Expert Systems with Applications 38 (2011) 3280–3286

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

A context-aware adaptive learning system using agents

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ARTICLE INFO

Keywords:
Intelligent tutoring systems
Ontology
Adaptive learning
Agent
SCORM

ABSTRACT

Evolution of Web technologies has made e-learning a popular common way of education and training. As an outcome, learning content adaptation has been the subject of many research projects lately. This paper suggests a framework for building an adaptive Learning Management System (LMS). The proposed architecture is based upon multi-agent systems and uses both Sharable Content Object Reference Model (SCORM) 2004 and semantic Web ontology for learning content storage, sequencing and adaptation. This system has been implemented upon a well known open-source LMS and its functionalities are demonstrated through the simulation of a scenario mimicing the real life conditions. The result reveals the system effectiveness for which it appears that the proposed approach may be very promising.

1. Introduction

The amount of learning material over the internet has grown rapidly in the recent decades. As a result, information consumers are faced with the challenge of choosing the right stuff. In e-learning systems, the one-size-fits-all approach has led to learners' confusion. Inevitably, adaptive learning has gained a great deal of attention in this area (Wang, Wang, & Huang, 2008; Yang & Wu, 2009).

Adaptive learning may be defined as "the process of generating a unique learning experience for each learner based on the learner's personality, interests and performance in order to achieve goals such as learner academic improvement, learner satisfaction, effective learning process and so forth" (Monova-Zheleva, 2005; Rosmalen et al., 2006).

Adaptive Hypermedia Systems (AHS) are systems that use user and concept models to provide a personalized version of the information for the end user. Adaptive Educational Hypermedia Systems (AEHS) are those that create a unique learning experience for each learner based on learner's knowledge-base, goals, learning style and so forth (Damjanovic, Kravcik, & Devedzic, 2005; Ruiz, Diaz, Soler, & Perez, 2008).

The whole idea of adaptive learning is that there exists no learning style that fits all types of learners' needs. Two approaches have been introduced in this area and the challenge of adaptive systems is to balance between these two different forms of adaptation: (1) adaptivity, which relates to the extent the system output is flexible based on some knowledge about the learner and (2) adaptability, which is system reliability in response to user modifiability. The former is controlled by the system while the latter is student-controlled (Magoulas, Papanikolaou, & Grigoriadou, 2003).

Obtaining a satisfying user model is necessary in adaptive learning systems. Many efforts have been made in the area of adaptive systems in order to propose a user model. In learning systems, most of such works are about gaining the learners' learning style (Liegle & Janicki, 2006; Magoulas et al., 2003; Stach, Cristea, & De Bra, 2004; Yang & Wu, 2009). The learning style is an acceptable factor in adaptation since it reflects learner's characteristic, preferences and needs.

There are two general approaches for adapting learning content (Olfman & Mandviwalla, 1994; Papanikolaou, Grigoriadou, Magoulas, & Kornilakis, 2002; Samuelis, 2007). The first approach tries to adapt learning content with individuals' needs while the second focuses on delivering the most appropriate order of learning contents based on the learners' needs. The former is referred to as adaptation in content level and the latter is called link-level adaptation. Neither of these approaches has been preferred to the other in literature.

Based on these approaches, many research projects have been conducted aiming at suggesting a new methodology for content adaptation. Some of these studies are about extending current learning content standards in order to improve the quality of learning process. This group claims that current standards do not support an adaptive system so they must be modified in some ways (Lu & Hsieh, 2008; Rey-Lopez et al., 2009; Sampson, Karagiannidis, & Cardinali, 2002). In response to the fact that the metadata in learning content standards is somehow insufficient for some applications, a group of researchers tried to replace these standards with semantic Web ontology (Chi, 2009; Jovanovic, Gasevic,

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doi:10.1016/j.eswa.2010.08.113

Knight, & Richards, 2007; Lee, Tsai, & Wang, 2008; Shih, Yang, & Tseng, 2009; Verbert, 2005; Wang & Hsu, 2006; Yang, 2006; Zitko, Stankov, Rosic, & Grubisic, 2009).

According to Brusilovsky (2004), AEHS has still some integrity issues. This means that although the learning quality is improved through such systems, not all of the Learning Management System (LMS) functionalities are supported by AEHS. In other words, current generation of AEHS are not ready for commercialization (Whurle 2.0, 2008).

In addition to the integrity issue, AEHS lacks the reuse support. Current adaptive educational hypermedia systems are self-contained systems and cannot be used as a component. This makes it almost impossible to reuse previously edited materials or share them between different systems (Brusilovsky, 2004).

Despite a great deal of research in the area of adaptive learning systems, little work has been done addressing the above mentioned issues. In other words, current studies are so focused on adaptation quality that they result in systems designated for special learning purposes and not operable with other systems. This paper puts the integrity and reusability factors in the highest priority. In fact the purpose of this research was to design an adaptive system that can be integrated with any LMS and the learning contents can be reused and shared between different platforms.

The remainder of this paper is organized as follows. In Section 2 the learning content standards specifically Sharable Content Object Reference Model (SCORM) and its shortcomings are briefly explained. Section 3 introduces the proposed system and its components. A scenario simulation mimicing the real life condition was conducted which explains the functionalities of the proposed system's components aimed at adaptivity is presented in Sections 4 and 5 offers discussions on the evaluation and simulation results of the proposed system. Finally Section 6 concludes and offers some research avenues.

2. Learning content standards

2.1. Importance

The evolution of e-learning systems has brought up the issues of reusing and sharing learning contents. The solution may be to organize contents based on a globally accepted standard. Organizations such as IEEE (see IEEE, 2002), IMS (see IMS metadata, 2006) and ADL (Advanced Distributed Learning) (see ADL SCORM, 2008; SCORM, 2004, 2008) have offered standards and specifications in response to such problem among for which ADL's SCORM has gained much popularity. The reason is that SCORM is a collection of several standards mainly IEEE's LOM (Learning Object Metadata) and IMS's simple sequencing (Rey-Lopez et al., 2009).

Learning content standards aim at sharing and reusing learning contents for different platforms. According to Samuelis (2007) these standards are important from different points of view. In Intelligent Tutoring Systems (ITS) reusability plays an important role (Inteligent Tutoring, 2007). Lack of such standards may result in a fragmented market where learners have limited choice. From instructor's point of view, the learning material quality may be improved since instructors may now share their resources with each other. Transfer of a learner to another academic institute, may be easier done since the academic information about each learner may easily be transferred to a different institute.

2.2. SCORM

SCORM was initiated by ADL group. SCORM's main focus is on four areas: reusability, durability, accessibility and interoperability (ADL SCORM, 2008; SCORM, 2004).

The basic concepts in SCORM are assets and Sharable Content Objects (SCOs). Assets are electronic documents deliverable to a Web client. Assets may be sounds, text, images and so forth. On the other hand, SCOs are collections of assets that form an independent logical unit of instruction. In fact SCOs are the smallest units that can be delivered and tracked via LMS (SCORM, 2004).

In favor of reusable and sharable learning contents, SCORM associates a bunch of metadata with each asset and SCO. This metadata is used to identify learning resources and make them distinguishable. Some fields of this metadata can be used in learning adaptation (SCORM, 2008).

In SCORM, the LMS sequences all activities between the SCOs and the learner based upon some rules created by the course designer. SCOs, assets, metadata and the sequencing rules defined for delivering the learning material are integrated into a package called content package. This package is based on the IMS Content Packaging standard (see IMS CP, 2005) and allows transferring a collection of digital resources between different LMSs (Brooks, Kettel, & Hansen, 2005; Monova-Zheleva, 2005; SCORM, 2004).

SCORM provides a Run Time Environment (RTE) in which information may be exchanged between LMS and the current SCO. This information is embedded in a data model designed for that SCO and is about current transaction occurred between the learner and LMS (Monova-Zheleva, 2005; Rey-Lopez et al., 2009; SCORM, 2004).

2.3. Adaptation in SCORM

The type of adaptation that is used in AEHS is based on learner while the SCORM adaptation is instructor-based. This means that through SCORM sequencing rules, instructor decides what is appropriate for delivery. SCORM's inability in adaptation is mainly due to the metadata structure (Jovanovic et al., 2007). This fact is explained in Rey-Lopez et al. (2009) with two reasons.

SCORM allows defining several content packages for a single learning session according to different learning styles and knowledge-bases. However LMS cannot figure out which one to deliver to the current learner. Most of the LMSs present the default package or leave the choice to the learner.

On the other hand sequencing rules help LMS decide what the next step is. The decision is made based on learner's progress in current activity, activity goal and activity situation which may be retrieved from the data model in RTE (Monova-Zheleva, 2005; Rey-Lopez et al., 2009; SCORM, 2004). In other words, the decision making criteria are information about current learners' interaction with LMS. They do not take into account external parameters such as learner's preferences and knowledge-base.

3. The proposed adaptive learning system

3.1. Solution statement

This paper proposes a model for adapting learning contents in learning management systems based on one or a group of learners' needs. Learning material should be adapted and delivered to every individual. This may be carried out through identifying each learner in the system and modeling his/her needs in a way that can be used in filtering learning content.

As described in Section 1, two levels of adaptation (link-level and content-level) exist for implementing adaptive systems (Olfman & Mandviwalla, 1994; Papanikolaou et al., 2002; Samuelis, 2007). In this paper both of these methods are used but at different levels. Adaptation at content level is accomplished by filtering the main topics of each course, i.e. in order to avoid learners' confusion when facing too many choices to pursuit, the system limits those

choices according to the learner model. Link-level adaptation is about adapting the order of presenting the learning material of each topic according to the learner's learning style. Hence link-level adaptation and content-level adaptation are implemented in two different abstraction levels (course session material and course main topics).

Since SCORM has limited ability in adaptation, semantic Web ontology is used for modeling course topics and learner interactions with the system (Chi, 2009; Jovanovic et al., 2007; Lee et al., 2008; Shih et al., 2009; Verbert, 2005; Wang & Hsu, 2006; Yang, 2006; Zitko et al., 2009).

To address the reusability issue, we use SCORM for each course session learning material. However, in order to avoid SCORM problems in adaptation, each session will have multiple content packages based on different learning styles. At run time, the system will choose which one to deliver according to the learner's learning style.

In order to reduce the dependency between the adaptive system and LMS, a wrapper is developed which is responsible for interacting with different LMSs so that the adaptive system dependency on the type of LMS used is avoided. This layer is in fact an infrastructure focused on sending and receiving messages between the LMS and adaptive system so that interoperability, portability and flexibility are increased.

The proposed system is based on multi-agent concepts. The agents' properties such as autonomy, pre-activity, pro-activity and co-operability can improve learning process quality by tailoring contents to learners' needs. Agents' application in ITS study has become more common since they manage to bring the supportive classroom closer to distance learners. Also agents simulate the human-side of learning more naturally than any other controlled computer-based method. There are some studies that have used agents in learning adaptation (Canales, Pena, Peredo, Sossa, & Gutierrez, 2007; Chen, 2008).

Four types of agent exist in the proposed system:

(1) Context management agent: This agent is responsible for retrieving the current learner model, i.e. when a learner logs into the system this agent sets his/her user model as the current context in the environment. In fact, context is the concept used in ambient intelligence for personalizing services (Schmidt, 2005). Also, if necessary, changes to the user model can be made by this agent.
(2) Content selector agent: Whenever a course has been selected by the learner, this agent decides which course topics are appropriate for the learner.
(3) Content organizer agent: When a course topic has been chosen, this agent decides which content package to deliver according to learner's learning style.
(4) Content presenter agent: The output from selector and organizer agents will be submitted to this agent so that they can be appropriately delivered to the LMS.

3.2. System architecture

In this section the architecture of the proposed system is explained and its components are introduced. JAVA programming language is chosen for implementing the architecture since it is simple, platform neutral and threaded. Fig. 1 shows the system architecture.

The first and most important feature about this design is that it does not have any dependency to the LMS used. In order to achieve this goal, the system is designed based on Service Oriented Architecture (SOA) concepts. According to this type of architecture, different components offer a collection of services to other peers. This means that the dependency between system components is only in their service layer (SOA, 2008). Here we have assumed that for integrating adaptive system with any LMS, some services must be defined for system and LMS interactions. Technically any LMS conforming to Web services may be easily integrated with the proposed adaptive system regardless of the platform in which it operates. Web services become handy when we want different platforms to talk to each other (Fowler et al., 2002). The service management layer is based on the Facade software design pattern. According to Larman (2004), Facade provides protected variations from changes in the implementation of a subsystem. Based on that, changing the LMS would result in some changes in Facade layer and the internal components may not be affected.

The internal components of this architecture include business layer, event logger, agent container, agent management system, ontology Application Programming Interface (API) and ontology repository. Business layer contains the business logic of the adaptive system. This layer has functionalities which are invoked by agents in order to achieve their goals. For implementing these functionalities, business layer processes the data stored in the form of ontology about learning content. Ontology repository contains the ontology about course topics. This repository is accessed through ontology API which is a tool for processing semantic Web ontology. The agent management system is also a tool which is used for managing the agent instances and their communication.

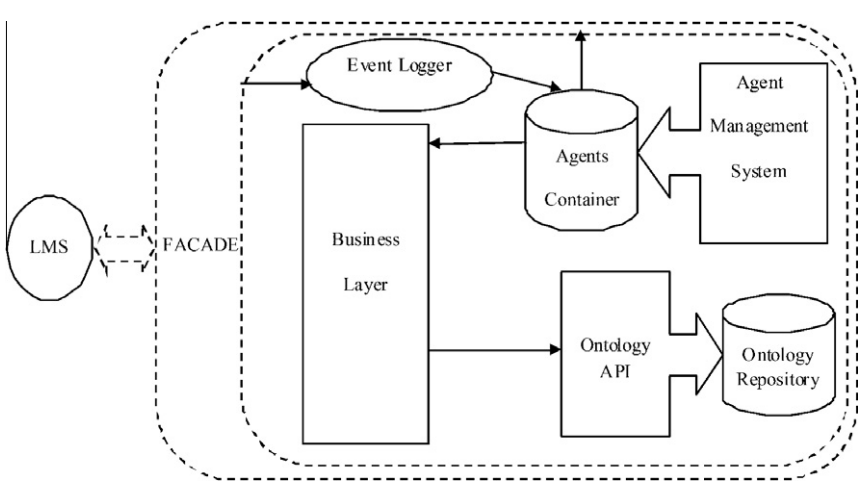

Fig. 1. The architecture of the proposed system for adaptive learning system.

The interactions between the proposed System and LMS are of two types. The first type includes informing adaptive system about special events occurring in the LMS. These events include learner login, course selection and topic selection. According to SOA, LMS will inform the adaptive system of these events by invoking methods from service layer. This invocation will activate a logger to save the event in the system. The saved events are accessed by context management, content selector and content organizer agents. Context management, content selector and content organizer agents will be activated by user login, course selection and topic selection respectively. Event logger is responsible for logging events in a way that each agent can access its correspondent event logs easily. This logger assures that every event is handled once and only once by the related agent.

The second type of LMS and system interactions is about displaying the personalized content generated by the adaptive system. This is done through services LMS offers for displaying content. Presenting the list of course topics and choosing a learning content sequence for a course topic are the two functionalities supported by these services. The LMS service layer will be invoked by content presenter agent.

When an event occurs, the corresponding agent is activated through event logger. This agent shows a rational and autonomous behavior by calling methods from business layer. Agents can also send requests to each other.

The business layer contains the main functionalities of the system. This layer is connected to the ontology repository through ontology API. From the semantic Web perspective, four concepts exist in this system: learner, learning object, learning object context and learning object content package, and the business layer is responsible for processing (save, update, search and load) them. Business layer is invoked exclusively by agents and is dependent only to the ontology API.

3.2.1. Agents design

As explained earlier, four types of agents are introduced in the proposed system. Each agent has one living instance which is created at system start up and will live infinitely. Fig. 2 shows the agents and their interactions. According to this figure, context management, content selector and context organizer agents will be notified of the occurred event by event logger and will react to that event by interacting with business layer. Content selector and organizer agents report their results to the LMS accordingly. They pass their requests to content presenter agent which will invoke the LMS through service layer for submitting those requests.

3.2.2. Ontology design

According to (Liu, Sun, & Fu, 2008), ontology is a formal explicit specification of a shared concept. In the proposed system, course topics, course topic learning sequence, learner model and learner interactions with the system are concepts that are represented as semantic Web ontology using Web Ontology Language (OWL) (OWL, 2004). Fig. 3 shows the ontology design in this system. Accessing the ontology repository is made through ontology API. OWL Reasoner is used for inferring logical consequences from axioms specified by means of ontology language (Semantic Reasoner, 2008). These inferences are made in business layer.

4. Scenario

A scenario simulation was conducted mimicing the real life conditions in order to evaluate the proposed system. The scenario starts from when a learner logs into the system, for which the context management agent receives the learner model from the ontology repository. The current learner's information such as needs and preferences define the context in which the system is running in.

Learner may choose between the registered courses. When a course is selected, the main topics should be shown to the learner to pursuit. These topics may be equivalent to one or more class sessions, but in many cases the number of these topics may cause confusion for learner. Knowing the context, content selector agent will be responsible for retrieving appropriate topics which are stored as ontology. The business layer searches in the ontology repository for learner-LMS interactions in which the learner has a learning style similar to the current learner's. From these interactions, the related course topics are retrieved. Once the personalized list of topics is found, it is passed to the content presenter agent. This agent informs LMS about the result by calling the appropriate method from the list of services offered by the LMS for displaying learning content. Since learner is faced with an adapted list of topics, he/she may choose from the list more easily, i.e. learner may no longer be confused compared to when he/she is faced with too many choices to pursuit.

The instructor creates several learning sequences for each topic based on the learner's learning style. By choosing a course session, the system finds the most suitable content sequencing for that

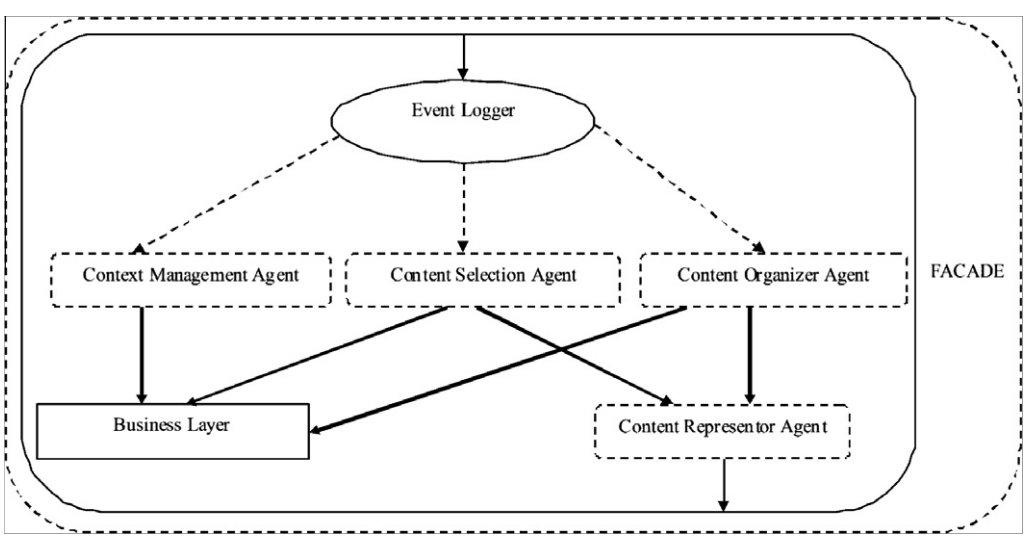

Fig. 2. Types of agents and their interactions in the proposed adaptive learning system.

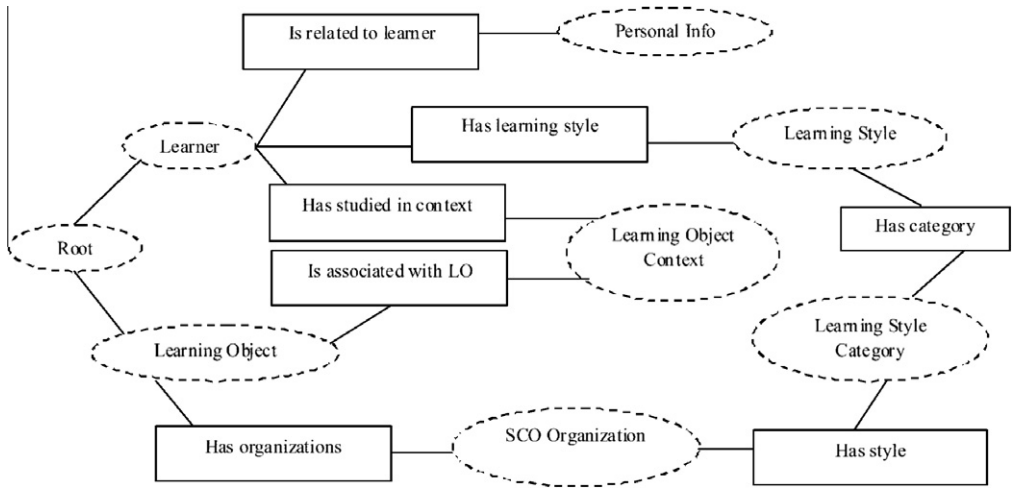

Fig. 3. The ontology chart designed for the adaptive learning system concepts.

session according to current context. Content selector agent passes the content package which is compatible with the current learner's learning style to the content presenter agent which will invoke the corresponding LMS service for displaying the selected content package.

Acquiring the learner's learning style may be carried out using Kolb or Honey-Mumford methods (Liegle & Janicki, 2006; Magoulas et al., 2003; Yang & Wu, 2009). Registration process may be the appropriate stage for acquiring learner's learning style via questioners such as Fedler and Silverman (Magoulas et al., 2003).

5. Discussion

The proposed system may be integrated into any LMS conforming to the Web services and SOA (Fowler et al., 2002). An LMS was chosen to implement and evaluate the proposed system. The adaptive system is added to the LMS as a new tool. This means that by using the new tool, learner can benefit from the personalized learning contents and also be able to study the whole learning content which is provided by the LMS itself. This way the learner may feel the difference between the public and personalized views of the learning content.

The proposed adaptive tool offers learner to choose from his/her registered courses which leads to a personalized list of course topics. From this list learner selects a topic and the system delivers the learning contents of that topic. The adaptive system chooses from the different sequences designed for this topic based on the learner's learning style. The selected sequence orders the learning contents in such a way that is consistent to the learner's learning style.

The following scenario has been simulated on this system and the results have been validated. Fig. 4 shows the information about learners and course material in this scenario. As shown in this figure, there are three learners with their own learning styles. The learning style categories are based on the Kolb method (Bostrom, Olfman, & Sein, 1990). There is also a course named C123 which has three topics. For each topic the instructor has provided the appropriate learning content sequences based on the learner's learning style. It is possible for a sequence to be suitable for more than one learning style. The scenario simulation assumes (from the previous interactions) that L1 has once studied C123-100, L3 has read C123-200 and C123-300 was once reviewed by L2. Fig. 5 shows the structure of the course C123 defined in the LMS.

Now suppose that L1 logs into the system through the LMS login module and decides to study using the proposed adaptive tool.

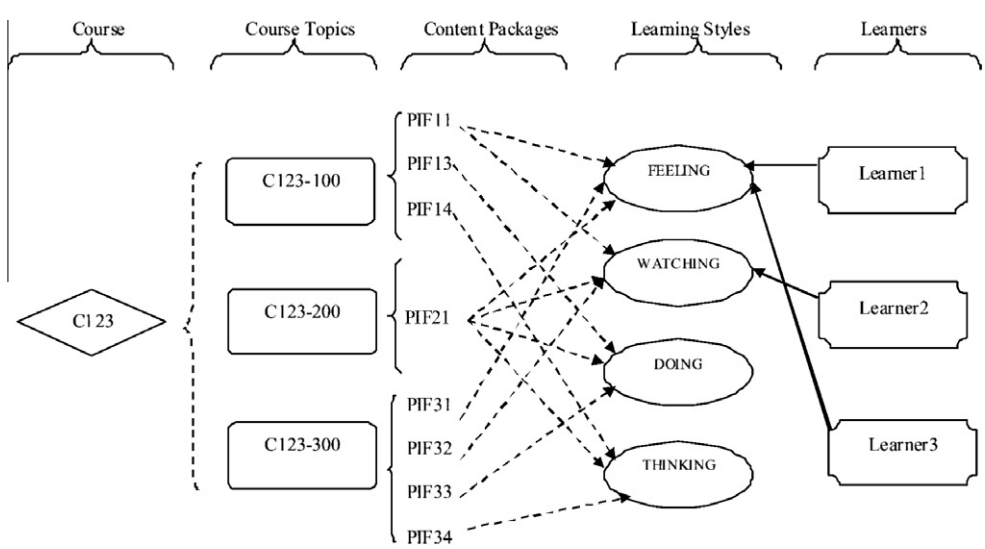

Fig. 4. The information about the scenario simulation.

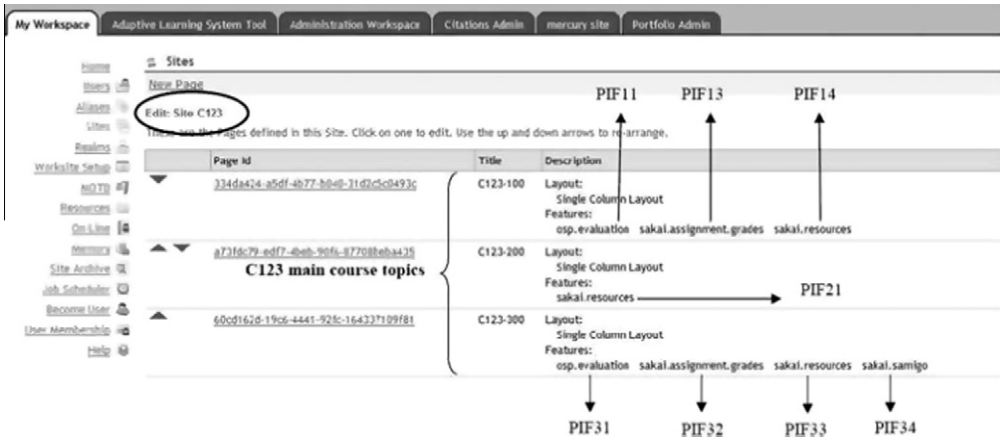

Fig. 5. The structure of course C123 defined in the LMS according to the given scenario.

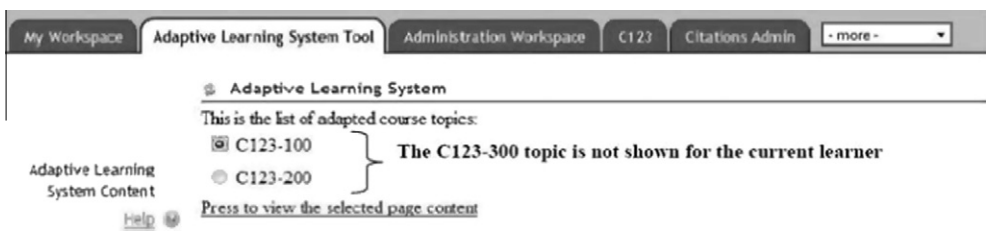

Fig. 6. The adapted course topics delivered to the learner by the proposed adaptive learning tool.

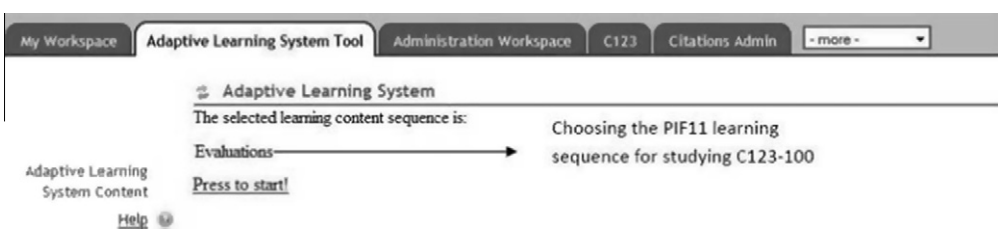

Fig. 7. The appropriate learning content sequence for the selected course topic displayed to the learner by the proposed adaptive learning tool.

From the list of registered courses, L1 chooses to study the personalized material of C123. The system must now find appropriate topics of the selected course. By appropriate we mean those topics that was once studied by a learner with similar learning style to the current ones. According to the information provided, the system will show C123-100 and C123-200 to L1 to pursuit as shown in Fig. 6.

Next the learner may be offered to select a topic. If C123-100 is chosen, the PIF11 should be delivered to the learner and if C123-200 is chosen, the learning content sequence will match PIF21. As shown in Fig. 7, this simulation shows that the adaptive system works properly in delivering personalized contents to learners.

6. Conclusions

Learning content adaptation has been the subject of many research projects lately. Some of such studies benefit from the strength of the learning content standards while others try to overcome these standards' shortcomings in personalization. Two main gaps may be observed in these studies. First, the adaptive systems proposed by most of these studies may not be integrated with current learning management systems. Second, the studies that avoid learning content standards for effective adaptation, fail in reusing other systems' learning contents.

The main purpose of this study was to design an adaptive system that covers the mentioned gaps. The proposed adaptive system is based on service oriented architecture and thus may be easily integrated with any learning management system. Also, for storing learning contents semantic Web ontology and learning content standards are used at two different abstract layers. Ontology is used to empower the adaptive system where learning content standards show weakness in personalization. However, referring to the main purpose of learning content standards which is re-usability and sharing of learning contents between different platforms, they cannot be eliminated from the adaptive system thoroughly.

The proposed system architecture is based on multi-agent concepts and implemented using Java programming. The implemented adaptive system is integrated into a well known learning management system and a simple scenario simulations reveals the functional validity of the proposed system. The results show that learning content adaptation is performed correctly in this system.

One of the future goals of this system may be the ability to update learner model according to his/her interactions with the LMS.

In response to LMS events about user interactions, the ontology related to the current learner may be updated accordingly. This may be added as a new behavior to content selector and content organizer agents.

Also the learners' learning style is currently acquired through questionnaires. However, since acquiring knowledge implicitly is much more preferred, a new functionality to context management agent may be added so that it can drive learner's learning style through mining his/her behavior (Liegle & Janicki, 2006).

This paper provides a way to adapt course topics according to learners' experiences whose learning style is similar to the current learner. Other criteria such as learner's performance and knowledge-base may also be considered. These criteria may be added to the learner model and updated according to his/her behavior.

References

ADL SCORM (2008). ADL SCORM (online) (cited 2008). Available from: <ttp://www.adlnet.gov/Technologies/scorm/default.aspx>.

Bostrom, R. P., Olfman, L., & Sein, M. K. (1990). The importance of learning style in end-user training. *MIS Quarterly, 14*(2), 101–119.

Brooks, C., Kettel, L., & Hansen, C. (2005). Building a learning object content management system. In *Paper presented at world conference on e-learning in corporate, healthcare & higher education, 24–28 October, Vancouver, Canada*.

Brusilovsky, P. (2004). Knowledgetree: A distributed architecture for adaptive e-learning. In *Paper presented at WWW 2004, 17–22 May, New York, USA*.

Canales, A., Pena, A., Peredo, R., Sossa, H., & Gutierrez, A. (2007). Adaptive and intelligent Web based education system: Towards and integral architecture and framework. *Expert Systems with Applications, 33*(4), 1076–1089.

Chen, C. (2008). Intelligent Web-based learning system with personalized learning path guidance. *Computers & Education, 51*(2), 787–814.

Chi, Y. (2009). Ontology-based curriculum content sequencing system with semantic rules. *Expert Systems with Applications, 36*(4), 7838–7847.

Damjanovic, V., Kravcik, M. & Devedzic, V. (2005). An approach to the realization of personalized adaptation by using eq agent system. In *Paper presented at workshop on personalization on the semantic Web: Held in conjunction with the 10th international conference on user modeling (UM'05), 24–30 July, Edinburgh, UK*.

Fowler, M., Rice, D., Foemmel, M., Hieatt, E., Mee, R., & Stafford, R. (2002). *Patterns of enterprise application architecture*. Boston, MA: Addison Wesley (Chapter 7).

IEEE (2002). IEEE learning object metadata standard (online) (cited 2008). Available from: <http://ltsc.ieee.org/wg12/>.

IMS CP (2005). Content packaging specification (online) (cited 2008). Available from: <http://www.imsglobal.org/content/packaging>.

IMS metadata (2006). Learning resource meta-data specification (online) (cited 2008). Available from: <http://www.imsglobal.org/metadata/index.html>.

Inteligent Tutoring (2007). Intelligent tutoring systems (online) (cited 2007). Available from: <www.adlnet.gov/technologies/index.aspx>.

Jovanovic, J., Gasevic, D., Knight, C., & Richards, G. (2007). Ontologies for effective use of context in e-learning settings. *Educational Technology & Society, 10*(3), 47–59.

Larman, C. (2004). Applying UML and patterns: An introduction to object-oriented analysis and design and the unified process (3rd ed.). Prentice Hall PTR. <http://download-ebook.org/index.php?target=desc&ebookid=3733>.

Lee, M., Tsai, K., & Wang, T. (2008). A practical ontology query expansion algorithm for semantic-aware learning objects retrieval. *Computers & Education, 50*(4), 1240–1257.

Liegle, J., & Janicki, T. (2006). The effect of learning styles on the navigation needs of Web-based learners. *Computers in Human Behavior, 22*(5), 885–898.

Liu, K., Sun, L., & Fu, Y. (2008). Ontological modelling of content management and provision. *Information and Software Technology, 50*(11), 1155–1164.

Lu, E., & Hsieh, C. (2008). A relation metadata extension for SCORM content aggregation model. *Computer Standards & Interfaces, 31*(5), 1028–1035.

Magoulas, G., Papanikolaou, K., & Grigoriadou, M. (2003). Adaptive Web-based learning: Accommodating individual differences through systems adaptation. *British Journal of Educational Technology, 34*(4), 511–527.

Monova-Zheleva, M. (2005). Adaptive learning in Web-based educational environments. *Cybernetics and Information Technologies, 5*(1), 44–55.

Olfman, L., & Mandviwalla, M. (1994). Conceptual versus procedural software training for graphical user interfaces: A longitudinal field experiment. *MIS Quarterly, 18*(4), 405–426.

OWL (2004). OWL Web Ontology Language, W3C recommendation (online) (cited 2008). Available from: <http://www.w3.org/TR/2004/REC-owl-features-20040210/>.

Papanikolaou, K., Grigoriadou, M., Magoulas, G., & Kornilakis, H. (2002). Towards new forms of knowledge communication: The adaptive dimension of a Web-based learning environment. *Computers & Education, 39*(4), 333–360.

Rey-Lopez, M., Diaz-Redondo, R., Fernandez-Vilas, A., Pazos-Arias, J., Garcia-Duque, J., Gil-Solla, A., et al. (2009). An extension to the ADL SCORM standard to support adaptivity: The T-learning case study. *Computer Standards and Interfaces, 31*(2), 309–318.

Rosmalen, P., Vogten, H., Van Es, R., Passier, H., Poelmans, P., & Koper, K. (2006). Authoring a full life cycle model in standards-based adaptive e-learning. *Educational Technology & Society, 9*(1), 72–83.

Ruiz, M., Diaz, M., Soler, F., & Perez, J. (2008). Adaptation in current e-learning systems. *Computer Standards & Interfaces, 30*(1), 62–70.

Sampson, D., Karagiannidis, C., & Cardinali, F. (2002). An architecture for Web-based e-learning promoting re-usable adaptive educational e-content. *Educational Technology & Society, 5*(4), 27–37.

Samuelis, L. (2007). Notes on the components for intelligent tutoring systems. *Acta Polytechnica Hungarica, 4*(2), 77–85.

Schmidt, A. (2005). Interactive context-aware systems interacting with ambient intelligence. In G. Riva, F. Vatalaro, F. Davide, & M. Alcaniz, (Eds.), *Ambient intelligence* (pp. 159–176). IOS Press. <http://www.ambientintelligence.org>.

SCORM (2008) SCORM best practices guide for content developers (online) (cited 2008). Available from: <http://www.lsal.cmu.edu/lsal/expertise/projects/developersguide/>.

SCORM 2004 (2008). SCORM 2004 overview (online) (cited 2008). Available from: <http://www.s1000d.org/events/user_forum/performance_fest2>.

Semantic Reasoner (2008). Semantic reasoner (online) (cited 2008). Available from: <http://en.wikipedia.org/wiki/Semantic_reasoner>.

Shih, W., Yang, C., & Tseng, S. (2009). Ontology-based content organization and retrieval for SCORM-compliant teaching materials in data grids. *Future Generation Computer Systems, 25*(6), 687–694.

SOA (2008). Service oriented architecture (online) (cited 2008). Available from: <http://en.wikipedia.org/wiki/Service_Oriented_Architecture>.

Stach, N., Cristea, A., & De Bra, P. (2004). Authoring of learning styles in adaptive hypermedia. In *Proceedings of the 13th international World Wide Web conference on Alternate track papers & posters* (pp. 114–123).

Verbert, K., Gasevic, D., Jovanovic, J., & Duval, E. (2005). Ontology-based learning content repurposing. In *Special interest tracks and posters of the 14th international conference on World Wide Web* (pp. 1140–1141).

Wang, H.-C., & Hsu, C.-W. (2006). Teaching-material design center: An ontology-based system for customizing reusable e-materials. *Computers & Education, 46*(4), 458–470.

Wang, T., Wang, K., & Huang, Y. (2008). Using a style-based ant colony system for adaptive learning. *Expert Systems with Applications, 34*(4), 2449–2464.

Whurle 2.0 (2008). Whurle 2.0: An adaptive Web service e-learning environment for the Web (online) (cited 2008). Available from: <http://www.cs.nott.ac.uk/mzm/Saudi_Conference_mmeccawy13.pdf>.

Yang, S. (2006). Context aware ubiquitous learning environments for peer-to-peer collaborative learning. *Educational Technology & Society, 9*(1), 188–201.

Yang, Y., & Wu, C. (2009). An attribute-based ant colony system for adaptive learning object recommendation. *Expert Systems with Applications, 36*(2), 3034–3047.

Zitko, B., Stankov, S., Rosic, M., & Grubisic, A. (2009). Dynamic test generation over ontology-based knowledge representation in authoring shell. *Expert Systems with Application, 36*(4), 8185–8196.