The Use of Ontological Knowledge for Semantic Search of Complex Information Objects

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***Abstract*—The problems deal with information retrieval by the Web intelligence applications are analyzed. The ontological analysis is used as a basis for knowledge representation in the semantic search. An ontological model of the interaction between the open information environment, intelligent information system and its users is proposed. A method of acquisition of knowledge about the complex information objects which structure is also formalized by ontologies is represented and described on example of competence analysis tasks.**

***Keywords*—semantic search; ontological model; information object; knowledge**

I. Introduction

A large part of modern information systems is more or less intelligent: they focus on the use and processing of knowledge about the subject domain that is interesting for user. Most of these systems are designed to operate in the open information environment; in particular, they use the search of the actual and pertinent information to achieve the goals of the user. The object of such search may be not only data, but also programs, services, knowledge, and other complex structured information entities.

The rapid increase of the amount of the Web information resources (IR) as well as the complication of their structure predetermine the need of the automated and intelligent means of information retrieval. Models and methods of the semantic search allow the use of knowledge about users, information resources and objects that should be obtained from external sources and the experience of performing the search process.

Personification of semantic search which is based on the use of knowledge about particular users and their spheres of interests (subject domains), their current information needs, the ability to perceive information and experience allows to retrieve information more efficiently.

II. Problem Statement

Development of the ontological model that formalizes the information relations between the open information environment, intelligent information system (IIS) and its users, is an actual scientific and applied problem which solution requires the development of knowledge representation of the search domain, its objects and subjects, construction of methods either for obtaining this knowledge from the variety of information sources or for use of this knowledge to improve the efficiency of the IIS work.

This model allows to describe formally the information objects (IOs) which are processed in the IIS, their structure and properties, and to develop the methods and tools for use and obtaining information about these IOs.

III. Features of Semantic Search

In the most general sense an information search is a matching of the user conceptions about relevant knowledge with the content of available IR and constructing of IO (or a set of IO) on the basis of such comparison where the values of IO property are acquired from these IR.

Semantic search uses in this matching various knowledge about it's subjects (users, resources, results of previously performed search procedures), as well as knowledge about the search domain. If ontology is used for formalization of such knowledge then we propose the ontological model of search.

Semantic search is a process of information retrieval which meets the user information needs arising from during the process of solving a particular problem if the knowledge about different subjects and objects of the search procedure is applied (explicitly or implicitly to user) and methods of analysis of this knowledge [1].

This knowledge can deal both to the user and his information needs (the personification of the search), and IRs among which the search procedure is executed (e.g., the Internet of Things or the Web of Things, GRID environment) [2], or IOs which results the search (e.g., search of Web-services or ontology).

Semantic Search System (SSS) is an information system that provides search and recognition of different types of IO and uses knowledge to match the request with the existing IRs on the semantic level. SSS can be considered as an intelligent superstructure over the traditional information retrieval systems [3, 4]. Modern SSS acquired knowledge dynamically from the open environment [5-7].

IV. Personification of the IO Semantic Search

Semantic search, in contrast to the usual one, allows user to specify the desired search object. SSS can find not any particular IR (document or some fragment of document) but an information about IO of the certain class that user can (explicitly or implicitly) specify. It can be quite simple and common class, for example, "human" of "multimedia object", or specific class of some domain such as "scientific publication", "abstract". The user can explicitly specify the desired IO type by use of the relevant standards and taxonomies, for example, for retrieval from the ontology repositories or Web-based services [8], RDF descriptions [9] and XML structures [9].

IO can be considered as an information model of domain object which defines it’s structure, attributes, integrity constraints, etc. From the viewpoint of the semantic search IO is the information that the user receives as a result of the search

V. Ontologies and Semantic Search

SSS user can describe IOs by use of appropriate ontology [11, 12]: the ontology class can be used as the basis for presenting the structure of IO, and instances of this class can be formed by information from IRs. Examples of IO are organizations, educational institutions, humans, Web-services etc.

User can choose IO ontology from any open repository or create it himself with the help of some appropriate methodology and software tools [13, 14].

User has to:

- Understand what type of IO (or the set of IO types) is interested for him from the viewpoint of current problem;
- Find an ontology which classes represent the structure of the required IOs;
- Identify the set of IRs that contains information about the values of the IO properties (for example, by the request to the external retrieval system).

SSS provides to user:

- Extraction of knowledge about these properties of the selected IO from the selected IR;
- Acquisition of desired knowledge in a form understandable and convenient for user.

VI. Classification of IOs and Retrieval Situations Associated with Them

Solving of the semantic search tasks associated with the recognition of the complex IO set causes a number of problems that need in special term definitions, in particular, to state which information deal with the search result and which one – with it’s conditions.

In the simplest version of the information search the search engine receives input as a set of keywords and provides the output as a set of links to the documents.

Search problem becomes much more difficult if it’s the input data is a description of a complex problem with the interaction of complex structured IO and output is a reference to the IO instances that satisfy the complex set of conditions.

IO ontology O_{IO} is an ontological structure that contains the IO class $t_{IO} \in T_{IO}$ and its subclasses that describe different subsets of IO, and the classes T_{Prop} that are used for describing of IO properties:

$$O_{IO} = \langle T_{IO} \cup T_{Prop}, R, A \rangle .$$

User can describe the IO of his interests by referring to the class of any formally described ontology. Thus, IO is the class of IO ontology which has a set of characteristics that describe its structure and possible links with other classes and class instances.

IO instance is an instance of IO subclass of corresponding ontology which can be clearly identified and that has a proper name.

Situation is a non-empty set of IO instances of one or different classes, such that every IO of this set has a link with at least one other IO from this set. If situation uses IO described with use of different ontologies then it is necessary (explicitly or by means of the automated comparison of ontologies) to establish links between these ontologies (or at least between those IO and the classes that describe the properties of IO appeared in the situation).

Situation scheme is a situation that is not used IO individuals but only IO classes. We can consider situation schema as a search query and the set of satisfying situations as its result.

Invalid situation scheme is a situation schema which the conditions can not be satisfied by any set of IO individuals.

The scheme is *invalid* if it contains inconsistent conditions: $f_0(a_1,\dots,a_n), f_1(a_1,\dots,a_n),\dots,f_m(a_1,\dots,a_n), a_i \in t_i \subseteq T_{IO}$

and a logical conclusion of some subset of them $f_1(a_1,\dots,a_n),\dots,f_m(a_1,\dots,a_n), a_i \in t_i \subseteq T_{IO}$ is a $\neg f_0(a_1,\dots,a_n)$.

Unique situation is a situation which conditions are satisfied only by the single set of the IO individuals. An example of such a situation is a search of book by it’s ISBN.

Concretized situation is a situation which description contains at least one IO instance. An example of such situation is a request about organizations where persons living in the same house with a person X with identification number work.

Personal situation is a situation that uses an instance of class "user" of semantic search ontology that characterizes the SSS user, i.e. the person who determines the situation. This variant of the search problem is quite common if the user is trying to find some information deal with himself – for example, links to his own publications, the possibility of his employment in a particular organization, the rating of his specialty etc.

Each personal situation is concretized through the use of specific instance of class "user", but the use of personal situations allows the development of the typical queries where a certain piece of information is not entered manually by the user but is imported from his profile.

For example, instead of the query "all references from the author's A publications to the publications of the author B " user can call much simpler query "all references to my publications from author's A publications" for which the list of "My Content" that can be built automatically and updated by searching of the relevant Web-resources.

The situation *satisfies the scheme* if conditions are satisfied for all IO and IO instances that are included to this scheme.

Search is *impracticable* if it’s condition is invalid circuit situation.

Search is *executable* if its conditions can be satisfied (even if combination of the IO, satisfying these conditions is not detected).

Search is *trivial* if it results the unique situation.

Recognizing of situations which use multiple IO of the same or different classes with a complex structure is in general a very difficult task for search engines, even for those that carry out the search based on semantics. But for some special cases quite effective methods and means of the search are already exist. These methods operate on base of the specifics of certain IO types. These tools are designed for the most widely used IO that need in automated association in certain situations as a prerequisite for their effective application.

The best known examples of such IO search is the composition of semantic Web-services (solving of user problems requires a set of services that implement the various sub-task, and the order of their implementation); and the problem of complex search of multimedia data (information that is retrieved from one multimedia IO is used to find another one that satisfies certain conditions – for example, all other films of some actor). Analysis of these examples can be used for generalization of best practices for wider class of IO.

VII. MATCHING OF COMPETENCIES

Model of semantic search can be adapted quite easily for a variety of applications including related with the search of complex situations which conditions use IO of different classes. We propose to consider it on example the problem of competence mapping [15] which is an integral part of such widespread practice tasks as finding by employer of suitable employees; ranging of experts in new domains; estimation of the successful implementation of the scientific project; comparison of specialists of different specialties (in particular, by qualification standards of different countries); choice of educational institution with a specific set of disciplines. Performing these tasks requires a knowledge of the respective organizations, persons and activities that should be compared.

Such problems can be considered as special cases of the search situation. For example, to choice by the entrant of the educational organization need to compare instances of "school" with instances of the class "discipline" that is used IOs of two different classes.

Both of these classes contain property of class "competence": for the first class of the property "provides the learning process", the second – the property "includes". Matching is provides by comparison of sets of values of these parameters. Due to the fact that the results of the comparison may not match exactly it is necessary to take into account the weight of the different disciplines for the entrant.

Use of the class "competence" provides the comparison of such IO as «discipline», «learning organization», «employer», «expert», «employee», «speciality» etc not on the level of names but on the level of their semantics.

Now the term "competence" is unclear and depends on the specifics of a particular subject domain. In general, the competence is an ability to operate successfully on the basis of existing knowledge and experience in problem solving. The first study of competencies for predicting the level of efficiency of execution of the work was proposed [16] to search for actors able to perform certain types of work.

The objective assessment of the transfer possibility for students from one educational institution to another is an example of the personal situation: various disciplines of different learning institutions from the list (this list can be proposed by user or forms automatically from those ones that satisfy some specific conditions – for example, those learning institutions that are situated in a selected by user city) are compared.

In this situation IO of classes "discipline", "educational institution", "competence" and "user" are applied. It should be noted that each personalized situation is concretized: it applies a specific instance that is associated with SSS user. In this case the user does not need to enter a list of what he learned – these data can be retrieved from his personal profile. A comparison is also performed using the properties of class "discipline" that contain instances of the class "competence". So it takes into account the semantics of the processed IO.

The solution to all these problems can be based on a common ontological model [17] which sets out the basic concepts related to competencies, their structure and relationships between instances of such basic classes that corresponds to this concept as "competence", "discipline", "person", "educational institution", etc. and their subclasses [18].

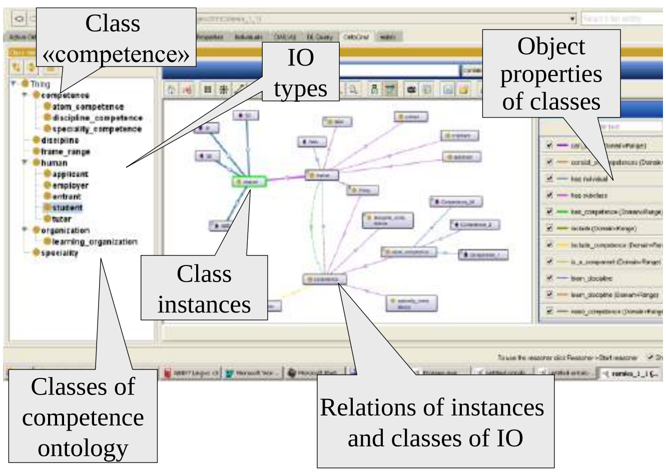

Fig.1 – Ontological model of competence analysis task

Furthermore, this model can contain classes relevant to the search resulted information objects (Figure 1). For example, resulted IO of the employee finding task belongs to the class "person", and resulted IO of the education evaluation task – to the class "organization" but both IOs can be characterized by the same sets of properties of a class "competence". The possibility of formal and unambiguous definition of the type and structure of desired IO improves pertinence of the search results and makes them much more suitable for the user.

This ontological model of semantic search allows to perform complex information requests, to import the personal characteristics of users with complex and stable information needs (specific to research activities and educational services), to take into account education, experience and expertise of users in various fields, and to integrate with other intelligent applications which are also based on ontologies.

The user describes his need for information by indicating the class of the ontology which required IO and conditions that are imposed on properties of IO values. Conditions can be described as a set of instances of the class "atomic competence". Thus, the query is reduced to comparison of these sets – for example, to comparison of the values of property "includes competence" that refers to the class of "atomic competence" with the values of property "speciality" for individual of class "specialist”.

This approach clearly indicates the semantics of information needs, so you can search that differentiates various relations between IOs and the required set of competencies.

For example, different subsets of atomic competencies can be associated with the same instance of class "human" by relations "owns", "has the certificate", "can teach," "has an experience in use". This enables more accurate satisfaction of users' information needs by semantic retrieval of pertinent IO.

To perform the comparison of different types of IO – for example, professions, skills and competencies of people and organizations we need to acquire their common parameters, i.e., the properties of instances of these classes that belong to the same class. Analysis of research in this area points to the appropriateness of the use for these purposes the values of "atomic competence" class which is a subclass of "competence". Thus, an individual of any of the above classes is characterized in terms of a given domain by the set of reference atomic competencies [19].

Class "atomic competence" is a subclass of "competence", so that $\forall a \in$ "atomic competence" there is at least one element of class "Competence", such that, but for a single element of the class $\forall b \in$ "atomic competence", $a \subseteq b$ that there is no other element of this class $c \in$ "atomic competence", such that $c \subseteq a, a \not\subset c$. Class "atomic competence" has the property "be part of the" of class "discipline" and the property "included in the" of class "competence".

The most important issues that arise in the process of solving this problem, are associated with the formation of the set of atomic competencies which requires considerable intelligent efforts of experts and can be automated only in part, and with the completion of the knowledge base by information about individuals of IOs that require permanent processing of a large volume data.

An instance is considered to be atomic, if any other instance of this class is not a subset of it, that is instances of the class "atomic competence" are not intersected.

This definition provides a generic mechanism for building of atomic competencies for selected domain on base of the set of competencies that characterize this domain and can be built from the normative documents – the descriptions of specialties, disciplines, etc. For example, if two competencies A and B are intersected than other three potentially atomic competencies A1, B1 and B are constructed: $A \cap B = C$, $A_1 \cup C = A$, $B_1 \cup C = B$.

VIII. STRUCTURE OF COMPETENCE ONTOLOGY

Competence ontology defines the of the semantic properties and relations of the main IO which relate to competencies of individuals, groups and organizations that are carriers of these competencies, their customers or means of their acquisition.

We propose to use competence $c \in C$ as a basic element of this ontology. Competencies are subdivided into atomic competencies C_{atomic} and complex competencies $C_{complex}$, $C = C_{atomic} \cup C_{complex}$.

$$c \in C_{complex} \text{ if } \exists c`, c` \neq c, c` \in C, c` \subseteq c.$$

Atomic and complex competencies belong to subclasses ontological class «competence». Other important classes of this ontology – "Discipline"; "Specialty"; "Human"; "Organization".

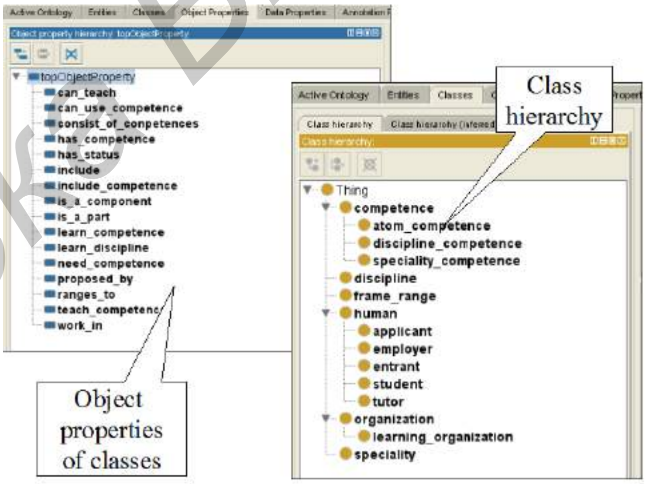

Fig.2 – Classes and object properties of IOs of competence ontology

All subclasses of these base classes have some common characteristics. For example, all subclasses of "person" have the data properties "name", "date of birth", "address", etc. and object properties «has parent» of class «person». These classes become more specific by means of different subclasses with various semantic properties of the object. For example, the class "person" has the subclasses of "student", "employer", "teacher", "researcher", "graduate student" and etc. These subclasses are distinguished by the presence of some additional properties: "student" has the object properties of a "place of learning", «speciality» and data properties "year of learning", "post-graduate" has object property "Supervisor" from class «human» and data property "topic of research" (Figure 2).

An important characteristic of this approach semantics is the fact that all the base classes of this ontology have the object properties with values of the class "competence" that determine their aspects related to competence analysis.

Today we don't have any universal ontology of competencies and qualifications that is harmonized with all national and international approaches. But we can use a set of such ontologies that would be matched one with others.

That's why we propose the following method of competence matching:

- define the documental content that can be used for description of the set of atomic competencies that define some complex information object (for example, requirements of employer or passport of postgraduate speciality)
- transform these documents into the Wiki representation
- build the ontology that defines relations of atomic and complex competencies, disciplines, specialities, professions etc.
- semantically mark up these Wiki resources by the concepts of this ontology that can be used as classes and by object properties of this ontology that can be used as semantic properties at Semantic Media Wiki
- at last, we can built semantic requests to these resources that are oriented on retrieval of individuals (humans, institutions etc.) with appropriate values of defined properties

We understand that there is no way to realize all these activities by any single organization. Some parties of this work can be executed by relevant educational organizations or governmental structures. But we propose the approach to decision of the knowledge-oriented part of this task – the development of structure of competence ontology and methods of matching of various information objects marked up by the elements of this ontology.

An important characteristic of proposed approach is the fact that all main classes have semantic object properties with value from class "competence" that define their semantic aspects deal with competence analysis.

This approach is compatible with different mathematical knowledge-oriented models of qualifications. For example, eight levels of qualification of the European EQF standard can be represented by subclasses of class "qualification" with numerical values of data property "level" from 1 to 8, value of data property "qualification system" equal to "EQF" and with object properties "Knowledge", "Skills" and "Communication" with values from class "Competence".

Every individual of class "Qualification" that has data property "qualification system" equal to "EQF" obligatory has unique value of data property "level" from 1 to 8 and three nonempty sets of object properties "Knowledge", "Skills" and "Communication" with values from class "Competence".

The simplest model of qualifications $q \in Q$ on base of competence ontology can be formally represented by triple, $Q = \langle Iq, Lq, Compet = Kn \cup Sk \cup Com \cup \ldots \cup Compet_p \rangle$, $p = \overline{0,r}$ where

- $iq_j \in Iq, j = \overline{1,n}$ – the identifier of qualification system;
- $Lq = \bigcup_{j=1}^{n} \left\{ lq_{i_1}, \ldots, lq_{i_{s_j}} \right\}$, where $lq_{i_{s_j}}$ is a number of various levels in classification system iq_j;
- Kn is a set of atomic competencies that characterizes the knowledge of appropriate qualification;
- Sk is a set of atomic competencies that characterizes the skills of appropriate qualification;
- Com is a set of atomic competencies that characterizes the communications of appropriate qualification
- $Compet_p$ is a set of atomic competencies that characterizes the p-th set of appropriate qualification (hear we don't concretize the criteria of building of these sets that deal with specifics of different national and international qualification systems).

Various sets $Compet_p$ can be used in different qualification systems, but we state that two qualifications $A \in L$ and $B \in L$ are equal if their sets of competencies are identical: $A \in L \equiv B \in L \Leftrightarrow Compet_A \equiv Compet_B$.

Specialties and disciplines are modeled similarly. The model of specialties $s \in Sp$ on base of competence ontology can be formally represented by triple $Sp = \langle Is, Ls, Compet = Compet_1 \cup \ldots \cup Compet_m \rangle$, where

- $is_j \in Is, j = \overline{1,n}$ – the identifier of classification system of specialties;
- $Ls = \bigcup_{j=1}^{n} \left\{ ls_{i_1}, \ldots, ls_{i_{s_j}} \right\}$, where $ls_{i_{s_j}}$ is a number of various levels in classification system of specialties is_j;
- Compet is a set of atomic competencies that characterizes the appropriate competencies of specialties.

The formal model of disciplines $d \in Disc$ on base of competence ontology can be formally represented by triple

$Disc = \langle Id, Ld, Compet = Compet_1 \cup \ldots \cup Compet_m \rangle$, where

- $id_j \in Id, j = \overline{1,n}$ – the identifier of qualification system;
- $Ld = \bigcup_{j=1}^{n} \left\{ l_{i_1}, \ldots, l_{i_{s_j}} \right\}$, where $l_{i_{s_j}}$ is a number of various levels in classification system of disciplines id_j;
- *Compet* is a set of atomic competencies that characterizes the appropriate competencies of disciplines.

Competence ontology and atomic competencies can be used for semantic markup of various natural language IRs, for example, for semantic Wikis [19] deal with learning, scientific research, qualification estimation, expert retrieval etc. Complex requests can be realized on base of this markup where classes of competence ontology are used as categories of Wiki pages, and competencies (atomic and complex) are used as semantic properties of page content. Such domain ontology can be built automatically by special functions of Semantic Media Wiki or by special algorithms according to personal needs of users.

We can build semantic requests to semantically marked up information objects that are represented by Semantic Media Wiki. For example, we can find all organizations from category “learning organization” where disciplines with proposed set of competencies are learned and show important information about these organizations. This request is based on the function “ask”.

```
{{#ask:
[[Category:learning organization]]
[[Discipline::Programming]]
[[Competence::C++]]
|?City
|?Country
|?Rating
|?Adress
|format=broadtable
}}
```

Personal domain ontology – for example, generated by pages edited by some user – can be used as a formalized model of user competencies and defines the sphere of expertise of this person. By comparing of such ontologies we can retrieve experts, tutors or other specialists by analysis of their competencies on semantic level

IX. Conclusion

Formalized ontological model that represents knowledge about the structure of complex IOs from the subject area user of interests allows IIS to find more efficient results by means of personified semantic search of information from the Web. It takes into account the individual information needs of users and explains him the obtained results.

The use of ontologies for knowledge representation provides access to information from outside sources and repositories and allows to use a variety of tools for analysis and semantic processing of this information. However, we need in further development of the terminology and tools for handling of multifarious sets of information objects hat are oriented on specifics of the different subject areas and types of information objects and their relations.

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ИСПОЛЬЗОВАНИЕ ОНТОЛОГИЧЕСКИХ ЗНАНИЙ В СЕМАНТИЧЕСКОМ ПОИСКЕ СЛОЖНЫХ ИНФОРМАЦИОННЫХ ОБЪЕКТОВ

Рогушина Ю.В.

Рассматриваются проблемы, связанные с поиском информации в Web интеллектуальными приложениями. Онтологический анализ используется как основа для представления знаний в семантическом поиске. Предложена онтологическая модель взаимодействия между открытой информационной средой, интеллектуальной информационной системой и ее пользователями. Такая модель позволяет формально описывать информационные объекты (ИО), которые обрабатываются в ИИС, их структуру и свойства, и разработать методы и средства использования и получение информации относительно этих ИО.

Разработан метод получения знаний о сложных информационных объектах, структура которых тоже формализуется с помощью онтологий, которые проанализированы на примере задачи анализа компетенций.