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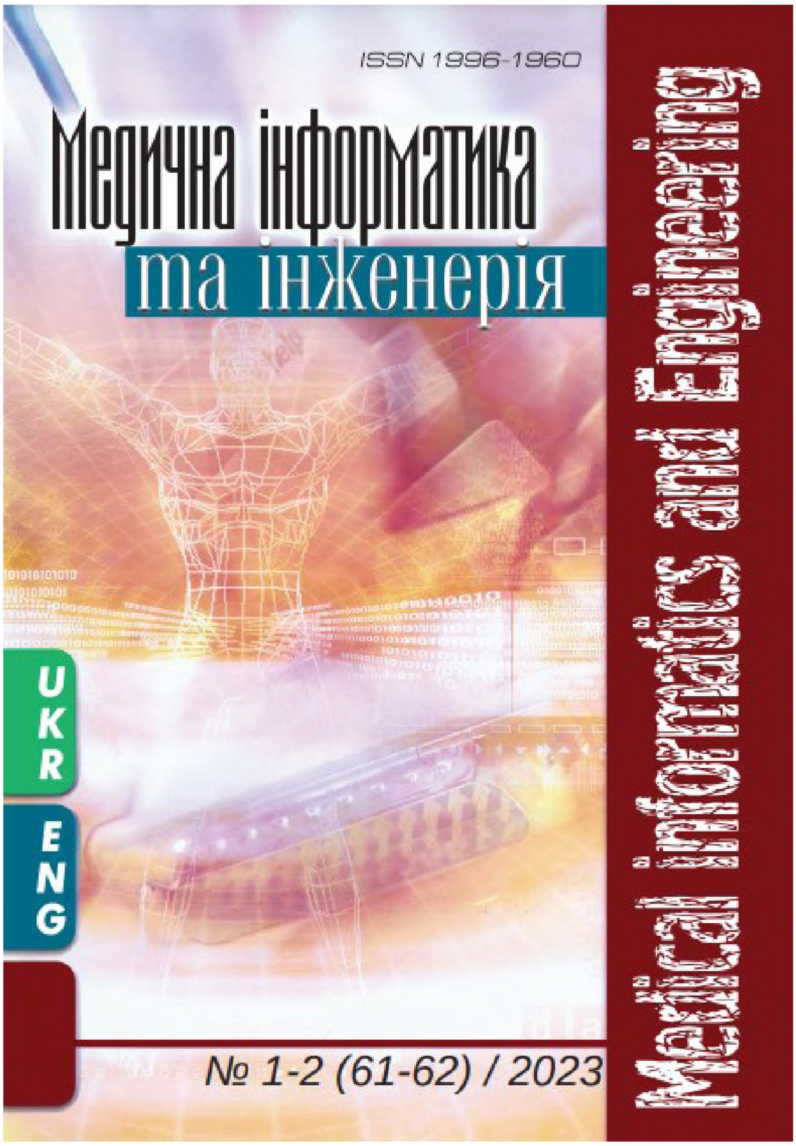

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CONTENT

Ontology-Based Approach for the Creation of Medically-Oriented Transdisciplinary Information-Analytical Platforms

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ABSTRACT

The process of development of information and communication technologies and the total informatization of the health-care sector led to significant changes to quantitative and qualitative characteristics of medical information, available to broad auditory. This led to the need to create effective informational-analytical platforms, that are required to cover vast arrays of polythematical informational resources that are characterized by a high degree of intensity, dynamism and diversity both in terms of content, structure, purpose, and formats, standards and creation technologies. Such platform should be used for finding, organizing and using the information needed by the users, and thus allowing them to process these arrays effectively.

One of the most useful tools for organizing all kinds of knowledge is ontology as a formal representation of some subject area. A system, capable of effective utilization of such formalization with the means of interactive documents is proposed. An example, designed for the effective finding of information based on ontologies is shown.

KEYWORDS

Transdisciplinarity, ontology, taxonomy, medical information resources, medical knowledge systems, narrative, discourse

1. Introduction

The rapid development of information technologies transforms the formats of interaction that developed at the previous stages of human evolution. A network-centric phase of evolution is being formed, the operationality of which is implemented on the basis of transdisciplinarity, which is a certain hyperproperty of all information resources and processes that make up the modern network environment.[1–4]

These processes are especially manifested in the medical sphere. A high level of integration of medical and engineering technologies requires ensuring their consolidation during application. There is also problem of doctors' consolidation while providing medical support to their clients. Today, almost every the problem of doctors' consolidation while providing medical support to their clients. Almost every patient contacts a certain clinic for help if he suffers from diseases that are treated by various specialists.

The transdisciplinary approach is to provide a consolidated interpretation of these approaches, methods and tools that are used in the modern treatment process. This is realized by taking into account the whole set of interdisciplinary contextual relations between medical information resources, as knowledge systems that have a manifestation in the processes of interaction between doctors and patients of different profiles. The transdisciplinarity of medical ontologies is able to ensure the implementation of cognitive-communicative scenarios of interaction between doctors and patients based on the constructive use of distributed systems of medical knowledge and their diagnostic data.

Processing medical information resources and medical knowledge systems, which are dynamically accumulating, is a rather difficult task. Firstly, this information has quite large volumes, especially in the share of the newest methods of treatment. Secondly, the set of information has a rather complex formation structure and is organized in different and more outdated formats and even more, in the process of active use of medical information resources in the network, network-centric transdisciplinary environments are formed in which extremely large volumes of medical information circulate, which defines the problem of big data.[1,5,6]

Digital formats of information resources, which form the basis of interaction in network medical environments, also determine the problem of their integrated and more consolidated use.[7–10] First of all, it should include the semantic consolidation of information resources, the cognitive procedures of which implement the presentation of combined information in the form of a complete model.[8] However, the very procedure of semantic unification with subsequent analytical processing during interaction is quite complex and has a reflexive-recursive nature.[1–11]

2. Analysis of recent publications and formulation of the problem

The problems of information consolidation and its further analytical processing have been actively studied over the past 30 years.[7–10,12] The directions of these studies can be conditionally divided into two groups.

Representatives of the first group[7,12,13] define the category of consolidation as the unification of the same type of information based on characteristic attributes. According to this approach, the difference between consolidation and integration is leveled. The selection of characteristic groups of attributes of relevant information and data is appropriate for the integration of databases that characterize the single-type information resources. In fact, this interpretation of consolidation reduces it to the simple use of certain data in the process of solving practical unified problems.

Contrary to this approach, other researchers[1,8–10] consider consolidation as a certain unification of semantic processes that are implemented in the network space. The use of ontological engineering mechanisms is proposed as a consolidation construct.[1,15,16] The use of the methodology of ontological systems provides a representation of the semantic properties of information resources and in a certain way implements interaction with them and between them.

For example, the concept of “consolidated information”[1,8] is considered in the format of system-integrated various information resources, which in aggregate are endowed with signs of completeness, integrity, non-contradiction and make up an ontological model of the problem area for the purpose of its analysis, processing and effective use in support processes of decision-making.

However, the use of ontology as a primary construct for the consolidation of information resources in the processes of analytical processing during network interaction has certain problems. The ontological system[1,9,10,15,16] can be represented in the form of an ordered six of the type (1):

$$O_t = <X,R,F,A,D,R_s> \tag{1}$$

where X – set of concepts of a given subject area (SA); R – finite set of semantically significant relationships between concepts; F – is a finite set of interpretation functions defined on relations; A – a finite set of axioms used to write always true statements in terms of concepts; D – set of additional definitions of concepts; R_S – a set of restrictions defining the scope of conceptual structures formed from concepts based on axioms.

As we can see from definition (1), the rules for handling information in the process of interaction based on the use of ontologies depend on axiomatic definitions. They impose certain strict restrictions on the interaction process. Based on formula (1), only conceptual structures forming true statements can be included in it.[16]

Therefore, for the further use of the ontological approach to the formation of consolidated information for its analytical processing in the process of network interaction, it is necessary to single out a basic construct to which axiomatic restrictions do not apply.

Taxonomy as a semantic platform of consolidation

As a construct for the formation of consolidated information, taking into account the semantics of all its thematic fragments, it is most effective to use the category of taxonomy.[1,18,19] The advantages of its use include the following:

- taxonomies determine the conceptual structure of the ontology;[1,16,18]
- nodes of taxonomies contain contextual descriptions of their meanings, which allows to consider them as concepts;
- taxonomies are formed by classes of concepts characterized by their certain properties according to the ontology definition (1);
- taxonomies can form multiple relations among themselves, each of which is a binary relation between certain contexts of concepts of the ontological system.

We single out the taxonomy from formula (1). An arbitrary taxonomy is an oriented graph without cycles and, according to Dovgyi & Stryzhak, Aksu-Koç, and Guajardo & Watson[1,18,20] it is formed by concepts that are hierarchically interconnected. That is, it is defined by an ordered pair of the following form:

$$T = <X,R_t> \tag{2}$$

where:T – taxonomy, X – set of concepts, R_t – set of binary relations between taxonomy T concepts.

As we can see, formula (1) can be derived from formula (2) by the orderly inclusion of categories that define the subject area with the information resources of which network interaction is realized.

However, at the taxonomic level, we can form their variety, i.e. a certain hyperset of taxonomies, each of which, while forming an ontology, is characterized by the inclusion of certain sets of axioms that differ from each other. These axioms are determined on the basis of the interpretation of the contexts meanings, which in turn determine the concepts of the taxonomy and in the subsequent ontology.

If we define the contexts of the nodes of taxonomies as elements of certain knowledge, then their totality reflects a certain fragment of the picture of the world. However, when considering the whole variety of taxonomies, we will get the hyperproperty of reflection, which implements the reflection of all taxonomies on themselves. Such a reflexive reflection of the taxonomy on itself has a verbal character. This can be deduced from the fact that the nodes of an arbitrary taxonomy form specific statements that have the value of truth.[1,17,20]

We present the variety of taxonomies in the form of the following expression:

$$\grave{T}_{Rt} = \{T_{Rt} | R_t = \ll X_n(K_t^n), Y_m(K_t^m) \gg\} \tag{3}$$

Expression (3) defines the following: the variety of taxonomies, as a hyperset, is formed by all taxonomies that can be interpreted as complex concepts that have binary relations between them and form nested tuples. Each such concept is characterized by a set of contexts of the type – K_t^n.

What is the result in a constructive manner? Now we can claim that the consolidation of information resources, which is reflexively reflected by the variety of taxonomies, is formed on the basis of intercontextual relations formed between the concepts of these taxonomies. That is, the consolidation of information resources is a verbal-active function that implements the interpretation of a set of binary relations between all contexts that reflect the meanings of concepts that form the content of subject areas whose information resources are involved in network interaction.

This can be represented in the form of a characteristic predicate:

$$\Pr(x_1, \dots, x_n) = 0 \Rightarrow \exists T \subseteq \grave{T} : \forall x \in X \exists Y \subseteq X : T = YG_{rx} \tag{4}$$

where, x_n – simple concepts of taxonomies T and corresponding diversity $\grave{T}$,G – hyperproperty of the class of concepts forming a specific taxonomy, in this case – Y.

According to Dovgyi & Stryzhak,[1] verbal-active reflection is a prerequisite for the existence of verbal-active recursion. We denote verbal-active reflection through F_f.

$$(F_f : X \to X \to Y) \tag{5}$$

Reflection (5) can be represented in a recursive form:

$$F_f(X) = \begin{cases} F_f(X, \grave{T}) \to \grave{T} \\ T \\ XG_X \end{cases} \tag{6}$$

Thus, we consolidated all concepts of a certain set of information resources, which can be represented in the form of a variety of $\grave{T}$ taxonomies of T concepts from different subject areas. Moreover, in fact, consolidation represents a certain knowledge base that combines facts from different subject areas, and thereby combines different network information resources.

Now we can define the category of information consolidation as a taxonomic diversity[1] of information resources formed by the concepts of all taxonomies, which in turn form this diversity.

Consolidation is characterized by the existence of verbal-active reflection and recursion, which are set over the corresponding taxonomic images of information resources involved in network interaction. According to Dovgyi & Stryzhak,[1] the information resources on which the verbal-active functions of reflection and recursion are set are transdisciplinary. That is, transdisciplinarity is a hyperproperty of consolidated information, which is activated in the process of network interaction, which has a manifestation in the format of a cognitive-communicative act between relevant information resources and users.

Narrative discourse as a format of active manifestation of consolidated information

Intercontextual connectivity of online medical information resources can also be defined through the concept of discourse.[21,22] The discourse itself can be represented by verbal-active reflection, on the basis of which taxonomic diversity is realized. This allows us to present the discourse through a cognitive-communicative act, which simultaneously is being realized, on the basis of inter-contextual connections, the consolidated use of selected information resources and their interpretation, as a display and representation.[1,21–23]

The use of consolidated medical information in a certain way realizes its systemology, which is quite important for its further analytical processing. That is, taxonomic diversity $\dot{T}$, formed on the basis of a certain classification of concepts, provides the implementation of the hyperfunction of semantic analysis, systematization, etc. According to Dovgyi & Stryzhak,[1] we can transform an arbitrary taxonomy of a species (2) or taxonomic diversity (3) to the format of an ontology of a species (1). This allows us to determine the format of narrative discourse for consolidated network information.[1,21–23]

Taxonomies according to Dovgyi & Stryzhak and Nadutenko[1,24] have one useful property. They are marked trees, in which the names of concepts act as marks. We will assume that all concepts form a certain set of names $\sum$, which are the marks of all taxonomy nodes T and taxonomic diversity $\dot{T}$. Under such conditions, the arbitrary taxonomy of the type T or taxonomic diversity $\dot{T}$ are univalent sets of Böhm trees.[11] That is, the topology of the interaction of sets of concepts of taxonomies can be represented as a set $\sum$ – marked trees formed by its nodes.

$$\sum = \{X_1, X_2, \dots, X_n, a_1, a_2, \dots, a_m\} \tag{7}$$

where X_i – concept class, a_i – terminal node.

Having defined property classes $R_1 R_2, \dots, R_m$, that implement the division of all concepts into hierarchical classes and determine the relations between concepts, we will get the corresponding taxonomy.

Also, the Böhm tree can be represented through the characteristic predicate (4) in the form of a semantic convolution:

$$\sum = XG_{X_i} \tag{8}$$

Moreover, repeated application of the characteristic predicate represents a hierarchically growing composition of Böhm trees in the following form:

$$\sum = \dot{T}GXG_{X_i} \tag{9}$$

It is clear that a hyper-relation G includes a relation of partial order.

We expand the interpretation of the notion ‘concept’. According to Barendregt and Nadutenko,[11,24] each concept of an arbitrary taxonomy can be defined as a term. This makes it possible to determine the process of taxonomies formation based on the use of certain sets λ-terms.[11] On their basis, the calculation of the semantic nature of the contextual values of the terms-concepts is implemented, which determines the conditions for the existence of interactive interaction with information resources in a consolidated format.

$$\{X_1, X_2, \dots, X_n, a_1, a_2, \dots, a_m\} \to \lambda \to \dot{T} \to \sum = \{X_1, X_2, \dots, X_n, a_1, a_2, \dots, a_m\} \tag{10}$$

where, ($\dot{T}$) – taxonomic diversity

$$\{X_1[..], X_2[..], \dots, X_n[..]\} \to \{X_1[B], X_2[D], \dots, X_n[V,P]\} \to \dot{T} \tag{11}$$

$$\sum = \{\perp\} \cup \{\lambda x_1, \lambda x_2, \dots, \lambda x_n, \lambda a_1, \lambda a_2, \dots, \lambda a_m\} \tag{12}$$

$\perp$ – the smallest element of all taxonomy context meanings; B, D, V, P – semantic values of contexts.

Expressions (10)–(12) reflect the generalized metaprocedure of forming consolidated information in the process of interactive interaction with network information resources.

Inputting the smallest context value and defining the contexts themselves passively defines the order relation over the set λ-terms, and thereby creates the conditions for the formation of taxonomic diversity, as a technological basis of consolidation for subsequent analytical processing.

The main components of transdisciplinary information and analytical environment

The operational component of the transdisciplinary consolidated medical information environment is implemented in the format of a narrative discourse. It is the discourse that determines the conditions for further analytical processing of medical information and data. This operationality is determined by a set of hyperproperties – reflection, recursion, reduction, which define a closed set $\mathscr{R}3$ of the type:

$$\mathscr{R}3 = \{\mathscr{R}_f, \mathscr{R}_k, \mathscr{R}_d\} \tag{13}$$

where is the reflection – $\mathscr{R}_f$, recursion – $\mathscr{R}_k$ and reduction – $\mathscr{R}_d{}^2$, the specified hyperproperties are transdisciplinary and cognitive in nature.[1–4,19]

The functional interpretation of these hyperproperties is implemented through certain cognitive functions that implement structuring metaprocedures; analysis/identification of the problem; synthesis; of choice, etc.

The set indicated by $\mathscr{R}3$ ensures the implementation of the following rules, based on which analytical processing of medical information is performed.

Formation of classes of medical information. For this, such a class is named and further filled with document concepts that have a binary relation with the class name based on the formation of a stable binary relation between its property and one of the hyperrelations of the closed set $\mathscr{R}3$. Such a relation has the form:

$$< r^t_{kl}, R_g, > | r^t_{kl} \in \mathscr{R}^T_{kl} | \mathscr{R}_g \in \mathscr{R}3, g \in \{f, c, d\}, \mathscr{R} \tag{14}$$

where T – concept type, t – type property, kl – a special index that determines whether the concept belongs to a specific class.

The multiplicity of the given binary relation is determined by the fact that it associates some set of concepts with the name of the class that forms this set of concepts.

$$\{x^t_{kl} < r^t_{kl}, \mathscr{R}_g > X^T_{kl}\} \tag{15}$$

where X^T_{kl} – the name of the class that was formed by the set of concepts x^t_{kl}

Concept classes are also elements of the document taxonomy and can form new classes.

$$\{Y^{t_i}_{kl} < \mathscr{R}^{T^{t_j}}_{kl}, \mathscr{R}_g > X^{t_n}_{kl}\} \cong X^{T_1}_{kl} \tag{16}$$

Representation of the class name of the species $X^{t_n}_{kl}$ says that this class is formed from concepts that have t_n property.

Above each class, as an element of a taxonomy of a certain complexity, a binary relation of its partial ordering is determined. The entire set of classes forms a complete taxonomic system of the document, over which a complete partial ordering can be determined. Then the root vertex of the taxonomy of the entire document is a fixed point of the set that includes all concepts of the document. The taxonomic system, which is formed on the basis of the specified set of concepts with a fixed point[11,17] is also complete. For a complete taxonomic system, one of the fixed points is the name of this document.

Moreover, the complete taxonomic system is a structured object and can be considered from the standpoint of the homotopy type theory. Taxonomy, as a structured object, is formed on the basis of stable binary connections between document concepts. Thus, it can also be considered as a binary tree,[11,17,18] which is also a homotopy type and is characterized by the hyperproperty of univalence. This allows us to claim that the taxonomy of an arbitrary document is univalent to the entire space of binary trees that can be formed from its concepts.

$$T \cong B_D \tag{17}$$

where B_D – an arbitrary Böhm tree.

Transformations of the type (14)–(17) are determined on the basis of definitions and rules (1)–(13) and ensure the implementation of the following technological conditions of the doctor's information-analytical activity:

- creation of a complex IT solution for the formation of a united network-centric information environment, which will unite the information resources of all specialists involved in the interaction;
- ensuring the solution of cognitive meta-tasks when processing text documents, databases and knowledge-base: structuring, analysis, synthesis and selection;
- support for information search processes and the formation of network digital collections of text documents relevant to the topics of research and expertise;
- implementation of an interactive form of interaction with each document and ensuring its attributive integration with processed information resources;
- provision of continuous monitoring of information processes, analysis of their states and decision-making based on the received information;
- formation of interoperable protocols supporting network-centric interaction and interconnection between documents, information systems, databases and knowledge bases, which have a significant amount of interdisciplinary relations, and are created on the basis of the use of various information technologies and standards;
- provision of automated analysis and creation of rating systems of research objects and processes related to them, taking into account the whole set of factors affecting the relevant objects and processes;
- ensuring the processes of multi-criteria comparative analysis of information sources according to their properties and selection according to the specified criteria of relevant records and documents found in information systems and environments;
- selection of statistical data from documents being processed or already having been processed and their processing according to defined features and criteria;
- ensuring the processes of solving the problem of rational choice and developing, on its basis, alternative options for solving typical tasks and their substantiation according to determined indicators;
- formation of a multi-level scheme for the implementation of innovative solutions at all stages of the life cycle "problem–research–selection–justification–development–implementation–production–support" in the form of an ontology of processes;
- support for experts interaction with specialized information resources and with each other in the format of narrative discourse.

Based on the principles mentioned above, a constructive option that ensures the fulfilment of the specified requirements for the creation of an appropriate medical transdisciplinary information and analytical environment is the development and implementation of intelligent network-centric cognitive services that are able to provide analysis, evaluation and selection of certain descriptions that characterize the patient's health condition, including decision-making concerning the choice of treatment methods.

The implementation of the specified IT technological solution is possible only under the conditions of the formation of a united medical information space in the format of a narrative discourse. The specified format of interaction ensures full-scale integrated use of distributed information resources and corporate systems of medical knowledge.

3. Conclusions

Transdisciplinary ontologies of medical information resources ensure the implementation of the interaction of doctors with information resources in the format of narrative discourse. They are the network intellectual tool that is able to form an appropriate unified information space based on the transdisciplinary procedure of lexical-semantic analysis of information resources. They also provide encapsulation of an arbitrary information resource, which was created according to a certain information technology and to a different-from-others standard, into this united information space. Thus, transdisciplinary ontology forms this space in the format of a narrative discourse for the use of all kinds of descriptions and documentary display of information, all contexts of which are processed by cognitive services of a network dynamic system with a complex component-oriented structure of services. Then the basis of decision-making will be a transdisciplinary interactive medical document, which will be created on the basis of transdisciplinary ontologies.

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