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Considering the educational semantic web

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Abstract

Web-based Educational Systems (WBES) attempt to employ Semantic Web technologies in order to achieve: a) improved adaptation and flexibility for single and group users, and b) new methods and types of courseware compliant with the Semantic Web. In this paper, we consider the role of advanced networking in Education through the development of the Semantic Web. We provide a state-of-the-art literature review and present tools of e-learning in the Semantic Web. Furthermore, we explore what the Semantic Web can do for Adaptive WBES.

Introduction

The Semantic Web enriches the World Wide Web with semantic information to enable systems to access and use information more efficiently. The Semantic Web is a concept that enables better machine processing of information on the Web, by structuring documents written for the Web in such a way that they become understandable by machines. The Semantic Web allows content to become aware of it. This awareness allows humans and agents (viz. Internet-based programs that are created to act autonomously) to query and infer knowledge from information quickly and in many cases automatically.

Semantic Web technologies will influence the next generation of e-learning systems (Clark et al., 2004). Anderson and Whitelock (2004:3,4) state: "*…the Educational Semantic Web is a developing and futuristic vision, which is based on three fundamental affordances: a) the capacity for effective information storage and retrieval, b) the capacity for nonhuman autonomous agents to augment the learning and information retrieval and processing power of human beings and c) the capacity of the Internet to support, extend and expand communications capabilities of humans in multiple formats across the bounds of time and space*." Although there is a capacity and promise of the

Educational Semantic Web, a debate continues regarding the capacity, efficacy and even desirability of using such technologies in educational contexts (Noll, 2002).

The Semantic Web framework includes major components such as: ontologies, ontology languages, tools, semantic annotations, logical support, agents, and applications/services.

Current e-learning systems are characterized by usage of restricted set of educational materials. Furthermore, they cannot interoperate with other systems and data sources because they are *heterogeneous*. Data heterogeneity implies that these systems use different *meta-data* (viz. objective data about data) for representing learning modules. 'Good' metadata is a small set of descriptors that allows handily and efficiently to describe, locate, work with and also classify other, more extensive information sources. However, metadata is only useful when information producers use the same set of descriptors (Ravasio et al., 2003).

Ontologies are an emerging technology that offers a promising infrastructure to cope with heterogeneous representations of Web resources. The domain model of an ontology can be taken as a unifying structure for giving information in a common representation and semantics. An ontology is a formal, explicit specification of a domain and consists of concepts, concept properties, and relationships between concepts (Gruber, 1993). To be more specific, an ontology is an explicit specification of an application domain in a human-understandable and machine-readable form. Typically, it comprises the classes of entities, relations between entities and the axioms that apply to the entities. An example of ontology is depicted in Figure 1.

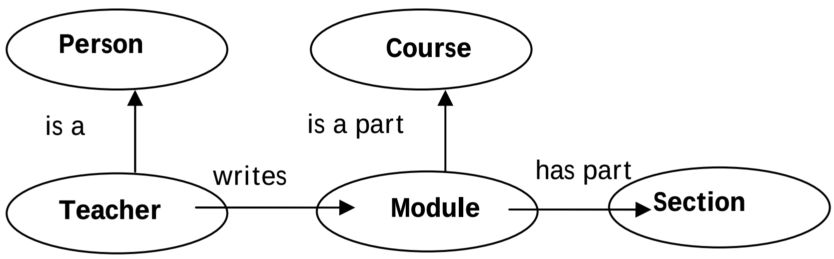

Figure 1. An example of ontology

Ontologies are needed for creating, interpreting and comparing meta-data annotations. Annotation languages have been developed in order to annotate information resources with content-related meta-data. Through the use of metadata organized in numerous interrelated ontologies, information is tagged with descriptors that facilitate its *retrieval, analysis, processing* and *reconfiguration* (Mizoguchi, 2004). The creation of a single network of semantically related mark-up requires:

- The development of appropriately scaled ontologies.
- Systems that relate and map different ontologies to each other.
- Systems that learn and mine ontology connections through use.
- The development of working prototype systems.

Hereby, we provide a state-of-the-art literature review and present tools of e-learning in the Semantic Web. Furthermore, we explore what the Semantic Web can do for Adaptive Web-based Educational Systems. The following Section describes the core technologies in the Semantic Web. Section 3 discusses the challenges to the Educational Semantic Web, while Section 4 considers the role of the Semantic Web in Adaptive WBES (Web-based Educational Systems). Some application scenarios of the Semantic Web in the Educational context are proposed in Section 5. Lastly, Section 6 concludes this paper with some interesting remarks.

Core technologies in the Semantic Web

There are major technologies available to create semantics on the Web:

UML (*Unified Modeling Language*) that provides a collection of models and graphs to describe the structural and behavioral semantics of any complex information system. UML class and object diagrams provide a modeling capability that is well suited for representing ontologies (Cranefield and Purvis, 1999). The semantics of UML are defined by a meta-model, some additional constraints expressed in a semi-formal language (the Object Constraint Language, OCL), and descriptions of the various elements of the language in English. Papasalouros and Retails (2002) presented an adaptive hypermedia application model that is based on UML.

XML (*eXtensible Markup Language*) and *XML Schema's*. XML is a markup-language for arbitrary document structure, as opposed to HTML, which is a markup language for a specific kind of hypertext documents. An XML document consists of a properly nested set of open and close tags, where each tag can have a number of attribute-value pairs. Crucial to XML is that the vocabulary of the tags and their allowed combinations is not fixed, but can be defined per application of XML. With XML schemas we can structure data and document according to a personal or community defined vocabulary (Decker et al., 2000). XML content formats and XML-based metadata systems can support learning and instructional technology (Buendía, 2001). In particular, IEEE LTSC (Learning Technology Standards Committee) develops an XML binding for LOM (Learning Object Metadata). This standard XML binding is based on W3C (World Wide Web Consortium) XML Schema (WXS).

RDF (*Resource Description Format)* and *RDF-Schema* is the metadata approach from the W3C. It does not structure the syntax of the data, but defines semantic meaning for data on the Web. RDF Schema is a set of predefined resources (entities with uniform resource identifiers) and relationships between them that define simple meta-model including concepts of classes, properties, sub-class and sub-property relationships (Decker et al., 2000). Domain schemas (i.e. ontologies) can then be expressed as sets of RDF triples using the (meta)classes and properties defined in RDF Schema. RDF is based on lower level technologies: 1) *Universal Resource Indicator* (URI) to identify Web resources and 2) *Namespaces* to identify different vocabularies. RDF schemas can be used to describe learning resources, e.g. the RDF bindings of LOM (Henze et al., 2004).

DAML (*DARPA Agent Markup Language*) is an extension of RDF and RDF Schema that will be able to express a much richer variety of constraints as well as support logical inference (Hendler and McGuinness, 2000). DAML makes possible the ontological metadata representation of the learning material (Araújo and Ferreira, 2004). RDF and DAML (which currently do not have any standard graphical form) could leverage the UML graphical representation.

Topic Maps can be viewed as an interchangeable hypertext navigation meta-layer above diverse electronic information sources supporting topical finding of various kinds of learning resources, such as documents, graphics, images, database records, audio/video clips, and so on (Dichev et al., 2004). A special characteristic of the topic maps model is the clear separation between the description of the information structure and the physical information recourses (like Web pages, multimedia content, images, and books). Topic maps define arbitrarily complex semantic knowledge structures and allow the exchange of information necessary to collaboratively build and maintain indexes of knowledge.

OWL (Web Ontology Language) provides greater machine interpretability of Web content than that supported by XML, RDF and RDF-Schema (McGuinness and Van Harmelen, 2003). With OWL it is possible to implement a semantic description of a certain domain by specifying its concepts and the relationships between the concepts. OWL is intended to help users to formalize ontologies and has three increasingly expressive sub-languages: OWL *Lite,* OWL *DL,* OWL *Full.* Ontology developers adopting OWL should consider which sublanguage best suits their needs. The choice between OWL *Lite* and OWL *DL* depends on the extent to which users require the more-expressive constructs provided by OWL *DL* and OWL *Full*. The choice between OWL *DL* and OWL *Full* mainly depends on the extent to which users require the meta-modeling facilities of RDF Schema (e.g. defining classes of classes, or attaching properties to classes). When using OWL *Full* as compared to OWL *DL*, reasoning support is less predictable since complete OWL *Full* implementations will be impossible. It must be mentioned that UML class diagrams can be translated to OWL and/or RDF-schema, depending on the richness of the UML model. Some examples of OWL representations that describe pedagogical resources are given in (Doan et al, 2004).

Software Agents can exploit the coded semantics on the Web (Hendler, 2001). For example, the author of an intelligent Web-based tutor that teaches geometry may want to insert a drawing of a square into a certain document that learners may subsequently want to see. If the drawing has associated pointers to the ontologies of edges and vertices, saving the document as a HTML page will automatically create a markup for a pedagogical agent to understand the context of the document. The Educational Semantic Web utilizes a variety of student, teacher and content agents to enhance the teaching/learning processes (Keleberda et al., 2004). For example, a teacher agent operating on the Semantic Web might undertake many of the routine administrative tasks, such as routine marking tasks, record keeping and document control for assessments requiring manual effort and consume large amounts of teacher time. Teacher agents communicate with individual student agents, tracking student progress, providing automated lists of resources such as tutorials, remedial help, and assisting scheduling and time allocation tasks. They schedule personal time between teachers and students to maximize the effect and affect of these interactions. Teacher agents can track professional interests of teachers relating to their field of subject expertise, developments in new pedagogies with active evaluation and testing of pedagogical interventions. On the other hand, student agents can assist learners in working collaboratively, finding sources of expertise and assisting students in documenting and archiving their learning products. An additional capacity of the Semantic Web is realized, when agents extract information from one application and subsequently utilize the data as input for further applications. In this way, agents create greater capacity for large scale automated collection, processing and selective dissemination of data.

To summarize, ontologies and the available Web standards, such as XML, RDF, XTM (XML Topic Maps http://www.topicmaps.org/xtm) and OWL, allow specification of educational components in a standard way.

Challenges to the Educational Semantic Web

The effective functioning of the Semantic Web requires systems for defining, creating and deploying sets of identifiers (*tags*) that describe, and in some cases, constrain the content on the Internet. These tags are organized and related to each other in the form needed for formally structured ontologies. Both humans and agents use these tags to retrieve, process and otherwise manipulate information found on the Internet. Particularly, we need: a) systems that allow tags to be acquired through use, b) systems that allow multiple tags to describe the same data, and c) systems that harvest and capture schema and tagging systems automatically.

In this sense, it is useful to develop data structures that provide enough structure to insure programmability without losing data or unduly confining the ways in which humans can express themselves. It is unlikely that there will be a single unifying ontology under which all information can be classified. The W3C's WebOnt group (http://www.w3.org/2001/sw/WebOnt/charter/) developed languages for creating multiple ontologies and systems to translate ontologies.

Besides, when educational services are subscribed to different ontologies, the various proposed frameworks have to deal with *ontology mapping* between ontologies. Syntactic heterogeneity arises when ontologies written in different ontology languages are combined. Four types of mismatch due to syntactic heterogeneity can be identified: 1) different syntax of ontology languages, 2) differences in the language constructs that are used to state something (logical representations), 3) semantics of primitives (constructs with the same name, but slightly different interpretations; constructs with different names, but the same interpretation) and 4) language expressivity (one language can express something that the other language cannot express). Differences in the expressivity between two languages are those, which have the most impact on the problem of integrating/mapping ontologies. For this problem, several approaches have been proposed such as the one taken in the GLUE system (Doan et al., 2002).

In the future, pedagogical agents will crawl web pages searching for mark-up and come up with relevant material. They can also collaborate with other pedagogical agents that will match the material found with the learner's knowledge level and preferences (as to what presentation format to use, or what teaching strategy to employ). The point is that the learner does not need to perform the discovery of the relevant educational contents manually.

Current web-based courseware is typically decomposed into independent modules, which are further combined in complete courses. This approach inspires reuse and makes it easier to create variants of courses adapted to different purposes or audiences, up to the level of individual students. This also leads to the chance that different students can take different learning paths through the content based on navigation demands and guided by their learning goals and current capabilities. Frequently various limitations are set, such as being given a fixed amount of time or being able to see the material only once. Different conditions can come from interaction of students such as queries, navigation requests, test results, or predefined conditions such as learning goals, previous experiences of students, and externally imposed limits. Such (semi-) automatic choices of learning material are at heart didactic choices, and a lot of effort has been put into finding didactic templates that formalize and encapsulate the underlying didactic choices in a simple model.

Adaptive WBES using Semantic Web

The problem of matching learner to material, which is relevant to his/her needs is called *customization of course/information discovery*. As we deal with a variety of learners and learner characteristics, Adaptive Educational Hypermedia (AEH) is the solution to the personalization on the Educational Web. Adaptive WBES cater to the needs of each individual student; adapt to their *goals* (Clifford, 2000); *knowledge level* (De Bra and Calvi, 1998); *background*; *interests* (Brusilovsky et al., 1996); *preferences* (Höök et al., 1997); *stereotypes* (Zakaria and Brailsford, 2002); *cognitive preferences* (Chen and Macredie, 2002) and learning styles (Stach et al., 2004).

A modular architecture for adaptive Web-based educational systems is depicted in Figure 2.

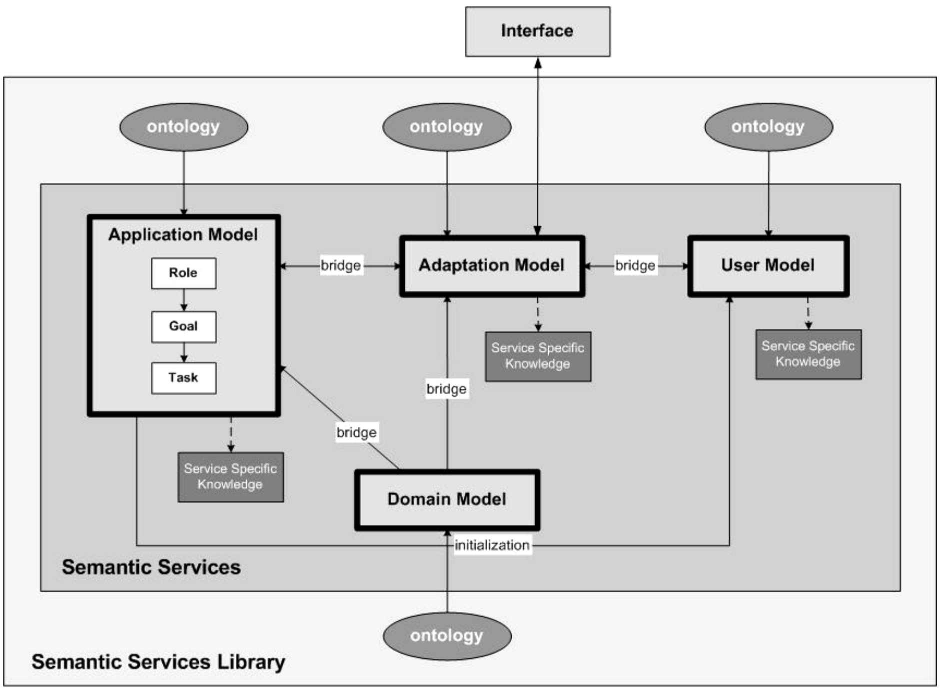

Figure 2. Architecture for adaptive Web-based systems
(Adapted from: Motta et al, 2003)

In this architecture, the different system components are all equipped with facilities to communicate with the (other) components in terms of service invocations. Bridges are used in accordance with the UPML (Unified Problem-solving Method description Language) framework connector defined by Fensel et al. (1999b), in order to specify mappings between the different model services within the architecture. Ontologies also play an important role to define and unify the system's terminology and properties to describe the knowledge of each system service. Each service can be specified by means of a corresponding ontology, providing common ground for knowledge sharing, exploitation and interoperability among the services. This leads to a highly modularized architecture, which offers a high degree of flexibility. In the interaction with the application the user is represented by a particular role (e.g. student, tutor or administrator). This role defines for the user a corresponding behavior in terms of goals to achieve. To accomplish the user's (student’s) goals appropriate applications are used, which realize one or several corresponding methods. The adaptation model service receives the direct student input and interacts with the application model service in order to define the context for the student input for its most precise adaptation. Further the adaptation model service queries the domain model service in order to select the relevant learning content to be presented to the student. The domain model service is responsible for the explicit storage and description of the domain knowledge in terms of concepts of an ontology concerning learning material.

In adaptive WBES learning contexts, there are three main apprehending structures that can be aided by the use of ontologies. These are:

- *Argumentation/debate*
- *Narrative, and*
- *Analogy*

Debate includes the various scientific controversies which arise about notions, such as continent drift, global warming (Masters and Oberprieler, 2004). These controversies are in themselves multi-dimensional since they are often ethical and economic, political aspects as well as scientific.

Narrative includes the historical narrative of how ideas change and evolve as well as the ‘stories’ we tell as a means of making sense of something e.g., the story of the Greek War of Independence of 1821 (Galanouli et al., 2004).

Analogies are an important factor in how one can make sense of something (Hanciles et al., 1997). Learners can better understand something if they can relate it to something already well understood. A teaching intervention can be based on a conceptual metaphor between a cognitive concept (*term*) and its *analogous*. Adamopoulou et al. (2004) proposed a semantic learning interventions management system that utilizes Web services technology. The proposed system is an integrated educational solution that offers interoperable, Web service-based, cross-platform learning services. It extends the available educational logic and content by publishing and consuming educational Web services.

The Web Services technology is a collection of standards for the next generation of e-learning applications that allows those server applications to "talk" to each other over the Internet. The Web Services technology can define a technique for describing web-based e-learning applications, methods for accessing them, and discovery methods that enable the identification of relevant applications' service providers.

These standards are:

XML for driving applications services.
SOAP (Simple Object Access Protocol) for communication among Web Services (http://www.w3.org/TR/soap/).
WSDL (Web Services Description Language) as the service description language (http://www.w3.org/TR/wsdl).
UDDI (Universal Description, Discovery and Integration) as the service discovery protocol (http://www.uddi.org).

In the Semantic Web, a user of an Adaptive WBES is involved in exploring the subject domain ontology and searching the repository for information related to a specific task. An example of such systems is AIMS (Aroyo and Dicheva, 2001), which focuses on providing contextual support that enables learners to identify information necessary for performing a specific task (e.g. *course assignment*). Cristea (2004) shows how the LAOS (Layered Adaptive Hypermedia System Authoring-Model and Operators) framework can be re-written in Semantic Web languages, in order to bring Adaptive Hypermedia and the Semantic Web closer together. The LAOS model is a generalized model for generic, dynamic Adaptive Hypermedia (authoring) that can be expressed using Semantic Web languages.

There are many ontology-driven adaptive WBES already developed, which include: ontology-driven subject domain, repository of learning resources, course presentation, adaptation and personalization (Aroyo and Dicheva, 2001; Dolog et al., 2004; Brusilovsky, 2004). Typically, course/learning tasks are annotated in terms of subject domain concepts and some instructional relationships between the involved concepts. The domain concepts are also used as a basis for implementing systems' adaptive behavior. Conclusively, context specific configuration of learning modules and their adaptation to the specific user needs can be enabled, as semantic meta-data are attached to learning modules. For achieving this, ontologies being used must be aligned with the ontologies defining the context and user profile.

Frequently, the educational content is changed and the content has to be malleable sufficiently so that can it be reused in different settings. This kind of change can focus on the new issues and refine the old. Therefore, a layered approach with appropriate *semantic labeling* is necessary. These layers should reflect a higher-level semantics, such as *domain model, user characteristics, machine characteristics* etc. (Cristea, 2004). If educational content is authored collaboratively, then appropriate semantic labeling becomes crucial, and the use of internationally accepted semantic standards is beneficial for the *scalability* of people and roles involved. Moreover, semantic labeling is indispensable, if we need to export between different learning systems.

Semantic-based e-learning application scenarios

The Educational Semantic Web is meant to enable an e-learning environment in which Internet–connected learning systems can exchange knowledge and action specifications (Schwartz, 2003; Anderson and Whitelock, 2004). Some application scenarios of the Educational Semantic Web may be:

- *Semantic-based search for educational content.*
- *Browsing knowledge or 'personal' portals.*
- *Semantic-based courses.*
- *Educational Semantic Web Services.*

Semantic search engines for educational content

Semantic browsers, such as *Magpie*, use ontologies to identify important concepts in a document and provide access to relevant material (Dzbor et al., 2003). Magpie is a suite of tools facilitating three distinct perspectives on the Semantic Web: a) as a methodology for supporting the interpretation of Web resources through 'ontological lenses', b) as a tool kit for supporting and realizing Semantic Web browsing, and c) as a framework for building semantic Web applications. *Semantic browsing* locates metadata and assembles point-and-click interfaces from a combination of relevant information: It should be able to allow easy navigation through resources, since users with any level of computing knowledge may use it.

Semantic search enhances current search engines with semantics: It goes beyond superficial keyword matching by adding semantic information, thus allowing easy removal of non-relevant information from the result set. In addition, *semantic ranking* is useful in those cases when too many results are returned.

Semantic-based search can be provided by Semantic Web tools, such as the *Ontobroker* System (Decker et al., 1999). This tool provides an ontology-based crawling and answering service. It comprises languages and tools that allow to semantically mark-up content on Web pages and let the user (e.g. student or tutor) semantically query the Web taking advantages of semantic inferences (Fensel et al., 1999). The Ontobroker is based on:

- the use of ontologies that guide the semantic mark-up of Web documents,
- the querying interface, and
- the semantic rule for the domain.

In this sense, conventional Web pages are augmented with a facility for intelligent brokering services without requiring to change the semiformal nature of Web documents. For example, Ontobroker has been applied to needs of the knowledge acquisition community. Similar to the Ontobroker, the *SHOE* project indented to annotate Web documents with machine-readable knowledge (Heflin and Hendler, 2000). SHOE is a set of tools including: a) a Knowledge Annotator, b) the Crawler Expose, c) the knowledge representation system PARKA, d) The PIQ (Parka Interface for Queries and e) the SHOE Search. Another well-established annotation tool is *Annotea* that provides RDF-based markup (Kahan et al., 2001). However, Annotea does not support information extraction nor it is linked to an ontology server.

Browsing knowledge or 'personal' portals

Knowledge portals

The idea of ontology-based knowledge portals has been described in (Staab and Maedche, 2001; Maedche et al., 2001). A knowledge portal (including those for e-learning) can be seen as a Web application providing access to data in a semantically meaningful way, making available a variety of resources for diverse target audiences. Differently from "dumb" Web portals, semantic portals are "smarter" and carry out intelligent reasoning behind the scenes. They should offer semantic services including semantics-based browsing, semantic search and smart question answering. Knowledge portals provide views onto domain-specific information on the Web, thus facilitating their users to find relevant, domain-specific information. Ontologies are used as a conceptual backbone for providing, accessing and structuring information in a comprehensive approach for building and maintaining knowledge portals. Staab and Maedche (2001) provided two examples for running knowledge portals: a) the research case study KA-2 portal that offers semantic markup about researchers, academic events etc, and b) the commercial case study TIME2Research knowledge portal.

Personal portals

Current knowledge portals are dynamic in respect to the content of the repositories and presentation means, but fairly prescriptive in terms of processes and individual user interaction. Dzbor et al. (2005) proposed refocusing the research from knowledge portals towards frameworks (named by them as '*personal portals*'), which the end-user can apply in many decision-making scenarios. They suggested a more distributed approach to accessing knowledge. The core facets of their approach include: a) choice from multiple ontologies, b) dynamic selection of ontological frames, c) customization of user interaction and knowledge-level inference results, and d) decoupling the content from a variety of contexts using the principles of conceptual (re)-framing. Moreover, they described a prototype of the 'personal portal' approach using *Magpie*.

Semantic-based courses

An explicit semantic representation can serve as a means to create more advanced and complex, but consistent learning designs than is possible without such a representation. This is a characteristic of any language with semantic that enables one to write, read, rewrite and share meaning (natural language, musical notation, etc.).

The Sharable Content Object Reference Model (SCORM) is the most well known standard, enabling learning content reusability and portability across diverse Learning Management Systems (LMS), and discoverability among content consumers (Aroyo et al., 2003). The SCORM's metadata model provides means for describing learning content from its most basic form – atomic resources such as text files, videos or presentations, to complex content aggregations, like lessons or entire courses. The SCORM standard has already addressed semantic annotations, content aggregation and sequencing. However, SCORM has chosen its own XML formats and methodologies, thereby making it much more difficult to integrate e-learning with other business processes.

In the context of the Semantic Web, there is a growing concern towards the need of extending the existent educational standards, such as the IEEE/IMS LOM standards (http://ltsc.ieee.org/wg12/), so as to allow improved semantic annotation of learning resources. Interoperability and/or integration of standards of the e-learning community with the Semantic Web meta-data standards are needed to realize the integration of Knowledge Management (KM) solutions and e-learning (Stojanovic et al., 2001). Aroyo and Dicheva (2004) outlined the state-of-the-art research along the semantic evolution of e-learning systems. They proposed a modular semantic-driven and service-based interoperability framework, in order to open up, share and reuse educational systems' content and knowledge components. Ontology-based brokerages match learners with course construction tools, which attempt to automatically combine learning objects into "courses" or sequences of objects (Stojanovic et al., 2001).

Educational Semantic Web Services

Introducing Semantics to educational Web services brings the following advantages:

Semantically enriched educational Web services handle the interoperability at the technical level; that is, they make educational applications talk to each other independent of the hardware and software platform. But even for educational applications interoperating at the technical level, there is still a need for semantic interoperability. This kind of interoperability can be addressed through *ontology mapping*.

Semantics can be used in the discovery and composition of educational Web services.

The main mechanism for educational service discovery is service registries and semantics can be used in the discovery of educational Web service registries.

So far, we have seen the development of educational semantic Web services, which range from assessment to short lectures. In the following, we discuss some of them.

Community-based Semantic Learning Webs

Many community-based Semantic Learning Webs (SLWs) have to provide learner-need oriented services, as the learner is faced with various, digitized versions of available sources (e.g. books, journal material, newspapers etc). Stutt and Motta (2004:2) envision "*a multiplicity of community-based Semantic Learning Webs each with its own, perpetually changing ontologies, knowledge bases, repositories and ways of making sense of the world*" where ontologies provide means for semantic communication within and across those "Knowledge Neighborhoods". SLWs will depend on three things: 1) annotated educational resources, 2) a means of reasoning about these, and 3) a range of associated services. Yang, Chen and Shao (2004) proposed two metadata models, content model and annotation for Collaborative Learning in Virtual Learning Community. In addition, the *ScholOnto* project is actively engaged in producing the ontologies and tools for the construction of a semantic scholarly Web (Buckingham et al., 2000).

Automated identification of educational material

Information extraction techniques (customized for the Semantic Web) can be used for the automated identification of educational material in un-annotated documents (Ciravegna et al., 2002). Anido et al. (2002) surveyed learning objects and their descriptions, which are provided using a variety of metadata schemes.

Personalized e-Learning

A service-based architecture for personalized e-learning is the *Personal Learning Assistant*, which uses Semantic Web technologies for realizing personalized learning support in distributed learning environments (Dolog et al., 2004). Henze et al. (2004) proposed a framework for personalized e-learning in the Semantic Web and showed how the semantic Web resource description formats can be utilized for automatic generation of hypermedia structures. They investigate a logic-based approach to educational hypermedia using TRIPLE, a rule-based query language for the Semantic Web. Furthermore, distance-learning systems provide insufficient level of *personalization* of the learning process. These difficulties can be overcome by the usage of *multi-agents software technologies* (Keleberda et al., 2004) in the framework of the Semantic Web activities of the W3C. Multi-agents software technologies are capable of extracting automatically necessary educational materials (disposed over the Web Space) to provide high-quality personalization of the education. Keleberda et al. (2004) proposed an algorithm according to which, the Multiagent Ontological System for Personalized Distance Learning (MOSPDL) solves the tasks of distant learning process automation, which assume utilization of the ontological models of students' and learning resources' profiles.

Interactive Learning Services

Human-to-human communication is a major component of the educational experience. This communication will be even less constrained by barriers of time or place, when the Educational Semantic Web is functional. Educational Semantic Web scenarios envisage the capacity to store, search, filter and otherwise process these human interactions (Koper, 2004). Consequently, this allows interactions to be used and reused in a variety of educational applications. In addition, the Educational Semantic Web could add to our concepts of virtual presence by defining and structuring virtual reality environments and net-based enhancements to real work and study contexts. A first step into the direction of the transactional Web has been established within the Herakles project where static data source structure descriptions have been combined with dynamic services (Knoblock et al., 2001). Furthermore, Knoblock et al. (2001) applied a general framework for creating information assistants. Devedzic (2003) proposed educational servers, which are based on using standards, ontologies, and pedagogical agents to support interaction between clients (authors and students) and servers (hosting educational content and services).

Semantic Discovery and Interoperability of Educational Web Services

Sycara et al (2003) introduced a vision for Semantic Web Services, which combines the growing Web services architecture and the Semantic Web. They proposed the DAML-S as prototypical example of ontology for describing Semantic Web services. Sakkopoulos et al. (2005) proposed techniques in order to facilitate semantic discovery and interoperability of Web Educational Services that manage and deliver Web media content. As a test-bed, they discussed a Web management system that provides vocational monographs for occupational guidance. Recently, various information semantic retrieval systems have also been proposed such as QuizRDF (Davies et al., 2003) and Spectacle (Fluit et al., 2003). Soon, the annotation registries will enable more ontologically-guided (or semantic) search. Devedzic (2003b) suggests developing Web-based educational services with more theory-and content-oriented intelligence, more semantic interoperation between two or more educational services.

P2P-based Semantic Educational Services

The EU-IST project SWAP (http://swap.semanticweb.org) demonstrated that the power of P2P computing and the Semantic Web could actually be combined to share and find "knowledge" easily with low administration efforts. The growth in educational repositories and P2P networks for sharing these is demonstrated in the *Edutella* network (Nejdl et al, 2002). In Edutella, each *peer* computer registers the metadata of the resources (e.g. learning objects) it stores, i.e. the schema and attributes that are used to describe the stored content, to its super-peer. An interesting P2P based semantic application is the "*Smart Space for Learning approach*" using the *Elena* mediation infrastructure (Simon et al., 2003). The *Elena project* defines a smart learning space of educational service providers based on the Edutella P2P framework for interoperability and resource exchange between heterogeneous educational applications and different types of learning resource repositories. Haase et al. (2004) designed and implemented the *Bibster*: a P2P system for exchanging bibliographic data among researchers. The data of Bibster are obtained from BibTex files or from bibliographic servers like the DBLP database (http://dblp:uni-trier.de/) or CiteSeer (http://citeseer.org).

In the near future, additional educational semantic Web services, such as *summarization, interpretation or sense making, structure-visualization, and support for argumentation*, will be provided by the Semantic technologies.

Conclusions

The capacity of the Semantic Web to add meaning to stored information (such as the information to be searched and processed) provides greatly expanded opportunities for education, simulation and real-time action anywhere on the distributed network. The Educational Semantic Web forms a platform for search engines, information brokers and ultimately the 'intelligent' agents. It propagates interoperability, reusability and shareability, all grounded over an extensive expression of semantics with a standardised communication among modular and service-oriented e-learning systems. The methodology of applying the Educational Semantic Web needs to mature, and the case studies have been relatively costly, labour intensive and have required input from skilled specialists. Standard ontologies must be developed to cover different aspects of teaching and learning and thus provide the necessary armature for building next-generation learning systems on the Web, sharing domain and pedagogical knowledge among the systems, and ensure interoperability and suitable machine interpretation of the course material. Moreover, methods for achieving *scalability* and *robustness* need to be developed.

Adaptive Web-based Educational Systems (WBES) should take advantages of semantic services, interoperability, ontologies and semantic annotation. The Semantic Web could offer more flexibility in Adaptive WBES through use of new emergent semantic Web technologies such as *collaborative/discussion* and *annotations tools*. Context specific configuration of learning modules and their adaptation to the specific user needs can be enabled by attaching semantic meta-data to learning modules. For achieving this, the ontologies being used have to be aligned with the ontologies defining the context and user profile. Future distributed e-learning architectures may comprise several e-learning services such as question-answering, online courses, tutoring systems and automated marking systems. In these architectures, visualisation services will provide a visualization of annotated categories relevant to the current question types. Moreover, extra annotations of the created resources, the building of ontologies to match the resources, and the merging of ontologies will be needed.

The actual conversion of the Adaptive WBES framework into Semantic Web language is feasible, if eLearning scenarios exploit ontologies in three ways: (1) for describing the semantics (*content*) of the learning materials, (2) for defining the learning context of the learning material and (3) for structuring the learning materials in the learning courses.

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