

Developments of Research on the Nature of Life from the Information Theory of Individuality [†]

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Abstract: The research on the nature of life from the perspective of information can be traced back to Schrödinger's theory on the negative entropy of life. Many system scientists and system philosophers inherited Schrödinger's research approach and emphasized the relationship between information science and the nature of life. Recently, David Krakauer, the current director of the Santa Fe Institute, and others proposed The Information Theory of Individuality, and further used information theory to define and classify formally individuals, deepening the relationship between information and the nature of life. Information individuals are divided into Organismal Individuality, Colonial Individuality, and Environmental Determined Individuality. The formal definition of information individuals is a new development in Schrödinger's research on the nature of life, and it is also instructive for contemporary artificial life research.

Keywords: the information theory of individuality; information; the nature of life; biological individual; informational individual



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1. Introduction

The study of the nature of life is a classic and cutting-edge topic in the philosophy of biology and the philosophy of science. Since Schrödinger put forward the famous view that “life feeds on negative entropy” in his book *What is Life*, he has pioneered the approach of studying the nature of life from physics [1]. Many system scientists and system philosophers emphasized the relationship between information science and the nature of life building on Schrödinger's research approach. For example, Shannon proposed that the concept of information is associated with negative entropy [2], which provides a foundation for the relationship between information and the nature of life. Shannon's information concept is regarded as the negative entropy of thermodynamics, which can be used to measure the certainty and the degree of order in systems. Furthermore, building on the theory of negative entropy and Shannon's concept of information, Prigogine has established the formulation of entropy change in open systems, which extends the understanding of the relationship between the degree of order in systems and the negative entropy flow of life [3].

Recently, David Krakauer, director of the Santa Fe Institute, has coined the information theory of individuality, based on the definition and formalization of life from the perspective of information, as a means to rethink the theoretical hypothesis of biological individuality [4]. It focuses on the individual's information characteristics, and defines individuals as aggregates that “propagate” information from their past into their future while maintaining a considerable level of time completeness. From the theory of negative

entropy of life to the information theory of individuality, the idea of “life feeds on negative entropy” gradually deepened.

2. From the Biological Individual to the Informational Individual

Unlike biological individuals, individuals defined by information are called informational individuals.

The Information Theory of Individuality reflects on the theoretical hypothesis of biological individuals. Individual hypotheses are common in biology. The standard hypothesis of individuals is the hypothesis of replicators [5]. But the replicator hypothesis has limitations. For example, worker ants in an ant society cannot genetically replicate, but they can survive continuously and have the ability to adapt to the surrounding environment. Worker ants are obviously living individuals.

Therefore, Krakauer believes that individuals can be individuals without copying. In Schrödinger’s book *What is Life*, the second chapter of genetic mechanism points out that living individuals have the characteristics of persistence, and their persistence is achieved through the duplication of genetic material. We believe that if persistence is regarded as the purpose of life, then replication is a means of persistence, and the persistence of life does not necessarily need to be realized through replication.

David Krakauer then abandons the preference for a single biological level or object and the dependence on various biological characteristics, focused on the individual’s own information form characteristics, and defines individuals that propagate information from their past into their futures and maintain a certain time integrity measurement aggregate. Here, to be an individual is a problem of a degree, which can be nested at any level, distribution, and possibility, and which means that individuals include, but are not limited to, individuals at the biological level.

The Information Theory of Individuality does not fix individuals on a single biological level, nor does it regard duplication as a necessary condition for individuals. Therefore, this proposition has a higher generality than the theoretical hypothesis of biological individuals.

3. Mutual Information and Formalization of Individuality

The information theory of individuality defines the informational individual formally by appealing to mutual information, and deepens the understanding of life from the perspective of information.

The definition of informational individual indicates that the living individual has a certain persistence. The informational individual is seen as a stochastic process that can maintain an orderly state during the passage of time, and can be identified by the amount of information in the process of information dissemination. If information transmitted in time is close to the maximum, it is taken as evidence of the individual [4]. Shannon describes entropy based on the information shared by the channel transmitted from a signal transmitter to a receiver. The transmission value of information can be measured by mutual information.

The future state of the system is not only affected by its own current state, but also by the current state of the environment. Therefore, the sender of the signal involves a complex situation, consisting of two parts: the system and the environment. By decomposing mutual information through the chain rule, the process information flow between the system and the environment can be quantified. Figure 1 is a causal diagram of the system–environment interaction constructed by David Krakauer.

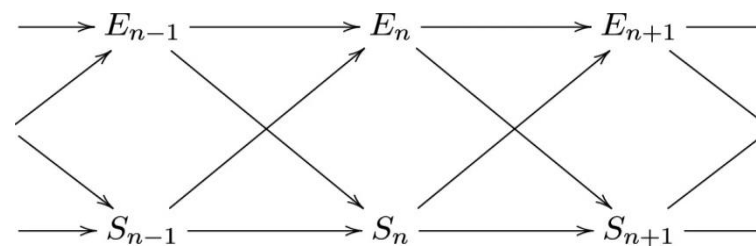


Figure 1. The causal diagram of the system–environment interaction [4].

The future state of the informational individual can be determined by the current state of the system and the current state of the environment, and its predictability can be quantified by mutual information. In order to rigorously formalize a different kind of individuality and clarify whether the factors affecting the state of the system originate from the system or the environment, David Krakauer refers to the information theory framework of “the partial information decomposition [6]” and introduces the notions of unique, shared, and complementary information. In this way, mutual information can be fine-grained in terms of the unique information of the system, the unique information of the environment, shared information between the system and the environment, and complementary information between the system and the environment. The different combinations of these four kinds of information allow for the classification of individuality into Organismal Individuality, Colonial Individuality, and Environment-Determined Individuality [4].

The formal definition of individuality not only makes life universal, but also explains the diversity of life and further deepens the relationship between information and the nature of life.

4. Thinking on the Information and the Nature of Life

The information theory of individuality is a contemporary answer to Schrödinger’s question “Is life based on the laws of physics? [1]”. It also provides a new perspective and enlightenment for the study of artificial life.

To the question “Is life based on the laws of physics?”. Schrödinger answered in the affirmative and pointed out that the new physics principle may be Quantum Mechanics. The informational individual focuses on its information characteristics and persistently ordered states, which are consistent with Schrödinger’s thoughts on life. However, the informational individual expands the scope of the living individual to different coarse-grained adaptive aggregates at various levels of nature, society, and culture, and deepens our understanding of the nature of life from information. Therefore, we believe that information theory based on entropy can be used as a candidate law for the life and the information theory of individuality, which uses information and information theory to define and explain life, and is a contemporary answer to the question “Is life based on the laws of physics?”.

The information theory of individuality can also provide a new vision and enlightenment for the theoretical hypothesis of artificial life. Informational individuals who focus on the characteristics of information provide a theoretical basis for artificial life’s view that “life lies in form rather than matter” [7]. The information theory of individuality provides a way to quantitatively identify individuals without physical boundaries, and can provide a scientific method for identifying individuals with artificial life. However, the information theory of individuality shows that replication is not the essential feature of life, and that life based on the hypothesis of replication is only a special form of life, not a universal form, which provides a new vision and enlightenment for the study of artificial life.

5. Conclusions

In conclusion, the information theory of individuality develops Schrödinger’s theory of the negative entropy of life, expands the scope of living individuals, and deepens the relationship between information and the nature of life. However, this paper argues that to

combine the hypothesis of replication with the formalization of the informational individual is a new and still unexplored topic.

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