Binary Relations in Educational Ontologies

Seremeti Lambrini
Mathematician, Researcher
Hellenic Open University (HOU)
+30 2610 367 963
seremeti@cti.gr

Aggelopoulou Nikolitsa
Mathematician, Researcher,
Hellenic Open University (HOU)
+30 2610 367 963
naggelop@eap.gr

Pierrakeas Christos
Lecturer, Dept. of Business Administration, Technological Educational Institute (TEI) of Western Greece and Hellenic Open University (HOU)
+30 2610 367 730
pierrakeas@eap.gr

Kameas Achilles
Associate Professor, School of Science and Technology, Hellenic Open University (HOU)
+30 2610 367 735
kameas@eap.gr

ABSTRACT

The Hellenic Open University's mission is to provide distance education at both undergraduate and postgraduate level, developing and implementing appropriate educational materials and teaching methods. For this purpose, educational ontologies are constructed, which are classified into anthologies of Learning Outcomes (LO), Learning Objects (LOb) and Cognitive Domains (CoD). In contrast to the conceptualization and implementation of LO and LOb 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 minimum set of binary relations to be used in the official representation of CoD. These relations are presented by experts with proposals consisting of triples (subject, verb, object) and classified into a Binary Relation (BR) ontology.

Keywords

Educational Ontologies, Binary Relations

1. INTRODUCTION

The 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, taxonomy of learning outcomes, which enables to the creation of individualized learning paths [1]. For this purpose educational ontologies constructed under the HOU context [2], [3], [4], [5], [6]. These domain ontologies divided into ontologies for Learning Objects (LOb), ontologies for Learning Outcomes (LO) and ontologies for Cognitive Domains (CoD). Regarding the engineering of LO and LOb ontologies, problems do not exist , since the conceptualization of ontologies LOb based on the standards available in the literature for the official description as the standard IEEE LOM [7], and the conceptualization of LO ontologies based on the Bloom's taxonomy [8], which is a widely accepted taxonomy of learning domains, which are often used in the design of educational processes.

In contrast, the engineering of LO and LOb ontologies when designing CoD ontologies, their conceptualization is based on subjective statements of the kind (subject, verb, object) triples that experts provide, describes the basic concepts of each CoD and 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 formal representation by means of ontology will restrict the use of inappropriate definitions of relations during the implementation of CoD ontologies.

In this paper, we conceptualize an ontology Binary Relations (BR) , which officially represents the relations needed to describe CoD concepts, under the framework of the HOU. The ultimate goal is to provide a minimum set of binary relations that are necessary to implement CoD ontologies. In this way, experts should be restricted 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. Section 4 describes the main points of BR ontology engineering, and Section 5 concludes the paper.

2. COGNITIVE DOMAIN (CoD) ONTOLOGIES

HOU educational ontologies concerned COD developed as graph structures by all terms of specific cognitive area concepts/ terms. These concepts/ terms represent the nodes of the graph and are interconnected by means of edges, expressing the relation (verb) between concepts, provided by experts in each cognitive domain.

These relationships are extracted by expert's statements. For example, statements from the experts in the course of "Waste Management MSc", module "Solid Waste Management" of the School of Science and Technology of the Hellenic Open University are "Biogas requires gas collection", "Biogas requires gas treatment", also statements from the experts in the course of "Computer Science", module "Introduction to Computer Science" of the School of Science and Technology of the Hellenic Open University are "Compilation involves high level language", "A memory word consists of bytes", finally a statement from the domain expert in the course of "Computer Science", module "Software Design" of the School of Science and Technology of the Hellenic Open University is "An expression consists of operators". In order to understand the knowledge expressed by experts in natural language, in a rigorous machine readable format, it is necessary to formalize the terms of relations (verbs), that are binary relations.

Another point to be emphasized is that the same natural language relation (verb) in natural language can be used by experts to connect different terms in the same area or in a 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 for unique defining and classification, according to a certain criterion, which is described in subsection 4.2, the extracted binary relations. This can facilitate ontology experts and experts to avoid mistakes in coding CoD.

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

3. BINARY RELATIONS

The relational expressions that experts provide the formal description of a CoD, sentences 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

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 "current assets includes requirements", "current assets includes inventories", "current assets includes debt instruments" can be formulated as the binary relation $R = contains$ from the set $X = \{current\_assets\}$ to the set $Y = \{requirements, inventories, debt\_instruments\}$. For some binary relation $R \subseteq X \times Y$, we can define its inverse $R^{-1} \subseteq Y \times X$, such that $yR^{-1}x \Leftrightarrow xRy$.

Binary relations are important, since relations of arity greater than 2 can be studied in terms of binary relations.

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) symmetricity (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 range. These relations are mainly related classes in the ontology. Relations usually initializedusing the knowledge from the domain representing the ontology. For example, to express that "the x processor executes the y software", a class "Processor" as the domain and a class "software" as the range of that relation, "executes"should be designed. Sometimes, the same relations used to relate classes, 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 at a value.

4. 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].

4.1 Specification of the BR Ontology

The CoD ontologies in the framework of HOU are designed to serve as 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 experts, that are expressed in sentences of the form (subject, verb, object). These sentences of the kind "A -relation- B" (where A and B are terms belonging to the same CoD ontology and "relation" symbolize connects for associating these terms) can be considered as binary relations between semantic terms in a vocabulary that is specified for a certain cognitive domain.

Our task is to develop a minimum set of coherently defined 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 COb 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.

4.2 Conceptualization of the BR Ontology

In the literature, binary relations are distinguished in the following three kinds:

- $\langle class, class \rangle$: for example, the relation "determines" holding between the class "chart of account” and “expenditure account”, or between the class “backward definition” and the class “mathematical induction”,

- $\langle ins\tan ce, class\rangle$: for example the relation “includes” holding in statements, such as “current assets –includes- requirements”, “current assets –includes- inventories”, “current assets –includes- debt instruments”, and
- $\langle ins\tan ce, ins\tan ce\rangle$: for example, the relation “contains” associating “unit of manure” and “80 Kg N”, which are conceptualized as instances, since they cannot be considered as sets of objects.

Thus the categorization of binary relations based on domain and range.

To this end, the main classes of the BR ontology are: “Relation” with its subclasses “ClassClass”, “InstanceClass” and “InstanceInstance” illustrates the main types of relations, as well as “Domain/Range” which may have as subclasses “Class” or “Instance”. Specific relations such as “Contains”, “Involves”, “Uses”, “Determines”, etc. are subclasses of the class “ClassClassRelation”.

The structure of the BR ontology, conceptualizing a specific binary relation is depicted in Figure 1.

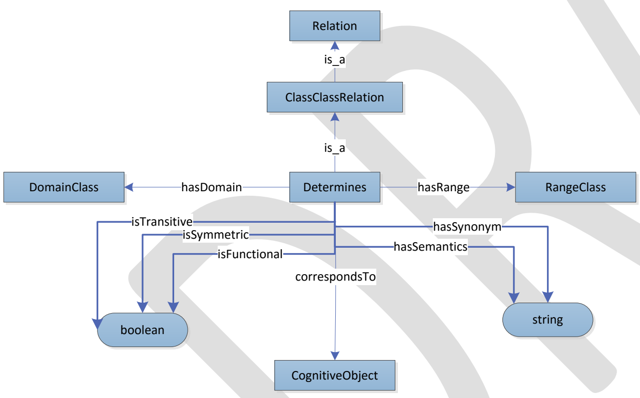

Figure 1. The structure of the BR ontology, conceptualizing the binary relation “Determines”

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

The natural language statement “chart of account –determines- expenditure account” is an instance of the class “Determines” of the BR ontology. Although this statement is understandable by humans, it has no meaning for a machine. Using the graph of Figure 1 upon which the structure of the BR ontology is based, the meaning of this statement can also become machine readable. The instance “chart of account –determines- expenditure account” shown in Figure 2.

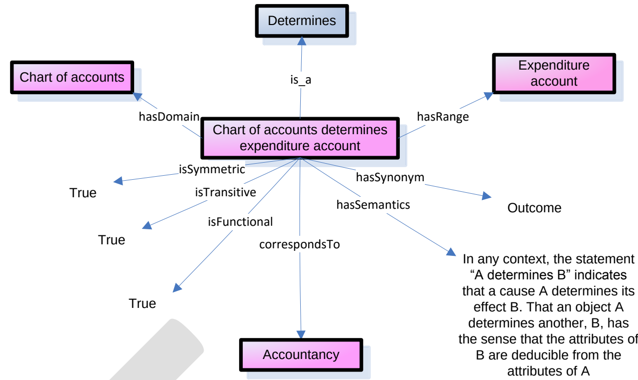

Figure 2. The statement “chart of account determines expenditure account” as an instance of the class “Determines”

According to the structure of the BR ontology, natural language statement “chart of account determines expenditure account” is conceptualized as an instance of the class “Determines”.

4.3 Implementation of the BR Ontology

The idea behind the structure of the BR is that the various statements considered as instances of the relation expressing considered a binary relation, and are categorized depending on the domain and range. For example, an instance of the relation “Determines” implemented in Protégé [11] is depicted in Figure 3.

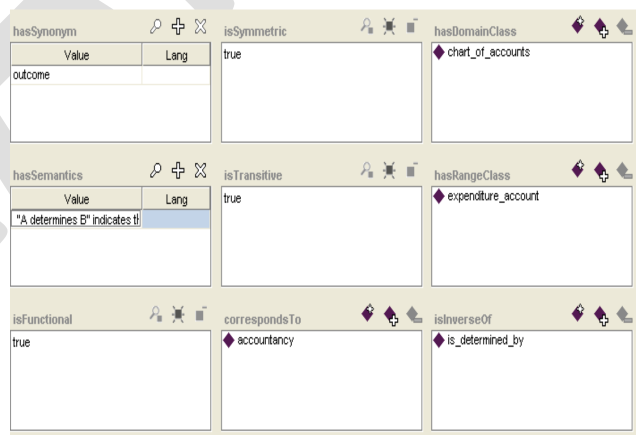

Figure 3. An instance of the class “Determines” implemented in Protégé

The BR ontology can be found at http://ontologies.eap.gr/webprotege.

4.4 Evaluation of the BR Ontology

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

In the future, the BR is also evaluated in relation to whether it contributes to achieving interoperability between educational ontologies to improve the performance of e-learning applications under the HOU.

5. 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.

6. ACKNOWLEDGMENTS

This research described in this paper has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) (Funding Program: “HOU”).

7. REFERENCES

[1] P. Monachesi, K. Simon, E. Mossel, P. Osenova, L. Lemnitzer. What ontologies can do for eLearning. Proceedings of the IMCL International Conference on Mobile and Computer aided Learning, 2008, pp. 1-10.

[2] A. Kouneli, G. Solomou, C. Pierrakeas, A. Kameas. Modeling the knowledge domain of the Java programming language as an ontology. Proceedings of the International Conference on Advanced Learning Technologies, LNCS, Vo. 7558, 2008, pp.152-159.

[3] G. Solomou, A. Kouneli, A. Kameas. Using ontologies for modeling knowledge domains in distance learning. Proceedings of the 6th International Conference in Open & Distance Learning, 2011, pp. 728-741.

[4] I. Panagiotopoulos, A. Kalou, C. Pierrakeas, A. Kameas. An ontology-based model for student representation in intelligent tutoring systems for distance learning. Artificial Intelligence Applications and Innovations 2012, Vol. 381, pp.269-305.

[5] A. Kalou, G. Solomou, C. Pierrakeas, A. Kameas. An ontology model for building, classifying and using learning outcomes. Proceedings of the 12th IEEE International Conference on Advanced Learning Technologies 2012, pp.61-65.

[6] N. Aggelopoulou, C. Pierrakeas, A. Artikis, D. Kalles. Ontological modeling for intelligent e-learning. Proceedings of the 14th IEEE International Conference on Advanced Learning Technologies, 2014, pp. 716-718.

[7] D. Roy, S. Sarkar, S. Ghose. A comparative study of learning object metadata, learning material repositories, metadata annotation & an automatic metadata annotation tool. In: Joshi, Boley, Akerkar (Eds.), Advances in Semantic Computing, 2010, pp. 103-126.

[8] D.R. Krathwohl. A revision of Bloom’s taxonomy: an overview. Theory Into Practice, Vol. 41, No. 4, 2002, pp. 212-264.

[9] P.V. Vinu, P.C. Sherimon, K. Reshmy, S.T. Youssef. Pattern representation model for n-ary relations in ontology. Journal of Theoretical and Applied Information Technology, Vol. 60, No. 2, 2014, pp. 231-237.

[10] R. Iqbal, M. Murad, A. Mustapha, N.M. Sharef. An analysis of ontology engineering methodologies: a literature review. Research Journal of Applied Sciences, Engineering and Technology, Vol. 6, No. 16, 2013, pp. 2993-3000.

[11] J.H. Gennari, M.A. Musen, R.W. Fergerson, W.E. Grosso, M. Crubezy, H. Erikson, N.F. Noy, S.W. Tu. The evolution of Protégé: an environment for knowledge-based systems development. International Journal of Human-Computer Studies, Vol. 58, No. 1, 2003, pp. 89-123.