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Integrated model of adaptation on learning with specifications

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Abstract: The aim of this document is to define an integrated model for adaptive learning, based on existing specifications. Such a model should help to achieve a common understanding of relevant concepts in personalized adaptive e-learning and to clarify their relationships with current learning technology standards.

Keyword list: adaptive learning, integrated model, learning standards

Summary

The GRAPPLE WP5 deals with packaging and learning standards to address the needs for expressing adaptation in learning materials and processes by means of existing specification frameworks. One of our tasks is to define an integrative and holistic model for adaptive learning with current specifications. The model is the main aim of this deliverable, the implementation issues will be addressed later on. It should help us to achieve a common understanding of relevant concepts in personalized adaptive e-learning and to relate them to current learning technology standards. Within the GRAPPLE project this model should provide sufficient expressiveness to model the various inputs, roles, interactions, adaptation methods & techniques (and defined by WP1 and WP3).

In the area of e-learning there are increased demands for flexibility, both regarding the delivery of the learning experience (place, time, and pace) as well as the learner's personal needs and preferences (see GRAPPLE Deliverables 9.1 and 10.1, which include also examples of adaptation considered in the project). Unfortunately, existing systems do not allow the developer to express various parts of the experience (e.g. content, design) independently (van Rosmalen et al, 2006). In addition, the lack of support for adaptive behaviour in current learning standards leads to higher authoring costs and a low level of possible reuse of the created components. In general this is also often referenced as a lack of interoperability, reusability, and exchangeability.

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. However, the authoring process can be simplified if at various levels of the application reusable components are constructed that can be assigned to the models mentioned in this document. Following standards requires an increased initial investment, but it can save a lot of effort in the future.

The more context information 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. Also, the notation must make it possible to identify, isolate, de-contextualise and exchange useful parts of a learning design (as well as other components) so as to stimulate their reuse in other contexts (Koper & Tattersall, 2005). Therefore it would be beneficial to distinguish well-defined 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 behaviour in existing learning standards that leads to higher costs and lower reusability of personalized learning solutions. 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 (B. Towle and M. Halm in Koper & Tattersall, 2005). The aLFanet system (van Rosmalen et al., 2006) was built according to a special standard-based model for adaptive e-learning. The project has found that learning standards are not harmonized to work with each other. Additionally, available tools are too complex for non-specialized authors and should better support users by providing suitable templates and catalogues. 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.

Specification of learning activities and adaptation strategies by separating the content, declarative and procedural knowledge in adaptive courses seems to be a good way to proceed. More generally, interoperability demands can be recognized not only between various systems, but also between different layers (models). The existing solutions are not harmonized for a holistic approach. Standardized learning design enables interoperability between systems, but its reusability (in various contexts) is limited. For the adaptation model standards are still missing. As the current standards themselves cannot fully realize interoperability in personalized adaptive learning, other facilities have to be employed to represent adaptation semantics and to enrich learning resources. For such enhancements new evolutions of the original Web are used – Semantic Web and Web 2.0. So we have to consider existing restrictions caused by the existing e-learning specifications and provide solutions to overcome them.

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List of Acronyms and Abbreviations

ADL	Advanced Distributed Learning
AHAM	Adaptive Hypermedia Application Model
GRAPPLE	Generic Responsive Adaptive Personalized Learning Environment
IEEE	Institute of Electrical and Electronic Engineers
IMS	Instructional Management Systems
LD	Learning Design
LIP	Learner Information Package
LOM	Learning Object Metadata
PAPI	Public And Private Information
SCORM	Sharable Content Object Reference Model
UOL	Unit of Learning
VDEX	Vocabulary Definition Exchange
WP	Work Package

Table of Contents

Tables and Figures

List of Figures

1 Introduction

The GRAPPLE WP5 deals with packaging and learning standards to address the needs for expressing adaptation in learning materials and processes by means of existing specification frameworks. One of our tasks is to define an integrative and holistic model for adaptive learning with current specifications. This model is the main aim of this deliverable, which is based upon several publications released by the authors of the document. The implementation issues will be addressed in other deliverables later on. An integrated model of adaptive learning is closely related to the work in other WPs, especially WP1 and WP3, where we deal with representation and authoring of adaptive learning applications. It should help us to achieve a common understanding of relevant concepts in personalized adaptive e-learning.

In the area of e-learning there are increased demands for flexibility, both regarding the delivery of the learning experience (place, time, and pace) as well as the learner's needs and preferences. Unfortunately, existing systems do not allow the developer to express various parts of the experience (e.g. content, design) independently. In addition, the lack of support for adaptive behaviour in current learning standards leads to higher authoring costs and a low level of possible reuse of the created components.

To get inspiration in a wider context we can look at the cognitive science area. Research of the brain confirms appropriateness of Minsky's approach (Minsky, 1987) that is based on Freud's theories considering 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. These issues are usually addressed either by means of learning standards or by using the Semantic Web. In fact, these two approaches complement each other. Many existing ontologies take into account the existing learning standards and contribute to their harmonization. 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. This means that concrete instances of various models (domain, user, context, instruction, adaptation) referring to the same specifications (sharing the semantics) can work together and generate adaptive learning. Of course, being relatively independent, they can potentially come from various authors.

As in D5.1 we are supposed to give a model of adaptive e-learning based on standards, we first introduce our understanding of adaptation and its various types. Then an overview of a model for adaptive learning follows, distinguishing several layers: domain model, user model, context model, instruction model, and adaptation model. In the next section for each of the models we identify existing standards and specifications. We proceed with an investigation of how the most relevant standard for the instruction and adaptation models, namely IMS Learning Design, can be used to represent various adaptation types. Finally we conclude with our understanding of main constraints and problems in this field, outlining possible improvements.

2 Adaptation

Recent research has addressed the definitions of adaptivity and adaptability, both focused on personalized learning (Ahmad et al., 2004; Burgos et al., 2006; Cristea, 2005; Chen & Magoulas, 2005). In summary, adaptivity is the ability of a software application to modify eLearning lessons using different parameters and a set of pre-defined rules. In contrast, adaptability is the possibility for learners to personalize an eLearning lesson by themselves. These two approaches go from machine-centred (adaptivity) to user-centred (adaptability). However, we contend that there is a vast number of stages in between which define a grey area, with some adaptivity and some adaptability (Burgos et al., 2006). In practice, it is quite difficult to isolate one from the other due to their close relationship (Klann, 2003). As a result, we view the concepts not as two opposite corners from which to look at personalized learning, but as describing a wide range of approaches taking the best of each. Hereafter, we use the word adaptation to cover the various approaches.

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). Generally, adaptation specifications can be considered at various layers:

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

2.1 Adaptation Types in E-learning

A combination of the following types on adaptation could support an eLearning process (Cronbach, 1957; He *et al.*, 2002). Traditionally, three types of adaptation have been proposed, differing in what is adapted:

1. *Interface-based* (also called adaptive navigation and related to usability and adaptability) where elements and options of the graphical user interface are positioned on the screen and their properties are defined (colour, size, shadow, etc) (Ahmad *et al.*, 2004); this is closely related to supporting people with special needs, which influence personalization, such as colour blindness or poor hearing, for instance (Chin, 2001).
2. *Learning flow-based*, where the learning process is dynamically adapted to sequence the contents of the course in different ways. The learning path is dynamic and personalized for every user, but even also for every time that the course is started (also called run or instance), so that the user can take a different itinerary depending on his performance.
3. *Content-based*, where resources dynamically change their actual content, as systems based on adaptive presentation (Brusilovsky & Miller, 2001; De Bra *et al.*, 2004). For instance, the information can be classified in various levels of depth, and every level is shown based on certain parameters.

The first block of adaptation types are the base for the following ones, dealing with various objects of adaptation. Additional kinds of adaptation are (Brusilovsky & Paylo, 2003):

4. *Interactive problem solving support*, which guides the user on the next step to take, in order to get the right solution to a problem. The guidance could come from an online or offline tutor or from a predefined set of rules.
5. *Adaptive information filtering*, taking care of appropriate information retrieval that provides only relevant and categorized outputs to the user (Baeza-Yates & Ribeiro-Nieto, 1999). It could be considered as an external facility linked to a learning activity and not as a real part of that learning activity itself.
6. *Adaptive user-grouping*, that allows ad hoc creation of groups of users and collaborative support on carrying out specific tasks. For instance, as a result of a pool of questions, two groups with beginners and advanced users are made.
7. *Adaptive evaluation*, where the evaluation model, the actual content and the running of a test can change depending on the performance of the student and the guidance of the tutor (Van Rosmalen *et al.*, 2006).

We extend the classification further with a consideration of the time of adaptation:

8. *Adaptation time*, the possibility to modify/adapt a course by the system or tutor in run-time (Van Rosmalen & Boticario, 2005), in contrast to changes defined in design-time (Merceron & Yacef, 2003; Romero *et al.*, 2003).

In a literature study, eight different kinds of adaptation being carried out in eLearning systems have been identified (Specht & Burgos, 2006). All of them use various inputs provided during the learning process and aim to tune the activities and actions of the learner to get the best possible learning experience (Butz *et al.*, 2003). A wide and consistent set of rules for dependencies among users, methods and learning objects is needed to describe these eight types of adaptation, and moreover their possible combinations (Karampiperis & Sampson, 2004).

3 Model of Adaptive Learning

There are various attempts to model pedagogy, hypertext, hypermedia, and adaptive hypermedia. In the next sections we introduce those that are most relevant from our perspective. Considering them, we use an approach (Kravcik & Gasevic, 2007) to model adaptive hypermedia, which is based on these principles:

1. Distinguish between essential types of knowledge in a 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 (including the learning objective).

A pedagogical model to facilitate learning may be described as follows (Lebrun, 2007): It is useful that relevant information is made available and it is equally important that learning takes place in a genuine, motivational context. High level cognitive activities (abstraction, analysis, synthesis, evaluation and critical thinking) can then be activated. These activities are sustained by the interactivity of the pedagogic setup and lead to the contents and methods being absorbed by the learner, who constructs knowledge. These are important observations that we should take into account when constructing our model of adaptive learning.

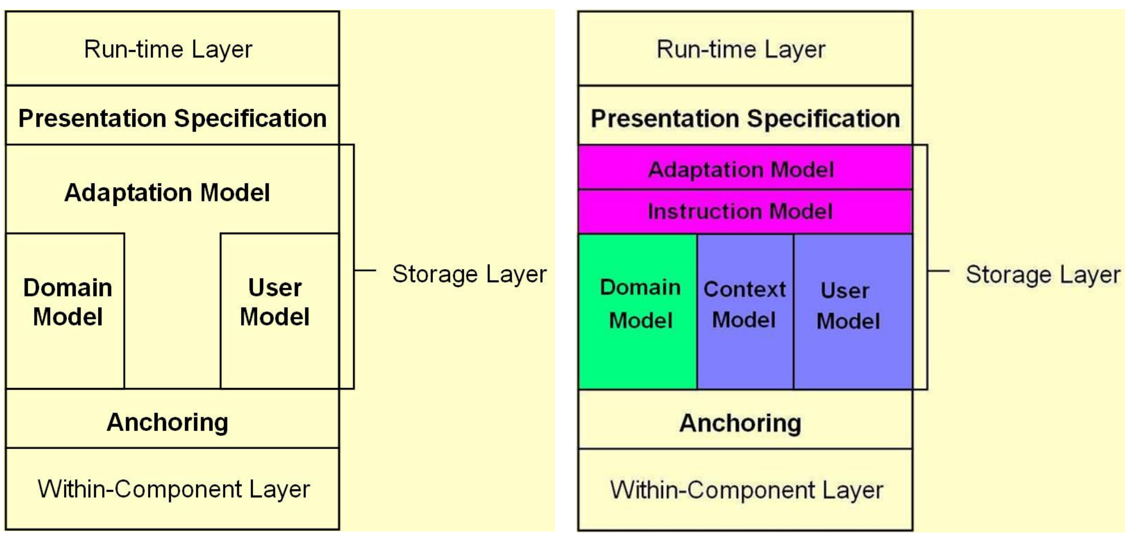

Figure 1: Adaptive Hypermedia Application Model (left) and its enhanced version (right)

More generally, we take into account the principles of adaptive hypermedia. 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* (De Bra et al., 1999; Wu et al., 2001) – AHAM (Figure 1 left), 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

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 (Figure 1 right). To specify the adaptation in a reusable way the adaptation model can be separated from the domain one and for learning purposes enhanced by an instruction (pedagogical) model, representing the procedural knowledge of the application. The suggested 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 between these models 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: instruction model and adaptation model.

Adaptive systems utilize various techniques characterized by the way they represent knowledge and by the algorithm they use. 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 instruction and adaptation models specify the learning process design and contextual adjustments for an adaptive hypermedia application. 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 instruction and adaptation models usually form its *procedural* knowledge. In the following subsections we shortly present each of the above mentioned models.

3.1 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 hyper documents

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 like "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 modelling. An individual educational goal can be modelled as a structure (e.g. sequence, tree, or stack) of subsets of domain concepts. Actually, concept prerequisites and goals are examples of pedagogical knowledge that can be represented in higher layers of the knowledge space.

3.2 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 modelled 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 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 the 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.

3.3 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 characteristics 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. Some of these parameters are represented as various types of metadata, indicating for instance the current learner's preferences and context constraints. 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.

Modern context-adaptive systems employ generic and mobile user models to provide human centred and ubiquitous services. For situated learning in the context of work, user competence profile has to be taken into account, as well as analyzing group modelling and pattern recognition in the user behaviour. Automatically generated metadata about the learner and her context should enrich queries into learning object repositories to optimize the recall and precision of information retrieval.

3.4 Instruction Model

The instruction (pedagogical) and adaptation models specify the scenario and 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 modelling 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".

3.5 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. It means that the actual delivery of learning resources depends on the current domain, user (learner), and context models, as well as the adaptive knowledge defined in the adaptation model. In addition, the instructional model can influence the adaptation semantics as well. 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 content selection, adaptive learning activity selection, adaptive recommendation, or adaptive service provision.

4 Specifications for Adaptive Learning

After presenting our big picture of adaptive learning we need to identify possible standards that can be used to express different knowledge in individual models as well as to share and exchange various knowledge representations in these models.

4.1 Domain Specifications

The *hyperspace* consists of hyper documents that can be for learning purposes considered as 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
- *Content objects* – sets of content fragments; abstract types
- *Learning objects* – they aggregate instantiated content objects and add a learning objective

The learning standards that can be used at this level include

- *IMS Question and Test Interoperability* – describing questions and tests
- *IEEE Learning Object Metadata* – description of learning resources
- *IMS Content Packaging* – description and packaging of learning material
- *IMS Vocabulary Definition Exchange* – defines a grammar for the exchange of „vocabularies“

Thus the domain model provides learning objects enriched with metadata and interlinked with related concepts for an adaptive e-learning system. Based on the current requirements, specified by metadata and concepts, the system can retrieve relevant learning objects to be provided to the learner. Learning objects distributed in various repositories with associated metadata can nowadays be retrieved by means of federated search (Simon et al., 2005). Early adopters have already started using these services. From the pedagogical point of view a seamless integration of content- and concept-based navigation, based on the domain model itself, can support cognitive flexibility and foster learning.

4.2 User Specifications

The following standards relate to user modelling:

- *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

The IMS Learner Information Package (IMS LIP) specification addresses the interoperability of internet-based Learner Information systems with other systems that support the Internet learning environment. The intent of the specification is to define a set of packages that can be used to import data into and extract data from an IMS compliant Learner Information server. A Learner Information server may exchange data with Learner Delivery systems or with other Learner Information servers. It is the responsibility of the Learner Information server to allow the owner of the learner information to define what part of the learner information can be shared with other systems. The core structures of the IMS LIP are based upon: accessibilities; activities; affiliations; competencies; goals; identifications; interests; qualifications, certifications and licenses; relationship; security keys; and transcripts.

4.3 Context Specifications

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. Composite Capabilities/Preference Profiles 2.0 (CC/PP, 2007) by W3C is a description of device capabilities and user preferences (delivery context) that can be used to guide the tailoring of content for a user agent.

CC/PP is based on the Resource Description Framework (RDF), which was designed by W3C as a general purpose metadata description language and became a standard format for data interchange on the Web.

4.4 Instruction Specifications

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, which means that the same learning methodology can be used in different situations with various learning objects. Main challenges include encoding dynamic interactions between users and system, representing scenarios (objectives, tasks/activities), and describing interactions between participating roles and system services. From our perspective, learning processes can be adapted to the learner's needs and preferences.

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

- *IMS Simple Sequencing* – representing the intended behaviour 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 behaviour 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.

All in all, *IMS Simple Sequencing* enables tailoring of learning materials to the learner's current context, but makes no distinction between users. *IMS Learning Design* provides an explicit notation to enable interoperability on the level of systems, enabling personalization by means of such constructs as conditions, DIV layers, and hide-visible properties.

4.5 Adaptation Specifications

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). This built on 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 would have to be powered by the adaptation engine. Already there 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. Also, this *adaptation language* might still be too difficult to handle for some authors (teachers). So, to increase reusability the goal should be to support it at the level of *adaptation strategies* (that correspond to cognitive/learning strategies).

4.6 Presentation Specifications

On a higher level in the Dexter and AHAM models 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).

A popular language for presentation specification on the Web is called Cascading Style Sheets (CSS, 2008). It is used to style web pages in HTML or more generally XML documents. It enables readers to define such aspects of document presentation like colours, fonts, and layouts. It enables the separation of document content from document presentation. This improves content accessibility and provides more flexibility and control in the specification of presentation characteristics. Additionally, it reduces complexity and repetition in the structural content. In general, it illustrates the aim we want to achieve in our model separating different layers of relatively independent specifications.

5 IMS Learning Design & Adaptation

The previous section shows that there are several standards that can be used at various levels to help in modelling adaptive learning. Several of them can be used to represent declarative knowledge as attributes in the domain, user, and context model. But to represent procedural knowledge and to some extend also the adaptation dynamics one learning standard plays a crucial role – IMS Learning Design.

IMS-LD (IMSLD, 2003) provides a modelling language able to design executable Units of Learning (UOLs) (Burgos & Koper, 2005; Koper & Olivier, 2004; Koper & Tattersall, 2005). There are two main approaches to create adaptive UOLs: first, an initial analysis by Towle and Halm (2005) sees the adaptation fully modelled inside a UOL, and describes four areas in IMS-LD where some kind of adaptation could take place: environment, method, roles and activities. Second, Van Rosmalen and Boticario (2005) examined the external adaptation of a UOL, making modifications to both the internal elements of the UOL and the playing layer through which the UOL is delivered (player).

The expressive power of IMS-LD deserves more elaboration and we deal with it in this section, where we examine how this standard can be used to represent each of the eight types of adaptation aforementioned (Burgos, 2008). All the examples in this section can be found at (LN4LD, 2005).

5.1 Interface based

Interface adaptation is based on menu options, navigation facilities and visualization facilities. This issue relates to the user interface provided with IMS-LD players (tools that allow for interpreting and viewing UOL) such as the player included with CopperCore (Vogten & Martens, 2005), the Reload Player (Reload, 2004) and Sled (The Open University, 2005). The current generation of these tools does not provide facilities to allow interface adaptation in run-time, although Sled can be customized during the set-up using style sheets. Current IMS-LD players cannot change the size and position of their panels or working areas, the definition of their windows or any other navigation facility. These players cannot change basic features, like font-size, font-colour, font-type or alignment, either. There is a distinction between the external wrapper of the UOL (player) and the actual UOL itself with real content and learning activities. Although interface adaptation cannot be carried out with the current players, some kind is possible inside the UOL, if we use two resources: DIV layers (DIV is a construct in the HTML language) and environments. We can work with DIV layers that can be shown and hidden in run-time by any of the main participants in the learning process (i.e., user, teacher, set of rules). Inside a DIV layer we can define different options and/or look and feels of the same content, meaning a de facto interface based adaptation. In the same line, we can use several environments to provide different setups (i.e., contents, approaches, and views) related to the same UOL, leading to a final personalized interface. Although neither of these two solutions (DIV layers and environments) is based on the external wrapper/player they can provide another view to interface adaptation.

5.2 Learning flow based

The description of an adaptive learning flow is mainly based on four out of the five different available elements of IMS-LD at Level B (Burgos & Koper, 2005; Koper & Burgos, 2005): properties, calculations, global elements and conditions. In addition, monitoring services can be added to track users' behaviour and allow the teacher to adapt the flow dynamically. An example of these features is provided by "Learning to Listen to Jazz". A student can learn something about four different Jazz styles in a sequential way, and he can choose between a thematic itinerary and a historical itinerary, following different milestones in the course. An additional example is "GeoQuiz 3" where the activities are defined by the performance of a student after answering an evaluation form. Depending on the final score and the related level acquired, one or another activity is shown. A final example is "Candidas II" showing full learner control by the student, who directly selects which is the best method to study a lesson among four different options.

5.3 Content based

The content of an activity needs a resource linked to the element Activity Description. Although this link cannot be changed at run-time, three other elements can be modified dynamically:

- the content inside an XHTML resource, defining classes and DIV layers that can be hidden and shown based on certain parameters;
- the content of pre-defined properties/variables, that can be replaced with other content entered on the fly;
- the content of an activity can be adapted switching showing or hiding one of several linked environments.

Two examples of the use of environments are "Learning Activities with Conditions", where a student decides the granularity level that he wants and "From Lesson Plan to IMS-LD Level B", where again a student takes control and switches on and off the audio support of the UOL. Finally, the aforementioned Learning to Listen to Jazz provides contents linked to several Activity Descriptions and related environments, progress-based.

An additional way of content-based adaptation is the modification of contents linked to fixed resources and based on external tools. For instance, a resource linked to a wiki service hosted outside an IMS-LD UOL could adapt its content dynamically, based on users', tutors' or authors' contributions.

5.4 Interactive problem solving support

This kind of adaptation could be considered as an extension of learning flow based, with the appropriate definition of properties and conditions modelling the itinerary, and the incorporation of a monitoring service allowing the tracking of the learning process of the student, making ad hoc remarks and changing the process as needed. These changes can be carried out 1) by modifying specific arguments by the tutor, 2) by the execution of specific design-time rules, or 3) by a combination of both mechanisms. An example is "What is Greatness" where the tutor moderates the contributions of a group of students on an open question, providing access to the next step when the tutor thinks that the current one is finished. A further example is "Free Style Assessment" where a tutor and a student carry out a commented open evaluation of an assessment. The tutor is entitled to close and block every step and to provide contextual feedback.

5.5 Adaptive information filtering

IMS-LD is not designed to provide adaptive information retrieval. Some rudimentary facilities are available through the index-search service. More practically, IMS-LD could point out to an external searching service providing the container for the run of this application and also for the visualization of the results.

5.6 Adaptive user grouping

User management has two approaches, one based on role creation, where the users are assigned to, and one based on the creation of the users itself. Using the management system provided by several tools and engines – Coppercore, Reload, CopperAuthor (Van der Vegt, 2005) – once the UOL is published, the administrator (maybe the teacher himself) can add and delete users and assign them to a specific run of that UOL. This means a de facto group (Burgos, 2004). However, the dynamic creation of roles after the publishing process is not currently possible. Once a definition of roles or stakeholders is available, and a run of a UOL is defined, specific users can be added to, or removed from; any of these groups and these users can play the run. Some representational facilities are available in IMS-LD to support creation of groups (min-persons and max-persons) and although assignment of users to groups can be achieved, fully automatic on-the-fly creation of groups may require additional representational devices.

5.7 Adaptive evaluation

Taking the performance of a student in a UOL as input, a full set of parameters can be stored in local properties to be used in the adaptation of assessments. As we have already explained related to "Geo Quiz 3", certain actions and answers of a user can be allocated into variables pre-defined in design-time and they can also be interpreted in run-time following a set of rules. In this way, both the evaluation system and the content itself, and even the interpretation of the results, can change for each user. An example is "Quo Builder 2" where a questionnaire can be fully set-up with questions, answers, thresholds and feedback being defined in run-time. Again, the main obstacle to overcome is the run-time modification of the skeleton itself, such as the ordering, grouping and numbering of questions and answers; something not possible so far with the current state of tooling. However we can define a wide set of questions that can also be hidden and shown on demand, providing a top-down 'simulation' of adaptive extensibility.

5.8 Adaptation time

Every UOL has three clearly different steps in its own life-cycle: design-time, publishing-time and run-time (Koper & Tattersall, 2005). With the current tools, once a UOL is published it is not possible to change structure, method or definition of basic parameters (such as conditions or properties, for instance). Of course, if a UOL is so designed, a tutor is able to change the way a student perceives the course and the flow: 1) tutors can update the content, based on pre-defined content or on new contributions; and 2) tutors can also influence the learning itinerary, uploading files, showing and hiding content elements and structure elements, etc. This means that a tutor is able to change things on the run, as long as he had previously defined that possibility in design-time. This solution comes with a high expense on implementation and support, though. An example is the already mentioned "Quo Builder 2" where a tutor makes the set-up and initialization of an evaluation form within run-time, which is subsequently filled by students.

5.9 Review of IMS-LD based on adaptation types

Adaptation is a quite complex process taking into account several stakeholders and inputs: user, teacher and set of rules. Also the right balance between the cognitive load of users and teachers and the non-voluntary actions that can be taken as inputs in the set of rules defined inside an engine should be composed. IMS Learning Design seems a promising expressive language that allows for several types of adaptation. We can use the elements available at Level B - such as conditions, properties, calculations, global elements and monitoring services- to model and run rich and adaptive Units of Learning.

The possibilities for adaptation supported by IMS-LD are diverse. From the eight types of adaptation described we identify three levels of support: a) learning flow, content, evaluation and interactive problem solving support are well supported, although they could be improved with specific structures focused on adaptation (i.e., modification of the learning design on the fly); b) user grouping, interface adaptation, adaptive evaluation and full modification of a course on-the-fly are partially supported; c) last, as some pending issues with no support at all are dynamic modification of learning structure and method in run-time, and adaptive information filtering and retrieval. Some of this lack of support leans on the current state of tooling, and not on the specification itself, though.

Nevertheless, with several types of adaptation (e.g. materials) it is possible to provide specific support on adaptation (i.e. linking a learning activity to an external tool that provides a related service). To this extent, adaptation comes from outside IMS-LD although the learning design acts as an integrator. In conclusion, with the appropriate support, IMS-LD can build adaptation and rather flexible learning experiences for every stakeholder, but designing more complex adaptivity behaviour might be not too easy.

6 Conclusion

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. Anyway, the authoring process can be simplified if at various levels of the application reusable components are constructed that can be assigned to the models mentioned in this document. Following standards requires an increased initial investment, but has a higher potential for the future.

What should these standards provide for knowledge representation? It has been observed that the more context information 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-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 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 behaviour in existing learning standards that leads to higher costs and lower reusability of personalized learning solutions. 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 (B. Towle and M. Halm in 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 and should be better supported by templates and catalogues. 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.

What matters is not only knowledge representation, but also the adaptation algorithm. Specification of concrete learning activity instances is usually context dependent and does not support reusability very well. 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.

All in all, interoperability demands can be recognized not only between various systems, but also between different layers (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, other facilities have to be employed to represent adaptation semantics and to enrich learning resources. For such enhancements new evolutions of the original Web are used – Semantic Web and Web 2.0. One of our ambitions in this project is to formulate recommendation on learning standards for responsible organizations as well as to develop new specifications, for instance a machine independent adaptation language for representation of adaptation semantics.

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