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Adaptive Hypermedia

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Abstract. Adaptive hypermedia is a relatively new direction of research on the crossroads of hypermedia and user modeling. Adaptive hypermedia systems build a model of the goals, preferences and knowledge of each individual user, and use this model throughout the interaction with the user, in order to adapt to the needs of that user. The goal of this paper is to present the state of the art in adaptive hypermedia at the eve of the year 2000, and to highlight some prospects for the future. This paper attempts to serve both the newcomers and the experts in the area of adaptive hypermedia by building on an earlier comprehensive review (Brusilovsky, 1996; Brusilovsky, 1998).

Key words: hypertext, hypermedia, user model, user profile, adaptive presentation, adaptive navigation support, Web-based systems, adaptation

1. Introduction

Adaptive hypermedia is a relatively new direction of research on the crossroads of hypermedia and user modeling. One limitation of traditional ''static'' hypermedia applications is that they provide the same page content and the same set of links to all users. If the user population is relatively diverse, a traditional system will suffer from an inability to be ''all things to all people''. For example, a traditional educational hypermedia system will present the same static explanation and suggest the same next page to students with widely differing educational goals and knowledge of the subject. Similarly, a static electronic encyclopedia will present the same information and same set of links to related articles to readers with different knowledge and interests. A Web bookstore might also offer the same selection of ''bestsellers'' to customers with different reading preferences. Finally, a static virtual museum will offer the same ''guided tour'' and the same narration to visitors with very different goals and background knowledge.

Adaptive hypermedia is an alternative to the traditional ''one-size-fits-all'' approach in the development of hypermedia systems. Adaptive hypermedia systems build a model of the goals, preferences and knowledge of each individual user, and use this model throughout the interaction with the user, in order to adapt to the needs of that user. For example, a student in an adaptive educational hypermedia system will be given a presentation that is adapted specifically to his or her knowledge of the subject (De Bra and Calvi, 1998), and a suggested set of most relevant links to proceed further (Brusilovsky et al. 1998a). An adaptive electronic encyclopedia will personalize the content of an article to augment the user's existing knowledge and interests (Milosavljevic, 1997). A virtual museum will adapt the presentation of every visited object to the user's individual path through the museum (Oberlander et al., 1998). These are just a few recent examples of the use of adaptive hypermedia.

2. Adaptive Hypermedia Research Before and After 1996

Adaptive Hypermedia research can be traced back to the early 1990s. At that time, the two main parent areas – Hypertext and User Modeling – had achieved a level of maturity that allowed for the cross-fertilization of research ideas. A number of research teams had recognized the problems of static hypertext in different application areas, and had begun to explore various ways to adapt the output and behavior of hypertext systems to individual users (Böcker et al. 1990; Brusilovsky et al. 1993; de La Passardiere and Dufresne, 1992; Fischer et al., 1990; Kaplan et al. 1993). The first research efforts were independent and the early researchers were generally not aware about each other's work. The support from the already established user modeling research community was influential in helping the existing research teams to find each other, and in recognizing and promoting adaptive hypermedia as an independent research direction in user modeling. For example, several early papers on adaptive hypermedia were also published in the User Modeling and User-Adapted Interaction (UMUAI) journal; the first workshop on Adaptive Hypermedia was held during a User Modeling conference (Brusilovsky and Beaumont, 1994); and, finally, a special issue of UMUAI on adaptive hypermedia was published in 1996. By that time, several innovative adaptive hypermedia techniques had been developed, and several research-level adaptive hypermedia systems had been built and evaluated. For more information, the reader is referred to the review of adaptive hypermedia systems, methods and techniques at that time (Brusilovsky, 1996).

The year of 1996 can be considered a turning point in adaptive hypermedia research. Before this time, research in this area was performed by a few isolated teams. However, since 1996, adaptive hypermedia has gone through a period of rapid growth. In particular, several new research teams have commenced projects in adaptive hypermedia, and many students have selected adaptive hypermedia as the subject area for their PhD theses. In addition, several workshops directly or indirectly related to adaptive hypermedia were held (Brusilovsky and De Bra, 1998, 1999; Brusilovsky et al., 1997a; Milosavljevic et al., 1997). Finally, a book on adaptive hypermedia (Brusilovsky et al., 1998b), and a special issue of the New Review of Hypermedia and Multimedia (1998) were published. There are two main factors that might account for this growth of research activity, and a careful reader who has a chance to compare a reasonable number of adaptive hypermedia papers published before and after 1996 (for example, the two special issues mentioned above) might be able to identify them. The first factor is the rapid increase in the use of the World Wide Web. The Web, with its clear demand for adaptivity due to its widely diverse audience served to boost adaptive hypermedia research, providing both a challenge and an attractive platform. Almost all the papers published before 1996 describe classic pre-Web hypertext and hypermedia. In contrast, the majority of papers published since 1996 are devoted to Web-based adaptive hypermedia systems. The second factor is the accumulation and consolidation of research experience in the field. It is clearly visible that research in adaptive hypermedia performed and reported up to 1996 has provided a good foundation for the new generation of research. As we noted above, early researchers were generally not aware about each other's work. The early papers provided no (or almost no) references to similar work in adaptive hypermedia, and described original methods and techniques. Almost all the systems developed by 1996 were laboratory systems developed to demonstrate and explore innovative ideas. In contrast, many papers published since 1996 are clearly based on earlier research. These papers cite earlier work, and usually suggest an elaboration or an extension of techniques suggested earlier. In addition, a large number of systems developed since 1996 are either real world systems, or research systems developed for real world settings. This is indicative of the relative maturity of adaptive hypermedia as a research direction.

The goal of this paper is to present the state of the art in adaptive hypermedia at the eve of the year 2000, and to highlight some prospects for the future. This paper is not intended to be a review of adaptive hypermedia research performed up to this point. Instead, it builds on our earlier comprehensive review (Brusilovsky, 1996, 1998), and provides an 'add-on' contribution that can be "best" (but not necessarily) viewed together with this review (referred in this paper as *the review*). The next section is structured similarly to the review and presents a brief classification of adaptive hypermedia systems, methods, and techniques. In very few occasions we provide references to earlier systems that were cited in the review (we indicate these systems by giving their names in *italics*). Instead, we cite the papers that present various extensions in the context of the original review framework. The following section provides a review of several important new trends in the area of adaptive hypermedia. The final section attempts to predict the most important research directions within adaptive hypermedia for the next 10 years.

3. Adaptive Hypermedia: Systems, Methods, and Techniques

3.1. Where it can be used?

The review identified six kinds of adaptive hypermedia systems in 1996 – *educational hypermedia, on-line information systems, on-line help systems, information retrieval hypermedia, institutional hypermedia, and systems for managing personalized views in information spaces*. The first two of these areas were most popular, the second two were reasonably populated being represented by 5–6 systems each and the last two were least investigated being represented by 1–2 pioneer systems each. Since 1996 these areas have been expanding at different paces.

Educational hypermedia and on-line information systems are now established leaders. Together, they account for about two thirds of the research efforts in adaptive hypermedia. Information retrieval (IR) hypermedia is challenging the leaders. The traditional scope of IR hypermedia was extended and now includes also systems for managing personalized views. We will consider these three application areas below. On-line help systems and institutional hypermedia systems have received almost no attention from adaptive hypermedia researchers in the last few years. Apart from an extended version of *ORIMUHS* (Encarnação and Stoev, 1999) we can cite no new interesting systems. One possible reason is that these kinds of systems are still in the process of transition from standalone hypermedia to Web-based hypermedia: standalone versions of these systems are not challenging adaptive hypermedia researchers anymore and Web-versions are not yet matured.

3.1.1. *Educational Hypermedia*

Many interesting adaptive educational hypermedia systems have been developed and reported since 1996. An interest to provide distance education over the Web has been a strong driving force behind these research efforts. The introduction of the Web has impacted both the number and the type of systems being developed. All the early systems were essentially lab systems, built to explore some new methods that used adaptivity in an educational context. In contrast, several more recent systems provide complete frameworks and even authoring tools for developing Web-based courses (Table 1). The appearance of a number of authoring tools indicates the maturity of adaptive educational hypermedia and a response to a Web-provoked demand for user-adaptive distance education courses.

The choice of Web as a development platform has become a standard. This choice has granted long life to a few Web-based adaptive educational hypermedia systems developed before 1996 such as *ELM-ART* (Brusilovsky et al., 1996a), *InterBook* (Brusilovsky et al., 1996b) and 2L670 (De Bra, 1996). These systems have been significantly updated since 1996, extended with a number of new techniques, and used for several experimental studies (Brusilovsky et al., 1998a; De Bra and Calvi, 1998; Weber and Specht, 1997). It is not surprising that nearly all adaptive educational hypermedia systems developed since 1996 are Web-based systems (Table 1).

3.1.2. *On-line Information Systems*

On-line information systems no longer form a homogeneous group of systems, and need to be divided into subgroups. Along with the "classic" online information systems described in the review, this group now includes a number of specialized systems such as electronic encyclopedias, information kiosks, virtual museums, handheld guides, e-commerce systems, and performance support systems (Table 2).

Table 1: *Adaptive Hypermedia systems in education (after 1996)*

New methods	ELM-ART (Weber and Specht, 1997), Medtec (Eliot et al., 1997), AST (Specht et al., 1997), ADI (Schöch et al., 1998), Hy-SOM: (Kayama and Okamoto, 1999), AHM (Pilar da Silva et al., 1998), CHEOPS (Negro et al., 1998), RATH (Hockemeyer et al., 1998), TANGOW (Carro et al., 1999), Arthur (Gilbert and Han, 1999), PAKMAS (Süß et al., 1999), CAMELEON (Laroussi and Benahmed, 1998)
New frameworks	*InterBook* (Brusilovsky et al., 1998a), KBS-Hyperbook (Henze et al., 1999), AHA! (De Bra and Calvi, 1998), SKILL (Neumann and Zirvas, 1998), Multibook (Steinacker et al., 1998), ACE (Specht and Oppermann, 1998), ART-Web (Weber, 1999), MetaLinks (Murray et al., 1998)

As expected, specialization provides some performance improvement. These specialized systems can take into account a specific type of user activity in a particular application area and provide better adaptivity and special kinds of adaptive behavior.

Electronic encyclopedias and information kiosks remain very close to our definition of classic on-line information systems, however, they benefit by providing some specialized enhancements that are not possible in generic systems. For example, an encyclopedia can trace user knowledge about different objects (for example, animals) described in the encyclopedia and provide adaptive comparisons (Milosavljevic, 1997). Or it can trace user browsing, deduce his or her interest and offer lists of most relevant articles (Hirashima et al., 1998).

Virtual museums and handheld guides retain some similarity with traditional information systems and have the same structured hyperspace of objects in their core. The unique feature of these systems is the ability to provide adaptive guided tours in this hyperspace, and to support the user's exploration of a virtual or real museum with context-adapted narration. In addition, handheld museum guides may have the ability to determine the user's location and behavior in the physical museum space (HYPERAUDIO and HIPS). Such handheld guides can trace and support user navigation both in the physical museum space, and in a virtual hyperspace. This results in a completely different type of adaptive hypermedia system, and allows

Table 2: *Adaptive hypermedia systems for serving on-line information (after 1996)*

Classic on-line information systems	SWAN (Garlatti et al., 1999), Ecran Total (Geldof, 1998), ELFI (Schwab et al., 2000)
Electronic encyclopedias	PEBA-II (Milosavljevic, 1997; Hirashima et al., 1998; Signore et al., 1997)
Information kiosks	AVANTI (Fink et al., 1998)
Virtual museums	ILEX (Oberlander et al., 1998), Power (Milosavljevic et al., 1998), Marble Museum (Paterno and Mancini, 1999), SAGRES (Bertoletti and da Rocha Costa, 1999)
Handheld guides	HYPERAUDIO (Not et al., 1998), HIPS (Oppermann and Specht, 1999)
E-commerce systems	SETA (Ardissono and Goy, 1999), TELLIM (Joerding, 1999; Milosavljevic and Oberlander, 1998)
Performance support systems	ADAPTS (Brusilovsky and Cooper, 1999), MMA (Francisco-Revilla and Shipman III, 2000; de Carolis et al., 1998)

for several specific user modeling and adaptation technologies. For example, walking away from an object in the middle of an audio narration can be considered to be a sign of low interest in that object. In addition, walking near an object that could be of interest to the user can trigger a relevant narration.

E-commerce systems and performance support systems have diverged quite far from classic on-line information systems and should be classified as two new kinds of adaptive hypermedia systems. While a hyperspace of information items still constitutes a major part of these systems, browsing of the hyperspace is not a major activity, but is a byproduct of the major activity (such as performing a particular job or shopping for goods). In fact, the better these systems work, the less browsing should be required. Adaptive performance support systems are particularly interesting here. Such systems can be seen as a combination of domain expert systems and domain information systems. In this way, they combine human and machine intelligence in solving particular problems such as providing medical treatment or technical repair. Since these systems support the user's *doing*, they have information about the context of the user's work and the structure of the user's goals. This results in a higher level of precision in user modeling, and in a superior level of adaptation which, in the past, had only been possible in educational hypermedia and on-line help systems.

3.1.3. *Hypermedia for Information Retrieval*

The Web has significantly influenced information retrieval (IR) hypermedia. All the new interesting systems have been inspired by the Web and implemented for the Web. The most challenging problem in this class of systems has been to support the user's retrieval activity in an unrestricted Web hyperspace. While a few interesting systems such as SmartGuide (Gates et al., 1998), SiteIF (Stefani and Strapparava, 1999; Hirashima and Nomoto, 1999), *WebWatcher* (Joachims et al., 1997) were developed for "classic" closed corpus settings (in the Web context this usually means a single Web site), the majority attempts to handle "the whole Web". From the large number of adaptive IR hypermedia systems developed to date, we can distinguish two large groups – search-oriented systems and browsing-oriented systems – and a few subgroups within each group (Table 3).

The goal of *search-oriented systems* is to create a list of links to documents that satisfy the user's current information request. Unlike simple "one-shot" search engines, adaptive IR systems take into account not only the set of words specifying the current request, but also a long-term or/and short-term model of users' interests and preferences. We distinguish two kinds of search-oriented systems (Table 3). *Classic IR systems* deal with a closed corpus infospace. The tight connection of this kind of system to classic pre-Web IR allows for the development of the first practical Web adaptive IR hypermedia systems such as SmartGuide (Gates et al., 1998). *Search filters* attempt to work with an unrestricted Web. They extend the power of existing "one-shot" Web search engines by applying different model-based adaptive navigation support (ANS) approaches such as link removal (Marinilli et al., 1999) and link annotation (Pazzani et al., 1996) to the result of the search, in order to help the user to select the most relevant links for further exploration.

Browsing oriented systems support their users in the process of search-driven browsing. As in other types of adaptive hypermedia systems this is done through standard adaptive navigation support technologies. Adaptive guidance systems mark one or more links on the current page that are most relevant to the user's goal. Adaptive annotation systems attach various visual cues to the links on the current page in order to help the user select the most relevant one. Adaptive recommendation systems attempt to deduce the user's goals and interests from his or her browsing activity, and build a list of suggested links to nodes that usually can not be reached directly from the current page, but are most relevant to that user.

An important distinction exists between adaptive recommenders working in a closed corpus infospace and those working with the unrestricted Web. Recommenders working in a closed corpus infospace can build an exhaustive list of links to the most relevant nodes. Recommenders working in a in an open corpus hyperspace suggest relevant links by turning some meaningful area of the full hyperspace into a closed corpus hyperspace and learning about the structure and content of the nodes in that area. At present we can identify two ways to "close" an open corpus hyperspace. In single user systems it usually involves the analysis

Table 3: *Adaptive hypermedia systems related to IR problems (after 1996)*

Search-oriented adaptive IR hypermedia systems	
Classic IR in Web context	SmartGuide (Gates et al., 1998)
Search Filters	Syskill and Webert (Pazzani et al., 1996; Marinilli et al., 1999)
Browsing-oriented adaptive IR hypermedia systems	
Adaptive Guidance	*WebWatcher* (Joahims et al., 1997), Personal WebWatcher (Mladenic, 1996)
Adaptive Annotation	Syskill and Webert (Pazzani et al., 1996), IfWeb (Asnicar and Tasso, 1997)
Adaptive Recommendation/Closed Corpus	SiteIF (Stefani and Strapparava, 1999), (Hirashima et al., 1998; Hirashima and Nomoto, 1999)
Adaptive Recommendation/Open Corpus	SurfLen (Fu et al., 2000), Letizia (Lieberman, 1995), IfWeb (Asnicar and Tasso, 1997)
Systems for managing personalized views	
Adaptive Bookmark Systems	WebTagger (Keller et al., 1997), PowerBookmarks (Li et al., 1999), Siteseer (Rucker and Polano, 1997)
Information services	
Search Services	FAB (Balabanovic and Shoham, 1997), PEA (Montebello et al., 1997), Edited AH (Höök et al., 1997; Newell, 1997)
Filtering Services	ELFI (Schwab et al., 2000), AIS (Billsus et al., 2000)

of a small portion of the Web a few steps ahead of the user's current browsing point; from this, the system can recommend the most relevant links to the user from the selected area (Asnicar and Tasso, 1997; Lieberman, 1995). In multi-user systems it may also involve the collection of browsing data from a community of users, which is then analyzed in order to learn something about the documents covered in the area (Fu et al., 2000).

In the review, we suggested a category of *systems that manage personalized views of information spaces*. These systems belong to the IR universe and can be considered complementary to classic IR hypermedia systems. While IR systems help the user to locate relevant information nodes, personal view management systems aim to organize this information in some way. In the context of the Web, we can name at least two common mechanisms for managing personalized views: personalized site views such as MyYahoo (http://my.yahoo.com/) or MyNetscape (http://my.netscape.com/), and bookmark organizers. While the majority of personalized sites and bookmark organizers are adaptable but not adaptive, we can already distinguish a small group of adaptive bookmaking systems such as WebTagger (Keller et al., 1997), PowerBookmarks (Li et al., 1999), and Siteseer (Rucker and Polano, 1997).

While different kinds of IR hypermedia systems listed perform different functions, the internal adaptive "engines" of all Web systems related to information retrieval are reasonably similar. It is not surprising that the same engine can support functions that are specific for different kinds of systems. For example, Syskill and Webert system (Pazzani et al., 1996) provides both annotation-based navigation support and search filtering. IfWeb (Asnicar and Tasso, 1997) provides annotation based navigation support and adaptive recommendation.

The possibilities to use the same adaptive engines to provide different kinds of user support in an IR context can be demonstrated by Web-based *information services*, a new class of IR hypermedia systems. An information service works by collecting a common pool of documents (URLs) from an open corpus hyperspace over a long period of time. Unlike the early prototypes of information services (such as *Basar* mentioned in the review), modern services work with a community of users, and have the opportunity to learn about both the pool of users and the pool of documents. In doing so, they can provide several types of support to their users, by applying both content-based and clique-based (collaborative) technologies. Information services are typically built using agent-based technology. User-supporting agents observe the actions of users, and provide an adaptive suggestion according to their short-term information need and long-term model of interests. The set of links can be collected by two different ways. *Filtering services* work with an existing stream of incoming documents such as news articles in AIS (Billsus et al., 2000) or funding announcements in ELFI (Schwab et al., 2000). *Search services* employ artificial agents (as in Fab and *Basar*) or human agents (as in Edited AH and PEA) that are aware of user interests, in order to perform an active search of new documents on the Web. Information services have the potential to provide all the known types of IR hypermedia services from search on one side, to managing personalized views on another side. Moreover, an information service can perform functions similar to a generic on-line information system within its closed corpus pool of documents, as illustrated by ELFI.

3.2. ADAPTING TO WHAT?

Traditionally adaptation decision in adaptive systems was based on taking into accounts various characteristics of their users represented in the user model. That was true for pre-1996 adaptive hypermedia systems and the section "Adapting to what" of the review was dealing exclusively with user characteristics. Currently the situation is different. A number of adaptive Web based systems are able to adapt to something else than user characteristics. Kobsa et al. (1999) suggest to distinguish adaptation to user data, usage data, and environment data. User data comprise the traditional adaptation target, various characteristics of the users. Usage data comprise data about user interaction with the systems that can not be resolved to user characteristics (but still can be used to make adaptation decisions). Environment data comprise all aspects of the user environment that are not related to the users themselves. We will discuss briefly two of these categories.

3.2.1. *User Characteristics*

The review discussed the following user features that were used by adaptive hypermedia systems built up until 1996: user's goals/tasks, knowledge, background, hyperspace experience, and preferences. Since 1996, goals/tasks, knowledge, background, and preferences were modeled and used for making adaptation decisions by many new systems. We cannot identify any new cases of modeling and adapting to the user's hyperspace experience, even though this feature is easy to model and meaningful to use. At the same time, we can add at least two more items to this list: the user's interests and individual traits.

User interests is not a new feature of the user to be modeled – in fact, it is the second oldest after user knowledge – but it was not used in early adaptive hypermedia systems. This situation has changed dramatically with the rise of Web IR hypermedia systems that attempt to model the user's long-term interests, and use these in parallel with the user's short-term search goal in order to improve the information filtering and recommendations. Web IR systems including adaptive bookmarking systems account for the majority of cases of applying user interests, but this feature is also becoming popular in various online information systems such as kiosks (Fink et al., 1998), encyclopaedias (Hirashima et al., 1998), and museum guides (Not et al., 1998). In these systems, the user's interests serve as a basis for recommending relevant hypernodes.

User's individual traits is a group name for user features that together define a user as an individual. Examples are personality factors (e.g. introvert/extravert), cognitive factors, and learning styles. Like user background, individual traits are stable features of a user that either cannot be changed at all, or can be changed only over a long period of time. Unlike user background however, individual traits are traditionally extracted not by a simple interview, but by specially designed psychological tests. While adaptive hypermedia researchers have begun exploring the use of individual traits for adaptation in several areas, it cannot be described as a success story at present. Many researchers agree on the importance of modeling and using individual traits, but there is little agreement on which features can and should be used, or how to use them. One illustrative example here is the work on adapting to the individual's learning style in educational hypermedia. Several systems that attempt to adapt to learning style (Carver et al., 1996; Danielson, 1997; Gilbert and Han, 1999; Specht and Oppermann, 1998) have been developed, however it still isn't clear which aspects of learning style are worth modeling, and what can be done differently for users with different styles. Moreover, several experimental studies (which have aimed to evaluate the value of treating users with different individual traits differently) have concluded without finding any significant differences. To progress in this area, we either need to learn more about the relationships between user traits and possible interface settings, or treat user traits as a black box and attempt to model them and adapt to them using non-symbolic technologies (Gilbert and Han, 1999).

3.2.2. *Environment*

Adaptation to user's environment is a new kind of adaptation that was brought by Web-based systems. Since users of the same server-side Web application can reside virtually everywhere and use different equipment adaptation to user's environment has become an important issue. A number of current adaptive hypermedia systems suggested some techniques to adapt to both the user location and the user platform. Simple adaptation to the platform (hardware, software, network bandwidth) usually involves selecting the type of material and media (i.e. still picture vs. movie) to present the content (Joerding, 1999). More advanced technologies can provide considerably different interface to the users with different platforms and even use platform limitation to the benefits of user modeling. For example, a Palm Pilot version of AIS (Billsus et al., 2000) requires the user to explicitly request the following pages of a news story – thus sending a message to a system that the story is of interest. This direction of adaptation will certainly remain important and will likely provoke new interesting techniques. Adaptation to the user location may be successfully used by many on-line information systems. SWAN (Garlatti et al., 1999) demonstrates a successful use of user location for information filtering in a marine information system. The most interesting type of application to explore this side of adaptation is handheld guides. The current research in this area shows a number of interesting adaptation techniques that take into account user location, direction of sight and movements (Not et al., 1998; Oppermann and Specht, 1999).

3.3. WHAT CAN BE ADAPTED?

The review suggested a classification of adaptive hypermedia methods and techniques by the type of adaptation provided. We distinguished two distinct areas of adaptation: content level adaptation or *adaptive presentation* and link level adaptation or *adaptive navigation support*. Adaptive presentation was subdivided into text adaptation and multimedia adaptation technologies; adaptive navigation support was subdivided into link hiding, sorting, annotation, direct guidance, and hypertext map adaptation. This simple taxonomy allowed us to classify several methods and techniques present in 1996 and described in the review. We do not have sufficient space here to describe the whole taxonomy in detail, so we will concentrate on the changes that are required of the original taxonomy in order to accommodate the new methods and techniques suggested and explored since 1996. From this point of view, new methods and techniques can be divided into three groups. The first and the largest group can be considered as variations of methods and techniques reported earlier, and can thus be easily classified using the old taxonomy. The second group requires relatively small extensions of the taxonomy. The third group demands more considerable changes. Here we will discuss the last two groups in more detail.

Small extensions of the taxonomy require addition of new technologies on the terminal level of existing taxonomy. For example, De Bra and Calvi (1998) have suggested and implemented several different variants for what was known as link hiding: disabling, hiding, and removal. We believe that these should be classified as independent technologies within a more general "hiding" technology. Another innovative way of adaptation is text dimming, as suggested by Hothi and Hall (1998). This should also be considered as a separate technology. At this time it would probably be wise to refine text adaptation further by dividing it into two essentially different groups: canned text adaptation and natural language adaptation. The main ways of canned text adaptation can now be considered as adaptation technologies: inserting/removing fragments, stretchtext, altering fragments, sorting fragments, and dimming fragments. Natural language adaptation can not be classified further at the moment. Of course, many natural language generation systems do, in fact, make use of fragments (and even paragraphs) of canned text. Our distinction here is made between those systems that use natural language technology as a foundation and those that do not. We may need to refine this distinction at a later stage.

A few methods and techniques developed since 1996 demand more considerable changes to the taxonomy to be accommodated. First, following Kobsa (Kobsa et al., 1999), we name adaptation of modality as a high-level content adaptation technology. Modern adaptive hypermedia systems may have a choice of different types of media with which to present information to the user; that is, in addition to traditional text, we can also use music, video, speech, animation, and so on. Quite often fragments of different media present the same content, and hence the system can choose the one that is most relevant to the user at the given node. In other cases, these fragments can be used in parallel, thus enabling the system to choose the most relevant subset of media items. Currently, we can identify several different methods for adapting the modality of presentation on the basis of user preferences, abilities, learning style and context of work, in several kinds of adaptive hypermedia systems (Carver et al., 1996; Fink et al., 1998; Joerding, 1999; Specht and Oppermann, 1998; Specht et al., 1997).

Second, the rise of recommender systems makes it necessary to distinguish between two essentially different ways of adaptive navigation support: adapting the links that were present on a page at the time of hyperspace authoring, and generating new, non-authored links for a page. Link generation includes three cases: 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 groups have been present in the neighboring research area of intelligent hypertext for years. Recent techniques of adaptive creation of global (Debevc et al., 1997) and local (Bollen and Heylighen, 1998; Marchand and Guerin, 1996) links and adaptive similarity-based navigation (Brusilovsky and Weber, 1996) demand their inclusion into the "taxonomy of adaptation". The third group of methods dealing with the generation of a dynamic list of additional relevant links is new, but already well-explored in the areas of IR hypermedia, on-line information systems (Hirashima et al., 1998; Hirashima and Nomoto, 1999; Schwab et al., 2000), and educational hypermedia (Kayama and Okamoto, 1998). We suggest considering adaptive link generation as a new high-level technology of adaptive navigation support. This technology can be used in conjunction with existing technologies such as annotation and sorting. The updated taxonomy of technologies for the year 2000 is shown in Figure 1.

4. Future Trends

After analysing the progress during the first ten years of research in adaptive hypermedia and current trends, we will attempt to predict some important trends in the development of this area for the next five to ten years.

4.1. Directions of expansion

The traditional direction of adaptive hypermedia research – bringing adaptivity to classic hypermedia systems – is being quite well explored. As we can see, the most recent 2–3 years have added very few methods, techniques, and ideas. Most of the work being performed in this direction is now centered on developing specific variations of known methods and techniques and in developing practical systems. While this kind of work is very important, some researchers may be more interested in *expanding* adaptive hypermedia beyond its traditional borders. We can foresee at least three directions of expansion that require a solid amount of new research.

Integration with other applications. A possible direction of expansion within classic hypermedia, is the embedding of adaptive hypermedia into various application systems. The majority of modern application systems (such as word processors or customer support systems) are very different from "classic hypermedia" systems that constitute a traditional area of adaptive hypermedia development. At the same time, almost any modern application system includes hypermedia components (information storage, on-line help, etc) that often suffer from the same problems as classic hypermedia (such as diverse user population

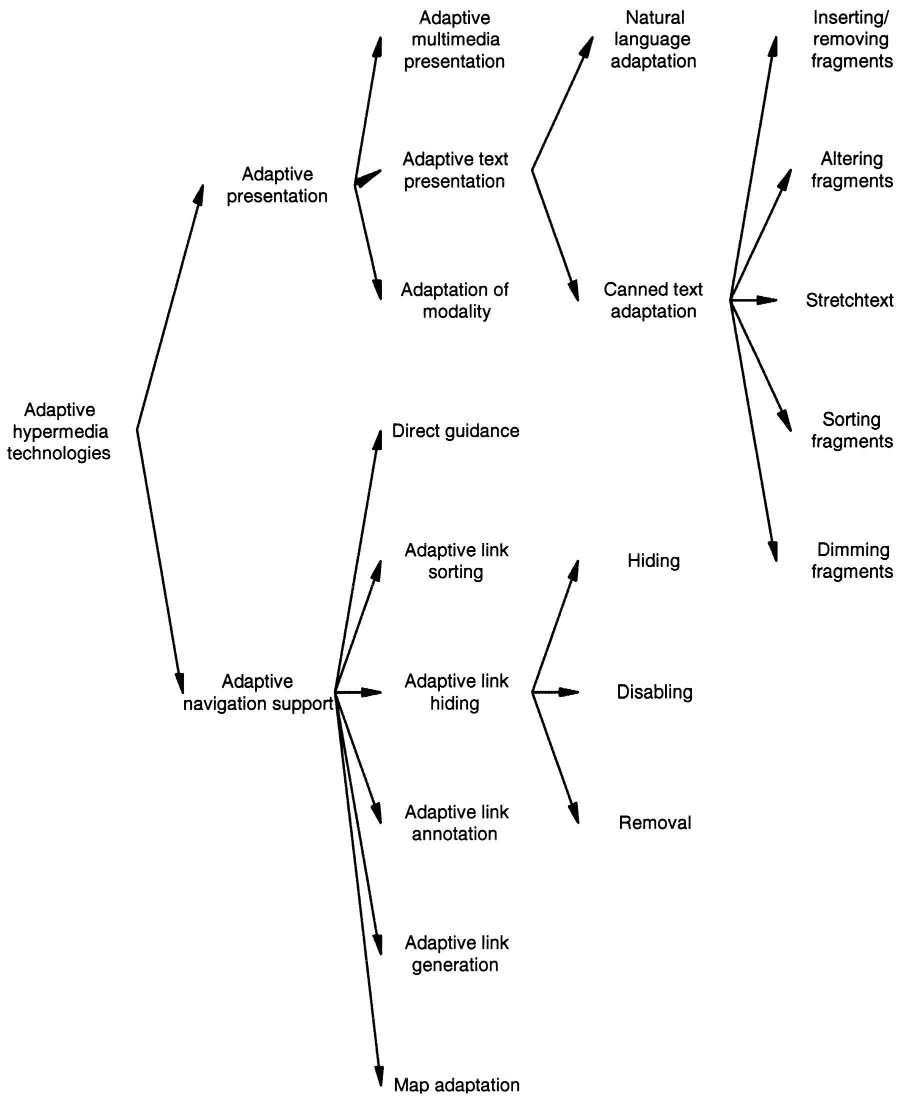

Figure 1. The updated taxonomy of adaptive hypermedia technologies.

and large hyperspace). Wherever there is a place for a hypermedia component in an application system, there may also be an ideal opportunity to develop a useful adaptive hypermedia component. Firstly, this will bring adaptive hypermedia to the foreground and inform the larger population of users of its value. Secondly, the adaptive hypermedia component will be able to determine more from the user's context of work within an application system, and will thus have more information for reliable user modeling than could be extracted from simple browsing history in traditional adaptive hypermedia systems. The on-line help systems analyzed in the review, and the performance support systems mentioned above both provide encouraging examples of application systems that would benefit from embedded adaptive hypermedia.

Open corpus adaptive hypermedia. One of the most exciting research directions for non-traditional Web-based hypermedia is the work on open corpus adaptive hypermedia systems. Currently, almost all adaptive hypermedia systems work with closed corpus data. The key to adaptivity in most of the advanced adaptive hypermedia systems is knowledge about hyperdocuments and links, on the basis of indexing of documents and fragments with the user's possible knowledge, goals, background, etc. This approach cannot be applied to the non-indexed open corpus infospace. One possible way to solve this problem is demonstrated by Web IR systems that are able to extract some meaning from an open corpus of documents. Adaptive hypermedia systems of the future should be able to "understand" hyperdocuments and links to some extent without the help of a human indexer.

Handheld and mobile devices. An exciting research direction that is not directly connected to Web hypermedia is "mobile hypermedia", implemented on various handheld and mobile devices such as portable computers or personal information managers (PIM). These devices can run several original hypermedia applications such as aircraft maintenance support systems (Brusilovsky and Cooper, 1999) or museum guides (Not et al., 1998). This context provides several research challenges. First, most of these devices have relatively small screens. Advanced adaptive presentation and adaptive navigation support techniques have to be developed to make a "small-screen interface" more useable. A combination of text and sound presentation becomes very attractive here. Second, user location and movement in a real space becomes an important and easy-to-get (with the help of such devices as GPS) part of a user model. A meaningful adaptation to user position in space (and time) is a new opportunity that has to be explored. A few pioneer examples are provided by HYPERAUDIO (Not et al., 1998), HIPS (Oppermann and Specht, 1999), and SWAN (Garlatti et al., 1999).

4.2. New technologies

Adaptive hypermedia systems are almost always based on some artificial intelligence (AI) technologies. However, the spectrum of AI technologies being used is quite limited, and include mainly early AI technologies such as concept networks and frames. We believe that solid progress can be achieved in adaptive hypermedia by employing some more recent AI technologies such as concept graphs (Akolulchina and Ganascia, 1997), machine learning (Webb et al., 2001), statistical models (Zukerman and Albrecht, 2001), and adaptive natural language generation and understanding (Zukerman and Litman, 2001). Two groups that look especially promising include the following:

Natural language generation. While simple technologies of adaptive presentation based on canned text (such as fragment variants or adaptive stretchtext) may be sufficient for many application areas, progress with adaptive presentation is clearly related to natural language generation (NLG) techniques. A few recent examples indicate that NLG techniques can expand known borders of adaptation in hypermedia by providing adaptive narration (Oberlander et al., 1998), adaptive guidance (Geldof, 1998), and adaptive comparison (Milosavljevic, 1997). We expect that some more NLG technologies will find their way to adaptive hypermedia systems.

Non-symbolic AI technologies. A solid amount of research in modern AI is connected with various "non-symbolic" approaches such as case-based reasoning, machine learning, Bayesian models, and neural networks. We believe that these technologies will help to expand traditional "symbolic" adaptive hypermedia in several directions. One of the most important directions is improved user modeling in hypermedia. As we mentioned in the review, a hypermedia application provides little information about its user, which is usually only the timed sequence of clicks. Traditional symbolic user modeling techniques that attempt to deduce some information about the user from each single click can hardly progress any further (especially since taking into account the time spent by the user on each single node has little meaning). Non-symbolic approaches are able to extract some information about the user from the navigation trace as a whole. Similar approaches could also be used to automatically extract some knowledge about hypermedia documents in an open corpus scenario. In addition, case-based reasoning may aid in making adaptation decisions in a situation where no well-known adaptation rules are available. Apart from the numerous examples of using machine learning technologies for Web information retrieval classified above, there are a few other promising examples of using various non-symbolic methods in adaptive hypermedia systems (Encarnação and Stoev, 1999; Gilbert and Han, 1999; Kayama and Okamoto, 1998; Marinilli et al., 1999; Micarelli and Sciarrone, 1996).

4.3. New architectures

Apart from exploring new application areas and using new ideas, adaptive hypermedia systems can achieve considerable progress by improving the very process of the development of new systems. This can not only improve the productivity of existing groups, but also provide an opportunity for the development of meaningful adaptive hypermedia systems for a wider community of developers. This demonstrates the importance of making a concerted effort to develop new architectures for adaptive hypermedia systems. Two current directions in architecture-related research that look especially promising include the following:

Authoring tools. In many cases, an adaptive hypermedia system developed for a particular domain can be generalized into a framework that can be applied to building several similar systems in the same domain. A framework applied to developing several systems almost always grows into a toolkit, a shell, or even an authoring system that could significantly simplify the development of new systems for the domain. This process has already begun in the well-investigated area of educational hypermedia. We can expect that this process will continue, and spread outside of this area and into others. Various specialized kinds of on-line information systems, on-line help systems and IR hypermedia provide fertile soil for this process. We can also expect the appearance of lower-level, domain-independent tools for developing Web-based adaptive systems, such as the WBI toolkit (Barrett and Maglio, 1998). Another type of authoring tool, user modeling shells (Kobsa, 2001), should also become a more active direction of research due to the large demand for personalized Web applications.

Component-based frameworks and user model servers. A system built with a component-based architecture consists of several components that interact with each other. A useful component-based architecture can improve the process of developing adaptive hypermedia systems (as well as other kinds of adaptive systems), since a development team may concentrate their efforts on building a few components, while re-using other necessary components developed by other teams. This component-based architecture has been the dream of developers for several years. The internet and the Web with its trend towards platform-independence and standardization bring this dream to reality. The most important part of the work towards component-based architectures, is the development of user model servers and protocols for inter-component communication. This work has already begun (Brusilovsky et al., 1997b; Kobsa, 2001). As soon as some useful and reliable servers and communication protocols are developed, we may expect more and more adaptive hypermedia systems to be developed as a set of reusable components.

Conclusion

At the eve of the year 2000 we can identify more kinds of adaptive hypermedia systems methods and techniques than we could a few years ago. The coming years will certainly bring more exciting examples of how hypermedia systems can adapt to the users and their environments. It is natural to expect that some adaptive hypermedia systems of the future will not be able to fit any classification or predictions. The taxonomy suggested in the review and extended in this paper will certainly need further extensions. For example, it looks meaningful to consider a two-dimensional classification of systems for the future – by *type* (i.e. on-line information, performance support) and by *application area* (i.e. education, medicine, e-commerce). The classification by *kinds* that mixes application areas and types was possible in 1996 can not easily fit such systems as educational encyclopedias (Signore et al., 1997) or e-commerce-oriented product catalogs (Milosavljevic, 1998; Milosavljevic and Oberlander, 1998). Analysing similarities and differences between systems of different type serving the same area, for example, medicine (de Carolis et al., 1998; Francisco-Revilla and Shipman III, 2000; Hirst et al., 1997) may be a very creative endeavour. We were not able to cover this and some other aspects in the single review. It is just an attempt to bring some order to the past and to predict the nearest future. We hope that it will be useful as an introduction into the field for newcomers and as a common ground for researchers and developers in the area.

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References

Akolulchina, I. and Ganascia, J.-G.: 1997, SATELITE-Agent: An adaptive interface agent based on learning interface agent technology. In: A. Jameson, C. Paris and C. Tasso (eds.): *Proceedings of 6th International Conference on User Modeling*. Wien: SpringerWienNewYork, pp. 22–32.

Ardissono, L. and Goy, A.: 1999, Tailoring the interaction with users of electronic shops. In: J. Kay (ed.) *Proceedings of 7th International Conference on User Modeling, UM99*. Wien: SpringerWienNewYork, pp. 35–44.

Asnicar, F. A. and Tasso, C.: 1997, ifWeb: A prototype of user model-based intelligent agent for document filtering and navigation in the World Wide Web. *Proceedings of Workshop 'Adaptive Systems and User Modeling on the World Wide Web' at 6th International Conference on User Modeling, UM97*, Chia Laguna, Sardinia, Italy, pp. 3–11, Available online at http://www.contrib.andrew.cmu.edu/~plb/UM97_workshop/Tasso/Tasso.html.

Balabanovic, M. and Shoham, Y.: 1997, Fab: content-based collaborative recommendation. *Communications of the ACM* **40** (3), 66–72.

Barrett, R. and Maglio, P. P.: 1998, Intermediaries: New places for producing and manipulating Web content. *Computer Networks and ISDN Systems* **30** (1–7).

Bertoletti, A. C. and da Rocha Costa, C.: 1999, SAGRES – A Virtual Museum. *Proceedings of Museums and the Web*, New Orleans, LA, USA, Available online at http://www.archimuse.com/mw99/papers/bertoletti/bertoletti.html.

Billsus, D., Pazzani, M. J. and Chen, J.: 2000, A learning agent for wireless news access. *Proceedings of 2000 International Conference on Intelligent User Interfaces*, New Orleans, LA, pp. 94–97.

Böcker, H.-D., Hohl, H. and Schwab, T.: 1990, $\gamma\pi$Adapt$\varepsilon\rho$ – Individualizing Hypertext. In: D. Diaper (ed.) *Proceedings of IFIP TC13 Third International Conference on Human-Computer Interaction*. Amsterdam: North-Holland, pp. 931–936.

Bollen, J. and Heylighen, F.: 1998, A system to restructure hypertext networks into valid user models. *The New Review of Multimedia and Hypermedia* **4**, 189–213.

Brusilovsky, P.: 1996, Methods and techniques of adaptive hypermedia. *User Modeling and User-Adapted Interaction* **6**(2–3), 87–129.

Brusilovsky, P.: 1998, Methods and techniques of adaptive hypermedia. In: P. Brusilovsky, A. Kobsa and J. Vassileva (eds.): *Adaptive Hypertext and Hypermedia*. Dordrecht: Kluwer Academic Publishers, pp. 1–43.

Brusilovsky, P. and Beaumont, I. (eds.): 1994, *Proceedings of the Workshop 'Adaptive Hypertext and Hypermedia' at 4th International Conference on User Modeling, UM97'*. Hyannis, MA:

Brusilovsky, P. and Cooper, D. W.: 1999, ADAPTS: Adaptive hypermedia for a Web-based performance support system, *Proceedings of Second Workshop on Adaptive Systems and User Modeling on WWW at 8th International Word Wide Web Conference and 7-th International Conference on User Modeling*, Toronto and Banff, Canada. Computer Science Report 99-07, Eindhoven University of Technology, pp. 41–47.

Brusilovsky, P. and De Bra, P.: 1998, *Proceedings of the Second Workshop on Adaptive Hypertext and Hypermedia at Ninth ACM International Hypertext Conference Hypertext '98*, Computer Science Report 98/12, Eindhoven University of Technology, Available online at http://wwwis.win.tue.nl/ah98/Proceedings.html.

Brusilovsky, P. and De Bra, P.: 1999, *Proceedings of the Second Workshop on Adaptive Systems and User Modeling on WWW at 8th International World Wide Web Conference* and *7th International Conference on User Modeling. Computer Science Report 99-07*, Eindhoven University of Technology, Available online at http://wwwis.win.tue.nl/asum99/contents.html.

Brusilovsky, P., Eklund, J. and Schwarz, E.: 1998a, Web-based education for all: A tool for developing adaptive courseware. *Computer Networks and ISDN Systems* **30**(1–7), 291–300.

Brusilovsky, P., Fink, J. and Kay, J. (eds.): 1997a, *Proceedings of the Workshop 'Adaptive Systems and User Modeling on the World Wide Web'* at *6th International Conference on User Modeling, UM97*. Sardinia, Italy: Carnegie Mellon Online.

Brusilovsky, P., Kobsa, A. and Vassileva, J. (eds.): 1998b, *Adaptive Hypertext and Hypermedia*. Dordrecht: Kluwer Academic Publishers.

Brusilovsky, P., Pesin, L. and Zyryanov, M.: 1993, Towards an adaptive hypermedia component for an intelligent learning environment. In: L. J. Bass, J. Gornostaev and C. Unger (eds.): *Proceedings of 3rd International Conference on Human-Computer Interaction, EWHCI'93*. Lecture Notes in Computer Science, Vol. 753, Berlin: Springer-Verlag, pp. 348–358.

Brusilovsky, P., Ritter, S. and Schwarz, E.: 1997b, Distributed intelligent tutoring on the Web. In: B. du Boulay and R. Mizoguchi (eds.): *Proceedings of AI-ED'97, 8th World Conference on Artificial Intelligence in Education*. Amsterdam: IOS, pp. 482–489. Available online at http://www.contrib.andrew.cmu.edu/~plb/AIED97_workshop/Brusilovsky/Brusilovsky.html

Brusilovsky, P., Schwarz E. and Weber G.: 1996a, ELM-ART: An intelligent tutoring system on World Wide Web. In: C. Frasson, G. Gauthier and A. Lesgold (eds.): *Proceedings of Third International Conference on Intelligent Tutoring Systems, ITS-96*. Lecture Notes in Computer Science, Vol. 1086, Berlin: Springer Verlag, pp. 261-269.

Brusilovsky, P., Schwarz, E. and Weber G.: 1996b, A tool for developing adaptive electronic textbooks on WWW. *Proceedings of WebNet'96, World Conference of the Web Society*, San Francisco, CA, pp. 64–69, Available online at http://www.contrib.andrew.cmu.edu/~plb/WebNet96.html.

Brusilovsky, P. and Weber G.: 1996, Collaborative example selection in an intelligent example-based programming environment. *Proceedings of International Conference on Learning Sciences, ICLS'96*, Evanston, IL, USA, pp. 357–362, Available online at http://www.contrib.andrew.cmu.edu/~plb/papers/icls96.html.

Carro, R. M., Pulido E. and Rodrígues P.: 1999, TANGOW: Task-based Adaptive learNer Guidance on the WWW. *Proceedings of Second Workshop on Adaptive Systems and User Modeling on the World Wide Web*, Toronto and Banff, Canada. Computer Science Report 99-07, Eindhoven University of Technology, pp. 49–57.

Carver, C. A., Howard R. A. and Lavelle E.: 1996, Enhancing student learning by incorporating student learning styles into adaptive hypermedia. *Proceedings of ED-MEDIA'96 – World Conference on Educational Multimedia and Hypermedia*, Boston, MA, pp. 118–123.

Danielson, R.: 1997, Learning styles, media preferences, and adaptive education. *Proceedings of Workshop 'Adaptive Systems and User Modeling on the World Wide Web' at 6th International Conference on User Modeling, UM97*, Chia Laguna, Sardinia, Italy, pp. 31–35, Available online at http://www.contrib.andrew.cmu.edu/~plb/UM97_workshop/Danielson.html.

De Bra, P. and Calvi L.: 1998, AHA! An open Adaptive Hypermedia Architecture. *The New Review of Hypermedia and Multimedia* **4**, 115-139.

De Bra, P. M. E.: 1996, Teaching Hypertext and Hypermedia through the Web. *Journal of Universal Computer Science* **2**(12), 797–804.

de Carolis, B., de Rosis, F., Andreoli, C., Cavallo, V. and De Cicco, M. L.: 1998, The dynamic generation of hypertext presentations of medical guidelines. *New Review of Multimedia and Hypermedia* **4**, 67–88.

de La Passardiere, B. and Dufresne, A.: 1992, Adaptive navigational tools for educational hypermedia. In: I. Tomek (ed.) *Proceedings of ICCAL'92, 4-th International Conference on Computers and Learning*. Berlin: Springer-Verlag, pp. 555–567.

Debevc, M., Meyer, B., and Rajko, S.: 1997, An adaptive short list for documents on the World Wide Web. *Proceedings of 1997 International Conference on Intelligent User Interfaces*, Orlando, Florida, pp. 209–212.

Eliot, C., Neiman, D. and Lamar, M.: 1997, Medtec: A Web-based intelligent tutor for basic anatomy. *Proceedings of WebNet'97, World Conference of the WWW, Internet and Intranet*, Toronto, Canada, pp. 161–165.

Encarnação, L. M. and Stoev, S. L.: 1999, An application-independent intelligent user support system exploiting action-sequence based user modeling. In: *Proceedings of 7th International Conference on User Modeling*. Wien: SpringerWienNewYork, 245–254.

Fink, J., Kobsa, A. and Nill, A.: 1998, Adaptable and adaptive information provision for all users, including disabled and elderly people. *The New Review of Hypermedia and Multimedia* **4**, 163–188.

Fischer, G., Mastaglio, T., Reeves, B. and Rieman, J.: 1990, Minimalist explanations in knowledge-based systems. *Proceedings of 23-th Annual Hawaii International Conference on System Sciences*, Kailua-Kona, HI, pp. 309–317.

Francisco-Revilla, L. and Shipman, F. M. III: 2000, Adaptive medical information delivery: combining user, task, and situation models. *Proceedings of 2000 International Conference on Intelligent User Interfaces*, New Orleans, LA, pp. 94–97.

Fu, X., Budzik, J. and Hammond, K. J.: 2000, Mining navigation history for recommendation. *Proceedings of 2000 International Conference on Intelligent User Interfaces*, New Orleans, LA, pp. 106-112.

Garlatti, S., Iksal, S. and Kervella, P.: 1999, Adaptive on-line information system by means of a task model and spatial views *Proceedings of Second Workshop on Adaptive Systems and User Modeling on the World Wide Web*, Toronto and Banff, Canada. Computer Science Report 99-07, Eindhoven University of Technology, pp. 59-66.

Gates, K. F., Lawhead, P. B. and Wilkins, D. E.: 1998, Toward and adaptive WWW: a case study in customized hypermedia. *New Review of Multimedia and Hypermedia* **4**, 89–113.

Geldof, S.: 1998, Con-textual navigation support. *New Review of Multimedia and Hypermedia* **4**, 47–66.

Gilbert, J. E. and Han C. Y.: 1999, Arthur: Adapting Instruction to Accommodate Learning Style. *Proceedings of WebNet'99, World Conference of the WWW and Internet*, Honolulu, HI, pp. 433–438.

Henze, N., Naceur, K., Nejdl, W. and Wolpers, M.: 1999, Adaptive hyperbooks for constructivist teaching. *Künstliche Intelligenz*, 26–31.

Hirashima, T., Matsuda, N., Nomoto, T., and Toyoda, J. i.: 1998, Context-sensitive filtering for browing in hypertext. *Proceedings of International Conference on Intelligent User Interfaces, IUI'98*, San Francisco, CA, pp. 21–28.

Hirashima, T. and Nomoto, T.: 1999, Context-Sensitive Filtering for Browsing on Web Pages. *Proceedings of WebNet'99, World Conference of the WWW and Internet*, Honolulu, HI, pp. 1294-1295.

Hirst, G., DiMarco, C., Hovy, E. and Parsons, K.: 1997, Authoring and generating health education documents that are tailored to the needs of the individual patient. In: A. Jameson, C. Paris and C. Tasso (eds.): *Proceedings of 6th International Conference on User Modeling, UM97*. Wien: SpringerWienNewYork, pp. 108–118.

Hockemeyer, C., Held T., and Albert, D.: 1998, RATH – A relational adaptive tutoring hypertext WWW-environment based on knowledge space theory. *Proceedings of CALISCE'98, 4th International conference on Computer Aided Learning and Instruction in Science and Engineering*, Göteborg, Sweden, pp. 417–423.

Höök, K., Rudström, Å. and Waern, A.: 1997, Edited adaptive hypermedia: Combining human and machine intelligence to achieve filtered information. *Proceedings of Flexible Hypertext Workshop at the Eight ACM International Hypertext Conference (Hypertext'97)*, Southampton, UK, pp. 54–58, Available online at http://www.sics.se/~kia/papers/edinfo.html.

Hothi, J. and Hall, W.: 1998, An Evaluation of Adapted Hypermedia Techniques Using Static User Modelling. *Proceedings of Second Adaptive Hypertext and Hypermedia Workshop at the Ninth ACM International Hypertext Conference Hypertext'98*, Pittsburgh, PA. Computing Science Reports 98/12, Eindhoven University of Technology, pp. 45–50.

Joachims, T., Freitag, D. and Mitchell, T.: 1997, WebWatcher: A tour guide for the World Wide Web. *Proceedings of 15th International Joint Conference on Artificial Intelligence, IJCAI'97*, pp. 770-775.

Joerding, T.: 1999, A temporary user modeling approach for adaptive shopping on the Web. *Proceedings of Second Workshop on Adaptive Systems and User Modeling on the World Wide Web*, Toronto and Banff, Canada. Computer Science Report 99-07, Eindhoven University of Technology, pp. 75–79.

Kaplan, C., Fenwick, J., and Chen, J.: 1993, Adaptive hypertext navigation based on user goals and context. *User Modeling and User-Adapted Interaction* **3**(3), 193–220.

Kayama, M. and Okamoto, T.: 1998, A mechanism for knowledge-navigation in hyperspace with neural networks to support exploring activities. *Proceedings of Workshop 'Current Trends and Applications of Artificial Intelligence in Education' at the 4th World Congress on Expert Systems*, Mexico City, Mexico, pp. 41–48.

Kayama, M. and Okamoto, T.: 1999, Hy-SOM: The semantic map framework applied on an example case of navigation. In: G. Cumming, T. Okamoto and L. Gomez (eds.): *Proceedings of ICCE'99, 7th International Conference on Computers in Education*. Frontiers ub Artificial Intelligence and Applications, Vol. 2, Amsterdam: IOS Press, pp. 252–259.

Keller, R. M., Wolfe, S. R., Chen, J. R., Rabinowitz, J. L. and Mathe, N.: 1997, A bookmarking service for organizing and sharing URLs. *Proceedings of Sixth International World Wide Web Conference*, Santa Clara, CA.

Kobsa, A.: 2001, Generic user modeling systems. *User Modeling and User Adapted Interaction* **11**(1–2), 49–63 (this issue).

Kobsa, A., Koenemann, J. and Pohl, W.: 1999, Personalized hypermedia presentation techniques for improving online customer relationships. Technical report No. 66 GMD, German National Research Center for Information Technology, St. Augustin, Germany.

Laroussi, M. and Benahmed, M.: 1998, Providing an adaptive learning through the Web case of CAMELEON: Computer Aided MEdium for LEarning on Networks. *Proceedings of* CALISCE'98, 4th International conference on Computer Aided Learning and Instruction in Science and Engineering, Göteborg, Sweden, pp. 411–416.

Li, W.-S., Vu, Q., Agrawal, D., Hara Y. and Takano, H.: 1999, PowerBookmarks: a system for perzonalizable Web information organization, sharing, and management. *Proceedings of 8th International World Wide Web Conference*, Toronto, Canada, pp. 297–311.

Lieberman, H.: 1995, Letizia: An agent that assists Web browsing. *Proceedings of the Fourteenth International Joint Conference on Artificial Intelligence*, Montreal, pp. 924–929.

Marchand, Y. and Guerin, J.-L.: 1996, Nestor: A Trail Blazer for Hypertext. *Proceedings of ICTAI'96, IEEE International Conference on Tools with Artificial Intelligence*, Toulouse, France, pp. 420–425.

Marinilli, M., Micarelli, A. and Sciarrone, F.: 1999, A case-based approach to adaptive information filtering for the WWW *Proceedings of Second Workshop on Adaptive Systems and User Modeling on the World Wide Web*, Toronto and Banff, Canada. Computer Science Report 99-07, Eindhoven University of Technology, pp. 81–87.

Micarelli, A. and Sciarrone, F.: 1996, A case-based system for adaptive hypermedia navigation. In: I. Smith and B. Faltings (eds.): *Advances in Case-Based Reasoning*. Lecture Notes in Artificial Intelligence, Berlin: Springer-Verlag, pp. 266–279.

Milosavljevic, M.: 1997, Augmenting the user's knowledge via comparison. In: A. Jameson, C. Paris and C. Tasso (eds.): *Proceedings of 6th International Conference on User Modeling, UM97*. Wien: SpringerWienNewYork, pp. 119–130.

Milosavljevic, M.: 1998, Electronic Commerce via Personalised Virtual Electronic Catalogues. *Proceedings of 2nd Annual CollECTeR Workshop on Electronic Commerce (CollECTeR'98)*, Sydney, Australia, Available online at http://www.dynamicmultimedia.com.au/papers/collecter98/.

Milosavljevic, M., Brusilovsky, P., Moore, J. D., Oberlander, J. and Stock, O. (eds.): 1997, *Proceedings of the Flexible Hypertext Workshop at Hypertext'97, the Eighth ACM International Hypertext Conference*, April 6-11 1997. Southampton, UK. Macquarie University Technical Report C/TR97-06.

Milosavljevic, M., Dale, R., Green, S. J., Paris, C. and Williams, S.: 1998, Virtual Museums on the Information Superhighway: Prospects and Potholes. *Proceedings of CIDOC'98, the Annual Conference of the International Committee for Documentation of the International Council of Museums*, Melbourne, Australia.

Milosavljevic, M. and Oberlander, J.: 1998, Dynamic hypertext catalogues: Helping users to help themselves. *Proceedings of Ninth ACM International Hypertext Conference (Hypertext'98)*, Pittsburgh, USA, pp. 123–131.

Mladenic, D.: 1996, Personal WebWatcher: Implementation and Design, Technical Report IJS-DP-7472, Department of Intelligent Systems, J. Stefan Institute, Available online at http://www.cs.cmu.edu/afs/cs/project/theo-4/text-learning/www/pww/papers/PWW/-pwwTR.ps.Z.

Montebello, M., Gray, W. A. and Hurley, S.: 1997, A Personal Evolvable Advisor for WWW Knowledge-Based Systems. *Proceedings of Workshop on Reuse of Web information at the Seventh International World Wide Web Conference*, Brisbane, Australia, Available online at http://www.mel.dit.csiro.au/~vercous/REUSE/pos7/index.html.

Murray, T., Condit, C. and Haugsjaa, E.: 1998, MetaLinks: A preliminary framework for concept-based adaptive hypermedia'. *Proceedings of Workshop 'WWW-Based Tutoring' at 4th International Conference on Intelligent Tutoring Systems (ITS'98)*, San Antonio, TX, Available online at http://www-aml.cs.umass.edu/~stern/webits/itsworkshop/murray.html.

Negro, A., Scarano, V. and Simari, R.: 1998, User adaptivity on WWW through CHEOPS *Proceedings of Second Adaptive Hypertext and Hypermedia Workshop at the Ninth ACM* International Hypertext Conference Hypertext'98, Pittsburgh, PA. Computing Science

Reports 98/12, Eindhoven University of Technology, pp. 57–62.

Neumann, G. and Zirvas, J.: 1998, SKILL – A scallable internet-based teaching and learning system. *Proceedings of WebNet'98, World Conference of the WWW, Internet, and Intranet*, Orlando, FL, pp. 688-693, Available online at http://nestroy.wi-inf.uni-essen.de/Forschung/Publikationen/skill-webnet98.ps.

Newell, S. C.: 1997, User models and filtering agents for improved internet information retrieval. *User Modeling and User Adapted Interaction* **7**(4), 223–237.

Not, E., Petrelli, D., Sarini, M., Stock, O., Strapparava, C. and Zancanaro, M.: 1998, Hypernavigation in the physical space: adapting presentation to the user and to the situational context. *New Review of Multimedia and Hypermedia* **4**, 33–45.

Oberlander, J., O'Donell, M., Mellish, C. and Knott, A.: 1998, Conversation in the museum: experiments in dynamic hypermedia with the intelligent labeling explorer. *The New Review of Multimedia and Hypermedia* **4**, 11–32.

Oppermann, R. and Specht, M.: 1999, Adaptive Information for Nomadic Activities. A process oriented approach. *Proceedings of Software Ergonomie '99*, Walldorf, Germany, pp. 255–264.

Paterno, F. and Mancini, C.: 1999, Designing Web User Interfaces Adaptable to Different Types of Use. *Proceedings of Museums and the Web*, New Orleans, LA, USA, Available online at http://www.archimuse.com/mw99/papers/paterno/paterno.html.

Pazzani, M., Muramatsu, J. and Billsus, D.: 1996, Syskill and Webert: Identifying interesting Web sites. *Proceedings of the Thirteen National Conference on Artificial Intelligence, AAAI'96*, Portland, OR, pp. 54-61, Available online at http://www.ics.uci.edu/~pazzani/Syskill.html.

Pilar da Silva, D., Durm, R. V., Duval, E. and Olivié, H.: 1998, Concepts and documents for adaptive educational hypermedia: a model and a prototype. *Proceedings of Second Adaptive Hypertext and Hypermedia Workshop at the Ninth ACM International Hypertext Conference Hypertext'98*, Pittsburgh, PA. Computing Science Reports 98/12, Eindhoven University of Technology, pp. 35–43.

Rucker, J. and Polano, M. J.: 1997, Siteseer: Personalized navigation for the Web. *Communications of the ACM* **40**(3), 73–75.

Schöch, V., Specht, M., and Weber, G.: 1998, 'ADI' – an empirical evaluation of a tutorial agent. *Proceedings of ED-MEDIA/ED-TELECOM'98 – 10th World Conference on Educational Multimedia and Hypermedia and World Conference on Educational Telecommunications*, Freiburg, Germany, pp. 1242–1247.

Schwab, I., Pohl, W. and Koychev, I.: 2000, Learning to recommend from positive evidence. *Proceedings of 2000 International Conference on Intelligent User Interfaces*, New Orleans, LA, pp. 241–247.

Signore, O., Bartoli, R. and Fresta, G.: 1997, Tailoring Web pages to users' needs. *Proceedings of Workshop 'Adaptive Systems and User Modeling on the World Wide Web' at 6th International Conference on User Modeling, UM97*, Chia Laguna, Sardinia, Italy, pp. 85–90, Available online at http://www.contrib.andrew.cmu.edu/~plb/UM97_workshop/Signore.html.

Specht, M. and Oppermann, R.: 1998, ACE – Adaptive Courseware Environment. *The New Review of Hypermedia and Multimedia* **4**, 141–161.

Specht, M., Weber, G., Heitmeyer, S. and Schöch, V.: 1997, AST: Adaptive WWW-Courseware for Statistics. *Proceedings of Workshop 'Adaptive Systems and User Modeling on the World Wide Web' at 6th International Conference on User Modeling, UM97*, Chia Laguna, Sardinia, Italy, pp. 91–95, Available online at http://www.contrib.andrew.cmu.edu/~plb/UM97_workshop/Specht.html.

Stefani, A. and Strapparava, C.: 1999, Exploiting NLP techniques to build user model for Web sites: the use of WordNet in SiteIF. *Proceedings of Second Workshop on Adaptive Systems and User Modeling on the World Wide Web*, Toronto and Banff, Canada. Computer Science Report 99-07, Eindhoven University of Technology, pp. 95–100.

Steinacker, A., Seeberg, C., Rechenberger, K., Fischer, S. and Steinmetz, R.: 1998, Dynamically generated tables of contents as guided tours in adaptive hypermedia systems. *Proceedings of ED-MEDIA/ED-TELECOM'99 – 11th World Conference on Educational Multimedia and Hypermedia and World Conference on Educational Telecommunications*, Seattle, WA.

Süß, C., Freitag B., and Brössler, P.: 1999, Meta-Modeling for Web-Based Teachware Management. In: *Proceedings of ER'99 Workshop on the World-Wide Web and Conceptual Modeling*. Lecture Notes in Computer Science, Vol. 1727, Berlin: Springer–Verlag, pp.

Webb, G. I., Pazzani, M. J. and Billsus, D.: 2001, Machine learning for user modeling. *User Modeling and User Adapted Interaction* **11**(1–2), 19–29 (this issue).

Weber, G.: 1999, ART-WEB. http://www.psychologie.uni-trier.de:8080/projects/ELM/elm.html

Weber, G. and Specht, M.: 1997, User modeling and adaptive navigation support in WWW-based tutoring systems. In: A. Jameson, C. Paris and C. Tasso (eds.): *Proceedings of 6th International Conference on User Modeling*. Wien: SpringerWienNewYork, pp. 289–300. Available online at http://www.psychologie.uni-trier.de:8000/projects/ELM/Papers/UM97-WEBER.html

Zukerman, I. and Albrecht, D. W.: 2001, Predictive statistical models for user modeling. *User Modeling and User Adapted Interaction* **11**(1–2), 5–18 (this issue).

Zukerman, I. and Litman, D.: 2001, Natural language processing and user modeling: synergies and limitations. *User Modeling and User Adapted Interaction* **11**(1–2), 129–158 (this issue).

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