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Enhancing the Collective Knowledge for the Engineering of Ontologies in Open and Socially Constructed Learning Spaces

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Abstract: The aim of this paper is to present a novel technological approach for enhancing the collective knowledge of communities of learners on the engineering of ontologies within a collaborative, open and socially constructed environment. The proposed technology aims at shaping information spaces into ontologies in a collaborative, communicative and learner-centered way during the ontology development life-cycle. The paper conjectures that such a collaborative environment can yield educational benefits, thus there is need to follow principles that apply in the Computer Supported Collaborative Learning (CSCL) paradigm. This work is mainly based on a collaborative and human-centered ontology engineering methodology and on a meta-ontology framework for developing ontologies, namely HCOME and HCOME-3O respectively. The integration of key technologies such as Semantic Wiki and Argumentation models with Ontology Engineering methodologies and tools serve as an enabler of learning spaces construction for different domain-specific information spaces in open settings. Inside these learning spaces innovative conceptualizations (both domain and development) are conceived, described by intertwined ontological meta-models following the HCOME-3O specifications for future reference and tutoring support. Such learning spaces support two types of ontology engineering courses: a) courses related to the know-how of shaping information spaces into ontologies (namely, the *development knowledge*) and b) courses related to the analysis of the domain itself (namely, the *domain knowledge*). The paper reports on the evaluation of the approach within a CSCL setting in Ontology Engineering, using the integrated set of tools and the framework that have been developed for the collaborative engineering of ontologies.

Key Words: collaborative knowledge building, argumentation models, semantic wiki technology, ontologies

Category: H.5.3, I.2.4, K.3.1, K.3.2

1 Introduction

Human learning and knowledge is considered to be constructed in certain physical and social environments. Organizations or communities of practice in specific domains constitute certain social contexts where their members, that is, *knowledge workers*, interact. Thus, knowledge is considered to emerge in day to day activities within these organisations in a dynamic and situated manner [Lave and Wenger 1991, Clancey 1995], rather than stored in the minds of individual participants. Being part of knowledge that people possess, innovative conceptualizations evolve in communities as part of knowing [Cook and Brown 1999]. Ontologies are explicit formalizations of specific knowledge domains and a widely adopted means of capturing common understanding of *knowledge workers* within certain contexts. Thus, due to this social dimension, ontologies are artefacts that should be collaboratively and iteratively developed, evolved, evaluated and discussed within such communities, shaping domain-specific information spaces.

For this aim to be effectively achieved, domain experts and engineers should be educated in the ontology engineering tasks. On the other hand, computer-supported collaborative learning (CSCL) is one of the most promising approaches to improve teaching and learning with the help of modern information and communication technology: "Collaborative or group learning refers to instructional methods whereby students are encouraged or required to work together on learning tasks" [Harasim et al. 1997].

CSCL utilizes computer and network technologies in order to establish communities of learners who interact, together with instructors, towards the construction of common meaning [Stahl et al. 2006]. Thus, emphasis is no more given in acquiring individual knowledge but in the design of shared activities where learners interact with the aim of coming into an agreement on the subject of study, whether it refers to the learning of concepts or in problem solving skills.

One way to organise this kind of interaction activities is through 'collaborative argumentation' [Andriessen 2006]. In this sense, argumentation is not considered as a debate activity where antagonizing participants are competing during a discussion but rather as a kind of dialogue where participants negotiate meaning towards establishing mutual understanding and agreement on the subjects under discussion.

This paper emphasizes on ontology engineering as a collaborative and communicative process that involves specific learning and innovation tasks (atomic or collective), where knowledge workers and knowledge engineers, exchanging learner and instructor roles, interact with each other towards enhancing their collective knowledge for the engineering of ontologies. Interactions between knowledge workers unfold in the form of an argumentation dialogue, which comprises *argumentation items* interlinked with elements specifying information concerning (innovative) development/evaluation actions: Information created during the ontology engineering tasks is recorded in a structured manner for future reference. In such a way, educational material related to ontology engineering is created on-the-fly. During the learning process, certain artefacts (resources) are created, which can be further reused by learners, and thus constitute learning objects [LTSC 2002]. There are two kinds of learning objects created: a) those concerning domain knowledge (i.e. domain classes, properties and individuals of classes) and b) those concerning the development and evolution of ontologies. The first kind refers to the innovative conceptualization of domain-specific information in the form of ontology classes, properties, restrictions and axioms and the latter to the knowledge about the steps/actions taken during the specification/evolution of the domain knowledge and the rationale behind these steps/actions, i.e. argumentation items that describe the motivation behind the actions taken or shall be taken. Both types of knowledge are important in ontology engineering education since both domain and ontology engineering expert knowledge must be acquired by knowledge workers in order for them to be able to be further involved in activities concerning the development and refinement of ontologies by supporting the reflection of learners upon their own individual and collective knowledge in a meta-cognitive fashion [Kumar et al. 2010].

In order to realize the potential of enhancing the knowledge of workers in engineering ontologies collaboratively, a methodology is needed that accentuates the roles of knowledge workers involved in the engineering task, and a suite of tools that support the recording and retrieval of the learning objects (educational material) constructed during the process.

The approach proposed in this paper uses the HCOME collaborative engineering methodology [Kotis and Vouros 2006]. Although other collaborative engineering methodologies could be applied [Pinto et al. 2004, Jarrar and Meersman 2009], HCOME, in a wider extend than other methodologies, places major emphasis on the conversational development, evaluation and evolution of agreed ontologies, which implies the extended sharing of the constructed domain ontologies that have been shaped from initial innovative (improvised) individual conceptualizations. HCOME is supported by the (Shared)HCONE integrated environment (suite of tools) enhanced with the HCOME-3O ontology engineering framework [Vouros et al. 2007]. The (Shared)HCONE system, which is used for the purposes of this paper, integrates the HCONE standalone ontology development tool with open and Web 2.0 community-driven technology, i.e. wiki technology, in order to enable the collaborative engineering of ontologies with the support of argumentation dialogues. This kind of integration has also been proposed in the literature by other authors [Siorpaes and Hepp 2007, Dellschaft et al. 2008]. Specific types of argumentation items and their relations are also specified in the argumentation ontology of the HCOME-3O framework.

Three meta-ontologies are defined in the HCOME-3O framework: the argumentation, evolution and administration [Vouros et al. 2007] (briefly described in Appendix A). These ontologies support the systematic recording of meta-information concerning the interlinking between argumentation elements and elements concerning ontology development and evolution (changes and versions of a domain ontology). This interlinking is the vehicle towards supporting the development of ontology engineering educational material and the sharing of continuously evolving and living domain ontologies within and across different communities [Kotis and Vouros 2006].

Given the above, the argumentation dialogue as a means for learning and knowledge building in the sense presented above is supported or "scaffolded" in two ways:

– By making the types of dialogue moves, in the form of argumentation items, explicit to discussion's participants [Andriessen 2006], an approach widely adopted both in relative literature and educational practice [Scheuer et al. 2010];

– by recording external representations of the outcomes of conversation [Sawyer 2006a] in the form of instances of the above meta-ontologies.

The proposed approach for the design and development of a collaborative and open learning environment aligns with the knowledge building approach as proposed by Scardamalia and Bereiter [Scardamalia and Bereiter 2006]. Knowledge building considers learning as collaborative production and continual improvement of ideas shared by a community.

The contributions made in this paper are as follows:

1. The HCOME-3O meta-ontology framework is presented which supports collective knowledge creation and sharing in the context of the existing HCOME ontology engineering methodology.

2. A new system, namely SharedHCONE, is described, which supports wiki-based argumentation integrating ontology management and implementing the HCOME-3O framework.

3. The paper emphasizes on collective knowledge advancement concerning the engineering of ontologies in open and socially constructed learning spaces by shaping information spaces into ontologies in an open, collaborative, communicative and learner-centered way, allowing experts (instructors) to assist non-experts (learners) in the proper execution of engineering tasks during ontology development life-cycles.

4. It is shown how innovative conceptualizations can be conceived, negotiated and advanced through argumentation by engaging participants in open on-

line critical discussions supported by Semantic Wiki technology. More specifically, argumentation elements, inherently embedded in the HCOME methodology and being formally interlinked with the other ontology elements of the HCOME-3O meta-ontology framework, support the on-the-fly and Wiki-based construction of learning objects for the different stakeholders'roles considered.

5. It is shown (via preliminary evaluation results) how the technological fusion of HCOME methodology, HCOME-3O framework, HCONE ontology development tool and Semantic Wiki technology towards an integrated, collaborative and open ontology engineering environment, constitutes an overall approach that can advance ontology engineering education.

The structure of this paper is as follows: Section 2 discusses related work in the fields of argumentation in knowledge and ontology construction. Section 3 describes the overall framework for enhancing collective knowledge for the engineering of ontologies, while Section 4 discusses the application of the above framework in creating learning spaces for Ontology Engineering. Implementation details are given in Section 5. The whole approach towards enhancing collective knowledge building is evaluated in Section 6 and the paper ends with conclusions and future work presented in Section 7.

2 Related Work

Since we emphasize on ontology engineering as a learning task, we provide information concerning related technologies that have been influencing the presented approach in two aspects: the aspect of collaborative/open ontology engineering and the aspect of collaborative learning.

In myOntology project [Siorpaes and Hepp 2007] the challenges of collaborative, community-driven, and wiki-based ontology engineering are investigated. The simplicity of Wiki technology and consensus finding support by exploiting the collective intelligence of a community is being used to collaboratively develop lightweight ontologies. The goal of myOntology is not only to allow co-existence and interoperability of conflicting views but more importantly to support the community in achieving consensus similarly to Wikipedia, where one can observe that the process of consensus finding is supported by functionality allowing discussion, however, not via structured dialogues and argumentation models.

The Semantic MediaWiki ontology editor [Simperl et al. 2010, Dengler et al. 2009] focuses on lightweight ontology modeling, which can be carried out by users that do not have a knowledge engineering background, on leveraging existing knowledge structures such as tags into ontologies, and on improving the results of the modeling process through knowledge repair techniques that identify potential problems and make suggestions to the users. The work-in-progress prototype mainly aims to support an enterprise-oriented approach, to allow for seamlessly increasing the expressiveness of semantic annotations ranging from shallow tags to expressive OWL axioms that would lead to the realization of the collaborative ontology engineering vision. Aiming at Enterprise 3.0 practices and technology, the engineers of this tool use various automatic techniques to determine equivalences between the tags used by different users for annotating files, folders, and bookmarks, and transforming the underlying folksonomy in a more formal and structured, lightweight ontology. Although this ontology editor implements a similar functionality with respect to ontology design and uses Semantic Wiki technology to allow openness and collaboration among Web users, it does not consider discussions or argumentation support.

In NeOn project [Dellschaft et al. 2008] the Cicero web-based tool supports asynchronous discussions between several participants. This social software application is based on Issue-Based Information Systems (IBIS) [Kunz and Rittel 1970] and DILIGENT [Pinto et al. 2004] argumentation frameworks. The DILIGENT argumentation framework was adapted for Cicero in order to make it more easily applicable on discussions and in order to reduce the learning effort by users. In Cicero, a discussion starts with defining the issue which will be discussed. Then possible solutions can be proposed. Subsequently, the solution proposals are evaluated via supporting or objecting arguments. Such works provide strong evidence that collective intelligence in the form of semantic Wikis can be used to support collaborative ontology engineering, with the advantages of openness and scalability. As far as concerns reaching a consensus on a shared ontology during argumentation, although it provides a mechanism to record the actual dialogues, meta-information concerning the recording of the interlinking between conversations and ontology evolution (versions of a domain ontology) is not recorded.

WebProtege [Tudorache et al. 2008] is a web based collaborative ontology engineering environment based on the very popular Protégé ontology editor. It is an environment similar to Collaborative Protégé but it is executed inside a Web browser. Being a collaborative tool, it enables users to discuss on the ontologies they develop, however it does not support a wiki-based discussion/authoring platform. This discussion is enabled by supporting the attachment of discussion topics on concepts inserted and by allowing users to post replies related to them. It resembles the discussion model of an Internet forum with the difference that all topics are attached on concepts instead of categories. It unifies the argumentation and development processes in an integrated environment and lets users collaborate without the need to switch between different tools. It lacks the extensibility of a modular and open environment like the Semantic Wiki which other approaches use, making it more difficult for organizations to adapt it or extend it in their environment. WebProtege supports comments on all classes, subclasses and individuals that are part of an ontology but not on properties. By definition such an argumentation system connects a discussion to domain ontologies and relates argumentation items to authors as (Shared)HCONE integrated environment does. WebProtege does not let users search between argumentation items but collaborative Protege does through its filter functionality. None of the above Protégé extensions though support semantic queries to related discussions easily and intuitively, as (Shared)HCONE integrated environment does.

CSILE and its successor system, Knowledge Forum [Scardamalia and Bereiter 2006, Scardamalia 2004], follow a certain epistemic and pedagogical approach which emphasizes 'knowledge building' for both learning in educational settings, and scientific progress. Knowledge is considered to advance in the context of communities, rather than individually, through collaboration in problem solving activities. CSILE/Knowledge Forum is a collaborative environment supporting a knowledge building process which advances through the interaction of participants by exchanging messages as well as by posting multimedia content and notes on previous messages. Each message can be associated with others or can be annotated. Thus, the contributions of participants are organized by their semantic relationships rather than in a thread discussion structure that is common in other collaborative environments. In this way, collective knowledge is made explicit through the visualisation of posts and their relationships, in the form of graphs, as well as through access to a corresponding hypermedia content which is produced as a result of discussion. The overall approach is applied in both educational and professional settings. (Shared)HCONE takes a step towards formalisation of the above approach through the use of ontologies. It considers knowledge building as a collaborative process which takes place through structured dialogue among participants, facilitated by the annotation meta-ontology. Furthermore, the outcome of the knowledge building process about a specific domain is registered in the system in the form of a domain ontology. Knowledge advancement is made explicit through instances of the evolution meta-ontology.

Belvedere [Suthers et al. 1995] is a collaborative environment aiming to support the acquisition of skills of scientific argumentation for students. Belvedere supports the diagrammatic definition of arguments for or against certain scientific theories, defined by students in the form of concept maps. Relations in these concept maps depict argumentation for or against interrelated arguments. The system also utilizes an on demand automated advisor for suggesting argument extensions or revisions based on matching of patterns in diagrams as well as on the textual descriptions of arguments.

Design models for specifying hypertext structures based on argumentation have been proposed by a number of authors. Streitz et al. [1989] adopt a well-known argumentation model, namely the Toulmin Argumentation Schema as a basis for hypertext design with no support for collaboration. In this model, hypertext nodes (pages) represent statements, that is, arguments, where links represent relations such as 'contributes' or 'contradicts'. Selvin [1999] focuses on collaborative modelling of hypertext systems by providing support for argumentation about such systems during the design phase.

Kumar et al. [2010] report on a solution for the recording and sharing of processes and products of interaction in a CSCL setting by using an ontology-based formalism. The purpose of these recordings and their automated analysis is both the assessment of participants' learning as well as the support for students to reflect upon their shared knowledge modelled in the proposed ontology. Our approach is also aligned with the above goals, however it further emphasizes knowledge construction through structured dialogue and argumentation, integrating Web 2.0 technologies.

The approaches and technologies discussed in this section have motivated the work presented in this paper. A thorough survey of computer-supported argumentation systems can be found in [Scheuer et al. 2010]. By reusing these technologies and extending them to be compliant with HCOME-3O framework it is possible —and this is proved in this paper— to achieve the goal of sharing knowledge about continuously and comparatively evolving ontologies within communities of knowledge workers. More importantly, none of the related works considers ontology engineering from the learning perspective. The presented approach strives towards putting the foundations of e-learning in open collaborative ontology engineering via a mapping between wiki-based collaborative ontology engineering functionalities/objectives and functionalities/objectives that have been proposed in foundational work on Semantic Web and Education [Bittencourt et al. 2008].

3 Enhancing Collective Knowledge via HCOME methodology & (Shared)HCONE integrated environment

HCOME is a human-centered approach for ontology development in the sense that it supports the active participation of knowledge workers in the ontology development process. It places major emphasis on the conversational development, evaluation and evolution of ontologies, which implies the extended sharing of the constructed domain ontologies together with the meta-information that would support the interlinking, combination, and communication of knowledge shaped through practice and interaction among community members. Furthermore, it provides a clear distinction between learning spaces in terms of personal and shared tasks that knowledge workers are enabled by the HCOME processes to perform. That is, it allows for the improvisation of innovative conceptualizations within local views of a shared ontology (personal learning space) towards achieving their convergence in a shared and agreed ontology (shared/agreed learning spaces). HCOME proposes three distinct phases of an ontology development lifecycle:

Specification when the requirements for the conceptualization of a specific domain are formed as shared and commonly agreed specifications;

Conceptualization when ontologies are developed based on existing descriptions as well as on new conceptualizations for a particular domain and

Exploitation when shared ontologies developed during Conceptualization are evaluated, used and critisized using an argumentation process discussed in this paper.

For each phase, the goals that should be achieved and the tasks that must be performed in order to achieve these goals are specified in detail. Engineering tasks are performed iteratively, until a consensus has been reached between knowledge workers/engineers. Each task is performed either individually (in the personal space using stand alone tools for the editing, exploitation and inspecting of personal ontologies) or conversationally (in a shared space using open Web argumentation technology that supports the recording of structured dialogues and argumentations). A knowledge worker/engineer can initiate any ontology engineering task in his personal or shared space, or participate in a task that has been initiated by other members of the community.

To enhance the potential of ontologies to be collaboratively engineered within and between different communities, they must be escorted with all the necessary information (namely meta-information) concerning the conceptualization they realize, implementation decisions and their evolution. The HCOME-3O framework [Vouros et al. 2007] proposes the integration of three meta-ontologies for achieving this goal. These meta-ontologies provide information concerning the conceptualization and the development of domain ontologies, the changes to ontology elements made by knowledge workers, the long-term evolutions, arguments and rationale behind decisions taken during the lifecycle of an ontology. As Fig. 1 shows, the framework supports ontology engineering tasks for a *domain* ontology and its versions, i.e. editing, argumentation, exploitation and inspection: meta-information is captured and recorded either as information concerning a simple task or as information concerning the interlinking of editing and argumentation.

Targeting the enhancement of collective knowledge in communities of knowledge workers, in this paper we further introduce the use of Semantic Wiki technology in the context of the HCOME methodology and HCOME-3O framework. The objective is to support the shaping of domain information collaboratively into shared and agreed ontologies (Fig. 2) while shaping learning spaces

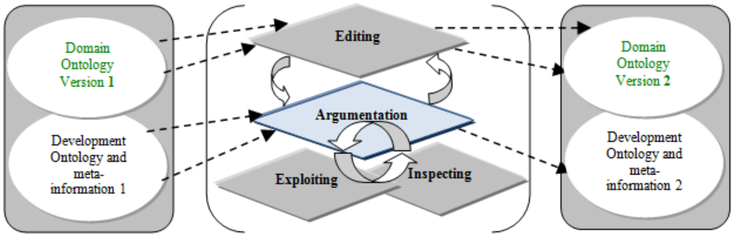


Figure 1: The HCOME-3O framework for recording interlinked meta-information concerning ontology engineering tasks.

by recording the rationale behind each development/change action and the developments (actions and versions) themselves. The overall framework, following the "Exploitation" phase of HCOME methodology [Kotis and Vouros 2006], supports the following tasks:

1. The inspection of shared ontologies (reviewing, evaluating and criticizing shared conceptualizations);
2. the comparison of shared versions of an ontology for identifying the differences (tracking changes) between them;
3. the post of arguments upon versions of ontologies for supporting decisions for or against shared conceptualizations and
4. the querying of existing ontologies in order to obtain useful (meta)information related to ontology evolution and associated argumentation elements.

Having said that, collaborators should be able to create, store, maintain, compare, merge, and manage different versions of ontologies at their pesonal space. This phase of the HCOME methodology, the "conceptualization" phase, includes the following tasks:

a) The improvisation of knowledge workers' conceptualizaions based on innovative ideas related to the description of the domain.

b) The import of existing ontologies, for the reuse of conceptualizations.

c) The consultation of generic top ontologies, thesauruses and domain resources, for better understanding and clarification of the domain conceptualizations.

d) The mapping, merging and management of multiple versions of ontologies, supporting reuse and evolution.

e) The comparison of different versions of an ontology for inspecting ontologies' evolution and for identifying ontologies that can possibly be merged.

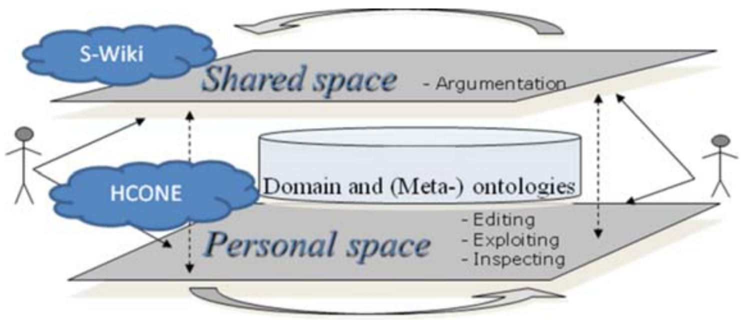


Figure 2: The HCOME-3O-based ontology engineering architecture integrating Semantic Wiki technology

f) Attaching to ontology classes/properties information items with further comments, examples and specification details.

Therefore, concerning the argumentation task that can be performed in a shared space, the Semantic Wiki-based functionality records structured discussions upon specific ontologies and supports the interlinking of arguments, administration, versioning and evolution meta-information, following the ontological specifications of the HCOME-3O framework. This functionality has been extended with the HCONE[1] prototype for supporting ontology engineering tasks in knowledge workers' personal space (editing, exploiting and inspecting ontologies) providing a collaborative environment for the engineering of ontologies, namely (Shared)HCONE integrated environment. (Shared)HCONE currently supports Ontology Web Language (OWL) ontologies (both domain and meta-ontologies). More specifically, it supports the modeling of relative knowledge using the sublanguage OWL-DL which allows the retrieval of relevant knowledge from inferred models, utilizing the reasoning capabilities of a well-known reasoning engine (Pellet)[2]. For instance, it classifies both 'suggesting' and 'responding' instances as positions related to specific contributors and ontology elements. Furthermore, the HCONE-3O argumentation meta-ontology is exploited for the structuring/recording of argumentation dialogues, and also for the retrieval of instances of the administration and evolution meta-ontologies that are related to specific argumentation items.

SharedHCONE supports users to share and discuss domain and meta-information in a guided manner: It provides a "shared space" where users are able to "discuss" specific domain conceptualizations, to upload and download their personal conceptualizations (developed in their personal space), to inspect, and

[1] http://icsd-ai.aegean.gr/hcone/
[2] http://clarkparsia.com/pellet/

agree/disagree with specific domain conceptualizations. More specifically, the tool allows users to publicize their ontologies and invite other SharedHCONE users (knowledge workers, ontology engineers or/and domain experts) to join an interest group and to provide support for collaboration, following a Wiki-enabled and HCOME-3O driven structured dialogue. Conceptualizations of information spaces that have been viewed, discussed, and agreed by all group members, are shaped into agreed ontologies that can be further evolved by initiating a new collaboration period.

A SharedHCONE user can initiate a working group in order to argue for or against ontological specifications formed by using his HCONE tool in his personal space. Users that accept the invitation become collaborators for the shared ontology under discussion. When a collaborator enters an existing argumentation dialogue, she is able to view the already recorded arguments, linked with ontology versions and the specific changes made from version to version. Essentially users are able to follow the whole ontology-evolution history and the reasons/arguments behind it. A dialogue does not evolve in a sequential way: It can evolve starting from any previously made dialogue/argumentation item. Argument dialogue items are annotated according to a scheme that follows a version of the IBIS argumentation framework [Kunz and Rittel 1970]. This scheme is based on the following item categories:

Item which represents a problem to be solved;

Position stating a solution to an issue or submitting a new version of a contributed concept and

Argument for or against a position.

Browsing/viewing the shared domain ontologies is supported, besides the participation in dialogues, by means of a functionality provided by the Wiki, which integrates a Web-based ontology browser. The information concerning the argumentation dialogues is recorded as individual objects of the "Argumentation Item" class of the argumentation meta-ontology and —as already mentioned— is related to other entities of the other HCOME-3O framework.

4 Learning spaces in Ontology Engineering education

4.1 Learning space creation and user roles

As already mentioned, the community of (Shared)HCONE integrated environment users comprises domain experts, knowledge engineers and knowledge workers, collaborating and communicating towards shaping their information spaces into ontologies. Although they carry different expertise, as stated in HCOME methodology, they may contribute equally to the development of conceptualizations. In such a methodology, there shouldn't be any restriction concerning "who takes the final decision" or "who should be the host of the dialogue". In practice, any member of the community can join a discussion group and any member of this group can be the host that invites others for discussion. All members participate in the discussion following an argumentation model and reach a consensus after several equally weighted arguments/positions/issues made by the members of the group. Based on this principle, all community members that join an Ontology Engineering learning space in the (Shared)HCONE integrated environment can have the role of "learner" or the role of "instructor" in different periods of time. In CSCL settings, this technique of shifting roles between peers is considered beneficial for collaboration [Bittencourt et al. 2008]. In this sense, ontology development is considered as collaborative knowledge building where each member contributes in a peer-to-peer basis. The created ontology is a formalization that reflects the collective knowledge of the team, where there are no privileged users or roles. Learners, both knowledge engineers and knowledge workers, equally participate in this knowledge building process with instructors, the latter not merely bringing knowledge to the learners but supporting the formation of a community of practice [Hartnell-Young 2003].

An ontology engineering learning space, typically initiated and hosted by an instructor, can also be initiated and hosted by a learner. In the latter case, a knowledge worker with no much previous experience invites other experienced community members to join and assist him in shaping of his information space. The organization of a learning space (collaborative learning setting) by a learner and not by an instructor accentuates the power of collective intelligence and social networking and underlines the need to design e-learning systems based on open and Web community-driven technology, such as the Wiki technology. As stated by Scardamalia and Bereiter [2006], "the proof of knowledge building is in the community knowledge that is publicly produced by the students —in other words, in visible idea improvement achieved through the students' collective efforts".

As already pointed above, from the perspective of learning spaces, the host-contributor of an ontology engineering learning space states the *title* and the *aim* of the learning space and places his first argumentation item i.e. post a *suggesting position* and a *starting ontology version* related to the domain-specific information space to be discussed. Such a position is linked with his first *personal conceptualizations* that have been put in a draft shape in the form of a kick-off ontology. This is considered as initial educational material of the learning space and it is provided to the group of learners for consideration and argumentation. Learners can view the educational material by browsing the ontology and place questions (arguments or issues) responding to the kick-off position of their instructor. Such a process implies that the domain knowledge represented in the kick-off domain ontology is learned by the application of the “learning by doing” paradigm.

4.2 Learning domain knowledge

(Shared)HCONE integrated environment captures the domain knowledge that is discussed in the argumentation dialogues in the following ways: a) as ontology versions linked to argumentation (position) items, b) as single ontology elements (class, property and individual formal items) linked with any type of argumentation items. Learners or/and instructors link their domain knowledge created in their personal space (using tools such as HCONE) with their argumentation items created in the shared space. Learners can view chunks of others’ personal domain knowledge and learn from them. Such learning is supported by the argumentations made during the shaping of such knowledge i.e. the rationale behind the development/evolution of ontologies.

4.3 Learning development knowledge

(Shared)HCONE integrated environment captures knowledge about the development of domain ontologies, the atomic changes made by knowledge workers in their personal space, the long-term evolution and argumentations behind decisions taken during the lifecycle of an ontology. Such knowledge is recorded in the HCOME-3O meta-ontologies repository. Learners can view the ontology-based knowledge building and learn from it (e.g. comparisons between ontology versions, changes within an ontology version, etc). Such learning is supported in the (Shared)HCONE system via the interlinking of argumentations and ontology versions. Learners should use their personal space environment in order to view development details.

4.4 Creation and reuse of educational material

Another important aspect of (Shared)HCONE integrated environment is that the educational material, apart from a draft kick-off version of the domain knowledge, is not present at the very early stage of a learning space. Both domain knowledge and development knowledge are constructed during the collaboration and discussion that community members have in the shared space. Educational material is created on-the-fly, as learning objects are recorded as instances of the HCOME-3O meta-ontologies. The recording of knowledge in such a structured and meaningful way allows its reuse as educational material, especially for learners in ontology engineering learning spaces in which there is no participation of an expert (knowledge engineers and domain experts). Knowledge

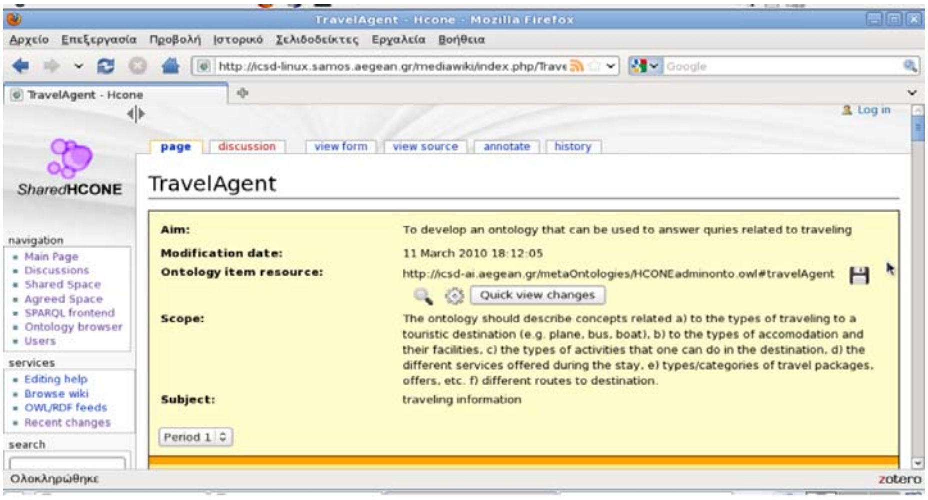


Figure 3: Kick-off ontology for the “Travel Agent” domain.

workers are able to query the recorded knowledge for learning purposes, either by browsing the meta-ontologies in a stand-alone fashion or by unfolding the stored structured argumentation dialogues of an ontology engineering learning space using the SharedHCONE. Advanced query implementations using special query languages such as SPARQL[3] can be used to combine knowledge from the three difference HCOME-3O meta-ontologies as well as to combine knowledge that is distributed in dialogues created by other (Shared)HCONE communities. Future extensions may utilize distributed RDF contextual representations of the constructed knowledge in the form of Linked Data[4].

Screenshots of the proof-of-concept SharedHCONE system are provided (Fig. 3 and 4), depicting a learning task in-progress for developing an ontology in the domain of “Travel Agent”.

Fig. 4 illustrates the description of the kick-off ontology in the “Travel Agent” domain. Fig. 5 illustrates a fragment of the dialogue for the above domain ontology. A “Suggesting Issue” suggests modifications in the current version of the ontology. These modifications are submitted by a “Suggesting Position” with a new version of the “Travel Agent” ontology associated with it. Then, a supporting argument follows posted by a participant who agrees with the last position. The full dialogue for the “Travel Agent” learning space can be accessed in a single Wiki page[5]. Browsing and viewing functionality of argumentations and ontology

[3] http://www.w3.org/TR/rdf-sparql-query/
[4] http://linkeddata.org/
[5] http://icsd-linux.samos.aegean.gr/mediawiki/index.php/TravelAgent

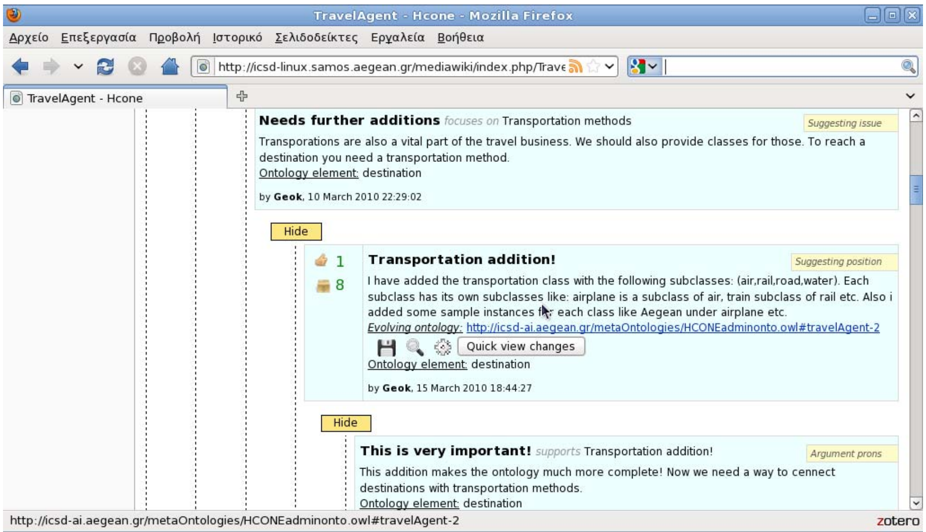


Figure 4: Dialogue fragment for the "Travel Agent" domain.

versions as well as the execution of example queries is allowed for demonstration reasons. The following Fig. 5 depicts how changes between ontology versions are displayed to users. Furthermore, Fig. 6 illustrates the SPARQL frontend of the SharedHCONE wiki system.

The emphasis is given on the Wiki-based technology in order to highlight the collaborative and open aspect of the approach. Both technologies, HCONE stand alone tool and SharedHCONE Semantic Media Wiki are accessible at `http://icsd-ai.aegean.gr/hcone/` and `http://icsd-ai.aegean.gr/sharedhcone/` respectively.

5 Implementation details

We have been experimenting with the reuse of an existing Wiki-based collaborative ontology engineering approach that supports an argumentation formalism based on IBIS model, namely CICERO. Most of the requirements set by our approach were not met. The large number of extensions needed as well as the incomplete documentation of the system at hand hindered us for reusing its technology eventually. Furthermore, the difficulty of integrating HCOME-3O framework with the existing technology was a major hindrance itself. Consequently, a new wiki was designed and developed, using however the experience that we have gained from studying CICERO. The SharedHCONE extension for MediaWiki has been build using a variety of technologies that are briefly described in the following paragraphs.

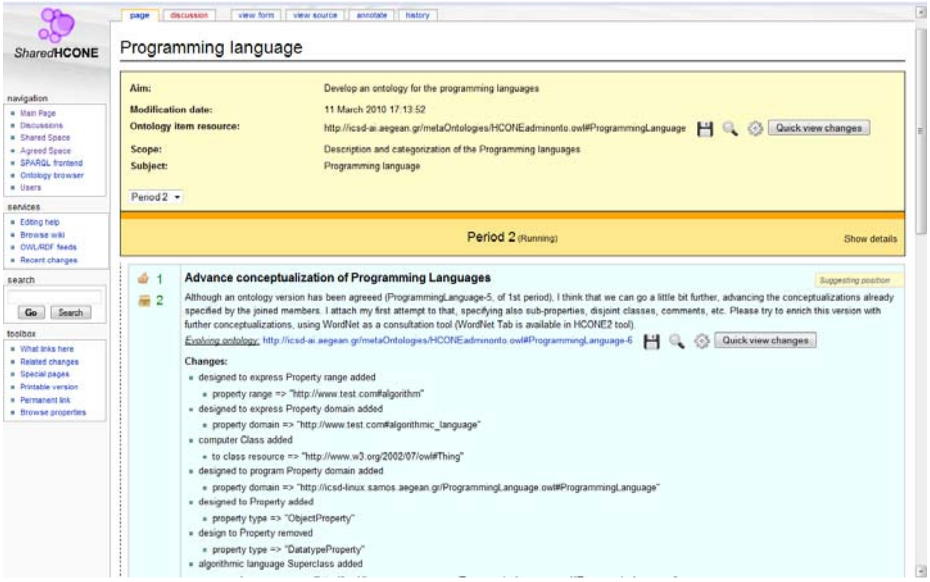


Figure 5: Individual changes made in version 6 of Programming Language ontology, posted with a suggesting position argument in period 2 of "ProgrammingLanguage" discussion. Only two users participate in this period and only one has voted for this version.

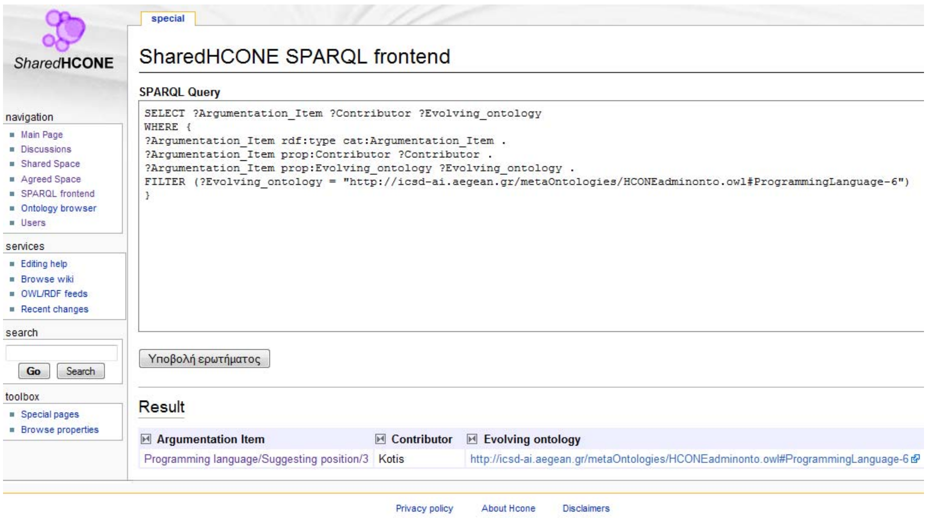


Figure 6: Query executed in the SPARQL frontend: Find all the Argumentation Items and Contributors that are associated with the evolving ontology version 'ProgrammingLanguage-6'.

Table 1: An RDF to SMW comparison

RDF	SMW
Class	Category pages (e.g. Category:Course)
Property	Property pages (e.g., Property:participant)
Instance	"normal" pages (e.g., Tim Berners-Lee)
A rdfs:subclassOf B	[[Category:B]] on page "Category:A"
A rdfs:subPropertyOf B	[[Subproperty of::Property:B]] on page "Property:A"

5.1 Technology

Semantic MediaWiki (SMW)[6] is a semantic wiki engine that enables users to add semantic data to wiki pages. This data can then be used for more effective searching (precise), browsing, and exchanging/reusing of information. The SMW is the most important component of SharedHCONE, since it enriches wiki pages with semantic content (categories, properties) that we have mapped to classes and properties of the Argumentation and Administration meta-ontologies. SMW technology is based on a subset of RDFS[7] language (see Table 1 for a mapping of SMW to RDF semantics).

Halo[8] is an extension to Semantic MediaWiki (SMW) that facilitates the use of Semantic Wikis for a large community of users. The most important usage of this component in SharedHCONE is its live storage and retrievel using RDF Triple Store functionality to store data in the relational database of SharedHCONE. SharedHCONE uses Halo for navigation between argumentation items in a structured hypertext and for authoring and importing of semantic information into the wiki.

Semantic Forms[9] allows the creation of forms for adding, editing and querying data in SharedHCONE, without needing any additional programming. Forms can be created and edited by wiki administrators but also by users themselves. Such forms are automatically installed with the installation of the SharedHCONE plugin.

The querying facility via SPARQL is important for SharedHCONE since it provides a mechanism for its integration with the HCONE tool and its database i.e. access to the HCOME-3O meta-ontologies and to their instances created in the personal spaces.

JENA[10] is a Java framework for building Semantic Web applications. It provides a programming environment for RDF, RDFS, OWL and SPARQL. This framework has been used in SharedHCONE for reading and writing semantic data in its triple store.

[6] `http://www.semantic-mediawiki.org`
[7] `http://www.w3.org/TR/rdf-schema/`
[8] `http://semanticweb.org/wiki/Halo_Extension`
[9] `http://www.mediawiki.org/wiki/Extension:Semantic_Forms`
[10] `http://jena.sourceforge.net/`

JOWL[11] is used for displaying OWL/RDFS documents. This component is used for the visualization of the HCONE personal domain ontologies within the SharedHCONE wiki. Users can browse ontology's classes, properties, and individuals and even execute SPARQL queries on a specific domain ontology they are viewing.

5.2 Architecture

The integrated environment is structured in layers in order to be modular and extensible. The (Shared)HCONE integrated environment comprises the "shared" (namely, SharedHCONE) and the "personal" (namely, HCONE) tools, integrated into a single environment, sharing a single RDF triple datastore. These layers are briefly described in the following paragraphs.

The *Modelling Layer* provides functionalities for the modelling of the Argumentation meta-ontology (a mapping of ontology classes and properties to MediaWiki 'categories' and 'properties') using the Semantic MediaWiki component. The Halo component Ontology Browser provides the functionality for browsing this ontology. By installing SharedHCONE extension in MediaWiki, a set of categories and sub categories enriched with semantic properties are installed in the MediaWiki environment. Special Wiki pages are added to the *category* and *property* MediaWiki namespaces. There is a correspondence between MediaWiki categories and HCOME-3O meta-ontology classes. For example, the MediaWiki category *Discussion* represents the class *Discussion* of the Argumentation meta-ontology. Respectively, the semantic properties of the *Discussion* category correspond to the properties of the class *Discussion*. Furthermore, the MediaWiki pages which belong to *Discussion* category correspond to the instances of the *Discussion* class of Argumentation meta-ontology. Following this logic several MediaWiki categories have been created, with the appropriate semantic properties, in order to model the necessary HCOME-3O meta-information.

The *Management Layer* provides functionalities for creating, reading, updating, deleting of Argumentation ontology instances (specific arguments made by users during a dialogue). It consists of semantic forms (templates) that are being used for handling category instances and consequently class instances of the Argumentation ontology. The Semantic Forms component allows users to add, edit and query data using forms. It enforces the use of templates in creating semantic data. It does not support direct semantic markup in data pages; instead, the entire semantic markup is meant to be stored indirectly through templates. A form allows a user to populate a predefined set of templates for a page. Templates are standard wiki pages whose content is designed to be embedded inside other pages. Therefore, we have created the templates and forms needed for all category instances and consequently for the ontology class instances.

[11] `http://jowl.ontologyonline.org/`

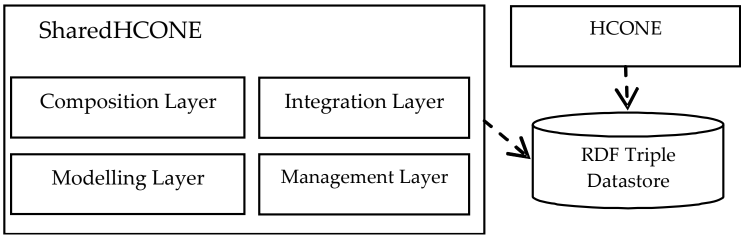


Figure 7: Architecture of the (Shared)HCONE integrated environment.

The *Composition layer* provides functionality for the composition of the Modelling and Management layers and the realization of system's logic. It consists of MediaWiki hooks, AJAX calls and system calls. The Composition Layer is also interconnected with the Integration layer (described next) in order to retrieve data from the (Shared)HCONE integrated environment triple datastore.

The *Integration layer* provides functionalities for the integration of the "personal" with the "shared" tools. It consists of the HCONE interactive gateway with JENA and the Triple Store Connector component. The first interacts with (Shared)HCONE integrated environment triple datastore and retrieves data that is needed for the SharedHCONE functionality. The second is used for the retrieval and storage of RDF statements (concerning instances of the Argumentation ontology) to the (Shared)HCONE triple datastore.

6 Evaluation

6.1 Evaluation setting

The evaluation of (Shared)HCONE approach is related to the following questions:

- What are the interaction patterns of participants during argumentation?
- Is the integrated (Shared)HCONE system effective in its use or does it hinder argumentation and ontology construction?
- What is the quality of the argumentation product, represented as a shared and agreed ontology?

In order to evaluate (Shared)HCONE integrated environment as well as the potential of HCOME methodology for ontology engineering education, we have used it in the context of a graduate course in Ontology Engineering. The course includes a sequence of introductory lectures on the theoretical background in Semantic Web technologies.

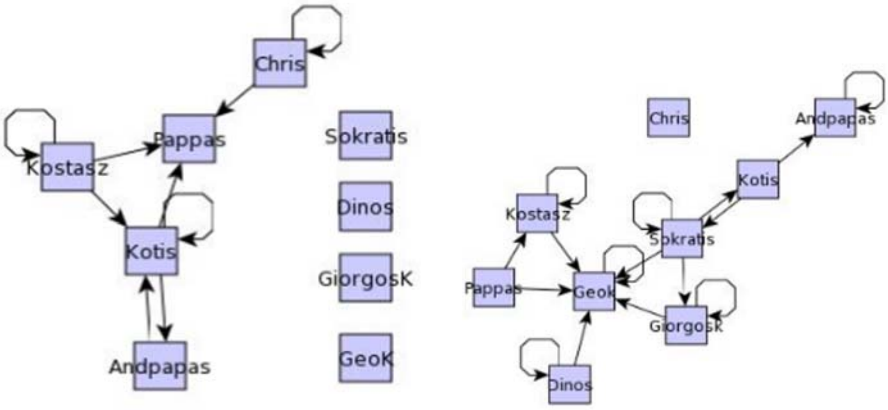
Seven students (learners) and two members of the academic staff (instructors) participated in the evaluation. The development of two domain ontologies was assigned to students, given that they would be assisted by the instructors. The ontologies were developed collaboratively based on the principles of the HCOME methodology, supported by the HCONE tool for ontology development in the personal space, and by SharedHCONE for argumentation and collaborative ontology evolution/evaluation. The first domain ontology referred to the domain of "Programming Languages", whereas the second referred to the domain of "Travel Agency".

For each domain ontology, an initial *position* was placed by a instructor, who posted a kick-off ontology. This posting was followed by *issues*, suggesting changes on particular ontology elements, *arguments* for and against certain positions leading to new positions, that is, new versions of the ontology under construction.

The evaluation aimed at engaging students in a setting where they were assigned the development of ontologies on a specific domain by following the HCOME engineering methodology. Thus, they were asked to participate in a *knowledge construction* collaborative activity situated in a realistic knowledge engineering environment. A combined evaluation approach was followed [Martínez-Monés et al. 2003], which was based on the following evaluation instruments: a) a questionnaire filled by students after the collaborative ontology creation and b) the analysis of the log data related to the argumentation dialogue and the ontology development. Furthermore, the products of argumentation, namely the ontologies constructed by the participants, were evaluated using certain Ontology Engineering methodologies described below.

6.2 Log data analysis

An important instrument for the evaluation of (Shared)HCONE integrated environment as well as for the *pedagogical evaluation* of the HCOME methodology is the use of log file data concerning the argumentation dialogue as well as the constructed ontologies. The argumentation dialogue evolves as a tree of posts, following the structure of messages in a discussion forum. Due to the architecture of the (Shared)HCONE, dialogue-related data are represented in semantically rich formats, thus facilitating a more effective analysis. More specifically, since (Shared)HCONE is based on Semantic Wiki technology, and thus it stores information related to message posts in RDF format. Furthermore, messages carrying arguments are instances of the Argumentation meta-ontology, allowing the identification of argumentation patterns. Information from the above ontologies is extracted by submitting appropriate SPARQL queries. Evaluation is based on Social Network Analysis (SNA).



(a) "Programming Languages" (b) "Travel Agent"

In Fig. 8a, a social network diagram illustrates message responses concerning the first ontology, "Programming Languages". This kind of diagram is a directed graph where each node corresponds to a participant, student or instructor, and each edge from node a to node b denotes a message posted by participant a as a response to a message posted by participant b. Each edge carries a weight denoting the number of responses from a to b (not displayed in the diagram). Correspondingly, Fig. 8b illustrates the dialogue concerning the construction of the second ontology, "Travel Agent".

The following SPARQL query returns a set of contributor pairs, *Contributor1*, *Contributor2*, such that the second contributor posts an argumentation item, *?Child*, as a response to an item, *?Parent*, posted by first contributor. Object property *Parent_of* relates two items so as the second is a reply to the first, thus allowing the construction of the message response hierarchy and *Contributor* relates a message to the name of the user who posted it.

```
SELECT ?Contributor1 ?Contributor2
WHERE {
  ?Parent prop:Parent_of ?Child.
  ?Parent prop:Contributor ?Contributor1.
  ?Child prop:Contributor ?Contributor2.
  FILTER regex(str(?Parent), "Programming","i")
}
```

The social network diagrams are constructed based on the results of queries such as the above. In order to facilitate the analysis and visualization of graphs, results are being transformed into GraphML[12] format. This method was preferred over existing approaches for Semantic Social Network Analysis [Erétéo et al. 2009] due to its easy integration with existing tools supporting SNA.

The following measures from SNA are used in order to evaluate the collaboration graphs: Network density, node in-degree and node out-degree centralities. Network density is the ratio of the number of vertices to the number of edges in the graph. Out-degree is the weighted number of edges originating from a particular node while in-degree is the (weighted) number of edges heading to a particular node.

As a measure of argumentation activity we consider weighted network density which is defined as the ratio of the (weighted) sum of edges to the number of vertices in the graph [Goldberg 1984]. Network density for the "Programming Languages" ontology is 1.22, corresponding to 11 replies, while network density for "Travel Agent" is significantly bigger, namely 2.556, corresponding to 23 replies.

Inspecting the process of building the first ontology, "Programming Languages", we see that neither the quality of the argumentation dialogue nor the quality of the produced ontology was satisfactory. More specifically, argumentation spanned for three periods. Each period ends with the agreement on an ontology version that is further developed in a subsequent period. Ten ontology versions were submitted (see Table 2). The first version of the ontology comprised six named classes, no properties and no individuals with a hierarchy depth of 3, whereas the last agreed version had only 14 named classes, 3 properties and 2 individuals. Furthermore, only 5 out of 9 participants actually participated in the dialogue. Since this cannot be attributed to the lack of domain knowledge, it is assumed that poor interaction can be attributed to the lack of acquaintance with the collaborative knowledge building process. Thus, building of the first ontology is considered as introductory phase in collaborative ontology building.

Concerning the second ontology, "Travel Agent" the dialogue comprised one period, that is, it ended with only one agreed ontology version, in a set of nine versions in total. The first version comprised 13 named classes, 3 properties and no individuals, while the last version comprised 58 classes, 17 properties and 18 individuals, with a hierarchy depth of 4. Participants were more active during argumentation than those in the first ontology (23 arguments in total). The dialogue involved all types of Argumentation Items, namely, "Arguments", "Issues" and "Positions" and their subclasses. After an initial position, the following patterns repeatedly occurred, regarding a new ontology version submission: An issue was raised, followed by a position, which submitted a new ontology version, typically by the same contributor. The position was followed by one or two arguments. While the number of arguments concerning a position was small, the

[12] `http://graphml.graphdrawing.org/`

quality of the dialogue can be considered satisfactory, mainly in the posting of issues suggesting rearrangements of classes and abstracting of concepts through the definition of super-classes. However, interesting argumentation involves negative as well as positive arguments; arguments of this kind were posted only by the two instructors. This may be due to the fact that students are reluctant in directly opposing to others' opinions. However, this does not mean that students do not question others' contributions. More specifically, several modifications and deletions of elements proposed in previous ontology versions have been submitted (and are stored in the evolution meta-ontology) although they are not reflected in the argumentation dialogue.

Table 2: Evolution of the "Programming Languages" ontology during discussion

Version	**Period**	**User**	**Discussion items**	**Actions**
1	1	Kotis	1	4
2	1	andpapas	3	4
3	1	Kotis	2	14
4	1	KostasZ	3	3
5	1	Pappas	2	15
6	2	Kotis	1	15
7	2	Chris	3	4
8	3	Pappas	1	2
9	3	KostasZ	3	6
10	3	Pappas	2	14
Totals			21	81

Tables 2 and 3 illustrate the density of 'evolution actions' (add, delete or edit of elements of the domain ontology under development) taken by specific users after certain argumentation items, during a specific period of discussion, towards contributing a new ontology version. From these data the following conjectures may be derived: a) The number of evolution actions towards a new ontology version is not clearly depended on the number of discussion items prior to this version. b) The number of discussion items prior to a new ontology version is rather small (not more than 3). This fact may be explained by the chat functionality available to users (synchronous communication was prefered more than the asynchronous) or by a latent (pre)agreement to ontology goals that makes social fermentation less necessary. c) The number of ontology versions during the discussion of the domain ontologies (for each period and in total) is high, showing that agreed ontologies at the end of each period (and especially at the end of the last period i.e. the end of discussion) are products of highly innovative

Table 3: Evolution of the "Travel Agent" ontology during discussion

Version	Period	User	Discussion items	Actions
1	1	Kostasz	1	16
2	1	Geok	3	37
3	1	Pappas	3	21
4	1	Kostasz	2	16
5	1	Geok	3	26
6	1	Giorgosk	2	25
7	1	Dinos	3	19
8	1	Sokrates	3	18
9	1	Sokrates	2	6
Totals			22	184

knowledge workers (improvising new conceptualizations). This conjecture is also supported by the large number of evolution actions taken by most individual workers at their personal space, contributing (to the community for discussion and evaluation) highly evolved and innovation-rich ontology versions. d) The number of ontology versions that leed to an agreed domain ontology is not the same for each period, and is not depended to the number of evolution items or the number of workers that participate. However, it can be conjectured that there is a bias to specific contributors of the last version prior to agreement i.e. more experienced workers are likely to contribute an ontology version that will be agreed. e) Finally, from detailed data collected (evolution actions, discussion items) that are not presented due to presentation reasons it can be conjectured that as the evolution process goes on, the discussion and changes in the ontology are more ellaborated, concerning actions beyond class and instance addition (concenring more expressive descriptions of the ontology). However, addition of elements (classes and instances) is the most common evolution action, with an increasing progression rate between the kick-off and the last version (agreed) of the last period of each discussion.

In addition to the qualitative and quantitative analysis presented in the abovementioned paragraphs, we have also conducted evaluation of the "Travel Agent" developed ontology against a gold one, using a widely accepted and well-known ontology evaluation methodology and tool, OntoEval [Dellschaft and Staab 2006]. The gold ontology[13] was obtained from a well-known tutorial that has been designed to teach OWL using the Travel domain. The experiments we run concerned the lexical and taxonomic similarity of the gold-ontology concepts against each one of the ontology versions that were contributed during

[13] `http://protege.cim3.net/file/pub/ontologies/travel/travel.owl`

the collaborative discussion of the learning community upon the Travel domain. Preliminary results support the conjecture that lexical precision and recall of concepts is quite low, but the high taxonomic similarity between the compared ontologies (taxonomic precision and recall) results to an increasing value of the TF measurement across ontology versions (from the first to the last agreed) i.e. the harmonic mean of overall lexical recall LR and the overall taxonomic F-measure (the mean of Taxonomic recall and taxonomic precision). Having said that, due to the use of simple/basic similarity measurements for the lexical features, and the absence of semantic similarity measurements, the values of the lexical measurements and the TF range from 0.11 to 0.24, whereas the value of taxonomic precision and recall ranges from 0.5 to 1.0.

Further experiments using a more advanced method for the evaluation of ontologies, namely DMA (Distributional Method for Alignment) [Zavitsanos et al. 2010], have also supported that our findings are related to the progressive positive similarity to a gold-ontology, strengthening the hypothesis that a convergence to a gold-ontology should be expected. The experiment showed that as the ontology versions are progressively evolving (from 13 to 58 classes), the number of their matched classes to the classes of the gold-ontology is also getting higher (from 13 to 34 matched classes). Furthermore, the range of class similarity values is between 0.82 and 1.0 and the highest similarity value for each class pair is never less than 1.0 for all ontology versions.

6.3 Questionnaire evaluation

After their participation in the experiment, students filled a questionnaire with questions related to a) their prior experience in and attitude towards Computer Supported Collaborative Work/Learning, b) the usability of the HCONE/(Shared)HCONE systems, c) opinions of participants on the HCOME methodology and d) generic open-ended questions aiming at the improvement of (Shared)HCONE integrated environment.

All students reported medium to extended experience in collaborative work. For most of them, the purpose of collaboration in previous work was the development of a shared product. They have used products such as version control systems, discussion forums and wiki-based systems. All students shared positive attributes towards collaboration as a means of improvement of quality of products. More specifically, 4 out of 7 consider collaboration as a means of ontology development of great importance (grade 5 in a 5-grade Likert scale). Interestingly, the two most active students during dialogue, in terms of in and out degree centralities, reported collaboration as of medium importance (grade 3).

Concerning the usability of the (Shared)HCONE integrated environment, system functionalities are graded by students with an average of 7.5 out of 10. The feature of Ontology Editing was marked with lowest grade (6.3 in average).

According to student comments this can be attributed to the existence of two different tools, one for ontology management, namely HCONE, and one for collaboration, namely SharedHCONE, a fact that hinders ontology creation and maintenance; students suggested the seamless integration of the two tools into one. They graded the learnability of the system with an average of 8 out of 10. Concerning acceptance of the tools, all but one students stated that they would definitely use the (Shared)HCONE integrated environment for collaborative ontology development projects in the future. Furthermore, they find it preferable over other collaboration support systems such as CVS/SVN, discussion forums or simple wikis.

6.4 Revised Features

The users of (Shared)HCONE reported at the evaluation phase that as the dialogues were progressing, it was really difficult to keep track of them and consequently this problem was preventing them from noticing important or interesting argumentation items. This was attributed to the fact that all argumentation items recorded in a specific period where expanded within a single page in such a high detail, resulting sometimes in really large dialogues. This problem, also identified in [Scheuer et al. 2010], was solved by extending the user interface to support a show/hide (toggle) functionality of the body for each argumentation item. The users now are presented with only the minimum selected amount of information that is required for them to understanding the main point of each item. This minimum information comprises the title, the user who posted it, the posting date, the type of the argumentation item and information regarding to which other items this one refers to. The users are then able to expand/hide more detailed information for all of the items at once or only for the ones they are interested to.

Another additional feature that has been implemented due to the evaluation feedback was the ability to have a more instant way of informal communication apart from and in parallel to the formal dialog. Users indicated that an embedded synchronous chat functionality would be really helpful as they would progress the formal dialog in less time. For this reason an embedded MediaWiki chat extension (`http://www.mediawiki.org/wiki/Extension:Chat`) has been installed and was made available to each wiki page in the integrated environment. Since each formal discussion is in fact a wiki page, all of the discussions where enhanced to support a dialog-specific chat room.

Finally, the integrated environment of (Shared)HCONE was extended to support a cascade delete functionality for maintenance reasons. A special Wiki page was introduced that allows the administrator to select a dialog page and remove it along with its sub-elements (related Wiki pages) through one single step.

6.5 Lessons learned

From the above it is presumed that the overall approach promotes dialogue and collaborative knowledge construction. Argumentation and interaction between students is rich enough, while recurring patterns in interaction indicate that students find the basic concepts of the approach (arguments, positions, and issues) meaningful and useful. The evolution of "Travel Agent" ontology in terms of quantity and quality also indicates that ontology construction is substantially augmented by the support of interaction which is mainly conducted through the SharedHCONE. The students find the system usable and have positive attitudes towards using it, although a deeper integration of HCONE and SharedHCONE tools could further enhance the overall system usability.

7 Conclusion

The work for ontology engineering education presented in this paper has been motivated by technologies in collaborative and wiki-based Ontology Engineering as well as in collaborative e-learning in order to support the design of systems that create learning spaces for learning ontology engineering collaboratively. The proposed technologies are integrated with the HCOME-3O framework in order to support the sharing of consistently evolved and living ontologies within and across different communities. This novel approach views ontology engineering from a learning perspective, striving towards putting the foundations of e-learning in ontology engineering via a mapping of wiki-based collaborative ontology engineering functionalities/objectives to functionalities/objectives that have been proposed in the collaborative e-learning paradigm. The paper reports on the creation of learning spaces and the recording/use of learning knowledge by different users' roles.

The initial evaluation of the educational use of the integrated (Shared)HCONE environment in a CSCL course in Ontology Engineering indicates that these systems can be useful in educational as well as ontology engineering environments. Further experimentation could accentuate additional results of the present study concerning the pedagogical potential of the HCOME or other related methodologies in Ontology Engineering Education.

The presented approach could utilize alternative tools and methodologies that also propose the use of a) argumentation models, and b) Semantic Wiki technology.

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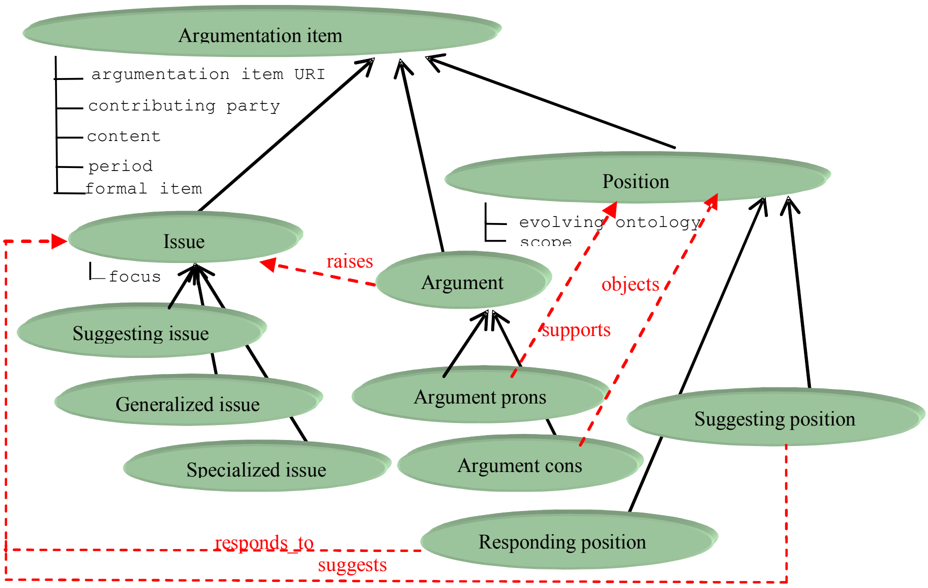
A HCOME-3O meta-ontologies

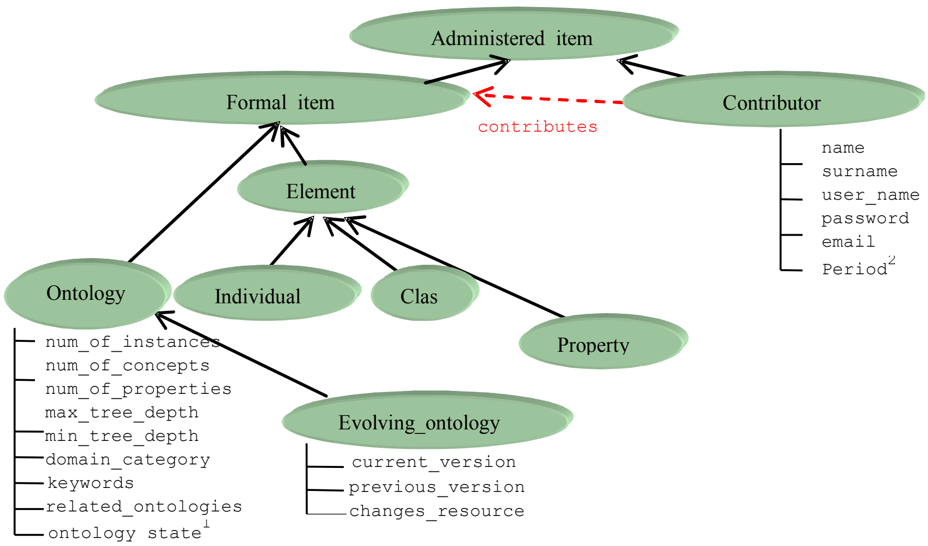
A.1 Argumentation meta-ontology

The Argumentation meta-ontology provides a schema for representing meta-information about issues, positions, and arguments that contributing parties make during an argumentation dialogue upon the collaborative evolution of shared ontologies. Specifically, an argument may raise an issue that either suggests changes in the domain conceptualization, or questions the implementation of the conceptualized entities/properties. Based on this issue, a collaborative party may respond by publicizing a position, i.e. a new version of the ontology, or by suggesting the change of a specific ontology element. A new argument may be placed for or against a position, and so on. Issues may be generalized or specialized by other issues. The connection of the recorded arguments with the ontology elements discussed by specific contributing parties and with the changes made during a period is performed through the properties of "Argumentation Item" and "Position" classes (formal item, contributing party, period, evolving ontology). The argumentation ontology supports the capturing of the structure of the entire argumentation dialogue as it evolves among collaborating parties within a period. It allows the tracking and the rationale behind atomic changes and/or ontology versions. It is generic and simple enough so as to support argumentation on the conceptual and on the formal aspects of an ontology.



A.2 Administration meta-ontology

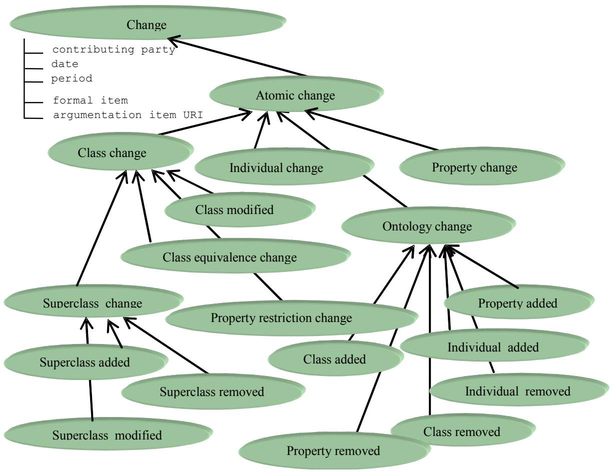
The Administration meta-ontology provides a schema for representing meta-information about administered items and contributing parties. Administered items can be either ontologies or ontology elements (classes, properties, individuals). All types of items are identified by a resource identifier. Formal items are contributed by contributing parties. Contributing parties may contribute to the development/evolution of a personal, shared or agreed ontology, or may contribute to the specification of a class, property or individual. Also, an ontology can have several uniquely identified versions, which result from the changes made and recorded during ontology development/evolution. The administrative ontology distinguishes between the informal and formal conceptualization of a domain by linking formal items to argumentation items (of the argumentation dialogue) that provide arguments for the conceptualizations/specifications made.



1. It specifies whether an ontology is personal, shared or agreed
2. A period starts when a personal ontology is send to the shared space and ends when a version of this ontology is in the agreed state.

A.3 Evolution meta-ontology

The Evolution meta-ontology provides a schema for representing information about the changes that contributing parties can make to the ontology elements during the evolution of a domain ontology. It also supports the reporting of differences between two versions of a single ontology. This ontology currently specifies only atomic changes: Any atomic change to the specification of a formal element (Class, Property, and Individual) made during the editing of an ontology is recorded together with the rationale behind it. The relations between a change made by a contributed party, the argumentation items (if any) behind this change, and the element that has been changed, are specified by means of the Atomic change class properties (contributing party, argumentation item, formal item).



For the OWL version of these ontologies please visit the page `http://icsd-ai.aegean.gr/metaOntologies/`. For a more detailed description of the developed system and for a demonstration of already developed learning material please visit the projects' web site at `http://icsd-ai.aegean.gr/sharedhcone/`.