Some Fundamental Concepts Underlying My Research Activities

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1. Introduction

Science & technology and religion are often talked about as being incompatible, but is that true? It was not so long ago in the history of humankind that science separated from religion, furthermore, it was only recent when technology was systematized as engineering. Both science & technology and religion are the result of human efforts to create a "complete system," and I think that the structures created by humans all have something in common. For example, the formulation of physical laws based on *the principle of least action* that appears in analytical mechanics seems to be motivated by the thought that physical laws should be derived from the first principle. This vision seems to be conscious of something that governs the laws of the world. In more detail, the existence of physics itself is based on the wishful assumption that *the laws of the world are indicative of a beautiful system* (which can be understood by mathematics). We may be able to interpret this is assuming the existence of God in a sense. Interestingly, the wishful assumption of physics remains undeniable after many measurements and validations and is still a force driving human effort.

In science and technology, "facts" that can be verified by experiments are sought after, and appeals to "the way it should be" are supposed to be denied. If these appeals are not adequately suppressed, there is a risk of biased observation that precludes direct observation of reality and generates incorrect conclusions. However, if there is no intimation of direction, the individual will be unable to secure guides to the understanding and systematization of unknown phenomena. Therefore, some intimations about how to proceed with research are necessary, making balance essential.

This essay introduces the fundamental concepts underlying my research activities. These have been introduced in detail in my Japanese textbooks [1], [2] (they are also outlined in [3], [4], respectively), but I will take the opportunity of this essay to elucidate them in English.

2. How is the Order of Our World Created?

The development of ICT has strengthened the linkage between users and information network systems. As a result, user behavior has come to affect the stable operation of information network systems. For example, the email generated to exchange New Year greetings is so large that receiving emails becomes problematic. Furthermore, the influence of the user's behavior also affects the behavior of other users via the information network. For example, when a web page takes too long to be displayed on a personal computer due to congestion of the server or the network, the user often clicks repeatedly. This behavior further loads the information network system, which makes it difficult for other users to display their requests, and the repeated click action propagates to other users. Following these considerations, it is difficult to think about the performance and stable operation of information network systems as a single isolated system, and it is necessary to enlarge the scope of the target to include users' behaviors. Furthermore, considering that various sensors and self-driving cars will soon be connected to the information network, the entire information network system will become massive in scale and complexity. It must be emphasized that no one knows all the details of the current state information of even the current information network systems. How can we properly operate a system that we do not know the whole picture? One way is to find a system that does not know the whole picture but is deemed to work well, and to draw conclusions about its mechanism.

The most well-known large-scale and complex system is our world. The number of components that form this world and their diversity readily confirm that it is the ultimate large-scale and complex system. So why is this ultimate large-scale and complex system, the world, stable? We believe that the world will still exist tomorrow and that the sun will rise tomorrow, just as in the past. Even though we know that no past state is ever repeated precisely at the scale of atoms or elementary particles that make up our world, we believe that the world is stable. Such orderly behavior of the world is created through so-called synergistic effect, self-organization, or the collective phenomena of fundamental structure. This framework is exciting and gives useful clues to engineering. The question of where the stability or orderly behavior of the world comes from probably corresponds to the following questions. Assuming that God created the world, what divine secrets were used at the Creation to yield the orderly behavior of the world? Conversely, even if we assume that God does not exist, what are the characteristics that make us feel that something is behind the orderly behaviors of the world?

If the characteristics indicative of the order in nature are known, it should be possible to create a mechanism

for creating order in a system by recreating it in an engineering system, even if there is no one who understands the state information of the entire system. In other words, it is a prospective attempt to create an engineering system that replicates the order assumed to indicate the presence of God.

Of course, we cannot create a complete answer with regard to these characteristics since the natural mechanisms are not completely understood. However, since our purpose is not to understand nature but to create engineering systems that replicate its characteristics, we should assess our current understandings in terms of their usefulness in systems engineering. My current research activities consider the following two characteristics.

- Action through a medium (Local interaction)

  In physical systems, there are two concepts that describe the interactions that can occur between two objects in spatially different locations; action at a distance and action through a medium (local interaction). The former yields a model in which two widely-separated objects interact directly. The latter does not permit the existence of direct interaction between widely-separated objects; it assumes that interaction occurs only between spatially adjacent objects, and the effect of interaction is incrementally exchanged between the objects. Modern physics supports the action-through-a-medium concept, so interaction occurs locally. In such a model, space is filled with physical quantities at all points (which forms a field), and any variation in the physical quantity at a point propagates through the field at a finite speed.

- Renormalizability (Reducing the degrees of freedom in dynamics)

  When attempting to observe a massive aggregation of extremely small objects that interact in complex ways, we can more easily comprehend the aggregate (or system) by reducing either the temporal or spatial resolution (or both), i.e., coarse-graining the system. In the renormalization theory, complex systems are understood by observing changes in a measurable attribute identified by the coarse-grain transformation. The coarse grain transformation of observations is called renormalization. We consider a system that exhibits large (or infinite) degrees of freedom at the microscopic scale. If the system is well described by small (or finite) degrees of freedom at the macroscopic (measurable) scale through renormalization, the system is called renormalizable.

In the action-through-a-medium concept, an object interacts only with its neighbors, at any instant. In the world of action at a distance, changes in or by an object instantly influence all places, including the end of the universe, and conversely, the changes of any object, regardless of its location, instantly influence the object. In this situation, the components of reality are associated with each other very strongly, which might limit the flexibility of the world. Therefore, the action-through-a-medium concept appears to be a key characteristic in producing stable systems while also ensuring the freedom of local action.

Even if we do not fully comprehend the attributes of micro-components such as atoms or we do not understand the complete mechanisms of nature, we can admire the orderly behavior of the world. This means that even if there are huge degrees of freedom when the world is observed at the micro-scale, almost all degrees of freedom are missing at the macro-scale of human perception, and only a small number of macro parameters are needed to describe the world. This confirms the renormalizability of the world.

Based on these ideas, my research activities have been considering a hierarchical model based on temporal and spatial scales as a framework for information network control technologies. At each layer, the hierarchical model considers local interactions on the temporal and spatial scales that characterize the layer. The rules that describe local interactions are described by a partial differential equation, and the resulting overall system state is the solution of the partial differential equation. In other words, a macro-scale state is realized as a solution of a partial differential equation by the micro-scale action rule given as a local interaction. What kind of effect occurs between different layers involves renormalization from the perspective of how coarse-grained the observations are.

3. User Dynamics and Relativistic Quantum Mechanics

Imagine if there is any object in the world that does not interact with others, can it be said that it really exists? Since it does not interact with light, it does not reflect light and is therefore invisible. Since it escapes gravity, it must have no mass, and of course, it escapes the sense of touch. Even if such a thing exists, isn't it the same as not existing? From that point of view, it can be seen that real existence is a concept based on interaction with others. Then, what are the unique properties possessed by objects that actually exist? For example, attributes of the object itself, such as its color being red, are recognized only when there is another object that permits comparison, so it is also a concept that is based on mutual relationships. The real objects themselves and their interrelationships are inseparable, and they together make up this world. In the relationship between the characteristics of the “object” itself that really exists and the “environment” created by the interaction with others, we can recognize that their boundaries are ambiguous. If we consider this whole and inseparable world as a network, our world is the network itself.

A network that represents the relationship between people through an information network is called an online social network (OSN). Due to the rapid

development and spread of ICT in recent years, communication between people has been dramatically activated, and the ability to transmit information generated by individuals has been strengthened; this has greatly stimulated the activities of users in OSNs. Therefore, understanding user dynamics in OSNs have become a significant issue. In my research activities, the *oscillation model* was proposed to describe the user dynamics in OSN; it is formulated as a wave equation on the network. In research on wired networks, the first-order differential equations with respect to time, such as Markov chains, are often used, but second-order differential equations with respect to time, such as the wave equation, are rarely used. The reasons why my research uses the wave equation for modeling user dynamics are as follows. The strength of the user's activity influences the strength of the activity of other users via the OSN, but the influence does not spread instantaneously, rather it propagates across the OSN at a finite speed. The wave equation describes the characteristics of propagation in a medium at a finite velocity. For example, consider a function that expresses the effect of influence propagation among users. If the effect propagates at a finite speed, then the trigonometric functions yielded by Fourier transformation also move at the same speed. With regard to the trigonometric function at each frequency, if the movement is observed at a fixed point, it appears to be oscillating. In other words, behind the phenomenon of propagation at a finite velocity, a structure that instantiates wave propagation is necessary. The oscillation model was introduced for a purely theoretical reason following this background, but the oscillation energy is related to node centrality, a concept often used in conventional network analysis. For example, under the condition of uniform OSN use, if all link weights are one, the oscillation energy of a node represents its degree centrality, and if the link weight is the amount of traffic passing through the link, the oscillation energy of the node represents its betweenness centrality. Furthermore, oscillation energy may diverge depending on the structure of the network, which is considered to represent the situations in which the intensity of user dynamics activity diverges, such as the flaming phenomenon.

The oscillation model enables us to understand the relationship between user dynamics and network structure. Thus, the oscillation model has the potential to yield countermeasures to explosive user dynamics, including flaming, such as altering the network structure. In this situation, don't you want to understand the causal relationship between the kind of OSN structure and the type of user dynamics evidenced by the structure? The wave equation that describes user dynamics is a second-order differential equation with respect to time. Note that the first-order differential equation with respect to time is essential here as it can explicitly describe the causal relationship between the network structure and user dynamics. Of course, its solution must describe propagation at a finite velocity so that it must also be a solution to the original wave equation. If the equations that satisfy both requirements are created, the OSN structure will not be conserved, and problems will arise in which all users all over the world will be directly linked to each other. Therefore, in addition to the above requirements, we must find an equation that completely conserves the OSN link structure. The literature [5] (also [1] in Japanese) has succeeded in giving a fundamental equation that satisfies all of the above requirements. Interestingly enough, the fundamental equations of user dynamics thus obtained have the same structure as the Dirac equation that appears in relativistic quantum mechanics. Here, relativistic quantum mechanics is a fundamental theory of physics that combines special relativity and quantum mechanics and is the starting point of quantum field theory. From this, the user dynamics are described by the wave function that is quantized by the anticommutation relations yielded by fermionic fields.

Note that the research did not artificially apply the equations of physics to describe user dynamics. The fundamental equation of user dynamics is naturally obtained from the goal of explicitly describing the causal relationship of the network structure and conservation of the OSN link structure. Quantum theory often details a mysterious world that differs from the real world, such as Schrödinger's cat, often mentioned in public awareness books. However, the findings obtained from the fundamental equations of user dynamics suggest that the framework of quantum theory is not unique to the microscopic world, but instead is inherent in the description of causal relationships.

In quantum theory, there are several mathematically equivalent formulations, depending on the temporal changes in the linear operator and/or the state vector appearing in the equation. The formulation in which the linear operator evolves with time is called the Heisenberg picture, the formulation in which the state vector changes over time is called the Schrödinger picture, and the formulation in which both change over time is called the interaction picture. In the fundamental equation of user dynamics, the linear operator is a matrix that represents the network structure, and the state vector is the state of the user. Therefore, the time evolution of the linear operator is the change of the relation between the users, that is, the environment changes and the time evolution of the state vector is the time change of the user's state. Since there are multiple mathematically equivalent expressions depending on which one changes over time, it can be recognized that there are various views on whether the user's state is his or her personality or is created from the environment. As stated at the beginning of this section, this means that the user and the environment are inseparable.

4. Conclusions

This essay has introduced some of the concepts I have become aware of in my daily research activities. Although these are rarely stated explicitly in research

publications, they are the ideas that have become the guiding principles for my research activities. I do not know if they will help others, but if you are interested, feel free to contact me at any time. I hope that we can discuss related topics together.

5. Acknowledgments

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