Collaborative Semantic Content Management: an Ongoing Case Study for Imaging Applications

Ioana Ciuciu[1], Han Kang[1], Robert Meersman[1], Jerome Schmid[2], Nadia Magnenat-Thalmann[2], Jose Antonio Iglesias Guitian[3] and Enrico Gobbetti[3]

[1]VUB – STARLab, Brussels, Belgium

[2]UNIGE–MIRALab, Geneva, Switzerland

[3]CRS4–Visual Computing Group, Sardinia, Italy

iciuciu@vub.ac.be

han.kang@vub.ac.be

meersman@vub.ac.be

schmid@miralab.ch

thalmann@miralab.ch

jalley@crs4.it

gobbetti@crs4.it

Abstract: This paper presents a collaborative solution for knowledge management, implemented as a semantic content management system (CMS) with the purpose of knowledge sharing between users with different backgrounds. The CMS is enriched with semantic annotations, enabling content to be categorized, retrieved and published on the Web thanks to the Linked Open Data (LOD) principle which enables the linking of data inside existing resources using a standardized URI mechanism. Annotations are done collaboratively as a social process. Users with different backgrounds express their knowledge using structured natural language. The user knowledge is captured thanks to an ontologic approach and it can be further transformed into RDF(S) classes and properties. Ontologies are at the heart of our CMS and they naturally co-evolve with their communities of use to provide a new way of knowledge sharing inside the network. The ontology is modeled following the so-called DOGMA (Developing Ontology-Grounded Methods and Applications) paradigm, grounded in natural language. The approach will be demonstrated on a use case concerning the semantic annotation of anatomical data (e.g. medical images).

Keywords: Knowledge Management, Content Management System, Collaborative Ontology Engineering, Social Web.

1. Introduction

Knowledge management is of tremendous importance nowadays in collaborative communities, in which data needs to be exposed and shared. In order for the collaboration to be successful, a shared and common understanding of a domain - that can be communicated between people and application systems - is needed. The formal specifications of the shared semantics are provided by ontologies. In computer science, ontologies were used to facilitate knowledge sharing and reuse. Since the beginning of the nineties, ontologies have become a more and more popular research topic involved by several AI research communities including knowledge engineering, natural language processing, and knowledge representation. More recently, the conception of ontology is also becoming widespread in the fields such as intelligent information integration, cooperative information systems, information retrieval, electronic commerce, and knowledge management.

In order to facilitate knowledge sharing between non expert users with different backgrounds, we choose to use natural language to describe their world. Our approach is based on an ontological paradigm – DOGMA – grounded in natural language. The knowledge can be further transformed into RDF(S) classes and properties.

This article addresses the problem of knowledge sharing and understanding among communities, by providing an interdisciplinary platform for co-developing ontologies by multiple users from different domains. Together with the proposed framework, the main contributions of the presented approach are: 1) the grounding in natural language, 2) the browsing and retrieval of the content in an easily understood format and 3) the reuse of knowledge.

The paper is organized as follows: Section 2 provides background on ontology engineering - introducing DOGMA approach on ontology - and its application to a semantic content management system designed for collaborative knowledge sharing. Section 3 demonstrates our approach on an ongoing use case for imaging applications and knowledge interaction. Section 4 concludes on the presented approach and discusses new research directions emerging from this work.

2. Collaborative Semantic Content Management Based on Ontologies

In order to interlink data, to share knowledge and express intents in collaborative projects, people need to understand each other and each other's data. We say that a conceptual common ground needs to be achieved. Ontologies play a central role in this process. An ontology is designed with the purpose of knowledge sharing and interoperation among agents. Semantic interoperability represents the ability of two or more agents to communicate and interpret data. This process requires that the information system understands the semantics of the user's information request and satisfies it as good as possible.

Tom Gruber defines ontology as "an explicit specification of a conceptualization" (Gruber 1993). Guarino (Guarino 1995, Guarino 1998) further refines the definition of conceptualization as the intended models, with which a set of logical axioms are designed to account for the intended meaning of a vocabulary. In other words, ontology explicitly defines a set of real world objects and the relations between them, in such a way that it is understandable by both humans and machines. Ontologies are thus used for communication and for reuse of knowledge, as pointed out in (Grüniger 2002). They are widely used for communication between machines (e.g. Semantic Web (Berners-Lee 1999)). Yet, ontologies can also be used to improve the interaction between multiple human actors and between humans and computer systems (Uschold 1996).

Based on the above definitions of Tom Gruber and Nicola Guarino, the DOGMA (developing Ontology Grounded Methods and Applications) paradigm for ontology engineering (Meersman 1999, Meersman 2001, Spyns 2002) was introduced. It is summarized in the following section.

2.1 The DOGMA Approach

DOGMA is a formal ontology engineering framework based on the idea of applying the principles of database design methodology (NIAM/ORM2 (Halpin 2001)) to ontology engineering. Different from data modeling (though motivated by it), DOGMA creates reusable resources (ontologies), not only for a specific application, but for as many applications as possible within a specific domain. DOGMA ontology is grounded in natural language and based on the "double articulation" (Spyns 2002) principle, which separates the concepts with their relations (facts) from their semantic constrains. As a result, the ontology is two layered (see Figure 1), with the intention to make the reuse of facts easier:

- The *lexon* base layer that contains a vocabulary of simple binary facts, called lexons;
- And the *commitment* layer that formally defines rules and constraints by which a set of applications may make use of the lexons.

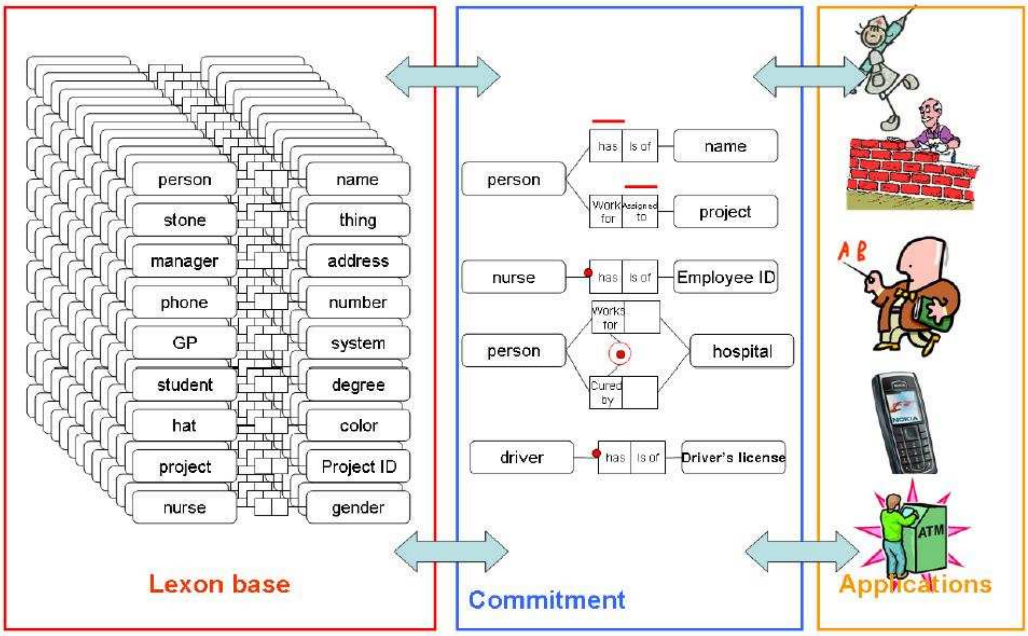


Figure 1. DOGMA framework (Tang 2009)

We will detail the two layers in the next paragraphs.

2.1.1 Lexon Layer

A lexon is formally defined as a quintuple *‹γ, headterm, role, co-role, tailterm›*, where *γ* is a context identifier used to disambiguate the terms (*headterm*, *tailterm*). For example, the lexon *‹Conference, Author, submits, is submitted by, Paper›* - illustrated in Figure 2 - explains that in the context *Conference*, *Author* plays the role of *submits Paper* and *Paper* plays the role of *is submitted by Author*. Context has been studied intensively in the field of Artificial Intelligence, as it plays an important role in the communication between human beings (McMacrthy 1993). The goal of the Lexon base is to reach a common agreement on the understanding of the ontology terminology and is therefore aimed at human understanding. In some cases, the meaning of the terms in the Lexon base is ambiguous (e.g. an abbreviation), therefore further explanations need to be provided for human understanding. This disambiguation is done by linking the lexon terms to their explanation, either via a Concept Definition Server (De Bo 2004) or by the bias of *Meta*-Lexons (Spyns 2007).

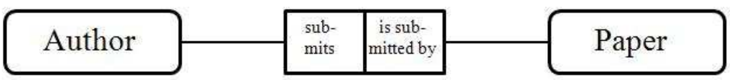


Figure 2. Visualization of the lexon: *‹Conference, Author, submits, is submitted by, Paper›*

2.1.2 Commitment Layer

Ontological commitments are "agreements to use the shared vocabulary in a coherent and consistent manner" (Gruber 1993). A commitment in the Commitment layer is a finite set of constraints, rules and axiomatized binary facts that specify how lexons in the Lexon base are interpreted in the committing application. The role of the Commitment layer is thus to bridge the gap between the ontology base and the applications, aiming at balancing the reusability (generic) with usability (specific), in order to "reuse and share application-domain knowledge" (Guarino 1998).

2.2 A Collaborative Semantic CMS

The collaborative semantic CMS presented here provides the communities with an interdisciplinary framework for knowledge sharing and a storage platform based on ontologies (see Figure 3). The problems arising from the users' different needs and backgrounds, affecting the communication, the interaction and the understanding (Faquhar 1997), are eliminated. The CMS enables non-expert users to enrich the ontology, by adapting the CMS to fit the DOGMA approach to ontology engineering, explained in the previous section.

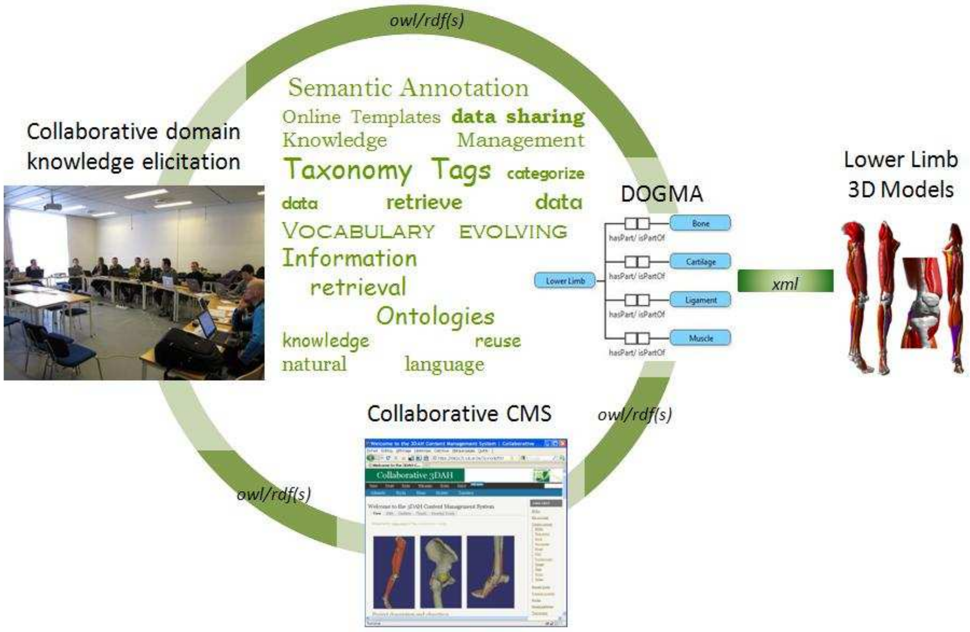


Figure 3. The collaborative semantic framework for knowledge sharing

The philosophy of this framework is presented in the following sub-sections.

2.2.1 Semantic Data Annotation

In order to analyze (process, retrieve) the information (data, resources), agents (human users, systems, software processes) need to understand the data. This is achieved by assigning meaning to the data, by means of semantic annotations. Annotating data models is often a social, collaborative process. Collaborative 3DAH is a highly suitable framework for supporting these social processes. It uses vocabularies grounded in natural language, which are part of what we call taxonomy - and it gives the users the possibility to freely express their knowledge by a free-tagging system. Taxonomy and tags are used to categorize and classify data. The knowledge can thus be further retrieved and published on the web in order to be shared and reused.

The tool we propose provides a framework which collects different parts of knowledge from domain experts (e.g. physicians, engineers, computer science researchers) in the form of templates which can be submitted on-line. Templates provide elementary data to fill an ontology framework by interacting with the ontology server. The CMS proposes different types of templates, each of them associated with a *content type*, corresponding to the users' modeling needs, and the corresponding fields of each template. For example, an *Image* content type is described - as illustrated in Figure 4 - by the following fields:

- Title
- Vocabularies (Taxonomy)
- Tags
- URL
- Text body

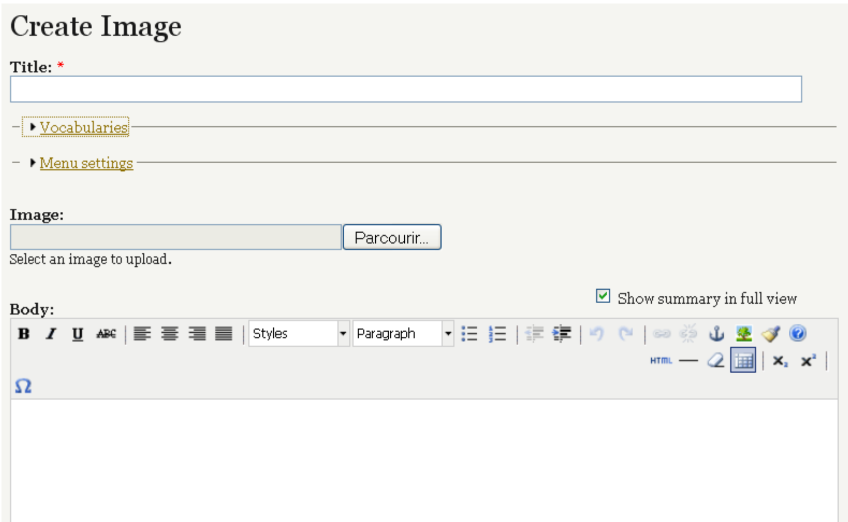


Figure 4. Content type *Image* with the corresponding fields

Other possible content types are: bibliography, blog entry, book, document, event, faq, forum topic, page, story and video.

A so called *vocabulary* (corresponding to the ontology and more precisely to lexons in the ontology) describes the content types and their fields used in the data model as RDF(S) classes and properties. Fields are assigned a property name and content types are assigned a class name. The generated RDF(S) can be reused by other users to publish their data on the web. The CMS may reuse/import vocabulary terms from common existing ontologies. This gives the user the chance to link/map the content to existing vocabularies and ontologies populating the Semantic Web by selecting terms from existing ontologies while setting up the content model. The idea of reusing existing ontologies belongs to the Linked Open Data principles (Bizer 2007).

The transformation of a semantic pattern to RDF(S) is shown in Algorithm 1. The reverse operation - the transformation of RDF(S) to lexons - is also possible, since lexons are binary fact types. We refer to

(Bizer 2007) for the transformation algorithm. As example, Figure 5 shows the transformation of the lexon illustrated in Figure 2.

Algorithm 1 Transforming a semantic pattern to RDF(S)

For all term in pattern **do**
    If term is a value-type **then**
        Create a new class that extends from rdfs:Literal
    Else
        Create a new class that extends from rdfs:Class
    End if
    Add term as label for that new class
End for
For all lexon in pattern **do**
    Create new property p_1 for the role of the lexon
    Add class of term as domain and co-term as range for p_1
    Add role-label as label for p_1
    Create new property p_2 for the co-role of the lexon
    Add class of co-term as domain and term as range for p_2
    Add co-role-label as label for p_2
End for

```
<rdfs:Class rdf:about="#Author">
<rdfs:Label>Author</rdfs:Label>
</rdfs:Class>
<rdfs:Class rdf:about="#Paper"/>
<rdfs:Label>Paper</rdfs:Label>
</rdfs:Class>
<rdf:Property rdf:about="#isSubmittedByAuthor">
<rdfs:Label>is submitted by</rdfs:Label>
<rdfs:domain rdf:resource="#Author"/>
<rdfs:range rdf:resource="#Paper"/>
</rdf:Property>
<rdf:Property rdf:about="#sumbitsPaper">
<rdfs:Label>submits</rdfs:Label>
<rdfs:domain rdf:resource="#Paper"/>
<rdfs:range rdf:resource="#Name"/>
</rdf:Property>
```

Figure 5. RDF(S) generated from the lexon in Figure 2

Vocabularies (taxonomy and tags) are used to classify and structure data (content/knowledge) in order to create links between data with the purpose of information retrieval and knowledge sharing. We further detail these notions.

2.2.2 Taxonomy and Tags

Taxonomy and tags are means to help evolving the vocabularies (and implicitly the ontology) with their communities of use (De Moor 2006). We create several vocabularies which cover topics such as human anatomy, medical imaging, ontology, etc. When clicking on a specific tag, all the related contents in the CMS can be retrieved and published.

Let us now define the meaning of taxonomy and that of tag.

Taxonomy is a term used to describe a vocabulary predefined by information professionals (domain experts). A taxonomy is a hierarchical structure (a tree), in which the information is sharply delineated and controlled. The inconvenient with taxonomies lies in the fact that they raise high barriers for laymen users for suggesting new conceptual terms. The search time is expensive, due to their structure (tree structure).

Opposed to taxonomies, but closely related to them, are the tags. Tags can be regarded as piles of leaves, therefore messy structures. Tags are reflecting the users' subjective level of knowledge and their interest in the annotated object. They represent an inexpensive, easy way of using the wisdom of the crowd to make resources visible and sortable (Weinberger 2005). Social tagging (folksonomy) grows organically as a collaborative, social process. We are using tags to help the vocabulary evolve. Table 1 summarizes the characteristics of taxonomies opposed to those of tags.

Table 1: Taxonomy versus tags

Taxonomy	Tags
Drive out ambiguity	Inherently ambiguous
Neat structure	Messy structure (piles of leaves)
Control of information	Wisdom of the crowd
Expensive	Inexpensive

Both taxonomies and tags are of interest for our approach. Taxonomies - because they provide recognized vocabularies, revised by domain experts, and tags - because they are a very rich source of information (they express the wisdom of the crowd), providing new means to classify and reveal data.

The taxonomy of the CMS provides a set of vocabularies revised by different partners. An example of vocabulary is the *Human Anatomy* vocabulary, designed to categorize and structure anatomical data. The taxonomy of the human anatomy, more specifically of the human musculoskeletal system of the lower limbs, is depicted in Figure 6. Every time content is created, the user has the possibility to choose terms from the available vocabularies in order to annotate the content (images, videos, publications, etc.). The system gives the user the possibility to enrich these vocabularies by suggesting new or existing tags, as shown in Figure 7. Every term (tag or taxonomic term) is hyperlinked to the content it classifies, as illustrated in Figure 8. This allows information to be easily retrieved and published. An example of information retrieval based on a tag related to segmentation (see next section for a definition) is shown in Figure 8.

Tagging is a social process from which important information can be inferred. As Van Damme discusses in (Van Damme 2007), tags are expressing and reflecting the actors' subjective level of knowledge on and their interest in the annotated object. Therefore, tags can be used to unlock explicit knowledge: for example, tags are illustrative of people's interests, so they are used to detect experts and their domain of expertise. This is useful in a company when creating teams and organizing meetings with experts in that company. Since tags show the evolution of the community focus, they are used in activity monitoring.

Attention must be paid concerning the quality of the tags (inconsistencies, redundancies, etc.): not all the tags are useful and reliable. Good tags can make a system better by linking entities to one another to enhance browsing or search (or may serve as a source of descriptive information). First, the shape of tags must be analyzed (for misspelling, similarity (singular/plural), etc.), and second - their meaning. The meaning of a tag can differ greatly, depending on users' experience, culture, etc.

We identify two ways to predict the quality of tags: explicitly (member feedback: tag rating, voting system, etc.) and implicitly (system usage: How many users apply a tag, how often is a tag applied, etc.). Cleaning the tags is the first step before analyzing and inferring information from tags. We refer to (Van Damme 2008) for methods to infer the tags' quality. The process of finding the best quality tags is planned for the future (see Section 4 on Future work).

Figure 6: Part of the Human Anatomy vocabulary

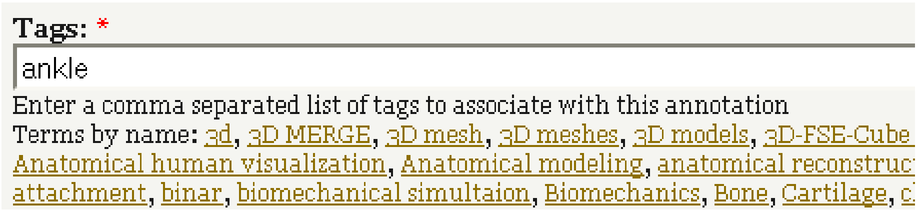


Figure 7: Categorizing content using tags

Figure 8: Result of information retrieval based on search in relation with the *segmentation* tag. This page gathers information such as publications, pictures, comments, associated tags, etc.

3. Use Case: Semantic Annotation of Images and Knowledge Interaction

One of the applications of the CMS proposed in this paper is the collaborative semantic annotation of anatomical data, and more specifically of medical images. The geometrical annotation of medical images is referred to as medical image segmentation. Segmentation is the process to identify and delineate homogeneous and non overlapping regions in an image. Regions usually correspond to anatomical entities, such as organs. From these regions three dimensional geometrical models can be constructed as exemplified in Figure 9 (we refer interested readers to (Schmid 2009) for more information). The CMS stores information related to the medical images and their segmentation such as medical image raw data or segmented geometrical models. The CMS plays the role of knowledge base and is collaboratively updated by the partners via the annotation system. The ontology is thus collaboratively constructed, by transforming the annotations to lexons, as illustrated in Figure 10.

In collaboration with two other partners from the 3DAnatomicalHuman (3DAH) project (3DAH 2006), we setup an interaction framework for the examination of the knowledge describing the musculoskeletal system of the human lower limb. The user can thus browse the anatomical structures which are of interest for him/her using the 3DAH Viewer (3DAH Viewer 2007) and in the same time query the 3DAH CMS for retrieving information on the selected structures.

Every time new structures are added to the anatomical browser resources, related information (text, images, associated publications, etc.) are updated on the collaborative CMS. Then a link is created between the application and the online data, enhancing the application with rich semantic information.

Figure 9 illustrates an example where a user selects a structure of interest (here the Vastus Medialis muscle) using either direct picking on a 3D view or a tree structure created from the anatomical taxonomy. By demanding information on the selected structure, a web page is opened which gathers information related to the structure (as in Figure 11). This is made possible by a query mechanism which interrogates the ontology and dynamically creates the appropriate page content.

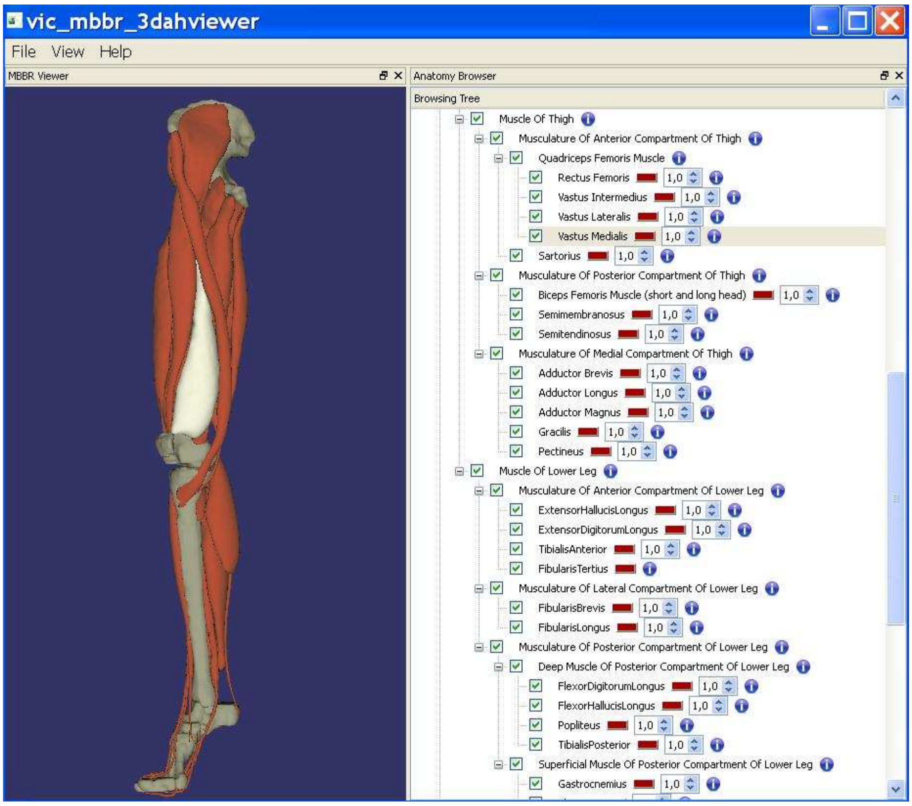
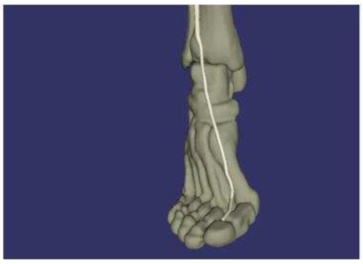


Figure 9: Anatomical browser. The user selects the Vastus Medialis muscle (in white) in a tree-structure derived from a taxonomy created from the collected knowledge in the 3DAH project



Lexons: Extensor Hallucis Longus Tendon			
Extensor Hallucis Longus Tendon	part of	part	Tendons Of Lower Leg
Extensor Hallucis Longus Tendon	affected by	affects	Rupture
Extensor Hallucis Longus Tendon	reconstucted with	reconstructs	Gracilis Tendon Autograft
Extensor Hallucis Longus Tendon	repaired by	repairs	Sugery
Extensor Hallucis Longus Tendon	replaced by	replaces	Accessory Tendon
Hallux Varus	is a	is	Hallux Deformity
Hallux Varus	treated by	treats	Accessory Tendon
Tendon Rupture	is a	is	Injury
Laceration	is a	is	Injury
Laceration	affects	affected by	Extensor Hallucis Longus Tendon
Laceration	affects	affected by	Walking

Lexons: Acetabular Labrum			
Acetabular Labrum	part of	part	Cartilage of Hip
Hip Arthroscopy	is a	is	Surgery
Hip Arthroscopy	repairs	repaired by	Acetabular Labrum
Acetabular Labrum	stabilizes	stabilized by	Hip Joint
Acetabular Labral Tear	affects	affected by	Acetabular Labrum
Acetabular Labral Tear	produces	produced by	High Stresses
Acetabular Labral Tear	produces	produced by	Joint Deterioration
Acetabular Labral Tear	produced by	produces	Direct Trauma
Acetabular Labral Tear	produced by	produces	Hip Dysplasia
Physical Therapy	heals	healed by	Acetabular Labral Tear
Anti-inflamatory Drugs	heal	healed by	Acetabular Labral Tear
Hip Pain	diagnoses	diagnosed by	Acetabular Labral Tear
Arthroscopy	diagnoses	diagnosed by	Acetabular Labral Tear
Arthroscopy	heals	healed by	Acetabular Labral Tear

Figure 10: Semantic annotations of an image (upper left) and a video (lower left)

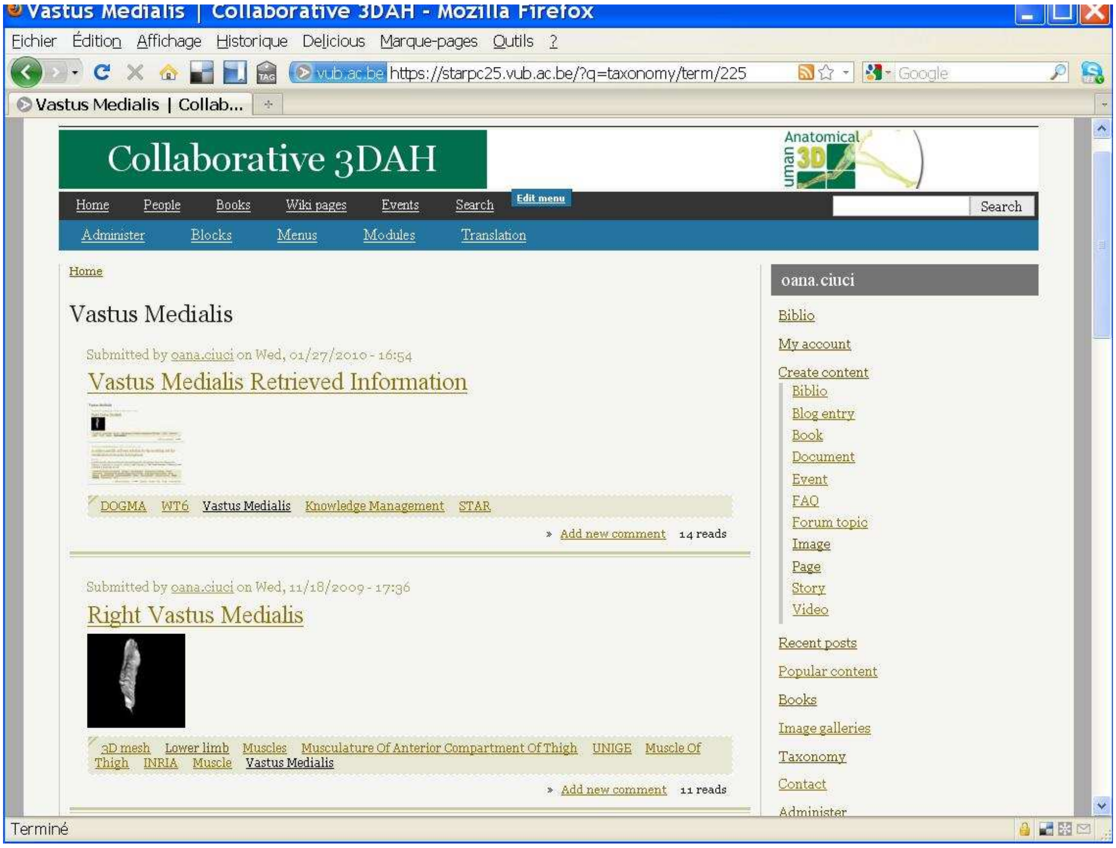


Figure 11: Page created by the collaborative CMS in relation with the Vastus Medialis muscle selected by the user in the anatomical browser. This page gathers information such as publications, pictures, comments, associated tags, etc.

We are currently investigating on a way to couple the knowledge interaction framework with ontology-based matching strategies for an E-learning scenario. A virtual teacher is simulated to evaluate the students' competencies and to help improve learning, by making personalized suggestions on the learning materials. It is based on three main components: 1) a semantically enriched CMS playing the role of knowledge base, 2) a 3D anatomy browser and 3) an ontology-based matching framework providing the evaluation methodology. We refer to (Ciuciu 2010) for details.

4. Conclusion and Future Work

In this paper, we have presented a collaborative framework for semantic annotations of data. The main contributions of the framework are: 1) the grounding in natural language, 2) the browsing and retrieval of the content in an easily understood format, 3) the reuse of knowledge and 4) the social and collaborative aspects of enriching the knowledge base. In the first part of the article, we made a brief description of the underlying concepts. Then we explained how these concepts and the underlying technologies are used within the CMS to categorize and organize the information for further analysis and retrieval. The collaborative semantic annotation of data is explained, which is at the basis of the building of a distributed ontology and consequently at the basis of knowledge sharing and reuse. Finally, we demonstrated that our approach is effective, by describing a case study on imaging applications.

An ongoing research (Ciuciu 2010) on information analysis applies ontology-based matching strategies (Tang 2010) to improve E-learning. We designed an intelligent system which is capable to evaluate the correctness of the student's answers to an anatomy test and to make suggestions on the learning material in order to improve the student's knowledge.

A future research work is to take into account the social aspect for the purpose of unlocking the knowledge via tags. Tags can be used as a mechanism to find clusters of users, grouped by similar interests, in order to find knowledge experts to form teams, and in order to monitor the users' activity.

Acknowledgements

This work was supported by the Marie Curie research Training Netwok project "3DAnatomicalHuman" within EU's Sixth Framework Programme. The project was under Contract No. MRTN-CT-2006-035763.

References

3DAnatomicalHuman (3DAH) 2006, website: http://3dah.miralab.ch.

3DAH Viewer (2007) available at:

http://3dah.miralab.ch/index.php?option=com_remository&Itemid=78&func=fileinfo&id=394

Berners-Lee, T. (1999) *Weaving the Web: Origins and Future of the World Wide Web*. Texere Publishing, US.

Bizer, C., Cyganiak, R., Heath, T. (2007) "How to Publish Linked Open Data on the Web", available at:

http://www4.wiwiss.fu-berlin.de/bizer/pub/LinkedDataTutorial/

Ciuciu, I.G., Tang, Y., Meersman, R. (2010) "Collaborative Semantic Annotation of Anatomical Data: An Ongoing Case Study for E-learning", *3DAH Summer School*, Chania, Grece.

De Bo, J., Spyns, P., Meersman, R. (2004) “Assisting Ontology Integration with Existing Thesauri”, *CoopIS/DOA/ODBASE (1)*, pp 801–818, Springer.

De Moor, A., De Leenheer, P., Meersman, R. (2006) “DOGMA-MESS : A Meaning Evolution Support for Interorganizational Ontology Engineering”, *14th International Conference on Conceptual Structures (ICCS 2006)*, Springer-Velrlag, Vol 4068, Aalborg, Denmark.

Farquhar, A., Fikes, R., ice, J. (1997) “The Ontolingua Server: A Tool for Collaborative Ontology Construction”, *International Journal of Human-Computer Studies,* Vol. 46(6), pp 707–727.

Gruber, T.R. (1993) “Toward Principles for the Design of Ontologies used for Knowledge Sharing”, *Workshop on Formal Ontology*, Padova, Italy, in book *Formal Ontology in Conceptual Analysis and Knowledge Representation*, Kluwer Academic Publishers (1993).

Grüniger, M., Lee, J. (2002) “Ontology Applications and Design” *Communications of the ACM*, Vol 45(2), pp 39–41.

Guarino, N. (1995) “Formal Ontology, Conceptual Analysis and Knowledge Representation”, *International Journal of Human-Computer Studies, Special Issue: The Role of Formal Ontology in the Information Technology*, Vol 43, pp 625–640, Academic Press.

Guarino, N. (1998) “Formal Ontology and Information Systems”, *Proceedings of FOIS’98*, pp 3–15.

Halpin, T. (2001) *Information Modeling and Relational Databases: From Conceptual Analysis to Logical Design*, Morgan Kaufmann, San Francisco.

McMacrthy, J. (1993) “Notes on Formalizing Context”, *Proceedings of 13th International Joint Conference on Artificial Intelligence*, Ruzena Bajcsy (eds.) Morgan Kaufmann, France.

Meersman, R. (1999) “Ontologies and Databases: More than a Fleeting Resemblance” *Proceedings of the International Symposium on Methodologies for Intelligent Systems*, Vol 1609, Springer.

Meersman, R. (2001) “Semantics Ontology Tools in Information System Design” *Proceedings of OES/SEO Rome Workshop*.

Schmid, J., Sandholm, A., Chung, F., Magnenat-Thalmann, N., Thalmann, D., Delingette, H. (2009) “Musculoskeletal Simulation Model Generation from MRI Datasets and Motion Capture Data”, *Recent Advances in 3D Physiological Human*, Springer-Verlag, pp 3–19.

Spyns, P., Meersman, R., Jarrar, M. (2002) “Data Modeling Versus Ontology Engineering” *SIGMOD Record: Special Issue on Semantic Web and Data Management*, Vol 31(4), New-York.

Spyns, P., Tang, Y., Meersman, R. (2007) “A Model Theory Inspired Collaborative Ontology Engineering Methodology”, *Journal of Applied Ontology*, Special Issue on Ontological Foundations for Conceptual Modeling, Vol 4, pp 1–23, Springer.

Uschold, M, Grüniger, M. (1996) “Ontologies: Principles, Methods and Applications”. *The Knowledge Engineering Review*, Vol 11(2), pp 93–155.

Tang, Y. (2009) *On Semantic Decision Tables*, PhD Thesis, Vrije Universiteit Brussel.

Tang, Y., Meersman, R., Ciuciu, I.G., Leenarts, E., Pudney, K. (2010) “Towards Evaluating Ontology Based Data Matching Strategies”, to appear in *Proceedings of the Fourth International Conference on research Challenges in Information Science*, Nice, France.

Van Damme, C., Hepp, M., Siorpaes, K. (2007) “FolksOntology: An Integrated Approach for Turning Folksonomies into Ontologies”, *Proceedings of the ESWC 2007 Workshop Bridging the Gap Between Semantic Web and Web 2.0*, pp 71–84, Innsbruck, Austria.

Van Damme, C., Hepp, M., Coenen, T. (2008) “Quality Metrics for Tags of Broad Folksonomies”, *Proceedings of the International Conference on Semantic Systems (I-Semantics), Journal of Universal Computer Science (J. UCS),* pp 118–125.

Weinberger, D. (2005) “Taxonomies to Tags: From Trees to Piles of Leaves”, *Esther Dyson’s Monthly Report, Release 1.0*, Vol 23, No. 2.