A Computational Model of the Interaction between Environmental Dynamics and Economic Behaviors

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Abstract

Environmental problems have been considered very important for a long time. We believe that they should be examined from an interdisciplinary view so as to reach a solution because they have been caused as the consequence of complex interactions among various factors. This paper proposes a new model termed *ColorChanger*. By using this model, we aim to explore the nature of ecological problems beyond separate discussions on specific subjects, and make the acquired knowledge available to encourage the solution of environmental problems. This paper also reports on the results of the preliminary experiments.

1 Introduction

Environmental problems have been considered very important for a long time. They have been discussed in a wide range from the fields of academic research to international arena of politics. There are many academic fields in which environmental problems are tackled. However, there seems to be an essential issue in conventional approaches.

For instance, there is a biological field termed conservation ecology which investigates environmental problems. Conservation ecology belongs to ecological science and aims at conservation of biological diversity by conducting basic/applied researches. Though the subjects of this approach range widely from genetic issues to landscape design, it rarely pays attention to the economic effects. On the other hand, environmental economics is a field in which the environment problems are discussed from an economic point of view. In environmental economics, the model of consumer and business behavior in traditional economics is evoked to explain who and why acts on environments and who and how suffers the environmental damage. However, consideration of dynamics of life is hardly at all involved in their investigations. In artificial society approach, which is a growing field, the dynamic models are investigated where both environments as resources and economic behavior are brought into view. So far, however, most of them leave environmental variation out of consideration, which must become very important when examining the environmental problem in real world from an interdisciplinary view.

Recently, Akiyama and Kaneko [1] have constructed a computational model so as to focus on the interaction between the dynamics of environment and agents' actions, and successfully analyzed the effects of the interaction on the dynamics of environment and the evolution of agents' actions. Their study doesn't necessarily cope with the environmental problems directly, but gives some indication of the possibilities that this type of constructive methodology could be very important when investigating the dynamics of the interactions between economic phenomena and ecological phenomena.

Encouraged by their results, we propose a computational model that makes it possible to discuss environmental problems from both economic and biological points of view. Our model consists of an economic activity model based on multi-agent modeling and a natural environment model based on cellular automata modeling. We focus on the interaction between economic activities and environmental variation based on the dynamics of an ecosystem surrounding human beings by conducting computational experiments.

2 The Model

2.1 Overview

There are several species of agents (players) and several game fields in *ColorChanger*. We denote a set of the agent species as $S = \{1, 2, \ldots, s\}$ and a set of the game fields as $G = \{1, 2, \ldots, g\}$. Each game field has a two dimensional space that is marked off into $i \times i$ hexagonal cells, on which players play some sort of economic games repeatedly. Each cell has a "color" which expresses the state of its biological environment and can be perceived by nearby players including the agent on it. Each cell changes its own color according to the color patterns on its nearby cells like cellular automata.

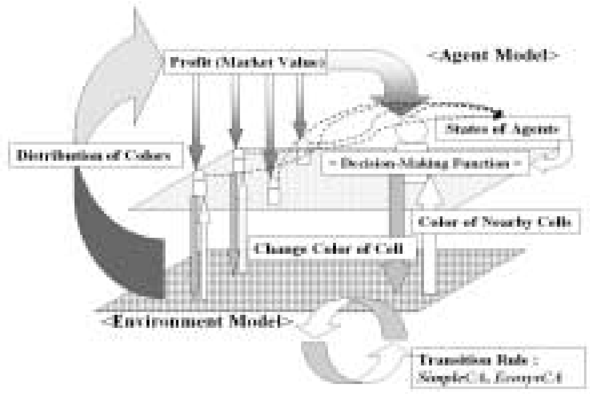

Figure 1: Conceptual diagram of *ColorChanger*: upper plane depicts the agent model, and lower plane depicts the environment model.

We define a set of players as $N = \{1, 2, \ldots, n\}$ in each game field. These n players are selected randomly from S respectively. Each agent gets a reward by affecting its environment, in other words, by changing the color of the cell on which the agent resides, which is meant to an economic action and is decided based on a species-specific decision-making function (Figure 1). An autonomous transition and a passive transition by the agent in color of each cell constitute one round. Each game consists of T rounds, and games in all game fields are played all at once. Each agent acquires its profit in every round. Genetic operations are conducted after all games in g game fields are finished, which is described in the subsection 2.4. Above described procedures are conducted again and again.

2.2 Details of the Games

The color density of the cells surrounding player i at time t is expressed as $e_i(t) = (e_i^{C(1)}(t), e_i^{C(2)}(t), \ldots, e_i^{C(c)}(t))$, where C is a set of colors which cells can be laid on. Each player has a state and a decision-making function. The state corresponds to the profit in the current round. So, the states and the decision-making functions of players are denoted by $y(t) = (y^1(t), y^2(t), \ldots, y^n(t))$ and $f = (f^{S(1)}, f^{S(2)}, \ldots, f^{S(n)})$ respectively, where the state of the player i who belongs to species $S(i)$ at time t and the decision-making function of the player i are denoted by $y_i(t)$ and $f^{S(i)}$ respectively. Player i decides its next action $a_i(t)$ based on $e_i(t)$ and $y(t)$. All of the players' actions are denoted by $a = (a^1(t), a^2(t), \ldots, a^n(t))$. Each player's individual action can be either a "wait" (doing nothing) w or a changing the color of the nearby cells into one of the set of colors $D = \{m_1, m_2, \ldots, m_d\}(m_n \in C)$. The set of these feasible actions is denoted by $A = \{w, x^{m_1}, x^{m_2}, \ldots, x^{m_d}\}$, where x^{m_i} is the action to change the color of cell into color m_i. A and D are shared among all players and is fixed through generations.

Initial state of each player is assigned a random number generated from a normal distribution with a mean of 0.10 and a variance of 0.10 before the first round of the game in each game field. Each round consists of following three steps: **1) environmental variation**, **2) decision making by players**, and **3) effects of actions on cell colors and allocation of profits to players**.

1) The environmental variation consists of two steps. One is to change colors of cells autonomously, and the other is to decrease the players' states to be $y^i(t)' = u_N(y^i(t))$. We set $u_N(y) = 0.9y$ in this paper.

2) A player i's decision-making function $f^{S(i)}$ decides its action $a^i(t)$ based on the states of the environment around the player, $e_i(t)$ (density of each color of cells), and the states of all players in its game field, $y(t)'$:

$$a^i(t) = f^{S(i)}(e^i(t), y(t)'), \tag{1}$$

where $f^{S(i)}$ is the inner structure of the player i and is invisible to other players, which could vary throughout the evolution.

3) Each decision-making function of player i selects the biggest motivation in the motivation map [2] where motivations for each feasible action under the situation $\{e_i(t), y(t)'\}$ are calculated as follows:

$$max(\{mtv_r\}) : mtv_r = \eta_r e_i(t) + \sum_{l \in N} \theta_{lr} y^l(t)' + \xi_r, \tag{2}$$

where mtv_r is the motivation for action $r (r \in A)$, $\{\eta_r\}$ is a $(d+1) \times n$ real number matrix, $\{\theta_r\}$ is a $(d+1) \times c$ real number matrix, and $\{\xi_r\}$ is a $d+1$ real number vector. So $\{mtv_r\}$ means motivation map. Each element of $\{\eta_r\}$, $\{\theta_r\}$ and $\{\xi_r\}$ of the initial species of players is set random numbers generated from a normal distribution with a mean of 0.0 and a variance of 0.1. Players' actions decided in previous step can change the colors of cells. The aggregate profit R is distributed to each action as $P = \{p^{D(1)}, p^{D(2)}, \ldots, p^{D(d)}\}$, based on the state distribution (at the time before state change) calculated on randomly sampled cells as market values in reverse proportion to the frequency of the states. Each $P^{D(i)}$ is equally divided among all players who chose action $D(i)$, which increases the states of the players. Then all players pay cost Q.

2.3 Rules of Color Change in Cell and Agent Actions

A set of colors of cells is denoted by $C = \{1, 2, \ldots, c\}$, and each cell always takes one of these

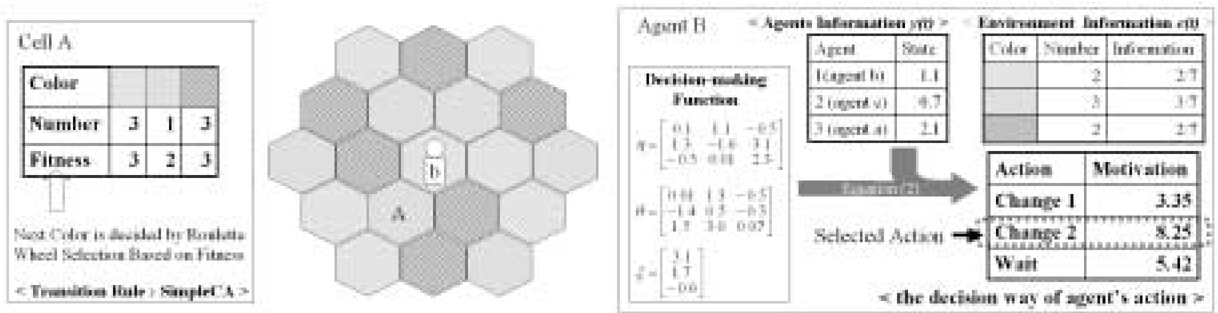

Figure 2: Details of the environmental model and agent model with $n = 3$, $c = 3$, $d = 2$, $v = 2$, and the *SimpleCA* rule; Center figure expresses the situation at time t, left box shows the example of color change on cell A, and right box shows the way of decision-making by agent b.

as a state. We adopt two types of rules by which cells change their color, **1) SimpleCA** (Figure 2) and **2) EcosysCA**. The actions of players are also defined according to the adopted rule as follows.

1) The next color of each cell is decided by the roulette wheel selection based on the distribution of colors in the group of the 6 neighbor cells and itself. In counting each color, the number of its current color is multiplied by v so as to take account of an inertial effect concerning change of color. The action that the players can do is to change the color of the cell on which they exist.

2) This rule expresses a dynamics of the ecosystem. Each color of cells represents the species of animate beings on them, and is denoted by $L = \{1, 2, \ldots, l\}$. An ecological food chain is predefined by links among the species based on the method by R. J. Williams and N. D. Martinez [3], and the ecological niche can be organized under this rule. Not more than one animate beings of each species can exist on each cell. In every time step, every animate beings on each cell execute one of the following actions, prey on, bear a child or move. Prey is an action with a top priority, and is possible only when there exists a prey on the same cell. Other two actions are conducted within nearby 6 cells. If there are no possible actions, it only stays on the same cell. These actions of animate beings change the colors of cells. The color pattern on the plane of the game fields corresponds to the ecological niche. Two types of experiments concerning the player actions are being conducted. One is that players directly affect the animate beings by hunting them and they are eliminated from the cell. The players can affect d kinds of animate beings randomly selected from L. The other is that players don't directly deal with the animate beings, but change the colors of the cells on which they exist. A change of color by an player means to let the animate beings dead and/or born. The players can change d kinds of colors randomly selected from C, which contains 2^l colors that the cells can be laid on.

2.4 Evolution

Genetic operations are conducted to the agent species. The fitness of each agent species is calculated as the average profit of all agents that belong to the species during T rounds. k species with lowest k fitness are eliminated, and the surviving $s - k$ species leave their offspring which has the same decision-making function to the next generation. The eliminated species are replaced by new k species, that are k mutant species randomly selected from surviving species. Mutation happens to every coefficient of the decision-making function that the parent species has. Each coefficient in the decision-making function of the new mutant is chosen as random number from the normal distribution where the variance is 0.1 and the mean value is corresponding element of $\{\eta\}$, $\{\theta\}$, $\{\xi\}$ in the decision-making function of the parent species.

3 Preliminary Experiments

SimpleCA was adopted as a transition rule in the preliminary experiments. Following parameters were used: c (number of cell colors) = 3, n (number of agents in each game field) = 3, and d (number of colors into which agent can change) = 3. The environmental model was initialized with equal frequencies of each color in a random spatial distribution. Other parameters were set as follows: $i = 50, g = 60, T = 400, s = 10, k = 3, R = 1.5, v = 2$, and $Q = 0.3$.

Figure 3 shows the typical transition of average fitness of each agent species. Fitness of agents shows a tendency to increase smoothly. During the first 1000 generation, the agents' strategy (decision-making function) has no clear tendency, which generates a lot of

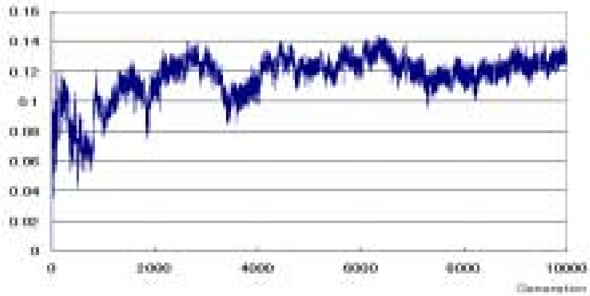

Figure 3: Average fitness of agent species (on a *SimpleCA* model, n = 3, c = 3, d = 3, i=50, g=60, T=400, s=10, k=3, R=1.5, v=2, Q=0.3).

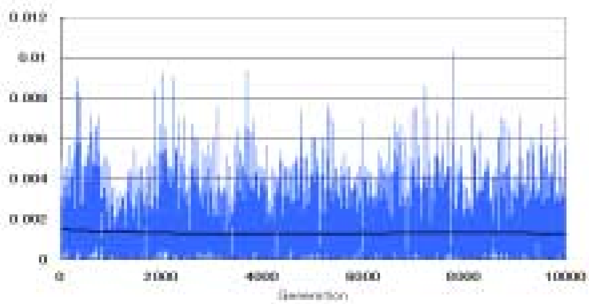

Figure 4: Degree of divergence between ideal and current environment: (gray line: the average of divergence degree of every colors, black line: the approximated curve).

"ambling" agents that behave by a hit-or-miss method. The strategy of agents comes to a relatively stable state without large oscillations beyond about the 1000th generation. At the same time, the behaviors of the agents also begin to change into the action intended to obtain assured income. The same strategy cannot always take a high fitness, because of the "noisy" situation in our model including some sort of bounded rationality. On the other hand, there is a case that a nice strategy continues to exist for a long time and similar strategies are generated by mutation, which cause a decrease in average fitness owing to decrease in diversity. The "wait" action gradually disappears as generation changes. The reason seems to be that it becomes more advantageous to do anything even though there is a risk to pay a cost rather than doing nothing.

Figure 4 shows the effect of agent activities on environments. The degree of divergence is measured as follows:

$$\frac{1}{c}\sum_{i\in C}(E_i - I_i)^2, \qquad (3)$$

where E_i is the actual existent rate of color i, and I_i is the ideal existent rate of color i, I_i is calculated as the average existent rate only with the autonomous change in environment and without agents. In this case, when *SimpleCA* is adopted, the ideal average existent rates of all colors are same because each color has same probability of existence. Figure 4 shows that they did not change remarkably though there are oscillations in any generation. There is no significant difference among the influences of agents on the environments through generations. It is a remarkable point that the evolution of agents doesn't have more effect on environments, while it brings about the increase in gains of agents.

4 Summary

ColorChanger is an attempt to throw light on the interactions between the agents that influence the environment and the dynamics of environment so as to resolve environmental problems. It is also very important not only the current issues but also to consider the problems in future which results from these interactions to solve environmental problems essentially in general. *ColorChanger* also aims to be a useful tool for that, and some results of our preliminary experiments with an environmental model based on a dynamics of the ecosystem were reported. There are some noises which influence the information in these experiments: the difference among the accurate environment information on the whole game fields, the environmental information obtained by agents, and the information on distribution of colors used for allocation of rewards. We have shown that the agents could increase their fitness in spite of these factors.

References

[1] E. Akiyama and K. Kaneko, "Evolution of Cooperation in Social Dilemma - Dynamical Systems Game Approach," *Proceedings of the Seventh International Conference on Artificial Life*, 186-195, 2000.

[2] R. Axelrod and D. Dion, "The Further Evolution of Cooperation", *Science*, 242, 1385-1390, 1988.

[3] R. J. Williams and N. D. Martinez, "Simple Rules Yield Complex Food Webs," *Nature*, 404, 180-183, 2000.