Applications of Description Logics to Improve Multimedia Information Retrieval for Efficient Educational Tools

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ABSTRACT

There is a growing discrepancy between the creation of digital content and its actual employment and usefulness in a learning society. Technologies for recording lectures have become readily available and the sheer number and size of such objects produced grows exponentially. However, in practice most recordings are monolithic entities that cannot be integrated into an active learning process offhand. To overcome this problem, recorded lectures have to be semantically annotated to become full-fledged e-learning objects facilitating automated reasoning over their content. We present a running web-based system — the e-Librarian Service CHESt — that is able to match a user's question given in natural language to a selection of semantically pertinent learning objects based on an adapted best cover algorithm. We show with empirical data that the precision of our e-Librarian Service is much more efficient than traditional keyword-based information retrieval; it yields a correct answer in most of the cases (93% of the queries), and mostly with a high precision, i.e., without supplementary hits. We also describe some ideas to improve the retrieval performance by user feedback.

Categories and Subject Descriptors: H.3.3 Information Systems: Information Storage and Retrieval [Information Search and Retrieval]; H.5.2 Information Systems: Information Interfaces and Presentation [User Interfaces, Natural Language]

General Terms: Algorithms, Measurement, Reliability

Keywords: semantic search engine, semantic distance, description logics, OWL, multimedia retrieval

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1. INTRODUCTION

The availability of online teaching material is increasing dramatically, e.g., the tele-TASK archive[1], World Lecture Hall (WLH)[2], the Multimedia Educational Resource for Learning and Online Teaching (MERLOT)[3], Deutscher Bildungsserver[4], Kidlink[5], MySchool![6], MIT Open Courseware[7], Explore e-Learning[8], and Learning Science[9]. However, its usage in an educational environment is poor, mainly due to two facts [21, 9, 24, 30]. First, there is currently no reliable mechanism to prove the correctness of the data. Second, there is way too much information, in particular redundant and not relevant information, so that finding appropriate answers in an efficient way is a rather difficult task being reliant on the user's interaction. The user is charged with the awkward, time consuming and diverting task of filtering the pertinent information out of the *noise*. Turning such knowledge bases into useful educational resources requires to identify correct, reliable, and machine understandable resources, as well as to develop simple but highly efficient search tools with the ability to perform logical inferences over these resources. This idea is fully in the stream of current Semantic Web thinking.

In this paper we describe a running system[10] — the e-Librarian Service CHESt [15] — that is able to understand a user's questions given in natural language (NL) and to retrieve semantically pertinent resources out of a multimedia knowledge base. We call such resources *Learning Objects* (LOs). By LO we refer to an entity about a precise subject that may be used for learning, education or training [26], e.g., a video sequence including machine processable metadata that semantically describe its content.

It has been realized that digital libraries do benefit from having its content understandable and available in a machine processable form, and it is widely agreed that ontologies will play a key role in providing the infrastructure to achieve this

[1] `http://www.tele-task.de/`
[2] `http://web.austin.utexas.edu/wlh/http://web.austin.utexas.edu/wlh/`
[3] `http://www.merlot.org/`
[4] `http://www.bildungsserver.de/`
[5] `http://www.kidlink.org/`
[6] `http://www.education.lu`
[7] `http://ocw.mit.edu`
[8] `http://www.explorelearning.com`
[9] `http://www.learningscience.org`
[10] `http://www.linckels.lu/chest`

goal. One of the basic building blocks of our e-Librarian Service is a common domain ontology, which has a double use. First, the domain ontology is used to describe the LOs in the knowledge base with additional semantic metadata. We developed solutions to automatically generate the semantic metadata based on the textual and audio data of the LOs [28]. Second, the domain ontology is used for the translation of the NL user questions into a formal language, i.e., Description Logics (DLs). DLs are a family of knowledge representation formalisms that allow to represent the knowledge of an application domain in a structured way and to reason about this knowledge [1]. The semantic interpretation, i.e., the translation of a NL user question into a DL is described in [17].

Our E-Librarian Service can be perceived as a specialization of passage retrieval techniques; see [18, 27] for an overview. It implements a retrieval algorithm that is based on the *concept covering problem* — a non-standard inference mechanism in DL. Among all the LOs that have some common information with the user query, our algorithm is able to identify the most pertinent match(es), keeping in mind that the user in general expects an exhaustive answer while preferring a concise answer with only little or no information overhead. The evaluation of our algorithm shows that in an educational environment our e-Librarian Service is much more appropriate than a traditional keyword-based search engine, because it delivers much less information overhead while simultaneously providing a higher precision.

The paper is structured as follows. After this introduction, section 2 discusses related work and projects. The main contribution of the paper is the algorithm for retrieving semantically pertinent LOs from a given knowledge base. The algorithm is presented in section 3, and explicitly discussed and evaluated in section 4. Section 5 provides an outlook and discussion how the system can be improved by user contributions and feedback, while section 6 concludes the paper with a brief summary of achieved results.

2. RELATED WORK

Instead of the traditional Question Answering (QA) as being subject in linguistics and information retrieval [22], our approach is not targeted to compute a coherent answer being expressed in NL. We simply provide a set of interrelated resources (LOs), which contain the information that is necessary to answer the user's question. The user has to read the provided LO(s) to obtain an answer. We address three different approaches related to document matching and retrieval based on DL inferences.

First, an approach for matching documents based on non-standard inferences in the DL sub-languages $\mathcal{ALNS}, \mathcal{ALN}^*$, and $\mathcal{ALE}$ is presented in [12]. A matching problem modulo equivalence and modulo subsumption is of the form $C \equiv^? D$ and $C \sqsubseteq^? D$ respectively, where C is a description and D a pattern. A solution or matcher of these problems is a substitution σ such that $C \equiv \sigma(D)$ and $C \sqsubseteq \sigma(D)$, respectively. The solution is based on computing homomorphisms between description trees. Although this is an excellent solution for dealing with complex descriptions such as for comparing complete documents, it is less appropriate for our purpose. In our case, LOs are described by simple semantic annotations with few role-imbrications. The resulting description trees are rather flat and comprise rarely more than two levels.

Second, the concept covering problem [10] is based on DLs with structural subsumption. The proposed algorithm for identifying the best cover relies on the computation of minimal transversals in a hypergraph. The algorithm has been implemented in the project MKBEEM (Multilingual Knowledge Based European Electronic Marketplace). That solution is very pertinent for our e-Librarian Service because it always finds the best cover, i.e., the best matching LOs w.r.t. the user's question (see section 3.2).

Another definition of the concept covering problem that eliminates the limitation of DLs to provide structural subsumption has been presented in [7]. There, the concept covering problem is based on the concept abduction problem (CAP) [25], which is able to provide an explanation if subsumption does not hold. It is stated as follows: S (supply) and D (demand) are two descriptions in a DL $\mathcal{L}$, and satisfiable in a terminology $\mathcal{T}$. A CAP, identified by $< \mathcal{L}, S, D, \mathcal{T} >$, is finding a concept $H \in \mathcal{L}$ (hypotheses) such that $\mathcal{T} \models S \sqcap H \sqsubseteq D$, and moreover $S \sqcap H \not\equiv \perp$. The algorithm was implemented in a project for semantic-based discovery of matches and negotiation spaces in an e-marketplace. One of the weaknesses of this solution is that does not always return an optimal cover.

We decided to base our e-Librarian Service on the concept covering problem as presented in [10] because for our application DLs with structural subsumption provide sufficient expressiveness. Furthermore, our system must always return an optimal cover. Finally, the solution is simple and adapted to our LO descriptions.

3. THE LO RETRIEVAL PROBLEM

In this section we describe the multimedia information retrieval aspect of our e-Librarian Service that can be perceived as a specialization of *passage retrieval* techniques. Passage retrieval techniques have been extensively used in standard IR settings, and have proven effective for document retrieval when documents are long or when there are topic changes within a document, thus making it an appealing candidate for the present work [18]. By *retrieval* we refer to answering a user's question by identifying only the semantically most pertinent LOs according to the given question. In addition, the system must be able to quantify the quality of the yielded results, i.e., to measure the semantic distance between the user's query and the identified LOs. This measure is also used to rank similar results.

Our solution is based on the *concept covering problem* and on the quantification of the *semantic difference* in DL. The novelty of our approach is that it always proposes a solution to the user, even if the system concludes that there is no exhaustive answer. By quantifying the missing and supplementary information, the system is able to compute and visualize the quality and pertinence of the yielded LO(s).

3.1 Least Common Subsumer and Semantic Difference

The least common subsumer (lcs) [2] stands for the least concept description (w.r.t. subsumption) that subsumes a given set of concept descriptions.

DEFINITION 1 (LEAST COMMON SUBSUMER). *Let $\mathcal{L}$ be a DL and C, D, E be $\mathcal{L}$-concept descriptions. The concept E is a lcs of C, D iff it satisfies:*

- $C \sqsubseteq E$ *and* $D \sqsubseteq E$, *and*

- *E is the least $\mathcal{L}$-concept description with this property, i.e., if E' is an $\mathcal{L}$ concept description satisfying $C \sqsubseteq E'$ and $D \sqsubseteq E'$, then $E \sqsubseteq E'$.*

The difference operation [29] allows to remove from a given concept description all the information contained in another concept description.

DEFINITION 2 (SEMANTIC DIFFERENCE). *Let $\mathcal{L}$ be a DL and $C, D \in \mathcal{L}$ two concept descriptions with $C \sqsubseteq D$. Then the semantic difference $C - D$ is defined by:*

$$C - D = max_{\sqsubseteq}\{E \in \mathcal{L} : E \sqcap D \equiv C\}.$$

This definition of semantic difference requires that the second argument subsumes the first one. However, the semantic difference $C - D$ between two incomparable descriptions C and D can be given by computing the least common subsumer of C and D:

$$C - D = C - lcs(C, D).$$

3.2 Finding Pertinent Documents

The concept covering problem [10] defines a cover of a concept C w.r.t. a terminology $\mathcal{T}$ as being the conjunction of some defined concepts in $\mathcal{T}$ that share some information with Q.

Although this principle is the most pertinent solution for our E-Librarian Service, we think that a user might not be satisfied if the delivered answer to his/her precise question is a concatenation of different — normally not related — resources from the knowledge base. First, there is no transition between the different LOs in the answer. Second, we risk that there is mean to much information because the original concept covering problems adds all LOs to the answer until the answer is covered completely.

We learned from experiments [16] that users prefer few but precise answers even if these answers are not complete, rather than a set of different concatenated documents. This assertion is confirmed by pedagogical analyzes, e.g., [14, 9, 11, 4] that students are searching for one — the best — answer, and do not consider different delivered search results. They would rather reformulated their query until they receive only a few results, or until they find the perfect result.

Our modified concept covering problem defines a cover as a concept description C w.r.t. a terminology $\mathcal{T}$ that shares some information with another concept description Q w.r.t. $\mathcal{T}$.

DEFINITION 3 (COVER). *Let $\mathcal{L}$ be a DL with structural subsumption, $\mathcal{T}$ be an $\mathcal{L}$-terminology and $C_{\mathcal{T}} = \{C_i \not\equiv \bot, i \in [1, n]\}$ the set of concept descriptions occurring in $\mathcal{T}$. Then $C_j \in C_{\mathcal{T}}$ is a cover of a $\mathcal{L}$-concept description $Q \not\equiv \bot$ if $Q - lcs_{\mathcal{T}}(Q, C_j) \not\equiv Q$.*

To find the best matching document among all candidates, we refer to the notion of semantic distance (or semantic relatedness); the smaller the semantic distance between the query and the candidate document, the more pertinent the document is for the user. Different alternative approaches exist, e.g., [20, 8, 5, 6, 13].

The best cover can be defined based on the remaining information in the query (denoted as $Miss$) and in the cover (denoted as $Rest$). The Miss is the part of the query that is not part of the cover, and the Rest is the information that is part of the cover but not required by the query (see figure 1).

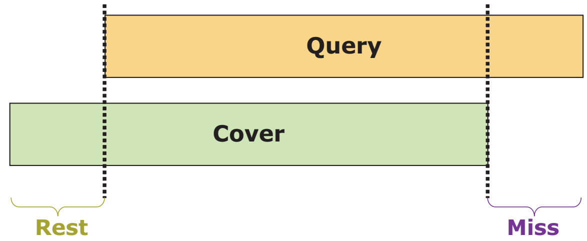

Figure 1: Graphical illustration of the Miss and Rest.

DEFINITION 4 (MISS AND REST). *Let Q, C be be two $\mathcal{L}$-concept descriptions.*

- *The Miss of Q w.r.t. C, denoted as $Miss(Q, C)$ is defined as follows:*
  $Miss(Q, C) = Q - lcs_{\mathcal{T}}(Q, C)$.
- *The Rest of Q w.r.t. C denoted as $Rest(Q, C)$ is defined as follows:*
  $Rest(Q, C) = C - lcs_{\mathcal{T}}(Q, C)$.

The best cover can be assumed as being the cover with the smallest Miss and Rest. Therefore, we have to quantify the Miss and the Rest, i.e., measure the size of a $\mathcal{L}$-concept description.

DEFINITION 5 (SIZE OF A CONCEPT DESCRIPTION). *The size of a $\mathcal{L}$-concept description, denoted as $|\cdot|$ is inductively defined by:*

- $|\bot| = |\top| = 0$,
- $|A| = |\neg A| = 1$,
- $|\exists r.C| = |\forall r.C| = 2 + |C|$,
- $|C \sqcap D| = |C \sqcup D| = |C| + |D|$,
- $|\neg C| = |C|$.

Hence, the size of the concept description $Q \equiv \mathsf{TCPIP} \sqcap \mathsf{Protocol} \sqcap \exists\mathsf{hasTask}$ — representing the question: "What are the tasks of the protocol TCP/IP?" — is computed as follows:

$$\begin{array}{rcl} |\mathsf{TCPIP}| & = & 1 \\ |\mathsf{Protocol}| & = & 1 \\ |\mathsf{Communication}| & = & 1 \\ |\exists\mathsf{hasTask}| & = & 2 \\ \hline |Q| & = & 5 \end{array}$$

DEFINITION 6 (BEST COVER). *Let C, D be two $\mathcal{L}$-concept descriptions. A cover C is called a best cover w.r.t. Q using a terminology $\mathcal{T}$ iff:*

- *C is a cover w.r.t. Q using $\mathcal{T}$, and*
- *there does not exists any cover C' of Q using $\mathcal{T}$ such that*
  $$(|Miss(Q, C')|, |Rest(Q, C')|) < (|Miss(Q, C)|, |Rest(Q, C)|)$$
  where $<$ stands for the lexicographic order.

By choosing a lexicographical order we give preference to a minimized Miss, e.g., for (Miss,Rest), the couple (1,2) < (2,1) because the first couple has a smaller Miss than the second one. In fact, the e-Librarian Service aims to give an exhaustive answer in the first place, i.e., to yield an answer that covers the user's query as much as possible, even if there is more information in the answer than required. Only in the second place, the Rest is considered in order to rank the results that have the same Miss.

3.3 Algorithm for the LO Retrieval Problem

Our best cover algorithm is called LOFind (see figure 2). As input a query Q is expected that was translated into a $\mathcal{L}$-concept description, and a $\mathcal{L}$-terminology $\mathcal{T}$, i.e., a set of semantic descriptions of LOs. The output of LOFind is the set E of best covers w.r.t. Q using $\mathcal{T}$.

```
Require: a query Q ≢ ⊥,
Require: a set of concept descriptions
    C_T = {C_i ≢ ⊥, i ∈ [1, n]}
Ensure: a set of best covers E = {C_j ∈ C_T, j ∈ [0..n]}
 1: E ← ∅
 2: MinMiss ← +∞
 3: for each C_i ∈ C_T do
 4:   if Q − lcs(Q, C_i ≢ Q) then
 5:     if |Miss(Q, C_i)| < MinMiss then
 6:       E ← C_i
 7:       MinMiss ← |Miss(Q, C_i)|
 8:     else if |Miss(Q, C_i)| = MinMiss then
 9:       E ← E ∪ C_i
10:     end if
11:   end if
12: end for
```

Figure 2: The algorithm LOFind

The algorithm works as follows. Let us suppose that $C_{\mathcal{T}}$ is the set of semantic descriptions of the LOs in our knowledge base. Then, each LO is tested if it is a cover (line 4). If so, then it will only be maintained, if either the size of its Miss is smaller than (line 5) or equal to (line 8) the smallest Miss found up to now. In the first case, the current LO replaces all the former best cover-candidates (lines 6 + 7). In the second case, the current LO is added to the best cover-candidates found up to now (line 9).

3.4 Illustrating Example

$\mathsf{LO}_1 \equiv$	Protocol
$\mathsf{LO}_2 \equiv$	$\exists$howWorks $\sqcap$ TCP/IP
$\mathsf{LO}_3 \equiv$	Protocol $\sqcap\exists$hasTask.ErrorHandling
$\mathsf{LO}_4 \equiv$	Protocol $\sqcap\exists$hasTask.FlowControl
$\mathsf{LO}_5 \equiv$	FlowControl

Figure 3: Example of a terminology of LO definitions.

For the sake of simplicity, let us suppose that there are 5 LOs in the knowledge base. The corresponding semantic descriptions are shown in figure 3. We use the DL sub-language $\mathcal{EL}$ that has structural subsumption and allows conjunction ($\sqcap$), existential restriction ($\exists r.C$), and the top concept ($\top$). The content of the LOs deals with the following topics:

LO$_1$: information about protocols in general,
LO$_2$: explanation how the protocol TCP/IP works,
LO$_3$: explanation that error handling is a task of a protocol,
LO$_4$: explanation that flow control is a task of a protocol,
LO$_5$: explanation of flow control.

3.4.1 Step 1: Expanding the Terminology.

Expanding the terminology means, making explicit some implicit knowledge. The expanded terminology uses the example taxonomy about networking (see figure 4) and is shown in figure 5.

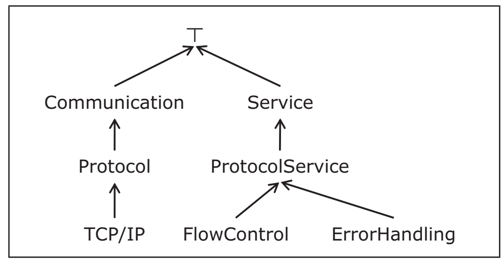

Figure 4: Sample of a taxonomy about networking.

$\mathsf{LO}_1 \equiv$	Protocol $\sqcap$ Communication
$\mathsf{LO}_2 \equiv$	$\exists$howWorks $\sqcap$ TCP/IP $\sqcap$ Protocol $\sqcap$ Communication
$\mathsf{LO}_3 \equiv$	Protocol $\sqcap$ Communication $\sqcap\exists$hasTask.(ErrorHandling$\sqcap$ ProtocolService $\sqcap$ Service)
$\mathsf{LO}_4 \equiv$	Protocol $\sqcap$ Communication $\sqcap\exists$hasTask.(FlowControl $\sqcap$ ProtocolService $\sqcap$ Service)
$\mathsf{LO}_5 \equiv$	FlowControl $\sqcap$ ProtocolService $\sqcap$ Service

Figure 5: Example of an expanded terminology.

3.4.2 Step 2: Computing the Covers.

Let us suppose that the user has entered the NL question "*What are the tasks of TCP/IP?* ", and that the question was translated into the following $\mathcal{EL}$-concept description: $Q \equiv \mathsf{TCP/IP} \sqcap \exists\mathsf{hasTask}$. In the expanded form the user's question can be denoted as:

$$Q \equiv \mathsf{TCP/IP} \sqcap \mathsf{Protocol} \sqcap \mathsf{Communication} \sqcap \exists\mathsf{hasTask}.$$

The aim is now to identify the candidate documents within the expanded terminology that cover the expanded query, i.e., that have something in common with Q; these are: LO$_1$, LO$_2$, LO$_3$, and LO$_4$ as depicted in figure 6.

3.4.3 Step 3: Computing the Best Cover.

Now, for each cover the according Miss and Rest have to be computed, see figure 7. The best cover is the one with minimal Miss and Rest, with a preference to the minimal Miss.

3.4.4 Conclusion:

LO$_3$ and LO$_4$ are the best covers and are delivered as an answer to the user's query. Both LOs have the same Miss and Rest, 1 and 3, respectively so that their rank is the same.

	common with Q	not common with Q
LO_1	$\mathsf{Protocol} \sqcap \mathsf{Communication}$	$\top$
LO_2	$\mathsf{TCPIP} \sqcap \mathsf{Protocol} \sqcap \mathsf{Communication}$	$\exists\mathsf{howWorks}$
LO_3	$\mathsf{Protocol} \sqcap \mathsf{Communication} \sqcap \exists\mathsf{hasTask}$	$\exists\mathsf{hasTask}.(\mathsf{ErrorHandling} \sqcap \mathsf{ProtocolService} \sqcap \mathsf{Service})$
LO_4	$\mathsf{Protocol} \sqcap \mathsf{Communication} \sqcap \exists\mathsf{hasTask}$	$\exists\mathsf{hasTask}.(\mathsf{FlowControl} \sqcap \mathsf{ProtocolService} \sqcap \mathsf{Service})$
LO_5	$\top$	$\mathsf{FlowControl} \sqcap \mathsf{ProtocolService} \sqcap \mathsf{Service}$

Figure 6: Common (cover) and not common parts of each LO w.r.t. a user question Q.

	size of the Miss	size of the Rest
LO_1	$\lvert\mathsf{TCP/IP} \sqcap \exists\mathsf{hasTask}\rvert = 3$	$\lvert\top\rvert = 0$
LO_2	$\lvert\exists\mathsf{hasTask}\rvert = 2$	$\lvert\exists\mathsf{howWorks}\rvert = 2$
LO_3	$\lvert\mathsf{TCP/IP}\rvert = 1$	$\lvert\mathsf{ErrorHandling} \sqcap \mathsf{ProtocolService} \sqcap \mathsf{Service}\rvert = 3$
LO_4	$\lvert\mathsf{TCP/IP}\rvert = 1$	$\lvert\mathsf{FlowControl} \sqcap \mathsf{ProtocolService} \sqcap \mathsf{Service}\rvert = 3$

Figure 7: Quantification of the candidate documents.

It is interesting to mention that the concept $\mathsf{TCP/IP}$ does not appear in one of the best covers, although it appears in the query and in LO_1. This shows that the best cover is not computed on a statistical evaluation of keywords, but that it is in fact the result of the logical inference.

Other covers, usually those where the size of the Miss is greater by one than the size of the Miss of the best cover, are yielded as second choice, here: LO_2.

4. EVALUATION

Our algorithm was compared in a benchmark test with a traditional keyword-based search engine. Unfortunately, no similar measurements are available for the related projects referred in section 2.

4.1 Knowledge Base and Set of Questions

We used the online tele-TASK archive[11] that contains hundreds of recorded university lectures, as knowledge base. We selected the lecture series about Internetworking, which is a set of 30 units with a total of 38 hours of recorded lectures. We split the 30 lecture units into 1000 smaller LOs. A set of 123 NL questions about the topic Internetworking has been created. We tried to work out questions as students would ask, e.g., "*What is an IP-address composed of?*", "*How does a datapacket find its way through a network?*", "*What is a switch good for?*", "*Do internetprotocols guarantee an error-free communication?*". We also indicated for each question the relevant answer(s) that should be delivered.

4.2 Evaluation Constraints

We call an answer from the e-Librarian Service a *perfect hit* if it covers the query completely, i.e., where the Miss and the Rest compute to zero. We call an answer from the e-Librarian Service a *sufficient hit* if it covers the query completely, but the answer contains more information than necessary, i.e., where the Miss equals zero and the Rest computes to some positive value.

For the evaluation we only considered the best covers with minimal Miss, not the second choices. This means that if the e-Librarian Service did not deliver an exhaustive answer as best cover but only as second choice, then we considered the answer to be wrong.

The results achieved with our e-Librarian Service have been compared with the results of a traditional keyword-based search engine. The keyword-based search engine is working in the usual way by browsing the textual content of the LOs. The textual content was generated by converting the PowerPoint-slides into pure text. A LO is considered to be a potential answer, if at least one (relevant) keyword from the user's query can be found. The keyword-based search engine does not consider stop words, i.e., words with no semantic relevance.

4.3 Benchmark Results

The benchmark test was performed on a standard Windows XP computer with a 1.4 GHz CPU and 512 MB of RAM. The e-Librarian Service has been implemented as a Java application. The processing time of the first question is about 200 ms, while for the rest it is less than 10 ms. The outcomes of the benchmark test are the following.

First, the e-Librarian Service scored better than the keyword search regarding the pertinence of the results. In most cases the e-Librarian Service yielded the correct answer, see figure 8.

These numbers emphasize the pertinence of our e-Librarian Service as an appropriate tool for an educational environment; in most cases the learner gets a satisfying, even perfect, answer from the system. The fact that some answers contain little more information than necessary is no problem at all and can even have a positive effect for the learner.

Second, the precision of our solution is confirmed by the fact that in average less than 0.7 LOs are delivered in addition to the perfect answer (compared to 6 LOs for the keyword-based search). Figure 9 shows the number of supplementary LOs being delivered in addition to the expected answer. This important outcome points out that the e-Librarian Service usually is achieving the correct answer with no additional information (for 93 out of 123), and in a few cases one (12 out of 123) or two (6 out of 123) supplementary LOs. The keyword-based search engine in general delivers a lot more of secondary LOs.

This result is an important evidence for the pertinence of

[11] http://www.tele-task.de/

	perfect hits	sufficient hits	total queries
e-Librarian Service	93 (76%)	112 (91%)	123 (100%)
Keyword search	9 (7%)	103 (84%)	123 (100%)

Figure 8: Benchmark results of our e-Librarian Service and a keyword-based search.

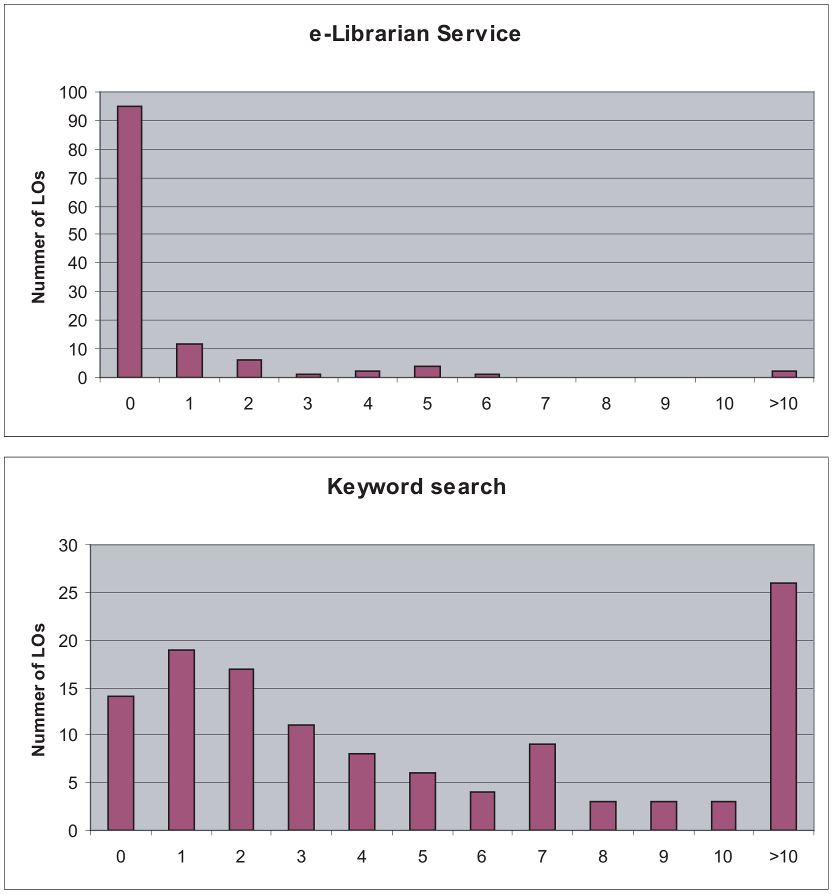

Figure 9: Number of supplementary LOs yielded with the optimal answer.

our tool in an educational environment; the user asks a precise question (or enters a keyword phrase) and expects few but concise answers. However, the keyword-based search leaves the user with the awkward task of filtering the pertinent answers out of the noise.

Third, in information retrieval the performance of a retrieval algorithm is measured by *recall* and *precision* [3]. Let use emphasize that for each question in the test set, there are only few relevant documents to be retrieved (in average 1.29 relevant answers per question). For this reason, we refer only to an average recall-level rather than to the 11 standard recall-levels. For an average recall-level, the precision of the e-Librarian Service is 84.41%, compared to 40.42% for the keyword-based search. These numbers confirm the previous outcome that our algorithm has a very high precision about the pertinence of the yielded answers; its average precision is more than twice as much than the precision achieved with the keyword-based search.

5. IMPROVING SEARCH RESULT QUALITY WITH USER FEEDBACK

In this section, we will briefly present some ideas how to improve the quality of our E-Librarian Service by using the user's intellectual capabilities. These are: direct user feedback, collaborative tagging and social networks, and diversification of user feedback.

5.1 Direct User Feedback

Direct user feedback can be achieved in different forms. The most simple way is to let the user determine whether a given result set of documents really is appropriate according to his/her question or not. The E-Librarian Service has to keep track of user feedback and to channel that data into the rank computation of the document result sets.

The E-Librarian Service faces the problem to provide both an *objective answer*, as well as a feedback-driven and therefore more or less *subjective answer*. Therefore, it displays both the (objective) best covers and the (subjective) feedback-based results. Thus, the user has the possibility to see objectively computed results, and the results according to the opinion of other users. If both results fit in the way that they both display the same top-rank result, the quality of our algorithm is confirmed.

5.2 Collaborative Tagging and Social Networks

User generated keywords (tags) are an additional source for the semantic annotation of documents in a knowledge base. A user might provide additional, otherwise not available semantic annotation. In this regard, *collaborative tagging* has gained increasing popularity, which is demonstrated by the growing number of prominent tagging and annotation sites such as Delicious[12], Flickr[13], or Bibsonomy[14].

An additional source of information is provided by the *social networking* information of the tagging service. Based on this networking information a similarity measure for documents can be determined. Users, who tag the same documents with the same or similar keywords can be considered to have similar or common interests. By retrieving documents with similar tags, similar documents can be determined.

5.3 Considering the User's Expectations

Different users asking the same question might expect different answers. This is due to the fact that different users prefer different levels of complexity, of difficulty, and of elaborateness [19, 23]. Moreover, different users come from different backgrounds, have different motivations, and thus, a different context. The user must be given the means to specify, if (s)he prefers complex and precise documents, or if a short overview about the requested topic is sufficient.

If our E-Librarian Service keeps track of the user's actions, then statistics can be gathered about document usage. If a user has already accessed and used a given document, this information can be used to customize the computation of the best cover w.r.t. the previous knowledge of the user.

6. CONCLUSION

In this paper we have proposed the e-Librarian Service CHESt based on a retrieval algorithm that returns only semantically pertinent LOs from a multimedia repository w.r.t. a user's query given in NL. We have applied two non-standard inferences of DLs — the least common subsumer (lcs), and the difference operation — to compute the best cover of the user's query. The e-Librarian Service has been developed in the context of the "Learning Engineering" project[15], which aims at exploring novel internet- and IT-technologies in order to enhance university teaching and research. Our solution is particularly interesting for education in a self-directed learning environment, where it fosters autonomous and exploratory learning [16].

A similar e-Librarian Service for learning fractions in mathematics with a different retrieval algorithm has already been tested successfully in school [16]. We were able to measure a relevant improvement in the students' scores. This is mainly attributed to the fact that the students were more motivated by using our system — because they quickly found the pertinent answer to their question(s) — and therefore put more effort into learning and acquiring new knowledge.

Currently, we are working to improve the quality of the achieved results by implementing approaches concerning the integration of user feedback and social networking information as described in section 5.

[12] `http://www.del.icio.us/`
[13] `http;//www.flickr.com/`
[14] `http://http://www.bibsonomy.org/`
[15] `http://www.hpi.uni-potsdam.de/~meinel/research/web_university.html`

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