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Accounting for System-Wide Patterns of Conceptual Systems in the Modeling of Conceptual Knowledge

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Abstract—This paper discusses the problem of applying the "Unit—Function—Object" system—object approach to conceptual systems. The results of a comparative analysis of the material systems are presented, i.e., phenomena (systems phenomena) and conceptual systems, i.e., classes (system—classes). A universal definition of the "system" concept has been developed that consider both types of systems. Variants of the formal description of the system class are proposed using the apparatus of calculus of objects and descriptive logic. It is shown that a number of known system-wide laws apply to material systems, i.e., systems—phenomena as well as conceptual systems, i.e., system—classes. The presented results substantiate the possibility of including system—classes on par with systems—phenomena in the theory of systems based on the system—object approach. In addition, the results make it possible to improve the existing and create new classification systems, which are an important type of conceptual model of conceptual knowledge, as conceptual models that take system-wide regularities into account become models that reflect the systemic nature of actual reality.

Keywords: system—object approach "Unit—Function—Object," conceptual knowledge representation, conceptual systems, system—classes, systems-phenomenon, system-wide regularities

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INTRODUCTION

The logic of the development of systems research requires the creation of a general or abstract theory of systems. However, today there is no such theory. The existing theoretical constructions have been subjected to harsh criticism. Critical discussions and the results of the formation of the theory of systems can be traced in numerous publications (for example, [1–3]), including those on the Internet (for example, [4–7]).

Among other shortcomings of the existing theoretical constructions it has been noted that they do not consider the various ways of manifesting systemicity. In speaking about systems, as a rule, they mean only specific material objects and phenomena. However, in [6, 8, 9], the necessity of considering not only specific material objects, but also conceptual systems in the theory of systems was substantiated. In these papers it was noted that the theory of systems cannot claim to be a general theory if it is not applicable to conceptual systems and it was also emphasized that the development of systemic principles applicable to both material and conceptual systems is most relevant for overcoming the abyss that separates the natural sciences and the humanities.

Moreover, in accordance with [8], depending on the path of manifestation of integrity, as the main sign of systemicity, it makes sense to consider two types of systems: *domestic* (i.e., "material" according to Ackoff) and *external* (i.e., "conceptual" according to Ackoff).

An internal system (our term is *phenomenon system*) is a holistic formation (a specific object), to which the division procedures can be applied, representing this system in the form of some structure of constituent parts [9]. An external system (our term *class system*) is a class of objects of a general nature, united by some integral entity. Elements of such a system "may have neither spatial nor temporal commonality, nor even a genetic connection ... Only the common nature of the nature of the objects forming the system is important" [9, p. 69].

Currently available descriptions of system-wide principles and laws do not explicitly stipulate which systems these laws relate to. Obviously, by default, we mean systems-phenomena, since they are used to describe the corresponding examples. Thus, in the interests of systems theory, it is relevant to study the features of accounting for system-wide laws of conceptual systems. In addition to the theoretical problem, there is the practical task of ensuring an adequate reality of knowledge modeling by conceptual systems. In fact, most of the knowledge used in science, technology, economics, and business is conceptual knowledge, for whose presentation conceptual models of various types are used. It is not difficult to assume that these conceptual models will be more consistent with reality if they are systemic, i.e., take system-wide principles and laws into account.

This study is a natural continuation of our work in [10].

1. A COMPARATIVE ANALYSIS OF SYSTEMS—CLASSES (CONCEPTUAL SYSTEMS) AND SYSTEMS-PHENOMENA

To compare class systems and system phenomena, we consider the features of the manifestation of the basic principles of a systematic approach for various types of systemicity, that is, internal ("material") and external ("conceptual").

The integrity principle. In reality, a system—phenomenon always manifests its integrity as a concrete object that has boundary and quality properties [11], characterized by spatio—temporal certainty (unity) and multidimensionality. Thus, an internal system is not called a "system—phenomenon" by chance, but quite naturally, as it represents the ontological embodiment of the philosophical category of "phenomenon."

The integrity of a class system is always the integrity of a class of objects that is not bound by any spatio—temporal restrictions corresponding to a certain (single-aspect) quality property [11]. Therefore, the external system can be called a "system—entity," as it represents the ontological embodiment of the philosophical category of "entity."

The integrity of the system—phenomenon can and will be reflected in the human mind at the level of perception in the form of knowledge of the current holistic concrete image and at the level of representation in the form of knowledge of a holistic generalized image [12]. The integrity of a class system, as a class of objects, can be reflected only at the abstract level in the form of knowledge of the corresponding concept (symbolic image) [13].

Principle of systematization. In reality, both in the system—phenomenon and in the system—class, subsystems can be distinguished that are part of their system in relation to maintaining the functional ability of the whole [11]. This feature, along with integrity itself, makes them systems. However, in a system—phenomenon, as an instance of a specific object, subsystems are components or elements, which are also instances of specific objects, but of a deeper tier. In a class system, as in a class of objects, subsystems are subclasses of this class.

Particular attention should be paid to the fact that any system subsystems support its functionality and purpose [11]. Therefore, not any element of a particular object or subclass of a given class of objects is a subsystem of this system.

The body, engine, and chassis are subsystems of any particular car, as they ensure that it performs its functions. If you simply cut a car into a sufficient number of arbitrary pieces, these elements will not be its subsystems, since there is no algorithm for assembling a functioning car from them.

Similarly, the classes of cars and trucks are subsystems of the external system of automobile transport, as they ensure its functional integrity. The classes of blue and red cars are not related to the functional properties of road transport; thus, they are not subsystems of the corresponding external system.

The relationship of maintaining the functional ability of the whole between the subsystem—phenomenon and the system—phenomenon (or system and super-system) is reflected in the human mind in the form of knowledge about the part—whole relationship. The same attitude, reflected on the material of class systems (subsystems and supersystems) appears in the human mind in the form of knowledge about the genus—species relationship. Consequently, the part—whole and gender—species relationships are forms of knowledge about the relationship existing in reality to maintain the functional ability of the whole.

In this regard, it is necessary to emphasize the difference between the functional-systemological approach (*evolutionary* [14]), which is widely used in the system—object approach, and traditional formal-logical approaches to the genus—species relationship. Traditionally, in addition to specific species, all the properties of the genus are attributed to the species. However, this is true only from the point of view of a formal approach, in which the substantive side of this relationship is not taken into account. Taking its content side into account, which corresponds to the relationship of maintaining the functional ability of the whole, shows that a species (subsystem) cannot possess the properties of a genus (system), since any system has properties that are not fundamentally reducible to the properties of subsystems. Genus properties are more general (abstract) in comparison with species properties, not only in the formal, but also in the substantial sense. These are the properties of a higher level of integrity (functionality), which occur due to the presence in the types of particular properties (particular functions) of a lower hierarchy level.

The principle of hierarchy. The hierarchy of system—phenomena is formed due to their physical interaction on each tier of the hierarchy in space and time. The connections of these systems (streaming) arise due to the presence of exponentially manifested properties, which provides the possibility of their perception, as well as instrumental observation. The hierarchy of class systems is the mutual correspondence of the properties (roles) of systems of various levels. Moreover, in this case, the systems are interconnected intentionally (potentially) due to properties that remain undeveloped and basically cannot be observed [15].

The named differences in the manifestation of the principle of hierarchy of systems–phenomena and systems–classes lead to differences in the processes and results of reflection and cognition of these systems. Knowledge of the hierarchy of systems of phenomena is figurative in nature. This allows one, as a result of the cognitive process, to have a partitive classification of these systems or meronomy [16]. Knowledge of the hierarchy of class systems is only abstract in nature. The result of the knowledge of these systems is a generic classification or taxonomy [16].

The development principle. The development of any systems, within the framework of the used system–object concept, is the process of constant correlation and coordination of the functional request of a supersystem for a system with a certain functionality (external determinant of a given system) with its current actual functioning (with the current internal determinant of this system). The formation, adaptation, and development of a system–phenomenon will be reflected in the human mind in the form of knowledge about the reduction of the redundancy of its properties and the properties of its subsystems on ever deeper tiers of the system hierarchy, i.e., in its meronomy. The same processes that occur with the class system will be reflected in the form of knowledge about lengthening the taxonomic chain of mutually agreed subclasses of deeper levels of the system hierarchy, as well as in the form of knowledge about increasing the correspondence of their properties. The last aspect is related to the features of the taxonomic structure of class systems.

An analysis of the features of the manifestation of the basic principles of a systematic approach for various types of systematization, that is, internal ("material") and external ("conceptual"), as well as an analysis of the characteristics of the reflection of systemic phenomena and class systems in knowledge of various forms, shows that the above principles are observed for both types of systems. This, in turn, can serve as an additional justification of the legitimacy of introducing systems into the theory of systems, in addition to system phenomena, also class systems, i.e., conceptual systems.

2. REPRESENTATION OF PHENOMENA AND CLASSES IN TERMS OF THE "UNIT-FUNCTION-OBJECT" APPROACH

Within the framework of the "Unit-Function-Object" system–object approach the initial representation of the system corresponds to the meaningful definition of the system of G.P. Melnikov as a functional object whose function is determined by the function of an object of a higher tier (i.e., a supersystem) [11]. Obviously, this definition is focused on systems–phenomena (material systems according to Ackoff).

The necessity affirmed by the classes and the possibility we have shown of considering classes (Ackoff conceptual systems) as the same systems obliges us to clarify the above definition so that it takes not only systems–phenomena, but also class–systems into account. The specifics of real systems–classes and the knowledge about them reflected in the human mind can be taken into account, for example, when representing a system–class as a class, whose role is due to the role of a class of a higher tier.

Combining the concepts of the system–phenomenon and the system–class, we come to the following universal definition: *A system is a phenomenon (functional/material object) or a class (conceptual system), whose function or role of is determined by the function of the phenomenon or the role of a class of a higher tier (i.e., the super-system–phenomenon or super-system–class).*

The representation of a system–phenomenon as a functional object in terms of the "Unit-Function-Object" system–object approach (that is, in the form of an ultraviolet element) is quite obvious. It follows directly from the definition that in a system–phenomenon s there is always a part of a system–phenomenon of a higher tier, i.e., supersystems within the framework of some meronomy. In order to be a part a given system–phenomenon must be connected with other systems of this super-system, i.e., the phenomenon system must have connections (input *Ls*? and output *Ls*!) and they must be threads. At the same time, these flows, which are functional for a given system–phenomenon, are components of a supersystem, since they are communication supersystems. Consequently, in the system–phenomenon s there is a crossroads of a finite set of connections (*Ls*? and *Ls*!), i.e., a us node in the structure of the supersystem. To maintain the functional ability of the supersystem, the node of the system–phenomenon must be balanced, which is ensured by the functional correspondence between the output *Ls*? and input Ls! threads of this node. Consequently, in the system–phenomenon s the *function* fs occurs. Actual balancing of the node, i.e., the process corresponding to the function is carried out by the substance, which is a functional *object Os* possessing a finite set of substantial characteristics (see Table 1).

Based on the above reasoning, in full accordance with the substantive definition of a system as a functional object (i.e., a system–phenomenon), a system–phenomenon s, can be formally represented as a special object calculus of Abadi–Kardeli objects, which formally describes a specific UFO element [17]:

$$s = \left[\left(Ls?, Ls! \right); fs\left(Ls? \right) Ls!; \left(Os?, Os!, Osf \right) \right].$$

In this expression, in accordance with the rules of calculus referred to *Ls*?, *Ls*! are fields for links corresponding to the system node s; O*s*?, *Os*! are fields for substantial (object) interface characteristics, and *Osf* are transfer characteristics corresponding to the sys-

Table 1. Representation of phenomena and classes in terms of "Unit-Function-Object"

Term	System phenomenon s	Class system S (specific)			Class system S (abstract)
Unit	$us \leftrightarrow Ls? \cup Ls!$ $Ls?$—many incoming functional links/system threads s; $Ls!$—many outgoing functional links/system flows s	$uS \leftrightarrow LS? \cup LS!$ $LS?$—many incoming functional links/system threads S; $LS!$—many outgoing functional links/system flows S	$uS \leftrightarrow LS? \cup LS!$ $LS?$—many incoming functional links/system threads S; $LS!$—many outgoing functional links/system flows S.	$US \leftrightarrow LS? \cup LS!$ $LS?$—class of incoming functional connections/system flows S; $LS!$—class of outgoing functional connections/system flows S	$US^i = S^{i-1}$ S^{i-1}—a class system of a higher tier of the hierarchy than a class system S^i
Function	$fs\ (Ls?)\ Ls!$ fs —system function/process s with scope $Ls?$ and range of values $Ls!$	$fS(LS?)\ LS!$ fS—system function/process S with scope LS? and range of values LS!	$FS(LS?)\ LS!$ FS—class of functions/processes of the system S with scope $LS?$ and range of values $LS!$	$FS(LS?)$ LS! FS—class of functions/processes of the system S with scope $LS?$ and range of values $LS!$	$FS^i = \exists R.S^i$ $R.S^i$—the role of a class system S^i in a class system S^{i-1}, those. $R.S^i \subset R.S^{i-1}$
Object	$Os = Os? \cup Os! \cup Osf$ $Os?$—a bunch of interface system input characteristics s; $Os!$—many interface system output characteristics s; Osf—many transmission characteristics of the system s.	$OS = OS? \cup OS! \cup OSf$ $OS?$—class interface system input characteristics S; $OS!$—class of system interface output characteristics S; OSf—system transfer class S.	$OS = OS? \cup OS! \cup OSf$ $OS?$—class interface system input characteristics S; $OS!$—class of system interface output characteristics S; OSf—system transfer class S	$OS = OS? \cup OS! \cup OSf$ $OS?$—class interface system input characteristics S; $OS!$—class of system interface output characteristics S; OSf—system transfer class S.	

tem object s. Moreover, $fs\ (Ls?)\ Ls!$ is the method that corresponds to the function of the system s.

Given the process of forming a system in accordance with the functional request of the supersystem in the form of a functional unit, we can clarify the formal expression for the system–phenomenon s in the following way:

$$s = [us \Rightarrow fs \Rightarrow Os] \quad \text{and} \quad s = (Ls?, Ls!) \Rightarrow fs(Ls?)\,Ls! \Rightarrow (Os?, Os!, Osf)].$$

The presentation of the class system in terms of Unit-Function-Object (i.e., in the form of an ultraviolet element) is not so obvious. However, the Unit-Function-Object system–object approach (UFO approach) provides such an opportunity.

First, if classes are specified rather than finite sets in the above expression for a special object of calculating objects in fields for substantial characteristics, (see Table 1), this expression will formally not describe a specific UFO element, but rather a class of such elements, the class system:

$$S = [(LS?, LS!); fS(LS?)\,LS!; (OS?, OS!OSf)].$$

The following expressions will be true:

$$S = [uS \Rightarrow fS \Rightarrow OS] \quad \text{and} \quad S = [(LS?, LS!) \Rightarrow fS(LS?)\,LS! \Rightarrow (OS?, OS!OSf)].$$

Second, if in the above expression for a special object calculus of objects in fields for substantial characteristics it is not finite sets that are specified but rather classes (see Table 1) and it is not a specific function but a class of functions that are specified in the method, then this expression will formally describe a class of such elements, i.e., a class system, and not a specific UFO element:

$$S = [(LS?, LS!); FS(LS?)\,LS!; (OS?, OS!OSf)].$$

The following expressions will be true:

$$S = [uS \Rightarrow FS \Rightarrow OS] \quad \text{and} \quad S = [(LS?, LS!) \Rightarrow FS(LS?)\,LS! \Rightarrow (OS?, OS!OSf)].$$

Third, if classes (see the Table 1) are specified in the fields for substantial characteristics in the above expression for a special object calculus of objects rather than finite sets and a class of functions rather than a specific function and in the fields for node relationships classes rather than specific sets are specified, this expression will formally describe a class of such elements, i.e., a class system and not a specific UFO element:

$$S = [(LS?, LS!); FS(LS?)\,LS!; (OS?, OS!OSf)].$$

The following expressions will be true:

$$S = [US \Rightarrow FS \Rightarrow OS] \quad \text{and} \quad S = [(LS?, LS!) \Rightarrow FS(LS?)\,LS! \Rightarrow (OS?, OS!OSf)].$$

The above expressions for system classes in the form of a special object for calculating Abadi–Kardeli objects correspond to representing the UFO element as a class in the UML object-oriented language [18], not of any class, but of the so-called *particular class*, i.e., a class that does not have subclasses and consists of instances (phenomenon systems). In the framework of the naive theory of sets such a class is in fact indistinguishable from a set.

However, for example, the object-oriented approach also considers so-called *abstract classes* that consist of subclasses (i.e., from other class systems), rather than instances. In the framework of the axiomatic theory of sets, such classes are distinguished from sets and are called proper classes.

Considering the structural and functional characteristics of conceptual systems (class systems) that correspond to abstract classes, as well as their independence from substantial characteristics, we obtain another way to formally describe them (see Table 1).

Structurally, a class—system also has connections, but within the framework of a taxonomy. Any class system has a connection to a class system of a higher tier of the hierarchy (generalization, from species to genus, i.e., to a supersystem), which can be considered as a functional relationship, since it will be supportive for a class supersystem. The relationships of the class system under consideration with subclasses (concretization from genus to species) can be considered as supporting for this class system. Thus, the class system S^i can be seen as the US^i node in the structure of an S^{i-1} class supersystem.

System—phenomena that support the super-system—phenomenon are interconnected by flows, which form nodes as sets of functional connections (flows). By analogy with systems—phenomena, a node of a system—class S^i as a set of functional relationships, can be designated as a class system of a higher hierarchy level: $US^i = S^{i-1}$, since all class systems of a given hierarchy level are interconnected through a top-level class system, i.e., through their supersystem. Maintaining the functionality of a supersystem class S^{i-1} provided with a specific functional role (*FS^i function*) of class systems S^i that together with other systems i is the functional role of the super-class system S^{i-1}. A substantial characteristic, i.e., the object of the class system (abstract class), is of course absent (see Table 1).

These considerations allow us to offer a formal description of the S^i class system as a class, whose role is determined by the role of a class of a higher tier, in the form of another special object of the calculus of objects using the notation adopted in descriptive logic: $\forall S^i\ \exists RS^i$ and $S^i = [S^{i-1}; RS^i \sqsubset RS^{i-1}]$. In this expression, in accordance with the rules for calculating Abadi—Kardeli objects, $S^{i-1}$is a field that indicates a class system of a higher tier of the hierarchy corresponding to the US^i node of the S^i system; $RS^i \sqsubset RS^{i-1}$ is the method that corresponds to the role (FS^i function) of S^i systems in the S^{i-1} supersystem. It is noteworthy that this expression corresponds in its structure to the generic definition of the concept representing a class system.

Given the process of forming a system in accordance with the functional request of the supersystem in the form of a functional unit, we can clarify the formal expression for the class system as follows: $S^i = [US^i \Rightarrow FS^i]$ and $S^i = [S^{i-1} \Rightarrow R.S^{i-1} \Rightarrow R.S^i]$.

3. SYSTEM-WIDE PATTERNS ASSOCIATED WITH THE STRUCTURAL (NODAL) CHARACTERISTICS OF CLASS SYSTEMS

Using the obtained informative and formal representations, we will further consider the possibilities of considering system-wide laws when modeling knowledge using conceptual systems, i.e., class systems.

We consider the patterns associated with the structural (nodal) characteristics of class systems, since it is the nodal characteristic of the system that is considered as a universal system-forming factor in the framework of the system—object approach.

From the meaningful definition of a class system and the representation of a class system in the form $S^i = [S^{i-1}; R.S^{i-1} \sqsupset R.S^i]$ the obvious use follows *of the communicative principle* (*the system is connected via many communications with the environment*) *and the hierarchy principle* (*a system on any tier of the hierarchy is part of a higher tier system, i.e., a supersystem*). $\forall S^i\ \exists\ US^i$: $US^i \leftrightarrow S^{i-1}$ and $\forall US^i\ \exists\ S^{i-1}$: $S^{i-1} \supset S^i$. Moreover, the principle of hierarchy is functional only if the principle of communicativeness is fulfilled, which is in good agreement with the meaningful interpretation of these principles in terms of a system—object approach [19].

The fulfillment of the principle of hierarchy leads to the fulfillment of the *principle of monocentrism* (according to Bogdanov, a *stable system has one center*). From the point of view of the authors, this principle can and should be understood more broadly, especially when it comes to class systems [20]. A *class system hierarchy has one single vertex* or $\forall S^i\ \exists!US^*$: $S^* \supset \ldots S^{i-1} \supset S^i$.

The fact is that the study of the hierarchy of class systems (external systems) from a certain system to the side of a chain of increasingly common super-systems (from species to genus) shows that such a hierarchy has a natural limitation. This is due to the fact that during the hierarchy transition from species to genus (from subclass to class), a transition occurs from the property of the subsystem to the property of the system (irreducible to the properties of the subsystems) towards generalization, i.e., with the reduction of many features (properties), due to which the system—phenomena belong to this class. The set of phenomenon—systems included in the class will be greater than the set of phenomenon—systems included in the subclass. This process corresponds to the law of the inverse relationship of the volume and content of concepts in which class systems are reflected in our consciousness [13], i.e., the content decreases with increasing volume. For the class systems themselves, this corresponds to a decrease in the set of features due to which the class system is formed, while increasing the set of phenomena related to this class. Moreover, due to the finiteness of the set of features [20], an increase in the volume and a reduction in the number of characters in a finite number of steps leads to a class for which there are no signs left, whose volume becomes infinitely large.

Thus, considering the hierarchical structure of class systems, we can conclude that this structure has a single upper node, i.e., there is a single supersystem class. If we assume the opposite, that is, the super-system is not unique and there is at least one more class system of the same level, then these systems can be considered as elements of a higher-level system. Thus, the supersystem class, which includes all types of class systems, is the only one.

An expanded understanding of the principle of monocentrism leads to the *principle of organizational continuity* (*this states the presence of links between any two systems that introduce them into one "chain of ingression"*), which we proved for system–phenomena in [10], while for system–classes it is completely obvious, that is,

$$\forall US^i \wedge US^j \, \exists S^k : (S^k \supset S^i) \wedge (S^k \supset S^j) \Leftrightarrow \forall S^i \, \exists ! US^*.$$

Thus, the principle of organizational continuity is observed only if the principle of monocentrism is fulfilled.

To justify the *feedback principle* (*which explains stability in complex dynamic systems by closing feedback loops*) within the framework of class systems it is necessary to consider the dynamics of such systems. The following processes can be attributed to dynamic phenomena in class systems (the first of these will be called "adaptive" and the second "evolutionary"):

– changes in the roles (functions) of classes in classes of a higher tier of the hierarchy;

– the emergence of new classes in classes of a higher tier of the hierarchy.

Examples of such processes can be seen by analyzing the processes of changing the properties of types of furniture or technical systems (cars) in the course of their improvement according to the requirements of society. Moreover, the processes of improving existing types, in the end, lead to the emergence of new types (systems–classes) of furniture or technical systems. As an example, the emergence of a new class of automobiles (mining dump trucks, car-houses, etc.) for the transportation of specific types of goods in accordance with the functional needs of the "road transport" class–system that adapts to the changing demands of the human community.

The same processes of changing the properties of species and the emergence of new species (classes) can be traced based on the examples of the adaptation and evolution of biological systems, i.e., types of these systems, as an example, the emergence of new species of poultry (indochka, etc.) in accordance with the functional request of the "poultry" class–system, which adapts to the changing demands of the human community.

The mentioned adaptation and evolutionary processes are due to the coordination, on the one hand, of the functional request of a system–class of a higher tier of the hierarchy to the system–class of the lower tier and, on the other hand, of the relationship of maintaining the functional ability of a system–class of a higher tier from the side of the lower-tier class system. Thus, any class system exists in conditions of constantly operating feedback. In this case, of course, the feedback principle is workable only if the principles of communicativeness and hierarchy are fulfilled and its formal expression coincides with the expression for the latter: $\forall US^i \, \exists \, S^{i-1}: S^{i-1} \supset S^i$.

To justify the implementation of the *principle of progressive segregation* (*fixing the progressive loss of interaction between the elements of the system during its differentiation while strengthening ties with some element acting as a system center*) within the framework of class systems we consider what constitutes differentiation of a class system.

Differentiation (according to G. Spencer, who first introduced this concept) is the separation in the process of evolution of a homogeneous system (biological organisms, representatives of a particular profession, etc.) into two or more groups that differ in their parameters. This can have several hierarchical levels. For a class system, this means the formation (union) of a plurality of species-specific systems of one or more class systems of the lower tier of the hierarchy relative to a given class in comparison with this level (subsystem classes), i.e.,

$$\exists S^i : S^i \supset (S^i_j \cup S^i_{j+1} \cup \ldots \cup S^i_{j+k} \cup \ldots \cup S^i_{j+n}) : (S^i_{j+k} \cup \ldots \cup S^i_{j+np}) \subset S^{i+1}.$$

Moreover, the role relationships of species systems $(S^i_{j+k}, \ldots, S^i_{j+np})$ that form a subsystem class S^{i-1}, with class system S^i become weaker, but strengthen the ties with this S^{i-1} subsystem. Examples of the operation of this principle correspond to the examples given in the discussion of the feedback principle. The principle of progressive segregation within the framework of class systems is fulfilled when the principle of hierarchy is fulfilled.

The implementation of the principles of hierarchy and feedback leads to the implementation of the *prin-*

ciple of external complement (*fixing the fact that the influences of coordinated elements ascending to the system center undergo a kind of "generalization" and the coordination impulses descending from the system center undergo "specification" depending on the nature of local processes due to feedback from these processes*). In a simplified form, this principle can be formulated as follows: "Any element of the system hierarchy has a function of generalizing information from underlying elements for higher elements and a function of specializing information from elements of the upper tier of the hierarchy for elements of the lower tier" [19]. Obviously, this is the essence of generic relationships in the hierarchy of class systems (taxonomy), i.e., $\ldots \supset S^{ik} \supset \ldots \supset S^{i-1} \supset S^{i} \supset S^{i+1} \supset \ldots \supset S^{i+n} \supset \ldots$. Thus, the principle of external complementation in the hierarchy of class systems is fulfilled in a natural way.

The principle of mutually complementary ratios/complementarity (*system stability is achieved by mutually complementary relationships between its elements in the form of closed feedback loops*) is efficient within the framework of class systems in fulfilling the feedback principle. In fact, this is the same principle. The fact is that in the hierarchy of class systems, each system is connected with other systems by two types of mutually complementary relationships: generalization (from S^i to S^{i-1}) and specialization (from S^{i-1} to S^i), i.e., class systems exist in closed loops of feedback, i.e., $\exists S^i\colon S^i \subset S^{i-1} \wedge S^{i-1} \supset S^i$. In this case, the first relationship corresponds to the relationship of maintaining the functional ability of the super-system—class from the side of the system—class, and the second, to the functional request of the super-system—class for the system—class with a certain role.

4. SYSTEM-WIDE PATTERNS ASSOCIATED WITH THE FUNCTIONAL CHARACTERISTICS OF CLASS SYSTEMS

Let us further consider the patterns associated with the functional characteristics of class systems, which, as part of the system—object approach, are a consequence of nodal ones.

The concept of a system—object approach [21] suggests that the main component of the environment surrounding the system is its supersystem, regardless of the way systemicity manifest itself. This supersystem "maps" its functionality to the functionality of the system with a request for a system with a specific function (an external determinant); thus, the system "reflects" some of the most essential properties of its supersystem with its functioning (internal determinant). Thus, the system—object approach assumes that *hypothesis of semiotic continuity* (*claiming that the system is an image of its environment, i.e., the system as an element of the environment reflects some of its essential properties*) is true both for phenomenon systems [10] and for class systems. Moreover, for the latter, the functional request of the supersystem (the external determinant of the system) is not a set of connections of the requested system with other systems, as for phenomenon systems, but the role of a top-level class system that requires support from the lower-level class system, i.e., . $R.S^{i-1} \Rightarrow R.S^i$ and $R.S^{i-1} \sqsupset R.S^i$. Thus, semiotic continuity is a consequence of the hierarchy of class systems.

The presented understanding of semiotic continuity naturally ensures fulfillment of the *principle of progressive mechanization* (*claiming that parts of the system during its development specialize or become fixed in relation to certain functions or mechanisms*) both for phenomenon systems and for class systems. The fact is that in both cases the parts of the phenomenon system and the types of the class system acquire their functionality or role under the influence of the corresponding supersystem, which ensures their specific specialization.

In the same way, execution is ensured by *the principle of updating functions* (*an object acts in an organized manner only if the properties of its parts (elements) appear as functions of the conservation and development of this object*). As in the framework of systems—phenomena, and in the framework of systems—classes, the principle of updating functions and the principle of progressive mechanization describe the same phenomenon of functional correspondence of systems of different levels of the hierarchy, but from different sides. Progressive mechanization describes the correspondence of systems from top to bottom (from a supersystem to a system; an external determinant) and the actualization of functions from bottom to top (from a system to a supersystem; maintaining the functional ability of a whole). Accordingly, this principle only works if the previous one is fulfilled, since the existence of any class system is determined by the request of the class super-system to the class system with a specific role in this super-system.

The implementation of the principle of progressive mechanization provides the *principle of self-organization* (*the process of progressive functionalization of system elements*), since, in fact, both principles describe the same process of adapting a system to a request for a supersystem for both phenomenon systems and class systems.

The law of hierarchical compensation (*in a system, the growth of diversity at the upper level of the hierarchy is ensured by its restriction at lower levels*) clarifies the effect of the principle of progressive mechanization, considering the influence of the principle of external complement, since it naturally takes the essence of generic relations in the hierarchy of class systems (taxonomy) into account, i.e., $\ldots \supset S^{ik} \supset \ldots \supset S^{i-1} \supset S^{i} \supset S^{i+1} \supset \ldots \supset S^{i+n} \supset \ldots$

One consequence of the law of hierarchical compensation is the *law of necessary diversity* (*to create a system that can cope with a solution to a problem with a certain variety, it is necessary to ensure that the system has a greater variety of possibilities than the variety of the problem to be solved*), since the mechanism of hierarchical compensation is used to ensure the necessary diversity. These two laws are related to each other, as well as the principles of progressive mechanization and actualization of functions.

CONCLUSIONS

The above considerations show that the main well-known system-wide laws (structural and functional) are satisfied both for phenomenon–systems and for class–systems. Therefore, both material and conceptual systems can naturally be included in the theory of systems based on a system–object approach. In addition, these arguments can be considered as additional arguments in favor of the real existence of conceptual systems, which is justified by other means, for example, in [15].

From a practical point of view, the fact that the hierarchy of class systems conforms to system-wide laws requires their consideration in modeling conceptual knowledge to ensure the adequacy of conceptual models of this knowledge. Conceptual models that consider the aforementioned system-wide laws become models that reflect the consistency of reality.

Thus, the results we obtained allow us to improve existing and create new classifiers (classification systems), which are an important type of conceptual model of conceptual knowledge.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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