A Study of the Basic Concept of Information in a Complex System

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Abstract

Neither the basic concept of information nor its fundamental properties have yet been clarified. A basic concept of information and its fundamental properties are given from the original viewpoint that information is both a kind of method of natural recognition and a kind of conceptual structure. The information properties that contribute to constructing actual complicated systems are also clarified.

Key words: basic concept of information, conceptual structure, and complex system

1. Introduction

In our modern society, which is a very complicated system, information fulfils an important role, along with energy and materials. In the world of living things, from humans to bacteria, complicated mechanisms operate based on information. Pure information systems, such as computer systems and the Internet, are the most complicated systems that human beings have ever produced. There are now many complex systems based on information. However, Wiener, Shannon, Noguchi, Bateson and Yoshida showed their concepts of information, they are different from each other. The basic concept of information and its fundamental properties have not yet been clarified. [1]-[6]

In this paper, we first clarify the basic concept of information and its fundamental properties. We then show that the fundamental properties of information greatly contribute to constructing actual complicated information systems, such as computer systems and network systems.

We work from the original viewpoint that information is a kind of method of natural recognition. From this viewpoint, as well as from modeling of a physical phenomenon as a conceptual structure composed of components and clearly defined relations, an information-based phenomenon can also be modeled as a kind of conceptual structure. This structure has the following features, differing from the model of a physical phenomenon:
(1) The components and the relations between components in the structure must be expressed in forms that do not depend on their physical properties. (2) Each component one-sidedly determines the effects of other components according to their relationships. (3) Each component has inputs, inner states, and outputs.

The property that information can be copied by using a small amount of energy is based on the model being expressed as a conceptual structure and having feature (1). Feature (2) represents the property of receiving information with sensitivity or susceptibility. The inputs and outputs in feature (3) correspond to transmitting information between components, while the inner states represent the memory or recording functions of information. In addition, the information quantity proposed by Shannon can be defined as a measure of the variety of stimuli from other components at the input interfaces of a component. By using this model, the properties of information can be clearly explained, and the main previous information concepts proposed by Wiener, Yoshida, and Noguchi can be systematically integrated.

Moreover, because information can be described as a structure, and a structure generally has the properties of facilitating easy generation of new components by combining multiple components and of enabling resolution of one component into multiple components, information systems combining computers and networks can be made extremely complicated. In addition, these properties are drastically accelerated through the digitization of information in computers and networks.

2. Previous views of information

2.1 Wiener and Shannon's concepts of information

In the middle of the twentieth century, Wiener advocated using the name "cybernetics" for the entire field of control and communication theory, whether in machines or in animals. Information thus fulfils a very important role in cybernetics, and Wiener wrote that "Information is a name for the content of what is exchanged with the outer world as we adjust to it, and make our adjustment felt upon it. The process of receiving and of using information is the process of our adjusting to the contingencies of the outer environment, and of our living effectively within that environment." [1][2] Though feeding is an important exchange activity with the external world of animal, this is clearly not included. Hence, information does not include exchanges of energy or materials.

At the same period, Shannon established the basis of communication theory, in which communication functions by utilizing an information source, a transmitter, a channel, a receiver, and a destination. He discussed only the "quantity" of information without mentioning its "meaning," and he advocated that that quantity of information is measured by a decrease in entropy. [3] Since an information source and a transmitter are assumed with regard to information transmission in Shannon's model, his concept of information has a narrower meaning than Wiener's.

2.2 Noguchi's concept of information

In 1974, Noguchi, a Japanese economist, gave the widest definition of an information concept, which was based on the capability of copying. He wrote that "The basic concept of information is the capability to copy it by using a very small amount of energy while leaving the original information in the same condition afterward. Although the copying capability is an important property of information, more precisely, something that can be copied is called information itself." [4]

The capability of copying as the definition of information can be intuitively understood from the routine work of copying paper documents with copy machines. However, information is not the only thing with the property of having the capability to be copied. For example, consider an iron bridge over which cars pass. It is possible for a similar purpose to be achieved by building an iron bridge of equal composition or structure in another place. In addition, it is possible for cars to pass over a wooden bridge, instead of an iron bridge. In general, the equivalent purpose can be achieved by any similar "structure" of stone, iron, or wood, which can be considered a kind of copying. However, a bridge with a similar structure cannot be copied by using only a very small amount energy, and thus, Noguchi thought that a copied bridge was not information. From a different viewpoint, consider the world of micromachining. The copied machines in this case also are not information, even though various structures can be copied with a very small amount of energy. Therefore, the capability of copying by using a very small amount of energy in Noguchi's definition should be reexamined in terms of structure. In addition, we must consider the fact that where Wiener regarded as system receiving information as important, Noguchi regarded the copied content as important.

2.3 Bateson and Yoshida's concepts of information

Bateson showed a view of information based on "difference" in his book, Steps to an Ecology of Mind, as follows: "The technical term 'information' may be succinctly defined as *any difference which makes a difference in some later event*. This definition is fundamental for all analysis of cybernetics systems and organization. … What is a difference? A difference is a very peculiar and obscure concept. A difference is an abstract matter. …What we mean by information– the elementary unit of information –is a *difference which makes a difference*, and it is able to make a difference because the neural pathway along which it travels and is continually transformed are provided with energy." [5]

Bateson defined information by referring to the information transfer in a neuron as "the difference which makes the difference," as shown above. On the key concept of "difference," however, he said only that it is abstract. It has not yet been clearly defined. Consider a system receiving multiple external stimuli. In this case, there are two viewpoints on determining whether these stimuli differ or resemble each other. One viewpoint is to mutually compare the multiple stimuli. The other viewpoint is to compare the effects that each stimulus has on the system. Whether the stimuli mutually differ or resemble each other depends on the properties selected for the comparison, which are limitless in their diversity. We think that the difference necessary for defining information must be based on the differences in the effects of the stimuli on the system. These differences are not abstract and can be treated very concretely. Bateson's concept of information must be reexamined from this viewpoint. In addition, Bateson's indication that neural pathways are provided with energy means a kind of physical condition for copying or transmitting information by using very little energy.

In addition to Bateson, the Japanese philosopher, Yoshida, has advocated the basic concept of information based on "difference". Moreover, he used the word "informational phenomena" in his argument. [6] Usually we express and model natural phenomena related to chemistry or physiology by using the terms chemical phenomena or physiological phenomena. It is very interesting that natural phenomena related to information can be similarly expressed and modeled in terms of "informational phenomena."

2.4 Watanabe's view

The Japanese physicist, Watanabe, who is investigating a mathematical model of information propagation, claims that the "sensitivity" of the receiver is very important, because the effect of information is greatly different as received by each person, even if it is the same information. [7] As described above, both Wiener and Bateson mentioned the importance of the component receiving information, but Watanabe clearly and intuitively conceptualized the importance by using the word "sensitivity."

3. Informational phenomenon and informational structure

In this section, we give our view of information in the widest sense.

3.1 Information and informational phenomenon as a method of natural recognition

We clarify information in the widest sense as a phenomenon reduced to a physical phenomenon. However, information cannot be clarified, even if we microscopically observe the mutual relationships between materials. It cannot be expected that information or functions of information are recognizable from the relationships between material particles under gravity. As shown in Figure 1, there are chemical phenomena in which materials react in chemical relations, and physiological phenomena overlaying the chemical phenomena. In addition to these phenomena, we recognize a phenomenon related to information as an "informational phenomenon,"as shown by the dashed ellipse. We thus recognize information as a kind of method of natural recognition, so that chemistry and physiology may also be methods of natural recognition. As an example of recognizing a complicated system, there are macroscopic observation or a method of coarse graining. Though it differs from these methods, a physical phenomenon of some kind plainly be grasped by recognizing its nature as an information phenomenon of information. Also, the basic concept of information can be clarified by modeling this informational phenomenon.

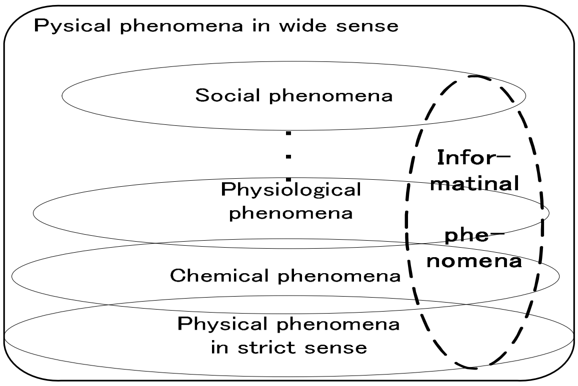

Fig.1 The positioning of informational phenomena

3.2 Modeling informational phenomena

The technical terms used here are defined as follows in order to discuss the idea of an informational phenomenon. We define the term "system" as "a sets of components or elements standing in interrelation," according to the definition of Bertalanffy in his book, General system theory. [8] A "system" is classified into two categories: a real system, and a conceptual system. The real system is entities that really exists, such as a solar system, a machine, a dog, a cell, or an atom. On the other hand, the conceptual system does not really exist but is a symbolic construct, such as mathematics, physical laws, or the plan of a bridge. We classify the conceptual system expressing a model of nature as shown in Fig. 2.

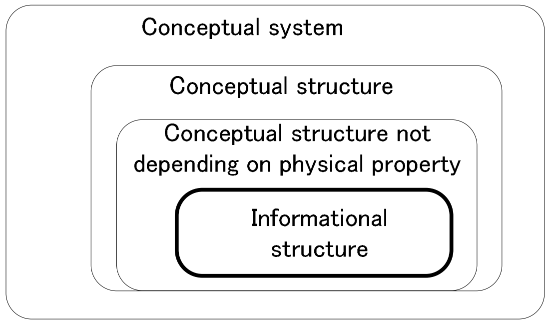

Fig.2 The positioning of informational structure

(1) Conceptual structure: A subset of a conceptual system, in which the relationships among components must be defined clearly. (An example is a model using physical laws.)
(2) Conceptual structure not depending on physical properties: A subset of a conceptual structure, in which the relationships among components must be expressed in forms that do not depend on physical properties. (A physical property means a property of a physical phenomenon in the widest sense, including chemical and physiological property, and so on. An example is a model using mathematical expressions.)
(3) Informational structure: A subset of a conceptual structure not depending on physical properties. An informational structure represents or models informational phenomenon and has the following properties:
a. Each component one-sidedly determines the effects of other components according to their relationships. (This property represents the sensitivity of a receiver.)
b. Each component has inputs, inner states, and outputs. Each component determines its outputs and inner states as functions of inputs and previous inner states.

In an informational structure, transmission, memory, and processing of information are carried out as follows. The relationship between components that send out or receive changes corresponds to "transmission." In some cases, these changes occur as physical stimuli originating from light, sound, or electric current. In other cases, they occur as a result of transferring material, such as DNA or document. The setting or retaining of the inner states of a component corresponds to "memory," and the conversion from input states to output states in the component corresponds to "processing."

The digital computer is an example of an informational structure modeling an informational phenomenon. Each logical circuit in a digital computer certainly works according to a very complex physical phenomenon based on the motion of electrons, where these actions are described by chains of ON or OFF values, whose effects are one-sidedly determined by adjoining circuits and as a whole are not dependent on physical properties.

3.3 Reexamination of the previous information concepts based on the informational structure

Recognizing information as a kind of process according to the view of Wiener and Bateson corresponds to recognizing the relations in an informational structure whose components are an animal, a neuron, and an environment. Components receiving various stimuli in a real system distinguish whether it is "information" by using the "difference" advocated by Bateson and Yoshida. In an informational structure, the "difference" is converted to a quantity that does not depend on physical properties. Under conditions that functions of the component receiving information are not changed in the informational structure, we can replace input stimuli or entities to the component by different ones in the corresponding real system. This capability of replacement corresponds to the capability of copying as the basic concept of information, as advocated by Noguchi, because a copy is a kind of replacement that maintains the same effects on the component receiving information.

The information quantity of Shannon shows whether a component receiving information recognizes the outside of the component to a certain degree of fineness. The input of information with a quantity of n bits enables the component to recognize the outside as a space composed of 2^n pieces.

4. Contributions of information properties to constructing complex systems

As shown above, an informational structure has the following three properties.

a. An informational structure is not dependent on physical properties.

b. The actions of an informational structure function in uni-directionally.

c. A real system represented by an informational structure can be simply replaced with different materials, or components while still maintaining all functions. Then information can be copied easily.

In addition, the next important property should also be applied.

d. Development is easy in an informational structure, and the result of the development is easily implemented as a real system.

Here, "development" means the generation of a new component from multiple components and the resolution of a component into multiple components. Generally, development is easy for the conceptual structure, as the mathematics is developable. The informational structure also has the property that the result of development becomes easy to implement as a real system, based on the properties of easy replacement and copying, and the lack of dependence on physical properties. Since these four properties work comprehensively, the construction of a complex system becomes very easy by applying them. By digitizing the informational structure, this tendency can be further accelerated. Representative examples include today's computer systems and communication network systems.

5. Conclusion

The basic concept of information and its fundamental properties have been clarified from the original viewpoint that information is both a kind of method of natural recognition and a kind of conceptual structure, called an "informational structure." Relations, actions, and states in this informational structure model "information" itself and its functions. This model can account for previous information concepts, such as those of Wiener, Shannon, Bateson, and Noguchi. The properties of information showed here greatly contribute to constructing complex systems.

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