called an "ultra-stable system". This new system has two feedback loops. The primary feedback loop is driven by a mutual interaction between an organism's complex sensory and motor channels and the environment. The other feedback loop develops from the interaction between viability constraints and the relevant reacting parts via the essential variables that control the reacting parts. Usually, the second feedback loop is intended to change the meta-parameters of the primary feedback-loop. When parameter values are outside the viability constraints, the second feedback loop adjusts the essential parameters so that the system will move toward a more stable state. This second feedback loop was identified in light of the self- mobility in our previous study, which we name "homeodynamics" (Ikegami & Suzuki, 2008). That is, two dynamics co-exist in the same system with different time scales that cooperatively control the homeostasis by maintaining fluctuations in the system. In other words, we need both stable and unstable dynamics to develop homeostasis and adaptation at the same time.

When we regard living systems as natural computing process, such computation may also require concurrent stable and unstable dynamics. Given this, the natural system should possess robustness (e.g. a required degree of insensitivity to environmental changes) in order to achieve certain task, and at the same time, it also needs instability to become sensitive to certain environmental changes. The former environmental change is called "noise" and the latter is called "information". The difference between noise and information is not determined beforehand. It can only be progressively defined.

In this paper, we study the notion of homeostasis and adaptation using Conway's Game of Life. A major drawback of most homeostatic models, including ours, is that many systems test their homeostatic nature in too stable environment. What this means is that such systems can survive without paying significant costs (or in other words, the system never dies). Therefore, our challenge is to see how homeostasis can emerge even in a very unstable world, such as that of the Game of Life. We intend to see how Daisy World is emerging in the evolutionary process, producing dynamical patterns in a bottom-up way, and not just using the predefined components. We propose a coupled cellular automata (CA) model to study evolution of homeostatic behavior in an unstable bit space.

A basic strategy is to apply another rule set in a site specific way on top of the Life rule. We will show that we can evolve different CA sets for stabilizing (insensitive) and memorizing (sensitive) conditions. Then we will discuss the homeostatic result with respect to the Daisy World setup, where black and white daisies are making the homeostatic adjustment. In the Daisy World setup, the population of black and white daisies and their growth as a simple function of temperature is assumed. In this paper, we are evolving corresponding daisy-like behaviors in the second CA layer. The evolving CA rules and their spatial configuration generate the homeostatic dynamics.

In the next section we describe how to use the Game of Life to study homeostasis. We then describe the evolved CA rules and how they work. We also analyze the results and discuss the observed characteristics of homeostasis and adaptation with respect to the daisy world setup.

THE MODEL

The basic idea of the model is inspired from work by (Taylor, 2004). In his model, the system under examination consists of two layers

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