Exploration in Complex Systems for Environmentally Symbiotic and Sustainable Society

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Abstract

The authors assume that it is necessary to find a set of solutions to the crucial issues concerning the relation between the global environment and the sustainable human society. Based on the assumption, the authors have been developing man-environment-society system models to simulate the characteristic phenomena related to the issue. This paper describes one of the models focusing on a social dilemma that actions rationally performed to make individual’s indoor thermal environment better bring about worse environment against the rational decision. Some results of the case study simulations with the purpose to find some crews to deal with the issues are also shown.

Keywords: man-environment-society system; multi agent simulation; genetic strategy; classifier; action to control indoor climate

1 Introduction

The final goal of this study is to propose how a social system is ought to be so that it is environmentally symbiotic and sustainable. Many architectural technologies and lifestyles are proposed with the expectation to give less impact upon the global environment than the others do. It is not necessarily convertible with the profit making activity of individuals who are members of the society to adopt these technologies and lifestyles. However, the sustainability of the society would be threatened and the individuals would suffer indirect losses if they were not adopted. In other words, the society would be caught in the dilemma that if every individual make a rational decision to make an immediate profit then the individuals as well as the whole society could not maintain the ideal state from both environmentally symbiotic and sustainable points of view (Hirose, 1995). It is not too much to say that this dilemma restrains the technologies and lifestyles from the infiltration into the individuals in the society.

This research also intends to propose a portfolio of the actions and technologies that enables our society to be both environmentally symbiotic and sustainable under uncertain situations. Some computational experiments to observe the behaviors of agents in the artificial societies and buildings in a computer system are being executed. It is expected to become clear how the social dilemmas could be emerged and resolved. Especially, the contribution of the restructuring of social systems and the changes in the attitudes of the agents by education and communication towards resolution of the dilemmas are focused on.

It is explained in this paper the framework of a man-environment-society model that couples a building simulation model, human action simulation models, and a society simulation model. A building simulation model is implemented based on the thermal network theories. Human action simulation models are implemented based on the artificial intelligence technologies. Human in the models, i.e., agents can learn something by the experiences in the artificial environment and society. The models of society simulation are implemented based on the multi-agent simulation.

This paper demonstrates how the proposed man-environment-society system model expresses the phenomena that we need to be dealt with for an environmentally symbiotic and sustainable society.

2. A Man-Environment-Society System Model

A man, the environment, where the man lives, and the societies, to which the man belongs, have transactional relations. The behaviors of a man, the environment, and the societies affect each other. Models that represent the transactional relations as a whole system have been constructed (Fujii, 2001; Tanimoto et al., 2001; Tanimoto and Fujii, 2002; Fujii and Tanimoto 2002). The authors integrate and expand the models and call them Man-Environment-Society System models or MESS models in short.

2.1 Artificial Community

Suppose a virtual and simplified community, which emphasizes the true nature of the issues concerning an environmentally symbiotic and sustainable society, exists in a computer. The inhabitants in this community are...
agents. Each agent stays in its room and controls the indoor climate without rest. An air-conditioner and a window are implemented in each room. The agents operate the air-conditioner or the window of their own room. They utter two different signals, too. These actions are performed by an agent based on the agent’s situation and the history of the situation. The agent’s situation is perceived based on the state of the environment and the society as well as the agent’s internal state. The states are described in terms of the current power of the air-conditioner, whether the window is open or closed, the relation between the room air temperature and the ambient air temperature, the status of the signals uttered by the agent and the other agents, the comfort of the indoor climate. The signals are the metaphorical representation of the messages sent from an individual to the society. The communication and cooperative behaviors among the agents are expected to emerge upon the signals.

2.2 Thermal Environment System Sub-Model

The thermal environment system sub-model simulates the thermal behavior of a building(s) and the environment based on the thermal network theories. The model for the case studies, described later, is shown in figure 1. The node in the thermal network represent the heat mass and is characterized by the heat capacity. The link, which connects two nodes, represents the heat transfer pass between two heat masses. It is characterized by the heat conductance. The values of the physical properties to get the heat capacity and the heat conductance are determined by the authors to emphasize the focused issues. They are not real in the sense that they are not the values for the actual materials. The absolute values themselves do not have the meaning corresponding to the things in a real world. The qualitative features, such as the relations among the values, however, are determined by following the physical laws concerning heat transfer. COP of an air conditioner, following Hagishima et al. (2001) for example, is represented as a function of the ambient air temperature. Even though it could be criticized that the model is too simple in the sense that it does not represent the quantitative features of the thermal phenomena, the model is assumed enough for us to estimate, from a macroscopic view, the feasibility of the representation that is coupled with the man-society system.

Fig.1. A Thermal Environment System Sub-Model

2.3 Social System Sub-Model

The behavior of the society is the consequence of the actions performed by the individuals belonging to the society. On the other hand, the society affects the actions of the individuals. The behavior of the social system sub-model is represented as the multi-agent system. It is composed of agents and the spaces where the agents act. The agent in a multi-agent system is a computational model of an individual or a group of individuals who performs an action corresponding to the situation. The agent autonomously interacts with the whole society or a part of it. The model for the case studies has windows, air-conditioners, and signals - the metaphor of a bulletin board. The agents perform actions on the basis of the state of them and change the state.

2.4 Agent

The agent performs an action on the basis of the state of the environment, the society, and itself and the history of the changes in the state (Fujio and Tanimoto, 2001; Gero and Fujii, 2000). The action changes the state of the environment, the society, and the agent. Agents in the MESS model learn, through experience, the actions that fit the environment and the society. The agent’s fitness for the environment is defined from biological and sociological points of view. With respect to the issues concerning an environmentally symbiotic and sustainable society, the fitness might be measured based on the comfort, economy, environmental symbiosis, and so on. It is, however, not easy to define the unique and universal fitness measure. The fitness of the agent in the case studies is measured in the two different ways; i.e., type-A reward and type-B reward described later.

2.4.1 Classifier System

The classifier system is a computational system for machine learning invented by Holland. The system organizes a set of classifiers, which couple the input to the system with appropriate actions based on the reward acquired as the consequence of the actions (Ohuchi et al., 2002). The input is represented as a string of symbols, which is called a message. Each classifier is represented as a rule with which a message is generated with respect to the input message. If an action is associated with the message generated by a classifier, the action becomes one of the action candidates to be executed by the classifier system. In the case that there is more than one candidate, the action to be executed is determined by roulette-selection based on the strength of the classifier that generates the message associated with the action.

The message that is selected to activate an action or that is not linked with any action let the classifier system generate new message(s) recursively. The classifier that generates the message activating an action acquires the reward from the environment. The classifier that generates the message activating other classifiers acquires the reward from the activated classifiers. This method of distributing the reward is called bucket brigade. Each classifier updates the strength by the bucket brigade. Since the classifier system has a diverse
of classifiers and the messages are generated recursively inside the system, it is able to learn actions under the complex and context-dependent circumstances.

The classifiers for the case studies are rewarded when they contribute to the maintenance of the comfortable air temperature, or, otherwise, pay the penalty.

2.4.2 Evolution of Classifier System

A genetic strategy is also employed for the learning of the classifier systems. The classifier system is regarded as a pool of genes and each classifier in the system is regarded as a gene. The fitness of the classifier is measured by its strength.

2.4.3 Update of Classifier System by Enlightenment

The winner agent of the roulette-selection with respect to the strength gives one of the other agents some of strong classifiers in the classifier system that represents a part of the internal mechanism of the agent. This is the metaphor of the instruction of the action rules by the leading person from a point of view to measure the strength. The case studies employ one of the following two fitness measures. Type-A reward, which measures how often the agent is in comfortable indoor climate, is the daily total of the reward from the environment. Type-B reward, which measures how much impact the agent gives upon the environment, is the daily energy consumption for air-conditioning. The former is the metaphor of the sense of values that regards the individual’s comfort as serious. The latter is the metaphor of the sense of values that regards the consideration towards the environment as serious.

2.4.4 Action and Changes in Environment and Society

The actions performed by the agent change the state of the environment or that of the societies. The agent controls the power of an air conditioning system, opens a window, or closes it. The agent also utters (or not) two kinds of signals, i.e., A-signal and B-signal. The changes of the power of an air conditioner correspond to the changes in the cooling energy input to the room with the air-conditioner. The changes in the states of a window correspond to the changes in the ventilation ratio of the room through the window. The signals uttered by the agent are broadcasted in the society.

2.4.5 Classifier Message

Every classifier message is composed of 9 bits binary numbers described below. This is an Ad Hoc setting for the case studies.

How does the agent feel? (2bits)
1: Hot,
10: Warm/Comfortable,
01: Cool/Comfortable,
00: Cold.

The state of the window (1bit)
1: Open, 0: Closed.

The state of the Air-Conditioner (1bit)
1: On, 0: Off.

The relation between the ambient air and the room air (1bit)
1: The ambient air temperature is higher,
0: The ambient air temperature is lower or equal to the other.

Agents generating signal-A (1bit)
1: Majority, 0: Minority.

Agents generating signal-B (1bit)
1: Majority, 0: Minority.

Did the agent generate signal-A? (1bit)
1: Yes, 0: No.

Did the agent generate signal-B? (1bit)
1: Yes, 0: No.

3 Case studies

Using the MESS model described above, some case study simulations are done. One day in a simulation is regarded as a cycle. The fixed outside air temperature swings between 22 degree and 30 degree in one cycle. The sub-models are synchronized every temporal unit (1/16 hour).

As mentioned above, the values of the parameters characterizing the thermal properties of a building in the MESS model used here are not real from a quantitative point of view. However, since the causal relations among the parameters are given on the basis of the natural laws in physics, the results of the simulations could be discussed from a qualitative point of view.

3.1 Conditions

Five cases, which are expected to emphasize the characteristics of the social dilemma related to an environmentally symbiotic and sustainable society, are considered. The initial setting of the classifier system in the agent, a point of view from which the fitness of each agent is measured, and the method of learning differ from one another. All cases use the same thermal environment system sub-model and the same social system sub-model.

CASE-0: The characteristics of the other cases are compared with this benchmark case. The parameters are set intentionally so that the social dilemma can easily be observed. Every agent powers up the air-conditioner when the room air temperature is higher than the upper bound of the comfort zone and powers down it when the temperature is lower than the lower bound of the zone. The classifier systems don’t learn anything, evolve, or be enlightened. The comfort zone is between 22 degree and 26 degree like the other cases. The fitness of an agent is measured based on type-A reward.

CASE-1: The classifier system of every agent is initialized as follows. It enables the agent to control the air-conditioner in the same way as the case-0 agent, to open the window when the agent feel uncomfortable, and to close the window when the ambient air temperature is more uncomfortable than the room air temperature. In addition, every classifier system has randomly generated classifiers in the initial state. The classifier systems learn something in every temporal unit (1/16 hour) and evolve everyday. After fifty days in a
simulation have past, some agents perform enlightenment everyday.

CASE-2: The conditions are equal to those of case-0 except that all classifiers in the classifier system of every agent are initialized randomly. No explicit rule to operate an air-conditioner or window is given.

CASE-3: The conditions are equal to those of case-0 except that the fitness of an agent is measured based on type-B reward.

CASE-4: The agents have different types of the initial classifier systems. 25% of the agents have the classifier system that is equal to the system in case-0. 25% of the agents have the classifier system that enables the agents to operate the windows in the initial stage. The other agents have the classifier system randomly initialized. The other conditions are equal to those of case-1 and 2.

3.2 Results and Discussion

Figure 2 to 8 shows the transition of the ambient air temperature, the energy consumption for cooling each room, and the room air temperature of the selected rooms. For the purpose of focusing on the qualitative discussion, the unit of the energy consumption is not shown intentionally. Since some values are not real in the quantitative sense, please do not be confused by the

Fig.2. Energy Consumption for Air-Conditioning (CASE-0 - CASE-4)
CASE-0 is regarded as the standard case. It is observed in the behavior of the room air temperatures after 200 days (figure 4) that they respond quickly to the actions such that the air-conditioners are powered down early in the morning when the ambient temperature becomes the lowest and that the air-conditioners are set to “high” in daytime. Since the agents used the air-conditioners everyday, the ambient air temperature becomes higher day by day (figure 3). As the consequence, the energy consumption increases because of the heat gain from the ambient air and the decrease of COP of the air-conditioners (figure 2). Even though the quantitative information dependent on the parameter setting is limited within the case studies shown in this paper, it could be claimed that the vicious cycle, which is observed in the current drastic increase of the air temperature in a city, is produced.

In CASE-1, figure 5 shows that there emerge two kinds of agent groups in the 50th day; i.e., the agents that operate the air-conditioners appropriately for their own comfort and the agents that randomly operate the air-conditioners. The latter agents make the room air temperature lower than the lower limit of the comfort zone. The latter,
though it is the consequence of the learning, update, and enlightenment of the classifier systems, could be interpreted as the metaphor or the people who wear warm clothes since the room is too cold because of their operation on the air-conditioner. The power of the air-conditioner is too high for the people to stay comfortably in the room. Unfortunately even today, we often encounter such situations in an office, in a train, and so on. We wonder why the people who make the circumstance are not aware that they are wasting energy.

Fifty days after, the period where the agents using the air-conditioner too much become the majority because of the enlightenment (figure 3, around the 80th day) and the period that the agents not using the air-conditioners and but operating the window as the rebound of the farmer period (figure 3, just after the 80th day, for example) emerges in turn. Finally, the catastrophic end where no agent stops the air-conditioners and the ambient air temperature and the energy consumption increase drastically. In other words, once a wrong action rule, which suggests that if you feel hot then turn your air-conditioner super, is propagated among the agents, through the increasing swing between too much use of the air-conditioners and use of the window without using the air-conditioners, another wrong action rule, from the aspect of the individual’s comfort as well as the environmentally symbiotic aspect, becomes de-facto standard in the community. This observation implies that it is important to inform people of truly right things and to give people the correct environmental education.

The above implication could be supported by the results of CASE-2, where the classifier systems are initialized in random manners. The air-conditioners are used during the whole period (figure 3), the monotonic increase of the energy consumption (figure 2) and that of the ambient air temperature (figure 3) are observed. In figure 6, showing the result of the 200th day, even though the room air temperatures are within the comfort zone, they are fluctuating. It is because some agents use the air-conditioners with leaving the windows open. Since rational information is given in the community in the early period, the wrong action rule ignoring the relation between an active air-conditioning and a passive cooling by window operation is acquired.

In CASE-3, where the strength of an agent is measured based on its environmentally symbiotic behavior and the stronger agents educate the others, the lifestyle adopting passive cooling becomes major, and the air-conditioners are seldom used. As the consequence, the agents can keep the room comfortable only by operating the windows (figure 7). An ideal transaction between the agents and the environment is observed.

In CASE-4, the agents are initialized heterogeneously. In spite that the agents, including randomly initialized agents, are expected to acquire environmentally symbiotic action rules through the enlightenment, the results are different. Even though the strength of an agent is measured from an environmentally symbiotic, or economical, point of view, setting of the power level of the air-conditioners are different among the agents (figure 8), and both the ambient air temperature and the energy consumption keep the higher values. This situation might be brought about by the inconvertibility between the aspect of the individual’s comfort - with which the classifier systems evolve - and the aspect of the environmental symbiosis - the base of the enlightenment. In other words, if we are aiming at an environmentally symbiotic society, each person is required to evaluate its lifestyle from the environmentally symbiotic aspect. That is to say, even if the superficial movement claiming environmentally symbiotic things occurs, unless each of us were ready to throw the individual’s comfort aspect, the goal would not be achieved.

4 Towards an Environmental Portfolio

What the case studies by using the MESS model are currently showing is that if the agents tend to acquire the action rules to resolve the social dilemma under changing circumstance, even though the circumstance has a brief period of tranquility, an unstable period follows the period. The two periods appears in turn. The case studies are not enough to conclude whether the unstable periods are brought about by the structure of the model or by the characteristics of the real human society. If we take a risk to raise an unsupported claim, the equilibrium under the limited senses of values is temporal. It might be possible to universal, unchanged, and only one and only value to construct an environmentally symbiotic and sustainable society. A sense of values could become either the base of a steady state or the seed of an unstable state.

If our circumstance, including environment and society, is too complex, what the environmental scientists and engineers are required is not only to find the most suitable solution available under a limited circumstance but also to seek a set of solutions whose element is expected to be available under an unpredictable circumstance. The authors, from now on, call the set of solutions as 'environmental portfolio.’ It is important to focus on the solutions of the immediate crises as well as to maintain the diversity of the solutions, even if the significance of some solutions are not evaluated on the basis of the current view points.
Conclusion

The exploration towards an environmentally symbiotic and sustainable society is described. The experiments, by using the MESS model, shown in this paper are under development and many tasks are listed up to brush up our approach. However, the observation that the bilateral relation between buildings and environment is given great influence by the system of the society including information and education system entails the important aspect from which the roles of scientists, engineers, and academic societies supporting them are discussed.

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Notes

1. Note that the values describing the thermal properties of a building are intentionally set so that the results of the simulation can emphasize the emergence of the social dilemma and the differences in the interactions between man and environment. Therefore, the simulation results shall not be analyzed from a quantitatively as building science but discussed qualitatively.

2. The authors have experienced, in apartment houses in the United States, the situation that they were forced to open window for cool air in winter since the rooms are too hot and the heating systems could not be controlled from either rooms.

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