An Ontological Approach for Domain Knowledge Modeling and Management in E-Learning Systems

Ioannis Panagiotopoulos, Aikaterini Kalou, Christos Pierrakeas, and Achilles Kameas

Educational Content, Methodology and Technology Laboratory (e-CoMeT Lab)
Hellenic Open University, Patras, Greece
{gpanagiotopoulos,kalou,pierrakeas,kameas}@ecomet.eap.gr

Abstract. One of the most important tasks in the process of designing educational material for distance learning is the representation and modeling of the cognitive domain to which the material refers. However, this representation should be formal, complete and reusable in order to be used by intelligent tutoring system applications, other knowledge domains or tutors. In the context of this work, we propose a methodology that relies on the notion of ontology so as to represent the knowledge domain. Moreover, this methodology has been applied to the educational material of the Hellenic Open University.

Keywords: e-learning systems, ontologies, ontology development, knowledge modeling, knowledge representation, Protégé.

1 Introduction

Knowledge modeling plays a significant role in the design of educational material for open distance learning systems [1]. The necessity for a formal representation of the educational content is crucial in the case of designing courses for intelligent tutoring systems. Firstly, an efficient, formal representation of the cognitive domain will facilitate the tutors to define the learning strategies, techniques and outcomes for every cognitive domain [2]. Moreover, the conceptual representation will make easier the selection of the appropriate educational material *(learning objects)* so as to support the teaching of the specific domain of knowledge. Especially in multi-agent tutoring systems this representation can be used as a domain-specific vocabulary for the communication between intelligent agents. For example, a domain agent is responsible for answering queries from other agents about cognitive domain's information. However, it is a difficult activity to perform, due to its complexity. For example, the creation of a unified model from separate and semantically heterogeneous models is a complex task.

As it is well known, ontologies are a widely-used technique for facilitating understanding, communication and inter-operation between human and software agents, by permitting the clear definition and explicit specification of all the basic concepts and

L. Iliadis et al. (Eds.): AIAI 2012 Workshops, IFIP AICT 382, pp. 95–104, 2012.

terms of a concrete field [3]. It includes machine-readable definitions of basic concepts in the domain and relations among them, while permits sharing common understanding of the structure of information among people and software agents and enables reuse of domain knowledge [4]. Thus, ontologies are seen as a basic tool for knowledge representation, especially in the case of educational systems [5].

So, in the context of our work, we have selected the notion of ontology as the most appropriate approach for the domain knowledge modeling and management. The process and development of ontologies require not only the knowledge of ontology engineers but also the knowledge and experience of the domain experts, independently of ontology domain. The methodologies that address to domain experts and knowledge (ontology) engineers and requires their cooperation could be characterized as collaborative. More precisely, such a collaborative methodology will enable domain experts to model educational domains through ontologies that can be used for the design of e-learning and tutoring systems. Several approaches of collaborative ontology development, which will be presented in the following Section, constituted a basis of our approach. In fact, we adopted some of the characteristics of these approaches, enriched them and concluded in a new approach specialized for educational purposes.

The proposed approach has been applied to support the educational domain of the Hellenic Open University, but it could be extended for any educational institution that offers e-learning education.

The rest of the paper is structured in five sections. In section 2, we discuss the related work in terms of the collaborative ontology engineering and provide justification of the proposed methodology. In Section 3, we describe in detail the basic steps of the proposed methodology. In Section 4, we outline an indicative case study in order to illustrate the proposed methodology. In Section 5, we describe how the result of this methodology can be used in learning systems. Finally, in Section 6, we discuss future work and summarize our conclusions.

2 Related Work

Several approaches for collaborative ontology development have been presented in literature. DILIGENT [6] is a methodology for Distributed, Loosely-controlled and evolvInG Engineering of oNTologies. This methodology supports domain experts in a distributed environment so as to evolve and develop ontologies.

Another approach, similar to DILIGENT, is the HCOME methodology [7]. The main difference is that HCOME is a human-centered methodology. The HCOME methodology consists of three distinct phases, the *specification phase*, the *conceptualization phase* and the *exploitation phase*. During the specification phase the knowledge workers[1] join groups that will develop the shared ontologies. In these

[1] A knowledge worker is any member of an information production-exploitation community. Such community may involve workers within an organization, Word Wide Web users with common interests. [7]

groups workers discuss the requirements and the scope of the new ontology that will be built. In the conceptualization phase, workers in their personal space develop the agreement in the previous phase. Finally, in the exploitation phase ontologies can be exploited and collaboratively evaluated. There are ontology engineering approaches designed for knowledge engineers [8] or domain experts [9].

Other approaches for collaborative ontology development are proposed by [1] and [10]. In [10], authors propose a collaborative methodology for ontology development that supports a team to reach consensus through iterative evaluations and improvements. In [1], authors introduce a methodology for constructing educational domains through educational ontologies based on the learning objects required for every concept. The concepts are interrelated with three different kinds of relations such as *hasPart*, *IsRequiredBy*, and *SuggestedOrder*.

A common characteristic of all the above methodologies is that they all include the following four phases: (a) the *specification phase* - the scope and the requirements of the ontology are defined, (b) the *conceptualization phase* - all the knowledge about a specific domain is gathered and conceptualized, (c) the *implementation phase* - the previous knowledge is modeled in a machine-readable format, and (d) the *evaluation phase*.

Our proposed approach also follows the aforementioned, basic steps. The main difference is that it does not require any special knowledge techniques by the domain experts. The domain experts design the cognitive domain and then the ontology engineers transform it into a real ontology. Then, the domain experts evaluate the final model created by the knowledge engineers. The methodology was designed in a way that exploits the knowledge of the domain experts which are responsible for each educational domain. So, the knowledge coming from different domain experts over a specific field is combined in order to produce an enriched, machine-readable knowledge model.

3 Methodology Steps

In this section, we describe the basic steps of the proposed methodology for domain modeling. In the context of these approaches, domain experts do not design an ontology from scratch, but they initially formulate a conceptualization map, with concepts, sub-concepts and relations between these concepts. During the implementation phase, the conceptualization map will be converted to ontology by ontology engineers.

3.1 Specification Step

During the first step, the ontology and knowledge engineers discuss about the requirements of the new ontology that is going to be built. The scope of the ontology is common, i.e. to be used as domain representation in an intelligent tutoring system.

Face-to-face or distance meetings with the domain experts may take place. Furthermore, during this step ontology engineers are responsible for: (a) preparing a tutorial for the domain experts, with guidelines for representing the cognitive domain, (b) designing a questionnaire including competency questions which will be used during the evaluation of the ontology model (evaluation step). Finally, the ontology engineers can consult any material related to the specific cognitive domain and retrieved from multiple sources.

3.2 Conceptualization Step

In the second phase (see Fig. 1), the domain experts (tutors in the case of our case study) are asked to design the cognitive domain, i.e. the basic concepts, the hierarchy of the concepts and basic relationships between these concepts. They are provided with a tutorial written by knowledge experts and ontology engineers, with regard to the knowledge representation. This tutorial contains guidelines and examples for the process of representing the cognitive domain. More precisely, each tutor designs a conceptualization map of the educational domain by using concepts and relations. Subsequently, the tutor lists the basic concepts of the domain (e.g. in the order they teach them) and next all their sub-concepts in an exhaustive way until no further analysis is possible. Listed concepts will constitute the class hierarchy of the final ontology.

Moreover, the tutor links the aforementioned concepts with relationships. The relationships could express the notion of hierarchy (e.g. is-a, has-a) or could be even more complex. For example, a more complex relationship between two concepts could be "*used for*", which states that a concept is used in order to realize the other one. The set of relationships between concepts will indicate the object properties of the final ontology.

3.3 Implementation Step

During this step, the ontology engineers, based on the outcome of the previous step (the domain representations provided by the experts) develop two or more ontologies, depending on the number of the tutors participating in the process (i.e. one ontology per tutor). Ontology engineers, at this step, have to select an appropriate tool for the implementation process and the representation language of the model.

The development of ontologies is followed by the process of merging them in an automated way into one unified model. When performing ontology merging, a new ontology is created which is the union of the source ontologies. The merged ontology captures all the knowledge from the original ontologies. The challenge in ontology merging is to ensure that all correspondences and differences between the ontologies are reflected in the merged ontology [11]. In the next section we describe in more details the merging process of the ontological models. This unified ontological model includes the knowledge of the previous individual models (see Fig. 1).

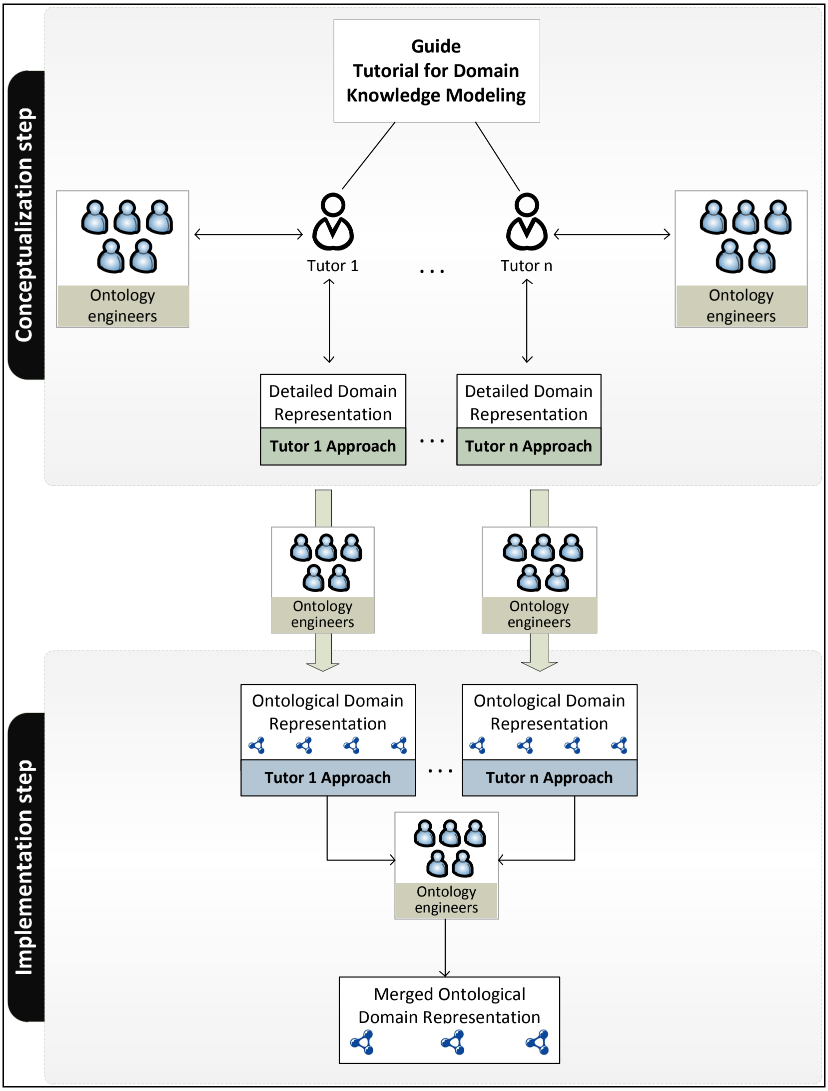

Fig. 1. Main steps of collaborative methodology

3.4 Evaluation Step

The final step of the proposed methodology includes the evaluation of the final merged ontology from the side of domain experts. A questionnaire that measures the competence of the final ontology is required for the process of evaluation. This questionnaire has already been prepared during the specification step in a way that helps the evaluator to check if the ontology meets predefined criteria. This questionnaire is distributed to the domain experts who (a) designed the domain representation during the conceptualization phase and (b) are related to the specific cognitive domain.

In our case, a set of generic criteria has been used, as proposed by Fox et al. [12]. These criteria include: (a) *minimality*, i.e. if the ontology contains the minimum number of elements, i.e. the basic concepts of the domain and the corresponding hierarchy relationships, (b) *functional completeness*, i.e. if the ontology could efficiently be used by a particular task, and (c) *perspicuity*, i.e. if the ontology is easily understandable by the users. In addition, domain experts list a number of competency questions where the ontology should be able to answer.

4 Case Study

In this section, we present an indicative case study that illustrates the application of the methodology, described in the previous section. The aim is to demonstrate that the proposed methodology can be realized for the representation of a cognitive domain in order to be used within the context of an educational system.

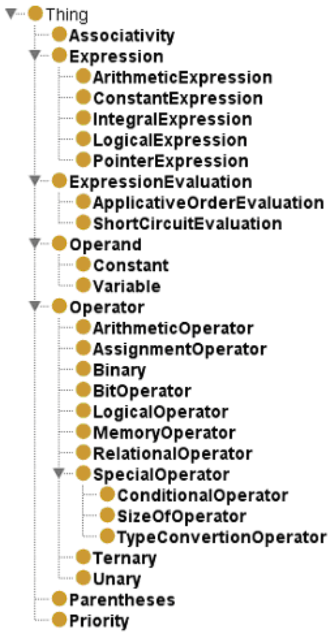

Fig. 2. First tutor’s ontological model

In the context of this case study, suppose that the cognitive domain is part of the first year's course module “PLI10 - Introduction to Informatics”. This course module is specialized in the subject area of Programming Languages (C Programming).

During the specification step, ontology engineers consulted the teaching material provided by the HOU and additional material by other additional sources (web).

The conceptualization of the domain was realized by two tutors responsible for teaching this particular subject. Domain experts in this case study can use a drawing tool by following the steps described in the tutorial which was already prepared during the conceptualization step. The developed diagrams should be stored in any type of image or XML format.

In the implementation step, ontology engineers selected to use the Protégé[2] tool in order to model the domain's representation. Protégé is a free, open source editor and management framework supported by a strong community of developers and academic users. The Protégé tool has been chosen because: (a) offers a user-friendly development environment, (b) it is possible to import other existing ontologies, (c) offers a large number of plugins and (d) is supported by a strong community of developers. Moreover, OWL-DL[3] has been chosen as the representation language of the model due to its maximum expressiveness.

Fig. 2 depicts the concepts of the ontological model that had been created by the first tutor. Fig. 3 illustrates the same model according to the second tutor's perception.

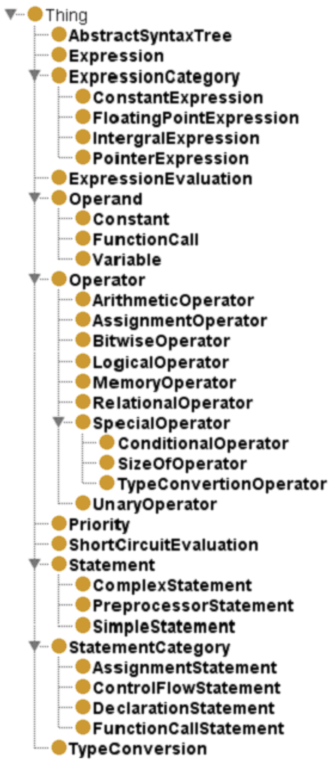

Fig. 3. Second tutor's ontological model

[2] http://protege.stanford.edu/

[3] http://www.w3.org/TR/owl-guide/

After having the two ontological models for the domain representation, the next step of the implementation phase is the merging of these two ontologies. For the merging process, ontology engineers have used the OWL-API[4]. The OWL-API is a Java API for manipulating OWL ontologies. During this process all the entities with the same name are merged into a single one. Then, entities with the same meaning but with different names or entities with a high degree of similarity are matched each other. For the matching procedure a number of tools have be used, such as ontology alignment tools and dictionaries.

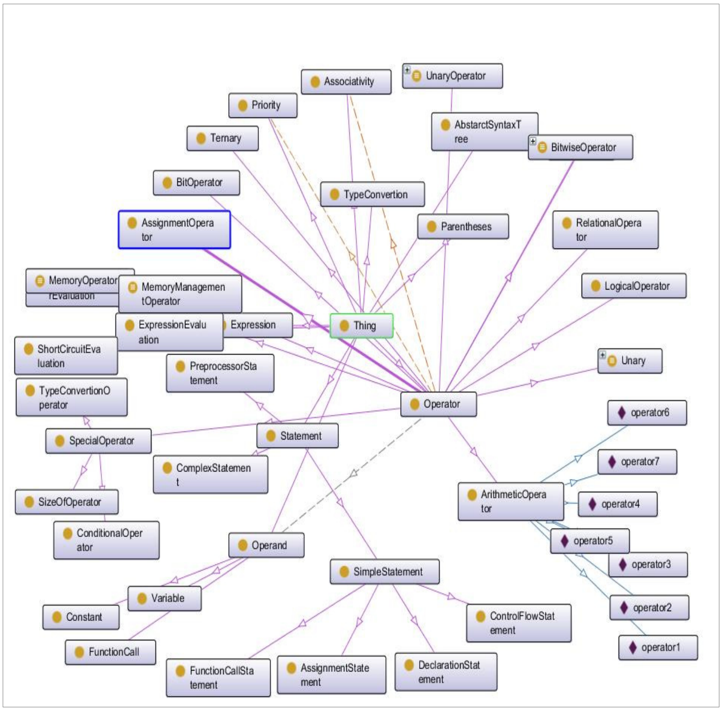

Fig. 4. An excerpt of the unified ontology for C Programming

Fig. 4 shows the final ontology model as a result from the merging of the two ontology models. Concepts and properties of the two individual ontologies with the same meaning were merged into a single one, while several instances were accommodated accordingly (e.g. a number of instances have been added to the class "*ArithmeticOperator*"). For example, the concept (class) *Operator* is common in both ontology models (Fig. 2 and Fig. 3). After the merging process, the unified ontology includes also the class "Operator". This class contains the union of subclasses of the concept Operator that come from the initial ontologies. It becomes clear that the new final ontology is richer and also covers all the necessary knowledge and information of the domain, according to the results of the questionnaires provided by the tutors during the evaluation step (section 3.4).

[4] http://owlapi.sourceforge.net/

5 Knowledge Representation and E-Learning Systems

In this section we will describe in more details how the representation of the cognitive domain as a result of the proposed methodology, can be further used for the design of a course.

This formal representation of the cognitive domain will allow the tutors to determine the *learning outcomes* for the specific course. According to the Bologna Project [13], a learning outcome is defined as a statement of "…*what a learner is expected to know, understand and be able to demonstrate after completion of a learning process (a lecture, a module or an entire program)…*". In the case study described above, the cognitive domain that has been modeled is part of a course module. In this way, each tutor that is responsible for each cognitive domain can easily define the learning outcomes for his/her domain.

Furthermore, the tutors having an explicit representation of the cognitive domain can easily select or design the appropriate educational content in order to support the teaching of this specific domain. This material is defined as *learning objects*. There are several definitions for a learning object. According to [14] a learning object is defined as "*any digital resource of content that can be reused to support learning*".

From the above brief discussion becomes clear that the modeling and representation of a specific domain of knowledge is the first and most important step when designing a learning process. The methodology described above, proposes such a modeling through an ontology as a result of the collaboration between domain experts.

6 Conclusions

This paper presented a methodology for modeling a specific domain of knowledge through ontologies, in order to be used in the context of an intelligent tutoring system. One major advantage of the proposed methodology is that the domain experts get involved in the ontology engineering process without having any previous knowledge on ontology development and management techniques. On the other hand, the concepts of a cognitive domain are specific; therefore any different approaches in the knowledge representation by the experts are not expected to deviate much. In this way the merging process of the individual ontologies is a relatively simple process and the resulting ontological model is semantically more rich as it was shown. We are now working on the improvement of the methodology, especially in terms of the implementation phase. Our future work is going to integrate the process of the ontology alignment in the implementation step, so as to produce better and richer representations.

Acknowledgment. This research described in this paper was partly funded by the National Strategic Reference Framework programme 2007-2013, project MIS 296121"Hellenic Open University".

References

1. Gaeta, M., Orciuoli, F., Ritrovato, P.: Advanced ontology management system for personalised e-Learning. Knowledge-Based Systems 22, 292–301 (2009)
2. Kalou, A., Solomou, G., Pierrakeas, C., Kameas, A.: An Ontology Model for Building, Classifying and Using Learning Outcomes. In: 12th International Conference on Advanced Learning Technologies, ICALT 2012 (to be published, 2012)
3. Panagiotopoulos, I., Seremeti, L., Kameas, A.: PROACT: An Ontology-Based Model of Privacy Policies in Ambient Intelligence Environments. In: 14th Panhellenic Conference on Informatics (PCI 2010), pp. 124–129 (2010)
4. Malik, K.S., Prakash, N., Rizvi, S.: Ontology Creation towards an Intelligent Web: Some Key Issues Revisited. International Journal of Engineering and Technology 3(1) (2011)
5. Breuker, J., Muntjewerff, A.: Ontological Modeling for Designing Educational Systems. In: Proceedings of the Workshop on Ontologies for Intelligent Educational Systems, 9th International Conference on Artificial Intelligence in Education, AIED 1999 (1999)
6. Pinto, H.S., Staab, S., Tempich, C.: DILIGENT: Towards a fine-grained methodology for DIstributed, Loosely-controlled and evolving Engineering for oNTologies. In: The 16th European Conference on Artificial Intelligence (ECAI 2004), pp. 393–397 (2004)
7. Kotis, K., Vouros, G.: Human-Centered Ontology Engineering: the HCOME Methodology. International Journal of Knowledge and Information Systems (KAIS) 10, 109–131 (2006)
8. Yun, H., Xu, J., Xiong, J., Wei, M.: A Knowledge Engineering Approach to Develop Domain Ontology. International Journal of Distance Education Technologies (IJDET) 9, 57–71 (2011)
9. Boyce, S., Pahl, C.: Developing Domain Ontologies for Course Content. Educational Technology & Society 3, 275–288 (2007)
10. Karapiperis, S., Apostolou, D.: Consensus building in collaborative ontology engineering process. Journal of Universal Knowledge Management 1, 199–216 (2006)
11. de Brujin, J., Ehrig, M., Feier, C., Martins-Recuerda, F., Scharffe, F., Weiten, M.: Ontology mediation, merging and aligning. In: Davies, J., Studer, R., Warren, P. (eds.) Semantic Web Technologies: Trends and Research in Ontology-based Systems (2006)
12. Fox, M.S., Barbuceanu, M., Gruninger, M., Lin, J.: An Organizational Ontology for Enterpise Modeling. MIT Press (1998)
13. Kennedy, D., Hyland, A., Ryan, N.: Writing and using Learning Outcomes. In: Bologna Handbook, Implementing Bologna in your Institution, C3.4-1, pp. 1–30 (2006)
14. South, J.B., Monson, D.W.: A University-Wide System for Creating, Capturing, and Delivering Learning Objects. In: Wiley, D.A. (ed.) The Instructional Use of Learning Objects (2000)