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System-objective representation of conceptual knowledge with description logic

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Abstract. The paper describes the possibilities of applying the system-object approach "Unit-Function-Object" in terms of descriptive logic for describing conceptual knowledge. Conceptual knowledge is represented using a hierarchy of conceptual systems. The syntax and semantics of the descriptive logic ALCOIQ and SHOIQ were described. These allow us to justify the structure of the hierarchy of class systems and the mandatory implementation of the principle of monocentrism for conceptual systems. The concepts of "volume" and "content" of systems-classes were introduced. The results allow us to improve the existing ways of presenting conceptual knowledge, as well as develop models of conceptual knowledge that reflect the systemic reality that exists when solving classification problems.

1. Introduction

The representation of knowledge is one of the main targets of development of artificial intelligence. This direction is associated with the development of methods for storing knowledge in information systems (IS). It includes models and methods for structuring and describing knowledge. Currently, the representation of knowledge and modeling of conceptual processes is one of the important issues of knowledge engineering. An information system has to solve certain applied problems. It is requiring to use an appropriate representation of knowledge. The problem of knowledge representation lies in the discrepancy between the information on the dependencies of a given topic available to a specialist and the possibilities of unambiguously presenting such information in an IS. The main component of modern man's knowledge is conceptual knowledge. Such knowledge is a set of concepts of the subject area of their properties and relationships. Moreover, most of the knowledge used in science, technology, economics, and business is precisely conceptual knowledge [1]. It is not difficult to assume that these conceptual models will be more consistent with reality if they are systemic. However, at present, the connection of knowledge representation methods and conceptual models with systems research in knowledge engineering is almost not considered.

This allows us to talk about the appropriateness of applying a systematic approach to research and develop systemic ways of representing conceptual knowledge. The authors use the "Unit-Function-Object" system-object approach. This is due to the fact that only this approach allows us to consider not only material (our term "systems-facts), but also conceptual systems (our term "systems-classes").

2. System-object approach "Unit-Function-Object"

The main point of system-object approach is that a system is considered as a functional object or class. The function or role of that system is determined by the function or role of the object or a class of a higher tier (supersystem). Its definition clarifies the definition of the system from [3].

A system's function is considered a function of a supersystem as a functional request of a supersystem for a system with a specific function, which is called the external determinant of the system. The latter is the cause of the create of the system, the purpose of its existence and determine its structural, functional and substantial properties. Thus, the external determinant of the system is considered as a universal system-forming factor.

It is convenient to specify the system representation in the form of a construction (Unit-Function-Object) that describes the structural, functional and substantial characteristics of the system [7]. Moreover, it is the node as a cross of connections that describes the functional request of the supersystem to this system, its outer determinant.

The system-fact s can be formally represented as a special object of object calculus of Abadi-Kardeli:

$$s = [(Ls?, Ls!); fs\ (Ls?)Ls!; (Os?, Os!, Osf)], \quad (1)$$

where (Ls?, Ls!) – a field for describing the unit us or the intersection of a finite set of inputs Ls? and outputs Ls! in the structure of the supersystem; fs(Ls?)Ls! – a field for describing the function fs defined by the supersystem; or a method that provides functional corre-spondence between the output Ls? and input Ls! connections of this node; (Os?, Os!, Osf) – a field for describing the substantial (object) characteristics of the system (in-put, output, transfer). A class system S^i, can be formally represented as another special object of object calculus Abadi-Kardeli using the notation adopted in descriptive logic [6]: $\forall S^i\ \exists RS^i$ and $S^i = [S^{i-1}; RS^i \sqsubset RS^{i-1}]$. where S^{i-1} is the field for indicating the class system of a higher tier of the hierarchy corresponding to the US^i node of the S^i system; RS^i – role is determined by the role of a system-class of a higher tier of the hierarchy. $RS^i \sqsubset RS^{i-1}$ – field for describing the method corresponding to the role of RS^i (FS^i function) of the S^i system, embedded in the role of RS^{i-1} of the S^{i-1} supersystem; $\sqsubset$ – a symbol for including a concept in a concept or role in a role in the language of discriminant logic.

3. Conceptual knowledge as knowledge of conceptual systems

The authors described the correspondence of the systems-classes to the system-facts in terms of the system approach and also substantiated the possibility of applying to both of them all the states of the system-object approach [3].

In this research it is necessary to pay attention to the fact that systems-classes (conceptual systems) are referents of conceptual knowledge [3]. It is important to emphasize that system-classes is forming a hierarchical structure. Moreover, the hierarchy of systems-facts formed by the «part-whole» relation does not have an upper boundary in accordance with the well-known principle of infinity. Contrary, hierarchy of systems-classes formed by the genus-species relation has an upper boundary in accordance with a known logical law the inverse relationship between the volume and content of concepts (classes) [7]. That law requires a reduction in content, i.e. reducing the amount of information that corresponds to the number of features describing the content of the class, while increasing the volume of the class, i.e. the number of subclasses that make up the class. The content, of course, can only decrease to zero. This determines the upper boundary of the hierarchy of class systems (conceptual systems).

The mentioned features are main for our research. The reason is that the basic properties of any system (including a system-classes) are determined by a supersystem (in this case, a supersystem-class).

Consideration of the features of the hierarchy of systems-classes (conceptual systems) is necessary.

Substantially these features were studied for example in [2]. It follows that at the highest level of the hierarchy of conceptual systems there are two types of class systems: classes (systems-classes) of system components or objects-classes and classes (systems-classes) of properties, i.e. properties-classes. Moreover, the latter also exist in two forms: property-classes of objects (properties of objects) and property-classes of properties (properties of properties).

The further study of the properties of the hierarchy of systems-classes in order to improve existing and create new classifiers (classification systems), representing an important type of conceptual models of conceptual knowledge is needed. It requires to justify the properties of this hierarchy of systems-classes by formal means, taking into account its substantial features. To solve this problem our research uses description logic.

4. Description logic as a means of representing conceptual knowledge

Description logic (DL) is a knowledge representation language for describing the concepts of a subject area in an unambiguous formalized form. Any DL has syntax and semantics. The basic syntactic elements of the language of description logic are the atomic concept and role. They are corresponding to single and double predicates of the language of mathematical logic. Concepts are used to describe classes. Roles are used to describe the relationship between concepts. Concepts and roles allow you to describe classes and their properties. One of the basic descriptive logics is ALCOIQ DL [4]. The syntax of the ALCOIQ logic is presented below in short form.

$$\{\top; \bot; A; A \sqsubseteq C; \neg C; C \sqcap D; C \sqcup D; \exists R.C; \forall R.C; \{a\}\}$$

The symbols $\top$ and $\bot$ are concepts (called truth and false). A – atomic concept, C, D – arbitrary concepts. R is the atomic role, $\{a\}$ – representation of the individual a in the form of a concept.

The DL distinguishes a set of terminological axioms called *TBox* and a set of statements about the relationships and properties of individuals – *ABox*. Together they form a knowledge base, or ontology K = *TBox* ∪ *ABox*. Here is an example of the subject area described by *ABox* and *TBox*:

$$ABox = \left\{\begin{matrix} \text{Man(Jhon);} \\ \text{Woman(Maria);} \\ \text{Love(Jhon, Maria);} \\ \text{Married(Jhon, Maria);} \end{matrix}\right\}; TBox = \left\{\begin{matrix} \text{Bachelour} = \neg\exists\text{Married} \sqcap \text{Person;} \\ \forall\text{Married} \sqsubseteq \text{Happy;} \\ \exists\text{Married.Woman} \sqsubseteq \exists\text{Love.Woman;} \\ \text{Person} = \text{Man} \sqcup \text{Woman;} \end{matrix}\right\};$$

5. Formalization of the hierarchy of conceptual knowledge (conceptual systems)

In descriptive logic (DL) you can define concepts for objects-classes while the roles in the DL will correspond to properties-classes. However, expressiveness of ALCOIQ logic is not enough to describe the hierarchy of roles. To solve the problem of constructing a hierarchy of conceptual systems we use DL SHOIQ [4]. It extends ALCOIQ and has axioms for roles called *RBox* (similar to *TBox* and *ABox*) which allows us to describe the hierarchy of roles as systems-classes. Hierarchy of roles (H): axioms of the form $R \sqsubseteq S$ are allowed, where R, S are any roles.

However, to justify the structure of the hierarchy of conceptual systems it is necessary to expand the SHOIQ logic by formally introducing into it the concepts of *volume* and *content* of a system-class.

The volume of the system-class (*Vol*) is the totality of the species systems-classes included in the systems-classes which is generic to them. The content of the system-class (*Cont*) includes the supersystem-class (generic class), as well as a set of distinctive features (roles in the supersystem) of this system-class. Will describe these concepts by means of DL.

The content of the class system is expressed through the role that supports the functional ability of the class supersystem, as well as through the class supersystem itself:

$$Cont\left(S_{ij}^{l}\right) = S_{i-1,l}^{n} \sqcap \exists RS_{i+1,p_j}^{l_j},$$

where $i = \overline{0, N}$, i is the number of the tier of the hierarchy; l, j, l_j, p_j – numbers inside the same tier of the hierarchy. Roles are also systems-classes they also have content (properties of properties).

The concept of the volume of a class system can be described using the operation of intersection concepts:

$$Vol\left(S_{ij}^{l}\right) = S_{i+1,1}^{j} \sqcup S_{i+1,2}^{j} \sqcup \dots \sqcup S_{i+1,\overline{N}_{i+1}}^{j},$$

where $S_{i+1,p}^{j} \sqsubset S_{ij,p}^{l}$, $p = \overline{1, \overline{N}_i}$. $\overline{N}_i$– numbers of nodes from i-level the hierarchy.

Consider the possibility of creating a formal model of the hierarchy of systems-classes using descriptive logic that describes the system relationships between classes. In accordance with the system (system-object) approach, a system is considered both as a fact (material object) and as a class (conceptual system), the function or role of which is determined by the function of the fact or the role of a class of a higher tier (i.e., the supersystem-fact or supersystem-class). A formalized description of this understanding of the system using the notation adopted in descriptive logic is as follows:

$$S^i = \left[S^{i-1}; RS^i \sqsubset RS^{i-1}\right]. \quad (2)$$

In expression (2) a formal description of the system is presented in accordance with the rules for object calculus Abadi-Kardeli. $\forall S_i\ \exists RS_i$ and S_{i-1} is a system-class to indicate a system-class (node) of a higher tier of the hierarchy S_i; $RS_i \sqsubset RS_{i-1}$ – a method corresponding to the role (function) of the system S_i in the super-system S_{i-1}. RS_i is a functional role (property-class) that supports the functional abil-ity of a supersystem-class (concept).

A.A. Bogdanov's principle of monocentrism states that a stable system "will be characterized by a single center, and if it is a complex, chain one, then it has one higher, common center" [5]. This principle is a consequence of the hierarchical ordering of systems, in our case, the hierarchical structure of generic relationships between class systems (conceptual systems).

The following are statements that substantiate this principle and the relationship structure of conceptual systems.

Statement 1. If a system-class is a type of a system-class of a higher tier and properties (properties-class) of a system-class are also a type of properties (properties-class) of a system-class of a higher tier, then this hierarchy has one root.

Proof. Let there exist systems-classes S_{ij}^l and RS_{ij}^l, where i – is the number of the tier of the hierarchy, *j* is the number of the node in the tier, *l* is the number of the supersystem in the tier. In terms of the SHOIQ expanded by the concepts of *volume* (*Vol*) and *content* (*Cont*) of a system-class: S_{ij}^l – concept, RS_{ij}^l – role (functional role). Suppose that there exist systems-class (descendants) $S_{i+1,p}^j$, that are in S_{ij}^l, i.e. $\exists S_{i+1p}^j \sqsubset S_{ij}^l : p = \overline{1,N}$. Suppose that there exist systems-classes (classes-properties) $RS_{i+1,p}^j$, in RS_{ij}^l , $\exists RS_{i+1p}^j \sqsubset RS_{ij}^l : p = \overline{1,N}$. We describe fragments of *TBox* and *RBox* as an expressions:

$$TBox = \begin{Bmatrix} \cdots \\ S_{i+1,1}^j \sqsubset S_{i,\mathrm{j}}^l \\ \cdots \\ S_{i+1,1}^j \sqsubset S_{i,\mathrm{j}}^l \\ \cdots \end{Bmatrix}; RBox = \begin{Bmatrix} \cdots \\ RS_{i+1,1}^j \sqsubset RS_{i,\mathrm{j}}^l \\ \cdots \\ RS_{i+1,1}^j \sqsubset RS_{i,\mathrm{j}}^l \\ \cdots \end{Bmatrix}.$$

We describe the system-class $S_{i,j}^l$ in terms of the logic SHOIQ and we get a composite concept that can be described using the intersection operation:

$$S_{i,j}^l \sqsubset S_{i-1,l}^n \sqcap \exists RS_{i+1,p_j}^{l_j},$$

where l_j is the serial number of the supersystem-class (property-class) in relation to $S_{i,j}^l$; p_j – the serial number of the class system in the tier, with respect to $S_{i,j}^l$.

We clarify the above expression in accordance with the definition of system (2), figure 1.

In the form of expressions for *TBox* and *RBox* we get the following:

$$TBox = \begin{Bmatrix} \cdots \\ S_{i,1}^l \sqsubset S_{i-1,l}^n \sqcap \exists RS_{i+1,p_1}^{l_1} \\ S_{i,2}^l \sqsubset S_{i-1,l}^n \sqcap \exists RS_{i+1,p_2}^{l_2} \\ \cdots \\ S_{i,N}^l \sqsubset S_{i-1,l}^n \sqcap \exists RS_{i+1,p_N}^{l_N} \\ \cdots \end{Bmatrix}; RBox = \begin{Bmatrix} \cdots \\ RS_{i,1}^l \sqsubset RS_{i-1,l}^n \sqcap \exists RS_{i+1,p_1}^{k_1} \\ RS_{i,2}^l \sqsubset RS_{i-1,l}^n \sqcap \exists RS_{i+1,p_2}^{k_2} \\ \cdots \\ RS_{i,N}^l \sqsubset RS_{i-1,l}^n \sqcap \exists RS_{i+1,p_N}^{k_N} \\ \cdots \end{Bmatrix}.$$

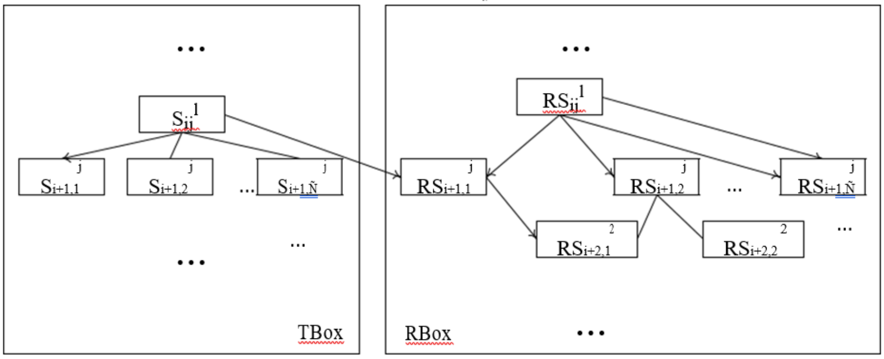

Figure 1. The hierarchical structure of systems-class.

As noted earlier systems-classes must have species characteristics (properties-classes) that are different from the generic ones. This is necessary for constructing subsequent tiers of the hierarchy and correlates with the logical law of the inverse relationship of volume and content in accordance with which a system-class inherited from the current system-class must have a large number of species characteristics, i.e. a large content $Cont\left(S_{ij}^{l}\right) \sqsubset Cont\left(S_{i+1,p}^{j}\right)$ but a smaller volume $Vol\left(S_{ij}^{l}\right) \sqsupset Vol\left(S_{i+1,p}^{j}\right)$. When applying the law as a whole to the entire hierarchy of systems the following relationships must be fulfilled:

$$Vol\left(S_{0,p_0}\right) \sqsupset \cdots \sqsupset Vol\left(S_{i-1,p_k}^{p_{k-1}}\right) \sqsupset Vol\left(S_{i,p_{k+1}}^{p_k}\right) \sqsupset Vol\left(S_{i+1,p_{k+2}}^{p_{k+1}}\right) \sqsupset \cdots \quad (3)$$

$$Cont\left(S_{0,p_0}\right) \sqsubset \cdots \sqsubset Cont\left(S_{i-1,p_k}^{p_{k-1}}\right) \sqsubset Cont\left(S_{i,p_{k+1}}^{p_k}\right) \sqsubset Cont\left(S_{i+1,p_{k+2}}^{p_{k+1}}\right) \sqsubset \cdots \quad (4)$$

From (3) it follows that if you move along the tiers then each parent system-class must have fewer features than the current one, therefore, have a larger volume. From it follows that the number of features decreases to the limit state at which the content is the most complete and $k = 0, p_0 = 0$. Moreover, we can talk about the root system-class S_0, which confirms the unity of the vertices of the classification scheme and Statement 1 (Figure 1).

Statement 2. The root of the hierarchy of systems-classes is divided into systems-classes representing objects-classes and properties-classes.

Proof. Let there be a root system-class S_0 which has no parents. Suppose that it has two descendants (systems-classes) S_{11}^{0} and RS_{11}^{0}:

$$S_{11}^{0} \sqsubset S_0;\ RS_{11}^{0} \sqsubset S_0;$$

$Vol(S_0) = S_{11}^{0} \sqcup RS_{11}^{0}$, $Cont(S_0) = RS_{11}^{0}$, where RS_{11}^{0} is a system-class that includes all the supporting features of the domain, i.e. being a functional role. RS_{11}^{0} is an extremely wide role corresponding to the property-class. In addition, this is consistent with the work [5] which describes the separation of properties into boundary and qualitative. It can be correlated with our reasoning. It is fair to say that in this case relations (3) and (4) will also here. This confirms the structure of the hierarchy of conceptual systems and Statement 2.

6. Conclusion

The method of describing knowledge considered in this paper is universal because takes into account not only material but also conceptual systems that are reflected in our consciousness in the form of conceptual knowledge. The presented method allows to describe the structural, functional and object characteristics of the studied subject area both at the level of fact and at the level of classes. Information system based on this method of describing knowledge allows you to store and process the experience of organizations in a convenient way.

The presented method for describing knowledge is formalized. It is shown that for a formal description of the model of conceptual knowledge, you can use the system-object approach "Unit-Function-Object" and formal means of descriptive logic.

In addition, the work shows that the concepts of a system-object approach "system-class" and "property-class" are unambiguously described with the concepts of descriptive logic. The syntax and semantics of the descriptive logic ALCOIQ and its original extension SHOIQ allow us to justify the structure of the hierarchy of class systems and the mandatory implementation of the principle of monocentrism for conceptual systems. The introduction of the concepts of "volume" and "content" of class systems and their description by means of descriptive logic expands the system theory based on the system-object approach. The obtained results will make it possible to improve existing and create new classifiers (classification systems) which are an important type of conceptual models of conceptual knowledge.

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References
[1] Ackoff R L 1964 General system theory and systems research: Contrasting conceptions of system science *Proceedings of the Second Systems Symposium at Case Institute of Technology* 10–14
[2] Melnikov G P 1978 Systemology and linguistic aspects of cybernetics *Soviet Radio*
[3] Matorin S I and Mikhelev V V 2020 Analysis of the role and structure of information (conceptual) systems *Automatic Documentation and Mathematical Linguistics*. NTI **2(4)** 10-17
[4] Baader F, Calvanese D, McGuinness L, Nardi D and Patel-Schneider P F 2003 The Description logic handbook: theory, implementation, and applications *Cambridge University Press*
[5] Bogdanov A A 1989 Tectology: universal organizational science *3rd ed. Revised. and add.* Economics
[6] Abadi Martin and Luca Cardelli 1996 A Theory of Objects *Springer-Verlag* 397
[7] Matorin S I and Zhikharev A G 2019 Accounting for System-Wide Regularities in System-Object Modeling of Organizational Knowledge *Scientific and Technical Information Processing* **46(6)** 388-396