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Adaptive Navigation Support: From Adaptive Hypermedia to the Adaptive Web and Beyond

Peter Brusilovsky[♣]

School of Information Sciences
University of Pittsburgh

ABSTRACT

Adaptive navigation support is a specific group of technologies that support user navigation in "virtual spaces" adapting to the goals, preferences and knowledge of the individual user. These technologies, originally developed in the field of adaptive hypermedia, are becoming increasingly important in several adaptive Web applications from Web-based adaptive hypermedia to adaptive virtual reality. This paper provides a brief introduction to adaptive navigation support, reviews major adaptive navigation support technologies, and presents a sequence of projects performed by our group to study adaptive navigation support in different contexts.

Keywords: *Navigation support, user model, virtual environments, adaptive system, personalization.*

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1. Introduction

Adaptive hypermedia (Brusilovsky, 2001) is a research area at the crossroads of hypermedia and user modeling. Adaptive hypermedia systems (AHS) offer an alternative to the traditional “one-size-fits-all” hypermedia and Web systems by adapting to the goals, interests, and knowledge of individual users represented in the individual *user models*. This paper is focused on *adaptive navigation support* technologies originally developed in the field of adaptive hypermedia. By adaptively altering the appearance of links on every browsed page using such methods as *direct guidance*, *adaptive ordering*, *link hiding and removal*, and *adaptive link annotation*, these technologies support personalized access to information. Adaptive navigation support technologies have been evaluated in several application areas and have

♣ Corresponding Author:
Peter Brusilovsky,
School of Information Sciences,
University of Pittsburgh
Pittsburgh PA 15260
Tel.: 1 (412) 624 9404
E-mail: peterb@mail.sis.pitt.edu

demonstrated their ability to let the users achieve their goals faster, reduce navigation overhead, and increase satisfaction (Brusilovsky, 1997).

Nowadays, adaptive navigation support technologies have been growing in importance in areas past the horizon of classic hypertext, their original application area. These technologies are now being used in several adaptive Web (Brusilovsky & Maybury, 2002) applications from Web-based adaptive hypermedia to adaptive virtual reality. This paper provides a brief introduction to adaptive navigation support, reviews main adaptive navigation support technologies and presents a sequence of projects performed by our group to study adaptive navigation support in different contexts.

2. Adaptive Navigation Support in pre-Web Hypermedia

The research on adaptive navigation support in hypermedia can be traced back to the early 1990's. At that time, several research teams had recognized the problems of static hypertext in different application areas, and had begun to explore various ways to adapt the behavior of hypertext and hypermedia systems to individual users. A number of teams addressed the problems related to navigation in hypermedia such as the problem of inefficient navigation or the problem of being lost that had been discovered when the field of hypertext reached relative maturity at the end of the 1980's (Hammond, 1989). Within a few years, a number of navigation support technologies were proposed (Böcker, Hohl & Schwab, 1990; Brusilovsky, Pesin & Zyryanov, 1993; de La Passardiere & Dufresne, 1992; Kaplan, Fenwick & Chen, 1993). While the proposed technologies were relatively different, they shared the same core idea: adapt the presentation of links located on a hypertext page (hypernode) to the goals, knowledge, and preferences of the individual user. The adaptive navigation support technologies introduced by early adaptive hypermedia systems were later classified as *direct guidance*, *sorting*, *hiding*, and *annotation* (Brusilovsky, 1996).

Direct guidance is the simplest technology of adaptive navigation support. Direct guidance suggests the "next best" node for the user to visit according user's goals, knowledge, or/and other parameters represented in the user model. To provide direct guidance, an adaptive educational hypermedia system usually presents an additional dynamic link (usually called "next" or "teach me") which is connected to the "next best" node, as illustrated, in ISIS-Tutor (Brusilovsky & Pesin, 1994), SHIVA (Zeiliger, 1993), and HyperTutor (Pérez, Gutiérrez & Lopistéguy, 1995). Direct guidance is very often applied in adaptive educational hypermedia systems that have roots in Intelligent Tutoring. In this group of systems, direct guidance is nothing else but hypermedia access to traditional curriculum sequencing mechanisms (Brusilovsky, 1992). A problem with direct guidance is that it provides no support for the users who don't wish to follow the system's suggestions. Direct guidance is useful but it should be used in conjunction with one of the "more supportive" technologies that are listed below.

The idea of *adaptive sorting* technology is to order all the links of a particular page according to the user model and some user-valuable criteria: the closer to the top, the more relevant the link is. Adaptive sorting was introduced in two early systems - Hypadapter (Böcker et al., 1990) and HYPERFLEX (Kaplan et al., 1993), however, it has not become very popular because of its limited applicability. It can be used with non-contextual links, but it can rarely be used for indexes and content pages (which usually have a stable order of links), and can never be used with contextual links and maps. Another problem with adaptive ordering is that this technology makes the order of links non-stable: it may change each time the user enters the page. For both reasons this technology is presently most often used for showing new links to the user in conjunction with link generation. The study of the HYPERFLEX system (Kaplan et al., 1993) showed that adaptive sorting can significantly reduce navigation time in search-oriented hypermedia applications.

The purpose of navigation support by *hiding* is to restrict the navigation space by hiding, removing, or disabling links to irrelevant pages. A page can be considered irrelevant for several reasons: for example, if it is not related to the user's current learning goal or if it presents materials which the user is not yet prepared to understand. Hiding protects users from the complexity of the whole hyperspace and reduces their cognitive overload. Educational hypermedia systems were the main application area where adaptive hiding techniques were suggested and explored. Indeed, beginning with just a part of the whole picture then introducing other components step by step as the student progresses through the course is a popular educational approach and adaptive hiding offers a simple way to implement this. Early adaptive hypermedia systems used a very simple method of hiding links - essentially removing the link together with the anchor from a page. A good example can be provided by the ISIS-Tutor system (Brusilovsky & Pesin, 1998) which made more and more links in an educational hypermedia visible following the growth of the student's knowledge of the subject (Figure 1). De Bra and Calvi (1998) later called the ISIS-Tutor approach *link removal* and have suggested and implemented several other variants for link hiding. In particular, link hiding and disabling became more popular since they leave the anchor (hot word) intact and just disable or hide the link itself. A number of studies of link hiding demonstrated that this is a "unidirectional" technology. While gradual link enabling as used in ISIS-Tutor was acceptable and effective, the reverse approach was found questionable: users become very unhappy when previously available links become invisible or disabled.

Fig. 1: Adaptive navigation support in ISIS-Tutor. The picture above provides an example of link annotation: the green color annotates links to known information, the red color annotates links to ready-to-learn information, and the light blue color annotates links to not-ready information. The picture below presents the same page now featuring a combination of link annotation and hiding. Links to not-ready information (shown as blue on the picture above) are removed.

The idea of *adaptive annotation* technology is to augment the links with some form of annotation, which can tell the user more about the current state of the nodes behind the annotated links. These annotations are most often provided in the form of visual cues. For example, Manuel Excel (de La Passardiere & Dufresne, 1992) associated links with different icons, ISIS-Tutor (Brusilovsky & Pesin, 1994) changed the color of the links (Figures 1), and Hypadapter (Hohl, Böcker & Gunzenhäuser, 1996) altered font sizes. Annotation can be naturally used with all possible forms of links. This technology supports a stable order of links and avoids problems with incorrect mental maps. Annotation is generally a more powerful technology than hiding: hiding can distinguish only two states for the related nodes - relevant and non-relevant - while existing applications of annotation can distinguish up to six states. For all the above reasons, adaptive annotation later grew into the most often used adaptive annotation technology.

Several early works have explored the value of adaptive navigation support. In the first published study, de La Passardiere & Dufresne (1992) conducted experiments with MANUEL EXCEL, providing the first evidence in favor of adaptive navigation support. A year after that, Kaplan et al. (1993) reported two studies of adaptive navigation support with their system HYPERFLEX, demonstrating that sorting-based adaptive navigation support can improve user performance in information search tasks. Our own exploration of two adaptive navigation support technologies, hiding and annotation as they were implemented in ISIS-Tutor system also delivered encouraging results (Brusilovsky & Pesin, 1998). We have compared three versions of the ISIS-Tutor: a non-adaptive version, a version with adaptive annotation, and a version with both hiding and annotation. The results of our study have demonstrated that the same educational goal can be achieved in either of the adaptive version with much less navigational overhead. The overall number of navigation steps, the number of unforced repetitions of previously studied concepts, and the number of task repetitions (i.e., trials to solve a previously visited task) were significantly smaller for both adaptive versions.

3. Adaptive Navigation Support in Web-based Hypermedia

The Web as "hypermedia for everyone" immediately provided an attractive platform for adaptive hypermedia applications. The majority of work on Web-based adaptive hypermedia has focused on exploring the original adaptive hypermedia technologies, but in the Web context. The work on pre-Web adaptive hypermedia provided a good foundation for the new generation of research. As the Web developed, the focus of work has also moved from exploring isolated techniques using "lab-level" systems to developing and exploring "real world" systems for different application areas such as E-learning, E-commerce, virtual museums, etc.. A good review of this generation of adaptive hypermedia systems was provided in (Brusilovsky, 2001).

Our own experience with the ISIS-Tutor system helped us to develop ELM-ART (Brusilovsky, Schwarz & Weber, 1996), the first practical Web-based system that used adaptive navigation support. ELM-ART has integrated a number of innovative techniques in a versatile adaptive Web-based course for the programming language

LISP, which have been used by hundreds of students over several years. In particular, ELM-ART has pioneered the idea of an adaptive electronic textbook and introduced the traffic light metaphor for adaptive navigation support in educational hypermedia. With this metaphor, green bullet in front of a link indicates recommended readings, while a red bullet indicates that the student might not have enough knowledge to understand the information behind the link. Other colors like yellow or white indicate other educational states such as the lack of new knowledge behind the link. Figures 2 shows adaptive annotation in its most recent versions of ELM-ART (Weber & Brusilovsky, 2001). A study of ELM-ART has demonstrated that casual users stay longer within a system when adaptive navigation support is provided. It also provided evidence that direct guidance works best for users with little previous knowledge while adaptive annotation is most helpful for users with some reasonable subject knowledge.

InterBook system (Brusilovsky & Pesin, 1998), a direct descendant of ELM-ART provided the first authoring platform for Web-based adaptive hypermedia. InterBook has refined the ideas of the adaptive electronic textbook and the traffic light metaphor for adaptive navigation support in educational hypermedia (Figure 3). Propagated by ELM-ART and InterBook, this metaphor has later been used in numerous adaptive educational hypermedia systems, including AST (Specht et al., 1997), KBS-HyperBook (Henze & Nejdl, 2001), and SIGUE (Carmona et al., 2002). A study of InterBook has shown that adaptive navigation support encourages non-sequential navigation and helps users who follow the system's guidance to achieve a better level of knowledge.

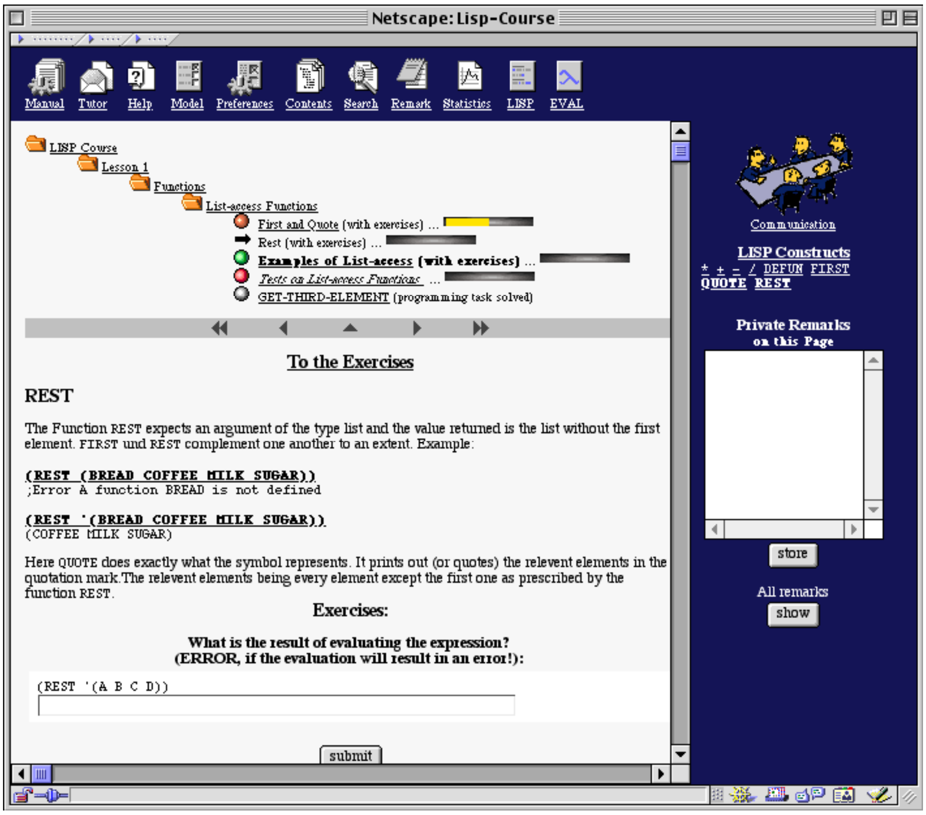

Fig. 2: Adaptive navigation support in ELM-ART. Adaptive annotation is provided in the form of colored bullets following the traffic light metaphor.

ELM-ART and InterBook have also explored a relatively new adaptive navigation support technology known as *link generation*. This technology became very popular in Web hypermedia with its abundance of resources. Unlike classic annotation, sorting or hiding technologies that adapt the presentation of pre-authored links, link generation creates new, non-authored links on a page. There are three known kinds of link generation: discovering new useful links between documents and adding them permanently to the set of existing links; generating links for similarity-based navigation between items; and dynamic recommendation of relevant links. The first two kinds of link generation are typically non-adaptive, though ELM-ART did explore an opportunity to use an episodic student model to generate adaptive links for similarity-based navigation. The third technology is naturally adaptive. It became immensely popular in the field of adaptive Web-based systems through the use of so-called Web recommender systems (Resnick & Varian, 1997). InterBook was among the first systems to have implemented adaptive link generation. It has also demonstrated that link generation can be naturally used in combination with link sorting and annotation.

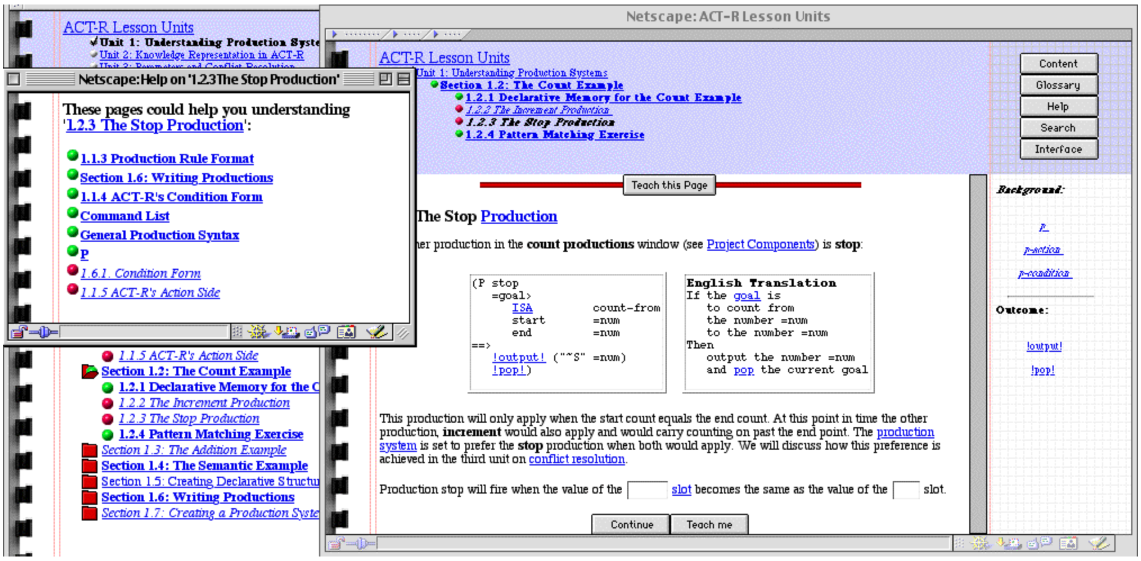

Fig: 3: Adaptive navigation support in InterBook. The system features several kinds of adaptive annotations. In addition, the help recommendation window (left) uses link generation and sorting.

4. From Adaptive Hypermedia to the Adaptive Web

Web-based adaptive hypermedia systems have demonstrated the power of adaptive navigation support in a number of application areas. Yet, they have failed so far to make adaptive navigation support widely available. The problem is that current adaptive navigation support technologies are only applicable within a relatively small set of documents that were structured and enhanced by metadata annotations at design time. Modern AH systems are predominantly *closed corpus* adaptive hypermedia since the *document space* of these adaptive systems is a closed set of information items manually indexed by domain experts. None of the classic adaptive hypermedia systems are applicable in *open corpus* (such as the Web). Closed corpus AH systems demonstrate what is possible to achieve with adaptive hypermedia, but they are impractical for most real world applications. No one is able to invest enough time to structure and index thousands of documents collected from all over the Web so that the result satisfies the requirements of modern adaptive hypermedia systems.

So far, the only adaptive systems that have achieved relative success in working with the open corpus Web are adaptive Web recommendation systems (AWR). Similar to AH, AWR systems support the user in the process of browsing a collection of information resources and use as the source of personalization the observed user activity: link selection, explicit document ratings and various actions indicating implicit interests (Claypool et al., 2001). Unlike AH, AWR employs different kinds of personalization mechanisms that work with open corpus documents: content-based filtering and collaborative filtering (Hanani, Shapira & Shoval, 2001). Content-based filtering relies on word-level document representation and user profiles inherited from information retrieval research and usually employs some machine learning technologies. Collaborative filtering is a social navigation technology (Dieberger et al., 2000) and relies on recorded information about past usage of the same set of documents by multiple users. It applies various profile matching algorithms to match users with similar interests.

There is, however, another important difference between AH and AWR systems that is critical in the context of adaptive navigation support. AH systems attempt to adapt to various “aspects” of the user (goals, knowledge, interests, browsing history) and apply a rich set of adaptive navigation support techniques to express several aspects important to the users at the same time (such as goal relevance, novelty, readiness, etc.). AWR focus their adaptation on one aspect that can be loosely classified as “user interest”. The personalization power of AWR is delivered through a less expressive one-dimensional form: a list of recommended links ordered by their perceived interest. Thus, despite their ability to handle open corpus documents, AWR are far from offering Web users the full power of adaptive navigation support as it is offered by classic AH systems.

We think that the current challenge is to develop adaptive navigation support technologies that can work with open corpus documents, i.e., the real Web. The existing technologies that are based on knowledge about documents will be quite useful in the future generation "semantic" Web. However, the best candidates to fuel adaptive navigation support for the current Web are the technologies used in AWR: information retrieval technologies treating a page as a "bag of words" and social navigation technologies rating documents by assembling the "collective wisdom" of their users.

We are investigating the feasibility of using content-based and social technologies for open corpus adaptive navigation support in a more recent project called Knowledge Sea. The first version of the Knowledge Sea system has focused on using content-based IR technologies (Self-Organized Maps) to develop a browseable hyperspace from a set of relatively independent open corpus items and to provide map-based horizontal navigation between open and closed corpus items (Brusilovsky & Rizzo, 2002a). The system was used in a practical context: to provide access to several online tutorials on the C language, as part of a programming course. Knowledge Sea has been evaluated in several user studies (Brusilovsky & Rizzo, 2002b). Students highly rated the system ability to help in selecting relevant open corpus sources, yet most of them have agreed that additional navigation support would be very useful. The Knowledge See II system (Brusilovsky & Chavan, 2003) coupled with AnnotatED social navigation system explored some simple forms of social navigation based on group user modeling and the idea of "footprints" (Wexelblat & Mayes, 1997). It uses the simplest implicit feedback: for each tutorial page it counts how many times it was accessed by a group of users. This amount of traffic is visualized as a color density that students observe during navigation. Each resource is annotated by a blue human-shaped icon on a blue background (right on Figure 4). The deeper the shade of blue the more times the page was accessed. The color of the icon shows the user's own navigation history, while the color of the background shows the cumulative navigation history of the group the user belongs to (i.e., a class). The color difference between the icon and the background visualizes the discrepancy between user and class navigation patterns. Light figure on a dark background indicates pages that the user accessed less frequently than the average person in his or her group and suggests that these pages deserve attention. A dark figure on a light background indicates a page that the user has accessed more than the group's average. The same approach is used to annotate horizontal links between pages (i.e., links provided by an author of a particular tutorial. Similarly, the icon/background colors for a knowledge map cell (left on Figure 4) shows total user/class navigation for all pages belonging to the cell.

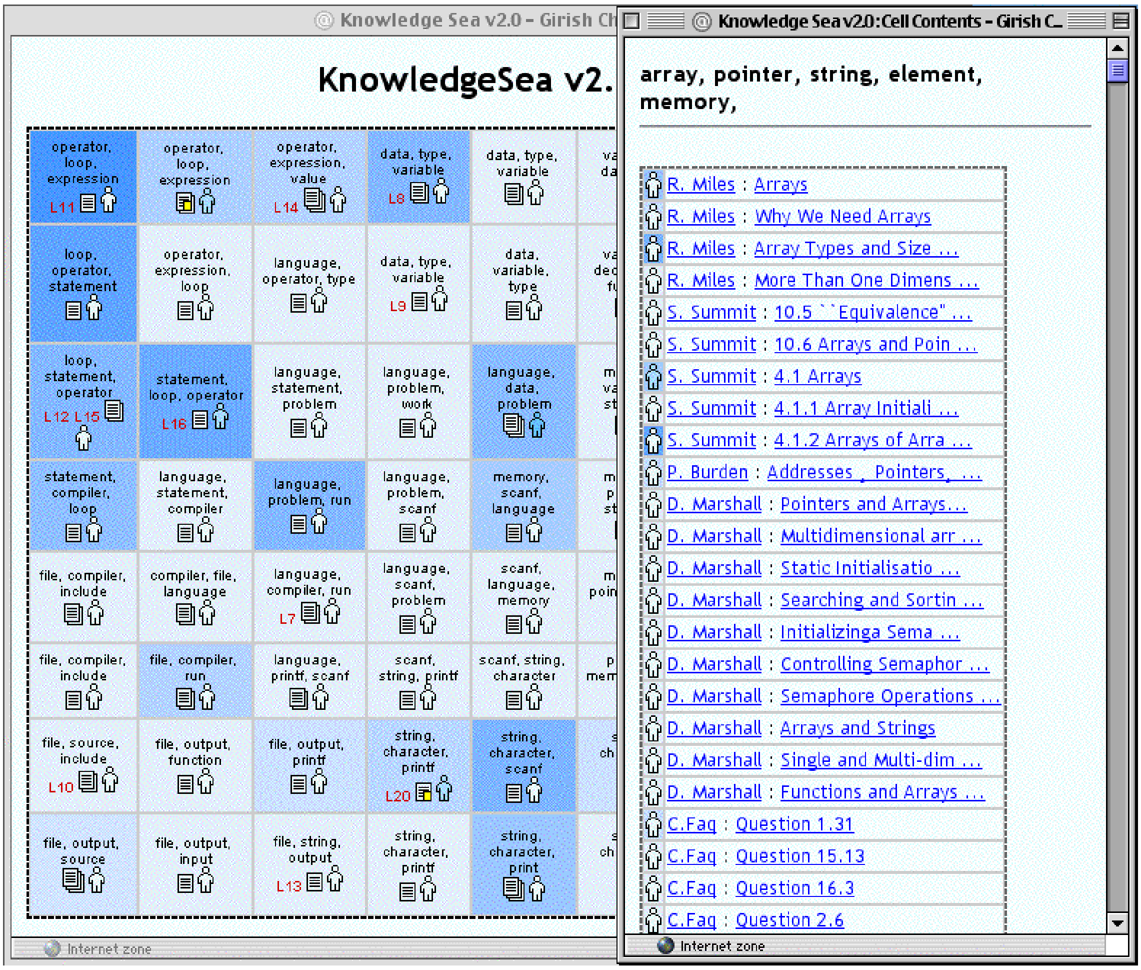

Fig. 4. The interface of Knowledge Sea II systems showing simple social adaptive navigation support.

We have just completed the first classroom formative evaluation of Knowledge Sea II, which brought some interesting results. On one hand, students have appreciated annotation-based SANS: 86% of students considered the visualization of group traffic as useful (in contrast, only 57% considered the visualization of their personal traffic as useful). On the other hand, a number of students realized that simple footprint-style social adaptive navigation support provides insufficient support in context of their needs. In their free-form answers they indicated their interest in seeing some measure of resource quality: ("resources regarded as helpful by classmates", links "rated at a level of importance"), and the relevance of resources to their course needs ("links could be marked as to which lesson they pertain to"). We plan to address these concerns in future work.

5. Adaptive Navigation Support beyond Web-based Hypermedia

Web-based adaptive hypermedia systems have demonstrated their ability to help individual users of hypermedia systems. However, a hyperspace of connected pages - that is the context of existing AH technologies - is no more the only kind of "virtual spaces" that is available for Web users. With advances in delivering complex graphics through the web, virtual reality provides Web users an access to different type of virtual spaces for browsing and exploration. The hyperspace and the 3D virtual environments (VE) are quite different in the nature of their area of applicability, yet there is a striking similarity. Both kinds of cyberspace are targeted for user-driven navigation and exploration. In both kinds of spaces, users can benefit from a personalized support provided by an adaptive intelligent system. We believe that starting from adaptive hypermedia and exploring similarities between hypermedia and 3D virtual environments, it is possible to develop interesting support technologies for 3D virtual environments.

A few known attempts to explore the power of adaptive presentation in the VE context deal with dynamic construction of virtual worlds (Chittaro & Ranon, 2000; Chittaro & Ranon, 2002). Our recent work focuses on adaptive navigation support for VE (Hughes, Brusilovsky & Lewis, 2002). Similar to the case of hypermedia, an adaptive virtual environment can help the user to work more efficiently and avoid common problems such as navigation in the wrong direction, overlooking an important part of the space, and being lost. Our main goal is to develop and evaluate a set of adaptive navigation support techniques for VE by drawing parallels between hypermedia and VE. We are confident that many of the techniques that are employed for adaptive navigation support in hypermedia systems can be extended to 3D visualizations. The paper (Hughes et al., 2002) presents our first attempt to suggest several adaptive navigation support technologies for VE that have clear analogs in hypermedia (i.e., direct guidance, adaptive annotation, etc). Since the original publication, most of the suggested techniques were implemented. Similar techniques have been also implemented by some other teams (Chittaro, Ranon & Ieronutti, 2003). The evaluation data that has been obtained so far delivers some solid evidence in favor of adaptive navigation support in VE. We think that this direction of work will become more important as VE becomes more widely available on the Web and we intend to continue work in this direction.

Fig. 5: Different kinds of adaptive navigation support in Virtual Environments - from direct guidance to annotation. To watch videos, go to www.psychnology.org/article501.htm.

6. Summary

Adaptive navigation support in "virtual spaces" is one of the major research topics of our group. We have explored adaptive navigation support technologies in different contexts from classic adaptive hypermedia to the adaptive Web to virtual environments. We have applied it in different domains from education (Brusilovsky, Eklund & Schwarz, 1998) to avionics performance support (Brusilovsky & Cooper, 2002). We have also investigated the use of different mechanisms to "fuel" the adaptive navigation support - from knowledge-based mechanisms of classic adaptive hypermedia to content-based and social navigation mechanisms of the adaptive Web. Currently, an important focus of our work is to extend the applicability of adaptive navigation support beyond classic adaptive hypermedia. Our work on adaptive navigation support for open corpus Web hypermedia and virtual environments represents our most recent efforts in this direction. By extending the borders of adaptive navigation support we hope to better understand this technology and to allow more users to benefit from it.

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