Reasoning about eLearning Multimedia Objects*

Michael Engelhardt[1], Arne Hildebrand[1], Dagmar Lange[1]
and Thomas C. Schmidt[2,1]

[1] FHTW Berlin, Hochschulrechenzentrum, Treskowallee 8, 10318 Berlin, Germany
[2] HAW Hamburg, Department Informatik, Berliner Tor 7, 20099 Hamburg, Germany
{engelh, hilde, langeda, schmidt}@fhtw-berlin.de

Abstract. The advancement of hypermedia technologies led teachers and learners to a daily use of multimedia components. Media bricks in educational content management have evolved into IEEE LOM eLearning Objects, which combine content with an expressive set of metadata and are structured by a variety of named relations. Such "eLOs" are nicely suited for self-explorative learning within adaptive hypermedia applications, but force authors not only into content editing, but the provisioning of meta descriptors and numerous inter–object relations. This paper reports on our ongoing activities to semi–automatically generate eLearning Objects from classroom recordings, to harvest metadata from context and content analysis and to generate a dense semantic net between eLOs based on extended LOM relations. Special focus is drawn on the processing of recorded speech and an Ontological Evaluation Layer for an autonomous derivation of object relations.
These solutions have been implemented in the Hypermedia Learning Objects System (hylOs), our prototype of an eLearning content management system. hyLOs is built upon the more general Media Information Repository (MIR) and the MIR adaptive context linking environment (MIRaCLE), its linking extension. MIR is an open system supporting the standard XML, CORBA and JNDI. hyLOs benefits from manageable information structures, sophisticated access logic and high-level authoring tools like the WYSIWYG XML editor and the Instructional Designer.

Keywords: Educational Content Management, Educational Semantic Net, LOM Metadata, eLearning Objects, Semantic Web

1 Introduction

Since hypermedia systems have been introduced to teaching and learning environments, the composition and reception of learning material have undergone a shift in paradigm. Linear instructional designs manifested in books or scripts are now complemented by meshed knowledge networks. Content access no longer

* This work has been supported in parts by the the European Commission within the EFRE program **eTrain** and within the EUMIDIS project **Odiseame**.

follows a single predefined path, but multiple, associative rules driven by individual inquiries. Portable multimedia components and hyperreferences in addition stimulate content exchange and composition between authors. Following these changes a new perspective on content as confined, self–consistent 'knowledge nuggets' has been developed.

In the field of educational content management the concept of atomic content units became standardised as IEEE LOM eLearning Objects (eLOs) [1]. eLOs may combine rich media content, a significant set of metadata and structural relations. eLO content itself may be composed from other eLearning objects, constructing a self–similar knowledge tree for navigation in this fashion. The LOM metadata subsume technical, textual and educational information, which are complemented by a set of named relations. Originally, the latter had been intended for technical and administrative purposes, but shall prove to be valuable for constructing a dense mesh of interobject guidance to the learner. LOM has been chosen as part of the high–level exchange format SCORM, the Sharable Content Object Reference Model [2].

LOM named relations form a key concept to content coherence. While single eLearning content objects should sustain isolated, and content composition only allows for hierarchical structuring along a single perspective, the relational part gives rise to a semantic net interconnecting different objects from mutually unaware authors. However, an author adding any eLO to some repository faces the challenge of discovering and defining relations between his object and the remaining repository. This task becomes intractable for large eLO collections. As part of our presently ongoing work on automated eLO recording and processing, we formalised the semantic of eLO relations within an ontology and an additional set of inference rules. Starting from some initial relations, any new object entering a repository can then automatically harvest named links to any other object from concurrent processing of an inference engine. Initial relations can automatically be derived from previous automatic classification and annotation or taken from limited manual editing.

In the present paper we first briefly introduce the Hypermedia Learning Object System hylOs, our eLearning content management platform used for all implementations. We further on present our ongoing project on automated eLO content acquisition and speech analysis in section 3. Section 4 proposes semantic specifications and extensions to the LOM relations and discusses an automated inference processing. Finally, section 5 is dedicated to a conclusion and outlook.

2 The Hypermedia Learning Object System hylOs

The Hypermedia Learning Object System [3, 4] has been designed to provide full educational content management based on the eLO information model. All knowledge bricks are composed of rich media content elements decorated with a complete set of IEEE LOM metadata and interconnected by qualified relational pointers. They reside within the Media Information Repository [5]. Grounded on a powerful media object model, MIR was designed as a universal fundament for ease in modelling and implementation of complex multimedia applications. All data embedded within the adaptable MIR data store are published in XML format, such that individual views and user interface behaviour can be achieved by lightweight style sheet programming. The rigorous use of the XML technology framework ensures a consistent separation of content, structural information, application logic and design elements. hylOs' adaptive eLearning functions are thereof derived and may attain any look & feel by applying appropriate XSL transforms. The system is used in several eLearning and content management deployment projects within our institutions.

hylOs offers variable content access views to the learner. Besides the primary content tree elaborated by the author(s), instructional design hierarchies may be compiled from repository objects for each teaching trail. Based on its qualified relations, the content additionally is organised in a semantic net, suitable for individual exploration in a constructivist fashion. Traditional hyperreferences, which provide a separate layer of content traversal, may be customized within hylOs, as well. By means of the MIR Adaptive Context Linking Environment MIRaCLE [6], links are processed as reified statements. Distinguished hyperlink layers may be applied onto the same content, as may have been predefined by the teacher or selected by the learner. Links are represented within contextual containers, each one suitable to express a narrative of a specific hyperlinking scheme. These link contexts may be understood as a composition of link rhetoric, as suggested in the early work of Landow [7]. Note that textually coherent hyperlink collections provide an additional, meaningful structure to be harvested in future applications.

A fully distributed authoring environment is part of the hylOs suite, as well. Authors are enabled to edit eLOs in full detail, i.e., rich media content (including mathematical formulae), the LOM metadata tree and all types of relations. Great care has been taken to simplify content elaboration wherever possible. An 'easy authoring sheet' within the SWING application provides WYSIWYG XML editing combined with extensive automated harvesting of metadata. Manual provision for only seven LOM attributes are needed, i.e., keywords, semantic density, difficulty, context, learning resource type, structure and document status, if presets taken from previous editing do not apply. While creating subsequent eLO content, authors implicitly generate an object tree. Re–use of content and structures is supported at any level of complexity. A variety of specific editors for glossaries, (TEX–compliant) bibliographies and taxonomies complement this first–level authoring suite.

Assisted by an additional authoring sheet, the Instructional Designer (iDesigner), any instructor will be enabled to compose overlay trees individually designed for a specific teaching trail. The process of forming a didactically structured outline from single learning components is commonly known as instructional design. This task of arranging the eLOs in different courses or units remains outside the scope of the eLO paradigm. Our approach to instructional design introduces the idea of an instructional container object (ICO). ICOs are inherited from eLOs retaining the complete LOM metadata set and the nesting facility. They implement either a structural container for nesting other ICOs or a visual container to embed eLOs. In addition they offer appropriate instructional types and an optional prolog or epilog. Instructional types are courses, sections or pages for example. In this way, the hylOs iDesigner bridges the gap between reusability and atomicity of eLearning objects on the one hand, and individually and coherently designed courses on the other. It very flexibly imposes instructional overlays onto any, possibly loose collection of eLearning objects.

3 From Content Acquisition to Automated Classification

A manual preparation of eLearning objects remains a tedious undertaking, no matter how well it is supported by appropriate tools. In addition, most presentation material currently in use is brought to lecture rooms by notebooks or offline media, not compliant to the LOM/IMS packaging standard. It is therefore the goal of our ongoing project to add an automatic content acquisition subsystem to hylOs and to produce eLOs 'out of the lecture room'. Complying to a predefined quality standard, these objects may then be used for rapid playout or manual refinement.

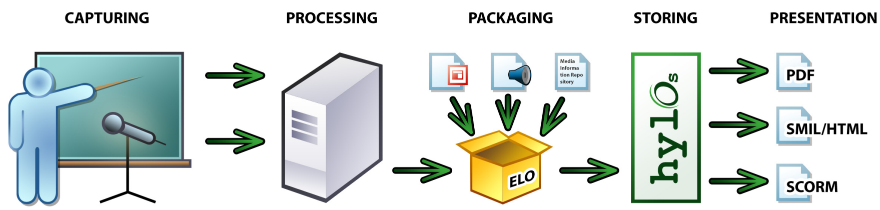

Fig. 1. Process Flow of the Content Acquisition Subsystem

We start from the observation, that audiovisual streams are available for capturing within modern, A/V–equipped lecture halls and concentrate on visual presentation material in combination with spoken audio. We abstain from taking video recordings of the lecturer in our standard scenarios, as shooting and play–back of video require high efforts, while adding limited value to the learning. The signals, i.e., images and audio streams, are continuously captured and analysed. For confining suitable sections, the perpetual media stream is segmented following triggers, which are fired at a change of slide or presentation material. Appropriate cuts are derived from the audio by a silence analysis: Within a neighbouring interval of $\pm 10\ s$ of the trigger moment, a large pause $>\sim 0,5\ s$ of the speaker is identified and used for the cut. Pauses are detected according to dynamically evaluated watermarks. Still in real–time, the obtained audio segment will undergo a rescaling of volume and pause lengths to approach a sound even in volume and rhythm of speech. Finally the data will be efficiently compressed using the Ogg Speex codec [8].

After segmentation the appropriately encoded media will be packaged and – annotated with technical metadata – stored as raw eLOs within hylOs as shown in figure 1. Satisfying the full LOM data structure, the eLearning objects obtained so far are suitable for rough online consumption, manual refinement or further automated processing.

The raw eLOs do not contain any semantically valuable metadata nor do they admit qualified relations to the remaining repository. Subsequent post processing therefore will be needed to assign keywords and a classification from a predefined taxonomy to the newly acquired objects. To achieve this goal, all available sources of information are used, which consist of a predefined context, a predefined classification system in particular, text written on slides and the spoken words from the audio. However, for practical reasons we cannot presuppose a training phase on any speech recognition system and have to refrain from the use of complete speech to text transcriptions. Thus little textual material is available and pure statistical techniques cannot be used.

Instead we employ a controlled vocabulary for keyword spotting. A selection of several thousand pre–classified technical terms is searched within the text and audio files. Speech recognition is done using the Philips Speech SDK[3]. This SDK offers the option to dynamically activate user–specific vocabularies defined in the Java Speech Grammar Format (JSGF) [9]. JSGF allows for the generation of tokens as a combination of synonyms, which we use for collecting flexion forms. Flexions of German words are automatically retrieved via a Web Service of the project "Deutscher Wortschatz" at Leipzig[4].

After keywords have been extracted, we further proceed in a dictionary based approach to derive the classification indices of the eLearning Object by using a simplified version of the statistical schemes in [10, 11]. Operating only on keyword sets, regardless of document lengths, classification is done according to a keyword hit rate for each taxonomic node. Employing Jaccard's coefficient our experiments vary significance levels around 0.5. Current classification is done with respect to DDC [12] and ACM CCS [13], the approach generalises, though, without restrictions. By analyzing text and speech content the recorded eLearning objects has thus been enriched by a title, the author, keywords and classification categories. Additional educational attributes s.a. context or age range may be harvested from presets within the session or from profiles associated with the author.

In the following section 4 we will take up these intermediary results to derive initial relations between eLOs from the annotations and classifications so far obtained.

First Evaluation It should be noted in advance that the procedure introduced above must be seen as a semi–heuristic approach to generate semantic metadata for raw content. There is no guarantee for completeness or correctness, which

[3] Philips Speech SDK: http://www.speechrecognition.philips.com/index.asp?id=521

[4] Projekt "Deutscher Wortschatz" der Universität Leipzig: http://wortschatz.uni-leipzig.de/Webservices/

needs to be assured by manual post–editing, whenever desired. Nevertheless we consider it a noticeable advancement to seamlessly retrieve multimedia content objects decorated with expressive, but semi-reliable metadata, rather than to insist on authors provisioning, which is rarely completed and may be mistaken, as well (see [14, 15] for a detailed discussion).

In detail the approach of keyword spotting has proven to work reasonably well with the untrained speech recognition systems, provided the employed number of terms remains small. For optimisation we partition our dictionary into sets of up to 50 keywords, selected according to an iteratively narrowing context along the classification hierarchy. Term sets then are subsequently applied. This procedure assures not only a largely improved reliability in keyword identification, but allows for consideration of pre–set context branches in taxonomic hierarchies. Fixing a *precision* of 75 % an average *Recall* of about 80 % is obtained. Failures dominantly originate from unrecognised keywords, while erroneous recognitions remain rare. Currently available preliminary results indicate that calculation efforts remain close to real-time.[5]

The selection and evaluation of keywords we consider the crucial part. As there seem to be no classified terminologies for the German language publicly available, we extracted a collection of nearly 2.000 technical terms from bilingual English–German encyclopaedias, which we complemented by additional sources and specific knowledge. Classification of these key–term collections has not only been tedious work, but a reliable source of inexactness. Consequently the quality and richness of our classified vocabulary varies with respect to the subfields visited in the ACM CCS, major improvements need to be achieved.

Classification results do not derive at a uniform level of exactness: A spotted keyword "Ethernet", e.g., will easily lead to highly reliable branches of the ACM taxonomy, whereas solely identified terms like "System" or "Design" will not. Presently the largest shortcoming of our scheme must be seen in its limited ability to arrive at statistically significant classifications, the latter naturally being a function of the preset significance level.

4 An Ontology Based Approach to Constructing Educational Semantic Nets

4.1 Advancing LOM Relations

eLearning objects compliant with the LOM metadata standard provide a section of qualified object relations, which allows to interconnect any two objects in a meaningful fashion. Facing a well maintained mesh of eLOs, a semantic learning net may be presented to the learner for navigation and knowledge exploration, as well as to the author or instructional designer.

However, the expressiveness of LOM relations is limited to the administrative view of librarians, as types and semantics of these relations have been directly

[5] We use a standard PC with a single 2.4 GHz processor. Note that keyword splitting allows for parallel processing of different term sets.

adopted from the Dublin Core library metadata set (see table 1). To gain expressions suitable for educational hypermedia, the semantic of DC relations needs adaptation, sharpening and a careful extension, which has been addressed in parts by several authors of educational systems [16–18].

Is part of	Is version of	Is format of	Is referenced by	Is based on	Is required by
Has part	Has version	Has format	References	Is basis for	Requires

Table 1. Original Dublin Core/LOM Relations

For an elaboration of a fairly comprehensive, viable notion on a semantic educational net, we proceed in three phases: At first, we select those relations from the DC set, which sustain suitable under minor modifications and specifications in the educational hypermedia context. The results are shown in table 2. The major, unobvious change consists in turning 'isFormatOf' into a symmetric property. The corresponding DC inverse property pair expresses bibliophilic editorial hierarchies, which remain absent in hypermedia systems.

At second, we redefine the semantic of those DC properties, which had been bound to pure technical terms. Even though similar reinterpretations have been commonly undertaken in LOM based educational contexts, an explicitly stated semantic is lacking, but needed for further operations. Table 3 displays the corresponding entities and their semantic values. These three DC property pairs now essentially express thematic dependencies of increasing strengths. 'references' and 'isBasedOn' both admit mandatory roles and thus fail to reach transitivity.

Relation	Semantic
hasPart/isPartOf	This inverse pair of transitive properties expresses the structural relation of nesting eLOs. There is no additional meaning related to content.
hasVersion/isVersion	This pair of inverse properties describes versioning as generated by updates or redesigns. Different versions may deviate in content and author, preserving thematic dedication and technical format, though.
isFormatOf	This symmetric property relates eLOs, which essentially cover the same content in different formats. It does not imply interchangeability, but a persistence of educational context.

Table 2. Modified Semantic for Selected DC Relations

Finally we choose a set of additional relation properties, which are missing in the LOM standard. Most importantly the taxonomic interdependence 'isBroaderThan' has been raised to the eLO net. Guided by the maxim of restraint, only three horizontal relations have been introduced for improved orientation in con-

Relation	Semantic
references/ isReferencedBy	This inverse property pair describes a weak form of content relation: An author references another eLO for mandatory information extensions, similar to common use of hyperlinks.
isBasedOn/ isBasisFor	This inverse property pair relates an eLO carrying content fundamental to another. It expresses a strong, but mandatory textual relation.
requires/ isRequiredBy	This inverse pair of transitive properties denotes an obligatory content dependence in the sense that eLO A cannot be understood without knowledge of eLO B.

Table 3. Redefined Semantic for Selected DC Relations

Relation	Semantic
isNarrowerThan/ isBroaderThan	This inverse pair of transitive properties encodes the standard taxonomic relation.
isAlternativeTo	This symmetric transitive property connects interchangeable eLOs. Alternative eLOs are meant to be of equivalent content, pedagogical and structural properties, but may deviate in formats.
illustrates/ IsIllustratedBy	This inverse property pair expresses illustration in an open fashion. For illustration an eLO need not be of specific content type.
isLessSpecificThan/ isMoreSpecificThan	This inverse pair of transitive properties relates two objects, which are of strong thematic familiarity, but differ in generality. A more specific object may cover subaspects or the identical subject in more detail or exhibit a thematic overlap while being more specific.

Table 4. Additional Educational Relations

tent access. Any additional values representing a meta discourse on content, as introduced by [16], were omitted for the sake of simplicity and clarity. Types and semantic of these newly introduced relations are visualised in table 4.

Note that all relations occur symmetric or in inverse pairs. Besides systematic considerations, this characteristic covers an important technical consequence. Any author may denote any relation by just requiring write access to his own objects.

An example of a semantic net derived from extended LOM relations is visualised in figure 2. All chosen subjects from the Semantic Web context are connected via qualified relations, which allow for a coherent, semantically guided content access. A learner, meeting a well maintained educational semantic net tied by the relations described above, will greatly profit in content navigation, orientation and exploration. It is moreover easy to implement, as has been done within the hylOs application. Any author exploring the current state of an eLO repository will likewise benefit from a dense mesh covering his region of interest.

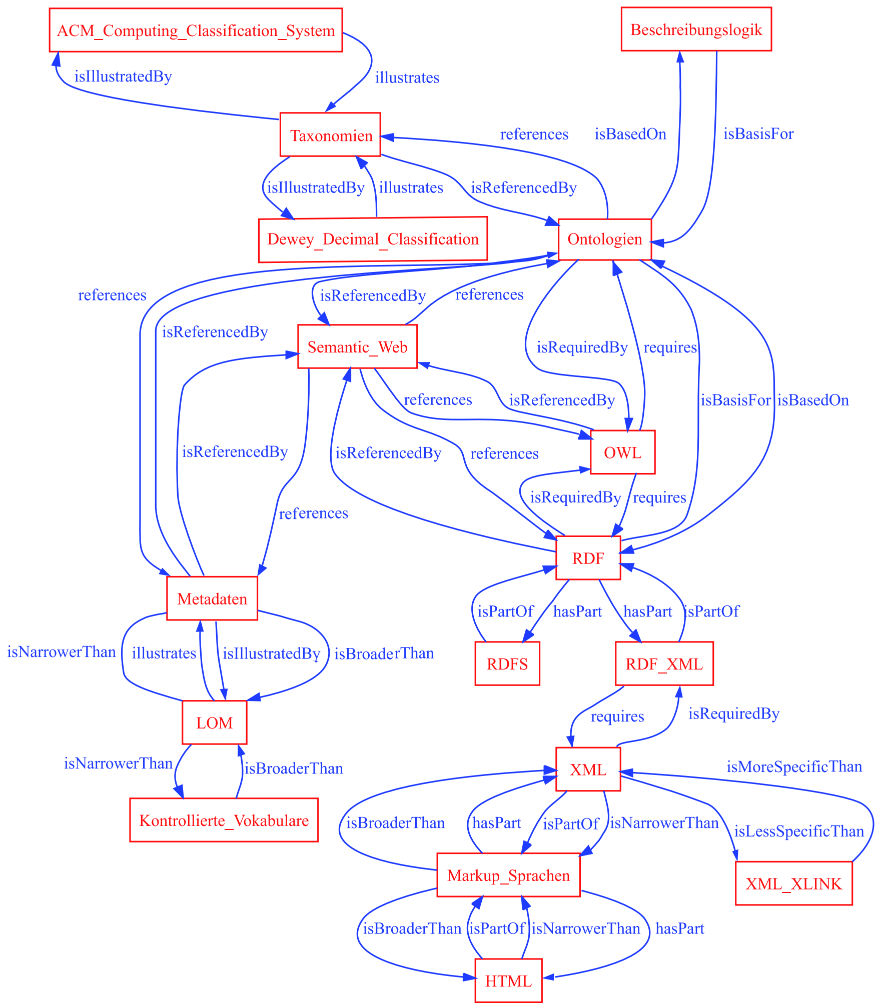

Fig. 2. Excerpt from a Resulting Semantic Net

4.2 Ontological Evaluation Layer

Adding a new eLearning object will require to identify and update appropriate relations with a possibly large amount of repository entries. Objects entering the repository by automated acquisition as described in section 3, will be predisposed as unconnected entities. Any classified object, though, may immediately inherit the relation 'isBroaderThan' from the taxonomy and 'isPartOf' from its structural disposition. Additional attributes may be conjectured from heuristic considerations, e.g., two eLOs of (almost) identical classification and keyword sets, as well as comparable educational attributes are likely to be 'AlternativeTo' each other. Inserting the objects "HTML" or "Markup_Sprachen" in our above example will initiate a fully automated generation of named interconnects.

To overcome the obstacle of further manual netting, an *Ontological Evaluation Layer (OEL)* has been designed and implemented in hylOs. The core concept consists in encoding relation semantics within an OWL ontology [19], which then can be processed by an inference engine. At this first step, relation properties/pairs along with their characteristics can be distributed across a repositories. To account for logical dependencies between related properties, additional inference rules need to be supplied to the inference engine. As outcome of a careful overlook we identified about 50 of such rules, giving rise to a dense inference set. Some typical examples of inherent conclusions read:

– A is narrower than $B \wedge B$ is format of $C \Longrightarrow A$ is narrower than C
– A is based on $B \wedge C$ has part $B \Longrightarrow A$ is based on C
– A requires $B \wedge B$ is based on $C \Longrightarrow A$ is based on C
– A is more specific than $B \wedge B$ is format of $C \Longrightarrow A$ is more specific than C
– (A is version of $B \vee A$ has version B) $\wedge A$ is format of $C \wedge B$ is format of C $\Longrightarrow A$ is alternative to B

Our implementation uses the JENA framework [20] to operate the reasoning, combining the extended relation ontology and the additional inference rule. A daemon triggered by object insertion or update within the repository concurrently adds appropriate relations to the new or changed object. By following a strategy of concurrent evaluation leading to immediate persistence, our hylOs implementation accounts for the rather slow reasoning process of the JENA framework, which is unsuitable for real–time interactivity.

Any newly inserted object or relation will lead to a chain of subsequent link placements within the hylOs system. Authoring thus is enriched by a forceful augmentation intelligence. Learners will profit from automated reasoning and envision a consistent and supposably dense educational semantic net. One of manifold application opportunities built on top of this semantic net is displayed in figure 3. An eLO–centered mind map type of view is dynamically generated from all relations of the currently displayed object, offering hyperlink navigation according to the semantic net perspective. Such content navigation scheme may equally be offered to learners, instructors and authors. While an author may intuitively explore content related to his personal editing, an instructor may be guided to specific content areas, e.g., for supplementary instructional use.

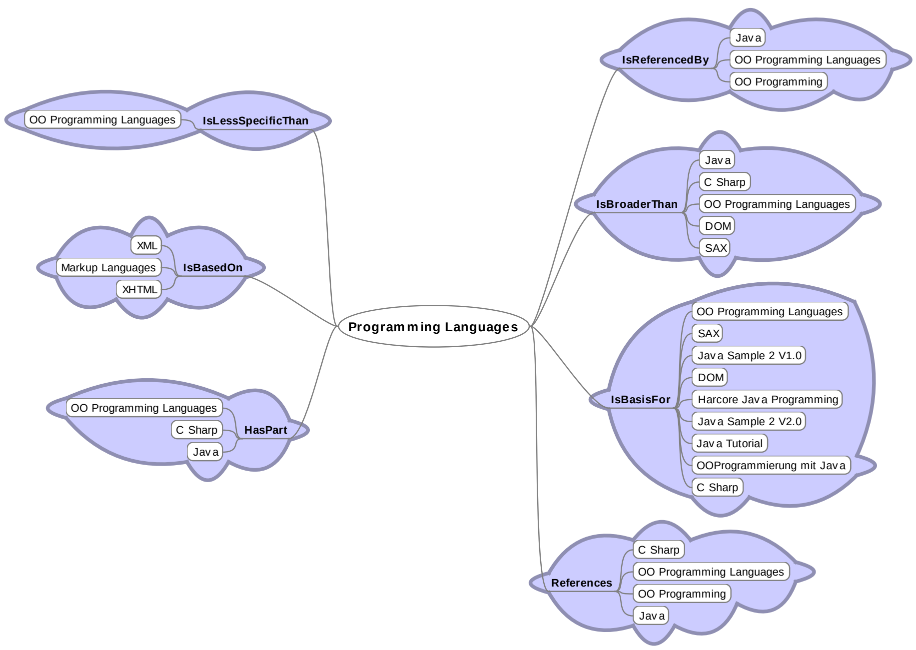

Fig. 3. Application Example: Mindmap Navigation

Finally a learner will experience a 'looking glass' onto his study field, giving rise to a self–directed constructivist kind of knowledge access. Such a view bares a transparent perspective not only on personal study needs, but also on conceptual interdependencies of the subject area.

4.3 First Evaluations

The thorough evaluation of the procedures and the axiomatic rule set introduced above must be recognised as a complex task and has not been completed in full in our ongoing project. At first we analyse efficiency of the proposed rigorous and heuristic schemes, i.e., a quantification of the gain in relations obtained by automated reasoning. For this purpose we select sample collections of eLOs from real–world teaching and proceed in the following way. We initially apply rigorous reasoning on the object set, which is structured and classified, but bare of any preset relation, and obtain result set $\mathcal{A}$. In the second step we add conservative heuristic conclusions, from which few relations of the types 'isAlternativeTo', 'isVersionOf' and 'isMoreSpecificThan' derive and subsequently apply full resoning to receive result set $\mathcal{B}$. At this stage we assume a typical contribution of an author in sparsely adding thematic dependencies, which will be processed by the reasoner into result set $\mathcal{C}$. Finally we added major relations we identified as missing and received result set $\mathcal{D}$ after a last processing.

Results for a sample set of 18 eLOs consisting of the two thematic islands "OO Programming" and "XML Technologies", exhibiting "DOM" and "SAX" as points of contact, are displayed in figure 4. In transition from set $\mathcal{A}$ to $\mathcal{B}$ 9 relations have been added by heuristics. 12 were produced by a virtual author in changing to $\mathcal{C}$ and 7 missings have been contributed to initiate result set $\mathcal{D}$.

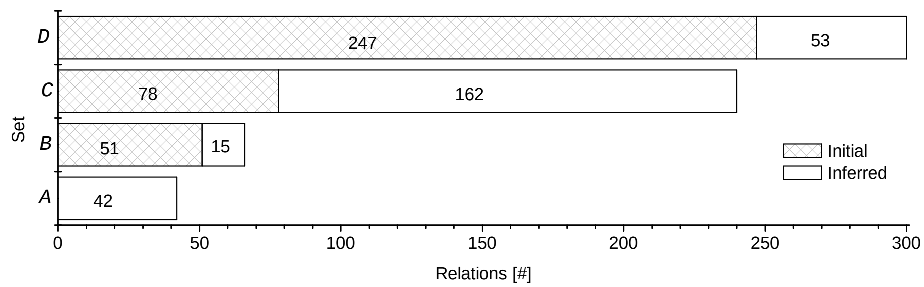

Fig. 4. Yield of Inferred Relations for Different Initial Conditions

A dense mesh of 300 relations has been created in this procedure, where 66 stem from á priori and heuristic conclusions. 206 semantic links were descended from 28 manual addings. Even though many of them stem from a direct transfer of classification or were concluded by a few straightforward steps, they may carry value by linking formerly seperate resources. Besides quantity it should be noted that the inferred relations are not at all limited to the obvious; according to the underlying effective rule set quite surprising results occur. The two initially unrelated eLOs "Markup Languages" and "Java Sample 2" inherit for example the relation "isRequiredBy" through the following chain: "Markup Languages" $\stackrel{hasPart}{\longmapsto}$ "XML", "DOM" $\stackrel{requires}{\longmapsto}$ "XML" and finally "Java Sample 2" $\stackrel{hasPart}{\longmapsto}$ "DOM".

A proof of correctness for the proposed rules requires a multistage analysis and is only achievable up to the semantic precision inherent in eLearning content and metadata definitions. Most importantly, evidence is required that our axiomatic rule set is contradiction–free. A contradiction occurs, if two object are related by mutually contradicting relations. Such contradictions obviously derive from inverse relation pairs, but also from exclusive semantics of unpaired relations s.a. 'isFormatOf' and 'isVersion'. To monitor for inconsistencies, which also may result from manual editing, we encode incorrectness–relations in a separate ontology, e.g.,

- A is part of $B \wedge B$ is part of $A \Longrightarrow A$ incorrectPart B
- A is format of $B \wedge B$ has version $A \Longrightarrow A$ incorrectFormatVersion B

and apply the reasoner likewise. Contradictory relations discovered in this way then requires a manual root cause analysis based on tracking the corresponding inference chains.

The semantic soundness of the rule set we analysed in two ways. Theoretically we carefully evaluated each single rule with respect to all formal semantic aspects of the related eLOs. Empirically we prepared several collections of "real–world" eLearning Objects with all relations we could accept as true. Subsequently automatic reasoning was applied to each collection and any additional result was taken up for an individual examination. It thereby has been our steady experience that erroneous inferences are quickly discoverable, since the outcome of rule–reasoning rapidly spreads among entities and soon leads to obvious incorrectness.

Further experiments and a continuous monitoring of inconsistency will be needed to establish a firmer judgement. An evolution of heuristic identification schemes shall promise further optimisations.

5 Conclusions and Outlook

In this paper we discussed key aspects of automated eLearning object acquisition and content augmentation. Starting from the LOM based Hypermedia Learning Object System hylOs, we introduced our ongoing activities of eLO generation and classification from lecture recordings. Focussing on the application of an educational semantic net, a detailed evaluation and a suggestion for improvement of the LOM semantic relations has been presented. It was shown that by turning the inherent relational logic into operational reasoning, a semantic learning net will actively evolve and monitor its consistency.

The approach of generating a learning net can be extended to inter–repository overlays in a straightforward way. Our future work will concentrate on the design of semantic peer–to–peer networks formed between distributed eLearning Objects. Furhter evaluations and improvements for our automated context recognition and classification schemes are under preparation, as well.

References

1. : Learning object meta-data. Draft Standard 1484.12.1, IEEE (2002)
2. ADL Technical Team: Sharable Content Object Reference Model (SCORM) 2004 2nd Edition (2004)
3. : The hylOs Homepage. http://www.hylOs.org (2006)
4. Schmidt, T.C., Engelhardt, M.: Educational content management. In García, F.J., García, J., López, M., López, R., Verdú, E., eds.: Educational Virtual Spaces in Practice. Ariel International, Barcelona (2005) 105–118
5. Feustel, B., Kárpáti, A., Rack, T., Schmidt, T.C.: An environment for processing compound media streams. Informatica **25** (2001) 201 – 209
6. Engelhardt, M., Schmidt, T.C.: Semantic linking – a context-based approach to interactivity in hypermedia. In Tolksdorf, R., Eckstein, R., eds.: Berliner XML Tage 2003 – Tagungsband, Humboldt Universität zu Berlin (2003) 55–66

7. Landow, G.P.: The rhetoric of hypermedia: some rules for authors. Journ. of Comp. in Higher Education **1** (1989) 39–64
8. : Speex - a free codec for free speech. http://www.speex.org (2003)
9. : Java Speech Grammar Format Specification. Technical Report 1.0, Sun Microsystems Inc., 901 San Antonio Road, Palo Alto, California 94303 U.S.A. (1998)
10. van Rijsbergen, C.J.: 3. In: Information Retrieval. 2 edn. Department of Computing Science, University of Glasgow (1979)
11. Maly, K., Zubair, M., Anan, H.: An automated classification system and associated digital library services. In: NDDL, ICEIS Press (2001) 113–126
12. : Dewey Decimal Classification System. http://www.oclc.org/dewey/ (2005)
13. : ACM Computing Classification System. http://www.acm.org/class/1998/ (1998)
14. Price, R.J., Shanks, G.: A semiotic information quality framework. In: Proc. of IFIP International Conference on Decision Support Systems (DSS2004): Decision Support in an Uncertain and Complex World, Prato (2004) 658–672
15. Najjar, J., Klerkx, J., Ternier, S., Verbert, K., Meire, M., Duval, E.: Usability evaluation of learning object indexation: the ARIADNE experience. In: Proceedings of the 3rd european conference on e-learning 2004, Academic Conferences International, ACI (2004) 281–290
16. Steinacker, A., Seeberg, C., Fischer, S., Steinmetz, R.: Multibook: Metadata for the Web. In: 2nd International Conference on New Learning Technologies, Bern, Switzerland (1999) 16–24
17. virtual campus team, T.: Architecture and conceptual model of Virtual Campus. http://www.elet.polimi.it/res/vcampus/download/MCwebVersion.pdf (2003)
18. Karampiperis, P., Sampson, D.: Learning object metadata for learning content accessibility. In: World Conference on Educational Multimedia, Hypermedia and Telecommunications (EDMEDIA). Volume 2004., Lugano, Switzerland (2004) 5204–5211
19. : OWL Web Ontology Language: Semantics and Abstract Syntax. W3C Recommendation, World Wide Web Consortium (2004)
20. : Jena – a semantic web framework for java. http://jena.sourceforge.net/ (2005)