

A Context-Based Framework and Method for Learning Object Description and Search

Xiaofeng Du, William Song, and Ming Zhang

Department of Computer Science, University of Durham, Durham, UK
{xiaofeng.du, w.w.song}@durham.ac.uk

School of Electronics Engineering and Computer Science Peking University, Beijing, China
mzhang@net.pku.edu.cn

Abstract. For the last decade, E-Learning has become an active research area. Many companies and organisations are now providing large amounts of online learning resources. These learning resources have covered most common education and learning areas and subjects and are always available so that the learners can access them from anywhere which has an Internet connection. Learners can flexibly choose the subjects they want and build up their own curriculum and study schedule. However, most of the online learning resources are poorly described and structured so causing huge problems in their use, search, organization, and management. To overcome the problems, we propose a novel and practical context-based semantic description framework which aims to describe information and knowledge about learning resources and their structures. Context-based semantic description is an effective way to extract knowledge from various aspects to depicting learning resources which are abstracted and termed as "Learning Objects". This framework consists of four parts: the definition of Learning Objects, a Context-based Semantic Description Model, an ontology, and learning concept dependency graphs. By using the Learning Object's attributes and their various semantic relationships addressed in the proposed framework, we attempt to search and match a learner's requirements against the description of Learning Objects provided by the framework with the help of knowledge from learning environments. A key step here is to compute semantic similarity using the modelled knowledge. The proposed work aims to support learners in using massive learning resources from the web to perform self-learning with or without the help of educators' advice and instruction.

1 Introduction

As the World Wide Web technologies have become mature, they have enabled people take conventional courses through the Internet without classrooms and instructors. Web-based training and distance learning have formed a new paradigm of education, known as E-Learning [11]. E-Learning has provided an easy way to access online learning resources at anytime and from anywhere and build up synchronous and asynchronous communication and collaboration channels between learners and between learners and instructors [1]. One of the most attractive features of E-Learning is that the learners can define their own learning goals and personalise their learning strategy.

The individual learner's requirements can be satisfied by combinations of different online learning resources.

The Web can be described as an ocean of information and knowledge usable for learning. There are many E-Learning resources providers, each of whom have provided a large number of learning courses, such as MIT OpenCourseWare¹, eLearners.com², and GreatLearning³. These courses have covered most common education and learning areas and subjects. They are available all the time through out the year and can be accessed from anywhere which has an Internet connection. Learners can flexibly choose the subjects they want and build up their own curriculum and study schedule which suits their personal needs. However, most of the learning materials have not been described sufficiently. Therefore, it is hard for learners to locate and judge which courses are the right ones for them. This is one of the reasons why education that done through E-Learning is still less effective than through personal interaction in a classroom [7]. We summarise the problems that web course users encounter when using the online learning resources below:

- Poor description of learning resources: The individual learning resources are poorly described and there lacks an effective description model for the relationships among different learning resources.
- Little support for effective resource search: It is difficult to efficiently search the provided learning resources, especially when a learner is new to a subject area. Learners have great difficulty in specifying exactly what they want and therefore, their requirements are vague and incomplete. Furthermore, many search engines for the current learning resources require precise information and terminologies to locate the relevant learning resources.
- Difficult matching adequate courses: It is more often than not that the chosen resources do not suit the learner's requirements. A learning resource may be too difficult to learn for a beginner whereas it may too easy for someone already educated in the domain. This is due to a lack of systematic organization of the learning resources on the web, and effective and formal description of the users' demands and background knowledge.
- Poor internal structures for managing learning resources: Most of the online course providers use a rough subject category-based structure to organize their learning resources and primary metadata models to describe them. Such organization schemes and models do not offer a well-defined structure to store and manage learning resources.
- Poor interoperability among the communities providing learning resources: This is an obvious consequence of the above-discussed problems.

In order to address the problems discussed, we need to make a clear and concise definition of the concept Learning Object. There are quite a number of different definitions for Learning Object, such as SCORM [12], LOM [9], and LOMD [13], but they lack a clear depiction of how a Learning Object is related to other Learning Objects. We believe this is crucial to making good use of learning resources from different learning communities. Taking Learning Object as the core concept to be defined,

¹ <http://ocw.mit.edu/>

² <http://www.elearners.com/>

³ <http://greatlearning.grids.cn/>

we propose a Context-based Semantic Description framework, consisting of a Context-based Semantic Description model describing relative concepts of a Learning Object, an ontology to describe a conceptual taxonomy structure, and a set of learning concept dependency graphs to depict, e.g. what pre-requisites there are for a Learning Object. By having a clear definition of Learning Object, we can know what kind of contextual information is relevant to describing it, which should be addressed in the Context-based Semantic Description model. The contexts we focus on here are the information that can help a learner to understand a Learning Object and make an effective use of it and also can emphasise the relationships among Learning Objects. The ontology is used to define the concept of Learning Objects and it is created based on ACM/IEEE Computing Curriculum [16]. The learning concept dependency graphs give an overall and abstract description of the relationships among learning concepts. They are represented using Conceptual Graphs [14].

Based on our framework, we develop a two-step search mechanism. When a learner presents a learning query, it is first represented in the Conceptual Graph and then matched with the learning concept dependency graphs to locate the relevant concepts, i.e. the relevant Learning Objects because each learning concepts in the graph associated with a set of Learning Objects, and relations. In the second step, based on the learner's further detailed requirements we use the Context-based Semantic Description model and the ontology to refine the results from the first step and return the most relevant Learning Objects to the learner. Our proposed framework and search mechanism aim to support learners in using massive learning resources from the web to perform self-learning with or without the help of educators' advice and instruction.

The rest of this paper is organised as follow; section 2 gives a detailed discussion on the proposed framework whilst section 3 discusses the two-step search mechanism. In sections 4, we evaluate our work based on experimental result and, finally, a summary of the related work and conclusion are given in section 5 and 6.

2 Context-Based Semantic Description Framework

The proposed Context-based Semantic Description Framework (CbSDF) follows the belief that the identification of meaning of a concept mainly stems from its contexts [8], i.e. its relationships to other concepts. To fully express the meaning of a concept, simply using its dictionary definition is not sufficient. For example in a dictionary a hammer is defined as “a hand tool with a heavy rigid head and a handle; used to deliver an impulsive force by striking”⁴. If a person has never seen a hammer, she will not get much impression on what a hammer is from the definition because that definition is a type definition [14], i.e. the vertical relationships between the concept and its super/sub type concepts, which does not describe how the hammer can be used, i.e. the horizontal relationships between the concept and other types of concepts. If we say “a hammer is a tool that can strike a nail into wood”, then the person will know at least one way of hammer's usage by understanding the relationships among “tool”, “nail”, and “wood”, although she will know more ways to use a hammer after she really understands what a

⁴ WordNet Search - 3.0, <http://wordnet.princeton.edu/perl/webwn>

hammer is. Following this idea we propose the CbSDF that defines, describes, and organises Learning Objects in both vertical and horizontal relational manner in order to improve the efficiency and effectiveness of Learning Object search, usage, and management. In the following sections, we discuss each of the components of the framework in detail.

2.1 Learning Object Definition

The IEEE working group for Learning Object Metadata (LOM) [9] defines Learning Object as being “*any entity, digital or non-digital, that may be used for learning, education or training*”. In our work, we extend this definition based on the Learning Object’s characteristics.

Definition 1. A Learning Object LO is a logical structure, defined as a 7-tuple:

$$LO = \langle id, C, A, \delta, P_r, P_o, R_s \rangle$$

where, id : an internal system identification number or a name of the Learning Object.

C : the learning concept of LO . This concept is a leaf node in the Learning Object ontology which we will discuss in 2.3.

A : a set of attributes that describe LO . Similar to the attributes in the Entity-Relationship Model, they will not describe relationships between this Learning Object with other Learning Objects.

δ : an internal structure of LO . This structure is a set of learning concepts that make up LO ’s deliverable knowledge. It enables us to compose (and decompose) Learning Objects.

P_r : a set of learning concepts that provides the pre-requisite knowledge for LO .

P_o : a set of learning concepts that requires the pre-requisite knowledge from LO .

R_s : a set of physical learning resources to implement LO .

It is of course allowed that the internal structure δ of a Learning Object to be empty. Consequently, we have two types of Learning Objects as follows.

Definition 2. A Learning Object is called an *atomic Learning Object*, denoted as LO_a , if δ is empty, i.e. $LO_a \rightarrow \delta = \emptyset$. A Learning Object is called a *composite Learning Object*, denoted as LO_c , if δ is not empty, i.e. $LO_c \rightarrow \delta = \{C_1, C_2 \dots C_n\}$, $n \geq 1$.

Here we use an example, a composite Learning Object “Java Programming”, to illustrate the definitions:

$LO(\text{Java Programming})$: id : #0015

C : “Java Programming”.

A : {“40 hours”, “English”, “Intermediate Level”}.

δ : {“Classes and Objects”, “Interface”}

P_r : {“Basic Programming”, “Object Oriented Theory”}.

P_o : {“Java Swing”}.

R_s : {ch1.avi, ch2.avi, ..., Java programming.pdf}.

2.2 Context-Based Semantic Description Model

A Learning Object can be viewed as a carrier of knowledge which the learners hope to acquire. As known to us, knowledge is not isolated at all, and always related to other knowledge. Therefore, when we describe a knowledge carrier, i.e. a Learning Object, we cannot describe it independently. The inter-relationship among Learning Objects is an important issue that should be addressed in the Learning Object description. It intended to give learners the information about how the knowledge delivered by the Learning Object can fit into a general knowledge structure, i.e. the context of the knowledge, and helps them to choose the most suitable Learning Objects for them. To emphasise the contextual knowledge of Learning Objects, we propose a Context-based Semantic Description Model (CbSDM).

Definition 3. The CbSDM is defined as a triple denoted as:

$$M = \langle LO, R, L \rangle$$

where,

LO : the described Learning Object.

$R = \{R_o, R_{pre}, R_{post}, R_{sub}\}$: a set of relations that contains four elements, which are explained as follows:

- R_o represents the relations between LO 's learning concept and its super-concepts in the Learning Object ontology.
- R_{pre} represents the relations between LO and its pre-requisite LO s.
- R_{post} represents the relations between LO and its subsequence LO s.
- R_{sub} represents the relations between LO and its sub-Learning Objects.

$L = \{L_{Attr}, L_{Rec}\}$: a set of links that contains two elements, which are explained as follows.

- L_{Attr} represents the links from LO to its attributes, i.e. the metadata.
- L_{Rec} represents the links from LO to its physical learning resources.

A graphical illustration of the CbSDM is shown below, see Fig.1.

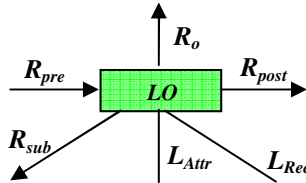


Fig. 1. A graphical representation of the CbSDM. It describes the direction of the relations from the LO to other LO s and the links to the LO 's attributes and physical learning resources.

2.3 The Learning Objects Ontology

The Learning Objects ontology in this framework plays a critical role in conceptual description of Learning Objects and hence in semantic search. In our practice, we use

the Computing Curriculum, a subject taxonomy for education systems, proposed by ACM/IEEE [16]. This taxonomy categorises the knowledge system of Information Technology into three levels: Area, Unit, and Topic. The Area represents a sub-domain of the knowledge system that is used to organise, categorise, and describe the top level knowledge structure of the knowledge system, the Unit represents a sub-direction in an Area, and the Topic represents a relatively independent content in a Unit. The Fig. 2 illustrates a part of the ontology created based on the taxonomy. This ontology has been applied to the *University Course Online (realcourse* in short) system [17] which is a Grid based video stream online education system. The leaf nodes of the ontology are the direct parents of Learning Object instances, i.e. the learning concepts in the Learning Object definition, which are normally the names of the courses that can be taken by the learners. A Learning Object instance of a leaf node concept can either represent the whole course or a part of the course.

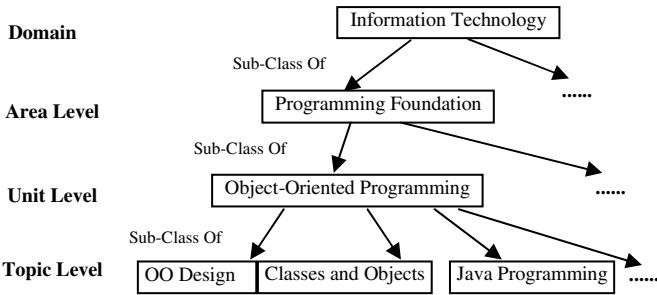


Fig. 2. Part of the Learning Object ontology. It gives the example nodes in different level of the Learning Object ontology.

2.4 The Dependency Graphs of Learning Concepts

In order to capture and represent conceptual dependency relations between Learning Objects, we propose a set of learning concept dependency graphs. As a part of the CbSDF, the dependency graphs are high level, abstract descriptions of the learning concepts and their relations. They can help the system in analyzing learner’s query and locating relevant Learning Objects, especially when the learners are new to a subject area and cannot provide concrete queries to describe what they want. The dependency graphs also can help the learner in understanding the conceptual dependency relations between required Learning Objects and other Learning Objects. We propose using Conceptual Graphs (CGs) [14] to represent the dependency graphs. In the following, we introduce CG with some basic definitions.

A conceptual graph is a finite, connected, bipartite graph with nodes of one type called concepts and nodes of the other type called conceptual relations [15]. *Concepts* represent entities, actions, and attributes. The label of a concept node consists of two fields separated by a colon, *[type: referent]*. *Type* represents the class of a concept. *Referent* represents an instance of the class. The functions *type()* and *referent()* can be used to get a concept’s type and referent. If the value of *referent(c)* is an individual

marker (an identification of an instance, such as name or id), e.g. [Cat: Tom], then the concept c is an *individual concept*. If the value of $referent(c)$ is “*”, e.g. [Cat: *], then the concept c is a *generic concept*. A concept only with type label is equivalent to a generic concept, i.e. [Cat] = [Cat:*]. *Conceptual Relations* represent the relationships between concept nodes. $type(r)$ is used to get the type of the relation r .

Suppose that u and v are two CGs. u is called a specialization of v (or v is called a generalization of u), denoted as $u \leq v$, if u is canonically derivable (derived by applying a sequence of generalization rules [14]) from v . In this case, there must exist a mapping $\pi: v \rightarrow u$, where $\pi_u v$ is a subgraph of u called a *projection* of v in u . The projection operator π has the following properties:

- For each concept c in v , $\pi_u c$ is a concept in $\pi_u v$ such that $type(\pi_u c) \leq type(c)$, “ \leq ” here represents the sub-type relationship between concepts. If c is an individual concept, then $referent(\pi_u c) = referent(c)$.
- For each relation r in v , $\pi_u r$ is a conceptual relation in $\pi_u v$ such that $type(\pi_u r) = type(r)$. If the i -th arc of r is linked to a concept c in v then the i -th arc of $\pi_u r$ must be linked to $\pi_u c$ in $\pi_u v$.

Let u_1, u_2 , and v be CGs. If $u_1 \leq v$ and $u_2 \leq v$, then v is called a *common generalization* of u_1 and u_2 .

Based on the definition of a CG, we can give the definition of the learning concept dependency graph.

Definition 4. A learning concept dependency graph G_d is a CG where the concept type is restricted to concepts within the Learning Object ontology, denoted as:

$$G_d = \langle C, R, \vec{E} \rangle, type(C) \in O$$

where, C : a set of learning concept nodes; $type(C)$ returns a set of leaf node concepts in the Learning Object ontology.

R : a set of relation nodes that represent the relations among learning concept nodes, including pre-requisite relation type and conceptual relation type etc.

\vec{E} : a set of arcs that associate relation nodes with concept nodes.

O : the Learning Object ontology.

An example G_d (Java Programming) is illustrated in Fig.3., where,

C : {[Java Programming], [Java A-Z], [Object Oriented Theory], [Java Swing]}.

R : {(require), (apply-to), (similar-to)}.

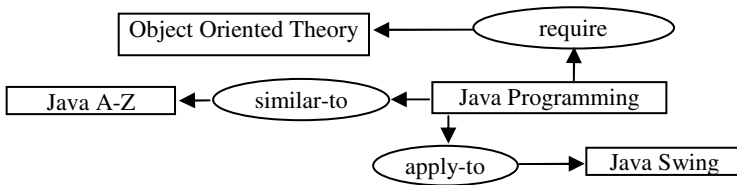


Fig. 3. A learning concept dependency graph example. It represents the relationships among different learning concepts.

3 Learning Object Semantic Search

As discussed previously, when a learner is not familiar to a subject area, it is unrealistic to expect her to provide a very detailed query. Therefore, a step-by-step process is required to lead the learner to gradually locate the suitable Learning Objects. Based on the CbSDF, we propose a two-step Learning Object search mechanism. The first step is preliminary learning concepts discovery step using CG matching technique. The proposed learning concept dependency graphs provide the information about learning concepts and their relations. When a learner submits a query, we first convert it into a CG and match it with the learning concept dependency graphs to obtain the query's relevant learning concepts and their relations. Because each learning concept corresponds to a set of Learning Objects, a series of Learning Objects related to learner's query are located. The second step, refining step, is to refine the results from the first step based on the learner's further query inputs which are captured using the CbSDM. At this step the learner can specify detailed requirements about a Learning Object, e.g. the metadata, because now she can browse through the returned Learning Objects from the first step and get some concrete information. Then the semantic similarity between the learner's requirements (i.e. the learner's queries) and the candidate Learning Objects is calculated and the matched Learning Objects are ranked according to their similarity degree to the learner's demands.

3.1 CG Similarity Calculation

After converting the learner's query into a CG, we turn the search in the learning concept dependency graphs for a match to the query into the computation of similarity of two CGs. According to Montes et al. [10], the similarity S between two CGs, G_1 and G_2 , contains a concept similarity S_c and a relation similarity S_r . The concept similarity S_c is calculated using the Dice coefficient [6] similar expression:

$$S_c = 2 \left(\sum_{c \in \bigcup O} (weight(c) \times \beta(\pi_{G_1, c}, \pi_{G_2, c})) \right) / \left(\sum_{c \in G_1} weight(c) + \sum_{c \in G_2} weight(c) \right)$$

where, $\bigcup O$ is the union of all of the common generalisation graphs of G_1 and G_2 ; O is a set of the common overlaps graphs of G_1 and G_2 , $weight(c)$ is the importance factor of the concept type c . We take $weight(c) = 1$ as we assume that all the concept types are of the same importance. The $\beta(\pi_{G_1, c}, \pi_{G_2, c})$ function is defined as follows to calculate the semantic similarity between two concepts:

$$\beta(\pi_{G_1, c}, \pi_{G_2, c}) = \begin{cases} 1 & \text{if } type(\pi_{G_1, c}) = type(\pi_{G_2, c}) \text{ and } referent(\pi_{G_1, c}) = referent(\pi_{G_2, c}) \\ depth / (depth + 1) & \text{if } type(\pi_{G_1, c}) = type(\pi_{G_2, c}) \text{ and } referent(\pi_{G_1, c}) \neq referent(\pi_{G_2, c}) \\ 2d_c / (d_{\pi_{G_1, c}} + d_{\pi_{G_2, c}}) & \text{if } type(\pi_{G_1, c}) \neq type(\pi_{G_2, c}) \end{cases}$$

The first condition indicates that the two concepts are exactly the same. The second condition indicates that the two concepts have the same type but refer to different instances. The depth represents the number of levels in the Learning Object ontology. The third condition indicates that the two concepts have different types. The dc represents

the distance from the least common super-type of $\pi_{G_1}c$ and $\pi_{G_2}c$ to the root of the ontology; $d_{\pi_{G_i}c}$ represent the distance from concept $\pi_{G_i}c$ to the root of the ontology. The relation similarity S_r is calculated using the following expression:

$$S_r = \frac{2m(G_c)}{m_{G_c}(G_1) + m_{G_c}(G_2)}$$

where, $m(G_c)$ is the number of the relation nodes in the common overlaps of G_1 and G_2 ; $m_{G_c}(G_i)$ is the number of the relation nodes of the common overlaps in G_i and the overlaps' adjacent relation nodes.

The overall similarity expression is shown below:

$$S = S_c \times (a + (1-a) \times S_r)$$

where, a is a value between 0 and 1 representing the impact factor of S_r . We use 0.9 for a to indicate that the concepts are overwhelmingly important over the relations.

3.2 Semantic Similarity Calculation Between Learning Object and Requirements

In the second step of the Learning Object search, in order to measure the semantic similarity between the learner requirements and the Learning Objects returned from the first step and rank the final results, we develop a semantic similarity measurement method, which is based on the CbSDM and the ontology, to measure semantic similarity between learner requirements and Learning Object, defined as:

$$sim(LO_r, LO) = \frac{\sum_{\alpha \in \lambda} \omega \times dist(\alpha(LO_r), \alpha(LO))}{\max(\lambda(LO_r), \lambda(LO))}$$

where, λ : a set of all the semantic characteristics functions;

$\lambda()$: a function that returns the number of semantic characteristics;

$\alpha()$: an element of λ that returns a semantic characteristic which can be, e.g. a element of the metadata;

$dist()$: a function that calculate the semantic distance between two semantic characteristic and its returned value is between 0 and 1;

ω : a weight factor that specifies how important a semantic characteristic to a learner is and its value is between 0 and 1.

$max()$: a function returns the greater of its two arguments values.

LO_r and LO : the required Learning Object and a candidate Learning Object.

Through this method, the similarity between learner requirements and each candidate Learning Object is calculated. Therefore, the result Learning Objects can be ranked according to their similarity degree to the learner's demands so that the learner can easily choose the best matched Learning Objects.

4 Evaluation

In order to evaluate the work proposed in this paper, we have implemented a web-based prototype system specifically designed for learners to search their required

Learning Objects. We collected approximately 2000 Learning Objects from different Learning Object repositories, including MIT OpenCourseWare and GreatLearning. We use descriptions based on CbSDF to describe collected Learning Objects and stored them in our local Learning Object database. Each Learning Object has hyperlinks to their physical resource locations so that the learners can search the Learning Objects locally and access the physical learning resources remotely. Our evaluation tries to compare two search methods: The first one is the advanced keyword-based search method that provides options for keywords matching, such as “with all of the words”, “with the exact phrase”, “with at least one of the words”, and “without the words” and options for metadata matching, such as “Language”, “Difficulty level”, and “Typical learning time”. The other one is our search method based on the CbSDF. Our method adopts the proposed two-step search mechanism. Through comparing and evaluating these two search methods, we aims to show our method can greatly improve the Learning Object search and discovery.

We choose two groups of users for evaluation. One group of users are computer science students who have strong computer background, thus they can create detailed concrete queries about computer learning courses. The other group of users know a little about computer, thus their queries about computer learning courses are general and vague. Therefore, we could observe how our method suits queries with different knowledge backgrounds from learners. The evaluation factors that we are interested in are the recall and precision rate from each group by using different search methods. The results represented using precision-recall curves are listed in Fig.4 (a).

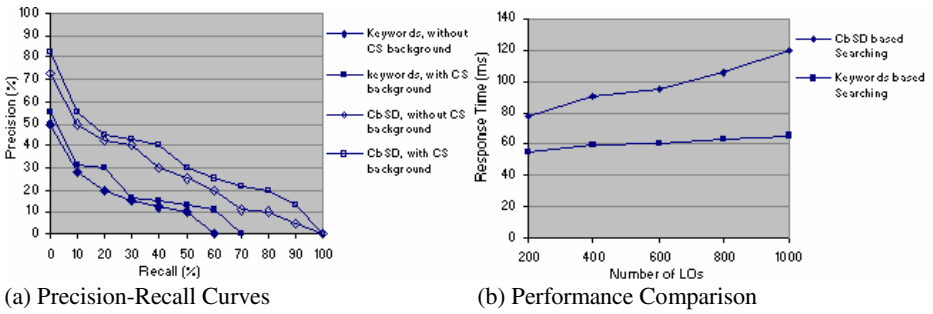


Fig. 4. The experiment results including precision-recall curves and performance comparison

The Fig.4 (a) clearly shows that our method significantly improves the search results for both the user groups. During the experiment we observed that a large number of metadata fields provided in the keyword-based search method remained empty according to the users’ query submissions no matter they have computer background knowledge or not. The graph, see Fig.4 (b), displayed that our method had a slight worse performance than the keyword-based search method because we adopted a complex algorithm for CG similarity calculation. However, our method provides high precise search results. So we consider our method offers a better general performance as the users have to spend longer time to retrieve the relevant results from the keyword-based search.

5 Related Work

Colucci et al. [3] propose a semantic framework and algorithms for automated composition of Learning Objects in order to achieve personalised E-Learning. They demonstrate in their work how a semantic specification, formatted in OWL-DL, of the Learning Objects can be used both to retrieve Learning Objects satisfying a user request from a repository and to compose such discovered Learning Objects in a courseware. The semantic description language used in their project is OWL-DL, the inference technique is based on Description Logic, and the framework can be integrated with other existing metadata specifications, such as LOM, SCORM, and Dublin Core [5].

Song [13] proposes a metadata framework for description of Learning Objects. The framework gives Learning Objects a structure- and metadata-based description. In this framework a Learning Object contains three types of components. The first is the resource type, which includes Learning Component, Learning Content, and Learning Carrier. The second is the reference type, which includes Learning Reference, Learning Neighbour, and Learning Link. The third is the attribute type, which has a Learning Intensity as its instance. Song also proposes a goal-driven Learning Object search method. This method pays attention to using synthetic representation of information from learning information consumers. It converts learning's requirements into goals and uses the goals matching with the Learning Object metadata model in the Learning Object repository to locate right learning materials.

Dichev et al. [4] discuss in their work how the topic map [2] can be used to manage a Learning Object repository. Each Learning Object in their repository is associated with a topic map which is a standard-based approach to encoding an expert's knowledge, i.e. to building educational ontologies and courseware components. By using topic map, the Learning Objects become reusable, sharable, and exchangeable.

6 Conclusion

E-Learning has become an important research area and is creating a new paradigm of modern education. More and more companies and organisations are starting to provide online courses and training materials. However, most of the online learning resources are poorly described and structured so causing huge problems in their use, search, organization, and management. To overcome the problems, in this paper we proposed a novel and practical Context-based Semantic Description Framework (CbSDF) to describe information and knowledge about learning resources and their structures. Based on our framework we developed a two-step search mechanism for searching learning resources by using the CG matching and the semantic similarity ranking techniques. The work proposed in this paper aims to support learners in using massive learning resources from the Web to perform self-learning with or without the help of educators' advice and instruction.

Our method was evaluated by a prototype using the learning resources from different Learning Object repositories. In next step, we will fully implement our framework

and develop more complete and suitable evaluation methods to assess the performance, scalability, and precision of the search methods, especially for large amounts of learning resources.

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