Interoperability in Personalized Adaptive Learning

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ABSTRACT

Personalized adaptive learning requires semantic-based and context-aware systems to manage the Web knowledge efficiently as well as to achieve semantic interoperability between heterogeneous information resources and services. The technological and conceptual differences can be bridged either by means of standards or via approaches based on the Semantic Web. This article deals with the issue of semantic interoperability of educational contents on the Web by considering the integration of learning standards, Semantic Web, and adaptive technologies to meet the requirements of learners. Discussion is m ade on the state of the art and the main challenges in this field, including metadata access and design issues relating to adaptive learning. Additionally, a way how to integrate several original approaches is proposed.

Keywords

Semantic Interoperability, Learning Standards, Personalized Adaptive Learning, Meta-Data

Introduction

Looking into the past, we can see that most ideas how to learn are not new. What is new, are the circumstances and opportunities. The existing education and training system has been engineered in an industrial age to suit the needs of routinely performed manufacturing processes. The knowledge age we live in, however, is demanding higher skilled jobs with capabilities for critical thinking, creativity, self-regulation, collaboration, and interpretation. Accordingly, the number of so called 'knowledge workers' is rapidly growing. Moreover, economic success has become increasingly dependant on flexible and anticipatory adjustment of business models, processes, and behaviours (Hamel & Välikangas, 2003). Again accordingly, studies show that 50% of all employee skills become outdated within three to five years (Moe & Blodgett, 2000).

As a consequence, we need new pedagogical methods to cover the exigencies in education and training visible today. For technology enhanced learning, this boils down to one of the contemporary grand challenges (CRA, 2003): to develop environments that effectively enable each learner to get *individual* support in filling ever-changing skills and competence gaps – i.e. to create environments for personalised adaptive learning. More

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specifically, this requires "developing semantic-based and context-aware systems to acquire, organise, personalise, share and use the knowledge embedded in web and multimedia content, […] and to achieve *semantic interoperability* between heterogeneous information resources and services" (IST, 2004).

If our educational solutions are to be cost effective they have to share and reuse distributed learning resources to achieve a critical mass of material. Then efficient retrieval mechanisms providing access to relevant and accurate information are needed, like federated searches over distributed learning repositories. To reduce the overload of retrieved resources and to provide individualized educational experiences personalization of learning activities and learning materials has to be considered. As learning repositories have distinct systems, semantic and structural heterogeneity, various interoperability issues arise that must be solved in open environments. These issues concern all the conceptual components in adaptive educational systems, like sharing of learning content, concepts, learner profiles, context models, learning design, adaptation and presentation specifications. There are already solutions; e.g. for the exchange of learning objects and learner profiles, but this is just a part of the whole complex problem.

Interoperability can be circumscribed as "a condition that exists when the distinctions between information systems are not a barrier to accomplishing a task that spans multiple systems"(Christian, 1994). To minimize costs and raise quality, we are not as interested in the possibility of interfacing through human effort. *Semantics* (the study of meaning) is usually defined to investigate the relation of signs to their corresponding objects. In our context, *semantic interoperability* thus denotes the study of how to bridge differences between information systems on two levels:

- on an access level, where system and organisational boundaries have to be crossed by creating standardised interfaces that sharing of system-internal services in a loosely-coupled way
- on a meaning level, where agreements about transported data have to be made in order to permit their correct interpretation

Semantic interoperability can be achieved when models are available that more or less resemble each other and where not too many (semantic) differences are to be detected and resolved. Here, we define *model* as a formal and explicit representation that can be used to precisely describe a part of the design, e.g. the content or a user's knowledge state.

The rest of this article is structured as follows. In Section 2, we are going to discuss the implications put forth by semantic interoperability when applied to adaptive systems. This encompasses types, architectures, representations, and interoperability problems emerging from distributed adaptive personalisation in technology enhanced learning. In Section 3, we are going to present a formal model for personalised adaptive learning and give an overview on existing interoperability alternatives, related standards, and projects. In Section 4 we investigate issues related to the access of meta-data in interoperable personalised adaptive learning solutions. We will focus on querying learning object repositories at first to subsequently present an illustrative example of querying learner profiles. The article will conclude by a summary of the status quo reached so far in personalised adaptive learning interoperability and the identification of problems which we feel need to be tackled in the future.

Semantic Interoperability of Adaptive Systems

The increasing demand for personalization in e-learning applications leads to a process of user (learner) profiling which is inherently *distributed*. For multiple applications to effectively share and exchange user information between them for the sake of adapting the content to the user, they need to know the semantics of this user information and therefore resolve the issues related to semantic interoperability. In this part of the article, before we go into details later on, we consider the general state of the art in semantic interoperability in relation to distributed user profiles by introducing methods, techniques, tools, and issues related to distribution and semantic interoperability of adaptive systems.

In the past decade we have witnessed a growing interest in applying adaptation and personalization in numerous application domains. The process of engineering information systems has shown a considerable change and adaptation has been a significant driver of this change. Concept-based systems are information systems that represent *content* using *concept structures*, i.e. that a model of the content (often referred to as *domain model* or content model) is a characteristic element of the design. This approach generally includes, as relevant aspects, the user's knowledge (*user model*) and the adaptation knowledge (*adaptation model*).

These systems are distinguished from systems in which the adaptation is defined without an explicit model of the content (e.g. because the content and structure are rather straightforward or small). *Adaptive concept-based systems* are becoming especially accepted in application areas where the main goal is to tailor large amounts of information to the characteristics of predefined groups, or to the individual preferences and knowledge state of the individual users. In the case of educational applications, it has become more or less standard that the systems express a behavior matching the individual user. The construction of concept-based systems is not a straightforward issue, certainly when the challenge is combined with the desire to add adaptation, e.g. for adaptive hypermedia systems, adaptive web information systems, and adaptive task-based systems.

When we talk about adaptation and personalization, the user necessarily plays a fundamental role in the system and therefore in its design. The system might want to record a user's preferences (e.g. learning and cognitive styles, language), but also its assumptions about the current user's (knowledge) state. The systems typically maintain a model of the individual user as an overlay of the domain model in order to record the current state of the user with respect to their knowledge of domain concepts. These application dependant *user models* with the preferences and the state of the user are integrated in the *user profile* that in general comprises the available information about a user, which is used as a basis for adaptation of the content presentation to the user. In the rest of this section we focus on the user model sharing. Interoperability of adaptive systems generally includes sharing of the content, concepts, context, learning design, and adaptivity.

Distributed User Profiles

The nature of interoperability between adaptive systems and applications implies that there is a *distributed* process of sharing and exchanging user profiles. This process includes on the one hand *providing* profile information and on the other hand *consuming* user models for personalization or adaptation. The issue of semantic interoperability in the context of user profiling is a direct consequence of the distribution in user profile information. The decentralized process of distributed user profile information management demands a control that is essential for a successful application of user profiles.

For a long time it has been very difficult or even impossible to share and exchange user profile data. More recently, suppliers and consumers of user profiles have shown an increased awareness of the need for *standards* for representing and exchanging user profile data, especially in the e-learning domain significant progress, (as we will see later in this article). At the same time we observe that the amount and diversity of profile-based applications makes it practically impossible to easily create a unified user profile infrastructure. One important aspect that should not be underestimated is that the meta-data for user profile data implies a lot of manual labor before it can effectively be exploited in data exchange between applications. However, the technological advances of the last few years, especially in the context of web and semantic web research, can come to the rescue with tools and methods to combine available data, to annotate profile information (semi-)automatically, and to provide applications with necessary profile metadata.

The (semi-)automatic *generation* of metadata is an essential prerequisite for the semantic interoperability of profile-based applications such as e-learning applications. The creation of such metadata usually requires considerable intellectual input of humans. Contemporary web technology may offer opportunities for semantic interoperability between applications and their meta-data on a large scale basis, which could not be achieved by uncoordinated human input alone. When we investigate the means of automatic creation of metadata, we observe that ontologies provide an option for achieving semantic coherence between profile data items. Tools can help to minimize user efforts required for creating and maintaining annotations – and could therefore help to increase their overall quality.

Architecture and Representation

To effectively manage distributed user profiles in adaptive concept-based systems, an architecture for distributed profile exchange and management is needed. Different types of systems use different kinds of architectural solutions. There are differences in the way in which user profiles are used, and this has consequences for the personalization. We want to differentiate three basic architectural types: adaptive web-based systems, adaptive hypermedia systems, and adaptive task-based systems.

All these architectures share the facility to maintain a representation of assumptions about one or more characteristic(s) in the models of individual users. In other words the system should maintain a model about the

user that for instance contains assumptions about their knowledge, misconceptions, goals, plans, preferences, tasks, or abilities. There are numerous issues that need to be considered regarding the user representation in a complex approach, including user environment (e.g. class, school, family, background), roles and stereotypes, historic and sensor information, trust and acceptance, generality and domain independence, expressiveness, inferential capabilities, import and export, privacy, and mobility.

Obviously we can also distinguish different ways to communicate user profile data, e.g. via a centralized server, via peer-to-peer communication, using agent-based techniques, or using a constraint-based approach. For distributed user profile architectures, we need data models and languages for profile meta-data, especially to describe the semantics and semantic differences.

The languages and technologies designed for the development of the semantic web provide useful instruments for the representation of semantics of profile data. We mention the concept of *ontology* as an explicit specification of a conceptualization. This basically means that an ontology is a formal way of describing (some aspects of) a possible real world. With this key concept, the semantic web research has given us languages that are useful for the basic interoperability of user profile data. The semantic web provides a framework for expressing and using ontologies through e.g. the use of RDF, RDF Schema and OWL (RDF, 2005). These languages come also with relevant tool support, such as APIs (e.g. Jena and Sesame), browsers and editors (e.g. Protege and KAON), as well as reasoners.

Interoperability Issues with Distributed Profiles

Representing user profile data is one step in the process, but with the distribution come several interoperability problems and issues related to their semantic differences. As examples, we have *incompatibility* (both between profiles and between profiles and applications), *incompleteness* in the sense of information missing from profiles, and *contradiction* in (unified) profiles.

The need to consider these issues arise from the fact that a learner may attempt to use an application that requires more information than the user's profile can provide, or that responds with information that cannot be accommodated in the user's profile. The complementary case arises when an application cannot handle parameters such as preferences, specified by the learner or provides a response that contains too little information to enable the user to choose between alternate follow-up actions. Another class of problems arises when the learner's profile contains sufficient information but the application possesses information of its own that disagrees with the information present in the learner's profile, because of conflicting values or meanings.

When two e-learning applications are directly interacting to provide a learner with a certain service, but without the direct involvement of the user, they may face the situation of having access only to partly overlapping, incomplete profiles. The question now is how to resolve overlaps and fill existing gaps. When applications are allowed to autonomously replenish missing data, it might happen that two applications create contradictory information. Can and should this be prevented from happening? And if not, how can contradictory data be corrected afterwards? How can co-existing, possibly conflicting data be dealt with?

Other sources of contradictory information are different versions of the same information (freshness). The issue here is whether to trust the most recent version or to establish a procedure to validate information. When facts are contradictory within one source (document), one speaks of an *inconsistency*. When information statements from different sources are contradictory, one speaks of *disagreement*. A disagreement may turn up when two sources are merged (e.g. in a data warehouse project or virtually as described above). These two situations require different handling. In the context of interoperability, one may assume as a starting point that the sources are consistent. The proper treatment of disagreement is the more relevant problem to tackle.

These examples illustrate the situations that have to be prepared for and dealt with. All these problems can be discussed from different angles: on the level of schemas or ontologies, at the level of instances, within an information source, or between information sources. The main question is how to identify and deal with missing or incomplete information. Interoperability problems in distributing user profiles include imprecise information, imprecise manipulation, uncertain information, schema and ontology mapping, data clearing, inconsistency, mediation, data dissemination, data replication, conflict detection and reconciliation. Techniques and architectures to be considered for solving these interoperability problems draw from different research areas – such as classical databases, data warehouses, mobile information systems, and semantic web technologies.

A Formal Model and Related Standards

After giving the general perspective on interoperability and distribution of adaptive components, we now turn to formal models and standards that play a role in the adaptive hypermedia systems that are at the basis of most adaptive learning systems. To start with, we observe that the knowledge driving the adaptation process can be represented in adaptive hypermedia systems as five complementary models (Figure 1) – the domain model specifies *what* is to be adapted, the user and context models tell *according to what* parameters it can be adapted, and the activity (instruction) and adaptation models express *how* the adaptation should be performed. This model enhances the *Adaptive Hypermedia Application Model* (De Bra et al., 1999; Wu et al., 2001), which is based on the *Dexter Hypertext Reference Model* (Halasz & Schwartz, 1994). We use an analytical approach to identify the different design aspects in which the separation between various types of knowledge asks for interoperability as well.

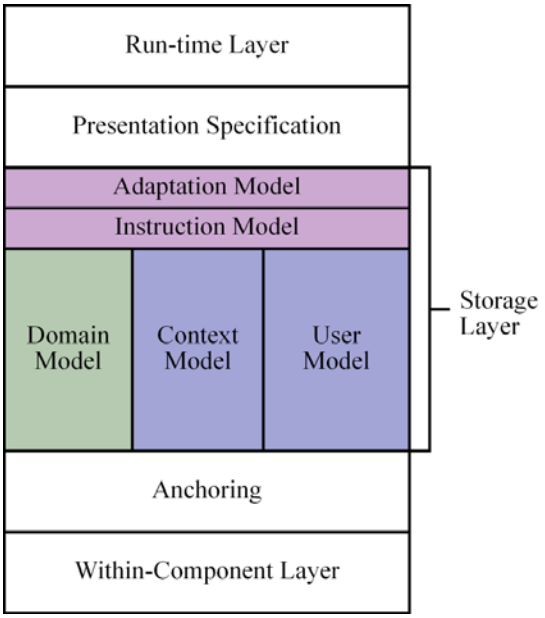

Figure 1: Enhanced Adaptive Hypermedia Application Model

Thus, in accordance with cognitive science results, instead of uniform rules that should control the whole personalized adaptive leaning experience, several specialized parts take care of particular functions and interact with each other. Note that individual models may be distributed in reality. In the following paragraphs we discuss formal models and standards that apply to each of the particular models. As we see, the existing standards do not really support interoperability as a common abstract model is missing. They can be used in isolation, but that is not desirable.

Domain Model

The domain model specifies the *conceptual design* of an adaptive hypermedia application, i.e. *what* will be adapted. The information structure of a domain model in a typical adaptive hypermedia system can be considered as two interconnected networks of objects (Brusilovsky, 2003):

- Knowledge Space – a network of concepts
- Hyperspace – a network of hyperdocuments

Accordingly, the design of an adaptive hypermedia system involves three key sub-steps: structuring the knowledge, structuring the hyperspace, and connecting the knowledge space and the hyperspace.

Modern adaptive hypermedia systems model the *knowledge space* of the domain as a semantic network (Brusilovsky, 2003). They use network models with several kinds of links that represent different kinds of relationships between concepts, e.g. prerequisite links between concepts which represent the fact that one of the related concepts has to be learned before another, or classic semantic links “is-a” and “part-of”. These domain

ontologies represent the expert's knowledge about the domain. The domain model offers also a natural framework for goal modeling. An individual educational goal can be modeled as a structure (e.g. sequence, tree, or stack) of subsets of domain concepts.

The *hyperspace* consists of learning objects. The Learning Object Metadata (LOM) standard defines a *learning object* as any entity, digital or non-digital, that may be used for learning, education or training (LOM, 2002). Content models identify different kinds of learning objects and their components. A comparative analysis of six known content models (Verbert & Duval, 2004) led to the creation of a general model that includes the existing standards and distinguishes between:

- *Content fragments* – learning content elements in their most basic form (text, audio, video), representing individual resources uncombined with any other; instances
- *Content objects* – sets of content fragments; abstract types
- *Learning objects* – they aggregate instantiated content objects and add a learning objective

The standards that can be used at this level include

- *IMS Content Packaging* – description and packaging of learning material
- *IMS Question and Test Interoperability* – XML language for describing questions and tests
- *IEEE Learning Object Matadata* – description of learning resources

Learning objects distributed in various repositories with associated metadata can be nowadays retrieved by means of federated search (Simon et al., 2005). Early adopters have already started using these services. These users can be either learners using learning objects in a similar way like textbooks, or teachers that need suitable materials to support their classes and possibly applying blended learning approaches.

User Model

A user model represents relevant user characteristics, like preferences, knowledge, competencies, tasks, or objectives. The majority of educational adaptive hypermedia systems use an *overlay model* of user knowledge (Brusilovsky, 2003). The key principle of the overlay model is that for each domain model concept, an individual user knowledge model stores some data that is an estimation of the user knowledge level on this concept. A weighted overlay model of user knowledge can be represented as a set of pairs "concept-value", one pair for each domain concept. Some systems store multiple evidences about the user level of knowledge separately. Another alternative to model the user knowledge is provided by a *historic model* that keeps some information about user visits to individual pages. Some systems use this model as a secondary source of adaptation.

The learner's goals can be modeled as a set of concepts (competencies) that can be represented similarly to the overlay model. Additionally to these dynamic dimensions the learner model includes also a more static one – *user preferences.* The most relevant ones are preferred cognitive and learning styles, as well as the language. The following standards relate to user modeling:

- *IEEE Public And Private Information* – specifies both the syntax and semantics of a 'Learner Model,' which will characterize a learner and his or her knowledge/abilities
- *IMS Learner Information Package* – learner information data exchange between systems that support the Internet learning environment

New approaches for *open-world user modeling* able to elicit extended models of users and to deal with the dynamics of a user's conceptualization are required to effectively personalize the Semantic Web. The ultimate goal is to pave the road towards utilizing the adaptive learning environments with an *enhanced learner model* that will integrate different learner perspectives, such as knowledge, personal preferences, and interests, browsing patterns, cognitive and physical state. Complementing to the open-world view is the fact that learner can be also modelled by various peers and learning service providers in a distributed network. The key research issues in this area are: interoperable learner model artefacts, techniques for describing such artefacts, methods for extracting relevant learner model parts for particular learning situations or services, techniques for exchanging and communicating such artefacts. Other major challenges and directions for further research include effective learner modeling, addressing personalization for disabilities, considering the time and evolving user context(s), including the user control, and relating them to the issues of privacy. New challenges are recognized with regard to moving to open educational semantic world.

Context Model

The term *context* can be defined as "the circumstances in which an event occurs; a setting". We are considering it as the environment characteristic rather than the user ones that are represented in the user model. The user (learner) and context models specify *to what parameters* the application should adapt. One of the primary aims is to generate both objective and subjective metadata automatically, based on the current context and by means of suitable sensors – physical as well as semantic ones. This will enable more precise retrieval of the data when learning objects are processed or elaborated by students and teachers.

Context management deals with such issues as automatic acquisition of context metadata, contextualized delivery of content, activities, and services. We observe that the current exchange formats for contextualization of resources need to be extended for capturing and handling additional context data. There are no relevant standards for the context model yet.

Modern context-adaptive systems employ generic and mobile user models to provide human centered and ubiquitous services. As the learner models will also include situated learning in the context of work where learning is an integrated part of working (learning on demand) user competence profile has to be taken into account, as well as analyzing group modeling and pattern recognition in the user behavior. Metadata about the learner and her context should enrich queries into learning object repositories to maximize the efficiency of information retrieval.

Instruction Model

The instruction (pedagogical) and adaptation models specify the navigational design for an adaptive hypermedia application. Together with the presentation specification they tell *how* the adaptation should be performed, so they describe the dynamics ("flow") of the system.

Learning design is a way of modeling learning activities and scenarios, as different types of learners prefer different learning approaches – learning styles. A key axiom that is common to all major educational approaches says that "learners perform activities in an environment with resources". The IMS Learning Design (Koper & Tattersall, 2005) uses the metaphor of a theatrical play to describe the workflow involved in learning and teaching scenarios. It separates the design of the pedagogical model from the content. Main challenges include encoding dynamic interactions between users and system, representing scenarios (objectives, tasks/activities), and describing interactions between participating roles and system services.

Standards that are related to the design of pedagogical activities are:

- *IMS Simple Sequencing* – representing the intended behavior of an authored learning experience
- *IMS Learning Design* – defining diverse learning approaches (scenarios); it defines 3 levels of implementation and compliance (IMS LDIM, 2003):
  - *Level A* – the core vocabulary needed to support pedagogical diversity
  - *Level B* – introduces *properties* and *conditions*, which enable implementation of adaptive strategies
  - *Level C* – notification that can support adaptive self-driven and collaborative learning

The primary aim of the learning design standard was to provide an explicit notation that would enable interoperability on the level of systems. Thus the instructional knowledge does not have to be hardwired in the learning environment, but authors can define it specifically for each learning application, representing an appropriate pedagogical pattern. To allow personalization a method can contain conditions, i.e. If-Then-Else rules that further refine the assignment of activities and environment entities for persons and roles. Conditions can be used to personalize learning designs for specific users. The 'If' part of the condition uses Boolean expressions on the properties that are defined for persons and roles in the learning design. Thus IMS Learning Design can be used to model and annotate adaptive learning design, but designing more complex adaptivity behavior can cause problems. Currently, it is not possible to annotate learning content or define student roles considering their characteristics. We can say that a primary objective of this standard was interoperability between various systems, rather than reusability of learning design methods in various courses or learning units.

Adaptation Model

This model specifies the specific *adaptation* semantics – seen, mastered, recommended objects, etc. Adaptation specifications define the status of individual objects (e.g. content objects or fragments) based on their metadata attributes and the current parameters of the user model and the context model. The adaptation effect is usually achieved by adapting contents and links using suitable adaptation techniques that can be chosen on this level. The taxonomy of adaptive hypermedia technologies (Brusilovsky, 2001) includes:

- *Adaptive presentation* (content level adaptation) to ensure for different classes of users that the (most) relevant information is shown and the user can understand it, e.g. adaptive text presentation, adaptive multimedia presentation, adaptation of modality
- *Adaptive navigation support* (link level adaptation) to guide the user towards the relevant, interesting information, e.g. direct guidance, adaptive link sorting, adaptive link hiding, adaptive link annotation, adaptive link generation, map adaptation

There can be also other adaptation dimensions, e.g. adaptive learning activity selection, adaptive recommendation, or adaptive service provision.

The Adaptive Hypermedia Application Model or AHAM (mentioned earlier) uses Condition-Action rules and due to their complexity, it is not supposed that authors will write all the rules by hand. Some other models build upon AHAM identifying additional relevant layers, with the objective to enable reusability at various levels, focusing mainly on adaptation strategies and techniques. *LAOS* (Cristea & de Mooij, 2003) is a generalized model for generic adaptive hypermedia authoring, based on the AHAM model and on concept maps. It aims at clear separation of primitive information (content) and presentation-goal related information (e.g. pedagogical information). Previously they have defined a layered model for adaptive hypermedia authoring design methodology for (WWW) courseware (Cristea & Aroyo, 2002). This model suggested the usage of the following main three layers:

- *Conceptual layer* expressing the domain model (with sub-layers: atomic concepts and composite concepts – with their respective attributes)
- *Lesson layer* (of multiple possible lessons for each concept map or combination of concept maps)
- *Student adaptation and presentation layer* (based on: adaptation model and presentation model)

All these layers should have been powered by the adaptation engine. Already they were using the lesson model as an intermediate one between the domain model, the user and adaptation model. *LAG* (Cristea & Calvi, 2003) is a generalized adaptation model for generic adaptive hypermedia authoring. The idea behind it was to let the author of adaptive educational hypermedia work on a higher semantic level, instead of struggling with the 'assembly language of adaptation'. Furthermore, these patterns should represent the first level of reusable elements of adaptation. However, reusability can go further than that. Even this *adaptation language* might still be difficult to handle for some authors (teachers). So reuse should be aimed for even at the level of *adaptation strategies* (that correspond to cognitive/learning strategies).

On a higher level the presentation specification defines how to present the chosen adaptation techniques as well as how the objects with a particular status should be presented to the user (e.g. hiding, sorting, emphasizing, annotation techniques).

Accessing Meta-Data of Adaptive Learning Systems

Part of solving the semantic interoperability problem is that systems have to mutually understand their access mechanisms to learning content objects and associated meta-data. More specifically, they must know programming interfaces to connect to, retrieve, and manipulate all necessary meta-data. The *Application Program Interfaces* (API) are either *domain specific*, i.e. they are based on specific metadata models, or they are *generic*, usually suitable to query metadata based on multiple schemas by making use of general purpose query languages like SQL. First we are dealing with the issues related to querying learning repositories and then we present an illustrative example for querying learner profiles.

Generic APIs to Access Learning and Learner Repositories

One possibility to access learning content and learner profiles is to use generic APIs. Those APIs usually provide functions to execute general purpose query languages independent of a domain. Examples of such APIs are

Simple Query Interface (Simon et al., 2005) used mostly exclusively for but not limited to querying metadata about learning objects or APIs to access user profiles at User Modeling Servers (Fink & Kobsa, 2002). Interoperability among learning object repositories requires a common communication framework for querying and retrieving references to the stored objects. In the following we present different query APIs in the learning domain.

The *Learning Object Interoperability (LORI) Framework* is an abstract model for interoperability issues in the context of learning technology (Simon et al., 2005). LORI is a layered integration architecture, which defines services in order to achieve interoperability between independent learning object repositories. These services can be differentiated into core services (e.g. authentication services, session management services) and application services (e.g. retrieval services, provision services). Part of the LORI framework is the *Simple Query Interface* (SQI 2005*)*. SQI is an API that provides method support for asynchronous and synchronous queries. Albeit SQI is in principle not bound to a specific schema and is thus only dependant on a jointly defined canonical schema of the specific community where it shall be applied, several examples like the HCD-Suite (www.hcd-online.com) can be found that use application profiles to mix standardized concepts from IEEE LOM, Dublin Core, and other standards simultaneously in order to satisfy the needs inherent in their community. One of its major design objectives of SQI was to keep the specification simple and easy to implement.

The *Content Object Repository Discovery and Resolution Architecture* (*CORDRA)* is supposed to develop into an abstract, formal model for repository federations and their interoperability (CORDRA, 2004). Currently, CORDRA encompasses similarly to OpenURL an identifier infrastructure and is currently not bound to any specific search interface implementation (Rehak, et al 2005). *OpenURL* (OpenURL, 2004) is an initiative to investigate the problem of uniquely identifying resources.

Z39.50-International: Next Generation (*ZING*) covers a number of initiatives by Z39.50 implementers to make Z39.50 (ZING, 2001) more broadly available and to make Z39.50 more attractive to information providers, developers, vendors, and users. *SRW* is the Search/Retrieve Web Service protocol, which is developed within ZING and aims to integrate access to various networked resources, and to promote interoperability between distributed databases, by providing a common utilization framework. SRW is a web-service-based protocol (SRW, 2004). SRW takes advantage of CQL ("Common Query Language"), a powerful yet human-readable query language. SRU, the Search and Retrieve URL Service, is a companion service to SRW. Its primary difference is its access mechanism: SRU is a simple HTTP GET form of the service (SRU, 2005). SRW encourages the use of Dublin Core, but is in general schema-neutral (like SQI).

The purpose of the IMS Digital Repository Interoperability (*DRI*) Specification (IMS DRI, 2003) is to provide recommendations for the interoperation of the most common repository functions. The DRI specification presents five core commands, i.e. search/expose, gather/expose, alert/expose, submit/store, and request/deliver, on a highly abstract level. The specification leaves many design choices for implementers. For example, while recommending Z39.50 (with its own query language) it also recommends XQuery as a query language.

OKI (Open Knowledge Initiative) is a development project for a flexible and open system to support on-line training on Internet (OKI, 2004). OKI has issued specifications for a system architecture adapted to learning management functions. One of the main characteristics of the project is its commitment to the open source approach for software component development. OKI supplies specifications for a model of functional architecture and an API called Open Service Interface Definition (*OSID*). OSID is directed towards specifications for a flexible and open source model of functional architecture. Service Interface Definitions (SIDs) organize a hierarchy of packages, classes and agents and propose Java versions of these SIDs for use in Java-based systems and also as models for other object-oriented and service-based implementations. Components developed by OKI are compliant with specifications issued by IMS and ADL SCORM.

Edutella is an RDF-based Peer-to-Peer infrastructure for querying distributed learning object repositories that comes with its own query language QEL (QEL, 2004). The Resource Description Framework (*RDF*) is one of the key pillars of the Semantic Web (RDF, 2005). RDF is an extensible way to represent information about (learning) resources. One of RDF's design assumptions is that resources are identified by a Unique Resource Identifier (URI) allowing various users and agents to make assertions about uniquely identified objects. The API in Edutella was used both to query learning resource metadata and learner profiles in Elena project.

Domain Specific APIs to Access Learning and Learner Repositories

Another possibility how to access learning and learner repositories is to use domain specific APIs. The learning repositories nowadays conform to Learning Object Metadata standard by applying its profiles. The concepts from LOM can be used to design APIs and libraries to query the repositories by using the concepts from the domain of interest. Similarly, several open specifications have emerged to provide shared information models to represent learner profiles like IEEE PAPI (IEEE PAPI, 2003) or IMS LIP (IMS LIP, 2001). The concepts from those information models can be used to build APIs for accessing learner profiles. An example of learning repositories domain specific API is *EduSource*. *EduSource* project (Hatala et al., 2004) aims to implement a holistic approach to building a network for learning repositories. As part of its communication protocol – referred to as the EduSource Communication Language (ECL) – the IMS Digital Repository Specification was bound and implemented. A gateway for connecting between EduSource and the NSDL initiative, as well as a federated search connecting EduSource, EdNA and Smete serve as a first showcase.

A different example of domain specific API is the API for accessing learner profiles. The Lerner API (Dolog & Schäfer, 2005) was developed in the context of FP5 EU/IST project Elena – Creating Smart Spaces for Learning. The API is based on a learner ontology. Figure 2 depicts an excerpt of a learner profile ontology configured from fragments based on three specifications (the Elena project web site http://www.elena-project.org and its personalization section provide the complete ontology in RDFS). The abbreviated syntax for namespaces is used in concept and relation labels (e.g. qti stands for Question and Test Interoperability namespace at http://www.elena-project.org/images/other/qtilite.rdfs). The default namespace is http://www.elena-project.org/images/other/learner.rdfs. The conceptual model describes a situation where a learning performance (IEEE PAPI is used to model performance and portfolio, http://ltsc.ieee.org/archive/harvested-2003-10/working_groups/wg2.zip) of a student is exchanged in terms of his achieved competencies (IMS RDCEO – Reusable Definition of Competency and Educational Objectives, http://www.imsglobal.org). The competencies have been evaluated by learner assessment (e.g. tests) and were derived from learning objectives of tests (IMS QTI). Furthermore, all other educational activities, further materials, and projects created within the activities are reported within the portfolio of the performance. Additional information which is reported under preferences (IMS LIP) comprises language, device, resource and learning style preferences. The standards and open specifications guarantee wider acceptance between e-learning systems and as such can be seen as good candidates for the learner exchange models. Currently, none of the referenced standards present their metadata in a way that makes it possible to use them in combination as depicted above. Therefore, an RDF translation of these standards had to be developed, which made it possible to use them in combination. This RDF translation is 'unofficial', and we therefore view it as an important direction for future standardization work that the standards use a common framework such as RDF and the Semantic Web, to enable the added value of using the standards together.

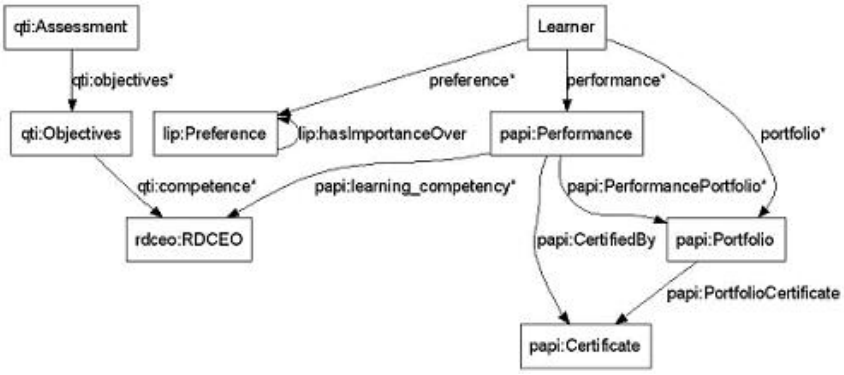

Figure 2: Conceptual model for learner profile – an excerpt

Figure 3 depicts several possible scenarios of how to access and exchange learner profile fragments. The fragments can be accessed programmatically by the use of a Java API, the web service which exports the learner model through the API and acts as a learner model server, and through a query infrastructure for RDF repositories like Edutella (Nejdl et al. 2002).

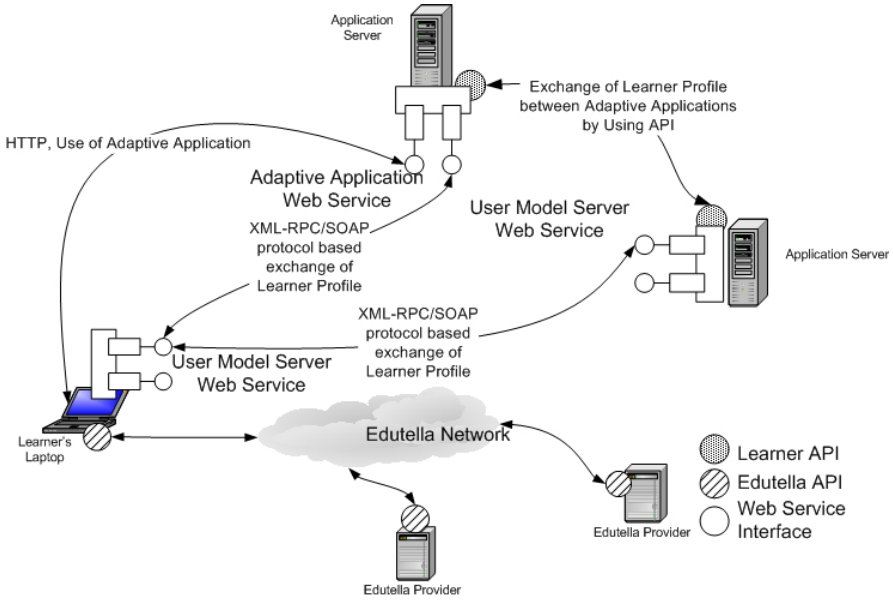

Figure 3: Use of API in several scenarios – an example

A Java API has been developed. It is structured according to the learner ontology fragments mentioned above. The API is meant to be used to retrieve, insert, and update the learner profiles stored in the structures described above. The API defines a class and properties for each class from the RDFS for the learner model. The interface provides access functions for getting, deleting and updating a model of the fragment. It provides further functions to derive additional information or to process more complex manipulations over referenced information types as well. The API is implemented for the RDF representation (instances of the RDFS described above). The API is easily extensible by providing further specializations if additional extensions and interface implementations for local repositories and data models are needed.

The second implementation is provided through web services where several clients can access one model which is persistent on one server. The server holds the main model, i.e. the data of a learner profile gathered from several sources, and handles all requests from the clients. Each client is uniquely identified at the server and can be used by a browsing or assessment system. Furthermore, a client can be used by other learning systems which want to make use of the learner profiles or which want to contribute to them. The model can be accessed directly by invoking functions of a web service or in a synchronized replicated way; i.e. each client has its own repository which is synchronized with the main server every time a change occurs. The web services framework can be used in a distributed way as well (several servers exchanging learner models between each other).

The learner profiles are created in RDF. Therefore, a query infrastructure for RDF data is another access option. Edutella provides a Datalog-based language to query RDF data provided in a distributed P2P environment. This option enables to collect various fragments by utilizing for example the algorithm from (Dolog, 2004). Another advantage of the P2P sharing infrastructure used with the learner profiles is that it can facilitate an expert finding based on the provided profile which can be queried by people who need a help in learning.

Summary and Conclusion

Complex problems require more knowledge than any single person possesses, therefore it is necessary that all involved stakeholders communicate, collaborate, and learn from each other. The process of arranging personalized adaptive learning experiences is a very complex one and usually people with different expertise have to collaborate to achieve a good quality solution. The complexity of this problem comes from the difficulty to formalize all the knowledge necessary in the pedagogical process. The authoring process can be simplified if at various levels of the application reusable components are constructed that can be assigned to the formal models mentioned earlier in this paper – learning objects, domain ontologies, pedagogical methods, and adaptation specifications. Following standards requires an increased initial investment, but has a higher potential for the future.

It has been observed that the more context is assigned to learning objects the lower is their reusability (Hodgins, 2005). The validity of this statement can be enhanced also for specifications of learning activities and adaptivity. As stated by R. Koper (Koper & Tattersall, 2005) "the notation must make it possible to identify, isolate, de-contextualise and exchange useful parts of a learning design so as to stimulate their reuse in other contexts". Therefore it would be beneficial to distinguish well-defined learning layers with clear interfaces, so that each object of a given layer can be substituted with other objects of the same layer and combined with other objects from different layers in order to build a comprehensive solution.

There is a lack of support for adaptive behavior in existing learning standards that leads to higher costs and lower reusability of personalized learning solutions. B. Towle and M. Halm claim that IMS LD provides a way to implement simple adaptive learning strategies, but not complex forms of adaptive learning, like multiple rules interactions or enforced ordering (Koper & Tattersall, 2005). The aLFanet system (van Rosmalen et al., 2006) was built according to a standard-based model for adaptive e-learning. They have found out that learning standards are not harmonized to work with each other. Additionally, available tools are too complex for non-specialized authors. It is necessary to improve usability and minimize complexity of the authoring tools. Another approach (Zarraonandia et al., 2006) has focused on reusability at the level of learning design. In this case an architecture is being developed that will automatically adapt units of learning to their actual context of execution via runtime interpretation of small adaptive actions that are specified separately from the Learning Design definition.

In the WINDS project (Kravcik et al., 2004; Kravcik & Specht, 2004) authors without programming skills could produce adaptive courses by specifying declarative knowledge for adaptation by means of pedagogical metadata. This together with procedural knowledge encoded in the course player generated adaptive delivery of courses. A generalization of this approach (Kravcik, 2004) aimed at more flexibility, reusability and interoperability of partial learning resources via separation of different kinds of knowledge and their interaction, taking into account a typical learning design process as well as content object preferences for various learner profiles and contexts. A challenge is the creation and use of ontologies to represent various types of knowledge relevant for personalized adaptive learning (Knight et al., 2006). Such ontologies could be used by software agents to assist authors in the design of individualized learning or even to directly generate such experiences themselves.

This article is aiming to map the current situation in the area of interoperability for adaptive learning components. We have focused on general aspects of semantic interoperability of adaptive systems, formal models and standards, as well as access to metadata, and have given examples of concrete tools, applications, and suggestions how to integrate different approaches. Interoperability demands can be recognized both at the horizontal level (between various systems) and at the vertical one (between formal models). In none of these two cases we can be satisfied with the existing solutions. There exist standard based solutions supporting interoperability of learning objects and learner models. Standardized learning design enables interoperability between systems, but is not reusable in general. Interoperability of domain ontologies is an open issue, for the context and adaptation models standards are still missing. We can state that in this field we are still far from achieving general interoperability, since the different standards are not enough to realize it and therefore a mediation based or Semantic Web based approach is still to be devised to reach reasonable results. This puts also the impressive looking list of standards and tools in the field in a realistic perspective.

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