Adaptive Interaction through WWW

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Abstract

The advent of graphical browsers has transformed the World-Wide Web from a tool for scientists to an information and recreation source for millions of people. The Web seems a natural vehicle for distance learning activities, yet is of limited effectiveness for that purpose due to extremely limited abilities to modify the format, pace and sequence of material presented in response to a student's preferences or performance. This paper discusses issues related to providing Adaptive Interaction and Instruction using the World-Wide Web. We include a brief survey of human-computer interaction topics relevant to the Web, describe the mechanism available to effect adaptive interaction, present a design model for an adaptive education system, and close with a summary of our experience with one such system for introductory programming and a few suggestions for future research activities.

1. INTRODUCTION

In the past year the World-Wide Web (WWW) has exploded in the national consciousness. Its technology, originally developed by scientists to exchange visual and audio information as well as text, seemed the solution for translating techno-speak into something people without a technical background could understand. With a click of the mouse, users could browse through colorful menus that offered everything from company brochures to tutorials of Home Page construction. It simplifies one thing: the way of communication.

Given years of interest in distance education and the wide accessibility to the Web currently available, it is natural to consider using the WWW for instructional delivery. Web documents, however, are typically designed for one-way communication, and the "stateless" nature of Web connections makes it difficult to adapt the presentation of instructional material to the student. There are no simple mechanisms to provide the level of interaction and participation available in systems such as New York University's Virtual College [Byte 95].

With these motivations, we are investigating the design of a system for Adaptive Interaction and Instruction on the WWW. Our project is focused on developing an integrated toolkit based on the WWW for adaptive tutorials and testing or distance learning, corporate training, and curriculum enrichment. The initial problem domain is introductory programming in C++.

The remainder of this paper discusses human-computer interaction in the context of the WWW, factors relevant to delivering computer-based instruction over the WWW, and a model of components for an adaptive instructional system on the Web.

2. HUMAN-COMPUTER INTERACTION AND THE WWW

Mechanisms for Human-Computer Interaction (HCI) have undergone amazing changes in the past 20 years, from command-oriented systems that placed all the burden of correct communication on the end user's ability to remember commands, to the direct manipulation systems common today, which place much of what is needed to control that communication "in the world" of the user interface [Norman 90], and allow even inexperienced users to make effective use of computers.

However, by comparison with human-human interaction, the current state of human-computer interaction is relatively spartan. Among themselves, humans use a wonderfully rich set of media: the words and tones of spoken language, gestures, facial expressions, "body language," drawings and other audio-visual aids. Human-computer interaction is usually limited to typed words, graphical displays, and menu selections via pointing devices. Part of the great interest in multimedia is the intuitive belief that making a wider range of media available to the participants in a human-computer dialog will significantly enhance that dialog.

Hypermedia adds another dimension to a multimedia dialog. The author of a hypermedia document not only presents material in the document, but also adds "links" to related information within the document or in external documents. The destination of a link may be text, graphics, imagery, audio, or video material, which in turn can contain links to other information, and so on. The author uses a particular medium to explain a particular concept based on the relationship of the semantics, dynamic nature, and information density of the medium to the nature of the concept. The path taken through the maze of interconnections, and sometimes the choice of the medium used to present information, is under the control of the human end user. The WWW is an example of a distributed hypermedia system.

Hypermedia is structured and non-linear in contrast to conventional unstructured and linear text, making it a good way to package information for efficient information retrieval. It is useful for some forms of interactivity, but because of its fragmented nature, it may not be the ideal medium to form the core of teaching materials. A learner-centered rhetoric is possible for hypermedia based on its malleability and its use in a *supplementary role* within the context of a more general instructional form. Web-based hypermedia offers considerable potential for education. Moreover, malleability allows us to offer multiple perspectives on a particular domain. It is possible to use hypermedia to present, and then re-present, ideas in ways that are difficult to achieve in regular text.

Communication and Interaction

We make a distinction between communication and true interaction [Nass and Steuer 93]. Communication involves the transfer of information from a source to a recipient. True interaction requires communication in two directions, with the information provided by each party influencing the actions of the other. Greater degrees of interaction are achieved by using more of the historical context of the dialog to influence actions. User interfaces which implement true interaction are referred to as adaptive interfaces (they adapt their characteristics to those of the user).

There are only a few moderately interactive experiences available on the WWW, typically games that support simple interactions not nearly as satisfying as games running on stand-alone computers. The argument is commonly made that the great individual control provided by hypermedia is enough to lead to a more satisfying user experience.

Our experience with student use of WWW information is that students demonstrate a great range of enthusiasm and persistence in seeking materials, and the poorer students (those most in need of supplemental enrichment) are the least effective at ferreting out the necessary information. This implies that simply providing a hypermedia enrichment environment may lead to an enjoyable experience but not necessarily to successful learning [Palmiter and Elkerton 91]. We believe the key to successful learning is an adaptive hypermedia environment which preserves most of the freedom of movement through the material while providing guidance on topic selection and, optimally, making choices on the set of media available to the student based on past learning experiences.

3. RELATION TO WEB-BASED INSTRUCTION

This mimics human-human communication, in which there is usually a significant amount of adaptation of communication style and content for both participants, in an attempt to maximize the exchange of information. This is especially true in student-teacher communication, where the teacher dynamically modifies both the style of presentation and even the material being presented in response to the student's understanding.

In computer-assisted instruction (CAI), researchers have sought to develop instructional systems that mimicked this adaptive behavior since the early 70s. [Wenger 87] provides an excellent overview of those early systems, and both [Polson and Richardson 88] and [Self 88] provide snapshots of recent active research projects. In general, these intelligent tutoring systems attempt to build a model of the student, and use that model in conjunction with knowledge about the domain of instruction and instructional strategies to modify the order of presentation of material, selection of hints and corrections, and style of interaction with the student.

As previously mentioned, this is difficult to do given the philosophy of the WWW, since the system never knows the path by which a user has arrived at a particular place in a hypermedia document. In addition, the hypermedia document should work with all of the various Web browsers available, so the enrichment materials cannot demand modifications to those standard browsers. In an educational setting, particularly one in which students are formally registered for a particular sequence of study, it is possible to provide constraints on materials and adapt the interaction to past user performance.

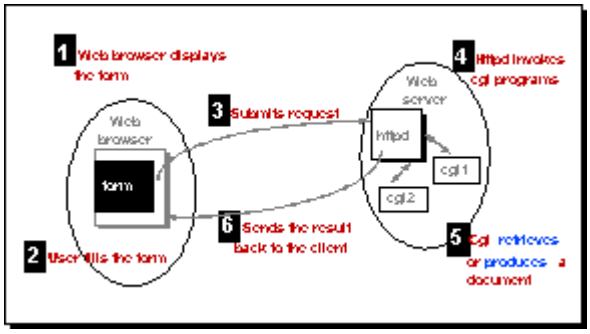

Figure 1: Common-Gateway Interface.

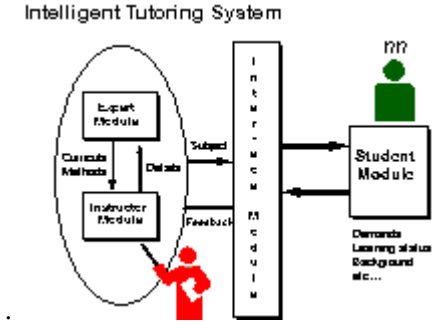

Figure 2: Intelligent Tutoring System

Common-Gateway Interface

The mechanisms that make this possible are the Common-Gateway Interface (CGI) and interactive forms. As shown in [Fig. 1], forms are transmitted from the HTML server (the HTTP daemon) to the WWW browser and submitted to the server once completed. Each form is associated with a particular CGI program, which is activated by the Web server when the form is received. The CGI has access to the data

populating the form and has full freedom to manipulate it in any way desired. In particular, the CGI can output to the HTTP daemon text which represents another page of information to be transmitted to the WWW browser for review by the student.

For purposes of Web-based instruction, then, forms are the mechanism for returning particular response information from the student and the CGI provides the programmatic mechanisms to record that input, relate it to previous inputs, and to select a particular set of choices sent back to the student for subsequent hypermedia browsing. That is, to control the presentation of material based on past dialog history.

Thus the structure for WWW-based education becomes a hypermedia document with periodic evaluation activities. The evaluation exercises are presented as forms, which are completed by the student and submitted by sending them to the server for evaluation. This CGI/forms combination allows us to offer a variety of evaluation methods:

- True/false or multiple-choice questions
- Matching items with a clickable map or graphic
- Short-answer questions
- Simple essay questions and, most importantly for our problem domain
- Perform procedures and evaluate the results

One of the most attractive characteristics of the WWW is that it allows rapid changes to and updating of content, as opposed to the stable homogeneous materials typically used in education. It is important that the evaluation mechanisms not interfere with that dynamism. Thus a major focus of our project is to develop toolkits which allow a document author to design and include evaluation and response mechanisms relatively easily.

4. SYSTEM DESIGN MODEL

It has been observed [Polson and Richardson 88, Self 88, Wenger 87] that the primary objective of an Intelligent Tutoring System (ITS) is to develop an effective teaching and learning environment. Most papers in the field of Computer-Aided Instruction introduce ITS by giving simple system descriptions and examples. A more general description is: an ITS is a system composed of four modules (expert module, instructor module, interface module and student module) working cooperatively to effect desired learning outcomes [Fig. 2]. The modules can be briefly described as:

- The expert module is a subject specialist or can be treated as a knowledge-base for the instruction. This module provides the curriculum as well as low-level teaching methods.
- The instructor module conveys the subject material to the learners in different ways based on student requests and responses.
- The interface module provides the interaction channels between the teacher and the students.
- The student module records students' basic information on the progress in learning, coverage of material, and preferences.

In our implementation, all four of these modules are located on the HTTP server machine and are invoked by the CGI programs as needed to modulate the interaction with the student. The browser machine with which the student is actually viewing the instructional materials simply displays the WWW hypermedia and transmits the forms filled in by the student back to the server machine and the CGI. The remainder of this section discusses each of the modules in more detail.

Expert Module

The expert module's knowledge of the subject area is encompassed in a set of HTML files that actually transmit the material to the student. The micro level instructional techniques are incorporated in the way in which the material is explained, as well as the particular media chosen to present a particular topic.

Instructor Module

In a traditional WWW-based system, control of the order of presentation of topics is strictly in the student's hands. But it is still possible to modify the student/system interaction to provide diagnostic hints and to somewhat modify the form of presentation. The instructor module varies the level and medium of the HTML documents actually presented to the student, using the information recorded by the student module. Currently, this is effected by connecting hypermedia links, from one major topic to another, to a form. Transmission of the form invokes the instructor module to select the actual HTML page transmitted to the browser. Alternative paths for presentation of particular topics are represented as a directed graph with labeled links.

The objective of this modification, of course, is to maximize the knowledge gain by the student. To do this we must address issues of both student learning style and teaching methodology. [Dunn, et al. 89] describe learning style as *the manner* in which various elements of four basic stimuli affect a person's ability to absorb and to retain information, values, facts, or concepts. The four stimuli are environmental, emotional, sociological, and physical.

- The four environmental elements are: sound, light, temperature, and design.
- The four emotional elements consist of motivation, persistence, responsibility, and structure.
- The six sociological needs that affect learning are believed to be peers, self, pair, team, adult, or a combination.
- The four physical elements are perceptual, intake, time, and mobility.

Of these elements, there is little adaptive interaction can do to modify the environmental and emotional stimuli, although the self-control and stimulation available through the WWW are often cited as enhancing factors for students' motivation and persistence. Similarly, there is little interaction can do about sociological stimuli in a 1-to-1 dialog, although there may be some aspects of a team approach that can be addressed on the Web (see the last section). Our efforts at adapting the interaction to the student will primarily address the physical stimuli through changes of medium, level of content, and pace.

[Dunn, et al. 89] also cite a study of teaching methodology in which students learned more and evaluated their teachers positively when the teaching methods were matched to the learner's cognitive styles. We are focusing on three measures to encourage optimal facilitation of learning:

- Adaptive: matching the teaching method to the learner's cognitive style;
- Progressive: incorporating classroom problem solving training into all curricula; and
- Interactive: the use of interacting methods.

Interface Module

Since we insist that our materials function with standard WWW browsers, our interface module is restricted to the features provided by standard Web servers and browsers.

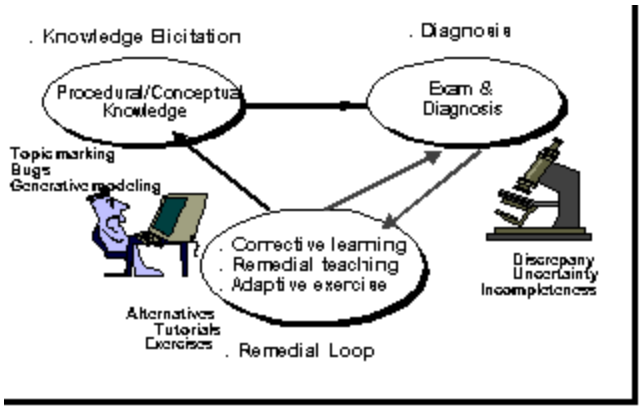

Figure 3: Adaptive Interaction.

Student Module

The student module records information about the student's current and previous interactions with the system. This student model information provides the "state" data needed to allow adaptive interaction, see [Fig. 3]. As indicated above, these data include performance on evaluation activities and paths selected at major branch points between topics (essentially, information about the level of material previously seen).

Following [Eberts 94], we categorize the approaches to developing a student model as:

- Topic marking: the system keeps track of the information presented to the student relative to a syllabus of topics to be covered.
- Context models: the extent of the student's knowledge is inferred from the dialog or from answers to direct questions to the student.
- Bugs: the student's knowledge is characterized in terms of the misconceptions demonstrated about the subject.
- Overlay: the student's knowledge is defined in comparison to the knowledge representation of a subject expert.
- Generative modeling: the plans used by the student to solve problems are used to build a model of knowledge about the domain of instruction.

Our approach combines the topic marking, bug, and generative approaches to student modeling. Selection of appropriate data to allow effective modeling, and the use of that data to correctly modify the interaction for maximum learning is a significant topic of our research.

5. CURRENT STATUS AND EXPERIENCE

Adaptive Interactive Tutorial System is an experimental prototype which we use to get practical experience with our ideas. As of now (Spring 1996), the most significant part of the development is the interface module with simple student modeling which relied on the existing CGI and Java Applet mechanisms. The prototype will be implemented completely in CGI and Java Applets to all the interactive facilities. In order to illustrate our approach we give an abtract model to describe the association of different components.

Let M and M' be the set of materials and methods for teaching. We use H to represent a set of HTML interactive forms. We have a group of students enrolled in the class, we identify them as U, user, and S, student. There is an one-to-one mapping between User and Student. We will keep track of the profile s_0 of each student to monitor her/his demands and progress. The interactive module will perform at least three functions: *identication, delivery*, and *update*.

$\Pi : U \rightarrow S$ (1)

$\Sigma : M \times M' \rightarrow H$ (2)

$\Delta : H \times U \rightarrow S$ (3)

(1) says when the users login, the system will identify them and retrieve the profile from *S*. According to the student profile, (2) indicates that the system will adopt material and methods to deliver an interactive form. This is the most critical part of our project. After a session of interaction, (3) shows that the system will update the student profile. Our prototype has completed the functionalities of (1) and (3).

Additional Research Areas

Perhaps the most intriguing future development is the possibility of downloadable "applets" that can be run on the browser machine and offer substantially greater opportunity for customization of the user interface provided by the browser based on the student model data collected by the student module.

This approach may also offer an opportunity to address the team aspect of learning, through group discussion possibilities similar to the on-line virtual group provided by the Sociable Web [Donath 95]. This project modifies the Web browser and server to provide a number of social and collaboration features on special Sociable Web pages. It shows who else is on the pages and allows the user to strike up conversations or to join in ongoing discussion. If such capabilities could be provided without modifying the browser or server, students might be able to use each other as on-line tutors to expand on the instruction provided by the hypermedia.

REFERENCES

[Byte 95] BYTE Magazine, March 1995.

[Donath 95] Donath, J. (1995). Sociable Web Page. MIT Media Lab.

[Dunn et al. 89] Dunn, R., J. Beaudry, and A. Klavas (1989). Survey of Research on Learning Styles. Educational Leadership, 46 (6).

[Eberts 94] Eberts, Ray E. (1994). User Interface Design. Englewood Cliffs, New Jersey: Prentice-Hall.

[Nass and Steuer 93] Nass, Clifford, and Johathan Steuer (1993). Voices, Boxes, and Sources of Messages: Computers and Social Actors. Human Communication Research, 19 (4), 504-527.

[Norman 90] Norman, Donald A. (1990). The Design of Everyday Things. New York: Doubleday/Currency.

[Palmiter and Elkerton 91] Palmiter, Susan, and Jay Elkerton (1991). An Evaluation of Animated Demonstrations for Learning Computer-based Tasks. Proceedings of CHI 1991, Association for Computing Machinery, New York, 257 - 263.

[Polson and Richardson 88] Polson, Martha C., and J. Jeffrey Richardson, ed. (1988). Foundations of Intelligent Tutoring Systems. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

[Self 88] Self, John, ed. (1988). Artificial Intelligence and Human Learning: Intelligent Computer-Aided Instruction. London: Chapman and Hall.

[Shneiderman 92] Shneiderman, Ben (1992). Designing the User Interface, Second Edition. Reading, Massachusetts: Addison-Wesley.

[Wenger 87] Wenger, Etienne (1987). Artificial Intelligence and Tutoring Systems: Computational and Cognitive Approaches to the Communication of Knowledge. Los Altos, California: Morgan-Kaufman.