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Software Tools for Ontology Development

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ABSTRACT

The relevance of the study is associated with the fact that the use of technologies related to ontological modeling in the organization of information processes will be actively disseminated in the near future. The study presents an analysis of research on various aspects of ontology development in teaching students. Based on an expert survey, the main directions of the use of ontologies in the education system, the problems of implementing the ontological approach in the education system, as well as the criteria for choosing software tools for ontology development are determined. Based on the selected criteria, a comparative analysis of ontology editors is carried out according to such software selection criteria as architecture and development of tools, interoperability, convenience and simplicity.

Key words: education, ontological models, ontologies, pedagogy, software tools, subject area.

1. INTRODUCTION

In modern conditions of the accelerated development of science-intensive industries and exponentially increasing volumes of information, on the one hand, and the need for structured knowledge bases, the information in which is presented in a unified form, authentic knowledge from poorly structured subject areas with subsequent replication of this knowledge, on the other hand. Thus, an objective need arose for the design of information systems [1]. The latter are based on knowledge processing technologies based on ontologies – hierarchical conceptual structures that are formed on the basis of research and structuring information from various sources and contain instrumental tools and mechanisms focused on special tasks [2, 3]. The primary among these tasks is the identification of inconsistencies in the data, ordering of disparate concepts of a loosely structured subject area, establishment of relationships between these concepts and modeling of the behavior of intelligent agents within an information system [4].

Consequently, the growth of scientific interest in ontological models as an effective tool of presenting knowledge on domain concepts and possible relationships between these concepts is associated primarily with the fact that ontological models create “transparent” conceptual representations for both structured and weakly structured subject areas. This allows to submit and use knowledge in some unified conceptual description in the form of a formalized presentation. This, at the same time, makes it possible to integrate knowledge from diverse sources, which results in the creation of conditions for the effective replication of knowledge in the information society [5].

The demand for ontological models by a wide range of practitioner-specialists in specific subject areas is evidenced by numerous examples where the tools of ontology successfully overcome the disordered accumulations of “labyrinths” of professional knowledge in various applied fields, for example, biology, medicine, geology, etc. Ontologies have become commonplace on the World Wide Web – the Internet. Online ontologies range from large taxonomies that categorize websites (as on Yahoo!) to some that categorize products for sale and their characteristics (as on Amazon.com) [6].

The public, multilingual, freely distributed network encyclopedia Wikipedia, through the use of ontological models, has evolved from a data warehouse into a distributed knowledge base on up-to-date structured information. Since taxonomy (classification structure) is an integral part of any ontology, the latter is practiced in numerous indexing systems, for example, in library classification codes.

In corporate systems, ontological models are used for three purposes: first, to unify corporation documents and collect data on their basis for entering into the corporation database; second, for the presentation and organization of meta-information with a view to its further use and the formation of queries for the economic analysis of the corporation; third, for maintaining, searching and keeping up-to-date normative and reference information [7].

Thus, as shown by the above examples, ontologies are an effective tool for systematizing knowledge in different subject areas. As original compilers of knowledge, ontologies are of great theoretical and practical interest for the field of education. After all, the latter, as the process and result of mastering the knowledge system, operates with knowledge. Therefore, it is an environment for building and further use of ontologies.

Educators who set themselves the goal of building an ontology for a specific subject area, in particular for an educational information system, objectively have a lot to choose from, on the one hand, tools for constructing ontologies of different levels of complexity, convenience and universality and, on the other, languages and presentation libraries of ontologies of different difficulty levels [8].

In this regard, the study of modern approaches to the development and use of ontologies in the field of education, including the creation of educational information systems, is becoming relevant.

Historically, ontologies have arisen from a branch of philosophy known as metaphysics, which deals with the nature of reality – that which exists. This fundamental teaching deals with the analysis of different types or forms of existence, often with particular attention to the relationships between features and universals, between internal and external properties, as well as between essence and existence. The traditional goal of ontological research is to divide the world (classification) and discover the fundamental categories or species into which objects in the world fall. In the second half of the 20th century, philosophers widely discussed possible methods or approaches to constructing ontologies, without actually building any more or less complex ontologies [9].

In computer science, the philosophical term “ontology” has acquired an independent meaning. For the first time, this term was used by T. Gruber in his work devoted to the analysis of various aspects of the interaction of intelligent systems between themselves and with a person. Gruber represented intellectual systems as ontology libraries and allowed for a double service: on the one hand, free exchange of ontologies inside intelligent systems and, on the other, ontology representations upon the user’s request. To designate the work of compiling, in fact, a description of declarative knowledge, as well as the result of this work, Gruber used the special term “conceptualization” and called the description itself “specification”. Thus, T. Gruber defines ontology as a generally accepted and generally accessible conceptualization of a certain field of knowledge (world, environment), containing a basis for modeling this field of knowledge, determining ways for interaction between agents who use knowledge from this field and, finally, including agreements on the presentation of the theoretical foundations of this field of knowledge [10].

Conceptualization is an integral part of modern definitions of ontology. Thus, M. Gruninger defines ontology as a set of concepts and connections between them without a specification of the subject area [11].

In computer sciences, ontology is the formal name and definition of the types, properties and relationships of subjects that really, or fundamentally, exist in the selected context (subject area). Thus, they are a practical application of the philosophical concept of ontology, using taxonomy [12].

On the whole, an analysis of modern definitions of ontology in computer science has revealed the existence of a unified approach to the interpretation of ontology as a means of comprehensive and detailed formalization of data knowledge using a conceptual scheme. The structure of such a scheme includes, as a rule, a description of the data structure, which contains definitions of all relevant classes of objects, their relationships and rules established in the subject area of the data set. Researchers of ontology in computer science pay attention to the need for a clear delineation of related concepts [13, 14].

Thus, researchers, considering the concept of ontology and metadata, come to the conclusion that there is a fundamental difference between them, despite the fact that both tools are used for semantic data integration. Accordingly, the fundamental difference between the ontology, which reflects an information resource, and metadata is the degree of human participation in integration processes. Metadata is created, edited and interpreted by people, so subjective factors, in particular limitations on the complexity of their presentation and understanding, are decisive. In contrast to metadata, ontology is the basis of a formal model of means of integrating information resources and implementing various additional functions. Therefore, the use of ontologies allows one to operate with more complex and formalized concepts, which often go beyond the limits of human competence [15].

According to K. Breitman and J.C. Leite [12], ontologies distinguish the variables necessary for a certain set of calculations and establish relations between them. In the field of artificial intelligence, semantic networks, engineering systems, software development, biometric informatics, library science, entrepreneurship and information architecture, ontologies are created to limit the complexity and organization of information.

As researchers indicate [13], ontological analysis allows to convert the perception of a certain person or group of people about the outside world into a formalized set of terms and rules for their use, suitable for automated processing. Therefore, ontology can be considered as a special kind of knowledge base with semantic information about a specific subject area. The components that are used in various formalizations of ontological descriptions of the subject area depend on both the presentation paradigm and the goals of constructing such an ontology.

According to most scientists, most formal models of ontologies include: individuals – cases or objects (main or "basic" objects); classes – sets, collections, concepts, programming classes, types of objects or types of things; relationships – ways in which classes and individuals can be related to each other; attributes – aspects, properties, features, characteristics or parameters of objects that a class may have; functional terms – complex structures formed from certain relationships that can be used instead of a single term; restrictions – formally specified descriptions of what must be true in order for the statement to be accepted as an input; rules – statements in the form of if-then (cause – effect) sentences that describe the logical conclusions that can be drawn from the statement; axioms – statements (including rules) in a logical form, which together make up the general theory that the ontology describes spheres of application (This definition differs from the "axioms" in generated grammar and formal logic. In these disciplines, axioms include only a statement that is a priori knowledge. The concept of axiom also includes a theory derived from axiomatic statements.); events – change in attributes or relationships [18-20].

In general, the analysis of modern research shows that it covers a wide range of issues that can be differentiated in the following areas:

ontological engineering (design and development of domain ontologies) as a component of knowledge management [21];

ontological approaches to the integration of incomplete and inaccurate data, to the construction of intelligent systems in specific subject areas, to knowledge management in the Semantic Web environment [22];

comparative analysis of ontology tools [23];

creation of knowledge bases based on the ontology system, improving ontological knowledge bases, construction of ontologies of subject areas [24].

O.M. Toporkova [25] identifies four properties of ontologies used in the system of pedagogy and education.

The first property. Ontologies are specifications created in a formal unified language, which, on the one hand, necessarily consider the specifics of the subject area (training course, curriculum, training scenario, knowledge testing, categorical apparatus, subject area glossary, etc.) and, on the other hand, clearly stick to the established agreements of a group of specialists in a particular branch of pedagogy and education on the system of concepts used by them, their properties and axioms, i.e. about what and how it will be indicated in a specific educational (teaching, educational, developing) subject area.

The second property. Since in ontologies, agreements of specialists in specific subject areas are recorded, ontologies can be presented by specialists in the relevant subject areas of pedagogy and education. In this regard, the language of presentation of ontologies should be convenient for specialists. On the one hand, educators should not be burdened with an excess technical component – the redundancy of the functions of languages and ontology editors, since this complicates the work of the educator and, therefore, subjectively reduces the activity in building ontologies in the educational sphere. On the other hand, if specialists need more complex ontologies, ontology libraries or new methodologies for their construction, it is necessary to provide them with tools for building complex ontologies. Unfortunately, as practice shows, many experts initially have certain difficulties in the process of using the ontology language due to the technicality of the latter. Moreover, in practice, the automation of the ontology development process mainly concerns those professions that are related to computerization and knowledge engineering.

The third property. At the logical level, a certain theory (or model) corresponds with each ontology. Ontology issues are interpreted as requests to the corresponding theory (or model). In this case, the queries are interpreted as a convenient way for a specialist to understand the presentation of ontology data or the consequences of the assumptions derived in the ontology.

The fourth property. Ontologies are built on a modular principle: in a new ontology, they can refer to previously built ontologies. This approach provides several advantages, the main of which are the possibility of reusing applied ontologies of subject areas and the ability to simplify the development of new ontologies, as well as modifying the pedagogy and education systems available for specific subject areas.

In general, as the analysis of publications shows, the use of ontologies in the education system is carried out in several directions:

research of ontology opportunities for harmonization of qualifications frameworks and educational standards [26];

consideration of computer ontologies as an instrumental platform for ensuring the transparency of qualifications frameworks [27];

analysis of the ontology of distance learning [28].

The analyzed works are completed studies of individual aspects of the use of ontologies in the education system. At the same time, the analysis of publications in professional scientific journals indicates that modern approaches to the creation of educational information systems based on ontologies require additional thorough scientific study.

The purpose of the research is to study modern approaches to the creation of educational information systems based on ontologies. To achieve the goal, the following tasks are performed in the study: the directions in which the use of ontologies in the education system are actively promoted are examined and the ontology tools that are used to develop educational information systems based on ontologies are compared.

The hypothesis of the study: The choice of the most convenient tool for ontology development when teaching students depends, first of all, on the goals of the developer and ontology that is being developed. Thus, one should pay attention to such criteria for choosing software as the architecture and development of tools, the interoperability of software tools, convenience and simplicity of software tools. According to the results of the study, we can conclude that the goal set in the study is achieved.

2. METHODS

During the study, the following methods were used:

– theoretical methods – an analysis of scientific literature on the theoretical aspects of the problem of ontology development in teaching students;

– empirical methods – an expert survey method to determine the main directions of the use of ontologies in the education system, the problems of implementing the ontological approach in the education system, as well as the criteria for choosing software tools for ontology development.

Based on the selected criteria, a comparative analysis of ontology editors was carried out according to such software selection criteria as architecture and development of tools, interoperability, convenience and simplicity.

Computer engineers (44 people) were involved in the online survey as experts, with more than 10 years of experience in the field of computer technology.

3. RESULTS

Taking into account the four properties of ontologies used in the education system given above, as well as relying on the available results of an expert survey, the directions in which ontology is used in the system of pedagogy and education were analyzed. According to the experts, today, the use of ontologies in the education system takes place in the following directions (Table 1).

Table 1: Directions in which ontology is used in the education system

№	Directions in which ontology is used	%*
1	Conceptualization of the components of the education system – educational disciplines, programs and courses, educational processes	91%
2	Web content management	79.5%
3	Construction of training scenarios, knowledge testing systems	75%
4	Building a body of definitions (terms) that will serve as reference information material, as well as formalizing thesauruses, knowledge maps, dictionaries, etc.	68%

Note: compiled on the basis of the expert survey; * – percentage of expert references

According to the experts, modern directions stimulate the mass introduction of ontological technologies in the educational sphere. At the same time, despite the obvious success and practical significance of these areas, according to one of the respondents, “we observe a relatively low rate of implementation of ontological models in educational practice”. This is due to the following implementation problems (Table 2).

Table 2: Problems of implementing the ontological approach in the education system

№	Problems of implementing the ontological approach	%*
1	the formation of ontologies of complex systems requires appropriate high-tech tools for testing and debugging ontologies, which also requires an additional technical competence from a specialist in pedagogy and education	77 %
2	the manual for most of the above tools is not russified, which complicates the user’s work since not every specialist in the field of education and pedagogy is familiar with specialized technical foreign language	66 %
3	in the case of complex ontologies, namely, those in demand among practitioners, it is still not possible to completely solve the problem of highlighting procedural and nonprocedural knowledge	57 %
4	the problem figuratively formulated as the problem of the “Tower of Babel”, when it is difficult and sometimes even impossible to integrate ontologies, is represented by different languages in different logical constructions and models. In practice, this means that, despite the richness of the market for relevant tools, they are narrowly targeted: they depend on the language of implementation, the limitations of the subject area and the low adaptability of existing program methods	50 %

Note: compiled on the basis of the expert survey; * – percentage of expert references

Building ontologies is both a complex and time-consuming process. To save ontology editors time and for convenience, the first environments for the ontology development process began to be created already in the mid-1990s. They provided interfaces that allowed to perform conceptualization, implementation and consistency checking. In recent years, the number of ontology tools has increased significantly. Among the main tools of ontology, the most numerous are the languages of ontologies and editors of ontologies.

Based on the analysis of the use of ontologies of computer systems in various fields, as well as software for developing these ontologies, the experts identify three main criteria for choosing software tools (editors) for ontology development (Table 3).

Table 3: Criteria for choosing software tools for ontology development

№	Criterion	Characteristic	%*
1	Software architecture and tool development	contains information on the necessary platforms for using the tool	86 %
2	Interoperability	contains information about the possibilities of interaction with other languages and tools for ontology development, translation from some languages of ontologies	84 %
3	Convenience and simplicity	includes work with graphic editors, the collaboration of several users and the need to provide reusable use of ontology libraries	77 %

Note: compiled on the basis of the expert survey; * – percentage of expert references

4. DISCUSSION

Let's consider the most famous tools for ontology development and compare them in accordance with the proposed criteria (Table 4-6).

Table 4: Architecture and development of ontology editors

Characteristic	Apollo	OntoStudio	Protege	Swoop
Architecture	Autonomous	client/server	Autonimous, clent/server	Web-base, client/server
Extensibility	Additional modules (Plug-ins)	Additional modules (Plug-ins)	Additional modules (Plug-ins)	Additional modules (Plug-ins)
Ontology Storage	In file	In DMS (Database Management Systems)	In DMS (Database Management Systems)	As HTML-model
Backup management	No	No	No	No

When comparing this criterion, information such as the default architecture (stand-alone operation, type of client/server operation, availability of applications), extensibility, ontology storage (databases, ASCII (American Standard Code for Information Interchange) files, etc.) and backup management are important.

Table 5: Interoperability of ontology editors

Characteristic	Apollo	OntoStudio	Protege	Swoop
Interaction with other ontology development tools	–	+	+	–
Import to languages	+	+	+	+
Export to languages	+	+	+	+

This criterion is an important feature of the integration of ontologies in applications and the choice of software tools for ontology development. Most of these tools support importing and exporting from many languages to various formats.

Table 6: Convenience and simplicity of ontology editors

Characteristic	Apollo	OntoStudio	Protege	Swoop
Graphic system	–	+	+	+
Multiuser interface	–	+	+	+
Ontology libraries	+	+	+	–
Interface help function	+	+	+	–

Apollo is a user-friendly application and allows to simulate an ontology from basic primitives, such as classes, instances, functions, relations, etc. The knowledge base consists of a hierarchical organization of ontologies that can be inherited from others and used if they come from the root. Each default ontology includes all primitive classes. Each class can create several instances and instances that inherit all the properties of the class. Apollo does not support multiuser mode and the ability to extract information for group processing. However, it has powerful functionality for checking consistency, ontologies storage (XML files only), as well as import and export formats.

OntoStudio is available for free evaluation in the demo version. Ontologies are developed and supported using graphical tools. It is based on a client/server architecture where ontologies are governed by a central server. Different clients can access and modify these ontologies according to their needs and activities. OntoStudio supports collaborative ontology development. The tool allows the user to edit the hierarchy of concepts or classes. It is based on an open plug-in structure and provides the ability to access the ontology in an object-oriented manner. There is also a logical inference mechanism, using which OntoStudio can present intelligible rules.

Protege has an open architecture that can be easily upgraded by supporting expansion modules. Protege allows to describe not only a concept but also specific objects and has a rich set of operators (intersection, union, negation, etc). It is based on a logical model that allows to create definitions that correspond to an informal description. Thus, definitions of complex concepts can be built on the basis of simple definitions. In addition, the logical model makes it possible to find out which concepts correspond to the given definitions and to check whether the concepts and definitions in the ontology are mutually compatible.

Swoop is an open source, ontology web editor and browser, providing multiple ontological environments in which entities and relationships from different ontologies can be compared, edited and combined. Different ontologies can be compared by describing their definitions. Navigation can be simple and easy due to the possible use of hyperlinks in the Swoop interface. This software tool allows not to stick to the ontology construction methodology since users can reuse external ontological data or import the entire external ontology. Swoop uses ontology search algorithms that combine keywords to find related concepts in the ontology. This search is performed on all ontologies stored in the Swoop knowledge base.

A comparison of ontology editors shows that Protege provides a friendly and easy-to-use graphical interface for most users. In addition, Protege and OntoStudio use an ontology interface and visualization layout, which greatly facilitates ontology development. Protege and OntoStudio allow to graphically revise a taxonomy. The help of the system is also important for users and should be easily accessible and easy to use. The Apollo, Protege, and OntoStudio help system consists of help and user guides. Swoop does not provide an interface help function. Collaboration is important in the process of constructing both simple and complex ontologies. Thus, Protege and OntoStudio allow group ontology development. Swoop enables users to write and share annotations on an ontological entity.

Thus, the tools as a whole are similar in functionality but have differences in the internal way of building a knowledge base. The choice of the most convenient tool depends primarily on the goals of the developer and ontology that is being developed.

5. CONCLUSIONS

The growth of scientific interest in ontological models is associated with the fact that they create conceptually "transparent" representations for both structured and weakly structured subject areas – both of which are widely represented in the education system. Accordingly, ontology is of interest to educators as an effective tool of versatile and detailed formalization of knowledge using a conceptual scheme. The structure of such a scheme includes, as a rule, a description of the data structure, which contains definitions of all relevant classes of objects, their relationships and rules established in the subject area of the data set.

The study identifies and considers directions in which ontologies are actively used in the education system. These directions include conceptualization of the components of the education system (educational disciplines, programs and courses, educational processes), Web-based content management designing learning scenarios, knowledge testing systems, structural construction of the corpus of definitions (terms), which will serve as reference information material, as well as the formalization of thesauruses, knowledge maps, dictionaries. The analysis of the directions of the application of ontology in the educational system shows that they stimulate the mass introduction of ontological technologies in the educational sphere. At the same time, despite the obvious success and practical significance of these areas, we observe a relatively low rate of implementation of ontological models in educational practice. In our opinion, this can be explained by implementation problems, the most important of which are described in the study.

The study compares ontology tools that are used to develop educational information systems based on ontologies. The analysis of the results of the study shows that when choosing the most suitable tool for constructing a specific ontology, a specialist should proceed from a specific task.

Thus, the results of the study confirm the hypothesis that the choice of the most convenient tool for ontology development when teaching students depends, first of all, on the goals of the developer and ontology that is being developed. One should pay attention to such criteria for choosing software as architecture and development of tools, interoperability of software tools, convenience and simplicity of software tools.

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