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RESEARCH ARTICLE

Informational ontological modeling

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Abstract
Objectives. Despite the wide application of the term "ontology" in philosophy and social sciences, ontological modeling in the fields of computer science and information theory remains poorly studied. The purpose of the work is to develop a methodology for the ontological modeling of information and to clarify the theory of information retrieval technology both in a broad sense and as part of ontological modeling. Relevant problems in ontological modeling include the necessity of demonstrating the difference between regularity and functional dependence.
Methods. To achieve the stated goal, a logically structural approach is used, including the construction of conceptual schemes and their description in terms of logical formalism. The logically structural approach includes the construction of conceptual schemes that serve to apply logical formalism. The basis of logical modeling involves the selection of related models. The extended information retrieval technology proposed for this purpose searches not for individual objects, but for groups of objects. Since ontological research is based on a transition from qualitative to quantitative description, the methods used include quantitative-qualitative transitions.
Results. A new concept of ontological modeling of information is introduced. The conditions of ontological modeling are substantiated. Relationships between the concepts of regularity and functionality are investigated. On this basis, an interpretation of regularity and functional dependence is given. Structural and formal differences between information modeling, information retrieval technologies, and ontological modeling are demonstrated. Three information retrieval tasks are described, of which the second and third tasks involving the search for a group of related objects and the search for relationships or connections within a group of related objects, respectively, are solved using ontological modeling. Formal schemes of ontological modeling are provided. The transition from relations to connections in the case of ontological modeling is demonstrated.
Conclusions. Ontological modeling is shown to be applicable only to related models or to models between which there is a commonality. A technology of ontological modeling is proposed, in which version information retrieval is the initial part, while the second option involves the use of cluster analysis technology. Since ontological modeling uses qualitatively quantitative transitions, the proposed variant can be used to extract implicit knowledge.

Keywords: modeling, ontological modeling, information retrieval, information field, regularity, generalization, logical structural description, related models

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НАУЧНАЯ СТАТЬЯ

Информационное онтологическое моделирование

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Резюме
Цели. Несмотря на широкое применение термина «онтология» в философии и социальных науках, в области информатики онтология и, тем более, онтологическое моделирование остаются мало изученными. Также мало исследована онтология в области информационного поля. Цель работы – разработка методики информационного онтологического моделирования и исследование технологии информационного поиска в широком смысле и как части онтологического моделирования. На основе онтологического моделирования необходимо показать различие между закономерностью и функциональной зависимостью.
Методы. Для достижения цели применен логически структурный подход, включающий построение концептуальных схем и логический формализм их описания. Логически структурный подход включает построение концептуальных схем, которые служат для применения логического формализма. Основой логического моделирования является выделение родственных моделей. Для этой цели предлагается применить расширенную технологию информационного поиска, которая ищет не отдельные объекты, а группы объектов. Онтологическое исследование строится на применении перехода от качественного описания к количественному. К числу применяемых методов относится метод количественно-качественных переходов.
Результаты. Вводится новое понятие – информационное онтологическое моделирование. Обоснованы условия онтологического моделирования. Исследованы отношения между понятиями закономерности и функциональности. На этой основе дается трактовка закономерности и функциональной зависимости. Показано структурное и формальное различие между информационным моделированием, технологиями информационного поиска и онтологическим моделированием. Раскрыты три задачи информационного поиска. При онтологическом моделировании решают вторую и третью задачи информационного поиска, соответственно, поиск группы связанных между собой объектов и поиск отношений или связей внутри группы связанных между собой объектов. Даны формальные схемы онтологического моделирования. Показан переход от отношений к связям в случае онтологического моделирования.
Выводы. Доказано, что онтологическое моделирование можно применять только к родственным моделям или к моделям, между которыми существует общность. Предложена технология онтологического моделирования, в варианте которой информационный поиск является начальной частью онтологического моделирования. Вторым вариантом является применение технологии кластерного анализа. Онтологическое моделирование использует качественно-количественные переходы и в предлагаемом варианте может служить для извлечения неявного знания.

Ключевые слова: моделирование, онтологическое моделирование, информационный поиск, информационное поле, закономерность, обобщение, логически структурное описание, родственные модели

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INTRODUCTION

In philosophy, ontology is used to conceptualize reality [1]. In computer science, by contrast, ontology is differentiated by subject areas and refers to an information artifact [2]. As such, an ontology includes a vocabulary used to describe a topic defined reality, conventions used for complementarity, concept matching and contextual relations, as well as construction and analysis schemes. Ontologies were originally proposed for the verification and construction of conceptual models. Since verification involves the domain of logic, logical constructs are widely used in ontological modeling. Nowadays, ontologies are applied for knowledge extraction and experience building. At the same time, information retrieval [3] should be mentioned as a one of the primary areas in which ontological modeling was subsequently used. Since ontology in computer science involves information field (IF) theory [4], the concept of information ontology acquires salience. An information ontology is one that acquires relevance as part of a finite element (FE) model. Various types of modeling are widely used in intellectual property (IP) systems, of which the main one is informational modeling. This feature gives reason to talk about informational ontological modeling [5].

Information ontological modeling is fully consistent with the theoretical provisions of ontology, which are related to the definition of types, properties, and relationships of entities [1]. Simply stated, ontology is a theory of entities of objects and entities of their relations [6]. Here, a distinction is made between formal, descriptive and formalized ontologies. Formal ontology was introduced by Edmund Husserl in his Logical Investigations. According to Husserl, the object of ontology is the study of essence and important categories. In information sciences, this formal approach links ontology with taxonomy. Nevertheless, it is necessary to distinguish between ontologies of information entities and ontologies of information systems [7]. The application of the ontological approach is driven by the needs of modern information societies, in which information support and knowledge sharing is a key development factor. In the context of global resource exchange, knowledge acquisition and its methods deserve special attention. While there is no single methodology for systematic information modeling, a proposed ontology-based approach provides a semantic representation of information [8].

Information modeling is used for different purposes, one of which is to extract meaning and knowledge. Moreover, information modeling is can be considered as conceptual modeling or semantic data modeling. Thus, information modeling and ontological modeling may have useful points of commonality. A variant of information modeling is aimed at building an information model that represents conceptual aspects of objective and subjective reality. Since the conceptual framework of this methodology relies on ontologies and concepts that arise in ontological constructs, this may be said to constitute the essence of ontological information modeling. Due to the diversity of models and information technologies generating redundant requirements and data exchange rules, the work presented in [9] utilizes ontological principles. In [10], research results are presented on an ontology-based approach for building information modeling to facilitate information exchange between different applications of a subject area. The described approach is based on a generic information entity ontology that models the types of IS elements and the relationships between them. The information systems to be integrated must be modeled using the common ontology, according to which each knowledge domain adds its own element properties to the common ontology.

In the artificial intelligence domain, ontologies are used to generalize and reduce the complexity [11] of information. The use of topological models in ontologies greatly simplifies their analysis. Ontological models that are extended to the field of information retrieval can be ontological models of information retrieval. Thus, the importance of ontologies in IS and the need for ontological modeling becomes clear. Ontological modeling [12] aims at generalizing the properties of a number of related models, finding patterns and knowledge in this generalization. However, information retrieval [3], which in a broad sense refers to scientific research aimed at obtaining knowledge, precedes ontological modeling. Therefore, the combination ontological modeling and information retrieval becomes a novel and relevant area of study.

1. METHODOLOGY

The logically structural approach of analysis was used. The second and third tasks of information search were applied, the essence of which is disclosed below. The method of qualitative-quantitative transitions, methods of comparative and qualitative analysis were used.

2. RESULTS

2.1. Conceptual diagrams

The logical structural approach implies the construction of graphical schemes, which further serve as a basis for the construction of logical constructs. In the presented ontological modeling system, it is reasonable to consider information modeling and information retrieval as related to modeling processes for the purposes of comparison. The conceptual scheme of information modeling is shown in Fig. 1.

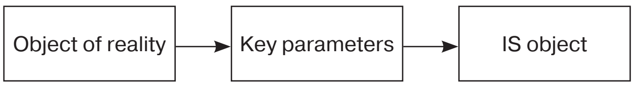

Fig. 1. Information modeling diagram

The basis of the model is formed by an object of reality, which is transformed into an IS object via key parameters, modeling conditions, and the set task. The IS object can be considered as synonymous with an information model. The structure of the information search model is shown in Fig. 2.

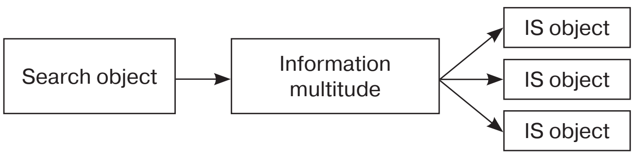

Fig. 2. Structure of information search

Information search can be performed for different purposes or tasks. The most common way to perform an information search is to find a single, user-required item. Here the first task will be to determine an object from the set of found objects in terms of the relevance of its features. The second task will be to find a group of related objects. In the third task of information search, it becomes necessary to find relations or connections within a group of related objects. Ontological modeling provides a means to solve the second and third search tasks. In all cases, the basis of the search is a search model, which may also be called a pattern. Linked objects in solving the second and third information search problem should be called *related objects*.

In the second and third search tasks, a discrete set of objects with commonalities is generated. The pattern generates a set of IP objects (Fig. 2). IP objects are identical to information models. Therefore, the information search in the second and third tasks generates a set of information models having commonalities.

The similarity between information retrieval and information modeling is that both technologies form information models. Single information modeling forms a single information model. Information retrieval forms a set of information models. In this totality, explicit and implicit patterns and relationships can be searched on the basis of ontological modeling. Figure 3 depicts a generalized model of ontological modeling.

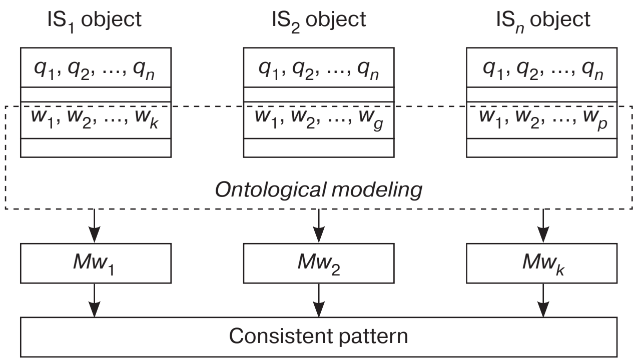

Fig. 3. Generalized model of ontological modeling

Three types of parameters are shown here: set or explicit $(q_1, q_2, \ldots, q_n)$; found or additional $(w_1, w_2, \ldots, w_k)$; generalized $(Mw_1, Mw_2, \ldots, Mw_k)$.

The number of these parameters is usually different. The number of given parameters may be greater or less than the number of found parameters. The number of generalized parameters is usually less than the number of found and set parameters.

2.2. Regularities of grouping of related objects

Objects that have commonalities and explicit or implicit connections may be described as related. Here it is necessary to distinguish between concepts of regularity, connection, and functional dependence. Regularity, as a rule, is a soft qualitative statement, having a logical or verbal form of representation. For example, an increase in the cost of a vehicle increases the cost of cargo transportation. Connection, on the other hand, is a hard dependence of one value on another or objects between each other. For example, the connection between cars in a train is realized by means of different types of couplings. Although there can be different kinds of couplings, all of them have a rigid connection in common. Finally, functional dependence is a relationship defined explicitly in the form of an analytic form. Any known law, such as Coulomb's law or the law of universal gravitation, is an example of functional dependence.

One way of finding related entities is information search in the aspect of the second and third search tasks noted above. Information retrieval starts with the formation of a search entity using cognitive methods. A user can form a morphological pattern and supplement it with alternative parameters: type, size, date of file creation and others. Here it is fundamental that the search pattern be formed morphologically, not semantically.

A pattern (*Pat*) contains the query parameters $\{q\}$. The designation $\{\}$ is used to describe a discrete set of values. In general, a search pattern can be represented as a regularity:

$$Pat\{q_i\} \to IR(IS) \to \{Ex_j\}, j = 1, \ldots, m; i = 1, \ldots, n. \quad (1)$$

Expression (1) is interpreted as follows. The query $Pat\{q_i\}$ is sent to the information set (*IS*) via the information retrieval (*IR*) technology. As a result, a discrete set $\{Ex_j\}$ is formed. The value n specifies the number of query parameters, while m specifies the number of instances selected in the information set based on the query. There is a regularity:

$$\uparrow n \to \uparrow m \to \uparrow t. \quad (2)$$

According to (2), an increase in the number of query parameters entails an increase in the number of instances and the search time t. This regularity leads to the need to minimize the number of search parameters.

Search $\{Ex_j\}$ as complete objects is an object search. In this case, the result of the query is an information model or an IS object, for example, a file. The result $\{Ex_j\}$ is a set of related objects for further analysis.

2.3. Modeling patterns

In contrast to information modeling, ontological modeling is a multi-stage process (Fig. 1). Ontological modeling begins with the selection of a group of objects that have commonalities. One variant of such selection is related to cognitive modeling. Another variant is based on the use of information search technology within the framework of tasks 2 and 3. Such information search can be represented as a process of clustering a heterogeneous multitude.

A search or clustering object can be an information model, a process model, a state model, relationships, or tacit knowledge. These objects have different degrees of abstraction. For task 1, there is an individual search, while for tasks 2 and 3 there is a group search. When forming a query for group search, an expert's experience or the search subject's cognitive abilities are used. The simplest search pattern is given in expression (1).

In expression (1) there are known, given parameters $(q_1, q_2, \ldots, q_n)$. Let us conditionally consider five instances in the group. We denote the newly found parameters by $(w_1, w_2, \ldots, w_k)$, where k is the total number of found parameters. As a result of the query, we have a total of $(n + k)$ parameters. The first sample of the group has the following form:

$$Ex_1(q_1, q_2, w_1, w_2, w_3, w_4). \quad (3)$$

From expression (3), we can see that the first instance contains two given and four found parameters. All six parameters describe the first sample.

The second sample of the group has the following form:

$$Ex_2(q_1, q_3, w_6, w_5, w_2, w_4) \quad (4)$$

and also contains two given and four found parameters. However, these parameters are different: q_2 appeared instead of q_3, while w_6, w_5 appeared instead of w_2, w_3. All six parameters describe the second sample.

The third sample of the group has the form:

$$Ex_3(q_1, q_3, q_n, w_1, w_3, w_6, w_8, w_4) \quad (5)$$

and contains three given and five found parameters. The parameters differ from the first instance. The parameter q_n appeared additionally, w_6, w_8 appeared instead of w_2. All eight parameters describe the third sample.

The fourth sample of the group has the form:

$$Ex_4(q_1, q_2, q_3, w_7, w_8, w_1, w_4) \quad (6)$$

and contains three given and four found parameters. The parameters differ from the first instance. Additionally, parameter q_3 appeared, while w_7, w_8 appeared instead of w_2, w_3. All seven parameters describe the fourth sample.

The fifth sample of the group has the form:

$$Ex_5(q_1, q_3, w_1, w_5, w_9, w_4) \quad (7)$$

and contains two given and four found parameters. The parameters differ from the first sample. Instead of the parameter q_2 there appeared q_3, instead of w_2, w_3 there appeared w_5, w_9. All six parameters describe the fifth sample.

The main disadvantage of group instance descriptions is that they exclude the description and influence of the situation in which the objects are located. Although it is acceptable to have different kinds of relations between parameters, different possible typical relationships between parameters should be emphasized:

$$Re_1(q_1, q_2, q_3, \ldots, q_n), \quad (8)$$

$$Re_2(q_1, q_2, w_1, \ldots, w_i), \quad (9)$$

$$Re_3(w_1, w_2, \ldots, w_k). \quad (10)$$

According to expression (8), there is a relationship between the query parameters. Expression (9) states that there is a relationship between a part of the query parameters and a part of the new found parameters, while expression (10) states that there is a relationship between the found parameters.

Relationships serve as a basis for establishing possible connections (Con) and functional dependencies (F). By analogy with (8)–(10) we can distinguish 3 possible groups of relations:

$$Con_1(q_1, q_2, q_3, \ldots, q_n), \quad (11)$$

$$Con_2(q_1, q_2, w_1, \ldots, w_i), \quad (12)$$

$$Con_3(w_1, w_2, \ldots, w_k). \quad (13)$$

Expression (11) states the possible existence of relations between query parameters, while expression (12) asserts the possible existence of relations between a part of query parameters and a part of new found parameters. Expression (13) states the possible existence of relations between found parameters.

The presence of relations can lead to functional dependence, for example, for expression (12) and (13) can appear a functional dependence of the following type:

$$Con_2(q_1, q_2, w_1, \ldots, w_i) \rightarrow \rightarrow Y = F_2(q_1, q_2, w_1, \ldots, w_i), \quad (14)$$

$$Con_2(w_1, w_2, \ldots, w_k) \rightarrow Y = F_3(w_1, w_2, \ldots, w_k). \quad (15)$$

Expressions (14) and (15) are of the qualitative-quantitative transition type. On the left side is a constant or a logical expression that serves as the basis for forming a functional dependence, while the functional dependence is indicated on the right side. Expression (14) hypothesizes that relationships between different parameters can lead to the formation of functional dependencies between different parameters. Expression (15) hypothesizes that links between new parameters can lead to the formation of functional dependence between new parameters. Expressions (14), (15), which can be considered as new knowledge, appeared after the identification of new parameters.

Ontological modeling is performed on the basis of additional analysis. For example, the analysis of instances in expressions (3)–(7) demonstrates the stability of occurrence of parameters q_1, w_1, w_4. This suggests that these parameters comprise common characteristics for different instances. This commonality is identified on a group of models related by a common theme. Common themes are organized either by the principle "from private to common" (information search) or by the principle "from common to private" (cluster analysis).

The result of further ontological modeling is three-level. On the first level, metaparameters are defined and emphasized. For expressions (3)–(7) these are q_1, w_1, w_4 and new metaparameters as functions are possible:

$$Mw_1 = \varphi_1(\{q\}, \{w\}), \quad (16)$$

$$Mw_2 = \varphi_2(\{q\}, \{w\}), \quad (17)$$

$$Mw_3 = \varphi_3(\{q\}, \{w\}). \quad (18)$$

Since the number and composition of arguments in functions φ_1, φ_2, φ_3 are different, we can generalize:

$$(\{q\}, \{w\}) \rightarrow Mw_k. \quad (19)$$

In expression (19), Mw are metaparameters whose number is equal to k.

Once the metaparameters are obtained, the relationships between them are found. This is the second stage of ontological modeling:

$$(Mw_1, Mw_2, \ldots, Mw_k) \rightarrow ReW. \quad (20)$$

In expression (20), ReW are the implicit relations between metaparameters, which are not initially identified by parameters q, w and determined only by metaparameters. New relations ReW give a reason to search for and establish new relations:

$$(Mw_1, Mw_2, \ldots, Mw_k) \rightarrow ConMw \rightarrow \rightarrow \psi(\varphi_1, \varphi_2, \ldots, \varphi_k). \quad (21)$$

In expression (21) $ConMw$ are previously unknown relations, while φ_1, φ_2, …, φ_k are metaparameter functions and ψ is the ontological function.

Expression (21) describes a new dependence. This dependence is implicit before ontological modeling and is revealed only at its third stage.

3. DISCUSSION

Since ontological modeling is performed on specific objects or models, it requires related or related models. So far, such a concept has not been applied in the theory of ontological modeling. At the same time, it is a prerequisite for ontological modeling. Ontological analysis of models that are not related in any way will not give a reliable result. However, ontological analysis and ontological modeling of models related by internal properties can leads to the identification of new patterns and acquisition of new knowledge. Ontological information modeling on related models is one of the methods for extracting tacit knowledge [13].

An important feature of ontological information modeling is the influence of cognitive factors on the modeling result. Cognitive modeling is required at the stage of forming a query to search for related models. This fact is also poorly taken into account in ontology theory. The disadvantage of the cognitive approach is that cognitive factors create ambiguity of search query formation, leading to ambiguity of related model formation.

Ontological information modeling, which uses the IS model [14, 15], is itself an IS technology. The information field creates an integral model of reality with all internal connections and relations, permitting their identification using ontological information modeling. The main advantage of IS is that it contains all internal connections and relations, which increases the adequacy of ontological modeling.

Nowadays, modeling—and especially ontological modeling—is affected by the problem of big data. In ontological modeling, it is necessary to carry out clustering using big data [16]. In addition, the task of data mining arises considering the volume of data [17]. Special methods are needed for this purpose. Therefore, modern ontological modeling methods must additionally include big data processing algorithms.

CONCLUSIONS

Ontological modeling can only be performed on models that have internal commonality and internal relationships. However, since ontological modeling and information retrieval are related, they can be considered as a single composite technology. In such a composite technology, information retrieval is a necessary preliminary stage, serving to select related models that form the basis for subsequent ontological analysis. Ontological modeling carried out as part of this composite technology identifies regularities and functional dependencies. As such, it represents a method for obtaining new knowledge. While researching the present work, the concepts of regularity and functional dependence were clarified to establish the presence of qualitative-quantitative transitions between them. Regularity is expressed with the help of logical descriptions. The relation of regularity is succession, while the main relation of functional dependence is equivalence. Regularity gives qualitative descriptions and qualitative evaluations, while functional dependence enables quantitative assessment of internal relations.

In this work, to obtain related models, we have proposed the technology of information inventory in the extended sense of group search. Cluster analysis, which can be used as an alternative approach, will be the subject of another paper.

Authors' contribution. All authors equally contributed to the research work.

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