Knowledge Representation for Adaptive Learning Design

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Abstract. This paper aims at addressing the issues of knowledge representation in the area of learning design and adaptive learning. A specification of concrete learning design instances is usually context dependent and does not support reusability very well, thus we need to represent the knowledge that could help us in generating the instances dynamically. As we are dealing with learning design and adaptation, especially the procedural knowledge is highly important. Attempting to examine the degree of reusability and interoperability of procedural knowledge in the current adaptive educational hypermedia systems, we discuss several strategies and techniques, including informal scripts, system encoding, elicited knowledge, standardized specifications, and ontologies.

1 Introduction

Based on Freud's theories, Minsky [1] suggests that we can see the mind as a collection of structures that can both cooperate with and oppose one another to find ways to deal with conflicting goals. He sees several causes of human resourcefulness [2] – multiple representations of knowledge (various descriptions, interconnections), 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), and analogies. People 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. Then if one approach to solve a problem fails, changing the point of view can lead to an alternative solution.

Solutions to complex problems require usually more knowledge than single persons possess, thus the involved stakeholders have to communicate, collaborate, and learn from each other. The process of arranging personalized adaptive learning experiences is a complex one and typically people with different expertise have to collaborate to achieve a good quality solution based on modern technologies. The complexity of this problem results from the difficulty to formalize all the knowledge necessary in the pedagogical process. Anyway, the authoring process can be simplified if relatively independent components with clearly defined interfaces are constructed at various levels of the application, ideally according to existing standards, to enable a high degree of reusability and interoperability.

The aim of this paper is to outline the current state of the art in the area of adaptive learning and learning design as well as some possible perspectives in this field. Currently, we have the IMS Learning Design specification [3] that enables creation of concrete instances for learning design, which can be processed by various systems that "understand" and support this standard. Reusability and reproducibility are among the basic requirements for standardized specifications, but they both still remain to be very important research issues in the field of learning design [4]. Another challenge is the complexity of adaptation that is enabled by the existing standard. Therefore, it makes sense to investigate opportunities for overcoming these issues in order to simplify the authoring process and to enhance the expressiveness of specifications. One possibility might be representation of various types of knowledge driving the process of personalized adaptive learning and then letting those types interact when generating the concrete instances of adaptive learning design dynamically. Aiming to examine the degree of reusability and interoperability of procedural knowledge in the current adaptive educational hypermedia systems, after presenting a model of adaptive learning, we discuss several strategies and techniques, including informal scripts, system encoding, elicited knowledge, standardized specifications, and ontologies.

2 Model of Adaptive Learning

In this section, we start discussion on adaptive learning from the description of the knowledge organization in adaptive hypermedia systems. The knowledge driving the adaptation process can be represented in adaptive hypermedia systems as five complementary models that specify the three aspects of adaptation [5]:

- *what* is to be adapted: domain model;
- *according to what* parameters it can be adapted: user model and context model;
- *how* the adaptation should be performed: pedagogical model and adaptation model.

This means that the 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 been comprehensively analyzed [6], while the context model has become important more recently, taking into account new challenges like mobile learning. The pedagogical and adaptation models specify the scenarios and navigational design for an adaptive educational hypermedia application. Together with the presentation specification they tell *how* the adaptation should be performed, so they describe the system dynamics. Thus, while the other models represent typically the declarative knowledge of an adaptive application, the pedagogical (activity) and adaptation models form usually its procedural knowledge. In the rest of this paper we are focusing on the models related to the procedural knowledge.

2.1 Pedagogical Model

To discus representation opportunities for pedagogical models in adaptive learning applications we need to consider learning design that is understood as the human activity of designing learning activities or scenarios. Two standardized specifications are related to the design of pedagogical activities:

- *IMS Simple Sequencing* – representing the intended behavior of an authored learning experience, without considering the characteristics of the individual learner;
- *IMS Learning Design* – describing a method enabling learners to attain certain learning objectives by performing certain learning activities in a certain order in the context of a certain environment; it defines three levels of implementation and compliance [3]:
  - *Level A* – the core language providing the basic structure, roles, activities, and method;
  - *Level B* – adds other facilities, like properties, conditions, global elements, monitoring services, calculations, allowing more sophisticated learning;
  - *Level C* – adds notifications that can support e.g. collaborative learning.

A key axiom that is common to all major educational approaches says that "learners perform activities in an environment with resources." The IMS Learning Design specification [7] uses the metaphor of a theatrical play to describe the workflow involved in learning and teaching scenarios. It separates the design of the pedagogical model from the content. Main challenges include encoding dynamic interactions between users and system, representing scenarios (objectives, tasks/activities), and describing interactions between participating roles and system services.

2.2 Adaptation Model

Based on the research in the field of adaptive hypermedia, this model defines the specific *adaptation* semantics. Adaptation specifications describe the status of individual objects (e.g. content objects or fragments) and activities based on their metadata attributes and the current parameters of the user and context models. The adaptation effect is usually achieved by adapting content and links by using suitable adaptation techniques that can be chosen on this level. The taxonomy of adaptive hypermedia technologies [8] includes *adaptive presentation* (content level adaptation) and *adaptive navigation support* (link level adaptation), but there can be also other adaptation aspects such as adaptive content selection, adaptive learning activity selection, adaptive recommendation, or adaptive service provision.

The Adaptive Hypermedia Application Model – AHAM [9, 10] uses Condition-Action rules, while some other models built upon it identify additional layers, with the objective to enable reusability at various levels, focusing mainly on adaptation strategies and techniques. On a higher level of the AHAM model, 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).

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 pointed out that when learning objects are more context-specific they become less reusable [11]. The validity of this statement may be enhanced for specifications of learning activities and adaptivity as well. As formulated in [7]: "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 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 [12] – 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, what 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; let us name at least WINDS as an example. In the WINDS project [13], 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 behavior 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 [14] 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* [15] 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 [16] 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 W3C or IMS).

3.4 Standards

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 behavior in learning standards that implies higher costs and lower reusability of personalized solutions. In [7], B. Towle and M. Halm claim that IMS LD provides a way to implement simple adaptive learning strategies, but not complex forms of adaptive learning, like multiple rules interactions or enforced ordering. The aLFanet project has delivered a system [17] 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 [18] shows that IMS LD can be used to model and annotate adaptive learning design, but designing more complex adaptivity behavior might not be too easy. For instance, it is not possible to annotate learning content or define student roles considering their characteristics. Another approach [19] has focused on reusability on 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 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 [4]. A challenge is the creation and use of ontologies to represent various types of *knowledge* relevant for personalized adaptive learning [20]. 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 done by Stojanović et al. [21]. 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 formally express 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 Hypermedia Educational Systems. Cristea [22] 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 et al. [23] go 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. show how rules (expressed in the TRIPLE Semantic Web rule language) can be enabled to reason over distributed information resources in order to dynamically derive hypertext relations. Jovanović et al. [24] 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.

3.6 Suggestions for Improvements

Although the abovementioned solutions are semantically enhanced, there is still some room for future improvements towards providing higher level of interoperability. First, relying on *one common information model*, or even better an official specification such as IMS Learning Design, for describing learning activities and scenarios can substantially improve interoperability and reusability among different adaptive educational hypermedia systems.

Second, providing a *formal definition of semantics* for such an information model can provide a stronger integration basis for different adaptive learning systems. For example, Amorim et al. [25] 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. Furthermore, Knight et al. [20] defined an ontology for capturing learning object context that bridges a learning design ontology (another ontology based on IMS LD) and the learning object content structure ontology proposed in [24]. In fact, this research is inspired by and extends the ecological approach proposing a more flexible method to creating learning object metadata, for example, by relating all learners' interactions to learning objects.

Third, *sharing adaptation rules* in an embedded application stored in application-specific formats or even in well-known rule-based languages (e.g., Jess, Lisp) is very hard. A natural solution to this problem is to use either RuleML or the Semantic Web Rule Language (SWRL) as the current proposals of specifications for sharing rules on the Semantic Web. MUSE is 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 [26].

Finally, using ontologies (e.g., domain, learning design, and user) does not necessarily mean achieving a full interoperability among e-learning systems, especially in the case when systems rely on different ontologies. One potential solution to this issue is to employ results of very extensive research on *ontology mapping* [27, 28].

In addition to the issues related to ontologies and adaptive learning designs discussed above, one should also consider integration of learning activities and resources in other business processes existing on the Web. In fact, an open learning space such as the Web offers a huge wealth of different services that can be employed in different learning 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 learners would prefer to use different learning services personalized to their learning styles, preferences, and foreknowledge. In fact, we need to provide a method for *composition of different learning resources* using well-known business process techniques and standards. An OWL-based Web Service OWL-S ontology seems as 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 et al. [29] proposed an approach to transforming SCORM Simple Sequencing into the DAML-S (a predecessor of OWL-S) ontology, while Dolog et al. [30] suggested the use of DAML-S for a personalized composition of learning services in distributed e-learning environments. To the best of our know, there is not any attempt to define relations between the IMS Learning Design specification and Semantic Web process ontology such as OWL-S.

4 Summary and Conclusion

In this paper, we have attempted to investigate the current state of the art regarding knowledge representation in the field of learning design and adaptive learning. 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 design 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.

In a wider context, interoperability demands can be recognized in two dimensions – between various systems and between formal models. The existing solutions can address the requirements to some extent, but they are not harmonized for a holistic approach. There exist standard based solutions supporting interoperability of learning objects and learner models. Standardized learning design enables interoperability between systems, but its reusability is limited. Interoperability of domain ontologies is an open issue, for the context and adaptation models 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.

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