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A learning object ontology repository to support annotation and discovery of educational resources using semantic thesauri

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Abstract
Open educational resources are currently becoming increasingly available from a multitude of sources and are consequently annotated in many diverse ways. Interoperability concerns that naturally arise can often be resolved through the semantification of metadata descriptions, while at the same time strengthening the knowledge value of resources. SKOS can be a solid linking point offering a standard vocabulary for thematic descriptions, by referencing semantic thesauri. We propose the enhancement and maintenance of educational resources' metadata in the form of learning object ontologies and introduce the notion of a learning object ontology repository that can help towards their publication, discovery and reuse. At the same time, linking to thesauri datasets and contextualized sources interrelates learning objects with linked data and exposes them to the Web of Data. We build a set of extensions and workflows on top of contemporary ontology management tools, such as WebProtégé, that can make it suitable as a learning object ontology repository. The proposed approach and implementation can help libraries and universities in discovering, managing and incorporating open educational resources and enhancing current curricula.

Keywords
Learning objects, linked data, ontologies, SKOS, thesauri, WebProtégé

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Introduction

The landscape of online educational services has recently been undergoing a major though silent revamping. Restricted access and tightly-bounded learning paths are gradually giving way to open-world, highly thematic and rich courses. The advent and relative success of Massive Online Open Courses (MOOCs) is among the driving forces for this evolution. At the same time, libraries and information services around the world are constantly striving to adapt their role in view of this open ecosystem.

But the openness of offered programs means that the learning material they depend on should be equally available for repurposing and synthesis. A learning object (LO) can be defined as 'any entity – digital or non-digital – that may be used for learning, education or training'. LOs are widely purposed and/or reused as a meaningful and effective way of creating content for e-learning (Polsani, 2003), especially within learning and course management systems. Learning object repositories (LORs) on the other hand make available and allow the reuse of high quality LOs for addressing multifaceted didactic goals (Ochoa and Duval, 2009). Easy componentization of LOs within LORs make it possible to glean learning elements and reuse them within larger settings, such as MOOCs (Piedra et al., 2014).

These changes put pressure on libraries to reengineer their business processes and gradually shift from centralized online catalogues to intermediate curation

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and facilitation authorities. This is often sought by adopting open repository policies and services, putting focus on long-term preservation of original content and fostering platforms for academic crowdsourcing (Lynch, 2005).

Metadata annotations for learning resources provided by LORs play a crucial role since they essentially convey machine-readable descriptions for the LOs. Even though they are often represented by well-defined and agreed upon standards, metadata elements and relevant schemas are not always adequate for the efficient description, dissemination and processing of the actual semantics they inherently carry. For example, a flat, XML implementation of metadata value-pairs amounts to little more than syntactic annotations. This becomes even more critical in situations such as aided annotation and discovery of educational resources in repositories, where semantic matches can provide considerable added-value, for example, by considering semantic networks and thesauri.

Therefore, in this paper, we propose the creation and maintenance of a semantics-aware learning repository where, by virtue of ontologies, LO metadata instances can be assigned machine-understandable semantic annotations. As such, interoperability with other repositories, discovery mechanisms and tools can be achieved at the semantic level. We design a learning object ontology based on the IEEE LOM standard (Hodgins and Duval, 2002) and we show how LOs can now be integrated with other semantic standards, like Simple Knowledge Organization System (SKOS)-based terminologies (Miles and Bechhofer, 2009), to ease their description and aid discoverability. In addition, by linking resources to standardized thematic taxonomies and/or additional ontologies and datasets, LOs are being opened up to the linked data world and the wealth of the Web of Data. Also, the ability to publish learning object ontologies through the repository makes it possible for LOs to be meaningfully consumed by and exchange information with other applications, such as a learning management system (LMS). In this setting, the role of libraries and curators can be enhanced towards that of an intermediate authority which, through continuous assessment and validation of appropriate terminologies, datasets and content linking, acts as a data quality hub (Giarlo, 2013). Additionally, the proposed approach can offer a useful tool for librarians to streamline the integration of open educational resources (OERs) into academic courses and automate previously ad hoc workflows and processes (Davis et al., 2016).

The main contributions of the work presented in this paper are summarized as follows:

- design and implement a learning object ontology repository (LOOR) to enhance manageability and discovery of LOs based on WebProtégé;
- integrate the LOOR with learning management systems in use by teachers/instructors to be able to discover, point to and reuse OERs and additional learning material for their courses;
- offer an institutional, shared pool of semantically enhanced LOs available for indexing and supported by collective intelligence;
- ‘semantify’ educational resources by exposing their LO metadata through ontologies;
- link LOs with SKOS thematic terminologies to support integration with other discovery mechanisms, digital repositories and the Web of Linked and Open Data (LOD).

As a proof-of-concept, we build upon the premises of a solid web-based ontology management framework, namely WebProtégé (Tudorache et al., 2013), and design a process and additional services that can allow its reuse as a LOOR. The resulting system has already been deployed to support online courses at the Democritus University of Thrace (DUTH), offering more than 1500 courses and labs, currently for two thematic disciplines: mathematics and medicine, and is available at: http://protege.staff.duth.gr/webprotege/. The proposed approach can therefore be reused by others, to provide their own, local-to-the-institution, cached pool of semantically enhanced LOs.

To give a more thorough understanding of our work, we first review related work in the field and identify common ground as well as differences to our approach (Related work). We then give an overview of our proposed approach and its rationale (Design process) Next, we describe the design and creation of the LO ontology. We proceed by giving the main characteristics of the SKOS model and its importance in knowledge organization, also presenting two thematic thesauri we have implemented in this format (Thematic descriptions using SKOS). Next we summarize the features of the WebProtégé system and describe the deployment of the LOOR on top of it (Deployment of a learning object ontology repository on WebProtégé). The use of the LOOR to enrich course material by instructors and evaluation results are discussed in the next section (On-line course enrichment and reuse of LOs). An example of a LO ontology and relevant use cases are given in the subsequent section (Use cases and examples), including linked data and SPARQL access. Our conclusions and future work follow in the last section (Conclusions and future work).

Related work

The information stored in digital libraries is now complex enough, enhanced with deep semantic structures, something that requires strong intelligent systems to gain the most out of them, while managing and searching (Franconi, 2000). The transition from information processing to knowledge management constitutes the basis for making libraries competitive and can help transform the library into a more efficient knowledge-sharing organization (Jantz, 2001; Teng and Hawamdeh, 2002). What is more, applying knowledge management theories and methods in building digital libraries can better strengthen the latters' services and improve their adaptability in a constantly changing digital environment (Islam and Ikeda, 2014). Ontologies are rich conceptual schemas, designed exactly to effectively capture knowledge and hence are capable of optimizing the management, searching and discovery among libraries' resources which are represented in the form of LOs. Therefore, employment of a LOOR in the context of library and information service institutions can act as the necessary knowledge representation infrastructure that bridges the gap between efficient knowledge management and LO ontologies.

Although the establishment of a LOOR is not always explicit in the literature, there are several studies which outline how ontologies can be put into practice for the description of LOs and how these semantic techniques can facilitate sharing and retrieval of educational resources within LO repositories. Wang (2008) presents an ontology model for the pedagogy design domain and presents a software system (LOSON – Learning Objects Sharing through the Ontology) which supports accessing LOs in accordance with the ontological knowledge structure for pedagogical design. Soto Carrión et al. (2007) describe an approach towards semantic LO repositories by designing a prototype which uses an ontology schema for the description of its entities. Similarly, Casali et al. (2013), propose a LOM ontology which models the LOM standard. Then, they create an 'Assistant' prototype which helps users with respect to loading metadata through automation. Another approach towards an ontology-based and rule-based LO discovery is addressed by Hsu (2012). All the aforementioned approaches, though, fail to further support thematic classification of LOs, based for example on their subject and they are mostly domain specific.

Saini et al. (2006), Jovanovic et al. (2006) and Gasevic et al. (2005) show particular interest in the automatic or at least semi-automatic process of generating ontological metadata for LOs, based on the fact that most LO repositories do not cover wide domains. In particular, Jovanovic et al. (2006) and Gasevic et al. (2005) propose the use of an ontology for describing both the content and structure of LOs, as well as of an ontology for modelling LO categories. Saini et al. (2006) are based on a probabilistic model which, through the automatic classification of LOs on a given taxonomic organization of the knowledge domain, allows the association of ontological metadata with the learning resources. However, these automatic processes have several drawbacks, as they require an exhaustive description of the knowledge domain and are thus prone to lack of accuracy in the characterization of the LOs.

A more recent work by Lama et al. (2012), proposes the classification of LOs based on a set of categories that Wikipedia provides through the DBpedia ontology. According to this approach, the LO subject – represented by the corresponding text-based field of the IEEE LOM standard – is correlated with a set of categories which are semantically described in DBpedia. The proposed ontology though, is not made available to other applications or services for further utilization within the Web of Data.

Compared to our work, all the approaches recognize without doubt ontologies as a powerful mechanism for capturing the characteristics of a LO. Some of them pay particular attention to alleviating the process of characterizing LOs, proposing ways to automate this particular task. Although they save time for librarians who traditionally used to take over this task, they usually lead to poorer representations of the resources' conveyed knowledge. In addition, although some of these approaches make an attempt towards classifying their LOs, they are not based on standardized thematic taxonomies and well-known semantic standards – like SKOS – which could more easily render their digital assets open to the world of Linked Data.

Design process

An outline of the overall proposed approach is depicted in Figure 1. First, we proceed with the design and adoption of a LO metadata profile, originating from the widely known IEEE LOM standard. The resulting profile combines terminology with the Dublin Core metadata terms specification (DCMI Usage Board, 2008) and is intended for the efficient characterization of LOs, preserved and managed by educational institutions. Our goal is not to simply create another specialized LO metadata profile, but to contribute towards knowledge discovery across

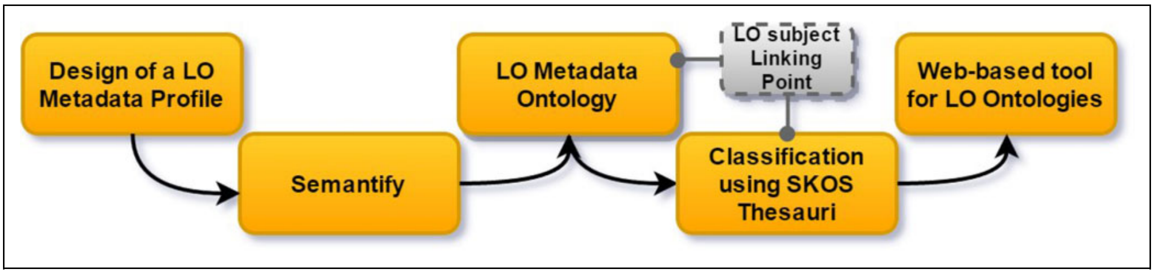

Figure 1. Overview of the proposed approach for the design of a LOOR.

digital LOs repositories, ultimately helping institutions access, maintain and enhance learning material.

We opted for IEEE LOM, due to its relatively wide acceptance in the academic environment and its extensive usage by institutional repositories. To build this profile, we considered the guidelines provided by CEN/ISSS (Smith et al., 2006), via which we had to accomplish the following steps:

- identify the specific characteristics of the distance learning material;
- identify which of these characteristics are reflected in the standard, existing elements of the base schema (IEEE LOM);
- modify the base metadata schema according to these specific requirements (extend it with additional, new elements, modify value space and/or data type of existing elements);
- provide a binding.

An essential step in this migration from LOR to LOOR is a 'semantification' process, i.e. the transformation of the textual information captured by a metadata instance into a semantically enriched and thus machine-understandable format. Ontologies are a knowledge representation technique, offering all the necessary constructs towards this process. They constitute the pillar of the Semantic Web, allowing knowledge reuse and sharing across applications. Ontologies have long been used for many applications in the field of education (Devedžic, 2006), so their utilization for describing educational resources can have many advantages, from facilitating the design of a LO-based course to improving the discovery of educational resources.

Going a step forward, in our LO profile's ontological representation, the subject of a LO is determined to be expressed not as a mere text keyword, but as a *concept* of a thematic thesaurus. The machine-readable format of a thesaurus is achieved by the exploitation of the SKOS standard (Miles and Bechhofer, 2009). SKOS provides a standardized way to represent thesauri – and knowledge organization systems in general – using the Resource Description Framework (RDF) (Klyne and Carroll, 2004) and the Web Ontology Language (OWL) (Motik et al., 2012). By combining our LO ontologies with SKOS thesauri, we can ensure a semantically enhanced characterization of LOs within the context of a digital repository, thus increasing discoverability of its resources. In addition, we set the basis for cross-repository semantic interoperability.

A learning object ontology

Although several educational metadata schemata have been proposed over time, we start with the IEEE LOM standard in order to build our LO metadata profile, which actually adopts a subset of the IEEE LOM element set. Our ultimate goal is the creation of a schema that would be broad enough to cover the most important educational and pedagogical aspects of an educational resource handled by a digital repository, but not exhaustively analytic, so as to become awkward in use.

The ontological binding of our LO metadata profile is expressed in the *LO Ontology Schema*. Apart from those entities representing elements originating from the IEEE LOM schema, we have also declared classes, capturing notions found in the DCMI recommendation for the Dublin Core (DC) metadata terms. This correlation helps control the values of fields for LOM properties and can increase interoperability with applications that are based on DC. In particular, the LOM concepts *IntendedEndUserRole*, *InteractivityType* and *TypicalLearningTime* have been defined as refinements of the DC classes *AgentClass*, *MethodOfInstruction*, *SizeOrDuration*, respectively (Figure 2). For the LOM-specific entities, the official LOM namespace has been used (http://ltsc.ieee.org/xsd/LOM/, prefix lom:), whereas DC classes have been declared under the namespace http://purl.org/dc/terms/, prefix dcterms.

The *lom:LearningObject* class is a top class used to capture the notion of an LO, or an educational resource in general. The various characteristics of an educational resource are represented as either classes or properties in this ontological schema. The datatype properties *lom:description*, *lom:identifier*, *lom:language*, *lom:rights*, *lom:size*, and *lom:title* are used to declare

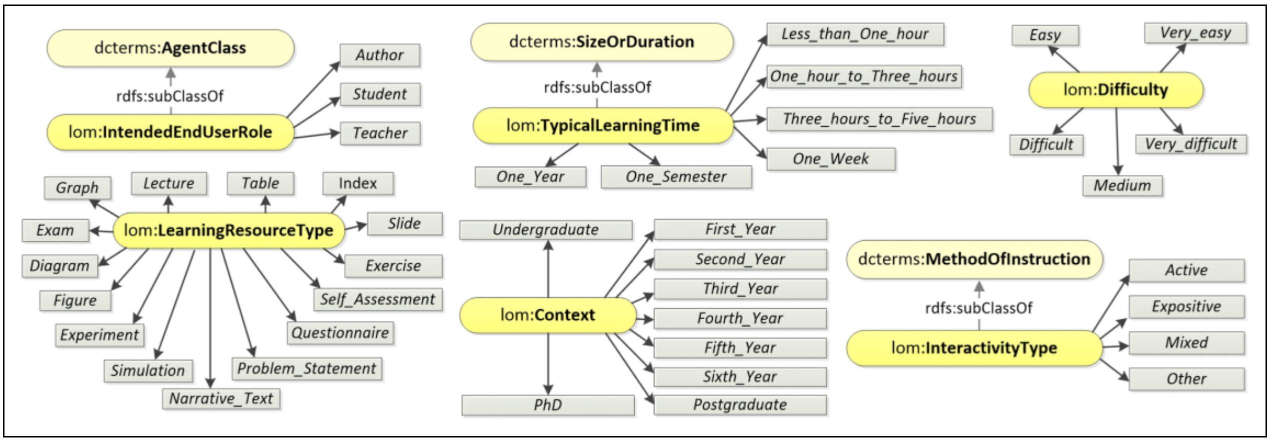

Figure 2. LOM defined classes, their instances and the subclass relationships with DC terms.

a short description, a unique identifier, the LO's content language, the copyright policies, and finally LO's physical size and title, respectively. We chose to express these elements of the LOM schema as datatype- and not as object-properties given that they simply assign values to some of the resources' basic characteristics and convey no correlations among them.

The *lom:LearningResourceType* class aims at specifying the different educational types that can be assigned to LOs and it is associated with a predefined list of terms (Exercise, Experiment, Figure, Lecture, etc.). Each such term is an instance of the *lom:LearningResourceType* class and works as a filler to the object property *lom:learningResourceType*. In a similar way, concepts met in our LO metadata profile, like the groups of end-users to which a LO applies, the intended instructional context, LO's level of difficulty, average learning time, level of completeness (draft, revised or final) and type of interaction (active, expositive, etc.) are captured using the appropriate object properties *lom:intendedEndUserRole*, *lom:context*, *lom:difficulty*, *lom:typicalLearningTime*, *lom:status*, *lom:interactivityType* respectively. These properties correlate a LO with a predefined set of values, each of which is represented as an instance of the corresponding class (Figure 2).

Note that the population of these classes is usually implementation specific and the LOM specification leaves it intentionally vague, so it can accommodate various use cases (Hodgins and Duval, 2002). In our implementation, these classes include instances appropriate for the context of a higher education institution. The class *lom:Context* for example includes some instances partitioning the education level of the resource, in university years of study. However, our approach makes it possible to fill this property with other, linked-data values that are maintained and mapped independently by a name authority, and this is outlined in the section 'SKOS and linked data'.

Potential relationships among LOs can be captured via the object property *lom:relation*, which is used exactly to correlate between instances of the *lom:LearningObject* class. In addition, we use the *dcterms: Agent* class to include any person or organization responsible for the creation (or other modifications) to an educational resource. The object property *lom:contributor* comes to implement this type of relation.

Finally, it is important to note that the *lom:keyword* property, used in our LO profile in order to express the thematic subject of the LO's content, is represented as an object- rather than a datatype-property. Our intention is to directly correlate the subject keywords of an LO to SKOS concepts, thus increasing the value of our LO ontology when used in the context of knowledge discovery applications. A summary of the classes and properties declared in the LO ontology, are described in Table 1.

Our LO ontology can form the basis for building more specific ontologies, targeting the description of LOs that serve the educational purposes of various knowledge domains, university courses, etc. Publishing these ontologies on the Web, using a LOOR, can significantly increase LOs management and discoverability across digital repositories. What is more, with their unique and directly accessible identifier – assigned through the *lom:identifier* datatype property – LO exposure to other discovery mechanisms, digital repositories and the Web of Linked and Open Data (LOD) (Heath and Bizer, 2011) becomes feasible.

Thematic descriptions using SKOS

SKOS is a model for expressing knowledge organization systems (KOS) (Hodge, 2000), including

Table 1. Classes and Properties of the learning object ontology.

Class	Usage
lom:LearningObject	*The notion of a LO*
lom:LearningResourceType	*Different educational types (Lecture, Exercise, etc.)*
lom:Difficulty	*Levels of difficulty*
lom:IntendedEndUserRole	*Groups of end-users to which a LO applies*
lom:InteractivityType	*Types of interaction (mixed, expositive, etc.)*
lom:TypicalLearningTime	*Average learning time*
lom:Context	*Expresses intended instructional context*
Object Property	**Usage**
lom:learningResourceType	*Filled by lom:LearningResourceType*
lom:intendedEndUserRole	*Filled by lom:IntendedEndUserRole*
lom:context	*Filled by lom:Context*
lom:difficulty	*Filled by lom:Difficulty*
lom:typicalLearningTime	*Filled by lom:TypicalLearningTime*
lom:status	*Expresses the level of completeness (draft, final, etc.)*
lom:interactivityType	*Filled by lom:InteractivityType*
lom:relation	*Correlates LOs*
lom:contributor	*Connects a LO to its contributor(s)*
lom:keyword	*Correlates a LO with SKOS concepts*
lom:format	*The LO's file format*
Datatype Property	**Usage**
lom:description	*Short description*
lom:identifier	*Unique identifier*
lom:language	*Content's language*
lom:rights	*Copyright policies*
lom:size	*Physical size*
lom:title	*Title*

thesauri, in machine-readable format. It provides a uniform representation of a set of terms and hence a common mechanism for the thematic indexing and retrieval of information. With the aid of SKOS, we can easily perform an integrated search against systems that are based upon controlled and structured vocabularies, such as institutional repositories and digital libraries. Additionally, as an RDF application, SKOS allows editing, publishing and interconnection of concepts on the Web, as well as their integration into other concept schemes. The terminology of SKOS has been formally expressed into RDF/OWL. An example of the SKOS structure is shown in Figure 3.

The SKOS vocabulary

Given that SKOS is designed exactly to describe concept schemes, *concept* is its basic structural element. A SKOS concept can be viewed as a unit of knowledge, i.e. an idea or notion, an object or a class of objects and events that govern many knowledge organization systems. Therefore, *concepts* are abstract entities, which are independent of their names (i.e. the labels) used to characterize them. SKOS introduces the class *skos:Concept* to indicate that a particular term is a concept. The individuals of the *skos:Concept* class can belong to a specific concept scheme. A concept scheme is expressed through the *skos:ConceptScheme* class.

The concepts/terms of a thesaurus, when expressed in SKOS format, are identified by URIs and assigned string labels in one or more languages. In addition, they are documented with various types of notes and interconnected with semantic relations through informal hierarchies.

To express these characteristics, the SKOS model uses a set of properties, firstly in order to define a concept itself and secondly to relate it with other counterparts in a concept scheme. Table 2 summarizes available SKOS properties, organized into categories according to their purpose, and gives a brief description of their usage.

Two thematic terminological thesauri

To take advantage of the potential of our LO ontology, when building ontologies that capture and describe LOs, we needed a thematic thesaurus in order to directly map an LO's subject (via the *keyword* property) with SKOS concepts. These concepts would be best to originate from a standard, authoritative and controlled vocabulary rather than being arbitrary literals.

To this end, we proceeded with the creation of two thesauri – initially not in SKOS format – that cover two very common fields of knowledge: *maths* and *medicine*. These thesauri were actually extracted from the *Thesaurus of Greek Terms*, a bilingual (Greek, English) controlled vocabulary published by the National Documentation Center in Greece[1] (EKT). The latter covers a very broad field of knowledge and was created in order to facilitate libraries, museums, information centres and other institutions in Greece in characterizing and managing their digital material.

The *Maths Thesaurus* is comprised of 76 terms, making reference to 17 other related terms, whereas the *Medicine Thesaurus* contains 54 terms and makes reference to 71 additional terms. Although both of these thesauri cover specific fields of knowledge, they are generic enough and thus sufficient for the

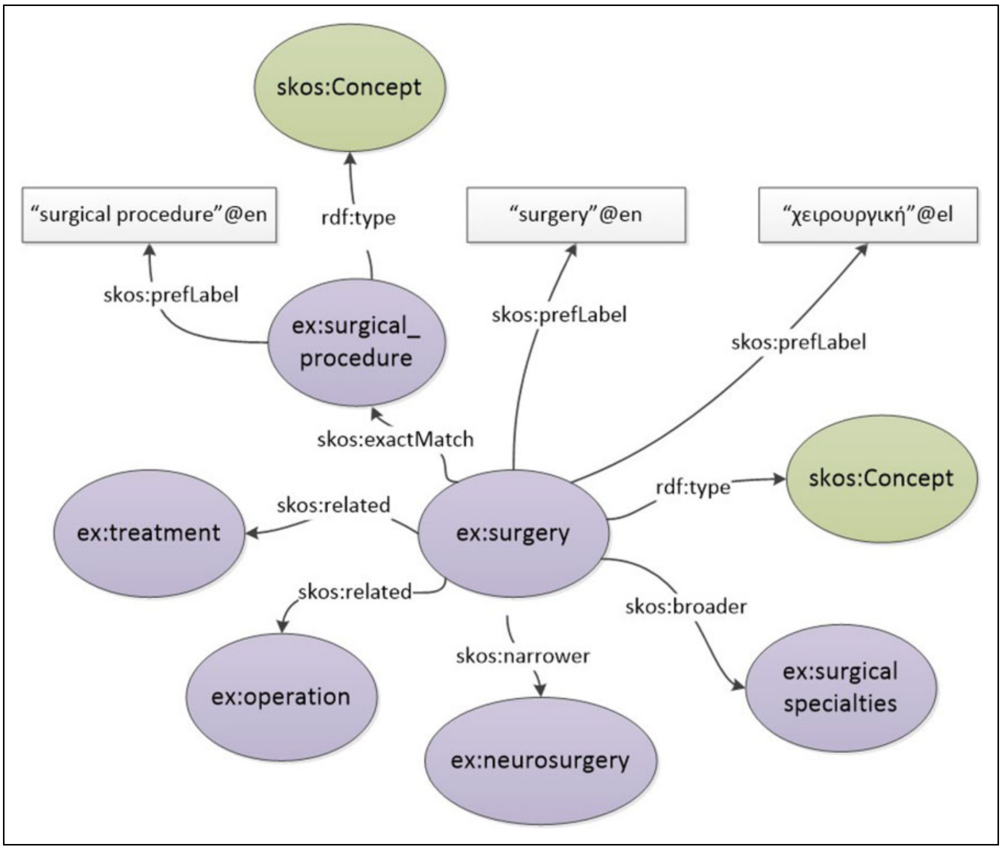

Figure 3. Example of the structure of a SKOS concept from the *Medicine Thesaurus*.

characterization of the most common subjects met in these thematic areas.

After extracting these two thesauri, our goal was to take care of their transformation into SKOS, so as to render them exploitable across different digital repositories and semantic applications. Besides, the migration of all type of knowledge organization systems into SKOS has long been recognized as a need, especially by those organizations that deal with controlled vocabularies. Some prominent examples are the Library of Congress Subject Headings (LCSH) (Summers et al., 2008) the Getty Arts and Architecture Thesaurus[2] (AAT) and the Food and Agriculture Organization Thesaurus[3] (AGROVOC).

In their initial format, both the *Maths Thesaurus* and the *Medicine Thesaurus* are expressed in XML syntax and follow the structure of any usual subject thesaurus, as defined by ISO 2788 (ISO, 1986): they make use of hierarchical (<BT>, <NT>, <MT>), associative (<RT>) and equivalence (<UF>) relations. In addition, for each term in Greek, its English translation is provided (<ET>), as well as its correspondence to the Dewey Decimal Classification system (<dewey>).

To achieve the SKOS transformation, we implemented a mapping of the XML elements to SKOS notions, as shown in Table 3. As a result, we took the SKOS version of these two thesauri, which is in alignment with what SKOS specification defines. A snippet of a SKOS concept belonging to the resulting SKOS version of the Medicine Thesaurus can be seen in Figure 4.

Deployment of a learning object ontology repository on WebProtégé

The basic services of our LOOR, that is to manage and render accessible our LO metadata schema and ontologies, as well as any thesaurus generated explicitly to be used in combination with them, are offered by WebProtégé.

WebProtégé is a lightweight, web-based platform for ontology editing that comes with useful collaborative features and has been extended to allow for the publishing of its maintained ontologies. It allows users to create, upload, share and collaboratively edit ontologies expressed in OWL. In its current version, it is underpinned by the OWL API (Horridge and Bechhofer, 2009), provides full support for OWL 2 ontologies and comes with a simplified user interface, suitable for users with different levels of ontology expertise (Figure 5).

Two major features of WebProtégé that render it suitable as a basis for deploying a LOOR are the following:

Table 2. The SKOS core vocabulary.

SKOS Term	Description
skos:Concept	*An abstract idea or notion; a unit of thought*
Concept Schemes	
skos:ConceptScheme	*A concept scheme in which the concept is included*
skos:inScheme	*Relates a resource to a concept scheme in which it is included*
skos:hasTopConcept	*A top level concept in the concept scheme*
skos:topConceptOf	*Is top concept in scheme*
Lexical Labels	
skos:prefLabel	*The preferred lexical label for a resource, in a given language*
skos:hiddenLabel	*A lexical label for a resource that should be hidden when generating visual displays of the resource.*
skos:altLabel	*An alternative lexical label for a resource*
Semantic Relations	
skos:broader	*A concept that is more general in meaning*
skos:narrower	*A concept that is more specific in meaning*
skos:broaderTransitive	*Has broader transitive*
skos:narrowerTransitive	*Has narrower transitive*
skos:related	*A concept with which there is an associative semantic relationship*
skos:semanticRelation	*A concept related by meaning*
Mapping Properties *(to other concept schemes)*	
skos:exactMatch	*Has exact match*
skos:closeMatch	*Has close match*
skos:broadMatch	*Has broader match*
skos:narrowMatch	*Has narrower match*
skos:relatedMatch	*Has related match*
skos:mappingRelation	*Is in mapping relation with*
Notations	
skos:notation	*A string used to uniquely identify a concept within the scope of a given concept scheme*
Documentation Properties	
skos:changeNote	*A note about a modification to a concept*
skos:definition	*A statement or formal explanation of the meaning of a concept*
skos:editorialNote	*A note for an editor, translator or maintainer of the vocabulary*
skos:example	*An example of the use of a concept*
skos:historyNote	*A note about the past state/use/meaning of a concept*
skos:note	*A general note*
skos:scopeNote	*A note that helps to clarify the meaning and/or the use of a concept*
Concept Collections	
skos:Collection	*A meaningful collection of concepts*
skos:OrderedCollection	*An ordered collection of concepts, where both the grouping and the ordering are meaningful*
skos:member	*A member of a collection*
skos:memberList	*An RDF list containing the members of an ordered collection*

- *Configurable user interface*: The WebProtégé user interface is built as a portal, composed of tabs and portlets that provide independent pieces of functionality. Users can personalize UI layout, removing tabs or portlets that are not useful in their projects or adding new ones. Overall, the user interface can be configured to reflect users' OWL expertise and satisfy their projects' specific requirements;

Table 3. Mapping to SKOS elements.

XML element	Function	SKOS notion
<TERM>	*The described term*	<skos:Concept>
<USER>	*Thesaurus' owner*	-
<CONTEXT>	*Term's label*	<skos:prefLabel lang="el">
<MT>	*Microthesauri term*	<skos:broaderTransitive>
<ET>	*English translation*	<skos:prefLabel lang="en">
<ET>	*Alternative English translation*	<skos:altLabel lang="en">
<BT>	*Broader term*	<skos:broader>
<NT>	*Narrower term*	<skos:narrower>
<RT>	*Related term*	<skos:related>
<UF>	*Opposite of the Used Instead (USE) term*	<skos:altLabel lang="el">
<SN>	*A short description*	<skos:definition>
<DEWEY>	*A number indicating the correspondence to Dewey system*	<skos:notation>

```
<skos:Concept rdf:about="http://ekt.example.org/vocab/pediatrics">
  <skos:prefLabel xml:lang="en">pediatrics</skos:prefLabel>
  <skos:prefLabel xml:lang="el">παιδιατρική</skos:prefLabel>
  <skos:inScheme rdf:resource="http://duth.example.org/vocab"/>
  <skos:broaderTransitive rdf:resource="http://ekt.example.org/vocab/
  medical_sciences"/>
  <skos:broader rdf:resource="http://ekt.example.org/vocab/medicine"/>
  <skos:related rdf:resource="http://ekt.example.org/vocab/child_psychiatry"/>
  <skos:related rdf:resource="http://ekt.example.org/vocab/children"/>
  <skos:notation rdf:datatype="http://dewey.info/schema-terms/Notation">
  618.92</skos:Notation>
</skos:Concept>
```

Figure 4. SKOS representation of concept 'pediatrics'.

- *Collaboration and access control*: WebProtégé allows users to track changes and choose to watch entities or even whole hierarchies of entities (branches), with the possibility of receiving email notifications on them. They can also have contextualized threaded discussions and notes attached to selected entities in the ontology. In addition, through an extensible access policy mechanism, users can define who may view or edit an ontology. Finally, it is possible to generate statistics of the ontology-development process.

To increase its user friendliness and aid LO ontology and thesauri maintenance and accessibility by other institutions, a couple of additional, repository-specific features have been implemented and deployed on top of the WebProtégé platform. These features include:

1. Facilitate direct access to the maintained ontologies, by exposing the ontology's download link in an extra column that has been added in the project view list of the WebProtégé home page (Fig. 6). This link offers an explicit view of the ID that WebProtégé assigns to its projects. Additionally, it gives direct access to the corresponding WebProtégé project (ontology) and it is appropriate for use with OWL *imports* declarations.
2. The ability to change the default namespace for created projects has been added. In WebProtégé this namespace is by default set to http://webprotege.standford.edu/, a value that is not always desirable by project administrators. The new, implemented feature has been incorporated as an additional property option to the WebProtégé configuration file and allows system administrators to customize a priori their projects' IRI prefix, based on their institutions' needs.
3. Similarly, another property, specifying the desired IRI suffix for each newly created entity, has been added to the same file. By setting this property, administrators can bypass a system's default configuration, which is determined to use a randomly produced Universally Unique Identifier (UUID) (Leach et al., 2005) for this purpose. Now, as an alternative, they can predefine to use the entity's label (name) instead.
4. Since WebProtégé UI is easily customizable, we have provided a stripped-down, but fully operational configuration of WebProtégé front-end to facilitate non-expert users. We also performed some additional enhancements and fixes, such as localization support, to further enhance user's interaction with the LOOR and make it more convenient for editing and publishing LO ontologies and SKOS thesauri.

Although WebProtégé bears features that significantly simplify its usage, it is a tool – and not a human expert – that cannot vouch for the semantic and structural correctness of the ontologies under development. Although such kinds of mistakes can be

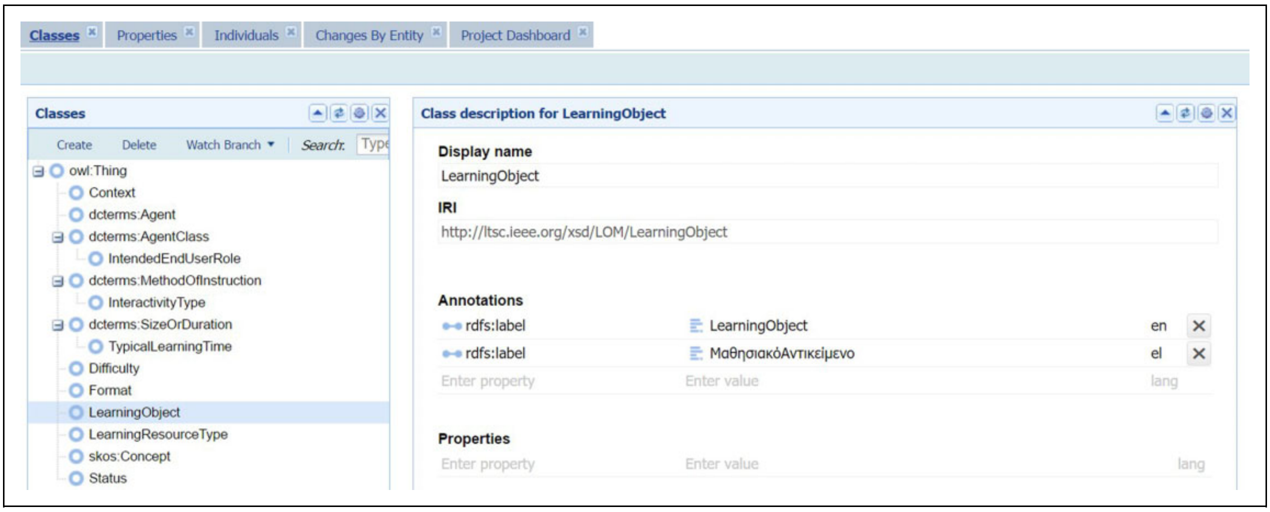

Figure 5. The WebProtégé front-end (ontology view).

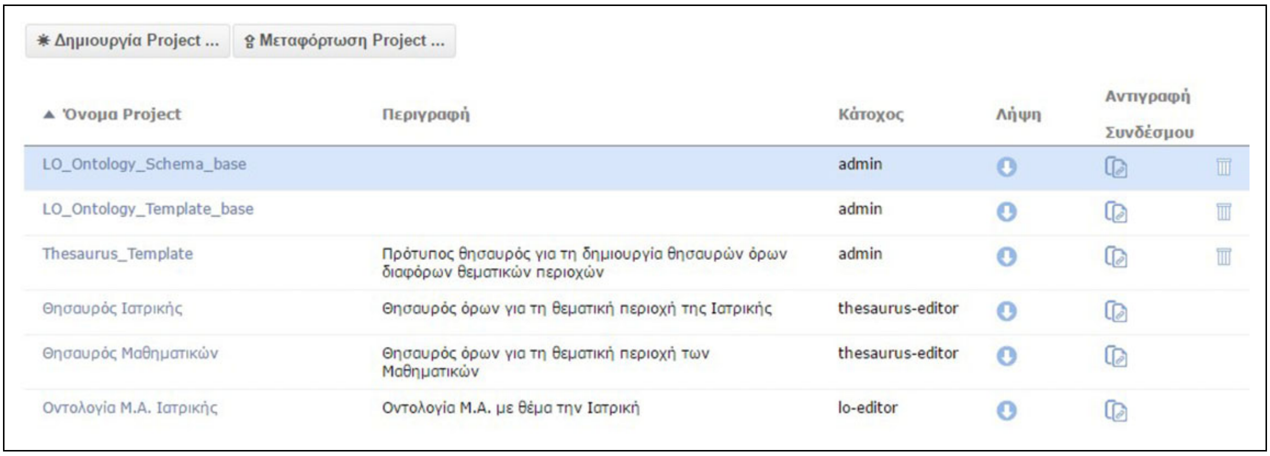

Figure 6. The WebProtégé extended home page (project view).

eliminated using WebProtégé collaborative features, the final result is always up to the ontology expert's familiarity with OWL.

To address this concern, we provide WebProtégé users with 'empty' templates, meant to be used as the basis for the creation of thesauri and LO ontologies. In this way an ontology expert, instead of creating a project from scratch, is encouraged to start by uploading the appropriate template. In particular, we implement a *thesaurus* template that imports the SKOS vocabulary and is used for the deployment of thematic thesauri, and a *LO Ontology* template that imports the LO ontology schema and leads to the creation of LO ontologies. The advantage of this approach is that users start building their projects having already at their disposal all necessary SKOS- or LO-specific *classes* and *properties*. As a result, they can eliminate common mistakes when building semantic correlations among entities. In addition, the process of editing an ontology becomes easier, given that allowable fillers for each class are known a priori and become available through an autocomplete feature (see 'Adding learning objectives'). The suggested procedure workflows for deploying thesauri or LO specific projects in the LOOR are depicted in Figure 7.

On-line course enrichment and reuse of LOs

Course organization and material dissemination in universities is often supported by synchronous and/or asynchronous learning management systems, such as the eClass LMS (GUnet, n.d.). Having access to the LOOR, instructors can use its LOs to further enrich their courses with extracurricular material, by adding them at the *external links* section of the course web page. Through an appropriate search mechanism (Kalou et al., 2015), the course manager can discover LOs at various external repositories, by performing keyword searches. To increase recall, these keywords are automatically expanded based

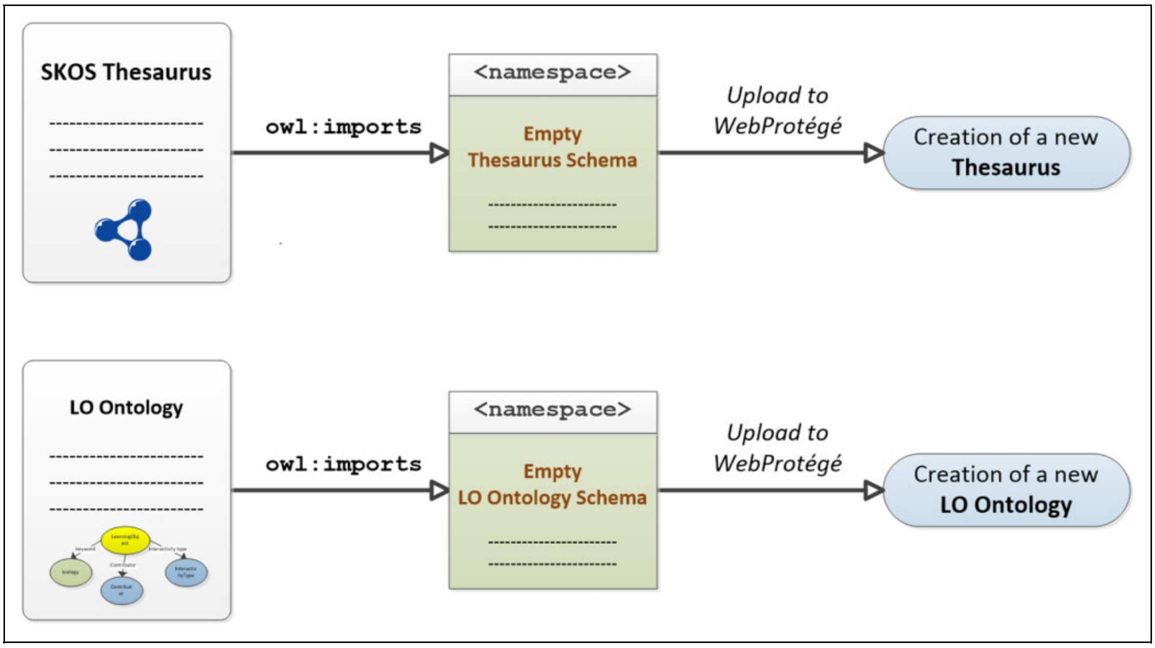

Figure 7. Suggested procedure workflow for building a new thesaurus or a LO ontology in the LOOR.

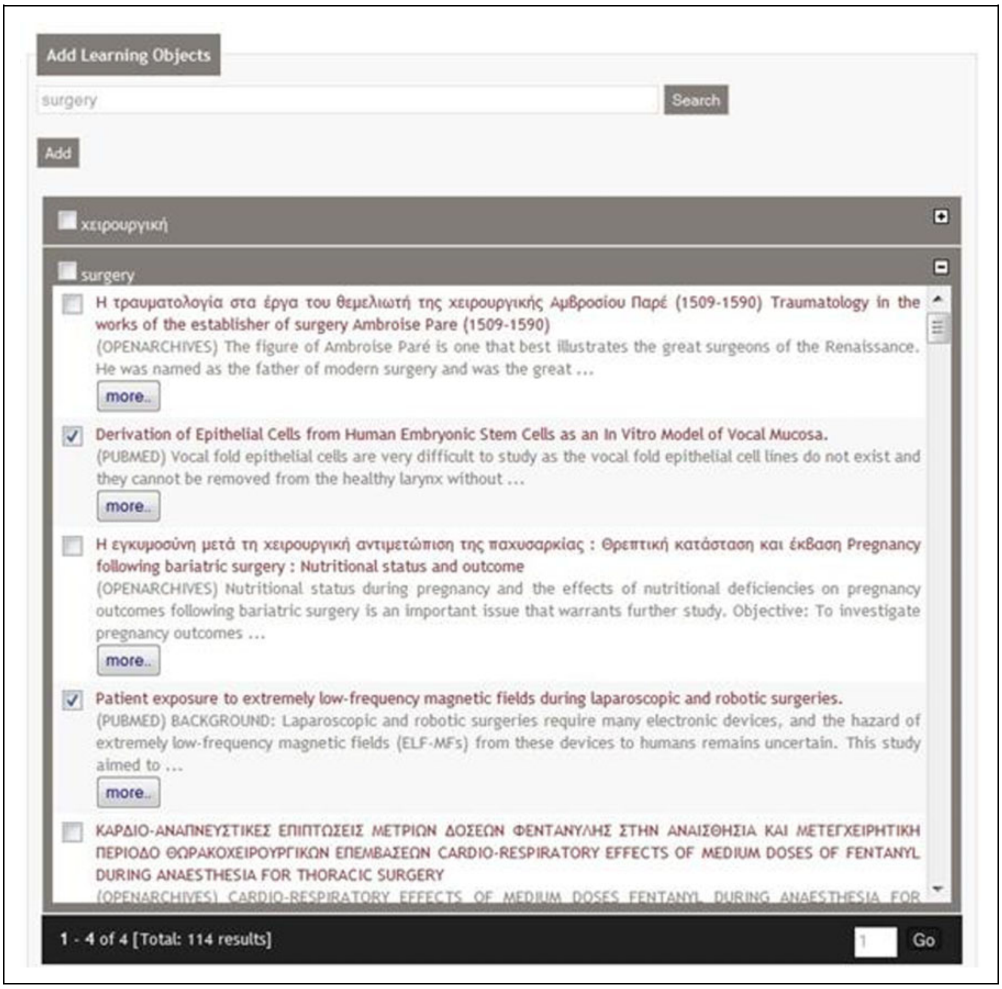

Figure 8. Search mechanism and results for LOs, implemented within the eClass LMS.
Notice the expansion on the translation of the thesaurus term ‘surgery’.

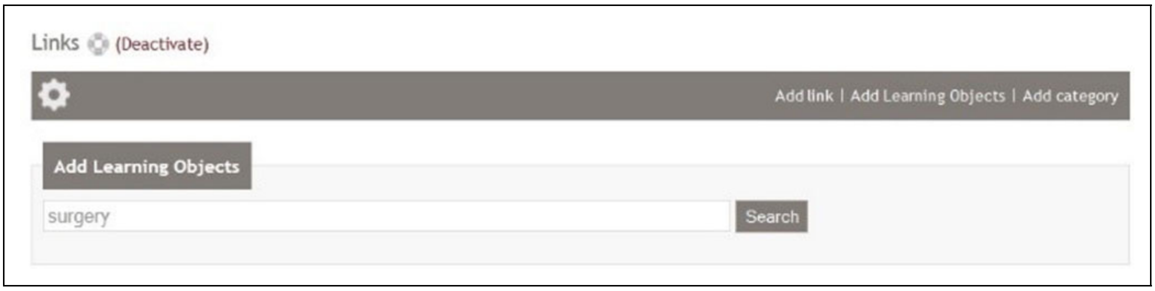

Figure 9. Search initiation for adding LOs in the LMS.

Figure 10. Available links to external LOs for a course.

on the terminological thesauri implemented; for example, to also include translations and narrower terms (Figure 8). Expanded queries are then addressed towards several LORs, including MERLOT (McMartin, 2006), PubMed (Europe PMC, 2015), ARIADNE (Duval et al., 2001) and our own LOOR, in a federated manner.

Conversely, learning material deemed interesting enough by an instructor to be included in their course's external links list at the hosting LMS, can be contributed back to the LOOR. A selected LO can also get its semantic subject annotation (*skos:Concept*) either manually or automatically, using the nearest matches of the search keyword within the thesaurus. This can even include multilingual terms, depending on the thesauri used.

Thus, the repository can act as a local-to-the-institution, cached pool of LOs each referencing its original source and be ready for retrieval (*lom:identifier* property). In addition, resources included in the repository are already semantically indexed by other experts. This facilitates the job of another instructor to easily and quickly discover additional material. It also has the added benefit of collaborative intelligence, by exposing material already trusted by colleagues.

LMS interoperability and instructor interaction

After successful authorization with eClass, the logged instructor can select the *Link* module from the navigation menu of their course and then the newly added *Add Learning Objects* option. A search form appears with a unique field that has a predefined set of keywords (see Figure 9). These keywords, separated by a comma, include the keywords that the instructor has already registered for his own course with the LMS. However, the instructor is free to set a different set of keywords each time.

Next, the query is expanded to also include narrower terms of the original keywords and their translations and sent to the remote repositories (Kalou et al., 2015). Once the application completes the loading process, the web interface presents a table of learning object metadata grouped into categories (Figure 8). These categories are in fact the labels of the matching and refining concepts found during the expansion process or the original keywords themselves, if no matches exist. The labels and their translations/alternatives are by default included in the response. Based on them, search results are ordered so that translating and alternate labels appear first and then move on to the next matching label.

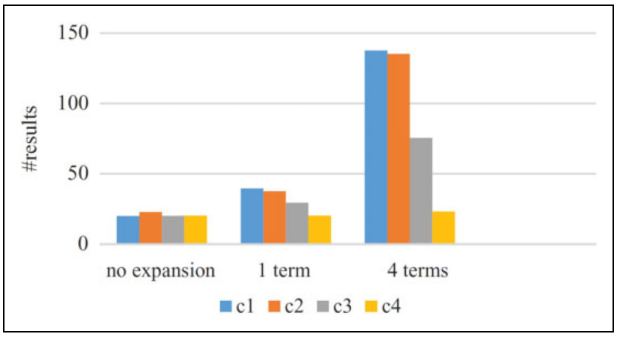

Figure 11. Search recall improvement when expanding queries over the LOOR.

For each learning object, the URL (*lom:identifier*), the title and the description are available to the end-user. For clarity reasons, there is a pagination capability of the results' categories. Besides, the categories are shown by default collapsed and the entire list of results is not presented at once.

Instructors can traverse through the results pages using the navigation buttons and select what to store by clicking the checkbox near the result's title. In case they desire to select all the results for a category, they can do it at once by clicking the checkbox near the category title. The full list view of results for a particular category/keyword can be toggled by clicking on the plus/minus button or on the category title, which expands or collapses category results, respectively. Added LOs are then available for students' reference in the '*external links*' section (Figure 10).

Evaluation

This process, when applied to searching over various LORs, including our LOOR ontologies, can yield improved results in terms of recall. For the purposes of evaluation, a group of instructors was asked to initiate several queries through the LMS, by selecting key phrases falling within each of four sets, based on their relative position within the *Medicine Thesaurus*: Set *c1* contains terms matching concepts at the top of the thesaurus hierarchy that would naturally have a lot of refinements; set *c2* contains terms matching concepts near the middle; set *c3* contains terms-leaves, i.e. they have no refinements, but have alternate labels and translations; set *c4* contains keywords irrelevant to the thesaurus used, i.e. they have no matches whatsoever.

Each instructor submitted 10 queries from each set. Figure 11 summarizes the number of LOs returned, when allowing no (zero) and up to 4 expanded queries/terms. We notice an average increase in recall by a factor of 3.5 which grows larger when moving towards *c1*. This is expected, since *c1* contains upper-level terms that have greater chance of expanding. Note also that these metrics assume an equal distribution of the four possible events for keyword matches in a thesaurus. However, the 'no-match' scenario (*c4*) is highly unlikely in practice, because the thesaurus has been developed using expert knowledge; at the same time keywords to the university courses are also assigned by experts – the course instructors themselves. As a result, a set of keywords for a given course will probably be within *c1-3* rather than in *c4*, thus containing at least one thesaurus match.

These results show that, when combined with a course management system, the LOOR can contribute towards increased results fetching by a considerable factor. This is possible owing to the bidirectional use of SKOS ontologies within the LOOR: first to characterize and annotate learning objects within premises and, on the other hand, to unfold query terms, addressed to external sources, based on their semantic relations in the thesauri.

Use cases and examples

In this section, we present a series of use cases and corresponding examples for the LOOR and the LO ontology. For demonstration purposes we use a sample ontology of learning objects about medicine that makes use of the thesaurus of medical terms SKOS representation. The resulting ontology has been published through the LOOR.

Adding learning objects

A basic requirement for the LOOR and therefore, a major use case, is the ability to create and add learning objects. Adding an LO to the LOOR is as simple as creating a new instance at WebProtégé. Each new instance can have a set of properties filled, which correspond exactly and actually come from the LO ontology (Table 1). The range of several properties, such as *difficulty* or *status* is specified by certain classes (first name capitalized), in an effort to bound the value space of these properties and make it easier for curators to annotate new instances correctly. In our implementation, these classes include instances appropriate for the context of a higher education institution (Figure 2).

A typical instance of the sample medicine ontology is shown in Figure 12. The following properties can be filled: *title* – the title of the LO, indicative of its content; *contributor* – person or agent that contributed to the creation of the LO (e.g. author); *description* – a short description of the LO's content; *identifier* – a unique identifier characterizing the LO. Typically, this is a URL pointing at the actual location of the specific LO resource (a pdf for example), which can even be another repository; *language* – the language

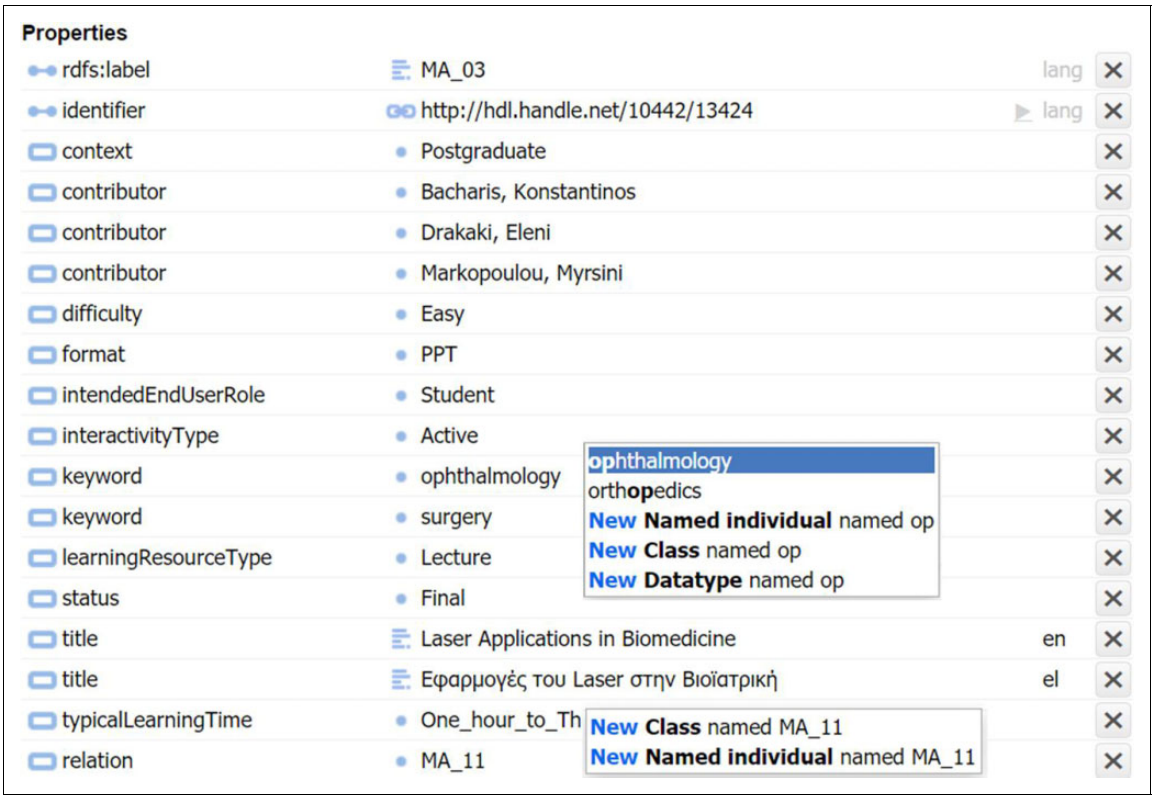

Figure 12. Properties and values when adding an LO, with autocomplete tooltips and dynamic entity creation.

which the LO is expressed in; *keyword* – one or more representative keywords specifying the content of the LO. This property is filled with values/instances of the class *skos:Concept*; *context* – the level of study to which the LO applies; *intendedEndUserRole* – group of individuals to which the LO applies; *learningResourceType* – expresses the learning type of the LO; *format* – the file format of the LO. Indicative values include *PDF, DOC, TXT, PPT* etc.; *difficulty* – indicates the learning difficulty level for the LO; *typicalLearningTime* – the learning duration necessary for interacting with the LO; *interactivityType* – the level of interaction with the LO; *status* – the current state of the LO, regarding its completion; and *relation* – relates the current LO with other LOs of the *LearningObject* class. Such a relation can be with a LO already present in the ontology or a LO that can be dynamically added on-the-fly, by choosing *New named individual* when typing its name.

SKOS and Linked Data

It is important to note that the keyword field of every LO has been filled using SKOS concepts coming from our *Medicine Thesaurus*. Because the LO ontology is linked to the SKOS thesaurus, the medical terms are available for auto-completion when filling in the *keyword* property. Hence, for every LO instance captured in the ontology, the corresponding object property *keyword* has been assigned to an existing *skos:Concept* individual. This alternative for expressing a LO's subject – instead of using a mere text keyword – can lead to improved interoperability and advanced retrieval capabilities. For example, resources with content characterized by related, narrower or broader in meaning concepts (and captured through the corresponding SKOS properties) can also be retrieved (see, for example, the section 'Exporting to a SPARQL endpoint'). In addition, concept descriptions themselves can be accessed as Linked Data. Each thesaurus term in the LOOR is linked to its source structured data in the parent institution, where one can navigate the term hierarchy and explore further relations (Figure 13).

Another aspect of data linking is the ability to link directly to the original resource representation in its initial container. This can include a machine- or human-readable form of the LO's metadata, possibly along with the resource itself, provided it exists in digital form. Through its *lom:identifier* property, the LO instance acquires a resolvable, unique identifier that provides direct access to the actual resource's location. In fact, this IRI is treated as a URL by the application and a clickable arrow appears next to it, resolving to the item in its original context (Figure 13).

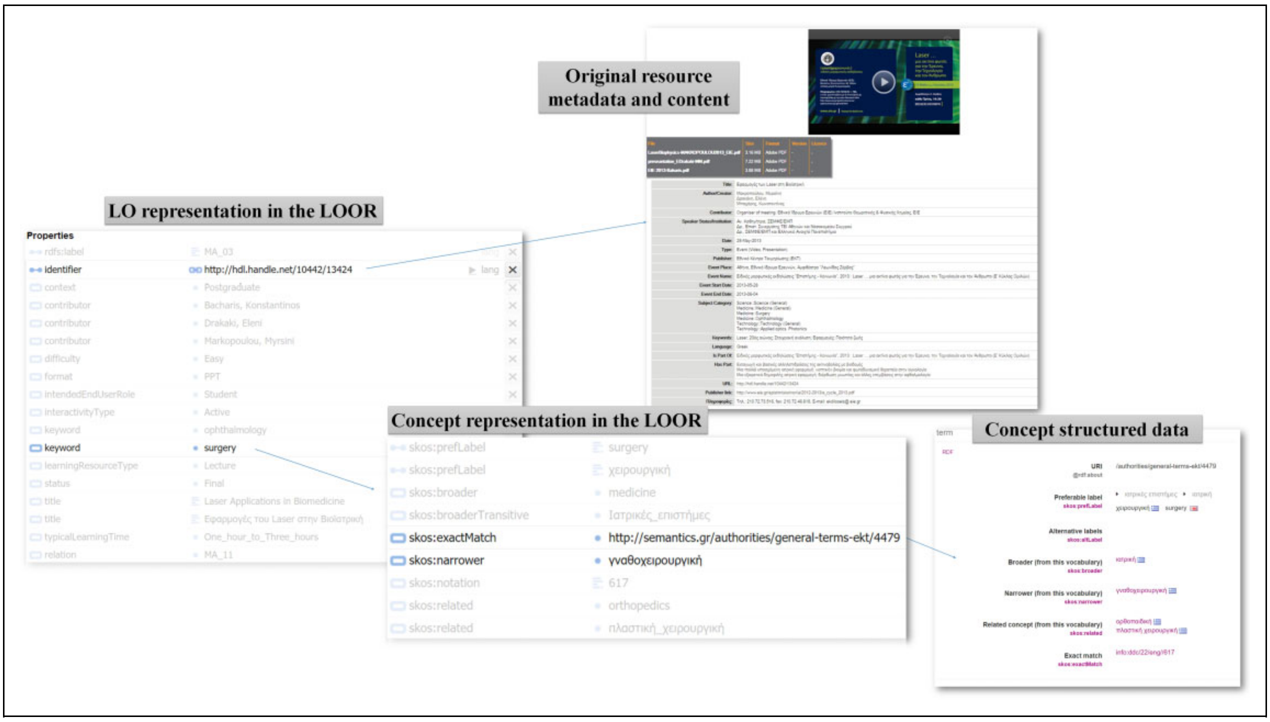

Figure 13. Linking LOs from the LOOR to external repositories and SKOS concept data.

Exporting to a SPARQL endpoint

The established LOOR presented above exposes a full-text search feature on the contents of the ontologies, based on the underlying facilities of WebProtégé. However, when dealing with ontology data and for the sake of interoperability with other datasets and services it might be desirable to provide a more powerful and structured search mechanism, one that can also be accessed by other applications. Given that the LOOR's ontologies can be published and shared through the direct access mechanism, it is then easy to route access to these ontologies through a SPARQL server and endpoint, such as one of the various available RDF triple stores (Curé and Blin, 2014). Jena's Fuseki[4] for example, is a framework and server to provide triple store services for RDF/OWL datasets and supports the SPARQL 1.1 protocol for query (Harris and Seaborne, 2013) and update (Gearon et al., 2013).

In the following example we perform a SPARQL query on the sample ontology about medical learning objects that have been classified under or relate to the *skos:Concept surgery* (also shown in Figure 3). Notice that we can take advantage of the SKOS model to discover not only direct matches to the query, but also *skos:related*, *skos:broader* or *skos:narrower* terms. Having loaded the ontology into Fuseki, the query can be performed either through the HTTP SPARQL endpoint or directly using Fuseki's query UI (Figure 14). In the former case, this SPARQL facility can also operate as an entry point for other applications to explore Linked Data within and outside the LOOR, including the LOs original pages or additional information on the SKOS terms and their further relations within the thesaurus.

Conclusions and future work

Semantification of LO metadata can help towards having machine understandable descriptions of learning objects as well as facilitating cross-platform semantic interoperability. Starting from a LOM-based metadata profile, we have shown how to create a LO ontology and how this can be populated to yield semantically-enhanced descriptions of learning resources for various domains.

This ontology is further enhanced by the fact that it is possible to integrate with other ontologies, namely ones providing organization of thematic terminologies or thesauri. To foster the potential of such an approach, thesauri are expressed in SKOS format. The transformation of thesauri into SKOS is adopted by many institutions worldwide, recognizing the need to increase LOs discoverability among heterogeneous educational repositories and dissemination of knowledge.

We have proposed and demonstrated the use of a LOOR as an environment suitable for the whole learning ontology lifecycle, from design to publishing, maintenance, administration and reuse. Our

Figure 14. SPARQL query about learning objects pertaining to the SKOS concept 'surgery'. Query returns more than the single direct match.

implemented additions on top of the underlying system only make it more useful and convenient for this purpose.

The system has been recently deployed and delivered to the Library and Information Centre of the University of Thrace. Currently there is content evolving for the disciplines of mathematics and medicine. The university offers more than 1500 courses, most of which are supported by eClass. The integration with eClass, that has been implemented and presented in the section 'On-line course enrichment and reuse of LOs' means that it is possible to scale and extend this approach to cover additional domains that pertain to or include various other courses and disciplines as well. The systematic creation and development of learning object ontologies of variable granularity (e.g. thematic-, course- oriented or other) following the LO ontology and using the LOOR can provide educational institutions with a simple yet powerful tool for exposing their LO collections publicly. Indeed, a university or library can, for example, utilize the infrastructure presented in this paper in order to establish its own LOOR. In addition, it can be used as an entry point into the Web of Linked and Open Data (LOD), given the integration capabilities of the schema with SKOS or other external ontologies and datasets, while at the same time maintaining the original context and provisioning information of learning material. Based on these premises, libraries and information services can act as quality guarantors of learning content and increase the validity of OERs.

The results of the evaluation confirm that the LOOR is capable of discovering additional learning objects and reveal the potential of this approach. In particular, we have shown that a LOOR: (1) makes it possible to retrieve additional LOs and achieve a corresponding increase in recall, while maintaining precision, (2) can enable federated searches and harvest material from various online repositories and (3) can benefit from the use of expert knowledge in the form of SKOS vocabularies maintained by curators and librarians in order to improve content annotation as well as querying.

However, as future work, it would also be useful to conduct a qualitative evaluation of the system and survey instructors' and students' perceptions of the system services and added-value. Then, semantic aware applications can be developed, that consume ontologies available through this infrastructure in various ways. For example, the thesauri we developed and maintain can seed a query expansion mechanism that searches and harvests external LORs, based on semantic matching and/or reasoning. Results from these queries can be integrated back into the LO ontologies or served to a LMS, such as e-Class, so as to widen the scope of extracurricular learning material available to students.

In addition to the workflows for thesauri and ontology deployment, additional workflows should have to be designed and tested; for example, structured processes to search for, select, and curate OERs and library resources. These processes should allow for review, evolvement and enrichment of the LOOR with additional content, and the data flows between external services and the LOOR, thus contributing to the specifications for the new and evolving role of libraries.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Notes

1. http://www.ekt.gr/en/
2. http://www.getty.edu/research/tools/vocabularies/aat
3. http://aims.fao.org/vest-registry/vocabularies/agrovoc-multilingual-agricultural-thesaurus
4. https://jena.apache.org/documentation/serving_data/

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Georgia D. Solomou holds a Master's degree in Computer Science from the University of Patras on distributed querying of semi-structured data and is a PhD candidate in the same department. She has served as a lab lecturer in the Technological Educational Institution of Patras, teaching informatics 101 and as a teaching assistant at the Computer Engineering and Informatics Department, University of Patras. She has been a member of the High Performance Information Systems Laboratory (HPCLab) since 2005 and has taken part in many European- and national-funded projects, focusing on solving semantic alignment, multilingualism and interoperability issues in digital collections and linked open data. Since 2011, Georgia is working as Senior Software Engineer in the public and private sector. Georgia's research interests are related to semantic interoperability, Semantic Web knowledge discovery, modelling of educational resources using ontologies and e-learning applications, where she has published over 20 indexed articles. Lately, she has been dealing with data analytics in Content Delivery Networks, aiming at the efficient management of big data.