Indirect Control Methods for Navigating the Agent-Based Recycle Society

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Abstract
An agent-based artificial society is known as a powerful tool for understanding complex group dynamics. In this study, this tool is adopted in the study area of environmental problems, particularly because it represents the society where agents are required to recycle used PCs. Discussions in this paper are focused on how we can navigate such recycling activities of multiagents without ignoring their own decision-making processes. Here, some indirect control methods are introduced and investigated using this simulator.

1. Introduction

Recently, we have been faced with various environmental problems caused by the accumulation of past mass production/consumption, and have tried to solve those problems through various means (e.g., restriction of amounts of materials used or exhausted resources). What makes the problem more difficult is that the group dynamics of our society is too large and complex for us to predict, making it difficult to understand the production/consumption behaviors of citizens. Here, we present a useful approach, called an agent-based artificial society, for grasping such complex group dynamics. It is known to have a great power of expression since it models the group dynamics as an accumulation of interactions among multiagents.

However, we have lacked sufficient discussing on controlling such group dynamics. Particularly, we need new methods of controlling group dynamics without ignoring each agent's decisions since we cannot assume to be able to control each agent's decision-making process directly in a real society. Indirect control methods are known as one alternative that can guide and direct the group dynamics of multiagents by controlling boundary conditions of that group (e.g., taxation for economic agents, traffic information for driver agents, and so on). The main purpose of this study is the establishment of a test-bed to investigate such indirect control methods and to define the key features for realizing a sustainable artificial society.

First, we established an agent-based artificial society modeled as a society which recycles used PCs. Second, taxation is adopted as one of the control variables for indirect control and the effectiveness of various ways to apply taxation is investigated by simulation experiments. Finally, this discussion is summarized.
2. Modeling of Agent-Based Recycling Society
2.1 Hierarchical Modeling of Recycling Society

In this study, hierarchical modeling is proposed in order to focus on the influence of the accumulation of the agent’s decision-making process. Figure 1 illustrates a conceptual image of the Hierarchical Modeling of a Resource Circulatory system. In particular, the target of this is the society where agents are required to make a decision on whether they recycle or dispose of the used PCs. This hierarchical model consists of two different types of layers: a logistics layer and a decision-making layer. Detailed explanations of each layer are given in the following paragraphs.

In this artificial society, there are different agents who have different roles: consumers, companies, municipalities, and so on. In particular in this study, agents other than consumer agents are all assumed to play the role of either recycling or disposing of used PCs (e.g., a retail store, a junk dealer, a municipality, a manufacturer and a disposal facility). The consumer agents are required to make a decision on whether they deliver their PC to another agent or dispose of it by themselves.

2.2 Logistics Layer for Agents except Consumers

In the first layer, the logistics layer, various parameters are defined in order to simulate the recycling flow for used PCs (e.g., a product price, a delivery cost and an environmental load). Figure 2 illustrates an example of a logistic layer model. In particular, other agents except for consumer agents are defined according to the following two factors: the cost of retrieving used PCs $P$ and an environmental load $E$. Based on these two factors, the consumer agents are required to select which agents they should deliver their PCs to.

First, the price $P$ is determined by the following equations,

$$ P = C \times M, \quad (1) $$

$$ C = \frac{C_f}{a + N} + C_s, \quad (2) $$

where $C$, $C_f$, $C_s$, $N$, $M$ and $a$ denote a total cost, a fixed cost, a fluctuation cost, a volume in a unit time, profitability and an invariable, respectively. Let $M_n$ and $N_n$ be the profitability and the number of products processed at time $n$. In this paper, profitability $M$ is also changed according to the volume $N$ by using the following equation:
\[ M_{n} = M_{n-1} + \frac{(N_{n} - N_{n-1})}{b}, \quad (3) \]

where \( b \) is a constant describing the variation rate of profitability. The environmental load \( E \) is determined by the following equation,
\[ E = \frac{(N-H)}{N}, \quad (4) \]

where \( N \) and \( H \) denote a volume in a unit time and the number of disposals, respectively. This environmental load \( E \) represents how many agents apart from consumers recycle or reuse PCs.

### 2.3 Decision-Making Layer for Consumer Agents

In the decision-making layer, each agent is assumed to make a decision on who the agent delivers used PCs to by following a utility function consisting of two parameters: a sense of economy and a sense of ecology.

\[ H = w_1 \times P + w_2 \times E \quad (w_1 + w_2 = 1.0), \quad (5) \]

where \( w_1 \) and \( w_2 \) denote coefficient values expressing how the agent gives priority to either the price of delivery or the environmental load. By the above-mentioned definition, the agent-based artificial society is established.

### 3. Indirect Control and Simulation Results

#### 3.1 Indirect Control Methods

One of the indirect control methods for controlling boundary conditions for the group has been formalized [2]. Deguchi controlled the behavior of agents by changing the tax rates in Tragedy of the Commons Problem. The Tragedy of the Commons Problem is regarded as a popular exercise in the study of social dilemma. In this exercise, there are many shepherds in a certain closed society and they earn by increasing the number of their sheep. However, the shepherds cannot always earn by selecting only the rational action for them (to increase the sheep), because having too many sheep may cause the common meadow to die when all of the agents eagerly seek to increase their earnings. Here, Deguchi’s proposed method is not to control each agent’s action directly but to apply taxation according to the number of sheep which each agent possesses. Deguchi insisted that this can decrease the chances of tragedy by controlling the boundary conditions for agents, and this method does not ignore each agent’s decision. This method is what we need, that is, a controlling method with which to direct group dynamics as hoped without ignoring each agent's individual decision-making process. In this experiment, two parameters are adopted as examples of boundary conditions: the percentage of taxed agents (\( \text{Rate} \)) and the time interval of tax collection (\( \text{Interval} \)). In the next paragraph, these parameters are defined precisely.

#### 3.2 Setup Simulation

The former parameter, the percentage of taxed agents (\( \text{Rate} \)), denotes the rate of population taxing in the artificial society. First, it decides the criterion that estimates how many used PCs are recycled by agents other than consumer agents. An agent is categorized as an excellent organization paying attention to ecology when their percentage of recycling exceeds the defined criterion. Then, the artificial society reduces taxation or exempts the said agent from it (the criterion was set as 0.5 in this study). The latter parameter is the time interval of tax collection (\( \text{Interval} \)). In this study, the price of taxation is assumed to be calculated at three times: every 20, 40 and 60 times.

As a consequence of the above-mentioned two types of taxation, the price of returning used PCs is changed. The price is determined by the following equation,

\[ P = C \times M \times T, \quad (6) \]

where \( C \), \( M \) and \( T \) denote a total cost, profitability and a tax rate at a unit time, respectively.
3.3 Experimental Results

Figure 3 illustrates the changes of standard deviation at the time when a consumer agent disposes of the used PCs by himself/herself.

![Graph showing changes of standard deviation](image)

**Fig.3 Changes of Standard Deviation of Disposal Rates**

Here, the disposal rate \( s \) is calculated by the following equation,

\[
s = \frac{h}{N},
\]

where \( N \) and \( h \) denote a volume in a unit time and the amount of waste disposed by consumer agents, respectively. The longer the time interval for which taxes is imposed, the further the standard deviation of disposal ratio decreases. The result implies that the price of returning used PCs should not be changed frequently since it is undesirable that the amount to be processed changes frequently for each agent.

4. Conclusion and Remarks for the Future

In this paper, the agent-based artificial society recycling PCs was proposed as a powerful tool for grasping complex group dynamics associated with environmental problems. Then, some indirect control methods were tested and investigated in this simulator. In particular, it seems to be useful for confirming the effectiveness of various indirect methods since such indirect control methods have not yet been systematized. However, we need to carry out further investigations to clarify the key features influencing each agent’s sense of not only economy but also ecology, since most studies on indirect control methods to date have focused only on agent’s behaviors concerned with economic activities.

References


