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THE DEVELOPMENT OF SYSTEMS SCIENCE AND ITS THREE CONTRIBUTIONS TO PHILOSOPHY OF SCIENCE

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Abstract

For a century since its inception in 1920s, systems science has constantly and consistently explored complexity, raising numerous new philosophical questions. Scholars have taken different approaches to understanding the development of systems science, which is of great significance to appreciating its philosophical value. In this regard, we concur with H. Simon that there have been *three eruptions* of interest in complexity and complex systems. We consider as the first eruption the research pioneered by A. Bogdanov and featuring Bertalanffy's general system theory, which marks the formation of systems science. The second eruption refers to the research of self-organization theory that developed from dissipative structure theory and synergetics. The third eruption refers to the research of complexity theory represented by complex adaptation system theory. We propose that there has formed a fourth eruption, as researchers now widely apply the concepts and methods of systems to economic, social and environmental systems, giving systems science research a strong application orientation. The advances in systems science have challenged some classical philosophical ideas and raised a new range of philosophical questions. Furthermore, the *Elsevier Handbook of the Philosophy of Science* incorporated *Philosophy of Complex Systems* into the framework of philosophy of science for the first time. We propose that the contributions of systems science to the philosophy of science manifests in the following three aspects: First, systems philosophy developed by Bertalanffy, including systems ontology, epistemology and value, has laid the foundation for systems philosophy to become a school of philosophy of science. Second, systems science addresses the relationship between whole and part, existence and evolution, and seeks to provide new justifications for ontological problems such as relational realism. Third, systems science also challenges the epistemological problems, carving out new explanatory approaches to complex systems emergence with condition-dependent laws and other principles of systems science.

Keywords

systems science, systems philosophy, philosophy of science, relational realism

1 | Introduction

For a century since its inception in 1920s, systems science has constantly and consistently explored complexity, raising numerous new philosophical questions. New systems theories and systems methodologies are constantly emerging, and new schools of systems science are constantly emerging. Scholars have taken different approaches to understanding the development of systems science, which is of great significance to appreciating its philosophical value. For example, in his book *The Science of the Artificial*, Herbert Simon(Simon, 2008), a Nobel Prize Winner in economics, has summarized the development of systems science and complexity exploration into three stages, namely *three eruptions* of interest in complexity and complex systems. He pointed out:

> An early eruption, after World War I, gave birth to the term "holism," and to interest in "Gestalts" and "creative evolution. " In a second major eruption, after World War II, the favorite terms were "information," "feedback," "cybernetics," and "general systems. " In the current eruption, complexity is often associated with "chaos," "adaptive systems," "genetic algorithms," and "cellular automata. " (Simon, 2008, p. 169)

However, with the continuous expansion of complexity theory and its application, we believe that the fourth eruption of interest has emerged in systems science. The advances of systems science not only poses challenges to some classical philosophy, but also makes an important contribution to the development of contemporary philosophy of science.

2 | Four Eruptions of Interest in Systems Science

As a modern systems theory, it germinated in the early 1900s, formed in the 1930s and 1940s, and developed in the 1950s and 1960s. We consider as the first eruption the research pioneered by A. Bogdanov and featuring Bertalanffy's general system theory, which marks the formation of systems science. The second eruption refers to the research of self-organization theory that developed from dissipative structure theory and synergetics. The third eruption refers to the research of complexity theory represented by complex adaptation system theory. We propose that there has formed a fourth eruption, as researchers now widely apply the concepts and methods of systems to economic, social and environmental systems, giving systems science research a strong application orientation.

2. 1 | First eruption of interest: the formation and development of systems science

Systems science was born in the early 20th century, and developed rapidly in the 1920s and 1960s, and the main representative theories is that of the general system theory(Ludwig von Bertalanffy, 1968), cybernetics(Wiener, 1961), information theory(Shannon, 1948), etc. The systems science of this period has presented the early cross-disciplinary thought.

The founders of the general system theory are Alexander Bogdanov and von Bertalanffy. When Bogdanov put forward *tectology* in the 1920s, the systems thinking proposed by Bogdanov was not only nearly 20 years before Bertalanffy's *general system theory*, but more importantly was groundbreaking and unique in content. Starting from the overall concept of behavior, Bogdanov strives to overcome the division between disciplines and explore the basis of universality with the universally recognized scientific language. Bertalanffy first proposed the concept of general system theory at a philosophical symposium in Chicago in 1937. In 1968, Bertalanffy officially published his *General System Theory: Foundations, Development, Application*, which comprehensively reviewed his thought, content and theoretical framework of general system theory. He established the framework of the general system theory by summarizing the system problems proposed by various disciplines and the concepts and methods of dealing with these problems.

2. 2 | The second eruption of interest: the establishment of the self-organization theory

In the 1960s, in the classical scientific fields of mathematics, physics, chemistry, and biology, the theory of system evolution was proposed from different angles, mainly revealing the mechanism of complex systems evolving into a new orderly structure or high-level organization under certain conditions. Therefore, under the title of the dissipative structure theory(Prigogine & Stengers, 1984), synergetics(Haken, 1983), and the hypercycle(Eigen, 1979), the second eruption of interest is formed in the study of the self-organization theory of complex systems. The subjects of these systems theories are mainly self-organization, a complex phenomenon widely found in natural and human social systems. Scholars put forward the concepts related to self-organization, such as away from equilibrium, nonlinear, feedback, emergence, bifurcation and fluctuation, trying to explain the conditions and mechanisms of the system self-organization, and explore how to make the system from disorder to orderly development, as well as the formation and evolution mechanism of a system. After the 1970s, scholars began a broader and more general sense of self-organized research. Erich Jantsch(Jantsch, 1980), for example, proposed the *The Self-organizing Universe*; Ervin Laszlo(Laszlo & Salk, 1987) also began to study the general evolution from a comprehensive perspective.

Exploring the combination of systems thinking and systems methods with management and applying them to practical management is also an important field for the application of systems science in this period. For example, hard system methodology, system dynamics, viable system model, soft system methodology, systems intervention, creative holism and critical system thinking(Jackson, 2019), etc. These applied studies not only innovate and develop management theory, but also provide scientific theories and methods for effectively solving complex management reality problems.

2. 3 | The third eruption of interest: the rise of complexity science

Since the 1980s, the research objects of systems science have increasingly turned to the overall study of the complex problems and complex systems in nature and society, so exploring the complexity and revealing the structure, function, law and evolution mechanism of complex systems has become the main goal and development direction of modern systems science. The rise of complexity science has injected new vitality into the development of systems science, and many scholars also recognize that complexity research is the latest stage of the development of systems science, and is even known as the science of the 21st century.

The Santa Fe Institute (SFI) is one of the earliest institutions to conduct a comprehensive complexity research. The study of SFI reveals that the generation of complexity as integrity and complexity is a *emergence* phenomenon, and that "… Complexity, in other words, was really a science of emergene. And the challenge that Cowan had been trying to articulate was to find the fundamental laws of emergence."(Waldrop, 1992, pp. 88–89) For instance, Stephen Wolflem found that while simulating cellular automata, elements under the constraints of simple rules will also suddenly appear in the macroscopic complex state; John Conway simulated game of life; Chris Langton, the founder of Artificial Life, has found that systems can develop new behavior patterns at the edge of chaos. Among them, the most important one is complex adaptative system theory proposed by John Holland (Holland, 1992, 1995, 2012). He emploied the computer to simulate how adaptive agent have evolved complex and orderly systems through mutual adaptation and adaptation to the environment, which has become a hot topic in the research of complexity science.

The complexity theories of this period are extremely fruitful, with chaos theory, fractal, complex adaptative system, genetic algorithm, artificial life, self-organized criticalit, etc. It focused on how complex systems arise and how adaptive agents learn, adapt and co-evolve. At the same time, the complexity scientific theory is applied to the fields of group decision-making, technological innovation, organizational management and economic strategic management, and has achieved remarkable results.

2. 4 | Fourth eruption of interest: applied research of systems science

Systems science has changed the way of thinking, and provided new ideas and ways for people to study the complexity problems in modern society, economic and various scientific fields. With the rise of complexity science, methodologies, models, and approaches to deal with complexity in natural science continue to mature, concept, principles and methods of system science have been widely used in economy, society, environment, and formed a series of methodology to solve the problem of complex systems, especially in the sustainable development of socio-ecological system, systems economics, system simulation, systems engineering, big data and artificial intelligence, deep learning, complex network.

During this period, complex system simulation methods such as agent-based model (ABM) are constantly mature. ABMs combines ideas like game theory, complex systems, emergence, computational sociology, multi-agent systems, and evolution to simulate the behaviour and interactions of autonomous agents, and agent-based modeling can also lead to a variety of complex and interesting behaviors. For instance, John Miller and Scott Page(Miller & Page, 2007) applied adaptive agent computational models to the dynamic behavior and management decisions of complex adaptive social systems; Brian Arthur(Arthur, 2014), a leading economist at the Santa Fe Institute, expanded into new areas of economics using complex system methods; Geoffrey West(West, 2017) put forward the law of scale to reveal the unified laws of the growth and demise of biology, cities and companies; Scott Page combs and summarizes 24 thinking models that explore the essential laws of the world, and advocates the use of multi-model thinking methods to understand complex phenomena.

To sum up, the general system theory not only marks the birth of systems science, but also opens the philosophical study of system and its complexity problems, namely the study of systems philosophy. The cross-sectional study of systems science and philosophy promotes each other, which can be described as a remarkable feature of the development of systems science, but also the internal power and value of the development of systems philosophy. From the initial main understanding and dealing with the complexity of the system in nature, to the current exploration of social systems management problems including value care, the research approach of systems science is more diversified. The development of systems science and systems philosophy has raised many new philosophical questions. Systems philosophy has become a new field under the paradigm of contemporary philosophy of science.

3 | The systematic philosophy proposed by Beralangfi became an important school in world philosophy

Elsevier's Handbook of the Philosophy of Science, published in 2011, first included the *Philosophy of Complex Systems* into the framework of the philosophy of science, opening a new paradigm of system thinking research. The book covers the complex systems philosophy problems in various fields such as economics, ecology and psychology. The handbook not only focuses on the development of the philosophy of systems science, but also reflects the influence of the complex system thought on the philosophy of science, and tries to incorporate the philosophical study of the complex systems into the theoretical paradigm of the philosophy of science.

The impact of complex systems on science is a recent, ongoing, and profound revolution. The theoretical paradigm of philosophy of complex systems tries to provide a complete knowledge framework for understanding the fundamental and philosophical theories triggered by the revolution of complex system. Due to the diversity of complex system phenomena and the diversification of the rules for describing complex systems, although after nearly 40 years of research, a unified complex systems science has not yet been formed. Therefore, exploring the philosophy of complex systems and complexity methodology has become a frontier field of systems philosophy.

In his classic book, Bertalanffy first proposed the systems science, which made the systems philosophy become a school of research in the world philosophy, thus establishing his pioneering position in the research of systems science. Systems science is inseparable from philosophy from its generation, and the general system theory proposed by Bertalanffy has also become what we call a broad systems science. He believes that, in a broad sense, this discipline system mainly consists of three closely related and distinct fields, namely, systems science, systems technology, and systems philosophy. Among them, systems philosophy includes three components: ontology, epistemology and value. Bertalanffy believes that the concept of *system* constitutes a new *paradigm* described by Kuhn, and that general system theory needs after science, or philosophical guidance.(Bertalanffy, 1972) In particular, he introduced value into the category of systems philosophy, intended to emphasize the complex relationship between people and the world in complex systems.

The systems philosophy proposed by Bertalanffy has a very important position and influence in systems science. In the coexistence and development with other schools of philosophy, such as analytic philosophy, oriental philosophy, structuralism, practical philosophy, philosophy of science, systems philosophy proposed by Bertalanffy has always maintained its own unique characteristics and theoretical characteristics, and was placed in the system of world philosophy, constantly collided and integrating with other philosophical ideas, and has been further developed and perfected. Systems philosophy summarizes the development achievements of systems science, and is applicable to both natural science, social science and humanities.

Since Bertalanffy initiated the general system theory, there was a great upsurge in the study of system theory. At present, there are still many scholars and institutions inheriting and developing the general system theory paradigm, for instance, Bertalanffy Center for the Study of Systems science in Vienna, Centre for Systems Philosophy founded by David Rousseau.

4 | Systems Science Provides A New Defense for Relational Realism

Systems science tries to analyse the relationship between the whole and the part, and makes a new defense for the ontological problems such as relation reality. Holism is the most basic and prominent feature of a system, and is also the basic problem of various systems theories. Since the early 20th century, with the development of mathematics, computer technology, and cross-disciplinary research, people found that practical problems in nature and human society are not isolated, they have complex correlation and holistic property. Bertalanffy noted that "… in one way or another, we are forced to deal with complexities, with 'wholes' or 'systems,' in all fields of knowledge. This implies a basic re-orientation in scientific thinking."

System is the most basic concept of the new paradigm of systems philosophy. The definition of system reflects the relationship between the elements and the whole. The scientific basis of contemporary systems thought first comes from Bertalanffy's scientific definition of *system*. Bertalanffy defined system as

> A system can be defined as a complex of interacting elements. Interaction means that elements, p, stand in relations, R, so that the behavior of an element p in R is different from its behavior in another relation, R'. If the behaviors in R and R' are not different, there is no interaction, and the elements behave independently with respect to the relations R and R'.(Ludwig von Bertalanffy, 1968, p. 5)

A system refers to a whole formed by the interaction of several components (elements, subsystems, individuals). Once the system is formed, the difference between the whole and the part exists objectively and relatively definitely. At the same time, a system also has its own holistic structure and function.

In addition to Bertalanffy's definition of system, different scholars or schools have different emphasis on the definition of the system, but all of them emphasize that the relationship between the components of the system. Hall and Fagan argue that "a system is a collection of relationships between object and object"(Hall & Fagan, 1968). In his work, GeorgeJ. Klir(Klir, 2001, p. 9) uses a formula $S= (T, R)$ to define the system,

> That is, the definition is simple in its form, but it contains symbols, T and R, that are extremely rich in content. Indeed, T stands for any imaginable set of things of any kind, and R stands for any conceivable relation defined on T.(Klir, 2001, p. 9)

In a sense, the concept of the system is the grasp of the relationship, and systems philosophy emphasizes that the *relationship* between the elements is more important, thus distinguishing it from the mechanical philosophy since modern times. Klir points out that "… systems science is fundamentally different from science in the traditional sense. The difference can best be explained in terms of the notions of thinghood and systemhood." (Klir, 2001, p. 6)

From the general system theory, the scientific thinking mode has realized the transformation from entity centered to relationship centered, which has laid a scientific foundation for systems thinking. The transformation of this scientific thinking is ways from linear to non-linear, from reductionism to holism, and from simplicity to complexity.

5 | Condition-dependent is A New Explanation for the Emergence of Complex Systems

In nature and human society, many complex phenomena are manifested as a emergence phenomenon. Emergence is the most core issue of complex systems science and philosophy, and it is also one of the frontier and hot issues in contemporary philosophy of science, philosophy of mind. Currently, a path is formed for the emergence research of complex systems, namely, to reveal the mechanism of emergence by computer simulation, and to provide an explanation for it. However, traditional studies on emergence generally believe that emergence is unexplained and unpredictable. This issue has attracted widespread attention from both scientists and philosophers.

As Hooker argued that,

> In the traditional conception of science, an assumed world governed by universal laws supported the assumption of universal generalisations and explanations as the basic forms of these features in science. If generalisations and explanations had to be hedged around with conditions of applicability, it was not the universality of law that was at issue but the prospect that the particular laws invoked might not be the basic ones. The hedging was taken to signal the presence of ignorance of the underlying universal principles that would allow

> the hedged accounts to be replaced by appeal to the ‘real’ underlying laws plus special initial and/or constraint conditions that remained independent of them.(Cliff Hooker, 2011, p. 878)

In contrast to laws of physics, many features or behavior patterns that complex systems exhibited do not seem to fit the laws. Therefore, condition-dependent generalizations of the emergence models of complex systems constructed through computer simulations are needed.

Condition-dependent explanation provides a new mode of interpretation for the emergence of complex systems. The condition-dependent explanation of emergence is very different from the traditional deduction-law explanation, induction-probability explanation, etc. This mode of explanation further enriches and develops the study of scientific explanation in the contemporary philosophy of science. In traditional scientific explanation, laws are the basis of explanation. “[T]hese ‘covering law’ explanations are intentionally condition-independent, the covering law is universal and picks out a universal pattern holding everywhere.”(Cliff Hooker, 2011, p. 882) Many emergent phenomena are very condition-dependent in structure and function, and therefore, their dynamics features similarly require a condition-dependent explanation. “Complex system behaviour is explained as the joint product of interaction dynamics (the true universal laws) and constraints (the operative conditions), together (as before) with initial conditions. A dynamical explanation then consists in specifying all three factors and deducing the behaviour from them, a direct generalisation of the original covering law formula. The fundamental aim of science continues to be provision of dynamical explanations of the behaviours of complex dynamical systems.”(Cliff Hooker, 2011, p. 883)

6 | Conclusion

As an important part of the study of systems science in the world, the study of systems science and systems philosophy in China has not only been in line with international standards, but also formed its own research progress and characteristics, and tried to analyze and summarize the theoretical paradigm of systems philosophy at the level of philosophy of science.First, we should fully excavate the holism thought contained in Chinese traditional culture, and integrated these ideas into the study of modern systems science and systems philosophy. For example, the traditional Chinese thought of "the unity of man and nature", the five elements and the eight diagrams, etc. Systems philosophy provides an opportunity and platform for the exchange and dialogue between Chinese and Western culture and science. Second, refine and summarize the complex system holism and basic system principles of systems science, and form different theoretical paradigms. Third, summarize the systems methodology from the practice of China's reform and opening up, and apply it to the new practice of China's social development.

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