



**Paisii Hilendarski University of Plovdiv**

Faculty of Mathematics and Informatics

Department of Computer Systems

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**RESEARCH ON THE CREATION OF SEMANTIC MODELS  
IN THE FIELD OF HUMANITIES**

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**ABSTRACT**

of the doctoral dissertation for the awarding the educational and scientific degree of Doctor  
(PhD)

Field of Higher Education 4. Natural Sciences, Mathematics and Informatics

Professional Direction 4.6. Informatics and Computer Science

Doctoral Programme: Informatics

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Plovdiv

2023

The dissertation has been discussed and directed for defense before a scientific jury at a meeting of the Department of Computer Systems at the Faculty of Mathematics and Informatics, Plovdiv University "Paisii Hilendarski", in the city of Plovdiv on October 27, 2023.

The dissertation contains 201 pages. The bibliography includes 162 sources. The list of the author's publications consists of 6 titles.

The defense of the dissertation will take place on February 9, 2024, in the Conference Hall of the New Building of Paisii Hilendarski University of Plovdiv.

The materials for the defense are available to interested parties in the secretariat of the Faculty of Mathematics and Informatics – office 330 in the New Building of Paisii Hilendarski University of Plovdiv every working day from 08:30 a.m. to 5:00 p.m.

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**Title:** “Research on the Creation of Semantic Models in the Field of Humanities”

Plovdiv, 2023

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# INTRODUCTION

Computer technologies have become an indispensable part of people's lives. Science and education are fields where computer technologies are increasingly applied. One rapidly developing approach to providing new knowledge is semantic models. They allow existing knowledge to be structured into a specific model that can be easily expanded with new concepts in the future. One of the main ideas behind the construction of this dissertation is the structuring and presentation of the rich history of today's Humanities High School Sts. Cyril and Methodius in Plovdiv and the life and activities of its students and teachers as a semantic model. Another important topic examined in the dissertation is how this structured information in the specific area can be used to enable the automatic generation of questions in Bulgarian, through which the knowledge of students can be tested and assessed.

## **Dissertation purpose**

**Main purpose behind the dissertation** is to conduct a study on semantic models that find application in the humanities.

To achieve this purpose five specific tasks have been devised:

- **Task 1:** Creation of a semantic model in the form of an ontology in the field of humanities.
- **Task 2:** Creation of algorithms for the automatic generation of questions from the ontology in Bulgarian language.
- **Task 3:** Creation of an application that uses predefined configurational structures to create the ontology and insert information into it.
- **Task 4:** Creation of an application that is used for extracting information from the ontology based on different algorithms.

## **Dissertation structure**

The proposed research work is divided into several logical components, which are examined in the separate chapters of the dissertation:

- **Introduction** - The introductory part of the dissertation presents the necessity and benefits of using semantic models in the fields of science and education. It defines the aim of the dissertation and describes the main tasks that will be followed to achieve this aim. It also outlines the strategy for the conducted research.
- **Chapter 1. Current state of the research area** - the section serves to acquaint the reader with what the Semantic Web and semantic modeling are. It examines technologies used to represent information as semantic models. It presents ontologies as semantic models. The need

for semantics in e-learning is presented, and various approaches to automatically generating questions from ontologies are researched and examined.

- **Chapter 2. Ontology structure** - This section describes the structure of the constructed ontology (classes, properties, and individuals), the approaches used within it to categorize the available information, and what relationships have been established to logically connect the information.

- **Chapter 3. Algorithmic queries for generation of different sentence types.** - This section describes the different types of questions and the algorithmic structures written in SPARQL that can be used to extract information from the ontology and to verify the correctness of a given answer.

- **Chapter 4. Applications for the generation of an ontology and data retrieval from it.** Presents logical diagrams of two applications. One of them, named "OntologyGenerator," describes the creation of JSON structures. By populating these structures with configured information, a new ontology can be created. The second application is called "OntologyReader" and it is used to extract information from the ontology using SPARQL queries.

- **Chapter 5. Анализ и проверка на предложения подход** – a new ontology has been introduced, which was created using the "OntologyGenerator" application. The extraction of information from it in the form of questions has been performed with the "OntologyReader" application. This chapter additionally examines the structure of the information returned from each algorithm, as well as the advantages of the proposed algorithms, their shortcomings, and how they can be improved in the future.

- **Conclusion** – Summarizes the results of the work done for the dissertation.

## **CHAPTER 1: CURRENT STATE OF RESEARCH AREA**

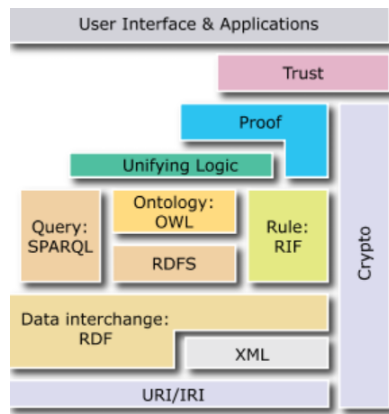
### **1.1 Semantic WEB**

The internet is increasingly becoming an integral part of people's lives. The popularity of the global network is due to the services it provides.

The term "Semantic Web" was indeed introduced by Tim Berners-Lee, the inventor of the World Wide Web (WWW) and the director of the World Wide Web Consortium (W3C). He describes the Semantic Web as a "web of data" that can be processed directly or indirectly by machines [1][2]

The Semantic Web enables data to be represented as knowledge and to be automatically processed. Key terms in the Semantic Web include: semantics [3], metadata [4], ontology, and the performance of automated logical inference (reasoning) through reasoning machines (reasoners) and software agents (agents).

The main standards and languages that the Semantic Web is based on are presented in (**Figure 1**).



**Figure 1.** Architecture and standards for the semantic web

- XML is used for structuring web documents [5];
- RDF (Resource Description Framework) allows the creation of a data model with imposed structural constraints, with the aim of providing unambiguous methods for semantic expression; [6];
- RDF Schema (RDFS) provides a language for defining vocabularies to describe the classes and properties of RDF resources; [7];
- OWL (Web Ontology Language) extends RDFS by allowing the definition of more complex relationships between web objects, thus representing a powerful language for creating ontologies [8];
- SPARQL is a protocol and query language for semantic web data sources. [9].

## 1.2 Ontologies

In contemporary philosophical literature, the concept of ontology is defined as a certain system of categories that are a consequence of a particular system of views of the world. Thus, the real world can be divided into parts, their properties can be described, in order to represent their development and behaviour.

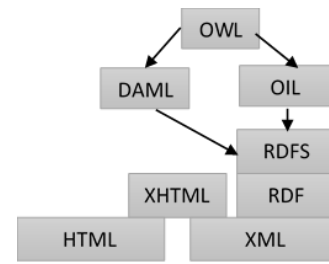
In computer science, ontology denotes a product that is created with the purpose of enabling the description of knowledge about a certain domain. The concept of ontology was introduced into computer science for the first time in 1993 by Thomas Gruber [10] and it represents an explicit specification of a certain conceptualization [11]. Ontologies clarify the structure of knowledge for a given domain and allow for the sharing of this knowledge. [12].

## 1.3 Ontology languages

The exchange of ontologies on the World Wide Web (WWW) and collaboration among heterogeneous agents within it is the primary reason for the development of a new set of languages for ontology specification. Languages for ontology exchange via the Web (**Figure 2**).

**XML** offers a superficial syntax for structured documents without imposing semantic constraints on the meaning of those documents.

**XML scheme** is a language that restricts the structure of XML documents and allows the use of datatypes in XML.



**Figure 2.** Languages for the exchange of ontologies via Web

**RDF** (Resource Description Framework) is a data model that contains objects (resources) and relationships between objects. This model provides simple semantics and can be represented using XML syntax.

**RDF scheme** (Resource Description Framework Schema) is a vocabulary that describes the properties and classes of RDF resources. It contains semantic information about the hierarchical generalization of these properties and classes.

**OIL** (Ontology Inference Layer) [13]

**DAML** (DARPA Agent Markup Language) is an emerging language for defining machine-readable ontologies on the web. [14]

**OWL** (Web Ontology Language) provides additional vocabulary elements for the description of properties and classes. The latest version of the language is OWL 2, which employs the open-world assumption. According [15] and [16], closed-world assumption embodies the idea that whatever we do not know is false, while the open-world assumption operates on the principle that whatever we do not know is undefined. The OWL language exists in three sublanguages. - **OWL Lite, OWL DL, OWL Full** [17].

#### **1.4 Applications of Ontologies in Various Fields**

Ontologies as models for knowledge representation and reasoning find wide application in various areas of social life. In the field of humanities and the presentation of cultural-historical objects, there are numerous developments where ontologies are used. A brief overview of the developed ontologies in the field of agriculture has been made. Ontologies in the field of education represent formal models of knowledge that describe the concepts and the relationships between concepts in the subject area. They help to structure and organize information by providing a semantic interpretation of the data. The application of ontologies in education can have various purposes and tasks. The ontological models created and used in the industrial sector store data on basic aggregates, raw materials, products, and processes in manufacturing.

#### **1.5 E-learning**

E-learning is a qualitatively new process of education that is not limited by time and place, where individualization of the learning process is provided, and the necessary educational resources are made available as needed or requested by the learner as a result of a recognized need. [18]. Over the years, the systems used in e-learning have varied.

#### **1.6 Tools for question generation**

Checking the acquired knowledge in the form of tests is a service provided by LMS and ALS - learning environments with access to a testing system. The most common platforms that offer a "Testing" module are: **Microsoft Teams** [19], **Google Classroom** [20], **Moodle** (Modular Object-Oriented Dynamic Learning Environment) [21], **PEGASO, DIPSEIL** (Distributed Internet-based Performance Support Environment for Individualized Learning) [22], **DisPeL** (Distributed Platform for e-Learning), **WolframMathematica** is a computer algebra system for assisting in the process of generating test questions in English.



## 1.7 Approaches for the automatic generation of question sentences

Automatic question generation plays a key role in the educational process. That's why many researchers focus their efforts on the automatic generation of questions for educational purposes.

## 1.8 Virtual Physical Space (ViPS)

ViPS as a reference architecture can be adapted to various application areas - tourism [23], agriculture [24], education [25] и others. The Virtual education space (VES) is an adaptation of ViPS in the fields of higher education [26] и [27], a BLISS for middle school [28].

The predecessor of VES is the Distributed eLearning Center (DeLC) [29]. DeLC is a distributed environment aimed at supporting the provision of educational services.

Part of ViPS is the module for automatic generation of test questions. The module has two functions – generating and assessing various types of test questions in English, extracted from an ontology in the field of software engineering [30], [31] и [32]. The module is developed as a multi-agent system.

## 1.9 Summary and conclusions from Chapter 1

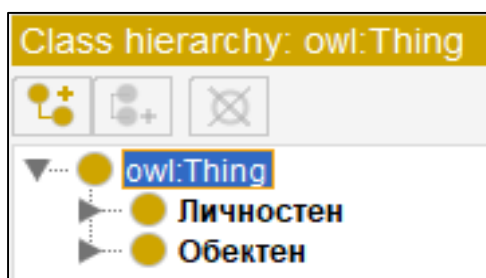
As a result of the presented studies, the following conclusions can be made:

1. The primary goal of the Semantic Web concept is for computers to comprehend the meaning of information and to utilize it. The RDF format, which describes network resources, is used to create a language understandable by computers.
2. Ontologies represent a knowledge base for a certain domain that can be reused. They find application in various fields and are used for different purposes.
3. Some e-learning environments and systems offer a "Testing" module. In most of them, the generation of questions is semi-automatic. Many researchers are working and sharing their experience on the automatic generation of questions and checking the answers in different systems.

# CHAPTER 2: ONTOLOGY STRUCTURE

## 2.1 Description of the domain and implementation of ontology in the field of humanities

An ontology has been created that represents a domain – a knowledge repository that describes the rich history of today's Humanities High School. Many notable personalities have been teachers and alumni of the school. [33].

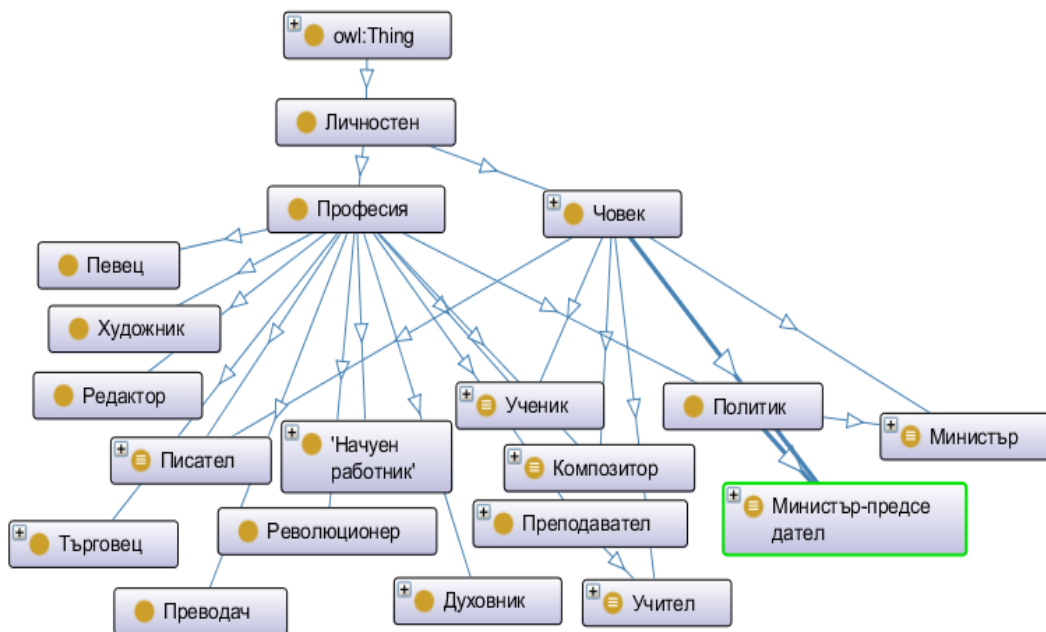


## 2.2 Classes

In the ontology, classes are divided into two types. Those that describe individuals (people) and those that describe objects (cities, books, poems, etc.). This division is a result of the semantics of the Bulgarian language (

Figure 3).

Figure 3. View in Protégé



**Figure 4.** Graphical representation of the children classes of the class „Personal“ through OntoGraf

The "Personal" class contains two subclasses: "Person" and "Profession". The relationship between the classes is represented through OntoGraf (**Figure 4**). All classes that describe people are compatible. This means that an individual can belong to one or many of these classes.

Another descendant of the base class Thing in the ontology is the class "Object". It and its descendants are shown through OntoGraf (**Figure 5**).

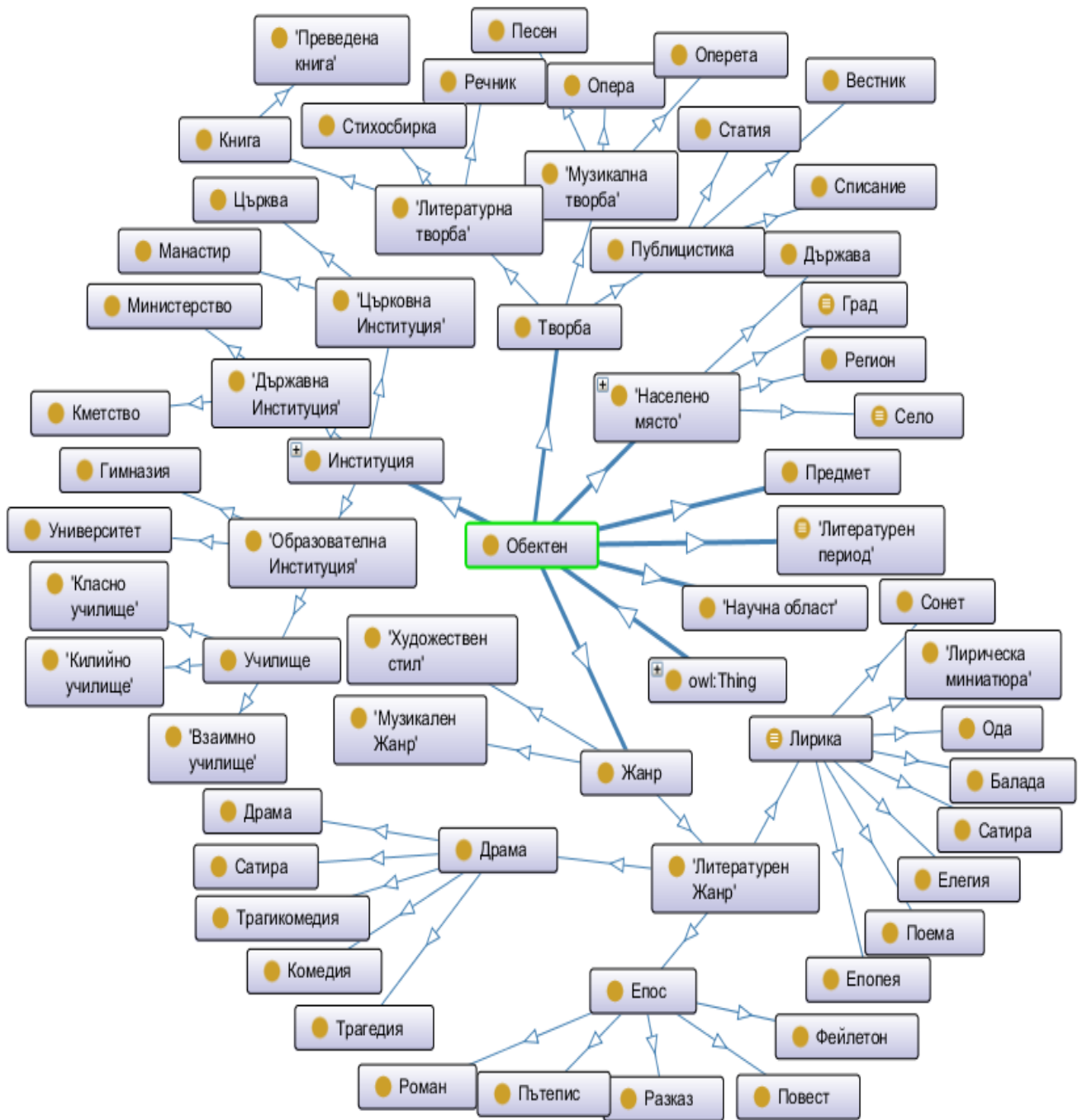


Figure 5. Graphical representation of the children classes of the class „Object“ through OntoGraf

All classes describing objects are incompatible with each other (Figure 6). This means that an individual belonging to one class cannot belong to another.

- Лирика
- Балада
- Елегия
- Епопея
- Лирическа миниатюра
- Ода
- Поема
- Сатира
- Сонет

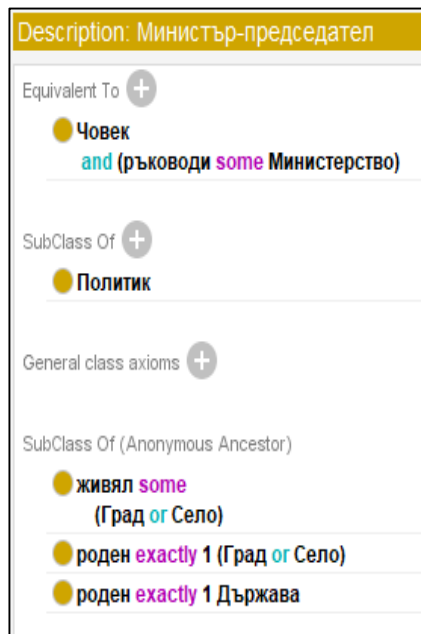
Description: Ода

Disjoint With +

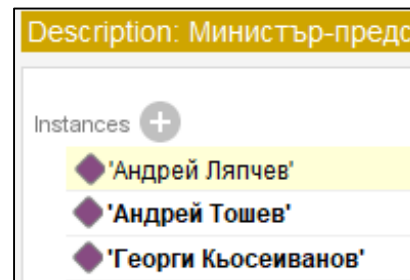
- Сатира, 'Лирическа миниатюра', Балада, Елегия, Поема, Сонет, Епопея

Figure 6. Disjoint classes with class „Oda“

Through various types of constraints - existential, universal, and cardinal, the main class is connected to the restrictive one, and new unnamed classes are created, which are either primitive or defined, depending on whether only necessary conditions or both necessary and sufficient conditions are specified. Most classes that describe personalities are of the defined type, while almost all classes describing objects are of the primitive type. Classes achieve their equivalence through the use of the structure "Equivalent To". In personal classes (**Figure 7**) the axiom is formed through a relationship between an object property and another class (restrictive).



**Figure 7.** Axiom for equivalency with an object property



**Figure 8.** Hidden knowledge – extrapolated based on an axiom for equivalency for class „Prime Minister“

In ontologies, there is often implicit knowledge, which distinguishes them from databases. In the structure "Equivalent To," an axiom is described which states that a Prime Minister is a person who has at least one connection with the class "Ministry" through the property "leads". This makes the class "Prime Minister" defined. When an individual meets these conditions, they will be classified into this "Prime Minister" class, even if such categorization is not directly assigned in the ontology (**Figure 8**).

## 2.3 Individuals

Individuals represent specific entities such as people, works, cities, etc., and conform to certain descriptive logic. They are among the fundamental components that make up the ontology.

Individuals in the ontology can be broken into two categories:

- **Personal** – individuals that are people (like Peyo Yavorov, Pencho Slaveykov) and can belong to multiple sibling classes. (**Figure 9**).



Figure 9. Individuals

- **Object** – individuals in the ontology that are specific objects like settlements, works, literary periods (e.g., Plovdiv, "Nemili-Nedragi") can be assigned only to one particular class from a given Parent-Child chain of classes. The object individuals do not possess their own gender. Their gender is determined by the gender of the class to which they belong (**Figure 10**) and (**Figure 11**).

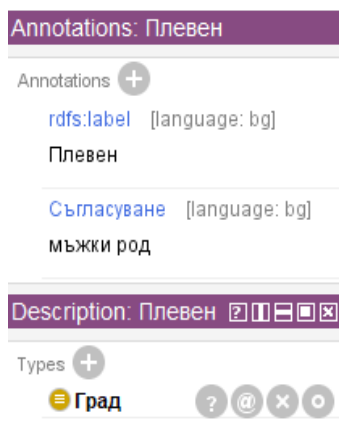


Figure 10. Definiteness of an individual belonging to class „City“

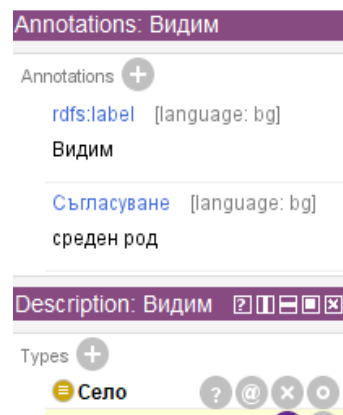


Figure 11. Definiteness of an individual belonging to class „Village“

## 2.4 Object properties

Object properties in an ontology (**Figure 13**) allow for the creation of a links between the individuals of two classes by creating a Resource Description Framework (RDF) triple: subject-predicate-object, where the subject acts as the sentence's subject, while the object plays the role of complement. By specifying the domain and range of the object property, the possibility of building a link between individuals from the domain class and individuals from the range class through the given property is demonstrated (**Figure 12**).



Figure 13. Object properties

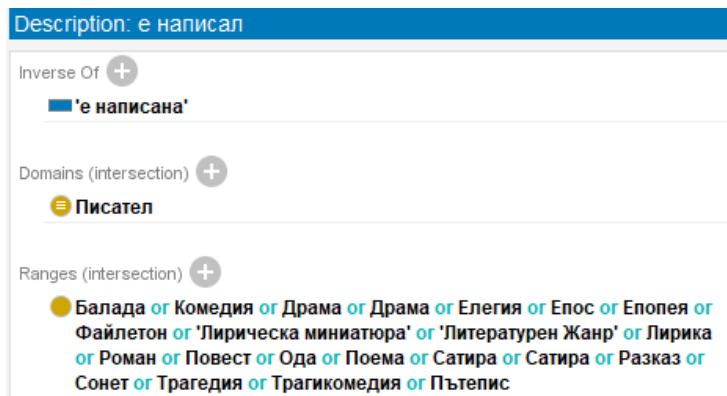


Figure 12. Domain and range

## 2.5 Data properties

Data properties describe the data of a given individual with various Resource Description Framework Schema (RDF(S)) data types. In this way, a given individual can be linked to a specific value of theirs.

The created and used data properties are shown in (Figure 14).

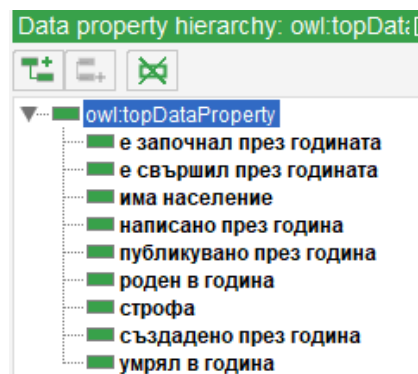


Figure 14. Data properties

By setting the domain and the range of the data property (Figure 15), provides the opportunity to establish a link between individuals from the domain class, with a value belonging to the type set as the range of the property.

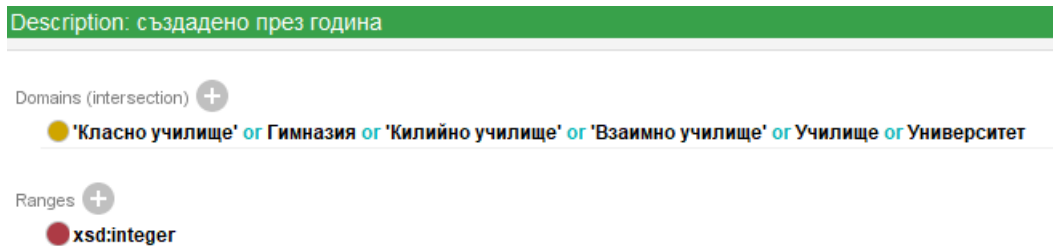


Figure 15. Domain and range

## 2.6 Annotation properties

In the “BulgarianLiteratureAndHistoryOntology” ontology, meta-knowledge has been added. They represent knowledge about the knowledge itself, that is, they provide additional information about the classes, individuals, object properties, data properties, or about themselves. Annotations in Protégé are set by using “Annotation Property”. In the Web Ontology Language (OWL), there are predefined annotation properties, but it also provides the possibility for user-defined ones. In the ontology, 11 annotation properties have been created (Figure 16), which are used when generating the different kinds of sentences in Bulgarian.

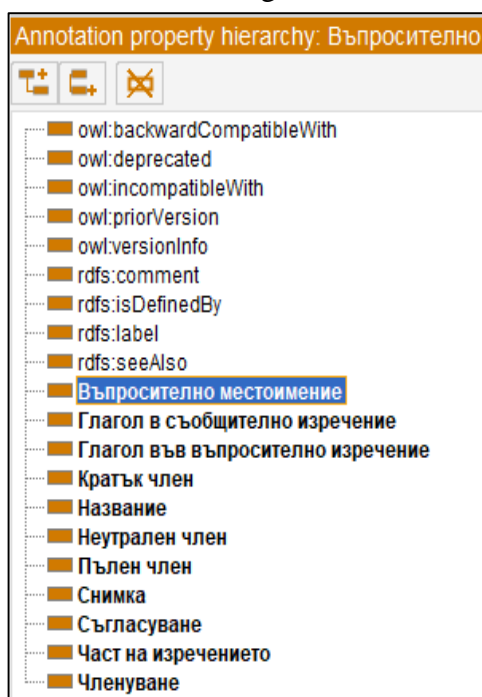
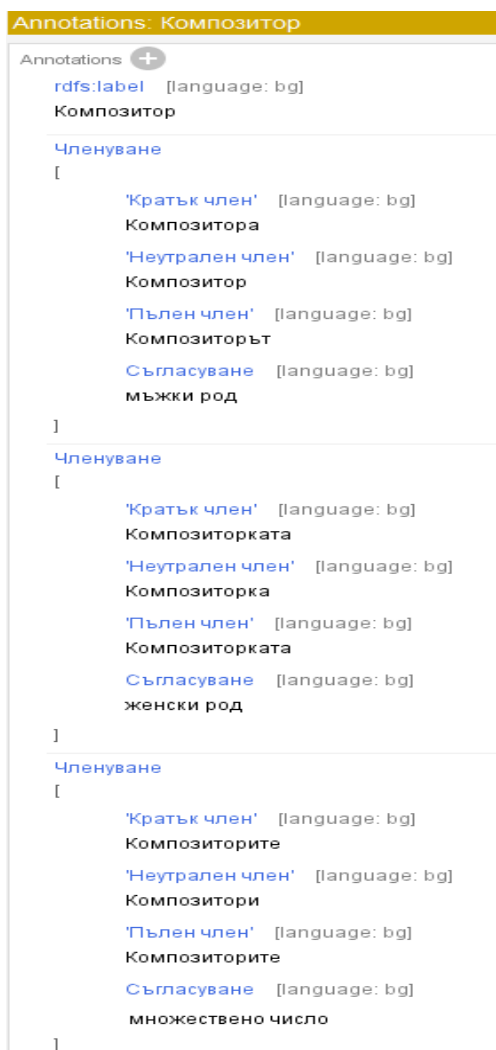


Figure 16. Annotation properties

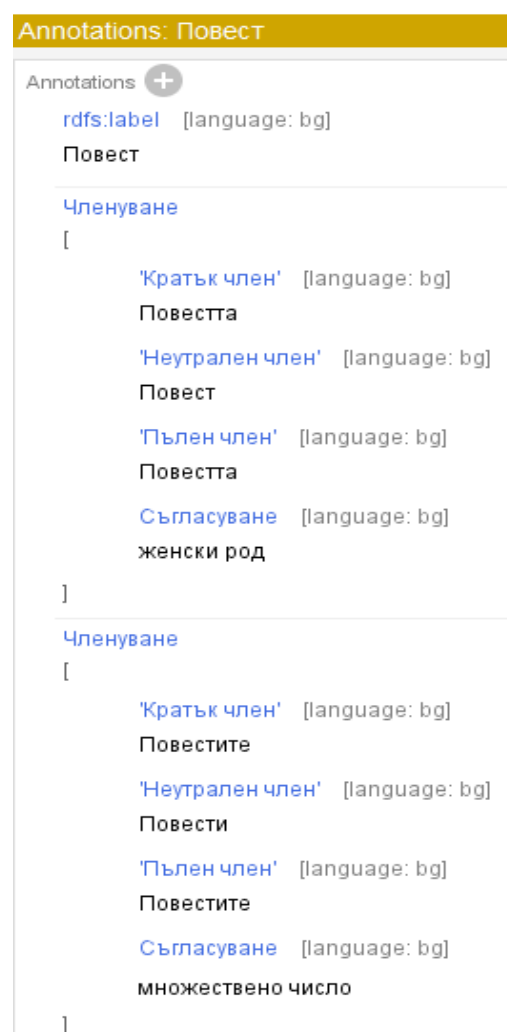
### 2.6.1 Annotation properties for a class

In the classes, two types of annotation properties are used - simple and complex. The simple property is always of the type "rdfs:label" and is not mandatory for generating questions. It is used in the ontology to represent objects in the Bulgarian language. The complex properties "Definiteness" are those that contain the full information about the given class. They have four sub-properties, in which the definiteness of the class is set.

The annotation property "Definiteness" can be assigned once or several times to a specific class. In the ontology, "Definiteness" is used multiple times for a given class when it describes a person, as individuals can have different gender and single/plural form. In the annotation property, the different genders and forms of the class (masculine, feminine, neuter for singular and plural) are set, so that an intersection with the gender and form of the individual belonging to that class can be made (**Figure 17**). In the classes describing objects (**Figure 18**) only two properties of the type "Definiteness" are used, one is for the plural form of the class (example: "novellas"), and the other is for the gender of the object, which is specific and determined by the semantics of the Bulgarian language and does not depend on the individuals belonging to it (example: "novella" is always in feminine gender).



**Figure 17.** Annotations of class „Composer“



**Figure 18.** Annotations of class „Novella“

## 2.6.2 Annotation properties for an object property

In the context of object properties, we use four types of annotation properties - one simple and three complex. The simple property is always of the type "rdfs:label" and is optional when generating questions.



The three complex annotation properties are: "Question pronoun" (**Figure 19**)

Annotations: роден			
Annotations +			
'Въпросително местоимение'	'Въпросително местоимение'	'Въпросително местоимение'	'Въпросително местоимение'
[	[	[	[
Съгласуване [language: bg]	Съгласуване [language: bg]	Съгласуване [language: bg]	Съгласуване [language: bg]
мъжки род	женски род	среден род	множествено число
'Част на изречението' [language: bg]	'Част на изречението' [language: bg]	'Част на изречението' [language: bg]	'Част на изречението' [language: bg]
В кой	В коя	В кое	В кои
]	]	]	]

**Figure 19.** Definiteness of the question pronoun

„Verb in question sentence“ (**Figure 20**)

Annotations: роден		
Annotations +		
'Глагол във въпросително изречение'	'Глагол във въпросително изречение'	'Глагол във въпросително изречение'
[	[	[
Съгласуване [language: bg]	Съгласуване [language: bg]	Съгласуване [language: bg]
мъжки род	женски род	множествено число
'Част на изречението' [language: bg]	'Част на изречението' [language: bg]	'Част на изречението' [language: bg]
е роден	е родена	са родени
]	]	]

**Figure 20.** Definiteness of the verb in annotation property „Verb in question sentence“

„Verb in expression sentence“ (**Figure 21**).

Annotations: роден		
Annotations +		
'Глагол в съобщително изречение'	'Глагол в съобщително изречение'	'Глагол в съобщително изречение'
[	[	[
Съгласуване [language: bg]	Съгласуване [language: bg]	Съгласуване [language: bg]
мъжки род	женски род	множествено число
'Част на изречението' [language: bg]	'Част на изречението' [language: bg]	'Част на изречението' [language: bg]
е роден в	е родена в	са родени в
]	]	]

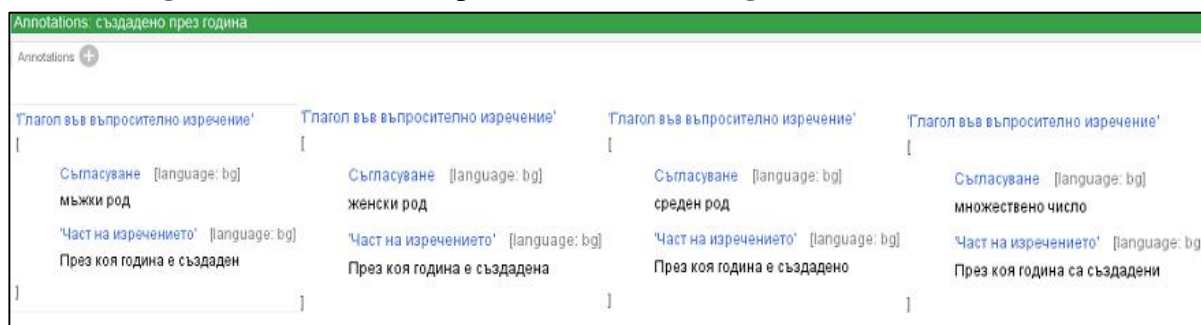
**Figure 21.** Definiteness of the property „Verb in expression sentence“

Each of them is present several times for each object property, depending on the types of definiteness it needs to possess. Each of the three properties contains two sub-properties of a primitive type.

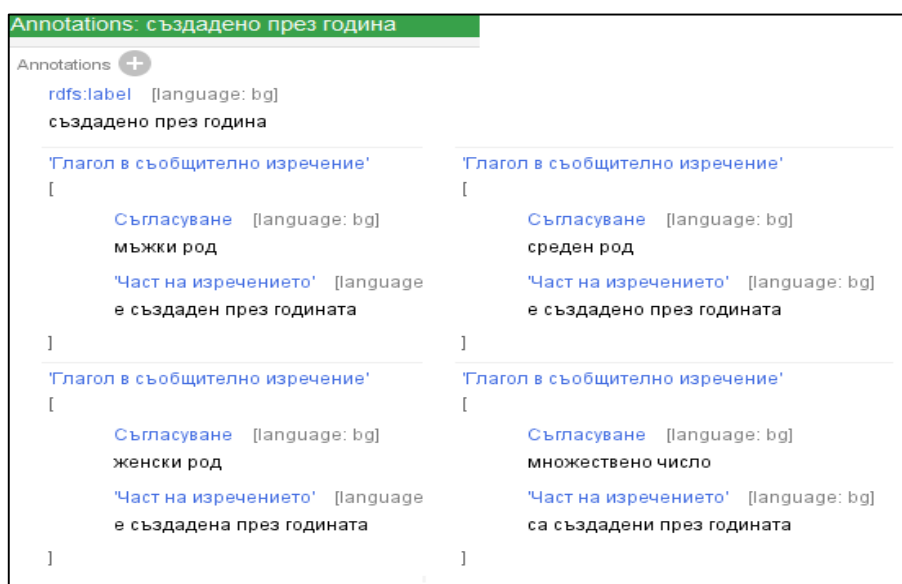
### 2.6.3 Annotation properties of data properties

For data properties, we use three types of annotation properties – one simple and two complex ones. The simple property is always of type "rdfs:label" and is not mandatory for question generation. It is used in the ontology to represent a data property in the Bulgarian language. The

two complex annotation properties that are used in question generation are: „Verb in question sentence“ (**Figure 22**) и „Verb in expression sentence“ (**Figure 23**).



*Figure 22. Definiteness of data property with the subject*



*Figure 23. Annotations of data properties in an expression sentence*

#### 2.6.4 Annotation properties of annotation properties

In the case of annotation properties, four types of annotation properties are used – one simple and three complex. The simple property is always of type "rdfs:label" and is not mandatory for question generation. It is used in the ontology to represent the annotation property in Bulgarian. The three complex annotation properties that are used in question generation are: „Verb in question sentence“, „Question pronoun“ and „Verb in expression sentence“ (**Figure 24**). Each of them appears several times for each annotation property, depending on the definiteness it needs to have.

The annotation properties „Verb in question sentence“ and „Question pronoun“ are used in the generation of question sentences, while the complex annotation property „Verb in expression sentence“ is used to describe the possible definiteness in expression sentences.

Annotations: Снимка		
Annotations +		
rdfs:label [language: bg] Снимка		
'Въпросително местоимение'	'Глагол в съобщително изречение'	'Глагол във въпросително изречение'
[	[	[
Съгласуване [language: bg] женски род	Съгласуване [language: bg] среден род	Съгласуване [language: bg] среден род
'Част на изречението' [language: bg] На коя снимка	'Част на изречението' [language: bg] е показано на снимката	'Част на изречението' [language: bg] е показано
]	]	]
'Въпросително местоимение'	'Глагол в съобщително изречение'	'Глагол във въпросително изречение'
[	[	[
Съгласуване [language: bg] множествено число	Съгласуване [language: bg] множествено число	Съгласуване [language: bg] множествено число
'Част на изречението' [language: bg] На кои снимки	'Част на изречението' [language: bg] са показани на снимката	'Част на изречението' [language: bg] са показани
]	]	]
'Глагол в съобщително изречение'	'Глагол във въпросително изречение'	
[	[	
Съгласуване [language: bg] мъжки род	Съгласуване [language: bg] мъжки род	
'Част на изречението' [language: bg] е показан на снимката	'Част на изречението' [language: bg] е показан	
]	]	
'Глагол в съобщително изречение'	'Глагол във въпросително изречение'	
[	[	
Съгласуване [language: bg] женски род	Съгласуване [language: bg] женски род	
'Част на изречението' [language: bg] е показана на снимката	'Част на изречението' [language: bg] е показана	
]	]	

Figure 24. Annotation values of the Annotation property "Image"

### 2.6.5 Annotation properties for individuals

Each individual has two mandatory simple annotation properties. The first, "rdfs:label," represents the name of the individual in Bulgarian and is used for its visualization in the ontology, as well as for generating questions. The second is "Definiteness," which determines the gender of the individual. The gender of individuals is set in the "Definiteness" property and depends on the type of individual. When it comes to a person, the individual's own gender is used (**Figure 25**) и (**Figure 26**). When the individual is of type "Object", the situation changes, as objects do not have a gender of their own. They take the gender of the class they belong to. (**Figure 27**) и (**Figure 28**).

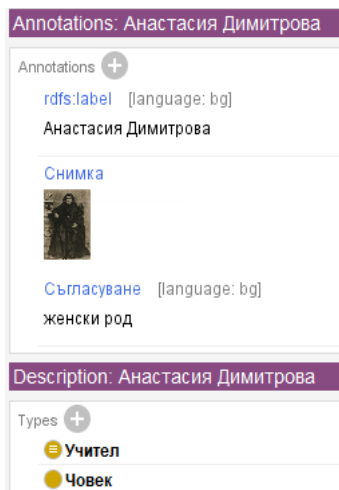


Figure 25. Individual of female gender

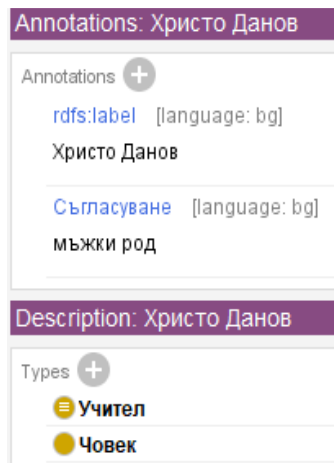


Figure 26. Individual of male gender

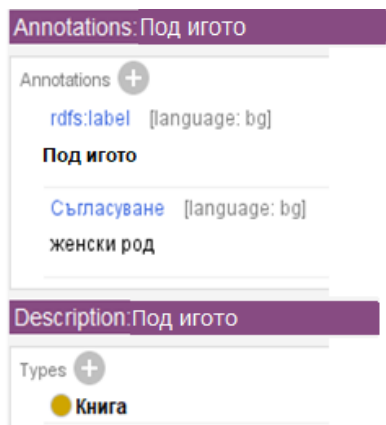


Figure 27. Individual of female gender belonging to class Book

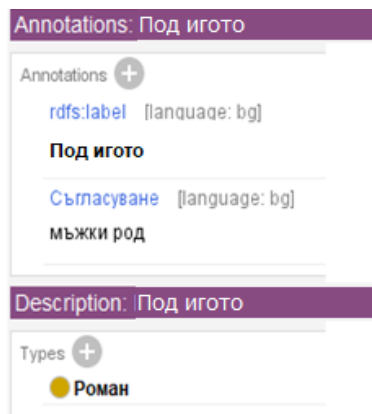


Figure 28. Individual of male gender belonging to class Novel

## 2.7 Summary and conclusion of Chapter 2

1. An ontology was created in the field of humanities and has the following metrics:

- Axioms - 5094
- Classes - 90
- Object properties - 22
- Data properties - 9
- Individuals - 330
- Annotation properties - 12

2. An extremely important part of the created ontology are the annotation properties, which achieve the generation of grammatically correct sentences in Bulgarian.

## CHAPTER 3: ALGORITHMIC QUERIES FOR GENERATING DIFFERENT TYPES OF SENTENCES

The algorithms created for extracting information from the ontology in the form of question (Figure 29) and expression (Figure 30) sentences are written in the query language SPARQL (SPARQL Protocol and RDF Query Language).

questionStart	answerType	questionLabel	fullMember	individual	answerCorrectA	answerWrongA	answerWrongB	answerWrongC
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Кино	Моторни песни	Детство мое	Подир сенките на облаците	Сън за щастие
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Кино	Моторни песни	Подир сенките на облаците	Подир сенките на облаците	Хубава си, татковино
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Кино	Моторни песни	Весели балони	Подир сенките на облаците	Хубава си моя горо
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Кино	Моторни песни	Сън за щастие	Подир сенките на облаците	Моторни песни
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Кино	Моторни песни	Хубава си, татковино	Подир сенките на облаците	Епични песни
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Кино	Моторни песни	Хубава си моя горо	Подир сенките на облаците	Евтим Евтимов - стихотворения
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Кино	Моторни песни	Епични песни	Подир сенките на облаците	Под сурдинка
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Кино	Моторни песни	Евтим Евтимов - стихотворения	Подир сенките на облаците	Пеньо Пенев - стихотворения
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Кино	Моторни песни	Под сурдинка	Подир сенките на облаците	Под тъмни небеса
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Кино	Моторни песни	Пеньо Пенев - стихотворения	Подир сенките на облаците	Да бъде ден
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Кино	Моторни песни	Под тъмни небеса	Българи от старо време	Маминото детенце
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Кино	Моторни песни	Да бъде ден	Българи от старо време	Яворов - събрани съчинения
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Самота	Пеньо Пенев - стихотворения	Детство мое	Българи от старо време	Разкази за деца
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Самота	Пеньо Пенев - стихотворения	Подир сенките на облаците	Българи от старо време	Йордан Йовков - разкази
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Самота	Пеньо Пенев - стихотворения	Весели балони	Българи от старо време	Христо Смирненски - избрани тво
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Самота	Пеньо Пенев - стихотворения	Сън за щастие	Българи от старо време	Епопея на забравените
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Самота	Пеньо Пенев - стихотворения	Хубава си, татковино	Българи от старо време	Ян Бибиян
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Самота	Пеньо Пенев - стихотворения	Хубава си моя горо	Българи от старо време	Немили недраги
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Самота	Пеньо Пенев - стихотворения	Моторни песни	Подир сенките на облаците	Да бъде ден
'В коя'@bg	Стихосбирка	'е отпечатана'@bg	'Поемата'@bg	Самота	Пеньо Пенев - стихотворения	Епични песни	Българи от старо време	Маминото детенце

Figure 29. Generated question sentences with one correct and three incorrect answers

Questions sentences are:

- With one correct and three incorrect answers;
- With two correct and two incorrect answers.

fullMember	individualLabel	propertyLabel	partialMember	answerLabel
'Мъжът'@bg	'Атанас Беляев'@bg	'е работил в'@bg	'Гимназията'@bg	'Пловдивска мъжка гимназия'@bg
'Мъжът'@bg	'Атанас Беляев'@bg	'е ръководил'@bg	'Гимназията'@bg	'Пловдивска мъжка гимназия'@bg
'Мъжът'@bg	'Пеньо Пенев'@bg	'е живял в'@bg	'Града'@bg	'Димитровград'@bg
'Мъжът'@bg	'Пеньо Пенев'@bg	'е живял в'@bg	'Държавата'@bg	'България'@bg
'Мъжът'@bg	'Пеньо Пенев'@bg	'е умрял в'@bg	'Града'@bg	'Димитровград'@bg

Figure 30. Generation of expression sentences with filling in the blank

Expression sentences are:

- With filling in the blank word;
- With attesting if the sentence is true or false.

When generating different types of sentences, the algorithms consider three different possibilities, depending on the elements used in the RDF triples:

- A sentence constructed based on a relationship between two individuals connected through an object property;
- A sentence constructed based on a relationship between an individual and its value through a data property;
- A sentence constructed based on a relationship between an individual and an image through an annotation property.

15 algorithms were created for the research and their representation has been achieved through activity diagrams.

The steps of the algorithm for generating a question sentence with one correct and three incorrect answers, extracted from RDF triples composed of two individuals connected by an object property, are shown in **(Figure 31)** through an activity diagram.

Algorithm workflow:

1. Annotations for the created annotation properties are loaded.
2. Individuals and the classes to which they belong are loaded.
3. A triplet is created.
4. Classes that are domains of the property are loaded.
5. A list of triplets is created, which contains all possible combinations of the subject, belonging to a set of classes, and the connection with the object through that property.
6. Classes are filtered, and those that are from the domain of the property remain.
7. Classes that are in the range of the property are loaded.
8. A list of triplets is created, which contains all possible combinations of the object, belonging to a set of classes, and the connections with the subject through that property.
9. Classes are filtered, and those that are from the range of the property remain.
10. The individual (correct answer) loads the class to which it belongs.
11. Three individuals (incorrect answers) that belong to the class of the individual (correct answer) are loaded.
12. The label of the individual (correct answer) is loaded.
13. The labels of the individuals (incorrect answers) are loaded.
14. Incorrect answers are filtered so that the three individuals are different.
15. Filters are applied that ensure the individual (subject) does not have a connection through this property with the individuals (incorrect answers).
16. The gender of the individual (subject) is loaded.
17. The gender of the individual (correct answer) is loaded.
18. The labels of the annotations of the subject's class are loaded.
19. The gender of the individual (subject) intersects with the gender of the class to which it belongs.
20. The definite article is extracted.
21. The annotations of the property "Verb in a question sentence" are loaded.
22. The gender of the individual of the subject (predicate) intersects with the correct form for verb agreement.
23. The correctly conjugated verb is extracted.
24. The annotations of the property "Interrogative pronoun" are loaded.
25. The gender of the class of the individual of the object (complement) intersects with the correct form for the agreement of the personal pronoun.
26. The correctly conjugated personal pronoun is extracted.



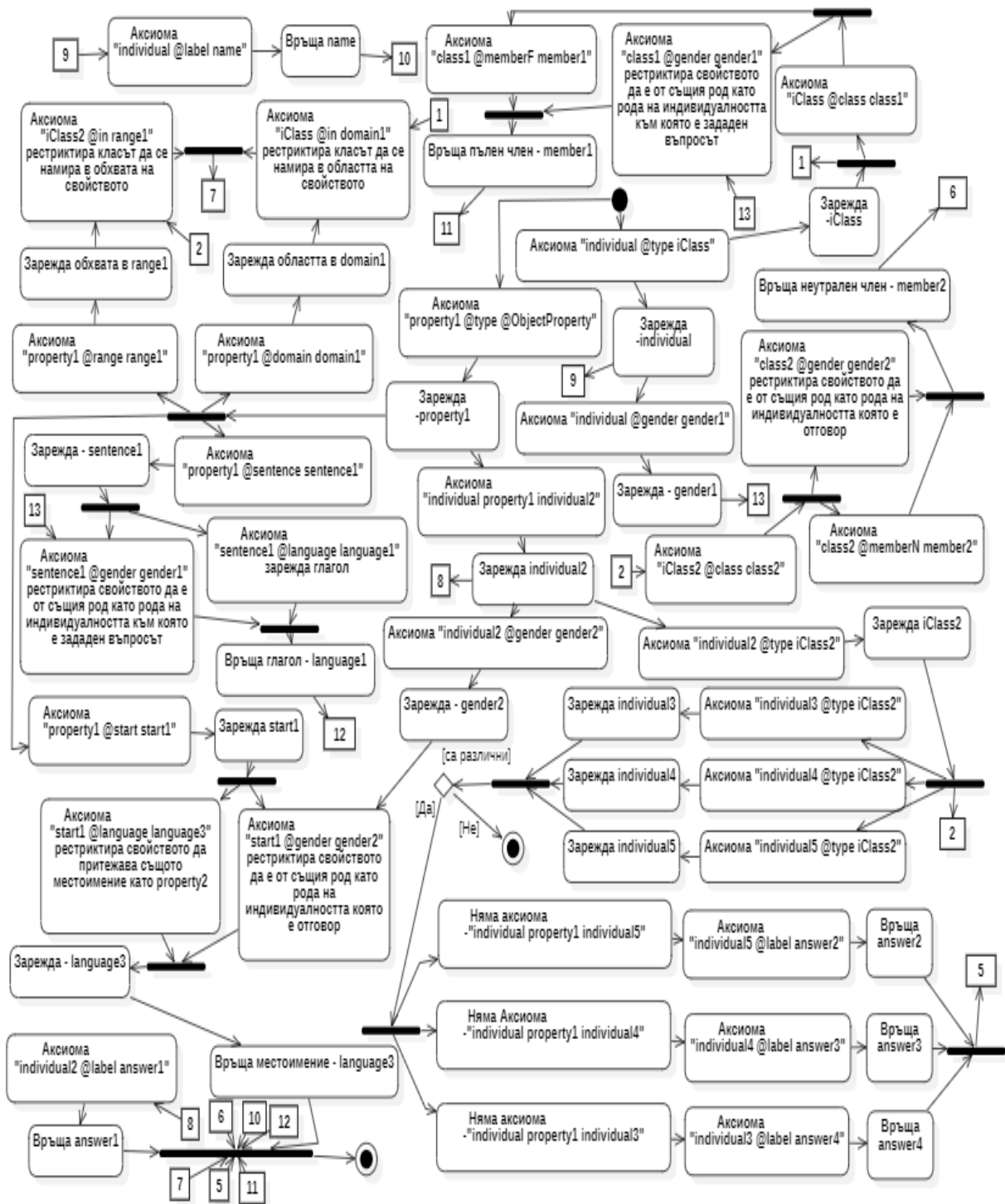


Figure 31. UML activity diagram

### Conclusions from Chapter 3

1. The algorithmic queries created utilize the annotation properties in which the main grammatical structures are embedded, based on which interrogative and declarative sentences are created that adhere to the literary norms of the language. SPARQL queries extract information from these annotation properties in order to create different types of sentences and generate the correct answer and suggestions for possible incorrect answers. The multitude of automatically










generated questions in Bulgarian depends on the information entered into the ontology in the form of classes and individuals. The variety of these questions is due to the multitude of developed algorithms. They use the annotation properties to generate different types of sentences based on object properties, data properties, and annotation properties.

2. The described algorithms return results only if the ontology structures described in Chapter 2 have been used.

## CHAPTER 4: APPLICATIONS FOR GENERATION OF AN ONTOLOGY AND THE EXTRACTION OF INFORMATION FROM IT

### 4.1 Application for the generation of an ontology

The application for the generation of an ontology is called „OntologyGenerator“. It is written in C# language and is a „Windows“ executable, which takes in configuration files and produces an ontology (**Figure 32**).

Name	Date modified	Type	Size
 configuration.json	6/11/2023 12:44 PM	JSON File	1 KB
 configuration_classes.json	6/11/2023 11:49 AM	JSON File	5 KB
 configuration_data_properties.json	6/11/2023 12:51 PM	JSON File	6 KB
 configuration_individuals.json	6/11/2023 12:13 PM	JSON File	2 KB
 configuration_object_properties.json	6/11/2023 12:47 PM	JSON File	7 KB
 links_with_data_properties.json	6/11/2023 11:49 AM	JSON File	5 KB
 links_with_object_properties.json	6/11/2023 11:49 AM	JSON File	5 KB
 onthology.owl	5/24/2023 8:01 PM	OWL File	1,059 KB
 OntologyGenerator.exe	5/2/2023 10:52 PM	Application	155 KB

*Figure 32. The ontology*

The created ontology is in format “owl/xml syntax”. For it to be used by the application for extracting information, the generated ontology needs to be opened in Protégé and saved in “rdf/xml syntax”.

### 4.2 Application for extracting information from the ontology

The application for extracting information from the ontology is called „OntologyReader“. It uses (**Figure 33**):



Name	Date modified	Type	Size
OnthologyReader.exe	5/2/2023 10:52 PM	Application	155 KB
ALG_1_A.json	6/10/2023 10:40 PM	JSON File	2 KB
ALG_1_B.json	6/10/2023 10:37 PM	JSON File	27 KB
ALG_2_A.json	6/10/2023 10:38 PM	JSON File	11 KB
ALG_1_A.mghsparql	6/10/2023 10:42 PM	MGHSPARQL File	3 KB
ALG_1_B.mghsparql	5/21/2023 12:53 PM	MGHSPARQL File	2 KB
ALG_2_A.mghsparql	5/21/2023 1:13 PM	MGHSPARQL File	3 KB
onthology.owl	4/12/2023 8:28 AM	OWL File	864 KB

Figure 33. Returned results

```
[
  {
    "startQuestionLabel": "В кои",
    "answerType": "градове",
    "questionSentenceLabel": "е живял",
    "fullMemberLabel": "цар",
    "individual": "Симеон",
    "correctAnswerLabel": "Константинопол",
    "correctAnswerBLabel": "Плиска",
    "wrongAnswerLabel": "Филипополис",
    "wrongAnswerBLabel": "Адрианопол",
  },
  {

```

Figure 34. Contents of the JSON files

- SPARQL query – input – a file with extension „mghsparql“, in which the algorithm for execution against the ontology is contained.

- Ontology – input – the ontology saved in format „RDF/XML“ and named „onthology.owl“.

- JSON file (Figure 34) – output – the file contains a list of JSON object, each of which is a returned result when executing the query against the ontology.

### 4.3 Conclusions from Chapter 4

1. An application "OnthologyGenerator" has been created that facilitates the work of creating a new ontology by using configuration files to eliminate the manual input of identical structures in the multitude of different objects of the ontology. The ontology is saved in the "OWL/XML" format.

2. An application "OnthologyReader" has been created that uses a SPARQL query, which is executed for an ontology saved in the "RDF/XML" format and returns results that are saved in a "JSON" file. The results store the generated sentences in Bulgarian, depending on the executed query, using a specific algorithm.

## CHAPTER 5: ANALYSIS AND VERIFICATION OF THE SUGGESTED APPROACH

A new (second) ontology has been created with the aim of analyzing the proposed approach for its generation and information extraction through question formulation. The created ontology represents the first Bulgarian state. It is used to check the performance of the algorithms to determine whether they return meaningful and syntactically correct questions.

Each of the created queries is executed for the second ontology for validation purposes. The execution of the queries is achieved by using the "OntologyReader" application.

```

{
  "className": 'Khan',
  "classVisualization": 'Хан',
  "classLabel": [
    {
      "fullMember": 'Хан',
      "partialMember": 'Хан',
      "neutralMember": 'Хан',
      "gender": 'мъжки род'
    },
    {
      "fullMember": 'Хановете',
      "partialMember": 'Хановете',
      "neutralMember": 'Ханове',
      "gender": 'множествено число'
    }
  ],
  "parentClassOf": [],
  "disjoinedWith": [],
  "equivalentTo": [
    {
      "connectingProperty": 'ruledCountry',
      "connectedClass": 'Country',
      "mainClass": 'Ruler'
    }
  ]
  "subClassOf": []
},

```

After the creation of the validating ontology and the execution of the queries, a problem was observed with some of its classes. Titles and place names in Bulgarian are not articulated (i.e., they do not have definite articles) when they act as appositions, regardless of which part of the sentence they clarify. This necessitated a change in the sub-properties "Definite Article" and "Indefinite Article" for them to take values like the sub-property "Neutral Article" (**Figure 35**).

*Figure 35. Specification of a grammatical category*

This change allows for an analysis from two perspectives. The first is to check whether sentences that are correctly articulated and agreed upon according to the given norms (definite/indefinite article) will be generated. The second is to check the possibility of generating sentences that comply with specific rules in the Bulgarian language. After the change, the structure of the sentence is preserved, but it acquires the form: (**Figure 36**).

```

{
  "questionLabel": "През коя година е завършило управлението на",
  "fullMemberLabel": "хан",
  "individualLabel": "Аспарух",
  "correctAnswerALabel": "700",
  "wrongAnswerALabel": "814",
  "wrongAnswerBLabel": "927",
  "wrongAnswerCLabel": "721",
},

```

*Figure 36. Returned results*

## 5.1 Comparative analysis

In the created ontology, a specific structure is imposed, which must be strictly followed to generate correct test questions in Bulgarian.

During the question generation, the algorithmic queries can be executed both in Protégé and in "OntologyReader". Both applications return identical information. A selection can be made to generate results for a particular individual or property. The created application facilitates the work

of extracting information from the ontology and automatically creates a file with the returned information in JSON format.

Testing of the two programs for the time needed to process the algorithmic queries and return results from them is shown in (**Table 1**).

Algorithm	Protégé			OnthologyReader		
	10 results	25 results	100 results	10 results	25 results	100 results
3.1.1	2.35 sec.	10.11 sec.	95.13 sec.	2.20 sec.	9.93 sec.	87.11 sec.
3.1.2	1.54 sec.	7.23 sec.	69.16 sec.	1.36 sec.	6.59 sec.	62.25 sec.
3.1.3	1.09 sec.	4.47 sec.	-	0.97 sec.	4.01 sec.	-
3.2.1	2.17 sec.	9.32 sec.	81.31 sec.	2.02 sec.	9.09 sec.	76.18 sec.
3.2.2	1.37 sec.	7.06 sec.	68.58 sec.	1.17 sec.	6.41 sec.	60.59 sec.
3.2.3	0.52 sec.	4.34 sec.	-	0.51 sec.	3.57 sec.	-
3.3.1	2.32 sec.	15.44 sec.	58.34 sec.	1.39 sec.	13.30 sec.	55.21 sec.
3.3.2	2.09 sec.	13.57 sec.	56.29 sec.	1.30 sec.	11.25 sec.	50.36 sec.
3.4.1	1.31 sec.	6.37 sec.	30.18 sec.	1.24 sec.	6.01 sec.	29.23 sec.
3.4.2	1.21 sec.	5.16 sec.	29.57 sec.	1.09 sec.	5.49 sec.	28.40 sec.
3.4.3	0.57 sec.	3.43 sec.	-	0.55 sec.	3.34 sec.	-
3.5.1	4.23 sec.	20.01 sec.	155.26 sec.	3.59 sec.	19.39 sec.	143.31 sec.
3.5.2	3.55 sec.	18.31 sec.	137.17 sec.	3.52 sec.	18.09 sec.	135.45 sec.
3.6.1	5.13 sec.	26.22 sec.	166.38 sec.	4.47 sec.	22.30 sec.	154.21 sec.
3.6.2	5.02 sec.	22.46 sec.	150.20 sec.	4.26 sec.	21.29 sec.	149.54 sec.

*Table 1. Findings from performance testing*

The analysis was achieved by executing each algorithm for one specific individual and the questions that can be asked about it. Each of the algorithms was executed five times for each environment, and the average statistical time required to obtain results is presented. The results show that the created application manages to extract information from the ontology slightly faster than Protégé.

## 5.2 Conclusions from Chapter 5

1. The provided analysis demonstrates that the developed algorithms execute algorithmic queries within ontologies with the proposed structure. Syntactically correct interrogative and declarative sentences are generated, adhering to the fundamental grammatical rules embedded in the Bulgarian language.
2. With the changes made to the values of the annotation properties, the detected exceptions for certain grammatical norms are resolved. This indicates that the developed structures can be adapted to incorporate new grammatical norms and rules.
3. The generated sentences are composed based on various elements within the RDF structures.
4. According to the experiments conducted, it is proven that the application "OnthologyReader" generates questions from the ontology in less time than the Protégé program.

## CONCLUSION

In the dissertation, research on the creation of semantic models in the field of humanities, which are applicable in information and communication technologies, is presented. In the developed ontology, information is structured appropriately so that it can be extracted by the created algorithms. Through them, grammatically correct sentences in the Bulgarian language are automatically generated.

### Results

The results achieved in the dissertation are a result of the following tasks:

1. A semantic model has been created in the form of an ontology within the humanitarian field.
2. Algorithms have been developed for the automatic generation of interrogative and declarative sentences from the ontology in the Bulgarian language.
3. An application called "OnthologyGenerator" has been developed in C#, using predefined configuration structures for creating and inserting information into the ontology.
4. An application called "OnthologyReader" has also been developed in C# for extracting information from ontologies based on the created algorithms.

The connection between the results, tasks, structure of the dissertation, and publications are presented in (Table 2):

Task	Result	Chapter	Publications
1	1	2	2, 3, 5, 6
2	2	3	1, 2, 3, 4
3	3	4, 5	
4	4	4, 5	

*Table 2. Connection between the contributions, tasks, structure of the dissertation, and publications*

### Future work

1. New information such as classes, instances, and properties can be introduced into the ontology, following the established structure.
2. The developed algorithms can be parameterized to cover a wider range of test question variants.
3. New algorithms can be created that return meaningfully segregated text.
4. The developed semantic model of the ontology can be applied in the creation of new ontologies in various disciplines and the developed approach can be used in generating test questions.
5. Modify the developed TGE electronic testing environment, which is implemented as a multi-agent system in a Web-based Learning Environment, using the algorithms for generating test questions in Bulgarian language.

### Acknowledgments

I express my heartfelt gratitude to my scientific supervisors Prof. Asya Stoyanova-Doycheva, PhD and Prof. Todora Glushkova, PhD for the positive energy, valuable guidance, and unwavering support. I extend special thanks to Prof. Stanimir Stoyanov, PhD. I also thank all my colleagues for their advice, recommendations, and assistance.

## Publications associated with the dissertation and research

1. Glushkova, T., **Grancharova-Hristova, M.**, Moraliyska, N., *Processing and use of knowledge about the Cultural-Historical and Natural Heritage of Bulgaria in school education*, Anniversary International Scientific Conference “Computer Technologies and Applications”, September 2021, Pamporovo, Bulgaria, ISBN 978-619-202-702-5, p.57-62, [https://cta2021.fmi-plovdiv.org/wp-content/uploads/2021/09/CTA2021\\_Glushkova\\_Grancharova\\_Moraliiska\\_57\\_62.pdf](https://cta2021.fmi-plovdiv.org/wp-content/uploads/2021/09/CTA2021_Glushkova_Grancharova_Moraliiska_57_62.pdf)
2. **Grancharova-Hristova, M.** Glushkova, T., Stoyanova-Doycheva, A., Stoynov, D., *Using Ontologies and Databases with Educational Information in Assessing the Knowledge of Students*, *Collection of Scientific Works from the VI National Scientific Conference with International Participation TechCo'22*, 1 - 2 Юли 2022, Ловеч, ISSN 2535-079X, стр. 73-78, <https://www.tugab.bg/images/tk-lovech/Techco-Lovech-22.pdf> .
3. Stoyanova-Doycheva, Asya & Madanska, Sebiha, **Grancharova-Hristova, Maria**, Glushkova, Todorka, Cholakov, Georgi. (2022). *Development of Ontologies in Different Domains for a Test Generation Environment*. [www.doi.org/10.4995/HEAd22.2022.14205](http://www.doi.org/10.4995/HEAd22.2022.14205), SCOPUS.
4. **Grancharova-Hristova, M.**, Moraliyska, N., Rusev, K., Ivanova, V., Tabakova-Komsalova, V. (2021). Application of ontologies and digital libraries in school education. *Informatics and Education*, 10 (329), 15-20. <http://doi.org/10.32517/0234-0453-2021-36-10-15-20>
5. **Grancharova-Hristova M.**, Moraliyska N., Madanska S., *Development of an Ontology in the Field of the Humanities*, *Cultural and Historical Heritage: Preservation, Presentation, Digitalization KIN Journal*, volume 7, Issue 2, 2021, <http://www.math.bas.bg/vt/kin/> , 2021
6. **Grancharova-Hristova, M.**, Moraliyska, N., Glushkova, T., & Rusev, K. (2022). *Virtualization, Processing, and Standardization of Knowledge about Bulgarian Cultural, Historical and Natural Heritage for Use in School Education*. *Digital Presentation and Preservation of Cultural and Scientific Heritage*, 12 (1), 131–140. <https://doi.org/10.55630/dipp.2022.12.10>, SCOPUS

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