

KnowledgeTree: A Distributed Architecture for Adaptive E-Learning

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ABSTRACT

This paper presents KnowledgeTree, an architecture for adaptive E-Learning based on distributed reusable intelligent learning activities. The goal of KnowledgeTree is to bridge the gap between the currently popular approach to Web-based education, which is centered on learning management systems vs. the powerful but underused technologies in intelligent tutoring and adaptive hypermedia. This integrative architecture attempts to address both the component-based assembly of adaptive systems and teacher-level reusability.

Categories and Subject Descriptors

H.4 [Information System]: Information System Applications.
K.3.1 [Computers and Education]: Computer Uses in Education - *Distance Learning*.

General Terms

Management, Design, Human Factors, Standardization.

Keywords

Adaptive Web, E-Learning, Learning Portal, Adaptive Content Service, Student Model Server, Learning Object Metadata, Content Re-use.

1. INTRODUCTION

The technological landscape of modern E-Learning is dominated by so-called learning management systems [10] such as Blackboard [4] or WebCT [42]. Learning management systems (LMS) are powerful integrated systems that support a number of activities performed by teachers and students during the E-Learning process. Teachers use an LMS to develop Web-based course notes and quizzes, to communicate with students and to monitor and grade student progress. Students use it for learning, communication and collaboration. As is the case for a number of other classes of modern Web-based systems, LMS offer their users "one size fits all" service. All learners taking an LMS-based course, regardless of their knowledge, goals, and interests, receive access to the same educational material and the same set of tools, buffered with no personalized support.

Adaptive Web-based Educational systems (AWBES), a recognized class of adaptive Web systems [9] attempt to fight the "one size fits all" approach to E-Learning. After almost 8 years of research on adaptive E-Learning, this field can demonstrate some impressive results [6]. For every function

that a typical LMS performs we can find a number of AWBES that can do it much better than the state-of-the-art LMS. Adaptive textbooks created with such systems as InterBook [8], NetCoach [44] or ActiveMath [29] can help students learn faster and better. Adaptive quizzes developed with SIETTE [34] evaluate student knowledge more precisely with fewer questions. Intelligent solution analyzers [43] can diagnose solutions of educational exercises and help the student to resolve problems. Adaptive class monitoring systems [32] give the teachers a much better chance to notice when students are lagging behind. Adaptive collaboration support systems [37] can enhance the power of collaborative learning.

The traditional problems involved in authoring adaptive learning content have been nearly resolved by the new generation of powerful authoring tools. Authoring support in modern AWBES such as NetCoach [44] or SIETTE [34] is comparable with modern LMS. Moreover, a number of existing AWBES are provided with a wealth of existing or newly created learning materials, while the typical LMS expects teachers to develop all learning materials themselves. For example, ELM-ART [43] comprehensively supports the most important portions of a typical Lisp course - from concept presentation to program debugging. Yet, seven years after the appearance of the first adaptive Web-based educational systems, just a handful of these systems are actually being used for teaching real courses, typically in a class lead by one of the authors of the adaptive system.

The problem of the current generation of AWBES is not their performance, but their architecture. Structurally, modern AWBES do not address the needs of both university teachers and administration. *The first issue is the lack of integration.* While AWBES as a class can support every aspect of Web-enhanced education better than LMS, each particular system can typically support only one of these functions. For example, SIETTE [34] is a great system for serving quizzes, but it can't do anything else. To cover all needs of Web-enhanced education with AWBES, a teacher would need to use a range of different AWBES together. This is clearly a problem for the university administration that is responsible to maintain and provide training for all these systems. It is also a burden for the teacher who needs to master them all and for the student who needs to manipulate several systems and interfaces - all with separate logins - and all at the same time. E-Learning stakeholders have a clear need for a single-entrance, integrated system that can support all critical functions in one package. LMS producers have recognized this need several years ago. Just in a few years after their emergence, LMS have progressed from one-or-two function systems into Web-based monsters that can cover all needs.

The second issue is the lack of re-use support. Modern AWBES are self-contained systems and can't be used as components. A teacher who is interested in re-using some

processes events by user and topic. It extracts records of different learning activities related to this topic and attempts to deduce the current student knowledge level of this topic. Student knowledge levels are currently used by WADEIn and the version of QuizPACK under development. A simple activity-inferring agent processes events by activity. It extracts all events related to a specific learning activity, counts the number of visits and annotation for this activity for any user and group, and calculates activity levels. Activity levels are currently used by KnowledgeSea and AnnotatED to support social navigation. In addition to these agents, CUMULATE provides a number of maintenance tools for a server administrator as well as several tools for teachers and students to examine the content of the student models (Figure 7).

3.4 The Protocols

The current version of KnowledgeTree implements a lightweight version of all the communication protocols that were necessary to make this version function in a classroom. When implementing these protocols, our group neither intended to "make it right" from the first attempt nor wanted to set up standards for other similar projects to adhere. Our main goal was to explore a distributed architecture in a practical context to find out which protocols are necessary for making the whole architecture flexible and what kind of information should be passed between servers of different kind. As for the running implementation, we were mostly concerned with simplicity and efficiency. Establishing standards for the communication protocols is certainly necessary to make the architecture widespread; however, we consider our current research a necessary precondition for this process. As soon as the needs and problems have been sufficiently explored, the standards themselves should be crafted by a group of like-minded stakeholders who have experience with distributed E-Learning architectures, understand different sides of the problem and are familiar with existing protocols and standardization efforts.

The first of the protocols we had to develop was the transparent authentication protocol. Each portal or activity server should be able to recognize individual users to report events to the student model and, possibly, to adapt to the user. The authentication should happen transparently without the need for the user to log in to each of the multiple servers used during one session.

Transparent authentication (or single sign-on) is a recognized industrial problem. A number of solutions were created over the last few years including Microsoft Passport (<http://www.passport.net/>) and SAML [14]. We use a simpler approach that we have inherited from our earlier ELM-ART [43] and InterBook [8] systems: all authentication data are passed from server to server as part of the launch URL (course URLs for a portal; activity URLs for an activity server). Currently a user ID, a group ID and a session ID are passed as a part of the http GET request. The session ID is generated for every student at the beginning of every session. A session ID - user ID pair can be used by any server to check the validity of each user. Every event or request sent to the student model should have a valid session ID in order to be processed. This authentication approach is very efficient, provides sufficient (for our context) protection and allows "chaining" of services (i.e., not only can a portal call a service, but also one portal can call another portal or one service can call another).

A protocol for communication between a portal and a pool of resources is an active research issue in the field of E-Learning. Ideally, this protocol should allow querying a pool for relevant content and services, to find properties of an activity or service, and to launch it. In addition to these protocols, a distributed E-Learning system should have a resource discovery framework. Currently there are two approaches to address the discovery issue: a centralized broker-based approach [24; 38] and peer-to-peer [31; 39]. In particular, EDUTELLA [31] suggest a very impressive architecture that can resolve all listed needs.

Our approach is conceptually similar to EDUTELLA. Our services and activities are identified by a unique locator (URL), but we use a very restricted set of metadata (learning outcomes, prerequisites, and complexity) and our exchange protocols are much simpler. The resource discovery issue has not been addressed in the current version of KnowledgeTree. Currently, we simply "tell" the portal about all existing activity servers.

The semantics of the student modeling protocols has already been presented in the previous section. Here we only wish to add that it is the least investigated problem in the field of E-Learning. As a result, a significant fraction of our work on KnowledgeTree has been devoted to investigating the problems of student modeling for E-Learning.

Technically, all our inter-server communication protocols are based on a simple model: HTTP GET request - XML reply. Even the student modeling event messages are sent by all servers to the student modeling server in the form of GET requests. The use of structured GET requests to pass information was inherited from our earlier work on distributed E-Learning [12] and can be currently considered rather archaic. We have analyzed a number of standard approaches, including RPC, CORBA, and SOAP and have very seriously considered XML-RPC, which was used by another distributed system, ActiveMath [29]. However, at the current state of our research we decided to stay with our current approach since it satisfies our research needs completely while being dramatically faster than other protocols. The latter issue is critical for any classroom experiments with a distributed architecture where frequent inter-server communication should not be allowed to slow down the student interface. The focus of our work is to determine what kind of information has to be communicated, not to find the best communication protocol. Since the protocol details are hidden from developers of portals and services (they use it through information-focused API), we can seamlessly adopt any commonly accepted efficient carrier protocol.

4. SIMILAR WORK

This section attempts to summarize similar and complementary research and development efforts. A number of references and comparisons were provided in the main body of the paper. Here we provide a systematic review, grouping similar works into three clusters: reusability standards, communication frameworks and research level architectures.

4.1 Reusability Standards

A number of educational technology standards are currently supporting content reusability goals. Several standardization bodies such as AICC (<http://www.aicc.org/>), IEEE LTSC (<http://ltsc.ieee.org/>), ADL (<http://www.adlnet.org/>), and IMS (<http://www.imsproject.org/>) have issued a number of

standards and drafts focused on reusability. From the prospects of our project, all standards can be split into two groups - *information exchange* standards and *interoperability* standards. Information exchange standards prescribe the way to store information about various entities of E-learning, from learning objects and packages to learners themselves. If standardized, this information can be easily moved from system to system, supporting the separation of learning contents and learners from LMS. Information exchange standards have less relevance to our architecture. First of all, these standards emphasize data storage, while our architecture represents the communication viewpoint. As long as a portal or a value-adding service can receive requested information about activities from activity servers, it does not matter how this information is represented or stored. Secondly, current standards were established before the needs being explored in KnowledgeTree were properly understood. As a result, the information that a standards-based system stores about content and users is almost useless for the adaptation needs of KnowledgeTree, while the information that is vital for adaptation is not found. To deal with this problem other research teams focused on personalizing E-Learning, attempted to combine several standards while complementing them with additional information [19].

In contrast, *interoperability* standards, which ensure that different components of E-Learning systems can work together, are very relevant to KnowledgeTree. Of all the interoperability standards, the one most similar to KnowledgeTree is the so-called CMI standard, which was originally introduced by AICC [3] and later adopted by IEEE LTSC and ADLI as a part of SCORM [1; 2]. CMI anticipates a very advanced level of communication between an LMS and a fragment of learning content. A content object can store and query information about student performance related to multiple educational objectives in an LMS. This is similar to the classic overlay student modeling in intelligent tutoring systems, which is capable to support adaptation. In addition, a course creator can associate advanced sequencing rules with a structured set of objects allowing it to inherently bear a number of adaptation effects within these sequenced learning objects. The most recent version of SCORM [2] can be considered several steps beyond the monolithic LMS of today in most aspects, including adaptivity. Yet, when one of the research groups working on service-based E-Learning did an honest attempt to use CMI for student modeling, it discovered conceptual and technical problems [15].

SCORM successfully separates learning content from its LMS allowing the content to be used with multiple LMSs. However, it has failed to separate learning content from sequencing and student modeling. SCORM recognizes only two components in a distributed E-Learning architecture - reusable content and the LMS. In SCORM, student modeling is "hardwired" into fragments of "intelligent" content. As a result, the reusability of adaptive content dramatically decreases since it becomes "tuned" to a specific student modeling approach and a specific set of objectives. In contrast, KnowledgeTree and similar advanced architectures use a student model server to separate the student modeling from reusable educational activities. Different servers can support different student modeling approaches and different domain concepts for the same activities. It supports a greater flexibility and makes these activities highly reusable.

Content sequencing in SCORM is also hardwired into the structured content. It immediately excludes adaptive use of

external content (open corpus) which conflicts with adaptive portals and value-adding services. In contrast, KnowledgeTree separates content from adaptive sequencing leaving the duty of sequencing to portals and value-adding content integration services. It allows the use of open corpus content and chaining of value-adding services and portals.

Despite of many advanced features introduced in of SCORM, its support of personalized E-Learning falls behind the state-of-the-art level in the field of adaptive educational systems. We think that the future student model servers should be based not on these standards, but on the earlier work on user model systems and servers, a popular research topic within the user modeling area [27]. Both our group and the University of Sydney group that developed the first comprehensive student modeling servers CUMULATE and Personis [26] have benefited from solid past experience developing user modeling architectures [5; 25].

4.2 Communication Frameworks

Communication frameworks such as OKI (<http://web.mit.edu/oki/>) or uPortal (<http://www.uportal.org/>) champion the ideas of component-based, distributed E-Learning.

The focus of uPortal project [23] is a seamless presentation of information coming from multiple external services (known as *channels*) through the user interface of an educational portal. KnowledgeTree and uPortal share the same portal/service architecture, but focus on different aspects of it. KnowledgeTree focuses on content while uPortal excels in presentation. As a result, these frameworks complement each other. As a research framework, KnowledgeTree has the luxury of ignoring the presentation aspect because it launches external services and activities in separate browser windows and frames. However, a practical system developed on the basis of KnowledgeTree will certainly benefit from uPortal's approach for assembling a coherent presentation.

OKI architecture [40] and KnowledgeTree architecture have a lot in common. Both frameworks define the generic architecture of an E-Learning system as being based on components and both focus on the communication interfaces between the components. As a result, components become highly reusable and replaceable. Unlike storage-oriented standards that prescribe what should be inside components, both KnowledgeTree and OKI standardize communication interfaces and ignore the internal organization of the components. Yet KnowledgeTree and OKI are quite different because they focus on different sides of the E-Learning process. KnowledgeTree focuses on the educational side of E-Learning, representing the educational needs of students and teachers as well as the needs of service and content providers. It originates from the domain's adaptive educational systems, strives to support an advanced educational process and mostly ignores the needs of university administration. In contrast, OKI focuses mostly on the administrative and management side of E-Learning, representing the needs of university administration and class management needs of teachers. It originates from campus administration systems and suggests a finer-grain component-based architecture. As a result KnowledgeTree and OKI complement each other.

4.3 Research Level Architectures

The problems of developing distributed adaptive and intelligent educational systems based on shared educational

resources have been originally explored in the field of ITS [12; 22; 30; 35; 36]. At that time, the lack of matching work in other fields and appropriately advanced technology in general limited these pioneer works to the theoretical level, with a few simple lab systems. The Web as a unified platform for E-Learning has changed the situation dramatically. The race for E-Commerce, E-Learning, enterprise systems, Web services, and personalization, has brought to life many technologies that can now be used for the development of adaptive, distributed E-learning and has inspired a number of research streams.

The focus of adaptive distributed learning research has now moved to the Adaptive Hypermedia and E-Learning research communities. Among several projects that focus on adaptive E-Learning, two projects are most close to the KnowledgeTree vision of distributed personalized service-based E-Learning.

ELENA, an international project focuses on personalization in distributed E-Learning Networks [19; 20; 21]. ELENA's architecture has several similarities with KnowledgeTree. It recognizes such entities as resource providers and value-adding services, though it currently integrates a student portal with the student model server in a personal learning assistant peer. As a result, it has no specific architectural component to support the needs of a teacher. An important difference between the projects is that ELENA starts from the analysis of global needs and focuses more on interoperability and technology. To support interoperability, ELENA attempts to define precisely the format for stored and communicated knowledge. KnowledgeTree starts with the needs of humans - the main stakeholders of the E-Learning process and focuses on the content rather than format. These projects are quite complementary and we hope, that we will be able to integrate our prospects in the context of ProLearn Network of Excellence.

Another relevant project originates from Ireland [15; 16; 17]. The group in Trinity College Dublin investigates value-adding services for the adaptive presentation of reusable content. This work is similar to the KnowledgeTree architecture in two main aspects. First, it stresses the need to move from reusable objects to adaptive reusable services. Secondly, through the mechanism of narration, it attempts to support the teacher's need to be an active integrator of educational content. This is exactly the same need that is anticipated and supported by a KnowledgeTree portal.

5. A SUMMARY OF EXPERIENCE

As we have mentioned, KnowledgeTree has been extensively used in teaching several real courses for about two years. Over this period we have created three different course trees with KnowledgeTree and two different knowledge maps with Knowledge Sea. Three main activity servers are currently hosting more than 200 interactive activities. In addition to that, Knowledge Sea provides access to more than a 1000 static C-tutorial pages that are currently served through AnnotatED. This large and comprehensive volume of learning material makes it very easy to structure a new course focused on teaching C programming. In addition, it allows us to use KnowledgeTree as a primary tool in supporting practical courses. We think that these are good proofs of the KnowledgeTree concept.

We have never run a subjective evaluation of KnowledgeTree as architecture; however we have evaluated several components, including Knowledge Sea [13] and several

activity servers. All these evaluation brought very positive and even remarkable results. Since all subjective evaluation questionnaires included a free-form feedback, we have collected a good amount of unsolicited praise for the system in general. The students have most of all appreciated the variety of tools provided and the simplicity of use of these tools, through a single-entry portal.

The presence of the CUMULATE server, which records time-stamped student performance with every activity made it very easy to observe what the students were doing with the system. Most interesting for us was to discover that the profiles of the activity usage differ a lot from user to user. Some users generated several hundred records with one or two of our tools while nearly ignoring the rest. We hypothesis that different kinds of activities correspond better to different learning styles. It provides another reason to choose the KnowledgeTree approach for providing access to very diverse activities from a single portal. Overall, the students used KnowledgeTree and its components a great deal. For merely a single QuizPACK server, the average number of questions answered by a user over the duration of the course was more than 180, while some students attempted more than 500 (!) questions. The results of user ranking of their learning tools showed that the activity servers offering advanced interactive activities were more popular than the lecture notes and textbooks that are the traditional "static" learning tools in a university.

6. CONCLUSION

This paper proposes an architecture for adaptive E-Learning based on distributed reusable intelligent learning activities that integrate the benefits provided by modern LMS and educational material repositories with the power of ITS and AH technologies. This architecture addresses both the component-based development of adaptive systems and the teacher-level reusability. We have started by implementing the core functionality of the system within our local group by using some rather simple approaches to implement the required protocols.

Some other groups driven by similar goals have proposed other architectures that match our vision [16; 19; 26; 29]. A significant amount of work and cooperation between several research groups will be required to turn the proposed architectures into the common practice of E-Learning. Fortunately, our work shares many goals with several other active Web-related research areas, enabling us to re-use possible standards, solutions and ideas from these areas. It gives our group, along with other similarly-motivated groups, a good chance of succeeding in bringing this new generation of adaptive E-Learning systems and tools to the educational world.

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