A Framework for Ontology Instructional Design and Planning

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Abstract

Although several standards have come out to define a common convention for learning object metadata definition and representation, knowledge and components embedded in most existing e-learning systems are far from being sharable and reusable. This is mainly due to the lack of a general framework for standard-based, ontology-aware courseware design and development. In this paper, we propose a new approach for developing ontology compliant learning objects. A set of ontology-based rules is applied for building ontology-aware learning material. The proposed e-learning environment is based on IEEE-LTSC LOM (Learning Object Metadata) standard. In this paper, the LOM is extended with ontology related metadata that provides common vocabulary for domain knowledge representation and conceptual information about embedded content. Thus, the use of ontology provides a great potential for exchanging learning material, facilitating collaborative learning, and efficiently retrieving context-based information from learning object repositories available on the web.

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1. Introduction

The production of e-learning material is an expensive and tedious task. Many standards such as SCORM (ADL Sharable Content Object Reference Model, 2004), LOM (IEEE-LTSC Learning Object Metadata, 2004), and Dublin Core Metadata Initiative (DCMI, 2003), have come out to define a common convention for learning object metadata definition and representation. The aim is to allow reuse, interoperability, and sharability of learning material in order to facilitate instructional authoring activities (Theorix, 2003). Metadata's mission however has been limited to inform learning management systems about format, ownership details, rights of use, underlying OS, and other technical features of Learning Objects (LOs). Less emphasis has been made on LOs' educational features. It is not yet well known how to use other metadata that describe educational features such as learning objectives, content sequence and pedagogical purpose. This is mainly due to the fact that this metadata represents subjective interpretations of resources. Therefore, they may support the existence of multiple, even conflicting descriptions (Saini, Ronchetti, 2003). This is also due to the fact that there is no common agreement on the domain content structure and the used vocabulary. Consequently, the problem stems from the lack of a general framework for standard-based, ontology-aware instructional design and planning in LOs construct. The use of ontology in e-learning provides a common vocabulary for domain knowledge representation and further supports interoperability of learning material. It also provides learners with powerful search tools that allow them to efficiently access desired learning resources. Moreover, instructors will be provided with powerful authoring tools for efficient reuse, update, and maintenance of ontology-aware instructional material. The proposed ontology in this paper contributes to reusability and sharability of learning objects through the provision of a semantic layer describing conceptual information about embedded knowledge. This process ensures both the inclusion of a shared conceptual agreement in the content and across the standard-based representation of the material. It also enables the organization of courseware structure, exchange of learning material, collaborative learning, and efficient context-based retrieval of information from learning object repositories available on the web (Darina, Dichev, Sun, Nao, 2004).

To achieve the above-mentioned benefits we propose a framework for standard-based, ontology-aware instructional design and planning. We present a new approach for developing ontology compliant learning objects, as well as a set of ontology-based rules to build ontology-aware learning material. The e-learning environment suggested in this study is based on the LOM (Learning Object Metadata) standard. This standard is empowered in the context of this paper with ontology related metadata that provides common vocabulary, conceptual information, and adjusts LO granularity to fulfill different learners' needs. The aim is to

facilitate learning object reuse in different learning contexts and to provide the e-learning community with standardized concept-based content to interchange semantic information on the Web.

The next section of this paper provides some background and related work. Section 3 motivates the need for standard-based ontology-aware e-learning systems. The proposed e-learning system architecture is then revealed in section 4, and finally, conclusions drawn from the work presented in this paper are discussed and future research directions are proposed.

2. Background and related work

Ontology is a conceptual information model that describes «the things that exist» in a domain (hence the name): concepts, relations, facts and rules, in a consensual and formal way. Ontology thus acts as a standardized reference model, providing a stable baseline for shared understanding of some domain that can be communicated between people and organizational application systems (Handschuh, Staab, 2003). Ontology provides both human-understandable and machine-processable semantic mechanisms needed to let enterprises and application systems collaborate in a smart way.

In the last decade a number of ontology-aware e-learning systems have been developed to provide support for both ontology development and ontology usage in specific domains. In the field of ontology development, few attempts were made to automate the process of constructing ontologies. Brewster et al. (Brewster, Ciravegna, Wilks, 2002) developed a semi-automatic user-centered approach for ontology construction based on the use of machine learning and natural language processing, while Apted and Kay (Apted, Kay, 2003) developed a fully automatic system to construct an extensive ontology of Computer Science field based on existing reliable resources. The latter includes tools for querying the ontology and visualizing the results.

Many other ontology-based systems and approaches were developed. Some research efforts were restricted to developing individual e-learning tools for specific domains, while others dealt with general frameworks for ontology-based e-learning. In the first category, Abraham and Yacef (Abraham, Yacef, 2003) developed an XML tutor based on an ontology described in terms of concept maps. Their ontology is used to represent and stereotype overlay students' models. In a similar way, Cimolino and Kay (Cimolino, Kay, 2003) introduced an approach to verify concept maps for eliciting learner's understanding of a domain. The developed tool allows students to construct a concept map, which is then checked against the instructor's map for validation or subsequent revision. However, a critical problem in using concept maps for student modeling is the verification of the maps before using them for reasoning about student knowledge (Dicheva, Aroyo,

2003). Guangzuo (2004) introduced OntoEdu, an educational architecture based on ontology, grid technology, and semantic webs. They have developed a web-service architecture that uses OWL (Ontology Web Language) to describe education-oriented ontologies, WSDL (Web Services Description Language) to describe services, and OWL-S (OWL-based Web Service Ontology) to publish the services. The authors claim that the developed system is flexible enough to dynamically add, and compose new e-learning services. Dicheva et al. (2004) and Denny (2002) however, developed a framework for ontology-aware digital libraries. They used the TM4L (Topic Maps for Learning) authoring tool for creating topic-maps based repositories of learning material. The system was developed to improve reusability and exchange of learning objects on the Web. In the same direction, Seta and Umano (2003) proposed an ontology-based framework for planning the problem-solving workflow in learning processes, where the domain independent problem-solving tasks are modeled separately from the domain-dependent components (knowledge and resources), thus allowing their instantiation to various domains. Meisel et al. (Meisel, Compatangelo, Horfurter, 2003) presented a framework for an intelligent tutoring system to support instructors in the design of a training session. They used ontology to capture instructional design knowledge along with a reasoning engine to provide the necessary inferences for the validation and verification of tasks and the retrieval of suitable teaching methods. In recent wok, Passier and Jeuring (2004) developed a system based on ontology to provide feedback to both learners and courseware developers. The system uses ontology to specify the knowledge to be learned (domain and task knowledge) and the way it should be learned (education). The ontology thus is used as arguments to the feedback engine.

This paper presents a new approach to using ontology for supporting standard-based, ontology-aware instructional design and planning. The proposed framework extends the meta-metadata layer of the LOM specification to include conceptual information about knowledge domain representation. A set of ontology-related rules is applied to guide courseware developers in organizing instructional material in terms of content, sequence, conceptual vocabulary, mandatory knowledge, prerequisite knowledge, and supporting knowledge.

3. Ontology-based e-learning design

Ontologies are one of the most important ingredients of the semantic web. Although it is agreed that the process of building a complete common ontology acceptable by a large community working in a specific domain is not a straightforward task, a generic expression of a domain-specific ontology is increasingly needed to develop a robust semantic web capable of filtering appropriate knowledge from the hugely unorganized worldwide web. In our approach, we use a class on a do-

main-related ontology. This class of the ontology is used to provide control over heterogeneous vocabulary which defines the domain knowledge (requirements and constituencies). Similarly to Santacruz-Valencia et al. (2005) work, we do not assume the existence of a large size canonical ontology. Instead, our approach accommodates multiple (and *vocabulary* heterogeneous) ontologies. However, to facilitate semantic interoperability, we assume the existence of mappings between these domain-related ontologies (Stuckenschmidt et al., 2003) and we consider our ontology class as a representative of these mapping relationships as suggested in Sinir (2004).

A number of research attempts were made to solve the complex problem of consistently representing knowledge on a global scale (Uschold, Gruninger, 1996; Fernandez Lopez, 1999; Firat et al., 2002; Biletskiy et al., 2004a; 2004b), and to improve the effective integration of heterogeneous learning objects. For instance, Biletskiy et al. (2004a) start from a set of basic ontologies of course descriptions with the goal of creating a common ontology to assist in achieving semantic interoperability between learning objects. The common ontology must explicitly specify the learning objects' basic ontologies, relationships between learning objects, and also relationships between concepts found within learning objects' metadata. The process of integrating the initial ontologies into a common ontology consists of linking semantically identical and equivalent objects found in these ontologies. The set of identical and semantically equivalent (synonymous) ontological objects are hence used as connections between basic ontologies in the integration process. In addition to optimizing the semantic interoperability between learning objects, ontology offers clear guidelines on how to produce reusable information for the web. However, production of reusable information for the web also requires standard metadata to abstract data details and to ease data exchange. Hence, the use of ontology and metadata allows the community to efficiently exchange learning experiences.

The proposed ontology-based learning system enables intelligent instructional design and planning in specific domain knowledge. Courseware authors are provided with a framework that guides them in developing their own instructional strategy using a set of ontology based rules. The system controls the granularity level of learning objects production and guarantees that these are named and sequenced to comply with the ontology vocabulary and knowledge structure. The system offers guidelines and services to build a *Learning Web* (LW), which is a connectivity of LOs according to a specific instructional design. Authors have full control over choice of the learning object sequences, depth of the material (i.e. LO granularity), prerequisite knowledge, support knowledge, and appropriate assessment material that mostly suit their instructional strategy. The rules associated with the ontology are only used to verify that these choices do not contradict the variety of relations enforced by the ontology, and that the content of the corresponding learning ob-

ject satisfies the content structure requirements and naming conventions of the ontology. The conceptual information derived from the ontology is stored in the meta-metadata layer of the LOM (see Figure 1), and includes information such as the name of the concept enclosed in the LO, its hierarchical level, and its relations with other concepts. The extended version of the LOM is empowered to provide a standard-based, ontology-aware specification with the following benefits.

- *Standardize e-learning system.* Standardization is of great importance for reusing and exchanging LOs for a specific field of knowledge. LOs designed according to a specific ontology, and belonging to a learning web, can be plugged in another learning web in order to cover the same concept outcomes.
- *Efficient LO search.* Using keywords which are part of an ontology vocabulary provides better context-based search results.
- *Adapting learning webs to learners.* Ontology describes a knowledge domain into a hierarchy of constituents. Usually, the main constituents, also called body of knowledge, are organized into units, which are themselves divided into topics, which in turn represent sets of related concepts. It should be noted here that LOs are not necessarily associated with the leaves of the ontology hierarchy, but can be mapped to concepts at different levels. Depending on the author's own understanding of the curriculum structure, teaching experience, and the nature of the course, he or she may devise learning objects that are associated to elements of higher levels in the hierarchy. Our system allows a great flexibility in the learning object granularity, provided that this complies with the ontology hierarchy. An ontology guided LO development enables production of LOs at different levels of the ontology, thus, helping authors finding learning resources that suit most of a courseware requirements.
- *A common vocabulary.* The terminology agreed upon in the ontology unifies the conceptual view of a knowledge domain and optimizes the search process for learning objects.

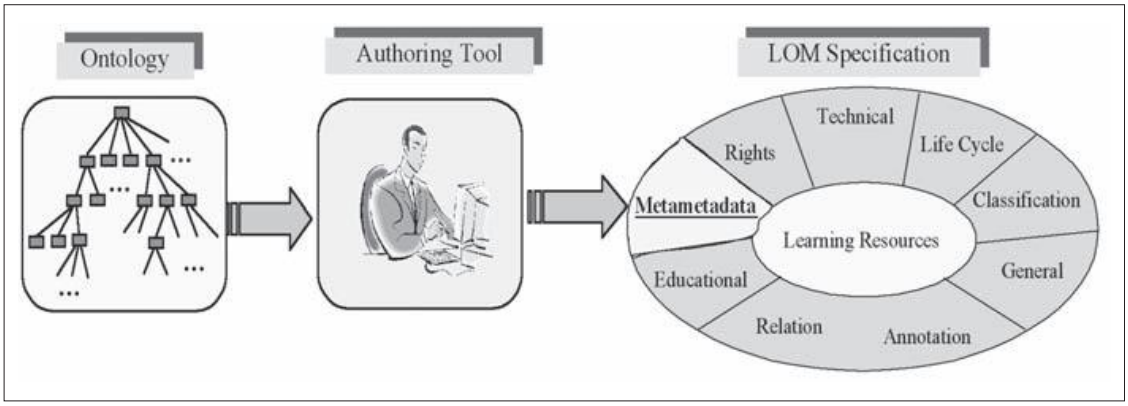

Figure 1 Ontology-aware LO Authoring process.

- *LO sharability and usability.* Ontology guided LO development will allow a number of authors and learners alike to develop, reuse, update, and maintain LOs at different ontology levels.

4. Ontology-based architecture

The proposed e-learning architecture is organized into three layers namely knowledge layer, authoring layer, and learning layer, as shown in Figure 2. The knowledge layer delimits the knowledge content of a specific learning domain. This layer includes the ontology which plays crucial role in controlling the structure of a courseware (learning web), as well as the involved LO granularity. The ontology acts as a standardized reference model for learning in a specific domain.

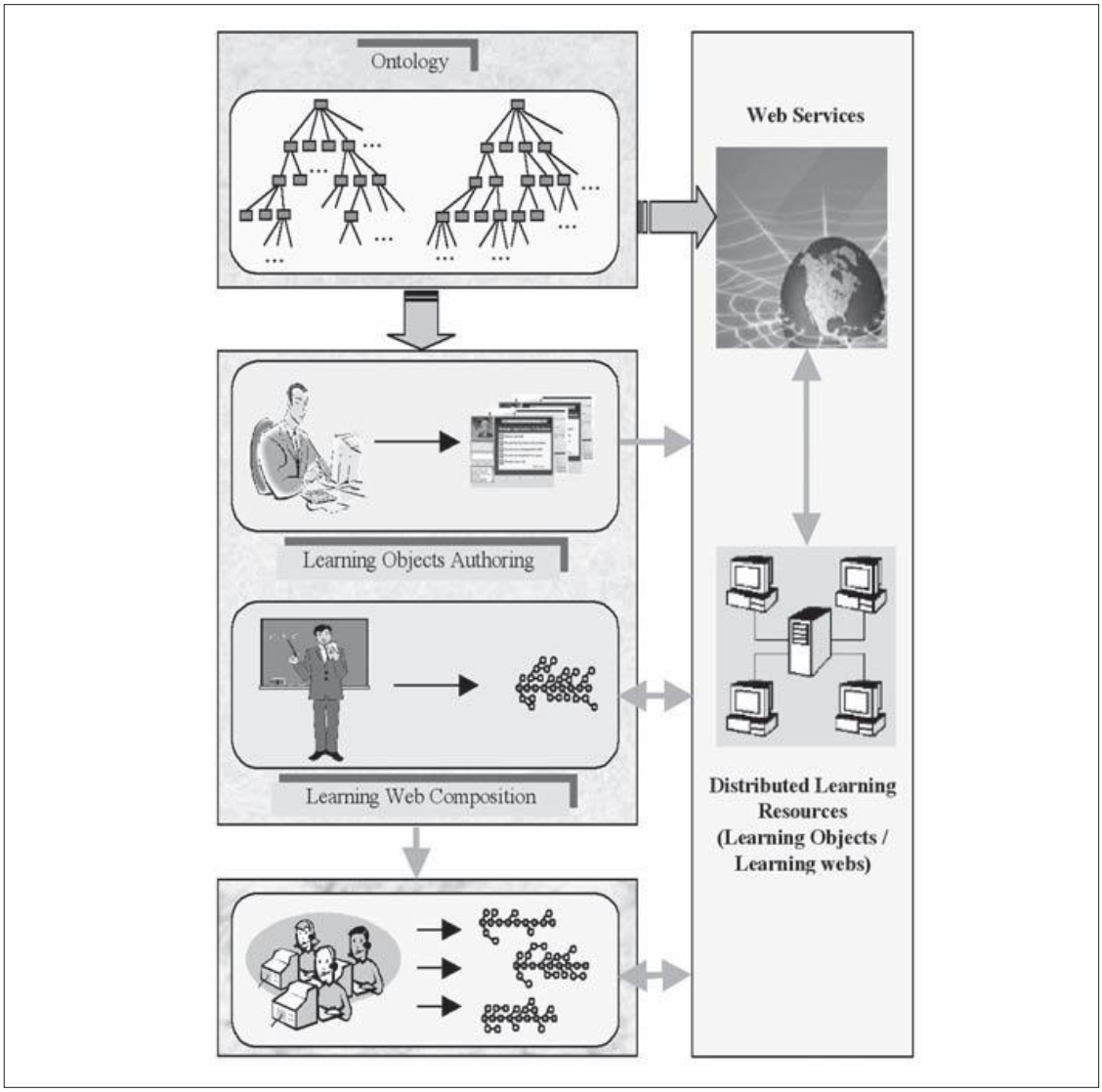

Figure 2 Ontology-based e-learning architecture.

It determines the concepts of the domain, the relations among them, and the concept granularity to which learning objects are mapped.

The authoring layer consists of two separate authoring activities: learning objects authoring and learning web composition. In a classical e-learning architecture, these two authoring activities are combined into a single activity where authors develop learning resources to build their own learning webs. In this work, the use of ontology relieves authors from such a tedious task by standardizing the used concepts, defining their granularity, and establishing clear relationships among them. Authors are hence given the choice to either develop their own LOs or to make use of already developed ontology compliant LOs available on the web. The learning web composition task is a major module of the system where ontology-related rules are used to guide authors in complying with the ontology-aware educational and domain knowledge structure.

Finally, the learning layer uses LO metadata and the ontology to adapt to different learners' needs, preferences and background. This is done by plugging the appropriate LO content that best suits the learner (Atif, Benlamri, Berri, 2003a; 2003b). The system allows learners to access a variety of learning webs. Learners also have the opportunity to choose the learning web that best suits a particular context. Learner routes are saved in a repository as new learning experiences for future use (Atif, Benlamri, Berri, 2003b).

The proposed system provides learners and authors alike with a set of web services to search for, browse, retrieve, and store learning objects as well as learning webs. These web services use the ontology common vocabulary and semantic relations for consistency check while composing learning webs.

4.1 LO authoring

The LO authoring process is generated by connecting the knowledge space (i.e. ontology) to the media space (LOs metadata). The connection of the knowledge space with educational material can be based on the use of the «Classification» Category, defined by the IEEE LOM Standard which describes where a specific learning object falls within a particular classification system. This approach, also used in Karampiperis and Sampson (2004), provides a simple way of identifying the domains (or concepts) covered by a learning object. The result of the merging of the knowledge space and the media space is a directed acyclic graph (DAG) of LOs which we refer to in this paper as Learning Web. Eventually, several learning webs may emerge as a result of this authoring process depending on the desired level of granularity. Further optimization of the generated learning webs may involve the selection of the shortest learning path using the typical learning time attribute of LOM standard as suggested in one of our previous research (Berri, Atif and Benlamri, 2004).

In order to enhance learning object reusability, we thus advocate an ontology as a standard reference model. The ontology uses a taxonomy of domain specific terms for describing domain knowledge representation. Hence, authors are guided by the hierarchy of concepts to build their specific learning objects. The ontology also allows adjusting granularity of LO content for authoring purposes. Granularity refers to the way authors map the concepts of the ontology into learning objects. For instance, a learning object may be very general, having a large grain size, if mapped to a higher-level concept in the hierarchy, while another learning object may represent in-depth concept, referred to as fine grain concept, when mapped to a leaf node of the ontology. Figure 3 shows different learning webs that can be generated from the same ontology. In learning web 2, the learning object E is presented at the largest grain size avoiding to consider its sub-concepts in the hierarchy, whereas in learning web 1, it is described at the finest grain size considering all elements of the E's sub-tree. Hence, our definition of granularity differs from the media-centric definition of granularity advocated by several standards in the sense that it is concept-centric.

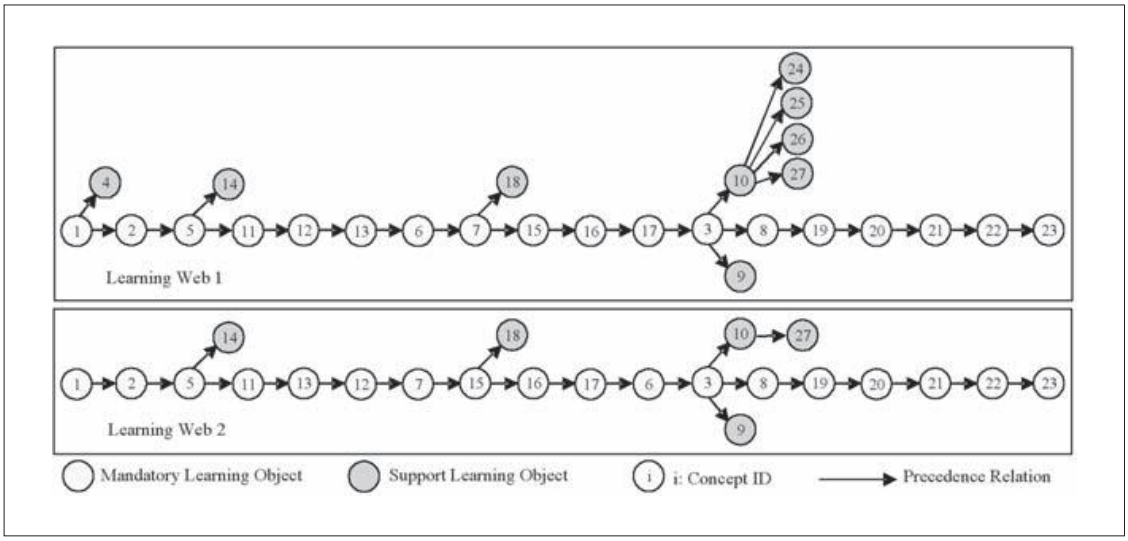

Figure 3 Ontology mapping at different granularity levels.

4.2 Learning web construction

The process of structuring learning objects in a learning web is of great importance. Ontology-based guidance for courseware construction provides solutions to many crucial courseware organizational aspects. It defines a framework for courseware authors to state the minimum learning requirements, support information, mandatory LO sequence, and pre-requisite knowledge. This is achieved through the rules describing relations among concepts embedded in the ontology.

For instance, the prerequisite relation establishes a temporal relation between a learning object and its pre-requisite, while the necessary part-whole relation forces the author to include LOs associated to all the necessary parts of a concept in the learning web in order to fulfill its educational purpose.

Figure 4 presents a fragment of a simple ontology for information retrieval designed for the purpose of this paper (Baeza-Yates, Ribeiro-Neto, 1999). The ontology includes a number of concepts and many instances of the following three ontology based relationships: *prerequisite*, *part-of* and *necessary part-of*. The objective is to assist authors generating ontology compliant learning webs by mapping LOs to the ontology concepts, and then, linking them according to the established rules. The rules allow planning LOs in the learning web while satisfying constraints imposed by all ontology relations. While the default mapping of the ontology to a learning web is a depth-first traversal of the ontology, the rules need to be checked at each LO addition to the learning web in order to comply with the relations' constraints.

In order to formulate the rules and facts, we use formulas in first order predicate logic with the usual connectors. The relation `prerequisite(`c_i`,` c_j`)` involving two concepts c_i and c_j, denotes that concept c_i is a required knowledge of c_j and needs to be covered prior to it. Rule `R1` in Table 1 establishes a temporal constraint represented by the temporal relation `before` between the learning objects LO_k and LO_i, representing respectively the concepts c_k and c_i. For instance, in Figure 4, concept c_{11} is a prerequisite concept for c_{12} and c_{13}. This is represented by the facts *a*1 in Table 1. Hence, by applying rule `R1`, facts a2 will be deduced.

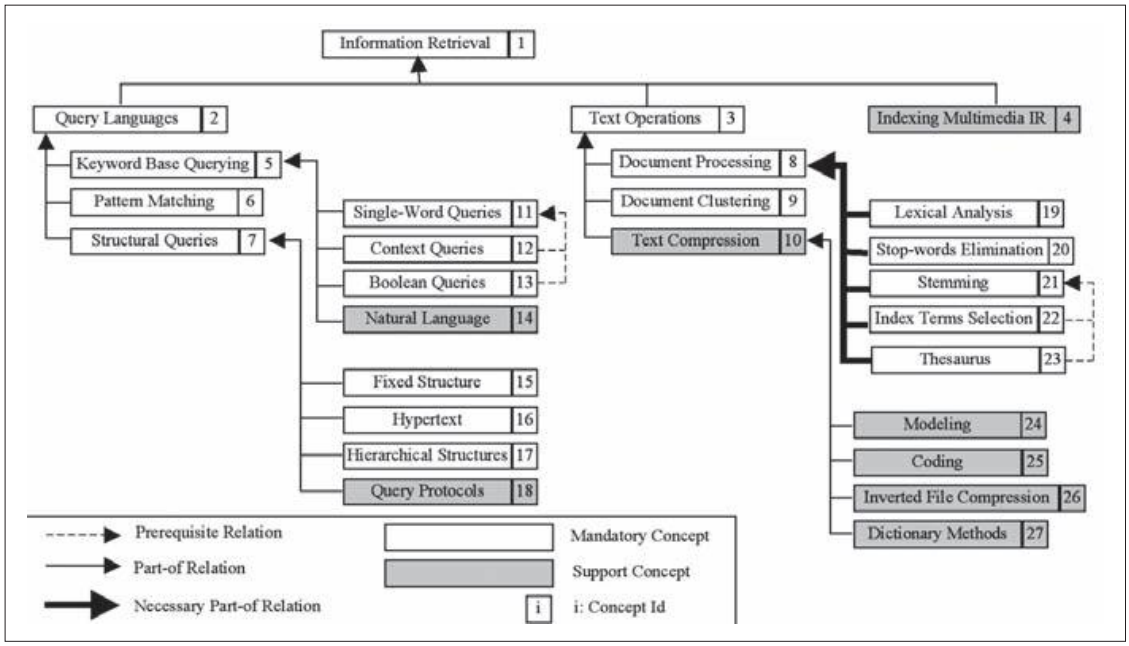

Figure 4 Fragment of an Ontology for Information Retrieval.

Part-of relation partof(c_i, c_j) represents the *part-whole* relation where concept c_i represents a knowledge component of c_j. For instance, in Figure 4, concepts c_{11}, c_{12} and c_{13} are part of concept c_5. These relations are represented by the facts *b* in Table 1.

The relation necessarypartof(c_i, c_j) represents the *necessary part-whole* relation where concept c_j can not be completely understood without covering concept c_i. This constraint is guaranteed by rule R2 in Table 1. This rule guarantees that if LO_k, representing concept c_k, is in the learning web, then, all learning objects LO_i representing concepts c_i, which are necessary-parts of c_k, must be in the learning web. For instance, in Figure 4 concepts c_{19}, c_{20}, c_{21}, c_{22}, and c_{23} are necessary parts of concept c_8. This is represented by the facts *c*1 in Table 1. Since LO_8 is included into the LW as shown in Figure 3, then rule R2 ensures by inferring the facts *c*2 in Table 1, that learning objects LO_{19} LO_{20} LO_{21} LO_{22} and LO_{23} are all in the learning web.

Although the system gives a default learning web structure, resulting from the order generated by the depth-first traversal algorithm, this structure is not compulsory for the authors. Authors can rearrange LOs, and the rules provided by the system are automatically applied to ensure that these rearrangements do not violate the ontology relations. For instance, in Learning Web 1 (Figure 3), learning object LO_{12} is covered before learning object LO_{13}, whereas LO_{13} is located before LO_{12} in Learning Web 2. Both schedules are possible since none of them violates the ontology rules. However, since concept c_{11} is a prerequisite for concepts c_{12} and c_{13}, both learning objects LO_{12} and LO_{13} should be scheduled after LO_{11} as shown in the learning webs of Figure 3.

Table 1
ONTOLOGY RELATED RULES AND FACTS

Rules	R1: $\forall c_i \exists c_k$ prerequisite(c_k, c_i) $\rightarrow$ before(LO_k, LO_i) R2: $\forall c_i \exists c_k$ necessarypartof(c_i, c_k) $\wedge$ LO_k LW $\rightarrow$ LO_i LW	
Facts	*Ontology related Facts*	*LW related Facts*
	a1) prerequisite(c_{11}, c_{12}) prerequisite(c_{11}, c_{13})	a2) before(LO_{11}, LO_{12}) before(LO_{11}, LO_{13})
	b) partof(c_{11}, c_5) partof(c_{12}, c_5) partof(c_{13}, c_5)	
	c1) necessarypartof(c_{19}, c_8) necessarypartof(c_{20}, c_8) necessarypartof(c_{21}, c_8) necessarypartof(c_{22}, c_8) necessarypartof(c_{23}, c_8)	c2) LO_{19} LW LO_{20} LW LO_{21} LW LO_{22} LW LO_{23} LW

The above-mentioned relationships and rules are just those needed to illustrate the example given in Figure 3. It should be noted that the proposed system uses additional rules and relations to deal with other types of correlations between concepts.

5. Conclusion

In this paper, we presented a framework for standard-based, ontology-aware instructional design and planning in specific domain knowledge. The proposed ontology-based system provides a great potential for enhancing the LOM capabilities. This is done by extending the LOM model to include conceptual information, common vocabulary, and by adjusting LO granularity to fulfill various educational needs. The extended LOM version proposed in this paper ensures both the inclusion of shared agreement in the content and the specification of standard-based metadata in the embedded material.

The proposed ontology-aware architecture is designed to allow separation of LO and learning web authoring activities. In our view, this is an important feature that makes instructional material reusable to a great extent. Moreover, the system offers flexibility in structuring learning webs according to the author's own understanding of the curriculum, experience, and objectives. It also enables the exchange of learning material, collaborative learning, and efficient context-based retrieval of instructional information from learning object repositories available on the web. Current research work investigates new approaches in using ontologies for learner modeling. This can be done by providing new mechanisms to dynamically build ontology-compliant learning webs that suit learner needs, preferences and background.

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