Adaptive Educational Systems on the World-Wide-Web: A Review of Available Technologies

Peter Brusilovsky
Human-Computer Interaction Institute
Carnegie Mellon University
Pittsburgh, PA 15213, USA
E-mail: plb@cs.cmu.edu

Abstract: This paper provides a short review and a state of the art report on Web-based adaptive educational systems. The systems are analyzed according to applied adaptation technologies.

1. Introduction

Web-based education is currently a hot research and development area (Khan, 1997). Benefits of Web-based education are clear: classroom independence and platform independence. An application installed and supported in one place can be used by thousands of learners all over the world who are equipped with any kind of Internet-connected computer. Thousands of Web-based courses and other educational applications have been made available on the Web within the last five years. The problem is that most of them are nothing more than a network of static hypertext pages. A challenging reset goal is the development of advanced Web-based educational applications which can offer some amount of interactivity and adaptivity. Adaptation is especially important for Web-based education for at least two general reasons. First, most Web-based applications are to be used by a much wider variety of users than any standalone application. A Web application which is designed with a particular class of users in mind may not suit other users. Second, in many cases the user is "alone" working with a Web "tutor" or "course" (probably from home). That is why assistance that a colleague or a teacher typically provides adaptively in a normal classroom situation, is not available.

2 Web-based Adaptive Educational Systems in a broader context

Web-based Adaptive Educational Systems (AES) are not an entirely new or unique kind of systems. Historically, Web-based AES inherit from two earlier kinds of AES: *intelligent tutoring systems* (ITS) and *adaptive hypermedia systems*. Traditionally, problems of developing AES were investigated in the area of intelligent tutoring systems (Burns & Capps, 1988). ITS use the knowledge about the domain, the student, and about teaching strategies to support flexible individualized learning and tutoring. Adaptivity was one of the goal features of any ITS. Adaptive hypermedia is a much newer research domain (Brusilovsky, 1996). Adaptive hypermedia systems apply different forms of user models to adapt the content and the links of hypermedia pages to the user. Education is one of the main application areas for adaptive hypermedia and a number of adaptive educational hypermedia systems was built before "Web Rush". From a systemic point of view current Web-based AES can be considered simply as ITS or adaptive hypermedia systems implemented on the Web. However, WWW context provides serious impact on design and implementation of these system and let us treat them as a special subclass. For example, very few standalone ITS use adaptive hypermedia, while almost all Web-based AES can be classified as both ITS and adaptive hypermedia systems. It is the impact of a "hypertext" nature of the Web.

In another context, Web-based AES is one of existing kinds of adaptive Web-based systems. WWW appears to be a nice platform for developing and testing various adaptive applications. From one side, it is challenging: Web-based systems really need adaptivity because they have to work with a much greater variety of users than earlier standalone systems. From another side, it is attractive: The Web gives complex AI-based adaptive systems a nice chance to reach many real users. While an adaptive system is installed on a powerful server which is serviced and updated by knowledgeable personnel, thousands of users can connect to it from cheap computers or kiosks. Web users can also help to solve a painful evaluation problem because all data about user interaction with an adaptive Web-based system can be recorded on the central server and used for comprehensive analysis.

The workshop "Adaptive systems and user modeling on the WWW" (http://www.contrib.andrew.cmu.edu/~plb/UM97_workshop/) showed that existing adaptive Web-based systems can be divided into three groups: adaptive information systems which serves personalized information online like AVANTI (Fink, Kobsa & Schreck, 1997) or PUSH (Höök, 1997), adaptive filtering systems which helps user to find relevant "drops" in the ocean of available information like ifWeb (Asnicar & Tasso, 1997) or WebTagger™ (Keller et al., 1996), and adaptive educational systems. AES is the biggest group: more than half of the existing adaptive Web-based systems are AES. Here we list some probable reasons. First, the borders between these groups are not clear-cut. An on-line information system, such as an encyclopedia which is used for education (Signore, Bartoli & Fresta, 1997) or an adaptive filtering system applied in education context (Nomoto et al., 1997) can be classified as an AES. Second, AES is a more versatile kind of system than the former two so more researchers from different areas are motivated to work on it. Finally, the developers of AES can rely on technologies (and even components) used and approved in earlier standalone ITS and adaptive hypermedia systems. A number of existing Web-based AES such as ELM-ART, CALAT, WITS or Belvedere were developed on the basis of earlier standalone ITS.

3 What Can Be Adapted in Web-based Educational Systems

This section provides a brief review of current research on adaptive Web-based educational systems. The goal of the review is to demonstrate what can be adapted in this kind of systems. To provide compatibility with earlier papers on adaptive hypermedia (Brusilovsky, 1996) and Web-based ITS (Brusilovsky, 1995) we call essentially different ways of adaptation as *adaptation technologies*. Currently, all adaptation technologies applied in Web-based AES are adopted from either the ITS area (curriculum sequencing, intelligent analysis of student's solutions, interactive problem solving support, example-based problem solving support, and collaboration support) or the adaptive hypermedia area (adaptive presentation and adaptive navigation support). In a near future, we expect the appearance of newer adaptation technologies, for example, adaptive collaboration support, specially designed for the context of Web-based education.

The goal of the *curriculum sequencing* technology (also referred to as instructional planning technology) is to provide the student with the most suitable individually planned sequence of knowledge units to learn and sequence of learning tasks (examples, questions, problems, etc.) to work with. In other words, it helps the student to find an "optimal path" through the learning material. The classic example from the domain of teaching programming is the BIP system (Barr, Beard & Atkinson, 1976), recent examples are ITEM-IP (Brusilovsky, 1992b) and SCENT-3 (Brecht, McCalla & Greer, 1989). It make sense to distinguish two kinds of curriculum sequencing techniques. High-level sequencing or *knowledge sequencing* determines next concept or topic to be taught. Low-level sequencing or *task sequencing* determines next learning task (problem, example, test) within current topic (Brusilovsky, 1992a). In the context of Web-based education, curriculum sequencing technology becomes very important to guide the student through the hyperspace of available information. Currently, it is the oldest and the most popular technology for Web-based AES. Curriculum sequencing was implemented in different forms in the following AES: ELM-ART (Brusilovsky, Schwarz & Weber, 1996), CALAT (Nakabayashi et al., 1997), InterBook (Brusilovsky & Schwarz, 1997), AST (Specht et al., 1997), MANIC (Stern, Woolf & Kuroso,1997), Medtec (Eliot, Neiman & Lamar, 1997), and DCG (Vassileva, 1997).

Intelligent analysis of student solutions deals with students' final answers to educational problems (which can range from a simple question to a complex programming problem) no matter how these answers were obtained. Unlike non-intelligent checkers which can tell not more than whether the solution is correct, intelligent analyzers can tell what exactly is wrong or incomplete and which missing or incorrect knowledge may be responsible for the error. Intelligent analyzers can provide the student with extensive error feedback and update the student model. The classic example from the domain of teaching programming is PROUST (Johnson, 1986), recent examples are CAMUS-II (Vanneste, 1994) and ELM-PE (Weber & Möllenberg, 1995). The intelligent analysis of solutions is a very suitable technology in the context of slow networks. It needs only one interaction between browser and server for a complete solution. It can provide intelligent feedback and perform student modeling when more interactive techniques will be hardly useful. Currently, there are at least two AES on the Web which implement intelligent analysis of student solutions on WWW adaptively (i.e., students with different student models may get different feedback): ELM-ART, an ITS for programming in LISP (Brusilovsky et al., 1996) and WITS, an ITS for Differential Calculations (Okazaki, Watanabe & Kondo, 1996; Okazaki, Watanabe & Kondo, 1997).

The goal of *interactive problem solving support* is to provide the student with intelligent help on each step of problem solving - from giving a hint to executing the next step for the student. The systems which implement this technology can watch the actions of the student, understand them, and use this understanding to provide help and to update the student model. The classic example from the domain of teaching programming is the LISP-TUTOR (Anderson & Reiser, 1985); recent examples 1985).are the ACT Programming Tutor (Corbett & Anderson, 1992) and GRACE (McKendree, Radlinski & Atwood, 1992). Interactive problem solving support technology in not as popular in Web-based systems as in standalone systems because, up to now, server-based WWW applications are not "interactive" enough to support watching the student actions and providing help on each step. Each interaction between browser and server may take a visible amount of time and the requirement to perform it on each step may ruin the problem solving process. The situation will probably change when Java technology become more mature. However, three systems demonstrate that Interactive problem solving support technology can work on the WWW. PAT-Online (Brusilovsky, Ritter & Schwarz, 1997; Ritter, 1997) uses server-based approach (i.e., a form-based CGI interface) and lets the student submit several problem solving steps for checking in one transaction (i.e., it is a combination of interactive problem solving support and intelligent analysis of student solutions). Belvedere (Suthers & Jones, 1997) and ADIS (Warendorf & Tan, 1997) uses the Java technology to support real interactivity. D3-WWW-Trainer (Faulhaber & Reinhardt, 1997) uses both Java and server-based technology. A reasonably small Java applet provides a nice interactive interface. The intelligent and adaptive part, however, resides on the server. The applet provides a connection with the server using CGI interface.

In an *example-based problem solving* context, students solve new problems using as help examples from their earlier experience. In this context, an ITS helps students by suggesting them the most relevant *cases* (examples explained to them or problems solved by them earlier). An example from the domain of teaching programming is ELM-PE (Weber & Möllenberg, 1995). Example based problem solving does not require extensive client-server interaction and can be naturally used in AES on the Web. The only system which uses this technology on WWW is ELM-ART (Brusilovsky et al., 1996).

The goal of *the adaptive presentation technology* is to adapt the content of a hypermedia page to the user's goals, knowledge and other information stored in the user model. In a system with adaptive presentation, the pages are not static, but adaptively generated or assembled from pieces for each user. For example, with several adaptive presentation techniques, expert users receive more detailed and deep information, while novices receive more additional explanation. An example from the domain of teaching programming is the "conditional text" technique applied in ITEM/IP (Brusilovsky, 1992b). Adaptive presentation is very important in WWW context where the same "page" has to suit to very different students. Only two Web -based AES implement full-fledged adaptive presentation: C-Book (Kay & Kummerfeld, 1994) and De Bra's adaptive course on Hypertext (Calvi & De Bra, 1997). Both these systems apply the conditional text technique. Some other systems use adaptive presentation is special contexts. Medtec (Eliot et al., 1997) is able to generate adaptive summary of book chapters. ELM-ART, AST, and InterBook use adaptive presentation to provide adaptive insertable warnings about the educational status of a page. For example, if a page is not ready to be learned, ELM-ART and AST insert a textual warning at the end of it and InterBook inserts a warning image in a form of a red bar.

System	Hypertext component	Adaptive sequencing	Adaptive navigation support	Problem solving support	Intelligent solution analysis	Adaptive presentation
CALAT	Some	Yes				
ELM-ART	Yes	Course, tests	Annotation		Yes	Some
AST	Yes	Yes	Annotation			Some
InterBook	Yes	Yes	Annotation			Some
Medtec	Yes	Tasks				Some (summaries)
C-Book	Yes					Yes
PAT-InterBook	Yes	Yes	Annotation	Server	Yes	Some
DCG	Yes	Yes				
De Bra’s	Yes		Disabling			Yes
WEST-KBNS	Yes		Annotation			
PAT	Yes					
WITS	No				Yes	
Belvedere				Java		
ADIS				Java		
Anjanejulu’s	Yes		Disabling			
D3-WWW-Trainer	Yes			Java		
Manic	Yes	Some				

Table 1. Adaptation technologies in Web-based educational systems

(in InterBook the type of supported sequencing depends on the domain - it’s a shell.)

Adaptive collaboration support is a very new ITS technology which was developed within last 3 years along with development of networked educational systems. The goal of adaptive collaboration support is to use system’s knowledge about different users (stored in user models) to form a matching collaborating group. Existing examples include forming a group for collaborative problem solving at a proper moment of time (Hoppe, 1995; Ikeda, Go & Mizoguchi, 1997) or finding the most competent peer to answer a question about a topic (i.e. finding a person with a model showing good knowledge of this topic) (Bishop, Greer & Cooke, 1997; McCalla et al., 1997). By now we have not seen any examples of using this technology in Web context. However, this technology is completely "Web-ready" and we expect that it will become quite popular in the coming years.

The goal of the *adaptive navigation support technology* is to support the student in hyperspace orientation and navigation by changing the appearance of visible links. In particular, the system can adaptively sort, annotate, or partly hide the links of the current page to make easier the choice of the next link to proceed. Adaptive navigation support (ANS) can be considered as an extension of curriculum sequencing technology into a hypermedia context. It shares the same goal - to help students to find an "optimal path" through the learning material. At the same time, adaptive navigation support is less directive than traditional sequencing: it guides students implicitly and leaves the choice of the next knowledge item to be learned and next problem to be solved to them. Two examples of ANS-based standalone systems from the domain of teaching programming are ISIS-Tutor (Brusilovsky & Pesin, 1994) which uses adaptive hiding and adaptive annotation and Hypadapter (Hohl, Böcker & Gunzenhäuser, 1996) which uses adaptive hiding and adaptive sorting. In a WWW context where hypermedia is a basic organizational paradigm, adaptive navigation support can be used very naturally and efficiently. The most popular form of ANS on the Web is annotation. It is implemented in ELM-ART (Brusilovsky et al., 1996), InterBook (Brusilovsky & Schwarz, 1997), WEST-KBNS (Brusilovsky, Eklund & Schwarz, 1997), and AST (Specht et al., 1997). InterBook also applies adaptive navigation support by sorting. Another popular technology is disabling, a variant of hiding which keeps link visible but does not let the user to proceed to the page behind the link is this page is not ready to be learned. The options are either to make the link completely non-functional (nothing happens when the user clicks on it) as implemented in De Bra's adaptive course about Hypertext (Calvi & De Bra, 1997) and the system (Anjaneyulu, 1997) or to show the user a list of pages to be read before the goal page as done in Albatros (Lai, Chen & Yuan, 1995).

System	Adaptive presentation	Adaptive sequencing	Adaptive navigation support	Problem solving support	Intelligent solution analysis	Collaboration support
Presentation	C-Book	na	na	na	na	na
Assessment: Tests	Possible	ELM-ART AST	Possible	na	na	na
Assessment: Assignments	Possible	Possible	Possible	PAT Belvedere ADIS	WITS ELM-ART	Possible
Communication	na	na	na	na	na	Possible
Control: Course logic limitations	De Bra	possible	De Bra Albatros	na	na	na
Control: Guidance	ELM-ART AST InterBook	ELM-ART AST InterBook CALAT DCG	ELM-ART AST InterBook WEST-KBNS	na	na	na

Table 2. Adaptation technologies and main directions of Web-based educational systems development. "Possible" means that a technology can be used in a particular direction, but no examples are available by now. "na" means that a technology is not relevant for this direction

4 Place of Adaptive technologies in the context of Web-based Educational systems

Adaptive technologies can contribute to several directions of research and development on Web-based Educational systems (Table 2). Adaptive presentation can improve the usability of course material presentation. Adaptive navigation support and adaptive sequencing can be used for overall course control and for helping the student in selecting most relevant tests and assignments. Problem solving support and intelligent solution analysis can significantly improve the work with assignments providing both interactivity and intelligent feedback. Adaptive collaboration support opens new possibilities for communication and collaboration. Currently all these technologies belongs to research level in respective areas, but in a close future we may expect moving of the most investigated technologies to the development level. For example, CALAT system with a well-designed adaptive sequencing is expected to be used commercially in 1998.

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