Educational Multimedia and Hypermedia, 1995

edited by
Hermann Maurer

Proceedings of *ED-MEDIA 95*—
World Conference on
Educational Multimedia and Hypermedia
Graz, AUSTRIA; June 17-21, 1995

AACE Association for the Advancement of Computing in Education

Adaptive Educational Hypermedia: From Ideas to Real Systems

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Abstract: Adaptive hypermedia is a new area of research at the crossroads of hypermedia, adaptive systems and intelligent tutoring systems. The goal of this paper is to present the ideas of adaptive hypermedia to an educational hypermedia-oriented audience and to show some ways of implementing adaptive hypermedia systems. This paper considers two kinds of hypermedia adaptation: adaptive presentation and adaptive navigation support. We provide a brief overview of existing works on each of these two kinds of adaptation and describe in more detail two existing tutoring systems which contain adaptive hypermedia components. These systems demonstrate some ways to implement adaptive presentation and adaptive navigation support in an educational context.

1 Introduction

The use of adaptive hypermedia systems (AHS) is one of the ways of increasing the functionality of hypermedia. AHS build a model of the goals, preferences and knowledge of the individual user and use this throughout the interaction for adaptation to the needs of that user. Adaptive hypermedia can be useful in any situation when the system is expected to be used by people with different goals and knowledge, where the hyperspace is reasonably big, or where the system can successfully guide the user in his or her work. Education is one of the most promising areas for adaptive hypermedia. Hypermedia is used in educational systems for providing student-driven exploration of educational material. Adaptive hypermedia can be applied here for all the above reasons: to adapt the presented information to the current knowledge level of the student [Brusilovsky, Pesin & Zyryanov, 1993][Beaumont, 1994], to provide navigation support on various levels [de La Passardiere & Dufresne, 1992][Brusilovsky, Pesin & Zyryanov, 1993] and to guide the student in the learning process [Brusilovsky, Pesin & Zyryanov, 1993][Kushniruk & Wang, 1994].

The goal of this paper is to present the ideas of adaptive hypermedia to a general hypermedia-oriented audience and to show some ways to implement AHS. This paper considers two kinds of hypermedia adaptation: adaptive presentation and adaptive navigation support. We provide a brief overview of existing works on each of these two kinds of adaptation and describe in detail two existing tutoring systems which contain adaptive hypermedia components. These systems demonstrate some ways to implement adaptive presentation and adaptive navigation support in an educational context.

Adaptive presentation is the most popular and the most studied method of hypermedia adaptation. The work on adaptive hypermedia presentation was influenced by work on adaptive user interfaces, namely, the work of C. Paris on adaptive explanations [Paris, 1989]. With adaptive presentation the content of a hypermedia page is generated or assembled from pieces according to the user's class and knowledge state. Generally, qualified users receive more detailed and deep information, while novices receive more additional explanation [Beaumont, 1994][Brusilovsky, 1992][Boyle & Encarnacion , 1994][Fischer et al, 1990] Two popular application areas for adaptive presentation are adaptive hypermedia-based help in knowledge-based systems [Fischer et al, 1990][De

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Rosis, De Carolis & Pizzutilo, 1993] and on-line documentation systems [Böcker, Hohl & Schwab, 1990][Boyle & Encarnacion , 1994]. The results reported in [Boyle & Encarnacion , 1994] show that adaptive presentation increases user performance. In an educational context adaptive presentation was implemented in ANATOM-TUTOR [Beaumont, 1994] and ITEM/IP [Brusilovsky, 1992]. [Section 2] describes the techniques used in the system ANATOM-TUTOR for implementing adaptive presentation.

By adaptive navigation support we mean all the ways to play with visible links which can support hyperspace navigation. In current systems, three kinds of adaptive navigation support have been suggested and implemented: hiding some of the links, adaptive ordering of visible links, and adaptive annotation of visible links. Hiding visible links was used in [Brusilovsky, 1992]. Hiding is a simple and effective way of reducing the cognitive load of the user, but critics argue that this can cause the building of incomplete mental maps of the hyperspace by the user. The importance of the user being able to build a coherent model of the system he is using has been stressed by many authors. HYNECOS [Vassileva, 1994] for example, supports adaptation based on the user's experience and displays preferences and requirements w.r.t. tasks, etc. However, it only allows adaptation to take place "at discrete points in time, and only after the user has given specific permission". The ordering of visible links according to some user-valuable criteria (the more close to the top, the more relevant the link is) can help the user to select the next link to follow. This technique was suggested in [Böcker, Hohl & Schwab, 1990][Tomek, Maurer & Nassar, 1993][Kaplan, Fenwick & Chen, 1993] , and the latter paper reports positive experimental results. We think that ordering links is a good way to support user navigation in the pages with dozens of possible links. This ordering, however, can not be applied in the case of embedded (context) links. Some research also shows that the stable order of options in small menus is important for general users. A promising and flexible technology for adaptive navigation support is the adaptive annotation of visible links (augmenting links with personal dynamic comments in any form) [de La Passardiere & Dufresne, 1992][Brusilovsky, Pesin & Zyryanov, 1993]. Recent research shows that even static annotation which tells the user more about the nodes designated by annotated links can increase students performance [Zhao, O'Shea & Fung, 1993] . Adaptive annotation can use icons [de La Passardiere & Dufresne, 1992] colors [Brusilovsky & Pesin, 1994] or other visual cues to reflect the state of the related nodes according to user knowledge and goals. The most simple adaptive annotation technique is just outlining the links to previously visited nodes, giving two states for visible links (links to visited/not visited nodes). This can be found in many hypermedia systems including NCSA Mosaic. Adaptive hypermedia systems [de La Passardiere & Dufresne, 1992][Brusilovsky & Pesin, 1994] can distinguish four and more states on the base of the student model. [Section 3] presents the techniques used in ISIS-tutor system [Brusilovsky & Pesin, 1994] to implement adaptive navigation support.

2 Adaptive hypermedia presentation in Anatom-Tutor

This section describes hypertext adaptation in the intelligent tutoring system ANATOM-TUTOR [Beaumont, 1994]. Developed for teaching anatomy of the brain at university level, ANATOM-TUTOR's hypertext component makes use of a user model to adapt hypertext lessons at both the link and the text level. Hypertext is one of three learning modes offered by ANATOM-TUTOR. In the browsing mode, menus and mouse-sensitive diagrams are employed for accessing the domain knowledge base. The user model is neither consulted nor modified in this mode. The question mode, which makes extensive use of the user model, is a simulated examination situation offering individually tailored responses to student misconceptions. In the hypermode, which also makes use of the user model, a hypertext based information system is used for the structured presentation of domain knowledge, together with illustrations of its use, in a manner suited to the users' level of knowledge. (Due to space limitations we will not go into details of ANATOM-TUTOR as a whole, but refer the reader to [Beaumont, 1994], which contains a fuller discussion with examples.)

2.1 The User Model

The user modeling component in ANATOM-TUTOR is rule based and uses both stereotypes for making assumptions based on the general information and deduction mechanisms for inferring new declarative information from that which is already in the model.

The user model contains:

1) general information on the user's pre-knowledge in anatomy - which semester he is in, which lectures he has heard, why he is using ANATOM-TUTOR (for an introduction to the material, for examination preparation, etc.), the bias of the lesson (histological perspective, etc.), an so on. This material is gathered using an initial

questionnaire at the start of the user's first session. The user himself is responsible for making changes here (for example when his reason for using the system changes).

2) specific knowledge of the material covered in the ANATOM-TUTOR lessons.

The deduction mechanisms fall into two categories: 1) those which make use of a structure on the domain knowledge (this is determined by domain experts using their knowledge of the domain and statistical surveys of users learning the material), 2) those which predict the learner's use of domain laws for inferring new declarative information

2.2 Adapting the hypertext

The idea behind ANATOM-TUTOR's hypertext component is to provide the learner with the full functionality of traditional hypertext with the additional advantage that the text has been adapted to the learner's individual needs, and that links relevant with respect to the user's reason for using the system, the lesson's bias, etc., are highlighted. ANATOM-TUTOR is still relatively small and no provision has been made for adaptive annotation as advocated, for example, by [de La Passardiere & Dufresne, 1992].

In ANATOM-TUTOR, the structure of the hypertext lesson results from didactic considerations and consists basically of loosely pre-defined sequences of nodes. Depending on the global classification of the user, the actual nodes to be presented and the links to be activated are determined and the resulting setting remains largely unchanged during the course of the lesson. Adaptation at the text level can involve both the style and the content of the text. People at different levels of proficiency talk about their subject material in different ways, as anyone who has compared the conversations of laymen on a subject with that of experts will readily admit, and texts prepared for a specific reader group orientate their presentation style on that group. ANATOM-TUTOR's hypertext component first chooses a default presentation style depending on the user's global classification, and can adapt this locally according to the user's (local) level of proficiency. Two basic categories of user are distinguished, beginner and advanced, and two expository styles correspond to these two user categories. This is also the approach taken by C.Paris [Paris, 1989] in her system TAILOR. (Paris distinguishes between parts-oriented and process-oriented descriptions, which can be compared to the morphologically and functionally biased descriptions in ANATOM-TUTOR.) Most users will fall somewhere between beginner and advanced, and the view taken by Paris and ourselves is that a presentation adequate for the needs of the individual user can be obtained by combining these styles in accordance with the user's local knowledge of the concepts involved. The effect produced is that of a continuous range of user levels. In addition to this presentation style, Anatom-Tutor also locally determines the content of the presented text, i. e. known material can be left out and additional material included. This is done by consulting the user model during the lesson.

2.3 How the model is used for adapting hypertext

ANATOM-TUTOR first decides on the general link structure by looking at the model to find out the user's goals. For example, if the user is reading the lesson on the pupillary light reflex and is interested in histological aspects, then links to sections with more detailed histological information are activated. At the text level, the user's level of experience, the lessons and lectures he has already worked through, etc., are taken into consideration for choosing a default expository style. Then, the content and actual local (i.e. for one or several sentences) expository style is chosen by comparing the user's (fine-grained) knowledge with the material covered in that part of the lesson. For example, if something is being taught about the area striata and the user has little or no pre-knowledge of this brain structure, then the system will use the morphologically biased descriptive style, while better knowledge can result in the functional style being chosen (or in the material being left out altogether, in keeping with our philosophy of non-redundancy of content).

3 Adaptive navigation support in ISIS-Tutor

ISIS-Tutor is an intelligent learning environment to support learning the print formatting language of the information retrieval system CDS/ISIS/M. ISIS-tutor [Brusilovsky & Pesin, 1994] is one (and the most recent) of several intelligent learning environments with adaptive hypermedia features which were implemented at the Moscow State University [Brusilovsky, Pesin & Zyryanov, 1993]. All the systems have the same general architecture: a set of adaptive functional modules integrated around central domain and student models. Three main functional modules of ISIS-Tutor are the tutor component, the exploratory environment to play with the language, and the hypermedia component. The tutor component supports guided tutoring. At any moment of learning it can analyze the state of the student knowledge reflected in the student model and select the next 'best' teaching operation from the knowledge base. The hypertext component supports student-driven learning from teaching material. Using the hypermedia interface the student can navigate in the hyperspace of teaching material and select the next learning activity, either a concept or construct explanation to read, an example to analyze, or a problem to solve. The learning environment allows the user to play and experiment with print formatting commands. It provides an editor and stepwise interpreter with extended visualization. A more complete description of ISIS-Tutor can be found in [Brusilovsky & Pesin, 1994]. Here we are concerned only with the hypermedia component of the system.

3.1 Knowledge representation

The central part of ISIS-Tutor architecture is the interrelated domain model and student model. In ISIS-Tutor the material being taught (knowledge about the language) is represented as the domain model. The material is divided into a set of elementary knowledge elements and structured as a directed graph (concept map) representing prerequisite relationships between the elements. The domain model in ISIS-Tutor contains about 69 concepts and constructs. The overlay student model (SM) reflects the extent to which the student has mastered language concepts by providing an integer weight for each concept. The student model is always kept up-to-date and supports the adaptive capacity of all modules. All learning material is also related with the domain model network. There are three kinds of teaching operations in ISIS-Tutor: concept presentations, problems to solve and examples to analyze. The teaching operations are stored in the knowledge base of learning material in the form of frames. Each of the teaching operation frames has a slot which contains the list of domain concepts related with this teaching operation; for example, the list of concepts used in the example. This list (called the spectrum of the teaching operation) provides the link with the domain model.

ISIS-Tutor and other systems of our research group use a knowledge-based approach to integrate the hypermedia component into the overall environment. The approach is based on three principal ideas. First, the central part of the hypermedia network is designed in a form of visualized domain network. Each node of the domain network is represented by a node of the hyperspace, while the links between domain network nodes constitute main paths between hyperspace nodes. Thus the structure of the overall hyperspace resembles the pedagogic structure of the domain knowledge. Second, each teaching operation is also represented as a node of the hyperspace and interlinked with all domain concepts listed in its spectrum. Third, hypermedia 'pages' which are external representations of all the mentioned hyperspace nodes are not stored in a fixed format, but generated by the hypermedia component from the internal frame-based representation stored in the knowledge base.

3.2 Adaptive navigation support

The idea of adaptive navigation support in ISIS-Tutor is to annotate the set of links leading from the current node to related nodes (and from index page to all nodes) according to the current user knowledge and educational goals. The student model and the hypermedia component distinguish three knowledge states for each concept and related hypernode: not-ready-to-be-learned (i.e. has unlearned prerequisites), ready-to-be-learned, and learned. Thus, at any moment the hyperspace is divided implicitly into three "zones". In particular, the ready-to-be-learned nodes form the "zone of proximal development" [Vygotsky, 1978] . Our idea is that different zones have different meanings for the student and marking these zones visually would help the student in hyperspace navigation. To mark the zones, the hypermedia component just marks the hyper-links of each node in three different colors. For example, the links to the nodes which are not-ready-to-be-learned are gray so as not to distract the student.

Adapting to the current educational goal is easier. The educational goal in ISIS-Tutor is just the set of concepts which the student expects to learn at the current session. The goal can be prescribed by the human teacher of by the student himself. We use two kinds of goal adaptation: hiding all the concepts outside the current goal (which really restricts the student to this goal) and outlining the goal concepts. Thus, the links from the index or current pages to related concept pages have different colors, and the color tells the student about the educational and goal states of the related pages. A similar method is used for representing the suitability of problems and examples.

Using colors to support adaptive navigation is definitely not the best way. Generally, colors are meaningless for the student. In addition, too many different colors on the screen is very distractive (that is why we distinguish only three educational states in ISIS-Tutor). We think that using icon-based [de La Passardiere & Dufresne, 1992] or text-based [Zhao, O'Shea & Fung, 1993] annotation is better in many ways. Unfortunately, these require advanced display facilities, while we were limited to IBM PCs. However, our preliminary experimental data shows that even color-based adaptation can improve student performance: to reduce the time and the number of visited nodes while keeping the same level of results. These results show that adaptive navigation gives the user enough information about related nodes to avoid unnecessary visits to them.

4 Prospects for adaptive educational hypermedia

We now briefly look at the reciprocal implications of fine grained hypertext adaptation for educational systems. In the domain of on-line information systems the main feedback which the adaptive hypermedia component gets is the request for more information, which is usually done by clicking menu buttons or active fields in the body of the text. This has serious consequences for adaptation at a fine grained level. Boyle and Encarnacion [Boyle & Encarnacion , 1994] recognize that the mouse click allows only a "narrow bandwidth of information" but make the most of it by enabling the user to remove superfluous information (i.e. information which the user does not understand or which is too basic) from the screen, thus providing another feedback dimension. (We believe that in a realistic situation a user will just gloss over what he cannot use, as he would do when reading a book, and not try to use paragraph deletion as a signaling device.) If the user asks for an explanation of an item of information which was assumed known, MetaDoc removes the item from the user model and gives the requested explanation (presumably then re-adding the item to the user model). Paris [Paris, 1989] avoids the problem, and assumes the existence of an adequate user model somewhere in the background, neglecting the effect that the use of her system has on the user's knowledge.

While there may be a question of the desirability and user acceptance of putting test questions in an on-line documentation system, in the tutoring systems such as ANATOM-TUTOR or ISIS-Tutor we can use test questions and problems to increase the bandwidth of information available from the user without leaving the teaching paradigm. Adding questions relating to the material is obviously superior to trying to accurately update the model solely from the user's requests for more or less material, and is in keeping with Self's [Self,1988] advice on bypassing the intractability problem of student modeling - "avoid guessing - get the student to tell you what you need to know". There is a big difference between saying on the one hand that the user is probably familiar with the concept parasympathic object, and being able to say that he knows that the corpus geniculatum laterale is a parasympathic object with a certain probability and being able to explain why this is so in terms he can (probably) understand, should he happen to think otherwise. Intelligent adaptive educational hypertext systems both allow and require a system/user interaction at this level.

The two systems described above show that adaptive hypermedia can be successfully applied in education. We would say more: education is one of the most promising areas of application for adaptive hypermedia. There are two reasons for this. First, an educational setting can produce better and more reliable student models than most other areas in which adaptive systems are used. This means more possibilities for hypermedia adaptation. Second, better adaptive hypermedia can lead to a breakthrough in educational computing by bridging the gap between traditional user-driven exploratory environments and machine-driven tutoring systems, resulting in better educational systems.

At present most educational systems belong either to the class of 'tutors' providing 'guided', 'adaptive', machine-driven education (CAI, ITS), or to the class of environments, providing 'free' student-driven learning (hypermedia, microworlds). Adaptive hypermedia can bridge the gap between these two poles. Adaptive hypermedia systems still leave the initiative to the student, however the system can adapt to the student and guide the student implicitly but significantly by changing the content and the links of hypermedia pages.

We conclude by saying that education is an attractive area for application of adaptive hypermedia. ITS can provide a fine grained user model which is important for adaptive hypermedia, while adaptive hypermedia can augment ITS with a component for user-driven exploration of teaching material. It's not by chance that the first work on adaptive educational hypermedia was made in the context of ITS. We think that for the next several years adaptive hypermedia systems will be going side-by-side with ITS. In fact, many existing ITS can be easily extended with adaptive hypermedia features and it's probably a nice way to go.

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