Adaptive Hypermedia Systems

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This paper examines adaptive hypermedia systems and interfaces. Adaptive hypermedia systems are hypermedia systems that adapt the presentation of material or the navigational support provided according to a user model. This user model may be based on expertise, learning style, or other criteria and may be implemented through a variety of techniques. The goal of adaptive systems is to address the difference in user goals, expertise or learning styles, or to prevent users from getting lost in hyperspace. The advent of the World-Wide Web (WWW) has sparked renewed interest in adaptive hypermedia interfaces and a number of systems have been implemented in the last ten years. This paper examines these systems and the techniques employed to provide user adaptivity.

General Terms: Adaptive hypermedia, adaptive interface design, user model

CONTENTS:
1. INTRODUCTION
2. ADAPTIVE PRESENTATION
   2.1. Conditional Text Filters
   2.2. Adaptive Stretchtext
   2.3. Frame-based Approaches
   2.4. Adaptive Multimedia Presentation
3. ADAPTIVE NAVIGATION
   3.1. Direct Guidance
   3.2. Hiding
   3.3. Map Adaptation
   3.4. Sorting
   3.5. Link annotation
   3.6. Comparison of Techniques
4. ADAPTIVE SYSTEMS
   4.1. AHA
   4.2. ARNIE and HyperMan
   4.3. AVANTI
   4.4. BASAR
   4.5. CHEOPS
   4.6. CS383
   4.7. CAMELEON
   4.8. ELM-ART
   4.9. EPIAIM
   4.10. HyperTutor
   4.11. I-DOC
   4.12. InterBook
   4.13. ISIS-Tutor
   4.14. ITEM/IP
   4.15. MediaDoc
   4.16. MetaDoc and MetaDoc V
   4.17. Personal WebWatcher
   4.18. PUSH
   4.19. RATH
5. EVALUATION OF ADAPTIVE SYSTEMS
   5.1. ISIS-TUTOR Evaluation
   5.2. ELM-ART Evaluation
6. OPEN RESEARCH ISSUES
   6.1. Multidimensional User Models
   6.2. Fine-grained Multimedia Adaptation
   6.3. Open Adaptive Hypermedia Systems
   6.4. Constructive Adaptation
7. SUMMARY AND CONCLUSION
8. REFERENCES

1. INTRODUCTION

This paper surveys adaptive hypermedia systems. Adaptive hypermedia is based on an adaptive hypermedia model, which consists of three components: data collection, user modeling, and adaptation [See Figure 1]. During data collection, the user, application, or hypermedia system collects data on the user. The user may explicitly tell the adaptive system that he is a particular type of user (expert for example) and ask that the website interface be appropriately adapted or the application or system may implicitly collect data on actual user performance to provide a basis for adaptation. Regardless of the technique used to collect data about the user, this data is then compared against the user model.

The user model is the adaptive system's representation of the user. Existing user models are based on the user's knowledge, goals, background, hyperspace experience, learning style, or preference [1]. The data collected on the user is compared against the user model and the user is classified as a certain type of user. The user, to more accurately represent themselves, may edit this classification. For example, the user model may classify a user as an expert on a system. The user, feeling uncomfortable with the material, may edit this classification and tell the system to model the user as a novice. This classification is the basis for adaptation in the next step.

Adaptation is the final result of the system. Adaptation can take two forms: adaptation of presentation or adaptive navigational support. Adaptation of presentation tailors how the hypermedia is presented to the user based on the user model. An expert user may receive a completely different presentation as compared to a novice user. An active, verbal, sequential user may receive a different presentation as compared to a passive, visual, global learner. Adaptive navigational support adapts the navigational means based on user characteristics. For example, if a page consists of multiple links to related information, those links may be adaptively sorted based on the user's declared expertise or interest. There are a variety of techniques for providing hypermedia adaptation.
The remainder of this paper will examine techniques for providing adaptive presentation of material and adaptive navigational support. After examining these techniques, several adaptive systems will be presented as well as open areas of research.

2. ADAPTIVE PRESENTATION

Adaptation of presentation adapts how the hypermedia is presented based on the user model. There are six techniques for adaptively presenting hypermedia material: conditional text filters, adaptive stretchtext, frame-based variants, and adaptive multimedia presentation [See Figure 2].

2.1 Conditional Text Filters

Conditional text filters is a divide and adaptively present technique. The information within the hyperspace is divided into components. Each component has an associated user knowledge level and is only visible if the user is at the appropriate level within the user model. This technique can be used effectively to tailor presentations to the user's knowledge level. Conditional text filters have been implemented in a number of systems such as ARNIE, AVANTI, I-DOC, ITEM/IP, and MediaDoc [1].

Conditional text filters are similar to the direct guidance and hiding adaptive navigational techniques in that they are an all or nothing approach. If the user model is accurate, the system provides good adaptation. If the user model is inaccurate, then the user cannot adapt the model to provide better adaptation.

2.2 Adaptive Stretchtext

Adaptive stretchtext is similar to a hyperlink but instead of link activation resulting in page replacement, link activation results in text replacement. Stretchtext can be expanded or collapsed to provide as much or as little information as necessary. Hypermedia information can be presented with all, some, or none of the stretchtext expanded depending on the user model. Adaptive stretchtext has been implemented in MetaDoc, and KN-AHS [1].

Adaptive stretchtext has the advantage of allowing the user to refine the adaptation support provided. The user retains the capability to expand or collapse stretchtext as necessary to meet their goals. Some adaptive systems keep track of which stretchtext the user expanded or contracted and modifies the user model based on this information.

2.3 Frame-based Approaches

Frame-based approaches use a frame to present information about a concept. Each frame is divided into slots and the information presented in each slot and the order in which the system presents information is adapted based on the user model.

Frame-based adaptation is a very common adaptation technique. While frame-based provides good adaptation, it requires that multiple versions of the hypermedia material be maintained. AHA, AVANTI, CAMELEON, ELM-ART, and EPIAM implement frame-based adaptation [1].

2.4 Adaptive Multimedia Presentation

Conditional text filters, stretchtext, and frame-based approaches alter the presentation of text based on the user model. The adaptive multimedia systems alter the presentation of multimedia elements based on the user model. It is similar to conditional text filters except multimedia information is adaptively sorted and presented instead of text. The CS383 Adaptive Interface and CAMELEON use this technique [2].

3. ADAPTIVE NAVIGATION

Adaptive navigation adapts the visibility, ordering, or annotation of links to provide adaptive hypermedia. There are five techniques for providing adaptive navigational support: direct guidance, hiding, sorting, link annotation, and map adaptation [See Figure 2].

Direct guidance, hiding, and map adaptation dictate that the navigational adaptation and the user can either use the adaptation or stop using the system. Sorting and link annotation provide the adaptation information to the user so that the user can select to use the adaptation information or to ignore it.

3.1 Direct Guidance

Direct guidance is the most restrictive form of adaptive navigational support. Users are presented with a single adaptive link and can either use it or not. For example, when taking an adaptive exam, the next question button will link to different questions based on the user's previous performance on the assessment. The user can either follow...
the link or not follow the link. Direct guidance navigational support has been implemented in ISIS-Tutor, Web Watcher, HyperTutor, and CS383 Adaptive Testing System [1].

Direct Guidance has the advantage of being simple to use. There is no user confusion as to which link to follow which can dramatically reduce cognitive overhead. It has the disadvantage that it is an all or nothing approach. The user can either follow the adaptive link or not. Consequently the user cannot provide feedback on the effectiveness of the system and the adaptive model cannot be adapted based on this feedback.

3.2 Hiding
Hiding is the most common technique for adaptive navigational support. Links are adaptively hidden so that users cannot access components of the hypermedia system until the user model decides that the user is ready for the information. Like direct guidance, hiding can only distinguish between two states: relevant or non-relevant. If the user model decides that a link is relevant, then that link is visible. If it is not, then the link is hidden. Hiding adaptive navigational support has been implemented in ISIS-Tutor, HyperTutor, MediaDoc, PUSH and RATH [1].

Hiding is advantageous in complex hypermedia systems as it can buffer the user from the complexity of the system and guide them to explore the site in different, but predefined paths suited to the user. This can significantly reduce user cognitive overhead. Like direct guidance, there is no mechanism for user feedback so if the adaptive model is incorrect, it cannot be adapted based on user feedback to model more accurately the user. Moreover, providing an incorrect mental model of the hyperspace may hinder users the longer they use the system.

3.3 Map Adaptation
Map adaptation alters the mapping of image components to different links depending on the user model. While the user is presented with the same image, the destinations of clicking on components of the image change based on the user. Map adaptation is a more visual technique of providing direct guidance navigational support. As such, it has the same advantages and disadvantages. HYPERCASE is the only system that has implemented map adaptation [1].

3.4 Sorting
Adaptive sorting orders the links on a page according to the user model so that the most pertinent links for each user are presented first. With an accurate user model, the user need only work sequentially down the list of links to retrieve information. Adaptive sorting has been implemented in the ARNIE, ELM-ART, Hyperflex, WebWatcher, and CS383 Adaptive Interface system [1].

Link sorting is an easily understood adaptive technique. The user retains the capability to overrule the adaptive model and selectively use the information presented as appropriate. Adaptive sorting is not appropriate for links where the order of the links is predetermined (indexes or table of contents for example) or conceptual links.

3.5 Link Annotation
Link annotation uses textual or verbal cues to suggest to the user which links to visit in which order. Links may have

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Table 1: Comparison of Adaptive Systems and Techniques
different icons, be color-coded, or have different font sizes or font types to distinguish between types of links. The annotation used is adaptively changed based on the user. Users can then use the link annotation to decide which links to follow and in what order. Link annotation has been implemented in AHA, AVANTI, CHEOPS, InterBook, ISIS-Tutor, ELM-ART, ITEM/IP, and WebWatcher [1].

Link annotation is an intuitive and natural method of providing adaptive support to users. Users can quickly and explicitly assess the adaptive support provided and then decide which links to follow or not to follow. Link annotation does not reduce cognitive overload but limited cognitive overhead reduction can be achieved by dimming some of the links. The user retains the capability to follow these links if they so desire.

3.6 Comparison of Adaptive Techniques

The use of adaptive techniques has changed as adaptive hypermedia systems have matured [see Table 1]. Earlier adaptive hypermedia systems used conditional text filters, stretchtext, direct guidance, and hiding as their principal means of adaptation. These techniques were restrictive in that the user could not override the adaptation but were easier to implement. More modern systems prefer link annotation, sorting, and frame-based approaches as their principal means of adaptation. With these techniques, adaptation is provided to the user but the user retains the ability to override the adaptation and choose their own navigational or presentation support. Those techniques that provide guidance but can be overruled are the most popular.

The use of particular adaptive techniques is also being influenced by the increasing use of online assessment to measure more accurately user knowledge. Earlier adaptive systems had a limited ability to assess user knowledge. Systems that are more modern measure user knowledge more frequently and more accurately through online assessments. Consequently, adaptive system designers can use a wider range of techniques due to their more accurate and timely discernment of user knowledge.

4. ADAPTIVE SYSTEMS

4.1 AHA

The Adaptive Hypermedia Architecture, of which the Eindhoven Adaptive Hypermedia Course is an example, provides course adaptation through a combination of frame-based approach, hiding, and link annotation [See Figure 3]. Links to pages are created when the user is ready for the course material and removed when it is no longer deemed appropriate. Different frames of information are presented as the user moves through the hypertext. Links are annotated by color and the browser's default behavior is overridden by the hypertext system. The user can edit the user model at anytime. The top of each page provides feedback on how many pages the user has visited and how many pages the user has not visited yet. The user can override the navigational links provided and directly access any previously visited page or page that the user has not seen. Furthermore, the user can directly access the user model through a configuration option and change the link colors of adaptive links or modify the concept mastery information the system is maintaining on the user. AHA can be found on the WWW at http://wwwis.win.tue.nl/2L670/.

4.2 ARNIE and HyperMan

ARNIE and HyperMan are NASA development projects to support production, storage, distribution, and usage of Mission Control documents in an electronic format [5-7]. ARNIE is the component of HyperMan that provides the adaptive navigation support based on an information relevance model. Users can search for information using a normal search engine or an adaptive retrieval system. The adaptive retrieval system modifies the search results based on the user profile and a system-maintained relevance network. Users provide feedback through a "thumbs-up" or
"thumbs-down" voting mechanism on the relevancy of the references provided through either search mechanism. Moreover, users can access the user profiles of other users or use a system average profile that averages all of the user profiles into a generic user profile. ARNIE and HyperMan can be found on the WWW at http://ic-www.arc.nasa.gov/ic/projects/aim/cid/cid.html.

4.3 AVANTI
AVANTI is an adaptive information system developed to meet the needs of a tourist or traveler [See Figure 3]. AVANTI adapts the interface based on: user expertise with the AVANTI system; user expertise with computers in general; interests; domain knowledge; and disabilities. AVANTI provides this adaptation at both the page and link level and using the techniques of hiding, annotation, conditional filters, and frame-based presentation. The user model also tracks user actions for indications of user difficulty and offers tailored advice. These adaptation techniques are interwoven to provide an effective user interface [8, 9]. AVANTI can be found on the WWW at http://zeus.gmd.de/hci/projects/avanti/.

4.4 BASAR
Building Agents Supporting Adaptive Retrieval (BASAR) is an adaptive agent-based approach for maintaining WWW, bookmark-based personal information spaces. User agents monitor user tasks, interests and preferences and add, update and remove information links based on the user model. The user model is constructed by implicitly observing user actions and explicitly asking the user for guidance [10]. BASAR can be found at http://zeus.gmd.de/projects/basar.html.

4.5 CHEOPS
CHEOPS is an adaptive hypermedia system based on system and user-generated link annotation. While it is a prototype adaptive system with limited functionality, CHEOPS is novel in several ways. While several systems provide system generated link annotation, CHEOPS provides system and user generated link annotation. Users can add comments to visited links and rate the links as they are visited. CHEOPS is also novel in the ease at which existing hypermedia documents can become adaptive. Categorization of the existing HTML files by category and knowledge level in a separate file is the principal requirement [11, 12]. CHEOPS is available on the WWW at http://stromboli.dia.unisa.it/CHEOPS/.

4.6 CS383
CS383 provides an adaptive navigational support through adaptive sorting and an adaptive testing system based on direct guidance [See Figure 4]. The navigational system is innovative in that the user model is based on the student's learning style as opposed to other methodologies for modeling users. Students take an online assessment of their learning style according to the Felder Model [13-15] and the results are stored on the HTTP server. The presentation of course material is then sorted according to its support for that learning style. There are multiple, equally valid approaches through the 1.5 gigabytes of course material. Users may modify the user model directly by changing their learning style profile. The CS383 interface implements approximately 700 different learning styles [2, 16, 17].

The adaptive testing component of CS383 uses direct guidance as it's adaptive mechanism. The system maintains statistics on each question as to how many users answered the question correctly or incorrectly. It also monitors how many questions the user has answered correctly or incorrectly and adapts the difficulty of the next question based on the user's previous performance. Question hints, references, and answers are provided for approximately three hundred questions. The adaptive testing and learning style interface are not integrated in that the learning style module does not incorporate the results of user assessments in determining what information to present. CS383 is a closed WWW site but some information and downloads are available at the external site at http://www.eecs.usma.edu/CS383/.
4.7 CAMELEON
Computer-Aided Medium for Learning on Networks (CAMELON) is an adaptive hypermedia system that like CS383, uses Felder's learning style model as a basis for the user model. Unlike CS383, CAMELEON significantly expands the amount of adaptation support. CAMELEON provides adaptation at the media element level instead of the media type level and provides a course-authoring tool to facilitate annotation of media elements with their support for a learning style. CAMELEON also incorporates a four level knowledge model (Prerequisite, Beginner, Intermediate, and Expert) into the user model. CAMELEON provides adaptation through frame-based presentation [18-20]. It is available on the WWW at http://lithwww.epfl.ch/~laroussi/ cameleon.html.

4.8 ELM-ART
The Episodic Learning Model: The Adaptive Remote Tutor (ELM-ART) is a distributed intelligent tutoring system on LISP that provides course adaptation through a combination of adaptive annotation and link sorting [See Figure 4] [21]. Links are color-coded according to user preparation for the information on a node. Red annotations indicate nodes that the user has not met the prerequisites for, amber nodes represent information the student is ready for but not recommended, and green nodes represent nodes that the user is ready for and are recommended. Links are adaptively sorted as well; links to the nodes that are most similar to the current node are presented first.

ELM-ART features extensive user feedback and is highly interactive. As the user completes exercises and reads nodes, status bars change to reflect the user's progress through the course. Link annotations change color and the navigational view changes to reflect the user's newly gained knowledge. Users can directly edit the user model and override the navigational choices presented to meet their educational goals. An extensive number of exercises engage the user and provide constant feedback to the user and the user model on the user's evaluated knowledge. ELM-ART can be found on the WWW at http://www.psychologie.uni-trier.de:8000/projects/ELM/elmart.html.

4.9 EPIAIM
EPIAIM is an adaptive interface to a statistical package that supports users with limited experience in epidemiology and statistics. It uses frame-based presentation where each frame is divided into slots and an ordered subset of slots, based on the user model, provides adaptation. The user mode is based on user background. A prototype of EPIAIM was implemented on a SUN workstation using Smalltalk 80 [22].

4.10 HyperTutor
HyperTutor is an adaptive presentation and navigation system that uses the adaptive techniques of hiding and direct guidance [23-26]. HyperTutor presents hypermedia documents based on the student's perceived knowledge level (novice, medium, or expert), performance on exercises, and concepts covered using the system. Initially, very little of the HyperTutor hyperspace is visible to the user. As the user explores the system and becomes ready for additional concepts, the links to those concepts become visible. Through the user session, the user completes a series of interactive exercises that are also adapted based on the user's performance. Like the CS383 adaptive testing system, question difficulty varies based on the student's actual performance.

4.11 I-DOC
I-DOC is a document-authoring tool that automates the process of generating documentation and features an adaptive hypermedia interface. I-DOC adaptivity is provided through conditional filtering and frame-based presentation. The user model is based on the user's role, expertise, and the task [27-29]. The I-DOC homepage is available at http://www.isi.edu/isd/I-DOC/i-doc.html.

4.12 InterBook
InterBook is an adaptive hypermedia presentation and
authoring system [See Figure 5] [30]. It provides adaptive navigational support through direct guidance, hiding, and link annotation. InterBook and Elm-Art use a similar link annotation with red, amber, and green link annotations. Direct guidance is provided through a "teach me" button, which takes the user to the most relevant page in relationship to the current page the user is on. The hiding technique is used based on user expertise. Novice users can receive hints on each page as they use InterBook while this support is hidden from expert users.

InterBook incorporates frame-based glossary support with adaptive concept support. Terms are not only defined; related concepts and sections of the InterBook are linked to the term definition. InterBook also features an incremental interface that reveals features as the user becomes ready for the node's information. InterBook is available at http://www.contrib.andrew.cmu.edu/~plb/InterBook.html.

4.13 ISIS-Tutor
ISIS-Tutor is an adaptive learning environment for the information retrieval system CDS/ISIS/M (ISIS) [See Figure 5]. ISIS-Tutor provides adaptive support through frame-based presentation, link annotation, and hiding. It presents an adaptive sequence of tasks and concepts based on the user model and maintains a four state user knowledge model (not-ready-to-be-learned, ready-to-be-learned, in work, and learned) on each concept within ISIS. As the user progresses through the system, ISIS-Tutor annotates each concept using color. Hiding can be enabled to remove concepts that the user is not ready for. ISIS-Tutor was one of the first adaptive models to incorporate more than a bipolar knowledge model and one of the first studies to have empirical support for the effectiveness of adaptive hypermedia interfaces [31-33].

4.14 ITEM/IP
ITEM/IP provides an adaptive navigational and presentation system for an on-line help system for a programming environment. It provides a menu-based interface that offered direct guidance navigational support in the form of a next "best" teaching operation. ITEM/IP was first implemented in 1985.

4.15 MediaDoc
MediaDoc is a software explanation and understanding tool that uses adaptivity to provide tailored information to the users [See Figure 6]. MediaDoc provides adaptive support through direct guidance, hiding, and conditional filtering. It maintains an explicit user model based on how software engineers understand software, user expertise, and the user's task [34]. MediaDoc accomplishes this adaptation through three models: a question model, a task model, and a user model. The question model explicitly captures the types of commonly asked questions and the appropriate explanations. The task model captures the patterns of questions associated with tasks. The user model captures user expertise and what information the user has already explored. MediaDoc uses these three models to tailor the presentation of information so that it is relevant to the user's current task. It also automatically generates animated diagrams that provide a simplified conceptual map of the current task and associated subtasks. MediaDoc is the successor to the I-Doc project. MediaDoc is available at http://www.isi.edu/isd/1-DOC/media-doc.html.

4.16 MetaDoc and MetaDoc V
Metadoc and Metadoc V are different implementations of the MetaInformation project. Metadoc V is a Macintosh-based implementation provides stretchtext based on user expertise while the Metadoc implementation is a Microsoft Windows-based implementation [35, 36]. Both were early adaptive systems that used simple stereotype-based user models.
4.17 Personal WebWatcher

Personal WebWatcher is an adaptive proxy-based, WWW interface that suggests relevant links to the user [See Figure 6]. It implicitly observes the pages and links that the user visits and, based on information retrieval and machine learning techniques, suggests relevant links to the user. The relevant links are then annotated for the user. Personal WebWatcher provides this adaptation through a proxy server and learner module [37-39].

The proxy server records the addresses of pages visited and annotates each page to suggest related links. These suggested links are generated based on the learner module. The pages recorded by the proxy server are analyzed offline using information retrieval and machine learning techniques and the user model is modified for the next time the user uses the system. Personal WebWatcher is available on the WWW at http://www.cs.cmu.edu/afs/cs/project/theo-4/text-learning/www/pww/index.html.

4.18 PUSH

The Plan and User Sensitive Help (PUSH) system is an adaptive on-line help system that documents an object-oriented software development method [See Figure 7]. It uses a combination of partial hiding, sorting, and frame-based presentation to provide adaptation [40, 41].

PUSH displays adapted information in three frames. The top frame provides a clickable image that provides an overview of the topic being displayed and a means of navigation. The second frame is a guide, which provides access to the headers of related information in the left frame. The center frame provides a textual description of the topic and provides the capability to pose queries and have the PUSH system adaptively answer the queries.

The PUSH user model is based on transparent task stereotypes and user verified task recognition. Transparent task stereotypes has the user characterize their current task from a limited number of available tasks. Once the user has begun to explore that task, PUSH uses plan recognition to estimate the user's intention through his or her actions. If the user follows the information presented, the user model guesses that the adaptation is accurate. If the user uses hyperlinks in the left frame or the query engine to explore information other than that presented in the main text frame, the user model infers that the adaptation is not accurate and attempts to adjust the perceived task based on the user's actions.

4.19 RATH

Relational Adaptive Tutoring Hypertext (RATH) provides navigational adaptation through hiding [See Figure 7]. RATH is currently a prototype for a Relational Adaptive Tutoring Hypertext WWW-Environment. It is based on three sources: a mathematical model of hypertext; relational database theory; and a correspondence between the mathematical hypertext model and knowledge space theory. The prototype's features are illustrated by a small course in elementary probability theory. As the user visits nodes, additional nodes become visible in the table of contents [42]. RATH is in early prototype form and is available on the WWW at http://wundt.kfunigraz.ac.at/rath/.

5 EVALUATION OF ADAPTIVE SYSTEMS

There have been three empirical studies evaluating the advantages of adaptive hypermedia systems. All of these studies have been done with limited participants so as to be statistically invalid.

5.1 ISIS-Tutor Evaluation

In 1994, Brusilovsky and Pesin used twenty-six undergraduate students to evaluate ISIS-Tutor [43]. The students were divided into three groups as follows: Group A used hypermedia without adaptation; Group B used ISIS-Tutor adaptive hypermedia without hiding; and Group C used ISIS-Tutor adaptive hypermedia with hiding. The results are presented in Table 2. All groups had to answer correctly ten questions on an assessment. While there are not enough participants to be statistically valid, the results of the study indicate that adaptive hypermedia without hiding is more effective than adaptive hypermedia with hiding and non-adaptive hypermedia.

<table>
<thead>
<tr>
<th>Group</th>
<th># of Steps</th>
<th>Repetition of Previously Studied Concepts</th>
<th>Transitions Concept to Concept</th>
<th>Transitions Index to Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>78</td>
<td>17</td>
<td>8.3</td>
<td>22.14</td>
</tr>
<tr>
<td>B</td>
<td>53</td>
<td>7</td>
<td>1.4</td>
<td>15.5</td>
</tr>
<tr>
<td>C</td>
<td>61</td>
<td>11</td>
<td>2.7</td>
<td>16.3</td>
</tr>
</tbody>
</table>

Table 2: ISIS-Tutor Empirical Study

<table>
<thead>
<tr>
<th></th>
<th>Adaptive Annotation</th>
<th>No Adaptive Annotation</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEXT Button</td>
<td>66.6</td>
<td>81.3</td>
<td>71.9</td>
</tr>
<tr>
<td>No NEXT Button</td>
<td>103.4</td>
<td>87.8</td>
<td>98.6</td>
</tr>
<tr>
<td>Totals</td>
<td>87.3</td>
<td>84.5</td>
<td>86.4</td>
</tr>
</tbody>
</table>

Table 4: Mean Number of Navigation Steps in ELM-ART Study
5.2 ELM-ART Evaluation

In 1997, Weber and Specht used thirty-three students to evaluate the effectiveness of adaptive annotation and the number of navigational steps required with and without adaptive navigational support using the ELM-ART system [44]. In the first experiment, the effectiveness of simple adaptive annotation of links and direct guidance in the form of a "NEXT" button were studied. The group of thirty-three students was initially split into two uneven groups: those with no previous experience in a programming language (fourteen students) and those that were familiar with at least one programming language (nineteen students). These two groups were then split into those receiving adaptive annotation support and direct guidance those that did not [See Table 3]. The number of users is so small when split into eight groups as to not be statistically valid. Direct guidance appears to be consistently useful while the results of adding adaptive annotation of links was mixed.

In a second experiment using twenty-four students as part of the same study, Weber and Specht examined the mean number of navigational steps required to complete the first lesson in ELM-ART [See Table 4] [44]. Like previous studies, the results are not statistically valid but indicate that direct guidance reduced the number of steps required while adaptive annotation actually increased the number of steps required to complete the lesson.

5.3 InterBook Evaluation

In 1998, Brusilovsky and Eklund used twenty-five undergraduate students to evaluate the effectiveness of link annotation using the InterBook system [30]. The students were divided into equally sized groups and over a four week period, accessed two InterBook presentations (Database and Spreadsheet lessons) with and without link annotation support [See Table 5]. Each group received link annotation support for one of the two presentations and no adaptive support for the second presentation. The results were surprising. Link annotation had a negative effect on database presentation and no quantifiable effect on the second study. Like the previous studies, there were not enough participants to be statistically valid. Further examination of the results showed that several students were well-versed with the subject matter and did not use the adaptive system while other students ignored the adaptive support and instead used the "continue" button as their principal navigation method.

6 OPEN RESEARCH ISSUES

There are a number of open research issues in adaptive hypermedia systems including: providing multidimensional user models; providing fine-grained multimedia-based adaptation; creating open adaptive systems; and providing constructive adaptive hypermedia. Each of these research issues is discussed below.

6.1 Multidimensional User Models

Future adaptive hypermedia systems should support multidimensional user models. Current user models measure limited user characteristics to normally a single dimension such as declared or demonstrated knowledge, or hypermedia nodes visited. For example, AHA [4] uses the number of nodes visited while CS383 [2] uses learning styles as the basis for the user model. Actual users in a learning environment are much more complex and are multi-dimensional and multi-faceted. Future user models must incorporate multiple dimensions of the user including expertise, user goals, interests, and preferred learning style by subject matter. These dimensions may be declared by the user, measured by the adaptive system, or a combination of both approaches.

Not only must the user model incorporate multiple dimensions, the importance of an individual user model dimension may vary over time. As a user progresses through hyperspace, their goals and interests may change as they learn new concepts. The user model must quickly adapt to these changes in the user to present relevant information to the user. Discrepancies between declared and demonstrated user characteristics must be resolved and presentation of material adapted. The users of adaptive hypermedia systems are not one-dimensional but instead are multidimensional. Future user models in adaptive hypermedia systems should be multidimensional and adaptive as well.

Providing adaptive, multidimensional user models raises a number of open research issues. Most current adaptive systems allow their users to manipulate explicitly the user model. This is most commonly done through a long list of checkboxes. Different presentation techniques will be required for users to manipulate effectively multiple user dimensions. The effective manipulation of a multidimensional user model clearly presents significant

<table>
<thead>
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<th>No Programming Experience</th>
<th>Adaptive Annotation</th>
<th>No Adaptive Annotation</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next Button</td>
<td>21.0</td>
<td>25.0</td>
<td>22.7</td>
</tr>
<tr>
<td>No Next Button</td>
<td>13.8</td>
<td>9.5</td>
<td>12.6</td>
</tr>
<tr>
<td>Totals</td>
<td>17.0</td>
<td>18.8</td>
<td>17.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Programming Experience</th>
<th>Adaptive Annotation</th>
<th>No Adaptive Annotation</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next Button</td>
<td>23.5</td>
<td>14.0</td>
<td>20.3</td>
</tr>
<tr>
<td>No Next Button</td>
<td>22.4</td>
<td>12.6</td>
<td>17.5</td>
</tr>
<tr>
<td>Totals</td>
<td>23.0</td>
<td>13.1</td>
<td>18.8</td>
</tr>
</tbody>
</table>

Table 3: Mean Number of Pages Completed in ELM-ART Study
user interface issues. Additionally, it remains an open research issue as to what is the proper type and number of dimensions to measure. Adding additional dimensions will not always increase the accuracy of the user model but will always increase the complexity of the user model and the requirements to collect additional user information. There is a balance between the number of dimensions, model complexity, and the accuracy of the model. Finally, determining techniques for modifying the weights associated with different dimensions dynamically so as to better represent the user is an open research issue.

6.2 Fine-grained Multimedia Adaptation
Future adaptive hypermedia systems should provide a fine degree of adaptation granularity and adapt more than just hypertext. With the exception of CS383, all current adaptive hypermedia systems provide text-based adaptation based on a user model with limited levels of user differentiation. In addition to using multidimensional user models, future systems must incorporate multiple levels in each user model dimension so that the adaptation provided is truly tailored to the user. Users are not just novice, intermediate, or expert users but range a scale of many intermediate values. Users are not simply sequential or global learners but instead are some combination of both characteristics. Adaptive hypermedia systems should not only model multiple dimensions of the user, but each dimension should have as many delineations as necessary to truly capture the user.

In the last five years, there has been significant growth in the granularity of user models in adaptive systems such as ELM-ART [21], InterBook [30], AHA [4], and RATH[42]. These systems incorporate numerous exercises to capture more accurately user knowledge of hypermedia material covered. Adaptive hypermedia must continue to build upon the successes of these earlier systems.

Adaptive hypermedia systems should adapt more than hypertext. Adaptive hypermedia systems have traditionally focused on text presentation or navigation support. Only two systems, CS383 and CAMELEON have implemented adaptation of other media types such as sound, graphics, or video but its implementation was limited to adaptation of media type (not individual media elements) by learning style. New systems must expand adaptation so that appropriate pictures, movies, slideshows, or sound files play to different users.

Introducing fine grained multimedia adaptation raises a number of open research issues. Like adding additional dimensions to the user model, adding greater granularity to each dimension requires a much greater implementation effort and increases the complexity of the user model. Assessing the proper balance between granularity and adaptive system performance remains on open research issue. Multimedia adaptation adds additional complexity and requires a greater implementation effort. Media elements, other that text, are more difficult to generate and are not as malleable to automatic recombination. It is extremely difficult to automatically adapt video segments on the fly and present the results to users for example. Techniques for adaptation and presentation of media elements other than text are open research issues.

6.3 Open Adaptive Hypermedia Systems
Adaptive hypermedia systems must support open adaptive systems. All known adaptive hypermedia systems, with the exception of Personal WebWatcher [38], are closed navigation systems. Adaptation is provided while the user is in the restricted hyperspace of the adaptive system and there are explicit, well-defined navigational boundaries on the system. The adaptive system is self-contained. Because the system is self-contained, the author of the adaptive system must ensure that all information the user might require is inside the system. If the user is not satisfied with the information resources within the system, they can either remain dissatisfied and use the adaptive system, or leave the system.

Adaptive hypermedia systems should allow users to stay within the adaptive system but travel to informational resources outside of the navigational boundaries of the adaptive hyperspace. This tunneling through adaptive navigational boundaries provides the user the ability to gather additional informational resources and return to the adaptive system when ready. These informational resources may be links provided by the adaptive system to non-adaptive information resources outside the system that are constrained in a separate frame or in a new window, or may be a general-purpose search capability.

This ability to integrate external informational sources within the adaptive system provides a number of advantages that current adaptive hypermedia systems cannot. The informational resources of the adaptive system are significantly increased without a large amount of work by the adaptive system author. Users have greater flexibility to more deeply explore information within the conceptual model of the adaptive system and pursue individual goals and interests. But more importantly, based on the number of tunneling attempts outside the adaptive hyperspace by concept, the adaptive system gains a quantitative measure of informational regions within the navigational space that are not meeting user needs. Armed with critical feedback, the adaptive system author can then add new information to the system, remove useless information, provide additional external links to known information resources, or provide a general-purpose search engine. Future adaptive hypermedia systems should be open systems with soft boundaries as opposed to closed systems with hard limitations.

There are significant implications in the construction of open adaptive hypermedia systems. Adaptive hypermedia is no longer self-contained but instead is part of larger body of information. The synergistic integration of search engines and glossaries becomes important. Some current systems, such as InterBook [30], have already begun to include adaptive glossaries and several systems use extensive
assessment to provide more accurate adaptation. As glossaries, digital libraries, search engines, assessment engines, and resources external to the adaptive system are added, adaptive systems will be more of a solution and less of a research prototype.

Opening adaptive hypermedia systems to include informational resources outside of the navigational space of the adaptive system raises a number of interesting research issues. Capturing the tunneling activity and correctly categorizing it becomes an important research area. Are multiple, successive tunneling attempts indicative of a confused, frustrated user, a novice user exploring every link, or a happy, enthusiastic user that wants to learn everything they can about the subject matter at hand? Controlling the effects of context shift is another open research area. Even if the material is appropriate, it may be in a presentation style that causes the student to lose focus or become confused. Ensuring that users do not become lost when leaving the adaptive navigational space is likewise an open research issue. Finally, how to capture and act on user tunneling efforts is an open research issue.

6.4 Constructive Adaptive Hypermedia

Adaptive hypermedia systems should be constructive in nature. The most accurate user model is the one that users construct themselves. Users should have the capability to easily add material to the adaptive system with a clear delineation of material from the original author and from users. Users should be able to view the original material only, all user comments, or their comments only. They should be able to add comments to pages as in the ELMART system [21] or annotate links that are not yet implemented in an adaptive hypermedia system. Constructive hypermedia provides the most precise and fine-grained form of adaptation. As the complexity or size of adaptive hypermedia systems grows, so too will the need for constructive hypermedia.

There are a number of open research issues associated with constructive, adaptive hypermedia. User construction may be indicative that the underlying adaptive system is not meeting the information needs of the user. Mechanisms for evaluating user constructions and modifying the user model as necessary need to be explored and developed. Providing access to all user comments may not be productive and may confuse the user more than help them. Methods must be developed for assessing the impact and utility of user construction on the user and adapting the system appropriately. Further assessment of this approach is necessary before implementation.

7 SUMMARY AND CONCLUSION

This paper has surveyed adaptive hypermedia systems and examined a number of implementations. These systems illustrate the potential for enhancing the navigational and presentation support in hypermedia systems through adaptive interfaces. Adaptive hypermedia systems have made great strides in the last fifteen years, but new capabilities and a better understanding of users and adaptive systems opens new avenues of research. Research into these issues will bring us closer to realizing the full potential of adaptive hypermedia.

8 REFERENCES


