Understanding The Principle of Simplicity of Science from The Science of Complexity

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1. Thinking Caused by Scientific Transformation

In the history of science, simplicity is the belief of almost all scientists, and it is also the logical and aesthetic standard for choosing a theory. As early as the 6th century BC, the ancient Greek mathematician and philosopher Pythagoras believed that the origin of all things is numbers, not things. Simplicity and harmony are the principles to establish the theory of natural sciences. During the 14th century, British Academy philosopher and Logician Ockham (W. Ockham) put forward the recognized thinking principles and logical tenets called "Ockham's razor", and he pointed out that "it is not necessary" not to increase the number of hypotheses. "Occam's Razor" is the prototype of the idea of simplicity. In Newton's time, Newton's laws of mechanics unified macroscopic motion phenomena in a simple form. In "The Mathematical Principles of Natural Philosophy", Newton pointed out: "Nature does not do useless things." Things will be done when you do less, when you do more, it becomes extra and useless; because nature likes to simplify and doesn't like to use superfluous reasons to boast oneself." In the era of relativity, Einstein put forward two criteria for testing theories: "external confirmation" and "internal completeness", that is, "logical simplicity". He believes that from the perspective of scientific theories reflecting the harmony and order of nature, true scientific theories must be in line with the principle of simplicity (1). It can be said that, for a long time, it is scientists' pursuit of the principle of simplicity that has promoted the development of science; On the other hand, simplicity is the foundation of human understanding of the world, and it is also the guiding principle of scientific research.

Since the 1960s, especially in the 1980s, the science of complexity characterized by non-linearity and centered on chaos have gradually matured and emerged. Scientists have realized that phenomena that are considered "pathological" and "strange" in classical science are quite universal. The nature of the world is complex, and non-linearity is the root of this complexity. The traditional principles of approximation and simplification of complexity have great limitations, and the rise of complexity science has challenged the traditional principle of simplicity. Founder of dissipative structure theory, Nobel Laureate Prigogine put forward the slogan "end the principle of simplicity in the real world" [2]. He pointed out: "Scientific interest is shifting from simplicity to complexity. The belief in the simplicity of the microscopic world has been broken. This shift has led us to focus on new concepts and methods [3]". In this country's academic field, there has also been a debate about "whether complex systems should abandon the principle of simplicity".

There is no doubt that science is transforming from the science of simplicity to the science of complexity. We must re-understand the principle of simplicity of science. In order to make the problem clear, two key points must first be clarified: the meaning of the principle of scientific simplicity and the content of complex scientific methodology.

2. The Meaning of The Principle of Scientific Simplicity

The author believes that the principle of scientific simplicity can be divided into the principle of simplicity and the methodology of simplicity, and the methodology of simplicity can be divided into the principle of simplicity of scientific models and the principle of simplicity of law selection.

(1) Simplicity of the worldview

The so-called simplistic worldview believes that the world is a unified and harmonious whole governed by a small number of logically extremely simple principles. When these principles are found, the development law of things can be grasped. Due to the different knowledge backgrounds of science and philosophy, scientists have different understandings of simplicity. Among them, the one that has the greatest influence on them is reductionism.

The so-called reductionism is to believe that the laws of movement of each part or level of the world can explain the laws of movement of another part or level. According to the two forms of reduction, reduction theory can be divided into the reduction theory of mechanical determinism and the reduction theory of statistical determinism: if the whole and high-level motion laws are reduced to parts, and the low-level motion laws are reduced, it is the reduction theory of mechanical determinism; on the contrary, it is the reduction theory of statistical determinism.

Reductionism believes that the laws of the whole can always be restored to partial laws through complex calculations. Some things are called complex things just because there are too many parts that make up these things, and we don't have enough data and the ability to process them, at this time, statistical methods can be used to obtain statistically average results. Reductionism is essentially determinism.

Reductionism does not recognize the complex nature of the world. From the point of view of reductionism, if there is sufficient data, with the improvement of human cognition, the laws of movement of the world can eventually be reduced to several simple laws, and the true complexity is almost non-existent.

(2) The principle of simplicity of scientific models

Scientific models are the core of scientific methods and the key to applying existing scientific knowledge to solve practical problems. Scientific models must follow the principles of similarity, simplicity, and verifiability. (4) The so-called simplicity, whereby the model is simpler than the prototype in terms of logical structure and subjective understanding, and it is easy to perform theoretical operations such as logical reasoning and mathematical operations, as well as practical operations such as experiments and measurements. The simplicity of the model mainly depends on two points. The first is the advancement of existing science. For example, the generation of calculus simplifies the solution of higher-order equations; the second is the simplification of the system. Traditionally, the simplification of the system is divided into two steps. The first is to simplify the whole into parts, and the second is to simplify the local model; this will be discussed in more detail below.

1) Simplify The Whole into Parts

For a long time, the reduction method (the analysis method) has been used for the simplification of the whole into parts, and the systematic method has appeared after the emergence of systematic science. (4,5) The reduction method was the dominant methodology from the 17th century to the 1940s. It is closely related to the reductionist worldview of mechanical determinism. Based on the view that "the whole is equal to the sum of parts", it believes that the understanding of a system "first reduces the whole to parts" and then synthesizes it to obtain an overall understanding of the system. French scientist, R. Descartes, the ancestor of modern deductionism said: "Break down each puzzle into as small parts as possible until it can be solved satisfactorily. " (6)

Systematic method is the methodology of systematic science developed in the 1940s. The American philosopher, E. Laszlo, believes that the system is "a whole with irreducible properties". [4,5] Based on the point of view that "the whole is greater than the part", the systematic method emphasizes comprehensively from the relationship between the whole and the part. The whole and the environment (other systems) comprehensively examine the objects to achieve the best way to deal with the problem.

The systematic method requires that it be based overall, and at the same time requires in-depth research on each part. Therefore, the systematic method includes the reduction method. However, this kind of reduction does not restore the object to a partial accumulation, but to the organizational structure of the system. For example, the reduction method reduces buildings to bricks, tiles, steel bars, and cement; and the systematic law looks at these materials according to the organizational structure of the building. Therefore, the systematic method is a supplement to the reduction method in a certain sense, and the systematic method is better than the traditional reduction method. The simplification principle of the system method can be used as a step-by-step approximation method: the first level is to approximate "the whole is equal to the sum of parts" as "the whole is greater than the sum of parts"; the second level is to add some interaction between subsystems based on the first level··· And so on, the simplified system approximates the complex system step by step. [4,5]

2) Simplification of The Local Model

The simplification of the local model is a simplification method for a single individual. From an epistemological point of view, this is a process of idealizing the real world. The direction of idealization is to move closer to existing knowledge, so it has a great relationship with the development of scientific theory itself. Traditionally, due to the dominance of linear theory, people are accustomed to simplifying systems into linear systems. Specifically, irregularity is simplified to regular; unevenness is simplified to uniformity; non- smoothness is simplified to smoothness; finite is simplified to infinite (or vice versa); continuous is simplified to discontinuous (or vice versa); high-dimensional is simplified to low-dimensional; anisotropic is simplified to isotropic; non-isolated systems are simplified to isolated systems. This kind of system was once an effective method in mechanics and physics.

(3) The Principle of Simplicity of Law Selection

The principle of simplicity of law selection refers to the premise that under the premise of ensuring strict logic, completeness, and comprehension. One should choose a theory that contains fewer basic hypotheses and simpler logical forms.

Obviously, the principle of simplicity in law selection is influenced by the worldview of simplicity. In addition, there are the following reasons for choosing simple laws: first, simple laws have a wider scope of application. Second, simple laws have strong reliability. This is because the simplicity of the law requires that the basic assumptions of the law be at least, so that there is less chance of errors due to the failure of the basic assumptions. Third, simple theories have higher testability. For example, simple laws have higher falsifiability. This is because the fewer independent elements the law contains, the easier it is to be falsified. Fourth, simple laws are highly understandable and actionable.

In summary, the simplicity of science is not only a worldview, but also a methodology. In the three hundred years of the development of classical science, single reductionism has always dominated. The emergence of systematic science has enriched the idea of simplicity, and people have begun to study the relationship between levels. For a long time, this relationship has been limited to linear relationships. This is because linear mathematics provides a feasible method. For non-linear relationships, since non-linear science itself does not provide an effective method, linear relationships are generally used to gradually approximate. The results of scientific development show that the previous principle of simplicity is not only effective, but also a driving force for scientific development.

3. The Complex Nature of The World

Since this century, with the in-depth exploration of the nature of things by mankind, the limitations of sexual relations as a single way of thinking in examining the world have been increasingly exposed. People have gradually realized that non-linear relationships are the universal relationships between all levels and parts of the system, and this relationship is irreducible.

In geometry, this relationship is manifested as self-similarity, whereby any small part is similar to the whole. This kind of fractal geometry, which was once considered "pathological", looks extremely irregular. In fact, it truly describes the natural world. Linear Euclidean geometry is just an idealized model. For example, foreign scholar A. P. Pentland believes through research that more than 92% of the natural landscapes on the surface have fractal characteristics. (7) In recent years, fractals have been widely used in natural and social sciences.

In terms of dynamics, the non-linear relationship between the various levels of the system is manifested as "folding" operations, such as iteration of nonlinear equations. This relationship of dynamics leads to chaos. Chaos manifests as irregular walking behavior. Chaos is currently the most complex movement mechanism. Scientific research has continuously confirmed that chaos is a more common phenomenon than ordinary order.

In set theory, this non-linear relationship is manifested as the continuous membership of sets of different elements from 0-1, which produces fuzzy mathematics. Fuzzy mathematics reflects the ambiguity of concepts, and truly simulates the fuzzy characteristics of human brain recognition and judgment. It is widely used in artificial intelligence and automatic control.

Fractals, chaos, and fuzzy mathematics are all typical complex sciences. This pervasive non-linear relationship between system levels leads to the complexity of system behavior. It can be said that the world is inherently complex, and the root of complexity is non-linear. Therefore, some people equate complexity with non-linearity. (8)

The rise of science in complexity, including dissipative structure theory, synergism, mutation theory, hypercirculation theory, chaotic dynamics, fractal theory, and neural networks have brought a new worldview: any change in the world is irreversible, and any objective thing shows randomness and conditionality. The specific form and direction of things because of cross-level changes are unpredictable. The blueprint of the world of beauty and harmony drawn by traditional science based on simplicity can only be understood as a temporary scene in the process of system evolution, even simple laws of generation can produce indeterminate motion phenomena. The world is changing and complicated.

4. Methodology of Complexity Science

Traditionally, people have been accustomed to approximating the non-linear relationship between the various levels of the system as a linear relationship. The main reason is that non-linear science has failed to provide effective mathematical tools. Traditional methods can successfully simulate phenomena that are like linearity in the system. However, the behaviors and characteristics that have been ignored that are very different from linear phenomena are rich in information. Hard simplification to linearity will greatly reduce the similarity of the model. This is the crux of traditional methods in dealing with certain application problems.

For example, strict acoustic theory proves that speech is produced by a complex, randomly time-varying dynamic physical system. Due to the limitations of mathematical tools, the traditional speech processing theory uses an all-pole time-varying linear system as a mathematical model of speech signals and has made significant progress. However, due to chaotic phenomena such as turbulence in speech, its behavior cannot be described by traditional linear equations. This makes it difficult to further improve the ability of voice processing. [9,10]

The traditional simplification principle of non-linear systems has certain limitations when dealing with "strange" phenomena that are far from linear behavior. This limitation is ultimately determined by the development of nonlinear science itself. In the past 30 years, nonlinear science has developed rapidly. People have found that many irregular and strange behaviors that are difficult for traditional science to handle may be generated by extremely simple rules. For example, the attractor called Rossiler's band shown in Figure 1 is composed by an iterative equation.

From the above analysis, the rise of complexity theory has broadened people's horizons and provided a new worldview. People began to replace the reductionist worldview of single determinism with a complex worldview. People realize that in the past, simple worlds were only approximations or special cases of complex worlds, just as the world reflected in Newtonian mechanics was only the best approximation of the world reflected in relativistic mechanics on low-speed macroscopic objects. The nature of the world is complex, and it is a world that is qualitatively very different and potentially strange. People should elevate the worldview that does not recognize the complexity of the world and believes that if they know a few "eternal" laws, they can grasp the simplicity of all natural phenomena to a worldview of complexity.

In terms of methodology, complexity science also provides new methods for model simplification. Many non-linear problems that cannot be dealt with by classical science can be simply solved by complexity science. In this sense, the non-linear characteristics of the system should not be simplified to the characteristics of each part by the reduction method, and the simplification of the local model should not be simplified to a linear system by the traditional method. The simplification principle of complexity science is strictly in line with the point of view of system law. It emphasizes the relationship between levels and requires a holistic view of the various parts of the system. At the same time, although complexity science provides a feasible model simplification principle, it does not mean that we can abandon the principle of model simplification in traditional science. Traditional science has provided a wealth of experience, methods, and techniques in the long process of development. It is extremely unwise to abandon it, just as the emergence of relativity does not mean abandoning Newtonian mechanics. When studying the linear characteristics of a system, traditional science can be used to simplify; and when studying the phenomenon with obvious nonlinear characteristics of the system, complex methods should be used; sometimes, two methods should be used in combination. For example, the coastline is essentially a fractal curve, but if the problem is to build roads along the coast, it is not necessary and impossible to treat the coastline as a fractal curve. The correct way is to approximate the coastline with smooth straight or curved segments. (1)

From the perspective of the principle of simplicity of law selection. Traditional science generally believes that simple systems have simple states of motion, and complex states of motion must have complex causes. Complexity science has changed this concept, believing that simple deterministic systems can produce complexity, and complex systems can still be considered to follow simple laws. It can also be seen from here that complexity science not only conforms to the principle of simplicity of law selection, but also deepens this principle. Scientific theory must be simple, and the more it correctly takes simple basic concepts and basic laws as its core and foundation in complex phenomena, the more it captures the essence.

6. Conclusion

Lastly, we can draw the following conclusions: in terms of worldview, the rise of complexity science has changed the single deterministic worldview and replaced it with a complex and evolutionary worldview; in terms of methodology, complexity science provides new content for the simplification principle of scientific models and strongly supports the principle of simplicity of law selection. Complexity science, on the one hand, abandons the single reductionist part of the principle of simplicity of classical science, and on the other hand enriches the content of the principle of simplicity of science. Its rise is the victory of dialectics over mechanism.