

Developing an ontology-based system for semantic processing of scientific digital libraries

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ABSTRACT

The development of theories, methods, and algorithms for the discovery and formation of new knowledge remains one of the most important tasks for any researcher, especially if they are actively working to create new scientific publications. Yet, there is no universal language to describe full formal concepts (i.e. knowledge) or the systemology of transdisciplinary scientific research. Because of this, researchers face a set of urgent challenges. One such challenge is how to speed up the process of finding information in their own sources. To address this challenge, we created an ontology-related system for processing digital libraries of scientific publications. This system implements the technologies of information retrieval and knowledge discovery in digital libraries with an emphasis on technologies and instruments such as those used in the Semantic Web and cognitive graphics.

Keywords: Transdisciplinary research, Semantic Web, Ontology engineering, SPARQL, Digital library

Categories: • Information systems ~ Information retrieval, Document representation, Ontologies

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1 INTRODUCTION

Many applications are available to search for information in different databases, and some are quite specialised. Most do not take into account the cognitive aspect of data processing that is needed for creative approaches, in particular for researchers.

A separate problem is the multimedia (conceptual and figurative) presentation of the search results, and their comparison with the conceptual structure of the subject area or knowledge domain. This interests us for the purposes of gaining new knowledge. For scientific research,

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it is relevant to process the scientific publications of one author, authors of a scientific unit, or of an institute by using the Semantic Web, known as Web 3.0 (W3C, 2023b), technology.

An ontology-related system (OrS) for processing digital libraries (i.e. databases or other types of digital repositories) of scientific publications (DLSP) uses technologies of information retrieval and knowledge discovery in databases with an emphasis on technologies and instruments of the Semantic Web and cognitive graphics (Palagin et al., 2014; V. Y. Velychko et al., 2014). This technology and corresponding instruments allow for the creation of multimedia presentations of conceptual and figurative structures, which are described in scientific papers. Semantic Web technologies allow for the creation and processing of the Resource Description Framework (RDF) (W3C, 2023a) repository of scientific publications, development of local and/or remote endpoints, and the assembling and execution of SPARQL-queries. Of the entirety of Semantic Web technologies, we need to highlight SPARQL-technology, which allows a researcher to create queries of arbitrary complexity and to receive a response that can include all kinds of information.

A generalised diagram for the development of OrS DLSP is shown in **Figure 1**, where SP denotes 'scientific publication'. It includes the preparation stage block and blocks of the main stage with variations A, B, and C. The preparation stage is described in detail in previous studies (Palagin et al., 2014; Palagin & Petrenko, 2020; Palagin et al., 2011) where ontology graphs of the subject area are provided. They serve as data for implementation of the main stage, variation B, *phase 2 (B2)*.

We can know about the personal knowledge database of a specific researcher, in which a sum of functional capabilities is declared. These capabilities support processes of scientific and creative activity. Such a personal knowledge database is:

- A tool that supports scientific research, and one of the central directions of practical informatics development (Palagin et al., 2017; Palagin et al., 2014; Palagin et al., 2020; Palagin, Velychko et al., 2018);
- A knowledge system development for researchers, for the purposes of new knowledge gain (or arrangement of existing knowledge, error checking and checking for contradictions, etc.) (Palagin, 2006, 2013; Palagin & Petrenko, 2018; V. Velychko et al., 2022);
- One of the main subsystems for the modern system of research design (Palagin, 2016; Palagin, Petrenko & Malakhov, 2018), and an automated workplace for researchers (Palagin et al., 2017; Palagin et al., 2020; Palagin, Velychko et al., 2018);
- One of the main elements for the creation of permanent canonical knowledge and support for knowledge-oriented information system functioning.

It is common knowledge that there is a tight connection between Semantic Web and Unified Modelling Language (UML) technologies. In particular, this is a connection between the Web Ontology Language (OWL) (W3C, 2022) syntax and the visual modelling of UML diagrams. UML is presented as a general-purpose language of visual modelling, which is developed for

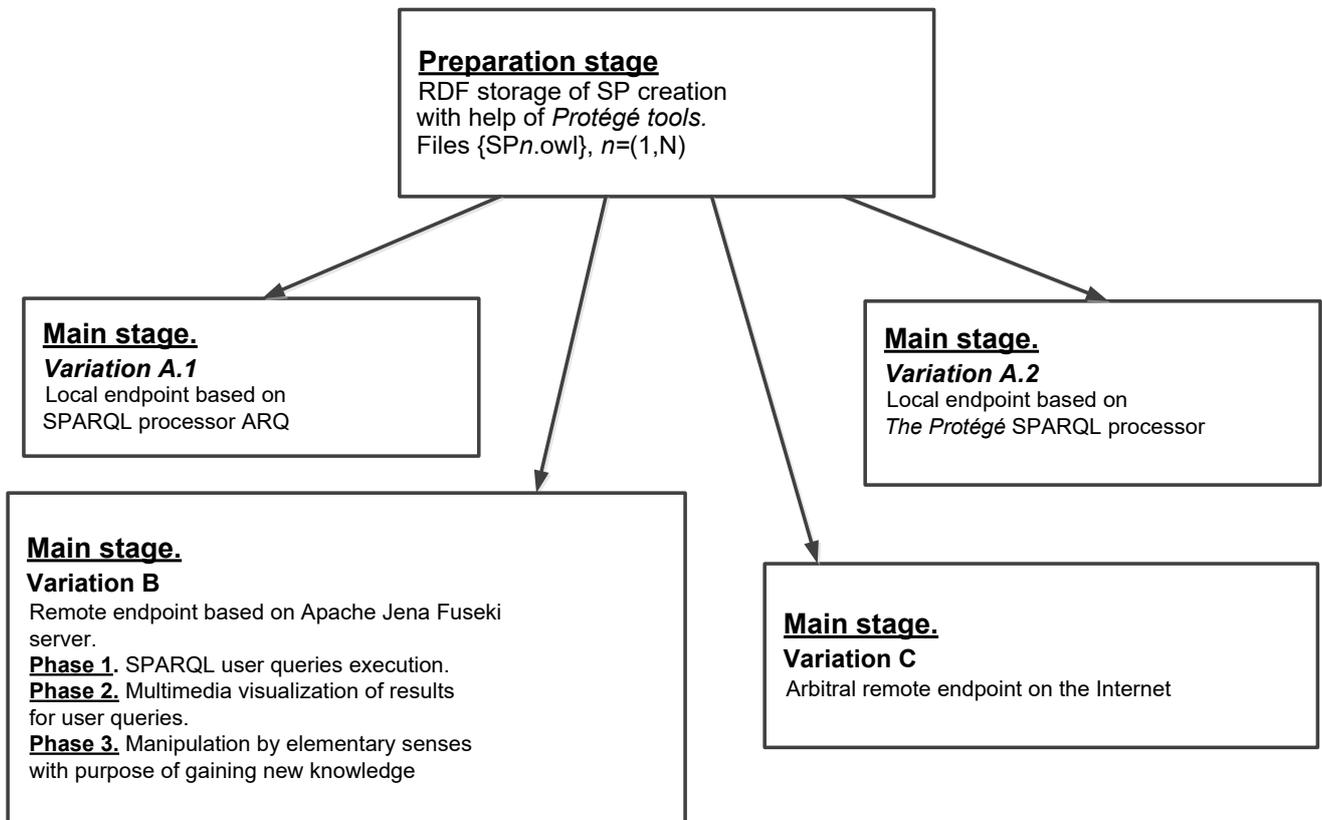


Figure 1: Generalised diagram of OrS DLSP development

the specification, visualisation, designing, and documenting of software components, business processes, and other systems (Booch et al., 2005). UML is an easy and powerful tool for modelling, which can be used effectively for the creation of conceptual, logical, and graphical models of complex systems that are built for different purposes. This language absorbed all the best software engineering methods and qualities, and has been successfully used for many years to model large and complex systems (Booch et al., 2005; OMG, 2022).

Visual modelling in UML can be presented as a process of a gradual descent from the most general and abstract conceptual model of the source system to the logical, and later physical model of the corresponding software system. For this purpose, a model in a form of a use case diagram is built first. This diagram describes the functional purpose of the system, and what this system will perform in a process of its functioning. A use case diagram is a conceptual presentation, or a conceptual model of the system in the process of its design and development (Schmuller, 1999).

An OrS “database of scientific publications” is created for an author who is actively engaged in the preparation and production of new scientific publications. Of course, searching through one’s own scientific publications can be done manually, which in most cases is how it

is presently done. However, with the help of OrS, this search can be accelerated significantly. In addition, it is possible to automatically structure received data into appropriate templates for future scientific papers.

Now we will discuss the development of architectural, structural components, and UML diagrams. These diagrams show OrS functioning on the base of remote Apache Jena Fuseki (Apache.org, 2022a) endpoints. In addition, we will discuss examples of the formal description of scientific paper usage by performing a set of queries.

The goal of this article is OrS development. The system allows significant acceleration of information retrieval by an author (from his DLSP), provides a visual presentation of scientific publication concepts and respective subject areas, and implements the famous Brooks formula for acquiring new knowledge (Palagin, 2006; Palagin & Petrenko, 2018):

$$K(S) + dI = K(S + dS)$$

where $K(S)$ denotes the source knowledge structure, which is modified by results of information processing of portion dI , creating new structure $K(S + dS)$ with new knowledge portion dS . It is assumed that components dI and dS are closely tied with elementary senses – a simple two-syllable sentence with a direct object (Palagin & Petrenko, 2020).

The main stage of user task performance is split into three OrS architecture variations – *A*, *B*, and *C*. These variations have different functional power. *A* is the least powerful (organised as a local endpoint on the user's PC). *B* is of average power (organised as a remote endpoint based on an Apache Jena Fuseki server). *C* is the most powerful (organised as a remote endpoint, which is implemented with the help of original software). We can see that these variations of OrS realizations fit different purposes.

The *A* architecture scenario applies to one user in a local network with a knowledge engineer (*KE* is an expert in artificial intelligence language and knowledge representation who investigates a particular problem domain, determines important concepts, and creates correct, and efficient representations of the objects and relations in the domain). In this scenario, the user can form queries and receive answers only by working with one scientific publication at a time.

The *B* architecture scenario can be employed by a few users of the same scientific unit. When applying the *B* variation, it becomes possible to form one query for retrieval of structured information from multiple articles simultaneously, which is impossible to do with popular search systems.

The most powerful *C* architecture scenario can be used by users from an entire institute. The primary focus of this paper is to describe the processes with UML diagrams usage for variation *B*, *phase 1 (B1)*.

2 ARCHITECTURAL AND STRUCTURAL ORGANISATION OF OrS DLSP (VARIATION B, PHASE 1)

For this variation, the OrS functions as a remote endpoint based on Apache Jena Fuseki (Apache.org, 2022a), and consists of three phases: *phase 1* – SPARQL (Apache.org, 2022b) user queries processing; *phase 2* – multimedia visualisation of user query results, or creation and usage of conceptual and figurative structures for the subject area; and *phase 3* – manipulation by elementary senses with the purpose of gaining new knowledge.

In **Figure 2** the *B1* variation of the OrS is presented. Initially, the knowledge engineer downloads the relevant files and deploys Apache Jena Fuseki as a remote endpoint (DuCharme, 2013). The knowledge engineer then uploads scientific publications in the form of RDF graphs to the server; this data is generated in the preparation stage.

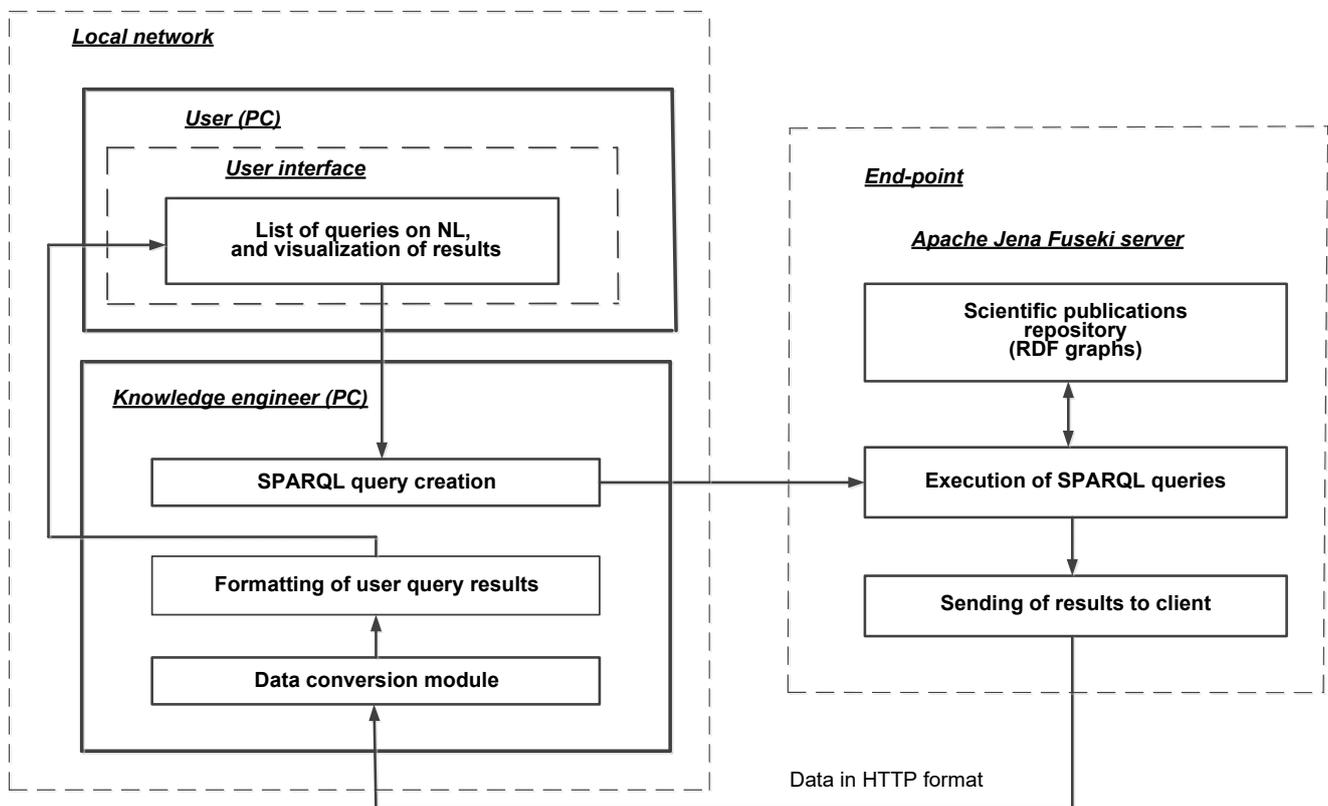


Figure 2: Generalised diagram of the *B1* variation of the OrS for processing digital libraries of scientific publications

The user can see the list of possible queries in natural language in their user interface. The user can choose any query from this list, one-by-one. The chosen query is transferred via the network to a knowledge engineer module. The user systematically validates the information

they are working with. Since it is possible to choose a subset of articles used for a search, this feature is useful if a researcher does not need to search in all databases.

2.1 Basic user queries

The researcher database contains N scientific papers published in popular scientific journals. Serial numbers of scientific publications (in this case we deal with articles) serve as arguments for queries and are numbered as follows:

$$m_1, m_2, \dots, m_k, \dots, N-1, N$$

Data is organised in such a way that the author of a scientific publication is the first co-author of the publication, or in another case, the author is the one who owns the database.

Below are examples of queries in natural language (NL).

1. Show titles of articles on the topic of “transdisciplinarity”.
2. Show titles of articles on the topic of “ontological”.
3. Show annotations of articles $m_1, m_2, \dots, m_k, \dots$
4. Show keywords of articles $m_1, m_2, \dots, m_k, \dots$
5. Show titles of all N articles:
 - 5.1. in the order of publication date
 - 5.2. without co-authors.
6. Show titles of articles $m_1, m_2, \dots, m_k, \dots$, where (query arguments are set by a user).
7. Show full names of co-authors for articles $m_1, m_2, \dots, m_k, \dots$

3 UML DIAGRAMS OF THE OrS FUNCTIONING FOR VARIATION B1

We now discuss UML diagrams, which reveal the core of OrS functions for variation *B1*.

Figure 3 is a use case diagram; **Figure 4** is a class diagram; **Figure 5** is a components diagram, and **Figure 6** is a sequence diagram (Figures are in **Appendix A**).

A discrete number of researchers are connected to a local network, which is administrated by a knowledge engineer. We will discuss the network operation for one user; the processes are organised in a similar fashion for other users.

For researchers, the PC functions as the module of the general interface. All the queries on NL are displayed in the interface, from which the researcher can choose one with desired arguments; a different element of the interface shows results of the query execution.

Another part of the system contains a module for the knowledge engineer. In this module, a *SPARQL*-query is formed out of the NL-query and transferred over HTTP protocol to the endpoint. On the Apache Jena Fuseki server, the *SPARQL*-query is executed and the response is sent via HTTP protocol to the knowledge engineer module and corresponding interface. The operation of forming and processing user queries, and receiving replies are shown in detail in the main UML diagrams in [Figure 3](#) through [Figure 6](#).

It is important to note that these diagrams do not show the process of argument selection and their transformation into article numbers in the database.

4 EXAMPLES OF SPARQL-QUERIES EXECUTION AND THEIR RESULTS

Below are some typical requests to the DLSP using the natural language requests and their corresponding representation in the form of *SPARQL*-queries. It is important to note that all NL and *SPARQL* queries are made to the digital library that contains articles in Russian and Ukrainian languages. The DLSP by [Alexandr Palagin](#) was taken as a basis for these examples. Requests to endpoints can be made either using the ARQ (Apache.org, 2022b) query engine or directly from the Fuseki user interface (which is shown in [Figure 7](#)). The Apache Jena Fuseki *SPARQL* server address is <https://triplestorage.ai-service.ml/>. Credentials for access can be provided on request.

Important note: The Jena Fuseki *SPARQL* server is in active development. For any technical clarifications and questions contact the first author via email. The recent Russian rocket shelling on critical infrastructure in Ukraine and Kyiv led to the shutdown of the <https://triplestorage.ai-service.ml/> server.

SPARQL-query:

```
1 PREFIX
2 <http://www.semanticweb.org/mykola/ontologies/2022/5/19/ontology-36#>
3 SELECT ?article_number ?article_title
4 {GRAPH ? article_number {?s1 : article_title ? article_title.
5 FILTER REGEX(?article_title, "transdisciplinarity", "i")}}
```

Listing 1: **NL-query 1:** Show titles of articles on the topic of “transdisciplinarity” (results are shown in [Table 1](#)).

SPARQL-query:

```
1 PREFIX:
2 <http://www.semanticweb.org/mykola/ontologies/2022/5/19/ontology-36#>
3 SELECT DISTINCT ?article_number? article_title
4 {GRAPH ? article_number {?s1 : article_title? article_title.
5 FILTER REGEX(?article_title, "ontological", "i")}}
```

Listing 2: **NL-query 2:** Show titles of articles on the topic of “ontological” (results are shown in [Table 2](#)).

SPARQL-query:

```

1 PREFIX:
2 <http://www.semanticweb.org/mykola/ontologies/2022/5/19/ontology-36#>
3 SELECT ?article_number ?article_title (group_concat(?abstract) as ?abstract_full)
4 FROM NAMED <https://triplestorage.ai-service.ml/articles/data/article1>
5 FROM NAMED <https://triplestorage.ai-service.ml/articles/data/article2>
6 FROM NAMED <https://triplestorage.ai-service.ml/articles/data/article7>
7 {GRAPH ? article_number {?s1 : article_title ? article_title.
8   {Abstract : sentence_exists ?sentence}
9   {?sentence :text_exist ?abstract}}} group by ?article_number ? article_title
    
```

Listing 3: **NL-query 3:** Show annotations of articles 1, 2, 7 (results are shown in **Table 3**).

SPARQL-query:

```

1 PREFIX:
2 <http://www.semanticweb.org/mykola/ontologies/2022/5/19/ontology-36#>
3 SELECT ?article_number ? article_title ? keywords
4 FROM NAMED <https://triplestorage.ai-service.ml/articles/data/article1>
5 FROM NAMED <https://triplestorage.ai-service.ml/articles/data/article2>
6 FROM NAMED <https://triplestorage.ai-service.ml/articles/data/article7>
7 {GRAPH ? article_number { ?s1 :Keywords_title ?Keywords OPTIONAL
8   {?s2 :article_title ?article_title}}}
    
```

Listing 4: **NL-query 4:** Show keywords of articles 1, 2, 7 (results are shown in **Table 4**).

Table 1: Query results for NL-query 1

article_number	article_title
article1	Methodological foundations of development, formation and IT support trans-disciplinary research
article2	Transdisciplinarity, informatics and development of modern civilization
article36	Problems of transdisciplinarity and the role of informatics
article7	Introduction to the class of transdisciplinary ontology-driven research systems design

Table 2: Query results for NL-query 2

article_number	article_title
article5	About some features of the construction of ontological models of subject areas
article7	Introduction to the class of transdisciplinary ontology-driven research design systems
article8	Ontological concept of informatization of scientific research
article10	Architecture of ontology-driven computer systems
article16	On the issue of system-ontological integration of domain knowledge

Table 3: Query results for NL-query 3

article_number	article_title	abstract_full
article1	Methodological foundations for the development, formation and IT support of transdisciplinary research	The foundations of the methodology of a transdisciplinary systematic approach to the formulation and implementation of scientific research and complex applied projects have been developed with an emphasis on their IT support using methods and tools of artificial intelligence, in particular, ontological engineering ...
article2	Transdisciplinarity, informatics and the development of modern civilization	The prospects and problems of the development of human civilization have always worried society ...
article7	Introduction to the class of transdisciplinary ontology-driven research design systems	The class of research design systems based on the use of paradigms of transdisciplinarity, ontological management and purposeful development is considered ...

Table 4: Query results for NL-query 4

article_number	article_title	article_keywords
article7	Introduction to the class of transdisciplinary ontology-driven research design systems	transdisciplinarity, ontological management, virtual structures (paradigm), developing systems, noospherogenesis, noosphere, scientific picture of the world, transdisciplinary approach (knowledge), convergence clusters, ontological approach
article2	Transdisciplinarity, informatics and the development of modern civilization	transdisciplinarity, computer science, monitoring, convergence cluster, computer ontology, knowledge engineering, Unified National Informatization Network, global network of transdisciplinary knowledge
article1	Methodological foundations for the development, formation and IT support of transdisciplinary research	scientific picture of the world, information technology, developing information system, transdisciplinarity, transdisciplinary research, transdisciplinary knowledge, convergence cluster, ontology, ontological concept, ontology-oriented support

5 CONCLUSION

The goal of our research was to develop an ontology-related system for processing digital libraries (i.e., databases or other kinds of digital repositories) of scientific publications, which will allow researchers to significantly increase the retrieval speed of required information (in the form of cognitive structures) from their sources.

This article introduced and described the architectural and structural organisation of OrS, which includes the local network with PCs of user and administrator/knowledge engineer, and remote endpoints based on the Apache Jena Fuseki server. This was shown via core UML diagrams of OrS functioning and examples of user query execution.

6 FURTHER RESEARCH

This research is far from its end goal. As we explained, it is necessary to implement phases 2 and 3, and for that we need to develop algorithms of creation for conceptual and figurative structures; algorithms of their comparison; an analysis with the further intention of building subject area knowledge; and algorithms for the discovery of new knowledge following the Brooks formula.

In a future study, our team plans to implement the ontology-related system as a part of the knowledge-oriented digital library of the smart-system for remote support of rehabilitation activities and services (Chaikovsky et al., 2023; Malakhov, 2022, 2023; Malakhov et al., 2022; Palagin et al., 2022). Further research will aim to develop original instruments and tools with the purpose of optimising user queries, and optimising usability for ontology-related systems.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Mykola Petrenko: Supervision, Conceptualization, Methodology, Writing – original draft, Validation. Kyrylo Malakhov: Software, Validation, Resources, Term, Writing – review and editing. Ellen Cohn: Writing – review and editing.

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- Transdisciplinary intelligent information and analytical system for the rehabilitation processes support in a pandemic (TISP), application ID: 2020.01/0245 (2020–2021, project was successfully completed).
- Development of the cloud-based platform for patient-centered telerehabilitation of oncology patients with mathematical-related modelling, application ID: 2021.01/0136.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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A APPENDIX

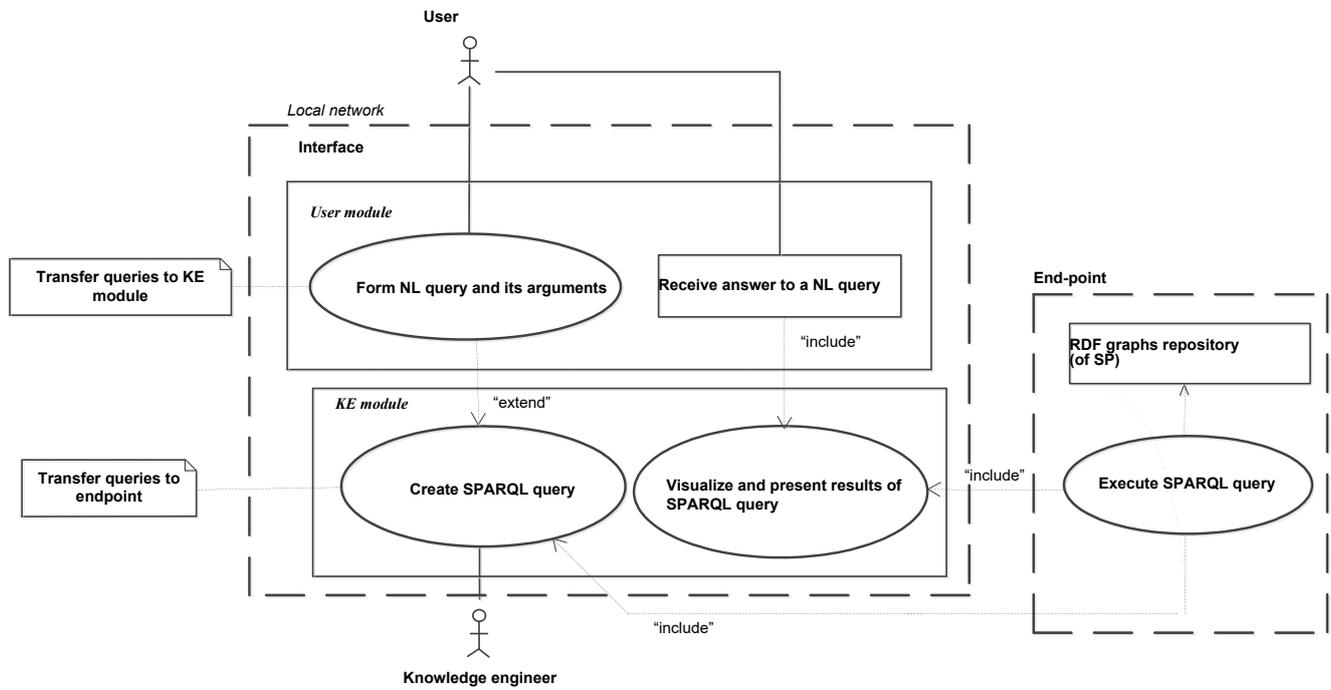


Figure 3: Use cases diagram of ontology-related system for processing digital libraries of scientific publications

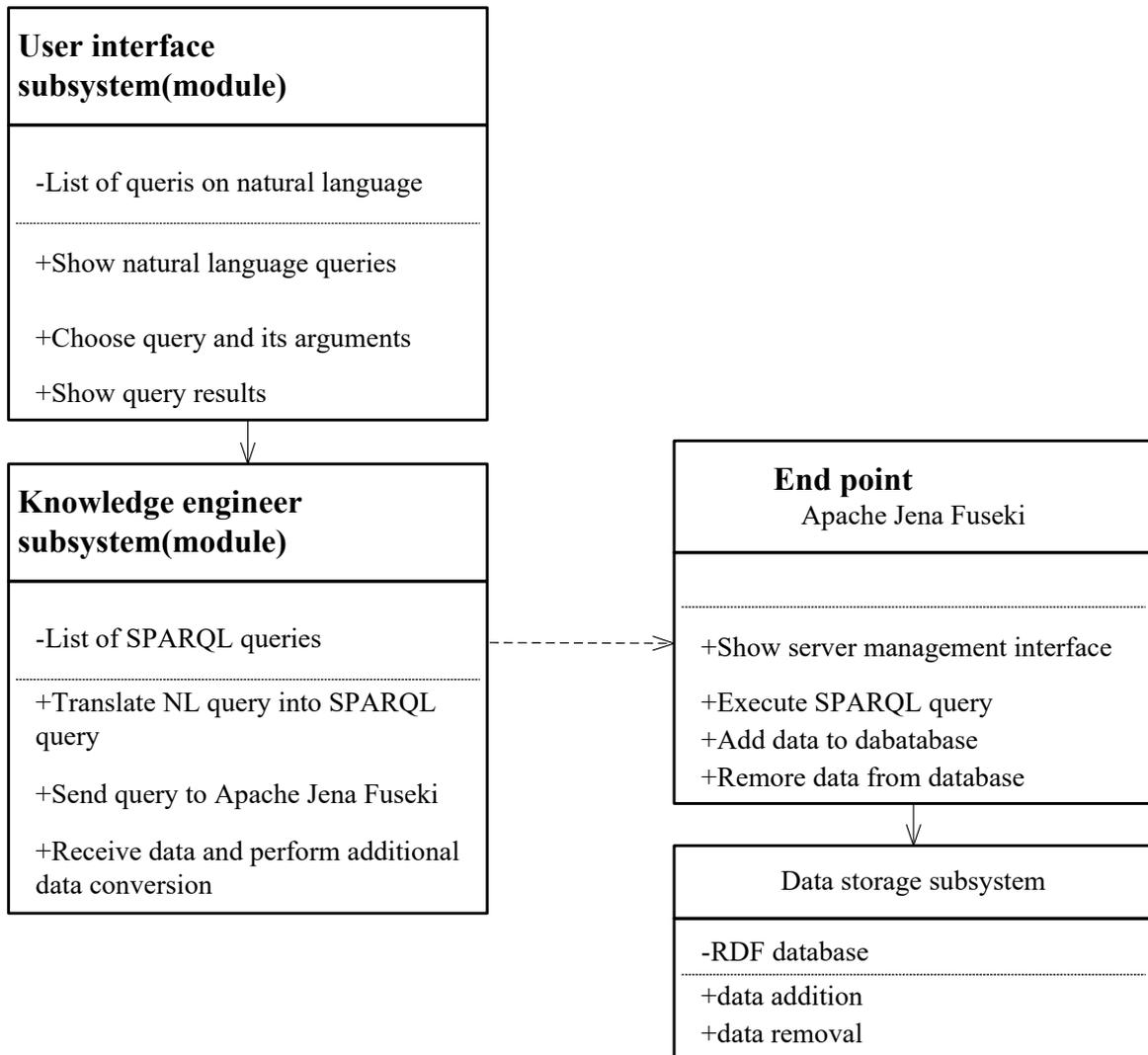


Figure 4: Class diagram of ontology-related system for processing digital libraries of scientific publica-tions

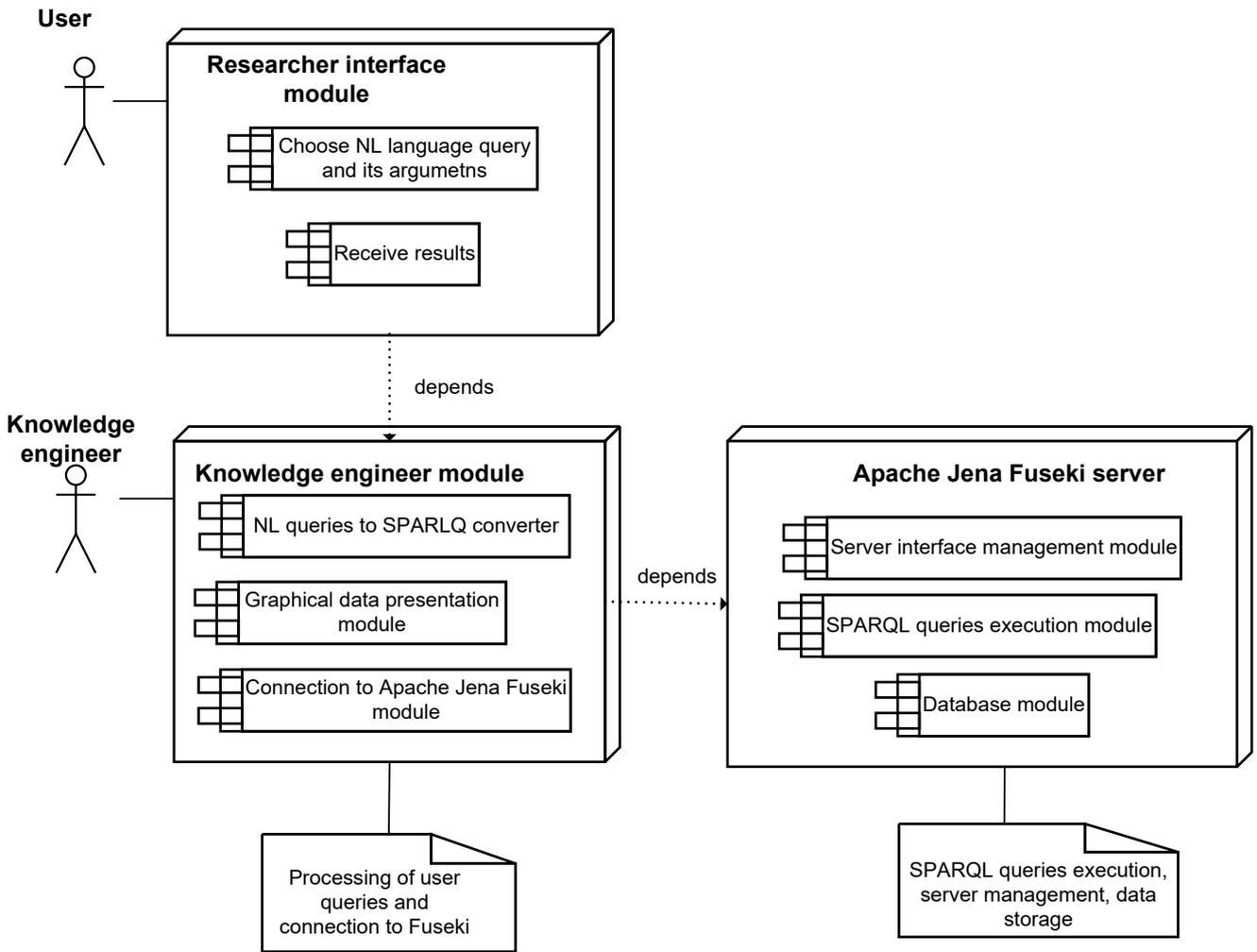


Figure 5: Components diagram of ontology-related system for processing digital libraries of scientific publications

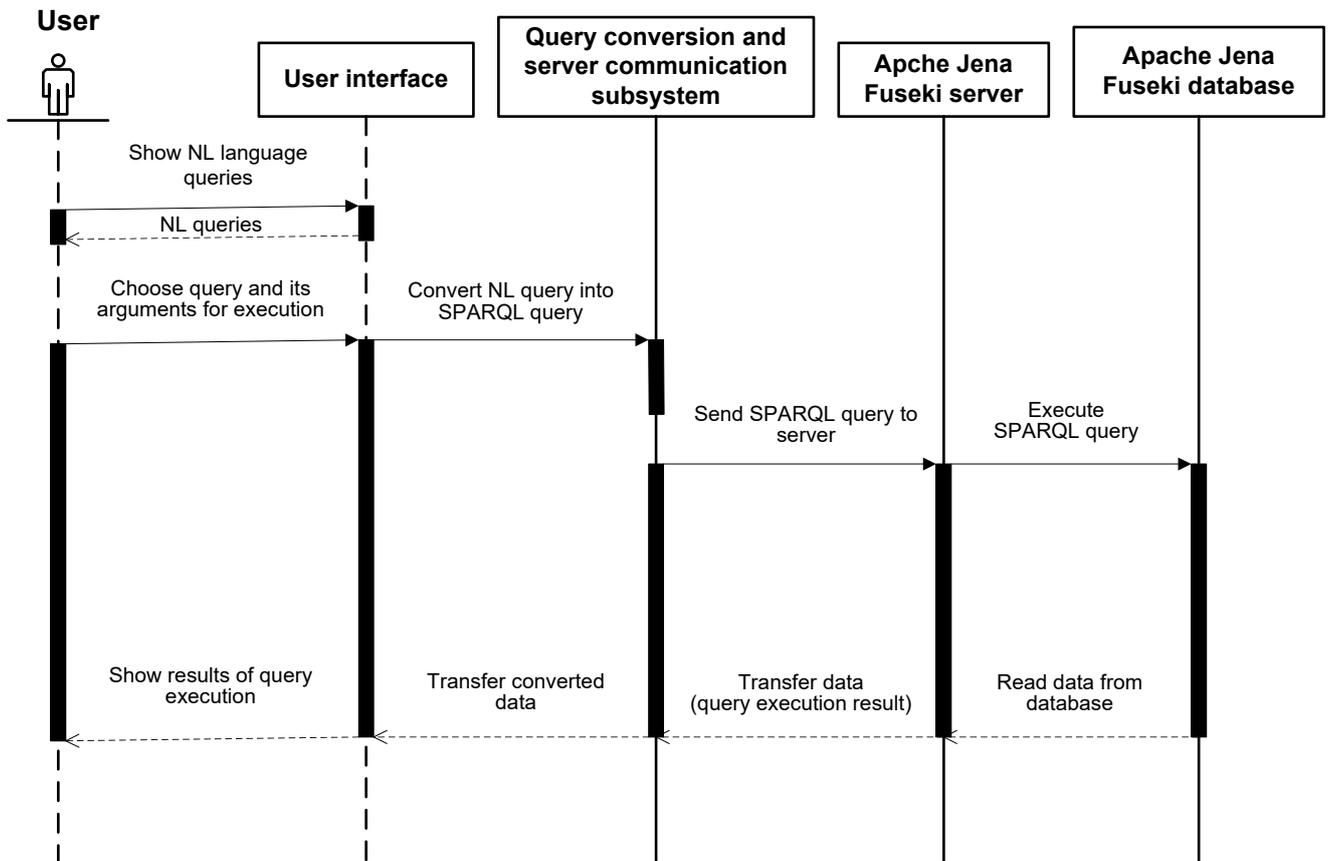


Figure 6: Sequence diagram of ontology-related system for processing digital libraries of scientific publications

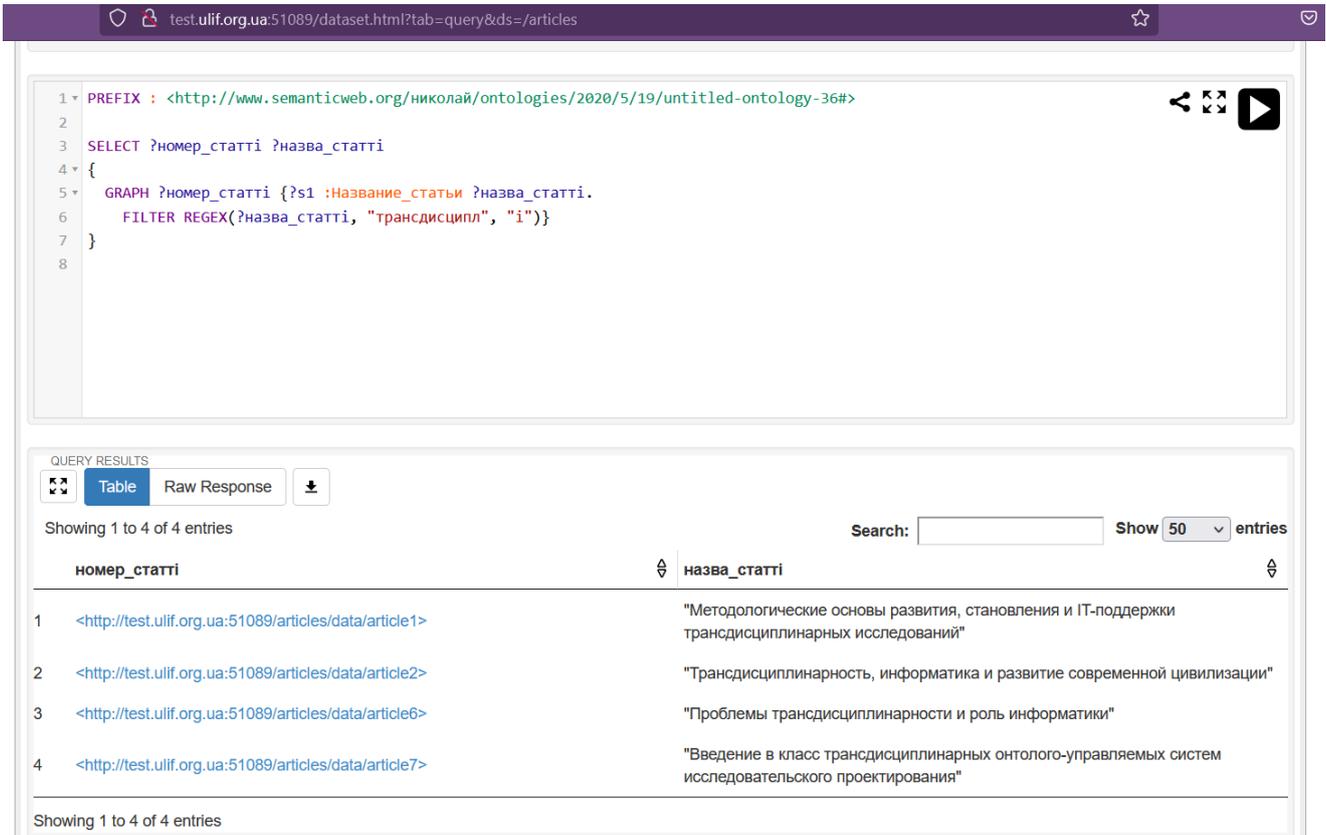


Figure 7: Fuseki user interface (NL-query: Show titles of articles on the topic of “transdisciplinarity”)