Theoretical Foundation of Collective Decision Making Processes in Society Based on Airtificial Society Model

Satoru Ozawa

***Abstract*—** The order-disorder phase transition is an interesting topic in modern physics. The phase transition phenomena in physical systems and decision making processes in society have some similarities; they are based on nonlinear multibody interactions. The theoretical foundation of the physical phenomena is given by statistical physics. The same method will also apply to decision making process in society. This paper deals with the study of theoretical foundation of collective decision making processes in society with referring the method of statistical physics. The mathematical description is based on Artificial Society Model (ASM). Peoples who have similar knowledge and similar character in society are classified into one agent and society is composed of several agents. It has been shown that social decision making occurs as result of nonlinear interactions between agents via message transfers. The fruits of this study provide frameworks of computer simulations of decision making processes for particular problems in actual society.

Keywords— Artificial Society Model, Statistical Physics, Decision Making, Computer Simulation

I. INTRODUCTION

A typical example of phase transition in physical system is the appearance of an ordered state in ferromagnetic material below the Curie's temperature [1]. At higher temperatures, the magnetic moments of atoms in ferromagnetic material have random directions because of their random motions with relatively high thermal energy. This high temperature state is called paramagnetic state. When an external magnetic field is applied to the system of the paramagnetic state, the magnetic moment of atoms is likely to have the same orientation as the direction of the external magnetic field. Neighboring atoms of ferromagnetic material have a tendency to take the same orientation of the magnetic moments. This ferromagnetic interaction comes from short-range spin-spin interactions between atoms. As the temperature decreases, namely, the random thermal motion of atoms is weakened, the magnetic moments of atoms begins to have one orientation. This phenomenon occurs spontaneously without applying any external magnetic field. The driving force of the spontaneous phase transition is called "internal field" or "molecular field".

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A society is ensemble of peoples. There are many problems in society that should be solved collectively; or, social decision making is needed to solve the problem. The examples of social problems are: Do we accept nuclear power plants to produce enough electric power supply? Do we suppress emissions of greenhouse gases because of global warming? Do we restrict smoking in public places? etc. The initial state of the society may be compared to the paramagnetic state of ferromagnetic materials. The individual people in the society have different idea or opinion regarding the problem. If an external field is applied in the forms of political forces, or economic pressures, direction of people's idea or opinion will be changed into an orientation guided by the external field. As the environmental condition of the society is changed, which may be compared to the decrease of temperature of ferromagnetic materials, there occurs atmosphere in the society just like "internal field" or "molecular field" of ferromagnetic materials that guides people's opinion in a certain orientation. In such a way, the social decision making is carried out spontaneously.

The phase transition phenomena in physical systems and social decision making processes have such similarities as described in the above. The theoretical frame work to describe the phase transition is given by "statistical physics" [2], which should be noted in the studies of social problems. It seems to be a challenging work to study the theoretical foundation of collective decision making processes in society in terms of statistical physics.

II. ARTIFICIAL SOCIETY MODEL

Humans are social beings. They live collectively with interacting each other. Each people have different knowledge, different idea and different characters [3]. They communicate each other and exchange their ideas. The actual society of human beings is very complicated. In order to study decision making processes in society, we need a modeling of society that gives a suitable framework of mathematical description of the elemental phenomena regarding social decision making. This is just like atomic model in material science. In the atomic model of matters, the elements are atoms. The elements of artificial society are called agents.

In general, how to model actual system is closely related what to study in the actual system. Let us explain this in the case of physics. In ideal gas theory that studies ideal gas state, the gas atoms are modeled by mass points. In the theory of ferromagnetism, atoms are modeled by particles with magnetic moment. In quantum theory of ferromagnetism, atoms are modeled by a quantum system that is composed of a nucleus and many electrons.

Figure 1 shows an example of artificial society models for studying collective decision making processes in society. In this case, the problem to be discussed is whether nuclear power plants are needed in society or not. It would be better to express the problem in the form of a question "Do you accept nuclear power plants to produce electricity?

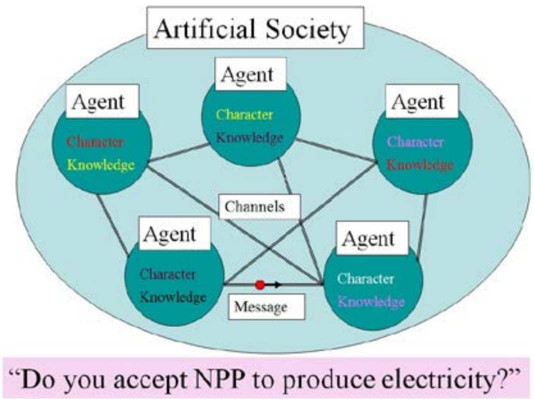

Figure 1. An example of Artificial Society Model

Each people have different knowledge, different idea and different characters regarding this problem. Those peoples who have similar knowledge and similar character in regard to the question are classified into one agent. For example, scientist of nuclear physics can be one agent. Workers of nuclear power plant company can be another agent. The other agents may be governmental people, mass media people, general people, etc. If needed, these agents are further classified. The agent of general people may be further divided into an agent of general people who live in the neighborhood of nuclear plants and that of people who live far from the plants. The various leveled ASMs can be considered depending on how detail the model represents the actual society. The ASMs has a kind of hierarchy. Which leveled ASM is adopted is decided by how detail the problem is to be studied.

Once the agents are decided, the next thing to do is to study interactions between agents. The interaction is based on message exchange between agents. Most dominant message channels should be identified between agents and how frequent message is transferred through the channel, i.e. the capacity of channel must be decided. For example, the capacity of the channel between agent of mass media and that of general people can be decided by investigating how frequent mass media issues news or reviews regarding the problem. When a message is transferred from Agent A to Agent B, the knowledge of Agent B will be modified by the received message. If we trace all message exchanges, we can study dynamics of knowledge modification of agents in society. The ASM is summarized as the followings:

- Artificial society is made of a set of agents A_i ($1<i<N$) .
- The agents represent ensembles of similar character people in society regarding a given problem
- Each agent has a certain knowledge regarding the problem.
- Each agent makes a decision of the problem based on the knowledge.
- There are channels between agents. Topology of channel network and capacities of each channel characterize interaction between agents.
- Agents produce messages and send them through the channels.
- Agents change their knowledge as the results of message exchanges.

III. MATHEMATICAL FORMULATION

In the previous section, ASM is introduced for the study of decision making processes in society. To make the description more mathematically, the elements of the model are defined precisely in mathematical.

A. Knowledge Function

Each agent of ASM has a well-defined knowledge structure regarding a given problem. The elements of knowledge are naturally defined when considering the given problem of ASM. One method to represent the elements of knowledge is to use key words, e.g., radioactivity, atomic bomb, global warming, etc. The knowledge structure is expressed mathematically by a knowledge function. Figure 2 illustrates the definition of knowledge function. Various knowledge K_jA_i ($1<j<N_{kn}$) is accumulated in agent A_i. The each knowledge can be labeled by a parameter x of which value is between 0 and 1. The knowledge labeled by x=0 relates to complete negative answer to the problem, while the knowledge labeled by x=1 relates to complete positive answer. For example, knowledge of previous nuclear power accident will lead to negative answer to the question and it is labeled by x=0. The knowledge of the fact that nuclear power plants do not produce so much greenhouse-effect gases is labeled by x=1. All elements of knowledge can be labeled by $0<x<1$. The knowledge labeled by smaller x is painted darker in Fig. 2.

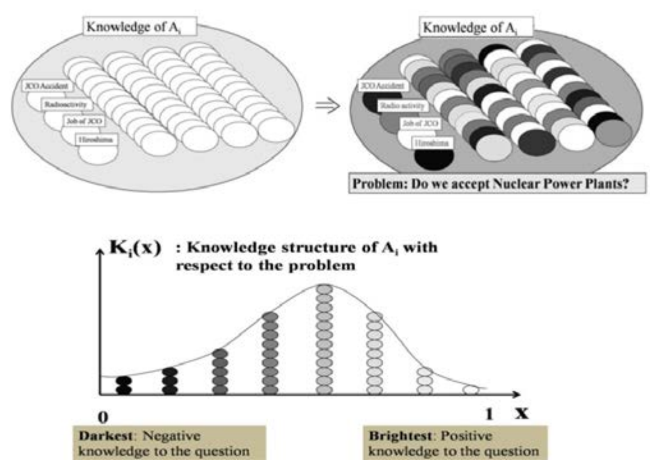

Figure 2. Definition of knowledge function $K_i(x)$ of agent A_i. The parameter x is the preferential parameter.

The distribution of knowledge against the parameter x produces a knowledge function $K_i(x)$ that characterizes knowledge structure of agent A_i. The parameter x is called preferential parameter.

The knowledge of agent is stored in the brain of the people of the agent. Since it is not possible to see in human brain, the knowledge function is not observable. The reason why we use non-observable knowledge function is that it presents enough information for the theoretical study of ASM. It should be worthwhile to note that the wave function in quantum physics is not observable but it satisfactorily describes quantum state of matters [4].

B. Decision Making

A decision is formed as a result of thinking in our human brain. We think about the problem on the basis of the knowledge that relates to the problem. According to the linkage model of cognitive phycology [5-7], thinking process is linkage of knowledge or memories stored in our human brain. Figure 3 illustrates the thinking processes in human brain. The human brain works in unconscious state as well as in conscious state. We have huge amount of knowledge or memories in our brain. However, we do not always aware of all of them, namely most of knowledge are stored unconscious part of the brain. When the brain is stimulated by a question, some memories become activated and link each other and make a sense. If this thinking process, i.e., the linkage of knowledge occurs in the conscious state, it can be a conscious thinking or intentional thinking. The linkage is partially controlled by intention in logical thinking. The conscious thinking is carried out with the help of some media. For example, in chess game, the players think with the help of chess board. The theoretical physicist use mathematics as the media of thinking. If the linkage of knowledge occurs completely in unconscious state, it can be instinct thinking or emotional thinking where the conclusion is obtained instantly. Our life is composed of sequence of decision makings. The most of them are intermediate between conscious and unconscious decision making.

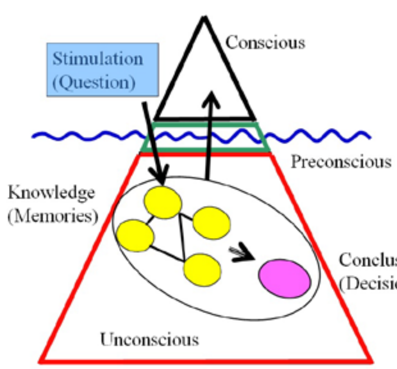

Figure 3. Human brain is compared to an iceberg. It is composed of conscious part and unconscious part.

The decision making of agents can be considered in similar way to the personal thinking described above, because by definition, an agent is ensemble of peoples of similar knowledge structure against a given problem. The decision making of agent is represented by that of a typical person in the agent. The point is how linkage of knowledge occurs in the typical person's brain. There are two kinds of approaches for this problem. One is to study linkage mechanism and linkage law or to look for causality in the dynamics of the linkage. This approach may be compared to the method molecular dynamics where the causality is given by Newton's law of motion. The other method is a statistical approach where which elements of knowledge are linked is statistically decided. The typical example of this approach is statistical physics and Monte Carlo method [8, 9]. In the present paper, we take the latter, i.e., the statistical approach.

The simplest method of the statistical approach is to adopt the principle of equal probability of appearance of microscopic state. This law is well established in statistical physics. It says that microscopic states of many particles system with the same total energy have the same probability of appearance. With referring the equal probability principle in statistical physics, let us consider the equal probability linkage of knowledge, which is named Equal Probability Linkage Model (EPLM). Figure 4 illustrates random transition between different knowledge in EPLM. As the result of 6 times equal probability random transitions, 7 elements of knowledge are linked in this figure.

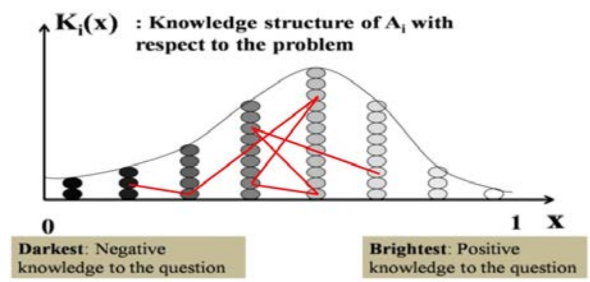

Figure 4. Example of linkage of knowledge in EPLM. The transition, i.e., the linkage is shown by the lines between elements of knowledge.

For mathematical formulation of ASM, let us consider linkages of M-elements of knowledge produced by (M-1) times random transitions. The decision or conclusion is characterized by the M-elements of knowledge, $K_kA_i(x_k)$, where k=1,…M. We like to express thus obtained decision by a suitable mathematical function. The required property for the decision function $D(x)$ is smooth continuous function with a single peak. In this paper, we assume that the decision function is a Gaussian type. The Gaussian function is characterized by three parameters and is given by

$$D(x) = D_0\, e^{-\frac{(x-\bar{x})^2}{\sigma^2}} \quad . \tag{1}$$

If the parameters are decided by

$$\bar{x} = \sum_{k=1}^{M} x_k / M \quad , \tag{2}$$

$$\sigma = \sum_{k=1}^{M} \left(x_k - \overline{x} \right)^2 / M \quad , \tag{3}$$

and,

$$D_0 = 1 \Big/ \int_0^1 e^{-\frac{(x-\overline{x})^2}{\sigma^2}} dx \quad , \tag{4}$$

then, Eq. (1) has the same distribution along x as that of the linked elements of knowledge. It should be noted that the decision function has a similar character to the knowledge function since it is produced from the knowledge function. However, due to the randomness of the linkage of knowledge, the character of decision function, i.e., the characteristic three parameters in (1) will also fluctuate. This fluctuation corresponds to real fluctuations actually seen in decision making processes in human brain. The equation (4) is for the normalization of the function. All functions in ASM are normalized in similar ways as in (4), because the absolute value of the functions does not make sense in ASM.

C. Message Production

Once conclusion is obtained, the agent produces a message and sends it to another agent. The message has similar character to the conclusion but it may be modified in some extent. For example, people do not speak 100% honestly. They omit unfavorable matters in speaking their conclusion. The message function is defined by

$$M(x) = C(x) D(x) \quad , \tag{5}$$

Here $C(x)$ represents the characteristic function of the modification of conclusion. $M(x)$ is normalized just like $D(x)$.

D. Knowledge Modification

When one agent receives a message from the other agent, the knowledge structure of the receiver agent will be modified. People do not always believe the entire message but receive selectively. The simplest idea of this modification is express by

$$K_{\mathrm{New}}(x) = K_{\mathrm{Old}}(x) + F(x) M(x) \ . \tag{6}$$

Here, $F(x)$ represents the selection factor and then, $K_{\mathrm{New}}(x)$ is normalized.

IV. APPLICATION

On the basis of the mathematical formulation described above, it is possible to carry out computer simulations of decision making processes in real society. Time evolution of physical system can be described as a sequence of transitions between the microscopic states. In molecular dynamics, time evolution of the system is calculated by using a set of equations of motion based on the Newton's law of motion [9]. If initial state of the system is assigned, the future of the system is uniquely decided by the equations. On the other hand, in statistical physics, time evolution of the system is simulated by a Markov chain of microscopic states [8, 9]. The Markov chain is produced by a series of sequential transitions between microscopic states of the system.

The time evolution of thinking process in human brain can also be described by a Markov chain, where the transitions between temporal states of human brain are considered. The temporal state is characterized by one element of knowledge (see Figure 4). Namely, one temporal state of brain is a state of thinking about one element of knowledge. People think about a matter of the element of the knowledge, and at the next moment, they think about the other element of the knowledge. The thinking process is composed of sequence of such transition of temporal thinking states. If we add the other processes, i.e., message production processes and knowledge modification processes, the total time evolution of artificial society can be studied by the following method:

With the aid of a random number generator, select one channel with the rate in proportion to the capacity of channels and decide the message source agent.

1) Select M elements of knowledge randomly with equal probability.
2) Calculate the parameters using (2), (3) and (4) and determine the decision function (1).
3) Produce message function using (5).
4) In similar way to 1), decide the agent that receives the message.
5) Modify the knowledge structure of the agent according to (6).
6) Go to the step 1) and repeat the steps until an aimed time period elapses. Here, the elapsed time can be estimated from the capacities of the channels, i.e. the frequencies of message exchanges through the channels.

In order to carry out a computer simulation of decision making processes for a particular problem in society on the basis of the method, i.e., the steps 1) to 7), we must have actual data for the functions, $K_i(x)$, $C(x)$ and $F(x)$ and the channel capacity parameters. This is a challenging work in social science. The author and the coworkers have already proposed a questionnaire and keywords analysis method for this purpose [11] and published some results of the preliminary studies of the computational approach of decision making processes in society for social acceptance problem of nuclear power plants in Bangladesh. [10-13]

V. CONCLUSION

The topic of this paper was studied in authors group in the last several years [10-14]. In this paper, the theoretical basis of the studies has been reexamined. With referring the theoretical basis of statistical physics, in particular Monte Carlo methods, the theoretical foundation is established for the mathematical description of decision making processes in society. The mathematical description is based on Artificial Society Model (ASM). Peoples who have similar knowledge and similar character in society are classified into one agent and society is composed of several agents. It has been shown that social decision making occurs as result of nonlinear interactions between agents via message exchanges which are carried out through well-defined channels between agents. It has been shown that the fruits of this study provide frameworks of computer simulations of decision making processes for particular problems in actual society.

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