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Complex Multi-Category Systems

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Abstract

The article explores the field of complex systems. The shortcomings of the existing theory of complex systems are noted. The article explores a special type of complex systems: large complex systems. Two concepts are introduced: a complex multicategory system and a local complex system. Large complex systems are divided into homogeneous and heterogeneous. Large heterogeneous complex systems include categorically different integral local complex systems as subsystems. A subsystem of an ordinary complex system does not have integrity, but is dependent on the main system. A local complex system has integrity. It can be used stand-alone or in combination with other systems. The content of complex systems is revealed based on comparison with simple systems. The article gives a formal description of a number of simple systems. A formal description of complex systems is given on the basis of the development of a description of simple systems. Four types of simple and complex systems are considered. The article identifies three types of emergence of complex systems and three types of structure of the system components. It is shown that emergence is a characteristic of complexity. The presence of a class of large complex systems is noted. This class includes a subclass of heterogeneous or hybrid systems. For this subclass, the concept of multicategory complex systems is introduced. the introduction of the term "multi-categorical complex systems" is justified. a number of properties and dependencies in complex systems are studied. The features of many categorical complex systems are described. The article gives a formal description of a complex multi-category system based on a systems approach. It is shown that the structure of a complex multicategory system is described by a multigraph. A feature of complex multi-category systems is the possibility of using corporate management technologies for local complex systems with the additional condition of their complementary behavior. The introduced models expand the application of the theory of complex systems in practical activities.

Keywords: complex systems, large complex systems, heterogeneous complex systems, categorical complex systems, complexity, emergence, simple systems, local complex systems.

1. Introduction

There are a number of gaps in the modern theory of complex systems. The traditional definition of a complex system as "a set of elements and connections" does not include the concept of complexity. One of the reasons is the variety of types of systems and types of complexity, another reason is the multidimensionality of consideration of complex systems. For example, there is an approach, which examines the relationships between parts of a system and the external

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environment. There is another approach that considers the behavior of the system and divides it into simple and complex. Both approaches use simplicity or complexity of description as criteria for complexity. It is believed that if a system is described simply, then it is a simple system. There is a subjective reason. It is more pleasant for a person to consider structures and easily structured models compared to poorly structured phenomena, which include complexity. The usual study of complex systems was limited to the triad of its components: elements, parts of the subsystem. This study of complex systems has so far bypassed large complex systems. Most theories of complex systems exclude the concept of simplicity and a simple system as a basis for comparison. In fact, complexity is a conditional concept, and it is determined from the level of simplicity. Another approach connects the complexity of systems with the presence of self-organization of the system or with the presence of emergence of the system. Synergistic effects are also a sign of complexity. Among the many complex systems, large complex systems are distinguished (May, 1972; Filip, 2008). Large complex systems use specialized complex systems as subsystems. Specialized complex systems can be of different types: complex information systems (Po-An Hsieh, Wang, 2007), complex technical systems (Leoshchenko et al., 2021), intelligent transport systems (Garg, Kaur, 2023), cyber-physical systems (Yaacoub et al., 2020), complex geographic information systems, multi-agent systems (Li et al., 2020), complex space monitoring systems (Kudzh, 2020), complex Earth-Moon system (Savinych, 2022) and others. Each variety of specialized complex systems has its own specifics, including modernization features. Specialized complex systems can be classified into different categories of systems. Large complex systems, composed of complex systems of different categories, should be called complex multi-category systems.

2. Results and discussion

Complex and simple systems

Complexity is a conditional and comparative concept. Therefore, it is necessary to determine a certain level in relation to which complexity is assessed. The opposite of complexity is simplicity. Using a systems approach, it is possible to analyze simple and complex systems and give a comparative analysis of them. Both types of systems include elements, parts and subsystems.

A system element is an indivisible component in accordance with the selected divisibility criterion. An element is a structural element of a system, indivisible according to a given criterion. Important for the element is indivisibility and the criterion of divisibility.

Part of a system is a set of related elements of the system, selected on the basis of the unification criterion, which enters into certain relationships with its other parts. A part is a structural block of a system that combines elements to solve a problem. Important for the part is the appearance of a function for a group of elements. It is rare for a part to have or not have the property of emergence. Let's call this emergence the emergence of a part or emergence 1. This emergence characterizes the complexity of a part of the system.

A subsystem is the largest part of the system. It brings together a group of system components to perform a common function. The subsystem can perform independent functions. A subsystem is a structural block that combines parts to implement one system function. For a subsystem, the property of emergence may or may not exist. Let's call this emergence subsystem emergence or emergence 2. This emergence also characterizes the complexity of a part of the system. Complementarity of parts and subsystems allows solving system-wide functions

A system is a combination of subsystems and connections between them to perform a set of common functions or the main function of the system. a false system, as a rule, has the property of emergence. Let's call this emergence system emergence or emergence 3. The system has the highest level, subsystems have lower level complexity, and parts have the lowest complexity.

To compare with a complex system, consider a simple system. Most often, such systems are additive systems that do not have the property of emergence. To formally describe a simple system (SYS) and a complex system (CSYS), we will use the apparatus of systems theory. As the parameters under consideration increase, the formal description of the system model will become more complex. As a first description, consider a simple abstract system SYS as the first model

$$SYS1 = \langle E, PS, C, B \rangle, (1)$$

In expression (1) E is the set of system elements; PS - many parts of the system; C – set of connections between parts and elements of the system; B is the set of system boundary points separating the system from the external environment. For simple systems, its parts and the system itself do not possess the property of emergence. Formula (1) describes a simple system as a set of elements and parts that interact with each other and with the environment. A more complex system model includes the structure of the system and its constituent structures

$$SYS2 = <PS, Str, E, C, B>, (2)$$

In expression (2) PS is the set of parts of the system. Str – system structure. E – set of system elements; C – set of connections in the system. B – system boundary, separating the system from the external environment. This definition indicates that a system consists of heterogeneous parts and has a structure. In this case, three types of structure are possible: structure of 1 subsystems, structure of 2 parts, structure of 3 elements. Complexity increases as we move from structure 1 to structure 3. For models (1), (2), the concept of complexity is not included, so they formally describe simple systems.

For a complex CSYS system there is a model.

$$CSYS1 = <Ps, PS, Str, E, C, B, R, Cx>, (3)$$

In expression (3) Ps is the set of subsystems of the system; PS – a set of parts of the system. Str – system structure. E – set of system elements; C – set of connections in the system. B – system boundary. R is a set of relationships between elements, parts and subsystems. Cx – one or more types of complexity. The complexity of Cx depends on the type of structure, on the number of elements, on the number of connections, on the number of relationships. This definition indicates that a system consists of heterogeneous parts, has structure, and has complexity.

A distinction can be made between a simple and a complex system. In a complex system, there are subsystems and a measure of complexity that may include emergence. Complexity can have different levels and belong to different components of the system. These are the particular complexities of the system components. General or integral complexity is a characteristic of a complex system. It can be considered as a function of particular complexities

$$Cx=F(Cv, Cp, Cr, Cd, Cc, Ccm, Cmd, Ca, Agc) (4)$$

In expression (4) Cv is the volumetric complexity. associated with large amounts of data or system volume; Cp – procedural complexity associated with the complexity of processing and interpretation, as well as time constraints of processing; Cr – complexity of representation (representation); Cd – descriptive complexity associated with the complexity of describing the system; Cc – cognitive complexity of perception and use of the system; Ccm – computational complexity (if it is present in the system); Cmd – complexity of modeling in the system; Ca – algorithmic complexity of system behavior; Agc is the complexity of the interaction of system components with each other.

Expression (4) itself provides a systematic description of complexity. Many systems have an additional target parameter (G). A simple target-specific system will be described by a species model

$$SYS3 = <Ps, PS, Str, E, C, B, G>, (5)$$

In expression (5) the parameters are the same as in expression (2) with the addition of a target parameter. A complex target-specific system will be described by a model of the form

$$CSYS2 = <Ps, PS, Str, E, C, B, R, Cx, G >, (6)$$

In expression (6) the parameters are the same as in expression (3) with the addition of a target parameter. A complex system may have multiple goals, e.g. be multi-purpose (Tsvetkov, 2012).

Systems are divided into open and closed. For open systems there are system models.

$$SYS4 = <Ps, PS, Str, E, C, B, int, out >, (7)$$

$$CSYS3 = <Ps, PS, Str, E, C, B, R, Cx, int, out >, (8)$$

In expressions (7), (8) int is the set of inputs, out is the set of outputs of the system. The presence of system inputs and outputs separates the system from the environment and allows one to model the informational and physical interaction of the system with the environment. In many cases, the boundaries of an interacting system are quite difficult to determine. As a criterion for determining these boundaries, you can choose the strength of connections between elements. This allows you to select elements from the system, determine boundary (input and output) elements, and determine the boundaries of the system. A system exists only when the strength of connections between the elements of the system is stronger than the strength of connections with the environment. The inclusion of the cognitive factor Cog in the functioning of the system is typical only for a complex system.

$$CSYS4 = <Ps, PS, Str, E, C, B, R, Cx, Cog, int, out >, (9)$$

The inclusion of artificial intelligence methods AI in the functioning of the system is typical only for a complex system.

$$CSYS5 = <Ps, PS, Str, E, C, B, R, Cx, AI, int, out>, \quad (10)$$

A complex system has the property of emergence, so it cannot be studied only on the basis of an analysis of its components, subsystems or elements. The study of a complex system by the decomposition method, that is, the method of decomposing the whole into parts, is insufficient, since it comes down to the study of only its individual parts. The study will be complete when the integration method is applied, allowing one to synthesize the whole from the elements of the system. This approach ensures the formation of a holistic view of a complex system. The presence of emergence (Em) of a complex system entails the appearance of its integral properties (integral PSoperties)

$$CSYS(Em) \rightarrow CSYS(\text{integral PSoperties}) \quad (11).$$

Along with general differences, there are differences in parameters between complex and simple systems. The data volume of a complex CSYS system (Data Volume) is greater than the data volume of a simple SYS system (Data Volume)

$$CSYS\ (\text{Data Volume}) >> SYS\ (\text{Data Volume}) \quad (12).$$

The physical volume of a complex system CSYS (Physical Volume) is greater than the physical volume of a simple system SYS (Physical Volume)

$$CSYS\ (\text{Physical Volume}) >> SYS\ (\text{Physical Volume}) \quad (13).$$

The variety of data in a complex CSYS system (Data Variety) is greater than the variety of data in a simple SYS system (Data Variety)

$$CSYS\ (\text{Data Variety}) >> SYS\ (\text{Data Variety}) \quad (14).$$

The number of components of a complex system CSYS (Components Number) is greater than the number of components of a simple system SYS (Components Number)

$$CSYS\ (\text{Components Number}) >> SYS\ (\text{Components Number}) \quad (15).$$

The number of connections in a complex system CSYS (Connections Number) is greater than the number of connections in a simple system SYS (Connections Number)

$$CSYS\ (\text{Connections Number}) >> SYS\ (\text{Connections Number}) \quad (16).$$

The adaptability of a complex CSYS system (adaptability) is higher than the adaptability of a simple SYS system (adaptability). In simple systems. as a rule there is no adaptability.

$$CSYS\ (\text{adaptability}) >> SYS\ (\text{adaptability}) \quad (17).$$

The structure of a complex CSYS system (structure) is larger and more diverse than the structure of a simple SYS system (structure)

$$CSYS\ (\text{structure}) >> SYS\ (\text{structure}) \quad (18).$$

The structure of a simple system is described by a planar or planar graph. The structure of a complex system is usually described by a multigraph or volumetric graph.

In reality, it is necessary to take into account that decision-making or problem solving by the system occurs within a certain permissible time interval - (ΔT). This is a dynamic characteristic of the system. The permissible time intervals of a complex and simple system are either proportional

$$CSYS\ (\Delta T) \approx SYS\ (\Delta T) \quad (19).$$

Or the permissible time interval of a complex system is less than the permissible time interval of a simple system

$$CSYS\ (\Delta T) < SYS\ (\Delta T) \quad (20).$$

Expressions (1), (2), (5), (7) describe simple systems. Expressions (3), (4), (6), (8), (9), (10), (11), (12) describe complex systems. Expressions (13) - (21) describe the comparative characteristics of complex and simple systems. Expressions (13) - (21) describe the comparative characteristics of complexity.

Properties of a complex multicategory system

The world is a system of systems. The solar system includes planets, each of which can be considered as a complex system. Human society can be viewed as a collection of qualitatively different systems. Any state is a complex system that includes different, smaller complex systems. The list can be continued, but the important conclusion is that there are systems of systems. There are special complex systems. which include other complex systems. They are called large systems. Large systems that consist of complex systems belonging to different categories can be designated as multi-category systems.

Multicategory complex systems have the following features. They are heterogeneous. They include entire systems as subsystems. They have the highest level of complexity among complex systems. The term “categorical” is due to the fact that the systems included in it may belong to different categories of systems and different categorical functions. Such incoming complex systems can be: complex data systems, complex computational processing systems, complex communication systems, complex information presentation systems, complex modeling systems, complex communication systems, complex robotic systems and others.

Most complex systems are homogeneous with respect to subsystems and parts. They have elements, parts, subsystems. However, for complex systems composed of other complex systems, such simple separation is not enough. It is necessary to introduce new gradations of division of complex systems which are composed of simpler complex systems. Such a gradation can be categories of system functionality.

A complex system that has categorically different complex systems as parts is called a complex multi-categorial system. This complex system is heterogeneous. It includes homogeneous complex systems that belong to different categories according to function and purpose.

There is systemic categorical theory. However, this theory is dedicated to non-deterministic systems. There is a theory of hybrid categorical systems (Ames, Sastry, 2006). It is much closer to the theory of many categorical systems.

It is possible to give a formal description of a multicategory complex system based on a systems approach. The multi-category complex system (CCSYS) is heterogeneous. It includes homogeneous complex systems (GCSYSi), which belong to different categories (Cat_i) according to function and purpose

$$CCSYS = < GCSYS_i\ [SS, PS, Str, E, C, B, R, Cx, G]\ Cat_i >, \quad (21)$$

Expression (21) describes the structural nesting of systems in a multicategory system. Expression (21) includes the following parameters: CCSYS – a complex multi-category system; GCSYSi is a homogeneous system included as a subsystem in CCSYS; index i shows the number of the homogeneous system within the categorical system; brackets characterize structural nesting; they mean that a homogeneous system can have its own set of parameters; Cat – denotes the category of a homogeneous system. The parameters of homogeneous systems are as follows: SS – a set of subsystems, PS – a set of parts of a homogeneous system, Str – the structure of a homogeneous system, E – a set of elements of a homogeneous system, C – a set of connections in a given system, B – the boundary of the system, R – relations of a homogeneous system, Cx – the total complexity of the homogeneous system, G – the intended purpose of the homogeneous system. Expression (21) describes a multigraph.

A specific feature of many categorical complex systems is the presence of an intersystem interface. Since the systems included in CCSYS contain qualitatively different interaction processes, for their joint activity it is necessary to coordinate the processes of information interactions of these systems. Such functions are performed by the intersystem interface.

It is necessary to note the difference between the intended purpose and the category of a homogeneous system. A complex system of one category can be used for different purposes. A complex homogeneous system may have several goals. In this case, it is multi-purpose (Tsvetkov, 2012). Local systems of different categories can be used for one common purpose. It is the last property that characterizes complex multicategory systems.

3. Conclusion

For quite a long time, systems theory developed in a simplified form as the theory of homogeneous systems. The development of science has shown the existence of heterogeneous complex systems. The development of science has shown the presence of systems that include complex systems. This leads to the concept of complex multi-category systems. Complex systems have varying degrees of complexity. Identification of a group of large systems in which systems are subsystems creates a group of many categorical complex systems. The term “categorical” refers to the use of complex systems of different categories to jointly solve a common problem. A group of many categorical complex systems is characterized by the heterogeneity of the systems included in it. The highest level of system complexity, the presence of an intersystem interface and a complex topological description in the form of a multigraph. There is no inter-system interface in conventional or homogeneous complex systems. Complex multi-category systems have a feature that is not characteristic of other types of complex systems. Complex multicategory systems include local complex systems which can function independently. For their joint actions it is necessary to develop an intersystem interface. Another feature of complex multi-category systems is the possibility of using corporate management technologies for local complex systems with the additional condition of their complementary behavior.

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