

Ontologies As a Foundation for Formalization of Scientific Information and Extraction of New Knowledge

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Abstract—“Ark of Knowledge” is a digital project developed by Lomonosov Moscow State University. It provides access to fundamental knowledge in Russian and should play a key role in the preservation and dissemination of Russia’s cultural and scientific heritage. “Ark of Knowledge” is an ontological information system. The article discusses modern ideas about ontology, the stages of creation and ontological features of the Great Russian Encyclopedia and Wikidata, as well as the design of an information system and its use for language models training. The initial working prototype of this information system is briefly described. Work on creating the system is being carried out by researchers and programmers from the Knowledge Engineering Laboratory of the Institute for Mathematical Research of Complex Systems of Lomonosov Moscow State University, as well as researchers from the Faculties of Philology, Mechanics and Mathematics, Computational Mathematics and Cybernetics, and the Branch of Moscow State University in Sevastopol.

Keywords: ontology, information system, fundamental knowledge, ontology design, information system “Ark of Knowledge,” Great Russian Encyclopedia

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1. INTRODUCTION

In the 21st century, the amount of accessible digital information continues to grow exponentially, and part of this process is a significant increase in the number of scientific publications. An attempt to facilitate human activities in these conditions is associated with the development of specialized information retrieval systems, which provide convenient access to scientific publications (e.g., Google Scholar), and specialized scientific information systems, such as Scopus, Web of Science, and eLIBRARY, which collect high-quality

sources of scientific information and form scientific ratings [1].

At the same time, new trends have emerged. First, the role of articles appearing in reputable journals is significantly reduced in new publications, as information begins to spread through online preprint services [2], repositories of models and datasets (e.g., hugging face [3]), online lectures, etc. [4]. Second, the situation with the quality of scientific information is becoming more complicated due to the development of large language models that can solve many tasks of automatic text processing, including their automatic generation. On the one hand, such models can help researchers analyze existing scientific publications and formulate their own results, thereby accelerating the publication of new results [5]. On the other hand, such systems can automatically generate fake scientific articles of no value [6–8]. Between these two extremes, there is a wide range of intermediate options, which is also a problem. To train large language models and improve their performance, it is important to employ, as useful tools, high-quality large-scale data [9]. This is especially important for creating specialized language models in various fields of science [10–12].

In the context of the above-described trends, we note an increasing role of high-quality, reliable scientific and educational content presented in trusted

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online resources, such as online encyclopedias, repositories of educational courses, specialized electronic libraries, etc.

In accordance with the decisions of the Government of the Russian Federation, the creation of the Great Russian Encyclopedia (GRE) in digital form began in Russia in 2016. The digital format provides significant opportunities for improving the quality, reliability, and accessibility of encyclopedic materials. The development of GRE materials is part of a broader task aimed at the preservation, development, dissemination, and use of the cultural and scientific heritage of the peoples of Russia.

In 2023, the Knowledge Engineering Laboratory of the Institute for Mathematical Research of Complex Systems of Moscow State University began work on the project “Ark of Knowledge of Moscow State University” (Ark). This project can be viewed from several sides:

1. as an incubator of encyclopedic articles: the expert community of Moscow State University creates and develops articles that are then transferred to the Great Russian Encyclopedia;
2. as a concentrator of articles and other information sources created by the broad scientific and educational community of Russia, which undergo review and editing by authoritative representatives of this community: heads of university departments and research institution departments, chairmen of defense councils, editors-in-chief of academic journals, etc.;
3. as a permanent repository of various information sources, such as textbooks, video recordings of lectures, and other educational and scientific materials.

Thus, the Ark combines both an online encyclopedia and a scientific information portal with various types of information. This project promotes the dissemination of knowledge and provides access to reliable information for all interested parties. One of its fundamental differences from information collections like Wikipedia is the use of a filter in the form of an authoritative professional community [13].

The creation of extensive encyclopedic, scientific, and educational resources requires the structuring of stored knowledge. Traditionally, this function was performed by rubricators, for example, UDC or SISIT, which are hierarchical (tree-like) systems of categories. Digital tools make it possible to use more complex structuring systems, such as ontologies with specialized sets of relationships and knowledge graphs, which are large-volume semantic networks containing, in addition to concepts and relationships between them, information about specific objects. In the case of scientific information, such specific objects are scientific publications, their authors, research institutions, etc. [4].

In what follows, we consider approaches to the ontological structuring of scientific and encyclopedic

information, as well as methods for constructing ontological resources within the Ark.

2. ONTOLOGIES AND KNOWLEDGE GRAPHS

Ontology is a formalized system of concepts about the world or its fragment (subject area) that describes objects, phenomena, and their properties and interrelations. In contrast to the philosophical concept of ontology, which is a discipline focused on principles, types, and basic properties of being, in computer science, ontology is used to denote a network of concepts. This network, also called a conceptual or semantic network, is built on the basis of a hierarchy of concepts linked by genus–type and type–instance relationships. Each concept is characterized by a set of properties and can have other, nonontological relationships with other concepts. Ontologies play an important role in the organization of knowledge, supporting the structure of our knowledge about the world. To represent knowledge, an ontology has an information language, which has its own vocabulary. It includes units of certain types: concepts, their instances, names of properties (parameters and attributes), values of parameters and attributes, and names of relationships.

An important subtype of ontological resources used to structure large amounts of knowledge is knowledge graphs. A knowledge graph is a semantic network in which the upper hierarchical levels include formalized descriptions of concepts and relationships between them (the ontology itself) and the lower levels contain descriptions of specific entities [14]. Typically, knowledge graphs contain representations for hundreds of thousands of more specific entities. Knowledge graphs have been discussed and developed since 2014, after their implementation in Internet search by Google [15]. A well-known example of knowledge graphs in the general subject area is the Wikidata resource¹ [16, 17]. In the scientific field, a well-known knowledge graph is the freely distributed OpenAlex resource², which is the successor to Microsoft Academic Graph (MAG)³ [4, 18].

In what follows, we consider approaches to structuring knowledge based on ontologies in encyclopedias and knowledge graphs.

3. STRUCTURING INFORMATION IN THE GREAT RUSSIAN ENCYCLOPEDIA

The Great Russian Encyclopedia (GRE), known as the Great Soviet Encyclopedia until 1991, is a uni-

¹ Wikidata: Q9081. https://www.wikidata.org/wiki/Wikidata:Main_Page. Accessed October 1, 2024.

² OpenAlex: The open catalogue to the global research system. <https://openalex.org/>. Accessed October 1, 2024.

³ Great Russian Encyclopedia: About the project. <https://bigenc.ru/p/about-project>. Accessed October 1, 2024.

versal encyclopedia of international level that occupies a worthy place among such reference publications as Britannica, Larousse, Brockhaus Encyclopedia, etc. The GRE is focused on presenting a holistic picture of the world, human, society, science, and technology. According to the definition on the website, the GRE is a scientific and educational portal. It serves as a collection of systematized reliable knowledge for students, teachers, scientists, researchers, and the general public. The main tasks of the modern GRE portal are to maintain an up-to-date electronic national knowledge base in Russian and to popularize science.⁴

To structure articles, the online version of the GRE uses a catalog, which is a three-component faceted classification system for encyclopedic articles. The GRE catalog includes:

- (i) areas of knowledge (Geology, Art, etc.);
- (ii) categories of object types (Astronomers, Mountain ranges, Rebellions, etc.);
- (iii) tags (keywords).

The GRE catalog in 2024 contains about 40 knowledge areas, more than 200 categories of object types, and tags that can be assigned to articles without restrictions. There is no direct connection between knowledge areas and categories, although the latter serve to create a kind of classification within a certain knowledge area. Tags are keywords for an encyclopedic article. They can be specific and allow navigation through articles with the same tags.

In addition, in encyclopedic articles for objects of different types, a formalized description of typical relationships and attributes of these objects (fields) is implemented. For example, for states, information is given about the parameters of the territory and population, participation in international organizations, etc. Articles about researchers provide information about the year of birth, country, and the field of activity.

The GRE portal implements a search by the listed components of the catalog. Each article is assigned to a certain category of object type, which allows one to navigate the portal and find articles of the same category. However, navigation by areas of knowledge according to the same principle is not available: the area of knowledge assigned to the article is not a link. In general, the presented system provides additional opportunities for finding the necessary information in the encyclopedia. At the same time, the GRE catalog system has features that complicate the indexing of articles by catalog elements and can complicate the search for information in the encyclopedia.

Our analysis of the GRE shows the following:

1. The categories of concepts are few and lack a clear hierarchical structure. They do not provide convenient navigation between articles.

2. Knowledge areas are not organized consistently and do not support clickable links for quick navigation.

3. In-text links are the only links between articles. However, most links in the current version are not active.

4. Tags cover various types of relationships of concepts and entities described in articles. However, among tags there are many that relate only to one article, which increases the number of tags and does not provide additional opportunities for searching for information. Tags are not related to each other and can implicitly specify different types of relationships.

4. SYSTEM OF CONCEPTS AND RELATIONSHIPS IN WIKIDATA

Wikidata, as a separate project, represents a central repository of structured data intended for other projects, such as Wikipedia (see [17]). A Wikidata storage unit has a name, a description that allows different units with the same name to be distinguished, and any number of synonyms. Each unit also has a unique identifier, Q, followed by a natural number. Information about a unit is presented and accessible to humans and computers on the unit page in the form of several statements about the unit. Statements can contain property names and values for these names, such as “place: Germany.” A property can have several values, for example, “being a child of the person described by the unit.”

Wikidata units are linked by classic ontological relationships (e.g., class–subclass, instance, etc.), which are supplemented with many new relationships that work on a similar principle; in Wikidata, they are all called properties. For example, for the object Moscow (Q649), there are such properties as an instance of the capital of Russia, part of the Central Federal District, founded by Yuri Dolgoruky, etc. Statements can also contain qualifiers, for example, an indication of the time to which the statement refers, the source of information, etc. Wikidata is currently the largest open knowledge base. On March 13, 2024, the Wikidata project announced the addition of the 2 100 000 000th unit to the database.

Although great efforts have been made in Wikidata to accurately represent structured data, researchers still find many inaccuracies and errors in descriptions. In particular, there are classes that are difficult to distinguish from each other, for example, *geographical location*, *location*, *geographic region*, *physical location*, and *geographical area*. Classes and instances are confused, and so are the instance–class and class–subclass relationships. According to [17], the Wikidata author community has problems with clear distinction for hundreds of thousands of relationships. In addition, the Wikidata taxonomy contains cycles: more than 47 pairs of classes are subclasses of each other, for

⁴ Great Russian Encyclopedia Portal. <https://bigenc.ru/>. Accessed October 1, 2024.

example, *method* and *technique*; there are 15 cycles of length 3 or more, for example, *axiom*, *first principle*, and *principle*.

The authors of Wikidata [16] point out that Wikidata adopted a flexible scheme for knowledge representation, which, on the one hand, led to the ability to describe various types of information, but on the other hand, led to problems of data heterogeneity and inconsistency, which have yet to be resolved. Despite its shortcomings, Wikidata is used to create the Ark ontology.

5. STRUCTURE OF KNOWLEDGE GRAPHS

Let us consider the structure of scientific knowledge graphs using, as an example, the graph of the OpenAlex catalog of publicly available resources of scientific articles, authors, and organizations (the name refers to the Library of Alexandria). The catalog is a noncommercial successor to the Microsoft Academic Graph (MAG) database. The MAG graph includes six types of entities: knowledge area, author, organization, article, publication place (venue), and event (e.g., conference). The graph also includes citation links between articles; authors, publication places, and knowledge areas are indicated for articles. Data for the graph were originally collected from electronic libraries (ACM and IEEE) by the Bing search robot. Different copies of the same articles are glued together into one graph entity. A procedure for automatic resolution of ambiguous author names is performed.

Research areas in MAG are hierarchically organized into four levels (0–3, where level 3 has the highest granularity). The top two levels of the field hierarchy are manually created. At the top level (level 0) there are 18 manually selected fields (in alphabetical order): biology, business, geography, geology, computer science, engineering, art, history, mathematics, political science, psychology, sociology, chemistry, economics, ecology, materials science, philosophy, and physics. The knowledge areas of the lower hierarchical levels are collected automatically using keywords of articles.

By March 2024, OpenAlex included metadata for 209 million works, such as journal articles and books; 13 million authors; 124 000 sites hosting works, including journals and online repositories; and metadata for 109 000 organizations.

In Russia, a certain analogue of OpenAlex is the Moscow State University information system ISTINA [19, 20], the purpose of which is to collect, systematize, store, analyze, and issue upon request information characterizing results of activities of scientific and educational organizations. At present, the ISTINA system is a developed system of scientific information with 186 857 registered users, of whom 30 598 work at Lomonosov Moscow State University. In particular,

the system contains information on 91 519 books, 392 874 talks given at scientific conferences, 963 917 scientific articles, and 136 493 training courses.

6. PROTOTYPE OF THE MSU ARK OF KNOWLEDGE INFORMATION SYSTEM

Ontologies underlying the MSU Ark of Knowledge information system are developed as based on a comprehensive approach that emphasizes the close integration and interrelation of both formal and real-language paradigms. Accordingly, the team of developers of this system includes specialists in applied mathematics, cybernetics, applied linguistics, and programmers. In addition, an integral part of the process is ongoing consultations with experts in relevant fields of knowledge (including professors and members of Russian and international academies of sciences).

As a formal mathematical guideline in constructing the system, we used the logic of definitions and concepts [21, 22].

In the initial stages of ontology creation, we used Protégé, an open-source tool that provides a graphical interface for developing, editing, and visualizing ontologies. Protégé supports the standard Web Ontology Language (OWL). For building ontologies in the fundamental sciences within Ark, we used OWL2, a version with extended features and specifications compared to its predecessor.

Creating high-level ontologies is a particularly challenging task. Such ontologies integrate knowledge common to several subject areas and allow for its multiple and multi-faceted use. Examples of best-known large-scale top-level ontologies are Cyc, DOLCE, SUMO, and John Sowa's. However, general attempts to create a top-level ontology applicable to all life scenarios have not yet yielded the expected results.

Currently, ontologies for specific groups of fundamental sciences (called level 3 ontologies) are under development. In our work, this process starts with mathematics, since most other disciplines rely on mathematical knowledge in its current state and evolution.

According to our concept of the information system, the ontology of scientific knowledge is constructed in line with the following requirements. The ontology

- offers flexible options for input and organization of information by both users and software agents, while presupposing the preservation of all versions, explicit recording of verification and approval in the next version, and direct user access to the last verified version;
- provides a unified data representation, public openness of formats with priority for using standardized ones, compatibility, and the possibility of integration with other ontologies, which is especially import-

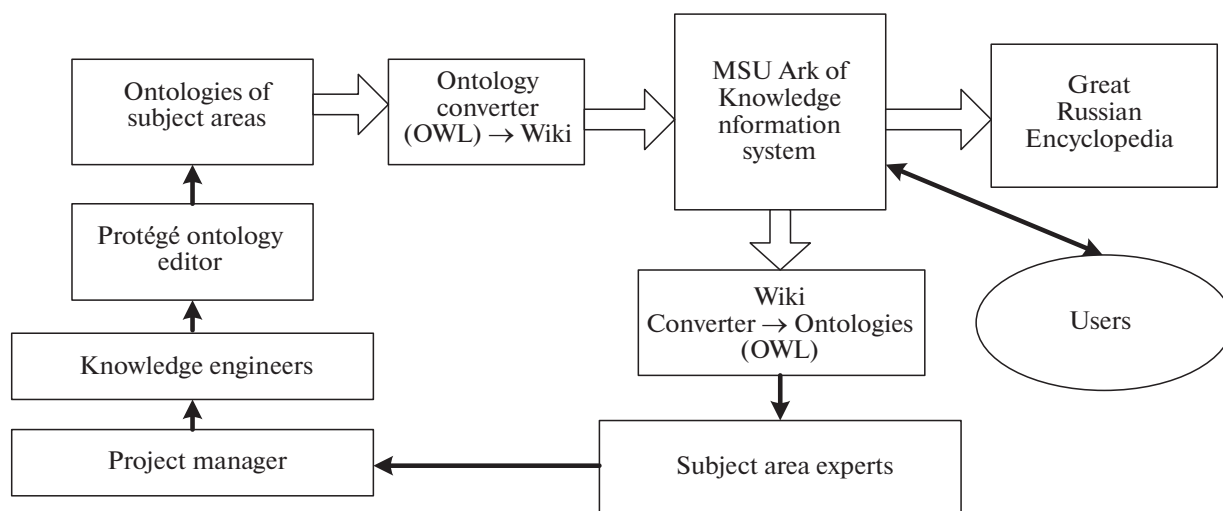


Fig. 1. Development and improvement of the Ark of Knowledge system.

ant for interdisciplinary research; integration with the MSU ISTINA system is initially provided;

- provides various options for rights to use posted information, with priority given to the open license;
- aims at solving problems in information analysis, classification, and extraction in response to user requests. In particular, it is planned to use the system for exploratory search [23], which provides users with valuable insights and recommendations;
- provides a user-friendly interface and technical support.

A system such as the Ark contributes to the formation of a holistic scientific space where knowledge is not only preserved, but also actively enriched and constantly verified, becoming accessible to researchers and specialists from related fields. The construction of an ontological system plays a significant role in the creation of this information system [24]. The specified processes and their interaction in creating and improving the MSU Ark of Knowledge are presented in Fig. 1.

At present, the first prototype of the information system has been developed and put into operation. It allows MSU researchers and specialists from our partners to participate in filling the Ark of Knowledge with information. An example of the system interface is given in Fig. 2.

The work on creating the system is carried out by researchers and programmers of the Knowledge Engineering Laboratory of the Institute for Mathematical Research of Complex Systems of Moscow State University headed by Academician of the RAS A.L. Semenov.

7. CONCLUSIONS

As a result of the conducted research, the following conclusions can be drawn.

1. The basis for the Moscow State University Ark of Knowledge system: in the course of the work, the foundation for the creation of the information system was laid. Key areas of research on the formation of ontologies in various natural science areas were identified. An initial working prototype of the information system was developed.

2. Structuring the MSU Ark of Knowledge system: the proposed structuring approach allows us to design a system that provides efficient storage, search, and sorting of scientific information for a wide range of users, including support for GRE authors.

3. Digital platform and collaboration: the MSU Ark of Knowledge system is built on a digital platform developed by MSU. The initial prototype facilitates collaboration on databases for specialists involved in the formation, development, and maintenance of a unified network structure.

4. Training language models: large text datasets, including information from Wikipedia, are used to train language models. The creation of the MSU Ark of Knowledge database involves the collection and systematization of knowledge in various areas of fundamental science by the MSU expert community. This database will also serve as training material for language models capable of processing and interpreting complex scientific concepts.

5. Textbook in the field of scientific knowledge: the creation of the MSU Ark of Knowledge database, which is formed by the MSU expert community, may lead to the creation of a Russian-language textbook on ontologies of fundamental scientific knowledge for higher education.

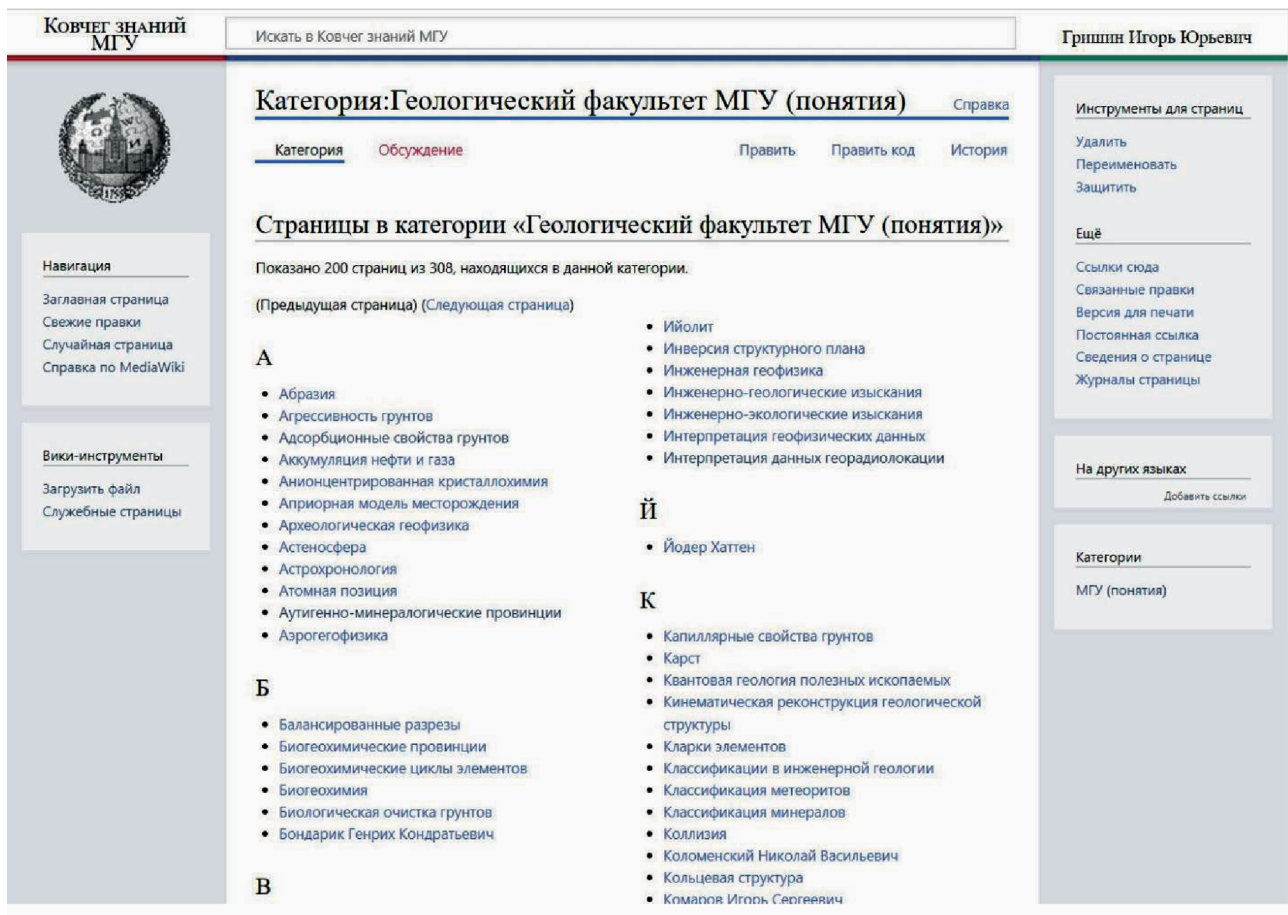


Fig. 2. Example of interface of the Ark of Knowledge information system.

6. Continuous improvement: the creation and development of the Ark is a cyclical process, which allows for continuous updating and improvement of ontologies and the content of the system. Consultations with experts and regular analysis of submitted materials ensure the high quality of provided data, which is critical to maintaining the relevance of the system.

7. Prospects for further development: in the future, it is planned to expand the functionality of the system, including integration with external data sources, such as databases of other scientific institutions, which would provide a more complete and up-to-date presentation of information. The possibility of creating a mobile application for convenient access to the Ark from various devices is also being considered, which would increase the availability of the system to a wider audience.

8. Impact on the scientific community: The MSU Knowledge Ark system has the potential to significantly impact the scientific community by facilitating knowledge sharing and promoting interdisciplinary research. The creation of a single platform for storing and processing scientific information will facilitate a deeper understanding and research of complex prob-

lems, which in turn will help in solving global challenges.

We consider the MSU Ark of Knowledge project as an important step towards creating a unified system for structuring and storing scientific knowledge. It is designed not only to preserve valuable data and research results, but also to facilitate access to them for a wide range of specialists and researchers, promoting new discoveries and interdisciplinary research. Thanks to the ontological approach to organizing and supporting information, the Ark can become a key tool for working with large amounts of scientific data and providing a source of high-quality knowledge, which is especially important in the context of the rapid development of science and technology.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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