Binary Relations in Educational Ontologies

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ABSTRACT

Educational ontologies are classified into onthologies of Student Learning Outcomes (SLO), Learning Objects (LO) and Cognitive Domains (CoD). In contrast to the conceptualization and implementation of SLO and LO ontologies, based on standards available in the literature, the CoD ontologies involve subjectivity derived from the analysis of basic concepts of each CoD and relational expressions that experts use in order to associate these basic concepts. This subjectivity can create inconsistent ontologies. The aim of this paper is to establish a set of binary relations to be used_in the official representation of CoD. These relations consist of triples (subject, verb, and object) and can be classified into a Binary Relation (BR) ontology.

Keywords

Educational Ontologies, Binary Relations

1. INTRODUCTION

In the last ten years technology offers opportunities to Universities to reconsider how to extend the teaching, to students beyond the traditional teaching and not limited by boundaries. Hellenic Open University (HOU) aims to bring together leading technologies and pedagogical approaches to implement e-learning environments, specialized to the needs of adult users with different knowledge background, skills and biases. In the realization of this objective, ontologies play a key role. They are machine readable representations of the content of educational material, users' profiles, and taxonomy of learning outcomes, which enables to the creation of individualized learning paths [1]. For this purpose the educational ontologies constructed for HOU [2], [3], [4], [5], [6], can be divided into ontologies for Learning Objects (LO), ontologies for Student Learning Outcomes (SLO) and ontologies for Cognitive Domains (CoD). Regarding the engineering of SLO and LO ontologies, problems do not exist. The conceptualization of LO ontologies is based on standards available in the literature such as the official description of IEEE LOM standard [7]. Tthe conceptualization of SLO ontologies is based on the Bloom's taxonomy [8], a widely accepted taxonomy of learning domains that is often used in the design of educational processes.

In contrast, when designing CoD ontologies, because their conceptualization is based on subjective statements of the kind (subject, verb, object) triples that experts provide, it describes the basic concepts of each CoD and the relations among them between concepts. The classification of these statements in a specific ontology could help to avoid polysemy and ambiguity of relations used to describe CoD. These relations are binary and their formal representation by means of ontology will restrict the use of inappropriate definitions of relations during the implementation of CoD ontologies.

Several existing ontology population techniques able to extract arbitrary semantic relations from text corpora focused exclusively in binary relations. Ontologies present binary relations (called properties in OWL).

In this paper, we conceptualize an ontology Binary Relations (BR), which officially represents the relations needed to describe CoD concepts, under the HOU framework. The ultimate goal is to provide a minimum set of binary relations that are necessary to implement CoD ontologies. In this way, experts should restrict to the proposed binary relations in order to conceptualize CoD.

The remainder of the paper is organized as follows: Section 2 explains the need for formally describing relational expressions used in CoD's description. Section 3 focuses on binary relations by giving their mathematical definition and their usage in ontology engineering and Section 4 describes related work for binary relations. Section 5 describes the main points of BR ontology engineering, and Section 6 concludes the paper.

2. COGNITIVE DOMAIN (CoD) ONTOLOGIES

Initially, domain experts define the basic concepts of cognitive domain and create relationships between basic concepts of CoD ontologies. Afterwards, they develop concept maps based on the concepts and relationships that have defined. [6]

These relations are been expressed through individual relations, known as properties. Properties are divided as object and datatype properties. Datatype properties link an individual to a specific value, namely an XML Schema datatype or an RDF literal. [2]

More specifically, the pair-wise inverse properties X and X^{-1} are used to declare a parent-child relation between two concepts. They can be a) functional, meaning it is a property that can have only one (unique) value y for each instance x, b) transitive, meaning that if a pair (x,y) is an instance of P, and the pair (y,z) is also instance of P, then we can infer the pair (x,z) is also an

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instance of P or c) symmetric meaning if the pair (x,y) is an instance of P, then the pair (y,x) is also an instance of P. The instance property connects class with its members, whilst Y correlates any individual with a certain modifier. Finally, to define the particular relation of a concept with a reserved keyword, the Z property is used.

Figure 1 presents as an example, based on a part of the concept map that has been created for the cognitive domain CoD: PLI30 as we can see in [6].

This conceptual map represents 32 identified basic relevant concepts (see the nodes of Fig. 1) and 5 relations (see the edges of Fig. 1; for example, "Associative Network includes Node").

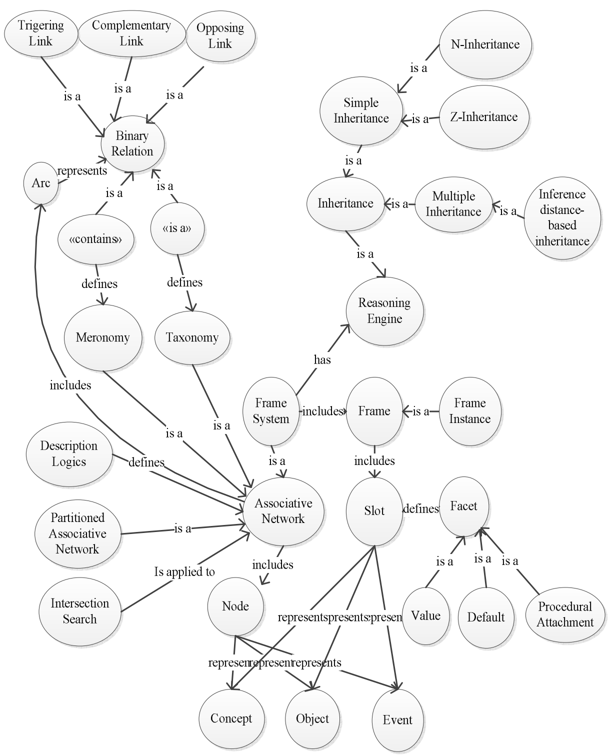

Figure 1: Part of the concept map expressing concept "Frame Systems"

It is necessary to formalize the terms of relations (verbs), which are binary relations, in a rigorous machine readable format, with the aim of understanding the knowledge expressed by domain experts in concept maps. There are several ontology development tools that implement concept model ontology in different languages. Ontology experts can apply Protégé [9] to convert a conceptual map produced by the experts into a formal model by using the formal OWL language. To evaluate the graphic representations of the concepts of the course through the concept maps in OWL.Then, they can use off-the-shelf automated reasoning tools.

Note that the same natural language relation (verb) can be used by experts to connect different concepts in the same field or in different cognitive domains. One way to develop consistency and clear standard definitions of relational expressions used in educational ontologies concerning CoD, is to develop an ontology providing definition and classification, according to a certain criterion, which is described in subsection 5.2, of the extracted binary relations. This can facilitate ontology experts and domain experts to avoid mistakes in coding CoD.

The resulting ontology can also promote interoperability of educational ontologies and support automated reasoning in e-learning environments.

3. BINARY RELATIONS

The relational expressions that domain experts use to provide the formal description of a CoD as we saw previously are sentences that simply indicate a relation between two basic concepts of the same cognitive domain, without any further information. These sentences are typically described by binary relations.

3.1 Definition of Binary Relations

We will give a formal definition for binary relation. Binary relations are important, since relations of arity greater than 2 can be studied in terms of binary relations.

Mathematically speaking, if X and Y are non-empty sets, a binary relation from X to Y is a subset $R \subseteq X \times Y$. We write $(x, y) \in R$ or xRy to denote that $(x, y) \in X \times Y$ and we say that X is related to Y through R. For example, in the accounting CoD, the natural language expressions "Slot represents Concept", "Slot represents Object", "Slot represents Event" can be formulated as the binary relation $R = \{represents\}$ from the set $X = \{Slot\}$ to the set $Y = \{concept, object, event\}$. For some binary relation $R \subseteq X \times Y$, we can define its inverse $R^{-1} \subseteq Y \times X$, such that $yR^{-1}x \Leftrightarrow xRy$.

An interesting point to consider about binary relations is their composition which is defined as follows: let $R \subseteq X \times Y$ and $S \subseteq Y \times Z$ binary relations. Their composition is a binary relation $S \circ R \subseteq X \times Z$ defined by $x(S \circ R)z \Leftrightarrow \exists y \in Y$ such that xRy and ySz.

We are also interested in certain properties satisfied by these relations, such as: (a) reflexivity (xRx for all x in X), (b) symmetric (xRx' implies $x'Rx$ for all x, x' in X), and (c) transitivity ($x''Rx'$ and $x'Rx$ imply $x''Rx$ for all x, x', x'' in X).

The main point is that to uniquely describe a relation R, the collection of all ordered pairs (x, y) such that x is related to y by R, must be listed.

3.2 Binary Relations in Ontologies

The relations contained in ontologies are usually binary. They have two arguments; the first is called the domain of relation, and the second is called range. These relations are mainly related to the classes of the ontology and usually initialized using the knowledge from the domain representing the ontology. For example, to express that "the x processor executes the y software", the relation "executes" should be designed and should have a class "Processor" as the domain and a class "software" as the range. On occasion, the same relations used to relate classes, are also used to express attributes of specific classes. These are also the binary relations, where domain is a certain class and their range is a datatype, such as string, number, etc.

In the case of n-ary relations, that is, relations which link an individual to more than one individual or values are represented by creating an intermediary entity that serves as the subject for the entire set of all relations [9]. In our approach, we refer only to binary relations, which are the most common type of relation mapping a single subject to a value.

4. RELATED WORK

The most common type of relation is a binary relation that connects two concepts. Discussions for binary relations have been researched in [9], [11], [12], and [13]. The problem of representing a binary relation is not new.

In 2014 [9] Vinu, Sherimon, Krishnan and Tarkoni discuss the issues in modelling n-ary relations. They support that the main elements of ontology are concepts, relations and individuals. W3C provides several patterns to represent n-ary relations. They examine the issues in n-ary relations, the concept of RDF reification and provide an appropriate pattern to represent the n-ary relations. The examples of n-ary relations are taken from Seafood Ontology they developed. In contrast to our work, they focus on the issues of n-ary relations. It explains the ontology languages followed by the n-ary relation, the issues in n-ary relations,reification and its drawbacks and outline an appropriate pattern to represent the n-ary relations.

Welty and Fikes in [11] discuss the standard approach to deal with relationships that change over time, such as OWL that are biased towards binary relations. Their approach involves treating entities in the domain of discourse as four dimensional with temporal parts that participate in the relation, corresponds to and stablished ontological position in analytical metaphysics called perdurantism.

Martin and Benard in [12] propose an ontology design pattern for leading knowledge to represent knowledge in a more normalized way. This pattern is: "using binary relation types directly derived from concept types, especially role types or types of process with nominal expressions as names". It provides an ontology deriving relation types from concept types; this derivation reduces having to introduce new relation types. It explains, formalizes and illustrates the different parts of ABP (advocated best practice) and relates this practice to other ODPs (Ontology Design Patterns).

In contrast to our work, in [13] Banek, Juric and Skocir introduce an unsupervised method for learning domain n-ary relations from Wikipedia articles. They claim that providing ontologies with n-ary relations instead of the standard binary relations built on subject –verb- object paradigm results in preserving the initial context of time, space, cause, reason that otherwise would be lost. They discuss the use of n-ary relations for discovering richer semantic context, the relation extraction process and the evaluation of this approach.

Our work is consistent with Martin and Bernard in [12]. We attempted to define the relations created from concept maps as binary relations in order to enable us to better construction of educational ontologies.

5. BR ONTOLOGY ENGINEERING

The main questions arising when engineering the ontology of binary relations used in the HOU context are: Which are the intended uses of the BR ontology? Which are the entities that require a unique categorization? According to what criterion? What kinds of binary relations are used in the literature? What kind of relations can we formally describe? What are the properties of the described relations? The BR ontology is engineered according to commonly accepted engineering methodologies, based on specification, conceptualization, implementation and evaluation phases, where all the questions stated above are answered [10].

5.1 Specification of the BR Ontology

The CoD ontologies in the framework of HOU are designed to provide reference points for the expression of the basic concepts of each cognitive object in a machine readable format. Their construction is based on natural language statements gathered by the domain experts, which are expressed in sentences of the form (subject, verb, object). These sentences of the kind "A -relation-B" (where A and B are concepts belonging to the same CoD ontology and "relation" symbolize connects for associating these concepts) can be considered as binary relations between semantic concepts in a vocabulary that is specified for a certain cognitive domain.

Our task is to develop a minimum set of coherently define binary relations involved in the formal representation of cognitive domains through ontologies and the scope to capture the relations currently expressed in the context of the CoD ontologies. This is important, since (a) the inability to distinguish relational expressions which are close in meaning, results in an erroneous reasoning process, and (b) the polysemy of relational expressions impedes interoperability between educational ontologies developed in the HOU.

5.2 Conceptualization of the BR Ontology

In the literature, binary relations are distinguished in the following three kinds. The categorization of binary relations based on their domain and range.

- $\langle class, class \rangle$: for example, statements such as the class "Slot" represents (relation) the class "Object" or the class "Slot" represents (relation) the class "Event".
- $\langle instance, class \rangle$: for example statements such as the instance "current assets" includes (relation) the class "requirements" or the instance "current assets" includes (relation) the class "inventories" and
- $\langle instance, instance \rangle$: for example, statements such as the instance "unit of manure" contains (relation) the instance "80 Kg N" , since they cannot be considered as sets of objects.

5.2.1 BR Ontology

By following our ontology engineering methodology [6], we constructed an ontological model for the relations of the cognitive domains in HOU. The BR ontology was constructed with the aid of Protégé based on the most recent version of the Web Ontology Language (OWL) and W3C standard, OWL 2.

The main classes of the BR ontology (see in Figure 2) are:

- the class “Relation”, which is divided into three different subclasses: “ClassClassRelation”, “ClassInstanceRelation” and “InstanceInstanceRelation” illustrates the main types of relations. Specific relations such as “Contains”, “Involves”, “Uses”, “Determines”, etc. are subclasses of the class “ClassClassRelation”.
- the class “DomainRange”, which is divided into two subclasses: “Class” and “Instance”, and
- the class “CognitiveObject”

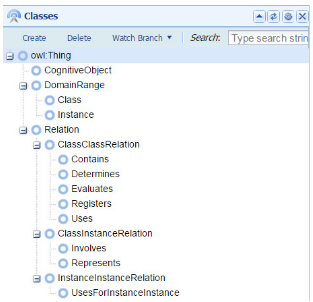

Figure 2: The class hierarchy of the BR ontology

5.2.2 *Description of Properties in BR ontology*

The various types of interaction among ontology concepts are expressed through respective relations, known as properties (see in Figure 3).

We have defined six (6) object properties and five (5) datatype properties. More specifically, the class “Relation” relating with the class “CognitiveObject” with the object property *correspondsTo*, the class “InstanceInstanceRelation” relating with the class “Instance” with the object property *hasDomainInstance* etc. The data property *isSymmetric* determine if the “Relation” is symmetric or not.

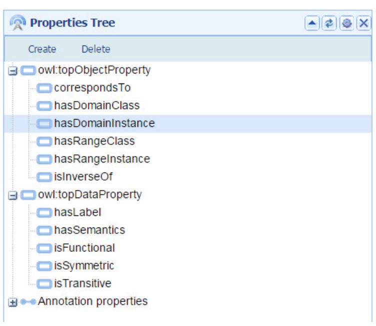

Figure 3: The properties hierarchy of the BR ontology

The structure of the BR ontology, conceptualizing a specific binary relation is depicted in Figure 4.

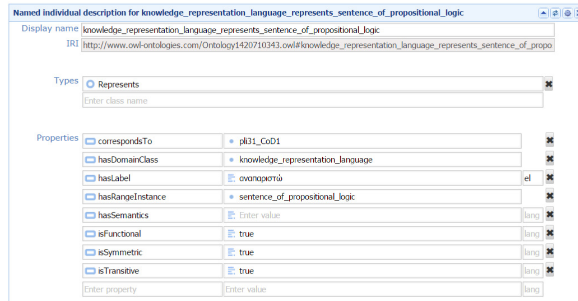

Figure 4: The binary relation “represents” from the BR ontology

This structure categorizes the relation “Represents” as a binary relation with domain and range classes. It corresponds to a specific cognitive domain and has properties, such as transitive, functional and symmetric. Synonyms and description of its semantics are also provided.

5.2.3 *Description of Instances in BR ontology*

The natural language statement “knowledge_representation_language_represents_sentence_of_ propositional_logic” is an instance of the class “Represents” of the BR ontology. Although this statement is understandable by humans, it has no meaning for a machine. Using the structure of the BR ontology, the meaning of this statement can also become machine readable. We can see the instance “knowledge_representation_language_represents_sentence_of_ propositional_logic” in Figure 5.

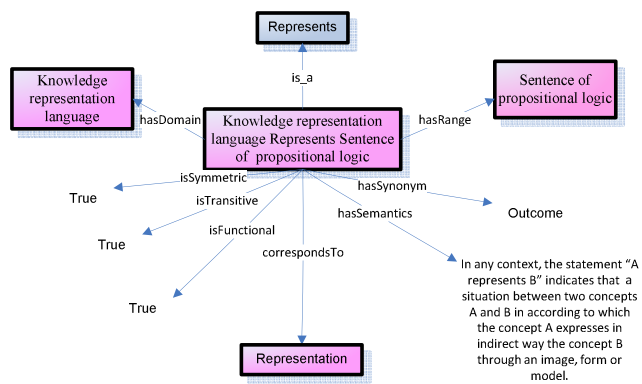

Figure 5. The statement “Knowledge representation language Represents Sentence of propositional logic” as an instance of the class “Represents”

According to the structure of the BR ontology, the natural language statement “Knowledge representation language Represents Sentence of propositional logic” is conceptualized as an instance of the class “Represents”.

5.3 Implementation of the BR Ontology

The idea behind the structure of the BR is that the various statements considered as instances of the relation can be considered as a binary relation, and are categorized depending on the domain and range. For example, an instance of the relation “Determines” implemented in Protégé [14] is depicted in Figure 6.

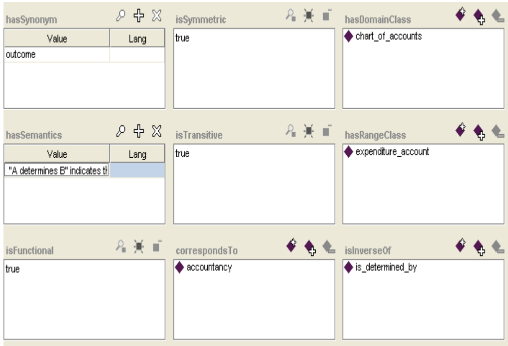

Figure 6. An instance of the class "Determines" implemented in Protégé

The BR ontology can be found at http://ontologies.eap.gr/webprotege/#Edit:projectId=4be4a475-b9ff-4b46-ab40-b884c0bf18fa.

5.4 The BR Ontology

The BR has been assessed, using the same competency questions, as in the specification phase. The questions answered concern finding the inverse of a relation, its instantiations, its domain and range, etc.

We present two examples of competency questions submitted to BR. The first example is for an InstanceInstanceRelation the relation *usesForInstanceInstance.* In the next Figures we can see the individual "backward_chaining_uses_for_resolution_conjuctive_normal_form". This individual hasDomain: backward_chaining (Figure 7), correspondsTo: pli31_CoD1 (Figure 8), hasLabel: χρησιμοποιεί (Figure 9), hasRange: conjuctive_normal_form (Figure 10) and isFunctional relation (Figure 11).

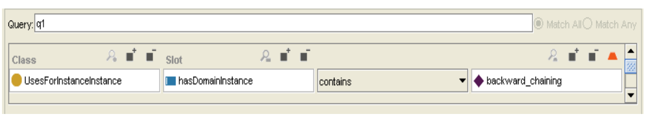

Figure 7: Competency question which answers what is the domain of the relation "uses_for_resolution"

Figure 8: Competency question answers to what cognitive domain belongs the relation "uses_for_resolution"

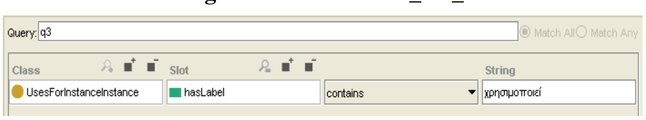

Figure 9: Competency question answers which is the label of the relation "uses_for_resolution"

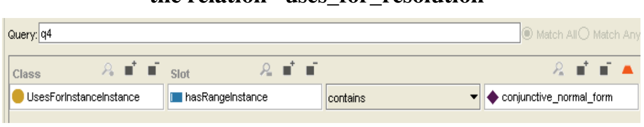

Figure 10: Competency question answers what is the range of the relation "uses_for_resolution"

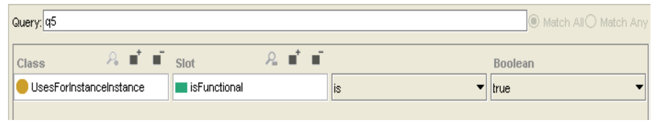

Figure 11: Competency question answers if the relation "uses_for_resolution" is Functional

The second example is for a ClassInstanceRelation the relation *represents.* In the next Figures we can see the individual: "knowledge_representation_language_represents_sentence_of_propositional_logic". This individual hasDomain: knowledge_representation_ language (Figure 12), correspondsTo: pli31_CoD1 (Figure 13), hasLabel: αναπαριστώ (Figure 14), hasRange: sentence_of_propositional_ logic (Figure 15) and isSymmetric relation (Figure 16).

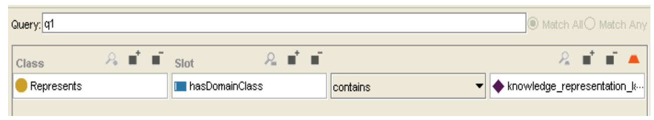

Figure 12: Competency question which answers what is the domain of the relation "represents"

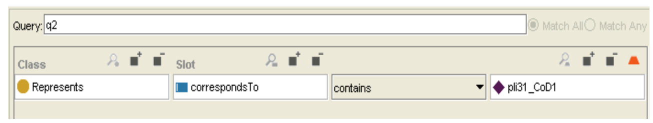

Figure 13: Competency question answers to what cognitive domain belongs the relation "represents"

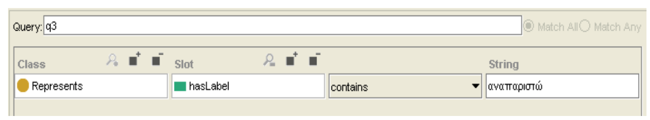

Figure 14: Competency question answers which is the label of the relation "represents"

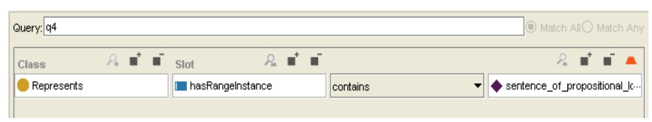

Figure 15: Competency question answers what is the range of the relation "represents"

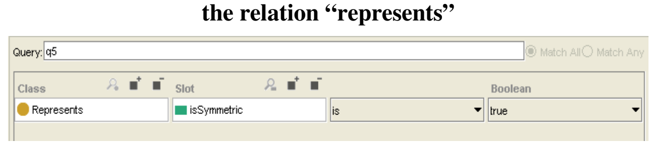

Figure 16: Competency question answers if the relation "represents" is Symmetric

6. CONCLUSION

In this paper we aim at systematically representing the binary relations involved while coding CoD ontologies in the HOU context, in order to avoid polysemy (the interpretation of a specific relation must be clear and unambiguous) and homonymy (different nomenclature may refer to the same relation).

To this end, we have developed the BR ontology which is used to solve interoperability issues, as well as a reference point from where a minimum set of binary relations, that are used in machine readable relational expressions of cognitive objects are extracted.

7. ACKNOWLEDGMENTS

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