Application of Ontology Design Patterns for Building an Ontology of Decision Support in Weakly Formalized Domains

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Abstract

The paper is devoted to the development and application of ontology design patterns for building ontology of decision support in weakly formalized domains. The requirements for the developed ontology and the main groups of patterns used are described. Examples of patterns used to define the main classes of ontology and their instances are given. The patterns that serve to define a multidimensional structure of ontology and organize interaction with data from external sources are also considered.

Keywords

Ontology development, ontology design patterns, decision support in weakly formalized areas, multidimensional structure, external data sources

1. Introduction

Decision support systems (DSS) are a popular class of software systems. Their development, especially for weakly formalized subject domains (SD), is an important and complex task, the solution of which also needs support. This paper describes the process of creating decision support ontology in weakly formalized domains (WFD), on the basis of which an information-analytical Internet resource (IAIR) and a repository of decision-making methods were developed. These IAIR and repository together with the ontology provide comprehensive support for DSS developers. In particular, the IAIR systematizes information about the decision support knowledge area and provides content-based access to it, and the repository contains software services that implement DS methods.

Ontology Design Patterns (ODPs) [1] were used in the development of the DS ontology. The ODPs are documented descriptions of practical solutions to typical problems of ontological modeling, The use of ODPs not only improves the quality of the developed ontologies, but also simplifies and accelerates the process of their development.

The most representative catalog of ODPs is presented on the portal of the Association for Ontology Design & Patterns (ODPA) [2]. There are six types of patterns: structural patterns, correspondence patterns, content patterns, reasoning patterns, presentation patterns, and lexico-syntactic patterns.

Currently, ODPs are widely used in the development of ontologies and ontological resources for various subject areas [3-7].

The paper is organized as follows. Section 2 tells for what purpose and for whom the DS ontology is being created, what requirements are imposed on it. Section 3 provides a general description of the types of ODPs used in the development of the considered ontology. Section 4 presents content patterns and examples of their use. Section 5 discusses the development and use of two structural patterns specific to the DS WFD subject area.

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2. Purpose of the ontology under development and requirements for it

The ontology considered in this paper is being developed for an information-analytical Internet resource for decision support in weakly formalized domains (DS WFD IAIR). When creating this resource, the methodology and technology developed at the A.P. Ershov Institute of Informatics Systems of the SB RAS [8] are used. According to this methodology, the IAIR is an information-analytical system, which contains systematized information related to a specific subject domain (in this case, it is the DS WFD), and provides content-based access to this information, methods of its processing, adopted in this subject domain, as well as methods for solving tasks typical for this SD. The basis of such an Internet resource is the ontology of the corresponding subject domain, which serves not only to formalize and systematize various types of knowledge, data and information processing and analysis facilities integrated into the information space of the IAIR, but also to organize convenient content-based access to them.

There are several main types of users who will be interested and useful to the DS WFD IAIR:

- experts and decision makers (DM) in their fields of activity;
- researchers developing decision-making methods;
- persons studying the field of knowledge "Theory of decision making";
- developers creating software products, in particular, decision support systems (DSS), for various WFDs.

All users of the DS WFD IAIR need, first of all, the information contained in it about the process, tasks and DS methods. The resource provides the capabilities of a high-level reference book that describes the properties and semantic relationships of the concepts of interest to the user. Ontology plays the role of a semantic catalog in this reference book. An important feature of the DS WFD IAIR, which distinguishes it from similar resources, is the provision of access to DS methods. This feature raises the efficiency and usability of the DS WFD IAIR to a qualitatively new level. The user receives a convenient tool for processing and analyzing the information he needs. The DS WFD IAIR also allows him to directly test different methods for solving problems of interest to him. User-developers, in addition to information and the ability to try out the necessary methods, also need concrete implementations of the methods that they can use in the products they create. The DS WFD IAIR offers such users a repository of already implemented methods.

The subject area of the IAIR is decision support in weakly formalized domains (Figure 1). This area is seen as an extension of classical decision theory (DT). Within the framework of such related scientific disciplines as artificial intelligence, cognitive psychology, systems analysis, approaches and methods have been developed that allow you to structure subject areas, diagnose problem situations, analyze objective and subjective factors, and find options for solving problems. At the same time, emphasis is placed on those methods that are used in weakly formalized domains, which are characterized by such factors as uncertainty and incompleteness of the initial data, the absence of an analytical model of the problem being solved, the qualitative, declarative nature of the information used.

Along with the concepts associated with the decision-making process and methods of its support, the subject area “DS WFD” also considers issues related to the software implementation of methods, as well as the activities carried out within its framework (Figure 1).

The peculiarity of the DS ontology is that, on its basis, a comprehensive support of DSS developers is organized. In this regard, the ontology should include not only traditional concepts for scientific subject domains (SSDs), such as methods, tasks, research objects, scientific results, etc. [9], but also reflect the orientation of information to various types of users, and also the connection of concepts and objects of ontology with data from external sources, which can be used in solving the decision support problems.

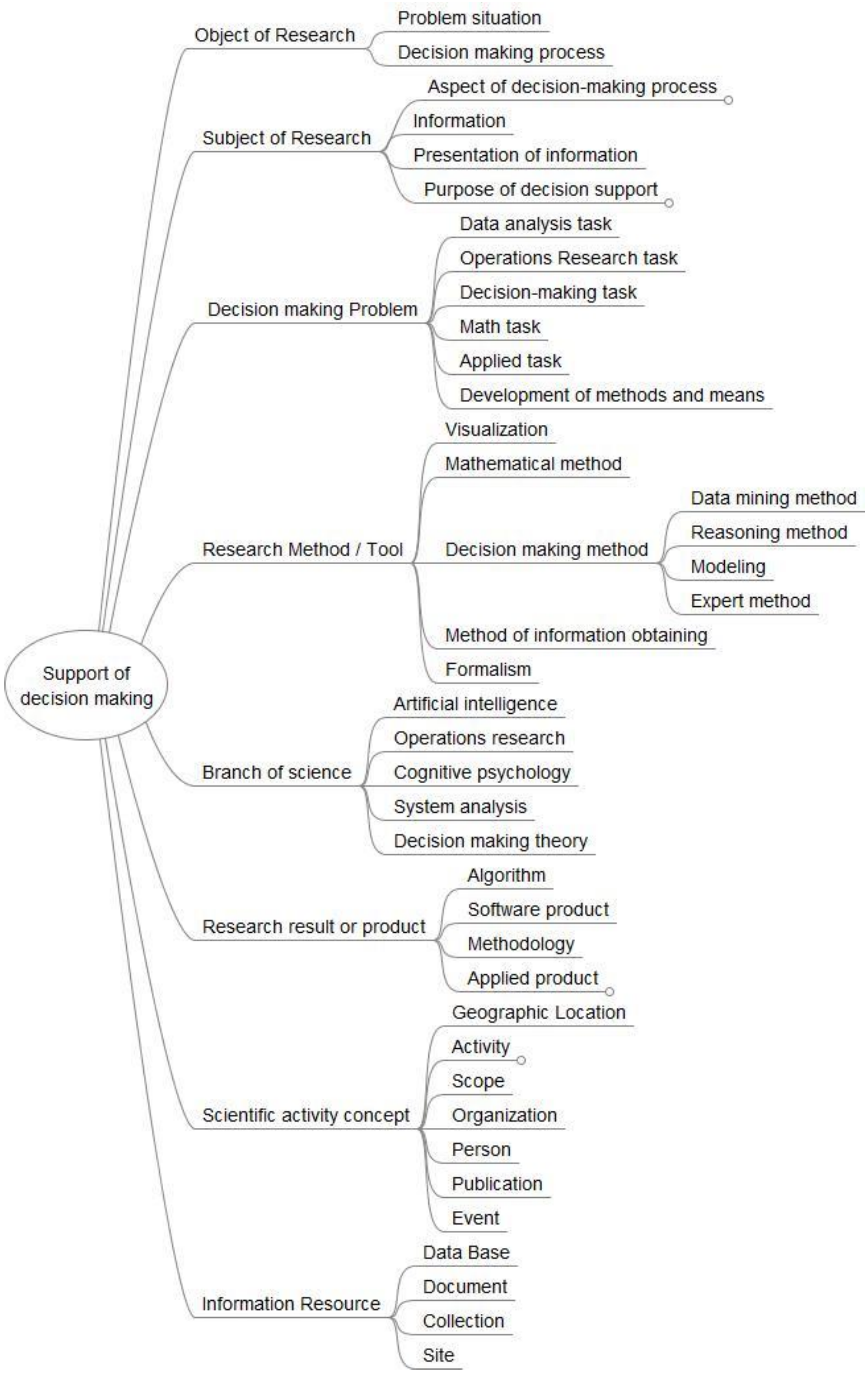

Figure 1: "Decision support in weakly formalized domains" subject domain

3. Types of Ontology Design Patterns Used

ODPs are created, as a rule, as a result of generalizing the experience of ontology developers and are subsequently used to create new ontologies. Such patterns can have a graphical representation, contain a description in natural and/or formal language. The visual representation of the pattern clearly describes its essence and makes it easier to use. If a pattern is described in the ontology representation language (for example, in the OWL language), then it can be directly imported into the ontology under development.

Three types of patterns were used in the development of the DS ontology: presentation patterns, content patterns, and structural patterns.

Presentation patterns were used for annotating and naming elements of the ontology, as well as for defining the names of ontology elements that will be used when they are displayed in the user interface of the DS WFD IAIR. Patterns of this type are described in detail in [4].

Content patterns were used to develop typical fragments of an ontology, as well as to populate ontology with specific objects that are instances of concepts. These patterns are the most representative class of ODPs used to develop the DS ontology.

The need to use structural patterns arose due to the lack of expressive means for representing complex entities and structures in the OWL language, which is used for the DS ontology representation. In particular, with the help of structural patterns, attributed relations (binary relations with attributes) and ranges of admissible values of attributes (domains), determined by the ontology developer, are represented [4]. In addition, with the help of structural patterns, a multidimensional structure of the DS ontology and connections with data from external storages were specified.

Let's take a closer look at some of the content and structural patterns.

4. Content patterns

Content patterns define ways of representing fragments of ontologies, on the basis of which ontologies of a whole class of subject domains are built by complementing and specializing the elements included in the pattern. Content patterns, as a rule, represent the semantic neighborhood of a concept typical for a certain class of subject domains.

For example, when building ontology of SSD, patterns are in demand for describing concepts such as *Research Object*, *Method*, *Task*, *Information Resource*, and others. Content patterns make it easy to populate an ontology with concept instances. Such typical fragments were concretized for the DS WFD knowledge area.

Let us consider as an example the pattern describing the *Result/Product* class (Figure 2). This class has a *Software System* subclass, which inherits all the properties of the parent class and has an additional *Software System Type* property. In Figure 3 shows the use of this pattern to describe a specific software system *SempNeMo-service*, designed to solve a set of decision-making problems.

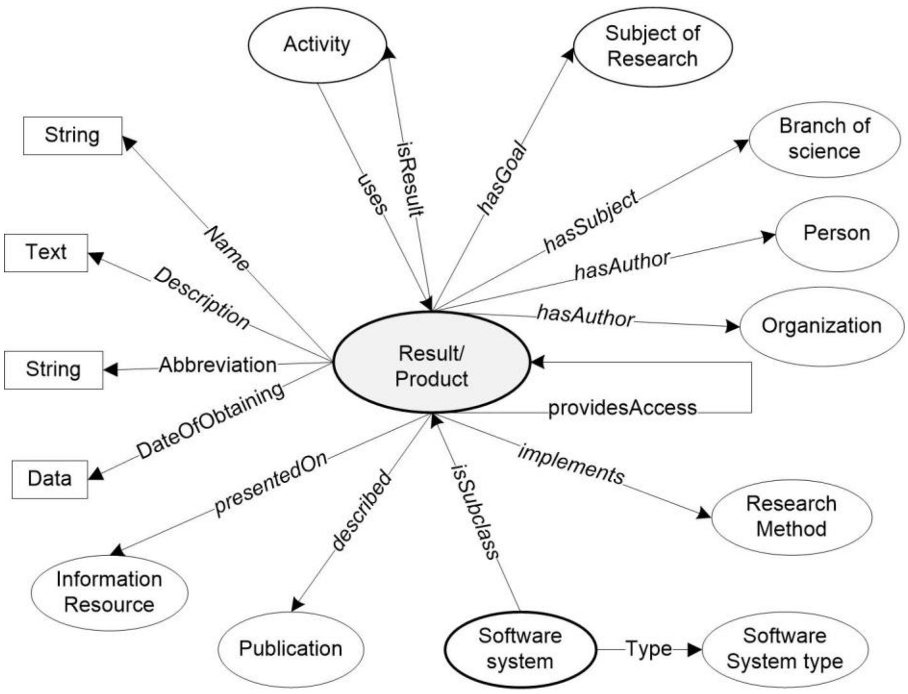

Figure 2: Pattern for description of Result/Product class

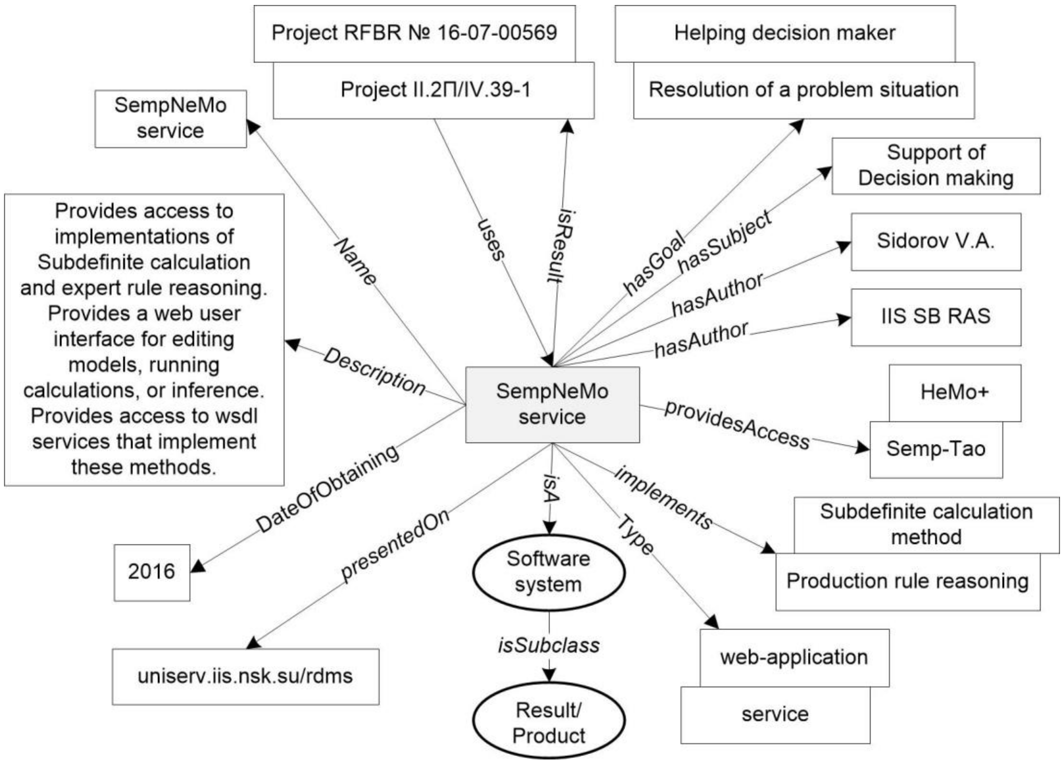

Figure 3: Description of the SempNeMo-service software system using the Result/Product pattern

The use of content patterns when populating the ontology with specific objects from the DS subject domain is supported by a special data editor [5]. Using the pattern corresponding to the class of the object being inserted in the DS ontology, the editor automatically builds an editing form in which the user can set the values of the attributes of this object and its relations with other objects.

5. Structural patterns

As mentioned above, structural patterns are used to represent attributed relations and areas of acceptable attribute values defined by the ontology developer. Patterns of this type are described in detail in [4]. In this section, we will focus on patterns that serve to define the multidimensional structure of the DS ontology and links with data from external storages.

5.1. Patterns for defining the multidimensional structure of an ontology

In some areas that use ontologies to solve practical problems, there is a need for an additional multifaceted structural organization of the ontology using several bases. This may be due to the need to provide the user with different fragments of the ontology, depending on the tasks which are he is solving, on his type (specialization) or level of his competence. For example, in order for the ontology to be a practical means of conceptual support for DSS developers (decision makers, experts, knowledge engineers, programmers), it must provide each type of developers with aspects of its concepts that are of particular interest to them. To do this, it must have a so-called "vertical-horizontal" structural organization, which makes it possible to represent the concepts of interest in two dimensions [10]. The first dimension (“vertical structuring”) is presented in the form of a traditional hierarchical structure, at each level of which concepts are described with varying degrees of detail. The second dimension (“horizontal structuring”) defines the description of concepts from the point of view of different types of specialists working on solving a common problem.

To implement such a possibility, a structural pattern shown in Figure 4 was proposed. According to this pattern, each element of the ontology is marked in accordance with the existing bases for structuring the ontology and their possible meanings. Figure 5 shows how this pattern is specialized for the considered subject area. As the basis for structuring, the *developer Type* property was introduced with the values {DM, EXPERT, KNOWLEDGE ENGINEER, PROGRAMMER}. This pattern was implemented using the Protégé editor by adding a new annotation property, namely d*eveloperType*. Using this pattern for marking the *Mathematical representation of information* class and an object of this class *Matrix* is shown in Figure 6. As can be seen from the figure, these elements of the ontology were assigned to the *Programmer* developer type.

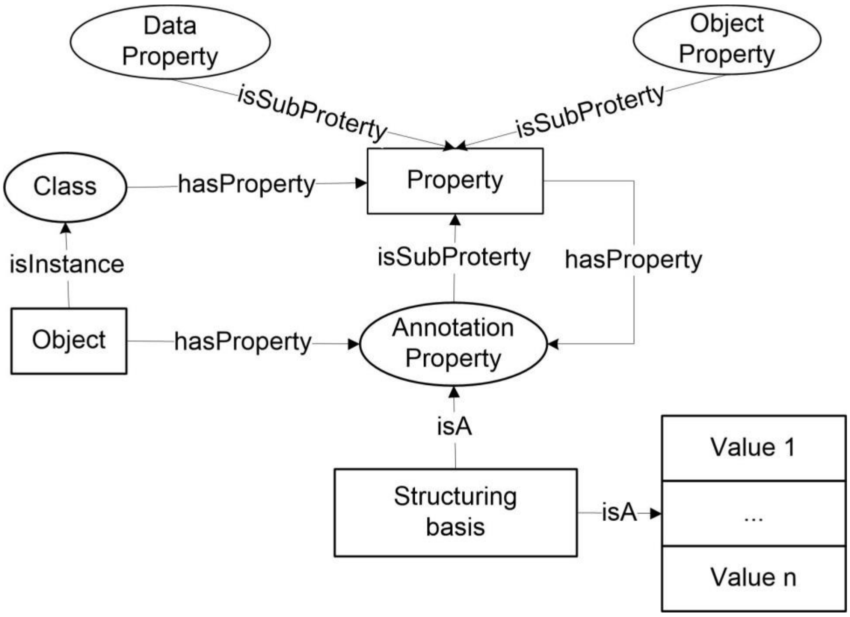

Figure 4: Structural pattern for specifying the basis of structuring

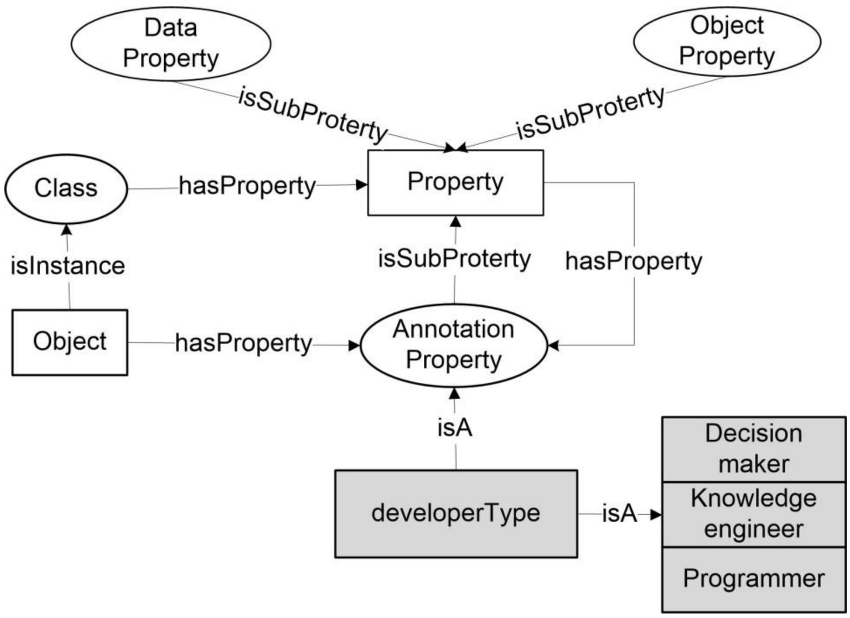

Figure 5: Specialization of the pattern for specifying the basis of structuring

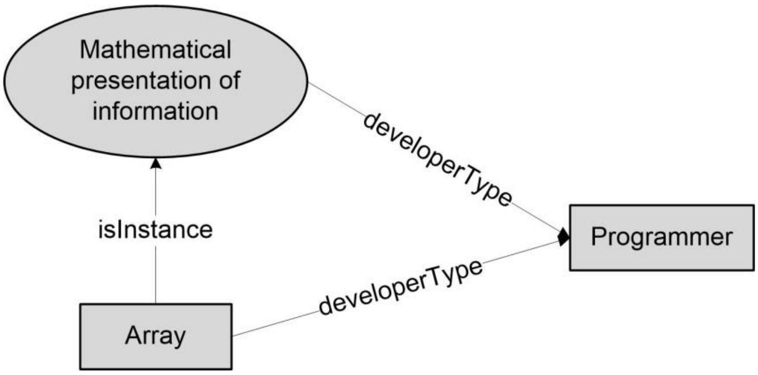

Figure 6: Use of the pattern for specifying the basis of structuring

Due to the use of the bases of structuring in the DS ontology, the user of the DS WFD IAIR can choose which type of developer he belongs to, and depending on this, only classes, objects and properties marked with the corresponding property (basis of structuring) will be shown to him. Note that unmarked elements of the ontology are considered generic and are shown to users of all types.

5.2. Patterns for defining communication with external data sources

Many of the DS methods use large amounts of data located in external storages. A subsystem for integrating the DS WFD IAIR with external databases was developed [11]. To provide a connection between a class of objects of a certain subject domain ontology and their properties with the parameters of a query to an external database, a special structural pattern was developed (Fig. 7). Using this pattern, the *tableid* annotation property is assigned to the ontology class, objects of which can have values from external storages. The value of this property will be a unique identifier reported to the knowledge engineer after registering the database with the integration subsystem. For the properties of this class that uniquely define the object and are included in the query template, the *tablelabel* and *tableorder* annotation properties have been introduced. These annotation properties specify, respectively, the name under which the class property is included in the query template and the order of its occurrence. The values of these properties are retrieved from the ontology for each specific object and substituted into the query template to retrieve values from external storage.

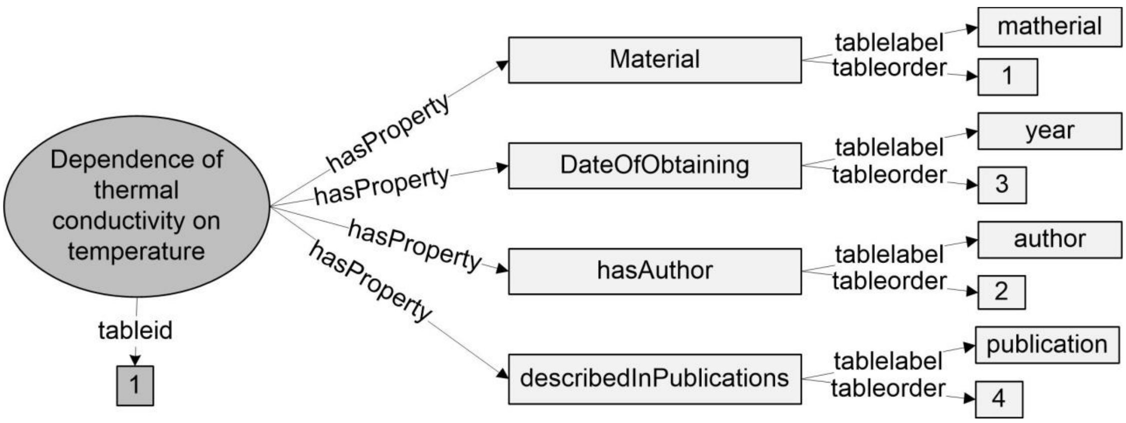

Figure 7: Pattern for binding a class with query parameters

Let us consider, as an example, how this pattern was used in the development of the subject domain ontology “Thermal-physical properties of chemicals”, integrated with the DS ontology. In this ontology, there is a class called *Dependence of thermal conductivity on temperature*. The objects of this class are specific dependencies stored in an external database. These dependences were obtained experimentally at different times by different researchers for different materials and are described in different publications. These properties (the material for which the dependency was obtained, the surname of the author who received it, the year of receipt and the name of the publication in which it was first described) make it possible to identify specific dependencies and are parameters of the database query template. Figure 8 shows how the above pattern is concretized for this example. Note that the name of a property in the ontology does not have to coincide with the name of the corresponding field in the external database.

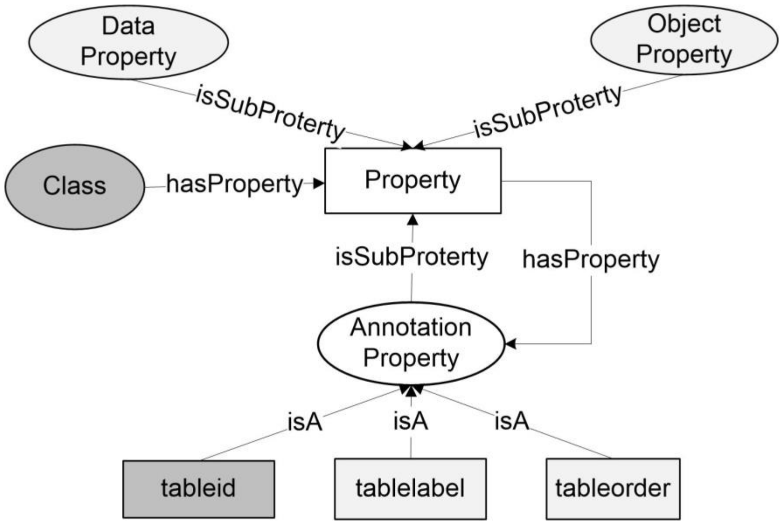

Figure 8: Pattern for binding a class with query parameters

Using the pattern discussed above in ontology development allows the knowledge engineer to establish a connection with data from external sources without resorting to the help of programmers.

6. Conclusion

The paper presents ontology design patterns that were used to create an ontology for decision support in weakly formalized domains. The development of such patterns and their use are considered. Examples of content patterns used to define the main classes of the DS ontology and their objects are described, as well as patterns for defining a multidimensional structure of an ontology and organizing interaction with data from external sources.

The use of ODPs made it possible to streamline and speed up the process of developing the DS ontology, as well as improve its quality.

7. Acknowledgements

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