# Leveraging the Semantic Web for Adaptive Education

*Miloš Kravčík* [1] *and Dragan Gašević* [2]

[1] Open University of The Netherlands
Valkenburgerweg 177, 6419 AT Heerlen,
The Netherlands
http://www.ou.nl/

[2] School of Computing and Information Systems,
Athabasca University
1 University Drive, Athabasca, AB T9S 3A3
Canada
http://scis.athabascau.ca/

**Abstract:** In the area of technology-enhanced learning reusability and interoperability issues essentially influence the productivity and efficiency of learning and authoring solutions. There are two basic approaches how to overcome these problems - one attempts to do it via standards and the other by means of the Semantic Web. In practice, these approaches meet and many existing solutions are based on ontologies that take into account the available specifications and try to integrate them. Moreover, these ontologies can help us to achieve a certain kind of consensus and to contribute to the harmonization of the existing standards. This paper aims at addressing the issues of leveraging the Semantic Web to improve mechanisms for knowledge representation in the area of adaptive education. We attempt to view adaptive education from different perspectives and consider relationship of various aspects that often appear not to be connected.

**Keywords:** Adaptive Education, Learning Standards, Semantic Web, Ontologies, Rules.

# 1 Introduction

Research of the brain confirms appropriateness of Minsky's approach (Minsky, 1987) that is based on Freud's theories, which consider the mind as a collection of structures that can both cooperate with and oppose one another to find ways to deal with conflicting goals. Minsky recognizes several causes of human resourcefulness (Brockman, 2003): multiple representations of knowledge, emotions as different ways to think (suppressing resources that one otherwise usually uses when thinking), learning on multiple levels (when and how to use knowledge), as well as analogies. Humans need to develop a wide range of ways to represent multiple dimensions of a problem and redundancy in knowledge representation is an important feature of our brains that enables viewing objects in various contexts and from different perspectives. If one approach to solve a problem fails, changing the point of view can lead to an alternative solution. This is especially important in the case of complex and ill-structured domains when there is a danger of incorrect representation or oversimplification. The ability to restructure the knowledge spontaneously in adaptive response to changing situational demands is called cognitive flexibility (Spiro and Jehng, 1990). It includes choosing a scope of the domain, a point of view, a level of abstraction, selection of concepts, as well as realizing their relationships.

Such cognitive science principles suggest that in the area of adaptive education among the major issues are those related to orchestration of various kinds of knowledge as well as their reusability and interoperability. They are usually addressed either by means of standards or by using the Semantic Web. In fact, these two approaches complement each other. Many existing ontologies take into account the existing standards and attempt to integrate them. Furthermore, these ontologies contribute to harmonization of the learning standards. A major challenge regarding interoperability and reusability issues might be the representation of various types of knowledge driving the personalization and adaptation processes, and subsequently letting those types interact when generating the concrete instances of adaptive experience dynamically.

The progress towards the Semantic Web vision includes several strands (Warren, 2006): extracting semantics from unstructured texts, developing predefined semantics for the WWW, creating a framework of Semantic Web standards (like ontology description languages), and implementing tools for managing ontologies. There is a continuum of approaches regarding how semantics can be built in the Web (Uschold, 2003): from implicit to explicit, informal vs. formal, processable just by humans or also by machines. The machine processable semantics include, on the one hand, ontologies that can be produced by anyone, and interoperable standards developed by organizations like the Dublin Core Metadata Initiative or W3C on the other. As the representation of semantics cannot be fully automated, there are trends towards integrating this activity into normal business processes and analyzing the context to generate useful annotations (Hendler, 2001).

Here we attempt to analyze various techniques applied in adaptive educational systems, in order to find out how such systems can be improved by leveraging the Semantic Web technologies to represent knowledge in different models utilized in these systems. Our discussion is grounded on the basic idea that the Semantic Web initiative tries to improve the current state of the Web by using semantic descriptions of Web resources, and thus enabling knowledge sharing on the Web (Hendler, 2001). The key components are ontologies that formally define concepts shared by a community. In this way, one can search Web resources based on their real meaning defined by ontological metadata, instead of using text-based keywords. On top of ontologies other important components of the Semantic Web are defined, including rules (Horrocks *et al*, 2004; Ginsberg, 2006) and policies (Bonatti *et al*, 2006), which have so far attracted limited attention in the research on adaptive educational systems.

The aim of this paper is to outline the issues of missing standards in the area of adaptivity and personalization as well as some possible perspectives in this field, especially those based on the Semantic Web. We intend to explore to what extent the Semantic Web can harmonize different aspects of an adaptive educational hypermedia system, improve automatic knowledge processing, and increase interoperability between different systems as well as knowledge reusability. First, we present an enhanced adaptive hypermedia application model. Due to a missing common abstract model, the existing standards do not support interoperability in a satisfactory way. Aiming to examine the degree of reusability and interoperability of procedural knowledge in the current adaptive educational hypermedia systems, we further discuss several strategies and techniques, including informal scripts, system encoding, typed knowledge, standardized specifications, and ontologies. Taking into account different components of the enhanced adaptive hypermedia application model, we can apply Semantic Web technologies to improve their interoperability. More specifically, we analyze which and how Semantic Web technologies can be used in various components of adaptive hypermedia systems in order to improve their interoperability. We also briefly reflect on some present solutions. Finally, a summary of our findings concludes the paper.

# 2 Model of Adaptive Learning

The term *adaptive hypermedia system* (Brusilovsky, 2001) has been defined as a hypertext or hypermedia system which reflects some features of the user in the user model and applies this model to adapt various visible aspects of the system to the user. The main characteristics of adaptive hypermedia systems are their ability of adaptation to the user characteristics (e.g., goals, tasks, knowledge, background, experiences, preferences, interests, and individual traits) and environment (e.g., location, computing platform, and bandwidth). The taxonomy of adaptive hypermedia technologies (Brusilovsky, 2001) includes

- *Adaptive presentation* (content level adaptation)
- *Adaptive navigation support* (link level adaptation)
- *Adaptive content selection* (content level adaptation).

There can also be other adaptation dimensions such as adaptive learning activity selection, adaptive recommendation, or adaptive service provision. But generally, adaptation specifications can be considered at various layers:

- Processes: their selection, design, and structure according to the current user and context;
- Materials: their selection, design, structure, and presentation according to the current user and context;
- Adaptation: selection of adaptation strategies and techniques on a meta-level according to the current context.

There are various attempts to model hypertext, hypermedia, and adaptive hypermedia. In the following paragraphs we introduce those that are most relevant from our perspective. Considering them, we propose our approach to model adaptive hypermedia, which is based on the following principles:

1. Distinguish between essential types of knowledge in a formal model,
2. Make them relatively independent of each other, but interoperable,
3. Specify concrete instances of knowledge, which can be composed into a holistic solution,
4. Select suitable instances on demand according to the current user and context.

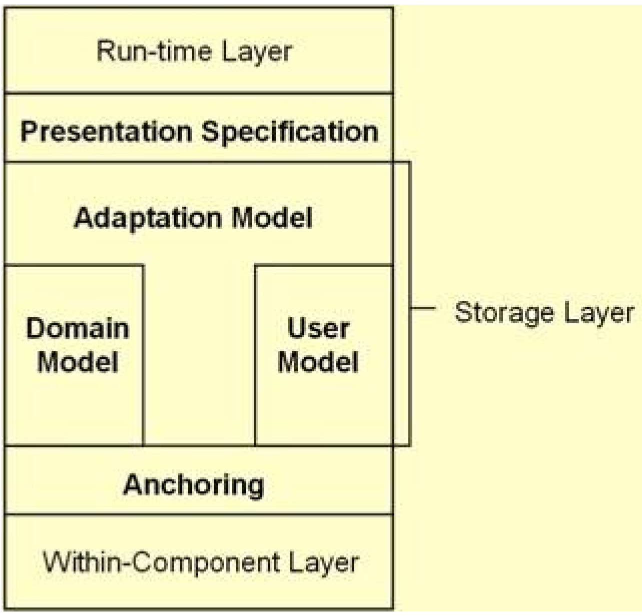


Figure 1: Adaptive Hypermedia Application Model (De Bra et al., 1999; Wu et al., 2001)

The basic formal model of hypertext systems is the *Dexter Hypertext Reference Model* (Halasz and Schwartz, 1994). Its goal was comparison of existing systems as well as development of interchange and interoperability standards. The model distinguishes between three layers of a hypertext system and two interfaces between them. The Dexter model is a very powerful one - it considers some sophisticated features, like composite nodes, multi-way links, links to links, etc. We refer to the *Adaptive Hypermedia Application Model* - AHAM (see Figure 1), which is based on the Dexter Model. AHAM provides a framework to express the functionality of adaptive hypermedia systems by dividing the storage layer into three parts that specify *what* should be adapted, *according to what* features should it be adapted, and *how* should it be adapted:

- *Domain model* - describes how the information content is structured
- *User model* - describes the information about the user
- *Adaptation model* - adaptation rules defining how the adaptation is performed

AHAM 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, like in the LAOS model (Cristea and de Mooij, 2003). The objective is to enable reusability at various levels, focusing mainly on adaptation strategies and techniques. LAOS is based on the AHAM model and on concept maps. It aims at clear separation of primitive information (content) and presentation-goal related information.

According to AHAM and other related approaches, it is common to base the adaptation process on the domain model and the user model, possibly enhanced by facilities such as the goal (task) model, but as nowadays there is a need to provide adaptive services in mobile and ubiquitous computing, the context model has to be added, in order to represent the current environment and settings (see Figure 2). To specify the adaptation itself in a reusable way the adaptation model has to be separated from the domain one and enhanced by an activity (scenario) model, representing the procedural knowledge of the application. The suggested formal models have already been discussed (Aroyo *et al*, 2006), together with the standards that apply to each of them. As a conclusion, the existing standards do not support interoperability in a satisfactory way, as a common abstract model is missing. They can be used in isolation, but that is not desirable. To investigate the knowledge types that are relevant for delivery of personalized adaptive experience in adaptive hypermedia systems it is crucial to specify the basic aspects of adaptation and the related complementary models:

- *What* is to be delivered and adapted: domain model,
- *According to what* parameters it can be selected and adapted: user model and context model,
- *How* the delivery and adaptation should be performed: activity model and adaptation model.

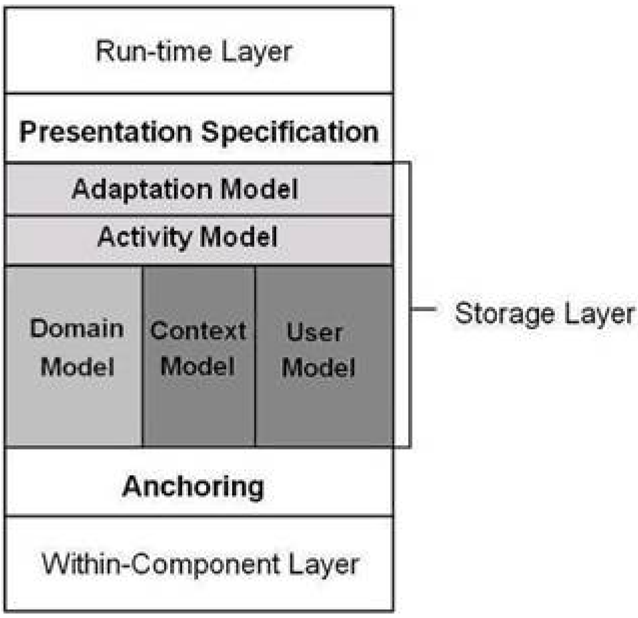


Figure 2: Enhanced Adaptive Hypermedia Application Model

Thus personalized adaptive learning experience is not controlled by uniform rules, but several specialized parts take care of particular functions and interact with each other instead. The individual models may be distributed in reality. The domain and user models have comprehensively been analyzed (Brusilovsky, 2003), while the context model has become important more recently, taking into account new challenges like mobile learning. The activity and adaptation models specify the process design and situational adjustments for an adaptive hypermedia application (activity modeling is well known from the educational area under the name "learning design"). Together with the presentation specification they tell *how* the delivery of the requested experience and its adaptation to the current context should be performed, so that they describe the system's dynamics. On the 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, and annotation techniques). Thus, while the other models typically represent the *declarative* knowledge of an adaptive application, the activity and adaptation models usually form its *procedural* knowledge. In the following paragraphs, we are focusing on the models related to the procedural knowledge, dealing with the above mentioned formal models and related standards and specifications.

# 3 Representations of Learning Activities and Adaptation

As we have already mentioned, *declarative knowledge* is typical for the description of the subject domain (e.g., learning materials, metadata, and domain ontologies), the user and context knowledge. On the other hand, the *procedural knowledge* is important for designing learning activities from the pedagogical viewpoint as well as for defining adaptation strategies. In the following, we present several different approaches to addressing these issues, together with related benefits and obstacles. Formal specification of concrete *instances* does not support reusability very well, thus we need to represent the *knowledge* that could help us generate these instances and their adaptation at run-time. Regarding learning design and adaptation, especially the *procedural knowledge* is highly relevant. It has been already articulated (Koper and Tattersall, 2005) that "the notation must make it possible to identify, isolate, de-contextualize, and exchange useful parts of a learning design so as to stimulate their reuse in other contexts." Therefore, it would be beneficial to distinguish between well-defined layers of learning applications with clear interfaces in order to build a comprehensive solution.

## 3.1 Informal Scripts

A. Bork attempts to address the problem of lifelong global learning for all and has suggested a new learning paradigm (Bork, 2001) - instead of the dominant *information transfer* or *classroom-teacher paradigm*, he proposes *tutorial learning*, based on the Socratic dialog with frequent questions and free-form answers delivered via modern technology. For this purpose adaptive learning units have to be designed by a team of people with different competencies, including domain experts and teachers. They first prepare an overall design and its result is a list of modules to develop. In a detailed design, they make the activity sensitive to individual students by generating diagnostic questions and providing suitable feedback. This is based on the concept called *zone of proximal development* by Vygotsky to find what the student is ready to learn next. Designers decide what student data to store, how to analyze answers, and what media to use. They sketch informal scripts to specify both the design logic and messages for the learner. Later on, programmers implement these ideas into programming logic, screen design, and suitable media.

This approach demonstrates that it is not easy to formalize all the knowledge necessary to deliver adaptive learning experience. In this case most of the knowledge is represented implicitly in the design scripts. As a consequence, this knowledge is generally not reusable in other learning units or in other applications. Although the authors can freely specify designs of learning units, which certainly simplifies their work, the authoring process is complicated by the fact that the specifications of learning unit *instances* always have to be eventually implemented by programmers in each individual case.

## 3.2 System Encoding

Other approaches try to abstract the procedural knowledge in such a way that it can be encoded in the learning environment and reused in various learning units created in the corresponding authoring tool. Several existing systems have followed this approach; we mention at least one example. In the WINDS project (Kravcik and Specht, 2004) teachers first specified their pedagogical requirements (for the field of design and architecture) and the ALE system was implemented accordingly. Then, authors without programming skills could produce adaptive courses by specifying declarative knowledge for adaptation purposes by means of metadata - like pedagogical roles of either learning objects or content fragments. This along with procedural knowledge encoded in the player generate adaptive delivery of courses.

It is important to note that the advantage here is that immediately after a learning unit has been created authors can check how it will be presented to learners and improve it if needed. On the other hand, after they have specified their requirements at the beginning of the project, it is not so easy to adjust the behaviour of the system later on, especially if it could change presentation of previously created learning units. Similarly, it is not possible to use an alternative learning design method for various learning units or to assign a different adaptation strategy to the method. The representation of procedural *knowledge* is fixed and the authors cannot tailor it according to their needs in a specific learning situation.

## 3.3 Elicited Knowledge

The authoring process can be simplified if specifications of learning design and adaptation strategies are separated from concrete learning materials and contexts. Teachers usually use one pedagogical method in various situations and in multiple learning units with different learning resources. Therefore, instead of having to specify again and again the same design or strategy, it would be highly efficient to have a relatively independent specification that can be reused. Two of such attempts are LAOS and FOSP.

Coming from the adaptation field, LAOS (Cristea and de Mooij, 2003) addresses the highly important objective of a clear separation of different types of knowledge, but those related to pedagogy and adaptation seem to be mixed together. Its adaptation language uses if-then-else rules and cycles were considered for the future. Adaptation is defined by the "select" and "sort" elements. The aim of *LAG* (Cristea and Calvi, 2003) 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. Reuse should be strived even at the level of *adaptation strategies* (that correspond to cognitive/learning strategies).

The FOSP method (Kravcik, 2004) is a generalization of the WINDS approach, aimed at more flexibility, reusability, and interoperability of partial learning resources via separation of different kinds of knowledge, taking into account a typical learning design pattern as well as content object preferences for various learning styles and contexts. FOSP is based on the experience that authoring of adaptive educational applications is easier if the procedural and declarative knowledge are separated. To support collaborative authoring through reusability of partial results, it is also beneficial to separate the procedural knowledge related to instruction, adaptation, and presentation. FOSP addresses these issues by means of several functions and one general design pattern. The main idea here is to separate different types of knowledge and let them interact.

These attempts can simplify the authoring work and provide reusability of procedural *knowledge* in the framework of a particular system or between systems sharing the same specification format. However, to achieve a critical mass of its instances, a specification language has to be standardized (if not by official standardization bodies, then at least as "de facto" standards adopted by large communities such as W3C or IMS).

## 3.4 Standards and Specifications

Two most relevant standardized specifications related to learning design and adaptation are *IMS Simple Sequencing* and *IMS Learning Design* (IMS LD). The former one provides learning material tailored to the learner's current context, but does not use any knowledge of each individual user, thus it makes no distinction between users. IMS LD offers more opportunities for specification of *instances*, focusing primarily on definition of diverse learning approaches and pedagogical scenarios.

The primary aim of IMS LD was to provide an explicit notation that would enable the interoperability on the level of systems. This means that the instructional knowledge does not have to be hardwired in the learning environment, but authors can specifically define it for each learning application representing an appropriate pedagogical pattern. To allow personalization, a method of a learning design can contain facilities like conditions, DIV layers, or hide-visible properties. Conditions are if-then-else rules that further refine the assignment of activities and environment entities for persons and roles. They can be used to personalize learning designs for specific users. The 'if' part of the condition uses expressions on the properties that are defined for persons and roles in the specific learning design. Thus, IMS LD can be used to model and annotate adaptive learning design with a certain degree of complexity. It seems that this specification currently satisfies better the requirements of interoperability between various systems than reusability of learning design methods in various courses or learning units.

Generally, we cannot be satisfied with the current support for adaptive behaviour in learning standards that implies higher costs and lower reusability of personalized solutions. Towle and Halm (2005) 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. The aLFanet project has delivered a system (van Rosmalen *et al*, 2006) that was built according to a standard-based model for adaptive e-learning. It provides valuable and interesting results, including those saying that learning standards are not harmonized to work with each other and available tools are too complex for non-specialized authors. The ongoing research brings additional findings. The experience with the ALD editor (Berlanga and Garcia, 2005) shows that IMS LD can be used to model and annotate adaptive learning design, but designing more complex adaptivity behaviour might not be too easy. For instance, it is not possible to annotate learning content or define student roles considering their characteristics. Another approach (Zarraonandia, Dodero, and Fernandez, 2006) has focused on reusability on the level of learning design, developing an architecture that should automatically adapt units of learning to their actual context of execution via runtime interpretation of small adaptive actions that are specified separately from the IMS LD definition.

## 3.5 Ontologies

IMS LD can help designers to represent pedagogical models and scenarios as specific results, but their knowledge itself cannot be captured by this means (Koper, 2006). A challenge is the creation and use of ontologies to represent various types of *knowledge* relevant for personalized adaptive learning (Knight, Gašević, Richards, 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.

The pioneering work on exploring potentials of ontologies for e-learning applications was carried out by Stojanović, Staab, and Studer (2001). They recognized the lack of standard vocabularies and the lack of formal semantics as major obstacles to interoperability of e-learning systems. They proposed the use of ontologies in order to overcome these issues. More specifically, they identified three different types of ontologies in e-learning systems: *content* (domain) ontologies enabling one to formally state what the learning material is about; *context* ontologies providing means to express formally in which form the learning content is presented; *structure* ontologies formalizing the structure of the learning material. In the recent years, researchers proposed various ways of employing ontologies for building e-learning systems. Here we just mention a few examples related to Adaptive Educational Hypermedia Systems. Cristea (2004) examined the potentials of the Semantic Web technologies by developing appropriate ontologies for each layer of the LAOS model, namely: domain, goal and constraint, user, adaptation, and presentation ontologies. Although the author proposes the use of ontologies, all the ontologies are represented by using XML Schema, and thus still suffer from the lack of the explicit semantic representation. However, the author proposes MOT as an authoring system for adaptive (educational) hypermedia authoring, which is based on RDF Schema, and hence explicitly defines semantics of the LAOS model. Henze, Dolog, and Nejdl (2004) go a step further and propose a reasoning and ontology framework for personalized learning on the Semantic Web. The framework is based on the Web Ontology Language (OWL), a W3C recommendation for the ontology language, comprising the following ontologies: domain ontology, user ontology, observation (interaction) ontology, and presentation ontology. Finally, Henze et al. (2004) show how rules (expressed in the TRIPLE Semantic Web rule language) can be enabled to reason over distributed information resources in order to derive hypertext relations dynamically. Jovanović, Gašević, and Devedžić (2006) developed a system called TANGRAM for dynamic assembly of personalized learning content on the Semantic Web. The system relies on the following ontologies: content structure ontology, content type (pedagogical role) ontology, learning path ontology, domain ontology, and user model ontology.

# 4 Leveraging the Semantic Web

Semantic Web technologies can improve reusability and interoperability of each model of an adaptive educational system (Figure 2). Following the research results presented in the previous section that indicated some initial steps done in the area, here we focus on how each model can benefit from Semantic Web technologies. Although our primary focus is on pedagogical (instruction or activity) and adaptation models (i.e., procedural knowledge), we also discuss other models of adaptive educational systems (i.e., domain, user, and context). This is due to the fact that the increased level of reusability and interoperability of instruction and adaptation models is efficient if all other models are based on semantic technology. Not only does it improve knowledge sharing with other adaptive systems, but this approach also improves sharing knowledge among all models inside of one adaptive educational system. We do not limit our discussion only on ontologies, but we also consider other important parts of the Semantic Web, namely, rules and policies.

## 4.1 Domain Model

Employing the Semantic Web technologies, the knowledge space of domain models can be represented by using *domain ontologies* as a formal specification of shared conceptualization of a shared domain (Gruber, 1993). Currently, the Semantic Web community adopted a standardized language (OWL) for sharing ontologies. Given such a standardized ontology language, adaptive hypermedia systems can share their domain models. Of course, there is no guarantee that two adaptive educational hypermedia systems can share their domain knowledge just because their ontologies are represented by OWL. One approach is to provide standardized domain ontologies, or at least ontologies that will be adopted by a wider community of users (Bodoff, Ben-Menachem, and Hung, 2005). An alternative is to employ results of very extensive research on ontology mapping (Gašević and Hatala, 2006; Shvaiko and Euzenat, 2005). Next, the original purpose of ontologies presumed involvement of domain experts to defined conceptualization of a domain, but ontology engineering and knowledge management practices report on the need to construct domain ontologies automatically by applying ontology learning techniques (Maedche and Staab, 2001) or to use ontology learning techniques to evaluate validity of the ontology to check whether it still properly represents the target domain (Warren, 2006). Furthermore, exploring relations between ontologies and Web 2.0 techniques (Mika, 2005) (e.g., folksonomies and collaborative tagging) is another important research direction for adaptive educational systems. Exploring potentials of these techniques might be an important stream for the future research in adaptive educational hypermedia.

## 4.2 User Model

User models can also be defined by using ontology language in order to enable better sharing of user models. One of the first *user model ontologies* (Dolog and Nejdl, 2003) is based on two vocabularies developed for sharing user profiles, namely, IEEE Personal and Private Information (PAPI) and IMS Learner Information Package (LIP). Leveraging these vocabularies with features for specific learning purposes in a form of an RDF schema, the user model ontology is developed and employed in the ELENA project. A similar approach is applied in TAGRAM (Jovanović, Gašević, and Devedžić, 2006), a system for dynamic assembly of personalized learning content. However, either of these approaches is based on application specific user model needs, and more likely they will not be suitable for other application domains. In fact, this is a similar problem that we have already addressed earlier for domain ontologies. One attempt is to develop a common user model ontology that will be adopted by a wider community. This was the main purpose of the User Modeling Markup Language (UserML), but there is no evidence about common acceptance of this approach. Alternative is, like with domain ontologies, to apply ontology mapping techniques in order to map between two different user model ontologies (Shvaiko and Euzenat, 2005). Furthermore, it is also possible to learn user profiles and automatically construct user model ontologies for a specific system or a class of systems (Davies *et al*, 2005). Note that there is a new IMS specification that can be considered for the purposes described above. It is called Accessibility for Learner Information Package (ACCLIP) and provides a means to describe how learners can interact with an online learning environment based on their preferences and needs.

## 4.3 Context Model

*Context models* usually deal with such issues as automatic acquisition of context metadata or contextualized delivery of content, activities, and services. This means that context models should connect other models of adaptive hypermedia systems. An example of such a contextual model is an *ontology* for capturing learning object context (Knight, Gašević, Richards, 2006) that bridges a learning design ontology (another ontology based on the IMS LD specification) and the learning object content structure ontology proposed in (Jovanović, Gašević, and Devedžić, 2006). In fact, this research is inspired by and extends the ecological approach (McCalla, 2004) proposing a more flexible method to creating learning object metadata, for example, by relating all learners' interactions (e.g., captured by user model snapshots) to learning objects. Note that it is very difficult to isolate context independent knowledge, which is often needed when building ontologies.

## 4.4 Activity Model

We have already mentioned that there is no general standard for defining *activity models*, but we have referred to the IMS Learning Design specification. Relying on *one common information model*, or even better an official specification such as IMS LD, for describing learning activities and scenarios can substantially improve interoperability and reusability among different adaptive educational hypermedia systems. Still, this specification can be improved by using *ontologies*. Giving a formal definition of semantics for such an information model can provide stronger integration basis for different adaptive systems. For example, Amorim *et al* (2006) developed an OWL ontology based on the IMS LD information model in order to address limited expressivity of the official specification in the form of an XML schema. Another aspect is to consider integration of activities and resources in other business processes existing on the Web. In fact, an open space such as the Web offers a huge wealth of different services that can be employed in different scenarios. However, we should also take into account that there are no guaranties that all of those services will always be accessible and that different users would prefer to use different services personalized to their cognitive styles, preferences, and foreknowledge. In fact, we need to provide a method for composition of different resources using well-known business process techniques and standards. An OWL-based Web Service OWL-S ontology seems to be a promising solution. OWL-S is supposed to facilitate the automation of Web service tasks including automated Web service discovery, execution, composition and interoperation. Aroyo, Pokraev, and Brussee (2003) proposed an approach to transforming SCORM Simple

Sequencing into the DAML-S (a predecessor of OWL-S) ontology, while Dolog *et al* (2004) suggested the use of DAML-S for a personalized composition of learning services in distributed e-learning environments. In addition, EU-funded project LUISA (http://www.luisa-project.eu) is using Web Service Modeling Ontology to enrich semantically the representation of learning objects and services, so that one can get more effective architectures (e.g., more adaptive and interoperable ) for Learning Management Systems.

## 4.5 Adaptation Model

*Adaptation models* are usually represented as rules embedded in adaptive hypermedia systems, stored in system-specific formats or represented in well-known *rule-based languages* (e.g., Jess, Lisp). A solution to this problem is to use Rule Interchange Format (RIF) (Ginsberg, 2006). RIF is an initiative by W3C RIF Working Group to address the problem of interoperability between existing rule-based technologies. Besides standardizing the use of an interchange format for rules, RIF is trying to devise an approach which is easily extensible for the future rule technologies and other enabling technologies. RIF is desired to play as an intermediary language between various rule languages and not as a semantic foundation for the purpose of reasoning on the Web. Besides RIF, one should also develop a (two-way) transformation between RIF and any rule language that should be shared by using RIF. Currently, there is no official submission to RIF, but RuleML (Hirtle *et al*, 2006) and REWERSE Rule Markup Language (R2ML, 2006) are two well-known RIF proposals. For example, there are a number of examples demonstrating how different rule languages can be exchanged via R2ML (e.g., Jess, Jena Rules, F-Logic, OCL, and Semantic Web Rule Language-SWRL). There have just been initial steps done in the area of the use of Web sharing rules in adaptive hypermedia educational systems. For example, Papasalouros, Retalis, and Papaspyrou (2004) focus on the development of a tool for the translation of Object Constraint Language rules to RuleML to facilitate the automatic transformation of UML models to Semantic Web descriptions used in adaptive educational systems. However, this is an initial step, as they have not exploited expressive prove of RuleML or R2ML to represent various types of rules, including derivation, integrity constraint, production, and reaction rules, as pointed out by Carmagnola *et al* (2005a). The same authors proposed MUSE as an example of a multidimensional framework for the representation of ontologies and rules in adaptive educational hypermedia systems that uses OWL ontologies and SWRL rules (Carmagnola *et al*, 2005b), but in this case they do not use SWRL as a rule interchange language, but as a rule level over OWL ontologies. Note also that this area has a lot of potential for future research by addressing how rules can be extracted from the present adaptive educational systems and reused in other systems by using languages such as R2ML and RuleML and how policies (e.g., security, privacy, QoS) can be integrated into adaptive educational systems (Gavriloaie *et al*, 2004) by means of rule interchange languages (Kaviani *et al*, 2007).

# 5 Summary and Conclusion

In this paper, we give a general comparison of different topics and models relevant for adaptive education, taking a wide perspective on various interesting efforts, which are often isolated. We have attempted to investigate the current state of the art regarding knowledge representation in the field of adaptive education. Specification of concrete learning activity instances is usually context dependent and does not support reusability very well. We have emphasized the importance of procedural knowledge for these purposes and outlined how it is managed from the perspective of reusability and interoperability, discussing various existing approaches. Specification of learning activities and adaptation strategies by separating the content, declarative and procedural knowledge in adaptive courses seems to be quite natural. As a possible solution of the current reusability and adaptivity issues, we suggest the representation of various types of knowledge driving the process of personalized adaptive learning, and their interaction when generating the concrete instances of adaptive learning design dynamically.

More generally, interoperability demands can be recognized not only between various systems, but also between different layers (formal models). The existing solutions are not harmonized for a holistic approach. Standardized learning design enables interoperability between systems, but its reusability is limited. For the adaptation model standards are still missing. As the current standards themselves cannot fully realize interoperability in personalized adaptive learning, the Semantic Web is usually used as the mediator. Here we have suggested various opportunities and perspectives regarding the progress that can be expected in this field.

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