Analyzing Sustainability of Circulatory System by Using the Rewriting System

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Abstract

The social system must be changed to a sustainable circulatory system immediately. A considerable number of studies have been conducted on environmental problems. Those studies, however, focused on optimizing the material flow on a certain time section, based on the belief that the pursuit of material circulation will lead to a sustainable society. Those studies have considered only one aspect of the subject. We consider this belief to be suspect. In this paper, we show the results of the analysis of the circulatory system using a model of an abstract social system and verify that the termination property is important for a discussion of the nature of the sustainable society.

1. Introduction

The social system up to now has given rise to various environmental problems, and it must be changed to a sustainable circulatory system immediately. The environmental problems have been receiving increasing attention, and a considerable number of studies have been conducted on this subject. Those studies, however, focused on optimizing the material flow on a certain time section. As a consequence, they have considered only one aspect of this subject, based on the belief that the pursuit of material circulation will lead to a sustainable society. Considering that a circulatory society has many degrees of freedom and high complexity, this belief is suspect. We consider that the basic analysis of the nature of the circulatory system should be investigated. We believe that we can construct an ideal sustainable society by clarifying the nature of the circulatory system.

In order to discuss sustainability in greater detail, we need to construct a methodology for analyzing a sustainable circulatory system. The purpose of this study is to model and analyze the circulatory system using an abstract model of a society as the first step toward the methodology.

2.Concept of Sustainability

Essentially, what is sustainability? Sustainability is an ambiguous concept. For many people, sustainability seems to be a big word that means everything and nothing [1]. Presumably, the most popular definition is Brandtland’s one [2]; however, this is not a sufficiently informative definition.

In recent years, the word ‘sustainability’ has been given various meanings. For example, the concept of sustainability means ‘stability’ or a ‘steady state’ [3]. The first point that we should discuss is what sustainability is and why we need to look at sustainability in a new light.

In this paper, we define the sustainability of the circulatory system from the viewpoint of the termination property. The termination property means that resources in the system cannot circulate when they are saturated or exhausted. A sustainable state, hence, can be defined as a state in which circulation is not terminated in the system.

3.Modeling of Circulatory System

In order to model a circulatory society, in this paper, the society and circulatory materials are regarded as a certain container and various elements. To put it more concretely, we implemented a model of society by regarding rewriting rules and the multiset in the abstract rewriting system on multisets (ARMS)[4] as production and consumption in the circulatory social system, respectively. When we apply this technique, we can discuss the termination property and deal with the social system abstractly.

ARMS is like a chemical solution in which floating molecules can interact with each other according to reaction rules, and a finite multiset of elements corresponding to molecules and reaction rules is specified by using rewriting rules [4]. ARMS can deal with systems with many degrees of freedom and simulate the emergence of complex cycles such as chemical oscillations that are often found in the emergence of life [4]. Furthermore, at present, the modeling and analysis of an ecological system by using ARMS are being attempted [5]. Hence, we expect that we will be able to make an analogy between a social system and an ecological system.

3.1.Abstract Rewriting System on Multisets

An ARMS is a pair

$$\Gamma = (A, R) \text{ [5]}$$

where:

A is a set of objects;

R is a finite set of multiset evolution rules over A.

In the simple example as follows;

$$A = \{a, b, c, d\}$$

$$R = \{a, b \to c : r_1, b \to d : r_2, c \to a : r_3, \quad d \to a, c : r_4, a \to a, c, d : r_5\}.$$

When the maximal multiset size is 4 and the initial state is given by $\{a, a, b, d\}$, a calculation in this system is performed as shown in Fig.1. In Fig.1, the rewriting rule per step is selected randomly.

$\{a, a, b, d\}$

$\downarrow$ r_1 was selected.

$\{a, c, d\}$ r_1 was applied.

$\downarrow$ r_3 was selected.

$\{a, a, d\}$ r_3 was applied.

$\downarrow$ r_4 was selected.

$\{a, a, a, c\}$ r_4 was applied

$\downarrow$ r_5 was selected.

$\{a, a, a, c\}$ r_5 was not applied

Fig.1 Example of rewriting steps

First, if r_1 is selected randomly, r_1 can be applied to the multisets of $\{a, a, b, d\}$ having the left-hand side of r_1. At the next step, if r_3 is selected randomly, r_3 can be applied to the multisets of $\{a, c, d\}$ having the left-hand side of r_3. At the third step, if r_4 is selected randomly, r_4 can be applied to the multisets of $\{a, a, d\}$ having the left-hand side of r_4. At the fourth step, if r_5 is selected randomly, r_5 cannot be applied. If r_5 is applied to the state of $\{a,a,a,c\}$, this multiset will exceed the size that has been determined previously. At the final state $\{a,a,a,c\}$, there are no rules that can transform the multiset. At this state, the termination of circulation occurs.

3.2.The Rewriting Rules for a Circulatory System

In order to apply the ARMS technique to a social system, we define A and R as follows;

$$A=\{a,b,d,f,X,Y,X',Y'\}$$

$$\begin{aligned} R=\{&a,a,a,b\rightarrow X:r_1, a,b,b\rightarrow Y:r_2,\\ &X\rightarrow X':r_3, Y\rightarrow Y':r_4,\\ &X'\rightarrow a,d,d,d:r_5, Y'\rightarrow b,d,d:r_6,\\ &d\rightarrow a:r_7, d\rightarrow b:r_8, d\rightarrow f:r_9,\\ &X'\rightarrow f,f,f,f:r_{10}, Y'\rightarrow f,f,f:r_{11}\} \end{aligned}.$$

$\{a,b\}$ are resources to which are needed in order to produce. $\{d\}$ is a resource to be recycled. $\{f\}$ is a waste product. $\{X',Y'\}$ are products after consumption. r_1 and r_2 denote the process of production $\{X,Y\}$, as a product is assembled from various parts. r_3 and r_4 denote the process of consumption, as a product is bought from a store . r_5 and r_6 denote the process of resolution, as a product is taken apart. r_7 and r_8 denote the process of recycling. r_9, r_{10} and r_{11} denote the process of waste generation, as a product or a part is dumped. A model, which we define as a circulatory society, is summarized in Fig.2.

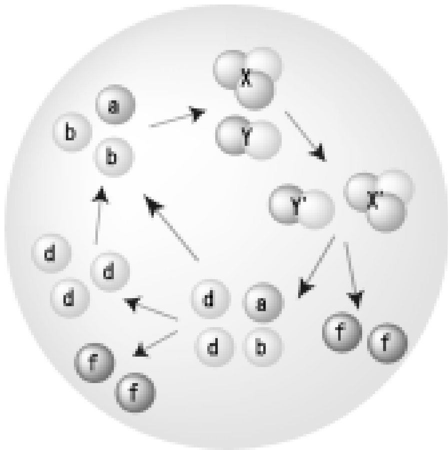

Fig.2 A model of the circulatory system

In Fig.2, each element is regarded as a circulatory material that reacts according to a rewriting rule. This model is a closed system, and there are no inputs and outputs.

Each rewriting rule has a reaction rate k_i $(i=1,2,...,11)$. For example, $k_2=0.6$ denotes that when r_2 is selected ten times, r_2 is applied six times. If k_9, k_{10} and k_{11} are higher than k_7 and k_8, this model is of a social system which has discharged many waste products. On the other hand, if k_9, k_{10} and k_{11} are lower than k_7 and k_8, this model is of a circulatory social system which recycles many resources.

4.Simulation

In this paper, we simulate the behavior of the simple circulatory system that is modeled by ARMS. First, in order to show the validity of this model, we represent a waste products' social system and a circulatory system. We compare the two social systems. Next, we analyze the sustainability from the viewpoint of the termination property.

4.1.Validity of Modeling Social System Using ARMS

4.1.1.Setup of Simulation

We show that this model has the validity to represent a social system. We give meaning to the applicability k_i of rewriting rules. First, k_i is determined as follows:

$$\{k_1,k_2,k_3,k_4,k_5,k_6,k_7,k_8,k_9,k_{10},k_{11}\} = \{0.7, 0.7, 0.7, 0.7, 0.7, 0.7, 0.1, 0.08, 0.3, 0.2, 0.2\}.$$

k_1,k_2,k_3,k_4,k_5 and k_6 are equal to each other. This means that supply and demand are equal. k_9, k_{10} and k_{11} are higher than k_7 and k_8. This indicates a waste products' social system, which has discharged many waste products. Next, k_i is determined as follows:

$$\{k_1,k_2,k_3,k_4,k_5,k_6,k_7,k_8,k_9,k_{10},k_{11}\} = \{0.7, 0.7, 0.7, 0.7, 0.7, 0.7, 0.5, 0.4, 0.1, 0.05, 0.05\}$$

Here, k_7 and k_8 are higher than k_9, k_{10} and k_{11}. This model is of a circulatory social system. The maximal multiset size is 1000, and the initial state is given as follows:

$$\{a,b,d,f,X,Y,X',Y'\} = \{150,150,150,0,100,100,100,100\}.$$

4.1.2.Results and Considerations in the Simulation

The transition of the number of $\{X',Y'\}$ in a waste products' social system is shown in Fig.3. The transition of the number of $\{X',Y'\}$ in a circulatory social system appears in Fig.4. In Fig.3 and Fig.4, the horizontal axis indicates rewriting steps and the vertical axis indicates the number of $\{X',Y'\}$.

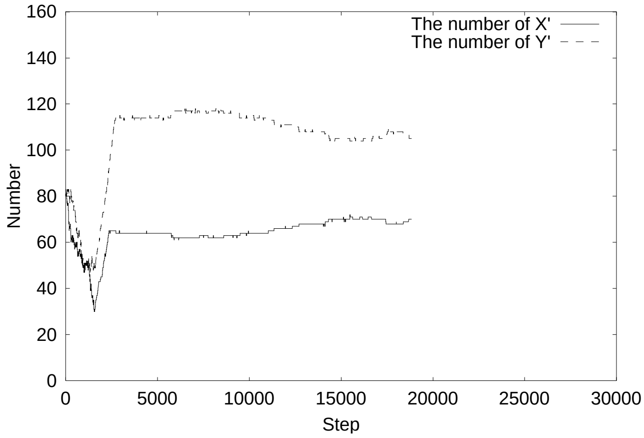

Fig.3 Example of a waste social system

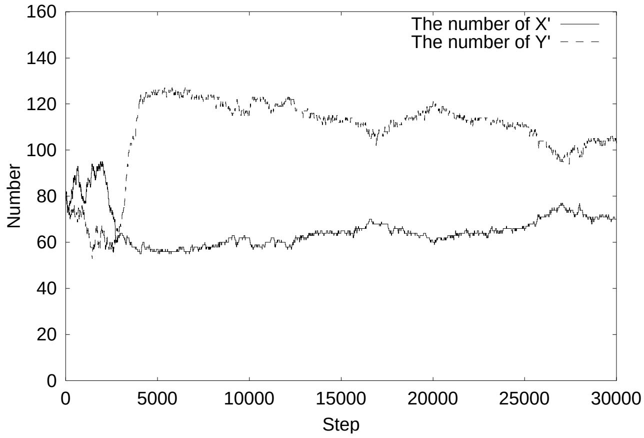

Fig.4 Example of a circulatory social system

Fig.3 shows that there are flat regions to which a rewriting rule is not applied. Finally, rewriting calculations are terminated, because of the increase of $\{f\}$ and exhaustion of $\{a,b\}$. Fig.4 shows that rewriting calculations continue and are not terminated. We see from Fig.3 and Fig.4 that this model can represent each characteristic of the social system.

4.2.Termination Property of Circulatory System

4.2.1.Setup of Simulation

We analyze the termination property of a circulatory system. The initial k_i is determined as follows:

$$\{k_1, k_2, k_3, k_4, k_5, k_6, k_7, k_8, k_9, k_{10}, k_{11}\} = \{0.7, 0.7, 0.7, 0.7, 0.7, 0.7, 0, 0, 0.1, 0.05, 0.05\}.$$

After the circulation is terminated, k_7 and k_8 change from 0 to 1 at intervals of 0.05. The others do not change. We conduct ten trials. If rewriting rules are not applied between n steps, we regard this circulation as having terminated because it is not desired that a circulation stop within a certain time section. In this simulation, n is determined as follows:

$$n = 120.$$

This value of n will be examined again later.

4.2.2.Results and Considerations in the Simulation

The average number of steps needed for termination appears in Fig.5. The standard deviation of steps needed for termination appears in Fig.6. In Fig.5 and Fig.6, the x-axis indicates k_8, the y-axis indicates k_7 and the z-axis indicates the number of steps.

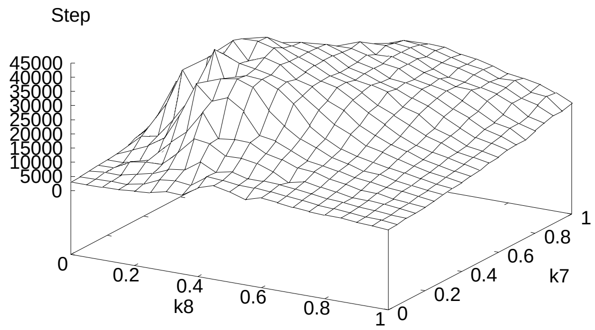

Fig.5 Average number of steps needed for termination

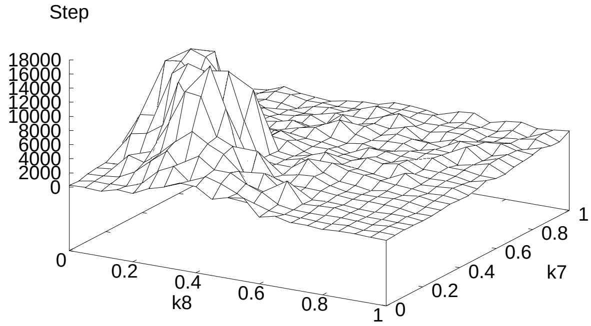

Fig.6 Standard deviation of steps needed for termination

Fig.5 and Fig.6 show that there are high points of terminating steps. The standard deviation of steps is very high around the point at which the average is high. The result shows that termination step of the circulatory system is unevenness. Termination of the circulatory system, namely, is uncertainty of time. This result causes that when rewriting rules are not applied between 120 steps, we regard this circulation as terminated. We will now examine this result more closely. If n is equal to 300, the unevenness partly decreases. However, the number of rewritings per step, which is the number of times rewriting rules are applied to a step, also decreases. Rewritings per step when n is equal to 120 appear in Fig.7. Rewritings per step when n is equal to 300 appear in Fig.8. In Fig.7 and Fig.8, the x-axis indicates k_8, the y-axis indicates k_7 and the z-axis indicates the number of rewritings per step.

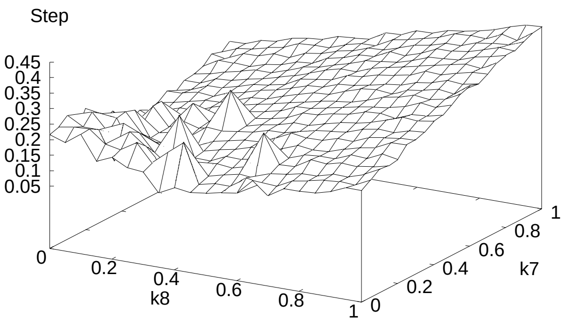

Fig.7 Number of rewritings per step (n=120)

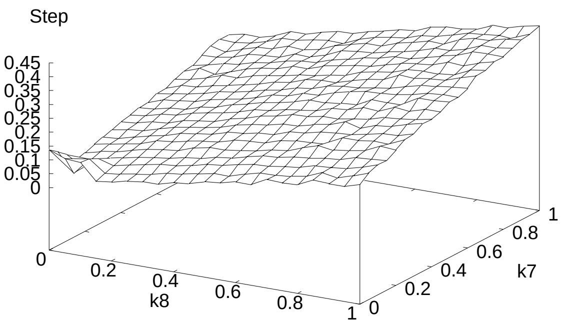

Fig.8 Number of rewritings per step (n=300)

The number of rewritings per step in Fig.7 is higher than that in Fig.8. To be specific, the average number of rewritings per step is 0.241 in Fig.7, and is 0.228 in Fig.8. These results mean that in order to sustain the circulatory system, a slowdown of the circulatory speed is also effective.

5.Conclusion and Future Prospects

In this paper, we began our discussion by stating that the belief in the pursuit of material circulation will lead to an ideal sustainable society is suspect. Then, we described the modeling of the abstract circulatory system using ARMS. As the first step toward the construction of a methodology for analyzing a sustainable circulatory system, we showed the validity of this model in representing a social system. Furthermore, we verified that the termination property of a circulatory system was very important for a discussion of the sustainable circulatory society. From what has been discussed above, we can conclude that modeling and analyzing a sustainable circulatory system using this method is an effective means of clarifying the nature of the circulatory system.

In this paper, we modeled the circulatory society using eleven rules. A real society, however, has greater complexity and dynamism. We must model such societies using rules that reflect diversity. We must also analyze their sustainability from the viewpoint of stability. In addition, it is important that we make an analogy between social systems and ecological systems.

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