Concept-based Navigation in Educational Hypermedia and its Implementation on WWW

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Abstract: This paper is centered around concept-based navigation, a powerful hypermedia navigation model. Main ideas behind concept-based navigation model are concept-based indexing and student modeling. We introduce the idea of concept-based navigation and describe its implementation in InterBook, an authoring system for designing Web-based adaptive hypermedia. We also demonstrate a number of benefits of the approach itself and its implementation in InterBook.

Introduction

Classic navigation model in hypermedia is page-to-page navigation using links between pages. This paper suggests and describes a more powerful navigation model which we call concept-based navigation. Main ideas behind concept-based navigation model are concept-based indexing and student modeling. Concept-based indexing is used to provide additional information about the content of each hypermedia page by indexing it with related domain concepts. In this context, by domain concepts we mean atomic pieces of knowledge in a given domain. Student modeling is used to represent the state of the student knowledge about domain concepts.

A hypermedia page in a system that uses indexing and student modeling is no longer a black box to the hypermedia server. Indexing tells which pieces of domain knowledge stand behind the page and student modeling tells how well the student is familiar with these pieces of knowledge. This additional knowledge turns a hypermedia system into a knowledge-based system. Including additional knowledge into regular hypermedia pages opens several ways for increasing functionality of a hypermedia system such as adaptive navigation support, adaptive guidance, intelligent help, and concept-based navigation.

We have implemented adaptive navigation support, adaptive guidance, and intelligent help in ELM-ART, a Web-based Intelligent Tutor for LISP [Schwarz, Brusilovsky & Weber 1996]. In our recent system InterBook [Brusilovsky, Schwarz & Weber 1996], an authoring system for designing Web-based adaptive hypermedia we have implemented all the above techniques adding concept-based navigation. This paper is centered around concept-based navigation. We describe special aspects of the implementation of concept-based navigation in InterBook and demonstrate a number of benefits of the approach itself and its implementation.

Background: Indexing in Educational Systems

Indexing was originally suggested in Computer Assisted Instruction (CAI) context by Osin [Osin 1976] who suggested a framework for indexing CAI frames by a set of topics which it covers. Such indexed sets of frames were not related to any pre-scribed order of presentation. They can be accumulated, stored in special libraries, and re-used by different authors to create their own courses. In the multimedia field, a similar idea of a re-usable database of multimedia learning material indexed by topics and keywords is elaborated by Olimpo et al. [Olimpo et al. 1990].

Later indexing was applied in hypermedia and ITS authoring area. In the hypermedia authoring area, an idea of indexing was elaborated by Mayes, Kibby and Watson [Mayes, Kibby & Watson 1988] in the StrathTutor system. They stressed additional preference of indexing the frames of learning material - the possibility to indicate related pairs of frames not by tedious glossary linking of pieces of learning material together, but dynamically, on the basis of similarity of corresponded sets of topics. In the ITS authoring area, indexing was applied to turn traditional CAI into a "slightly intelligent" ICAI [Elsom-Cook & O'Malley 1990; Grandbastien & Gavignet 1994; Vassileva 1992]. "Slightly intelligent" ICAI are based on both the CAI and ITS paradigms. The teaching material is not generated as in 'orthodox' ITS, but stored in CAI-like frames. However, these frames are indexed with the concepts from an explicit domain model network, so they can be selected intelligently.

The most recent application of indexing on the crossroads of the above directions is hypermedia-based ITS which uses the indexing technology to connect the learning material represented in hypermedia form with the domain knowledge base. One of the first hypermedia-based ITS HITS [Tang, Barden & Clifton 1990] separates authoring of teaching material (creating hyperbooks) and course design. The duty of the course designer is designing a syllabus (a hierarchy of subjects with topics attached to it), to choose the hyperbooks to be used and to specify the goal level of student knowledge (in terms of the student model). HITS will manage the course itself, selecting or suggesting the relevant information and tests from the chosen hyperbooks according the syllabus. More recent hypermedia-based ITS are SHIVA [Zeiliger 1993], ITEM/PG and ISIS-Tutor [Brusilovsky, Pesin & Zyryanov 1993].

Concept-based navigation in InterBook

Indexing

InterBook represents educational material as a set of electronic textbooks (ET). An electronic textbook is hierarchically structured into units of different level: chapters, sections, and subsections. Several ET on the same subject form a bookshelf. All books from the same bookshelf are indexed by the same set of domain concepts. This set of domain concepts forms a domain model for the given subject. InterBook uses role-based indexing as suggested by Osin [Osin 1976]. Each terminal unit has an attached list of related concepts (we call this list *spectrum* of the unit) representing a name and a role of each concept in the unit. InterBook mainly supports two roles: outcome concepts and background concepts. A concept is included in the spectrum of a page as an outcome concept, if some part of this page presents the piece of knowledge designated by the concept. A concept is included into the spectrum as a background concept, if a student has to know this concept to understand the content of the page. These two roles have been shown to be sufficient in many contexts [Brusilovsky 1992; Capell & Dannenberg 1993].

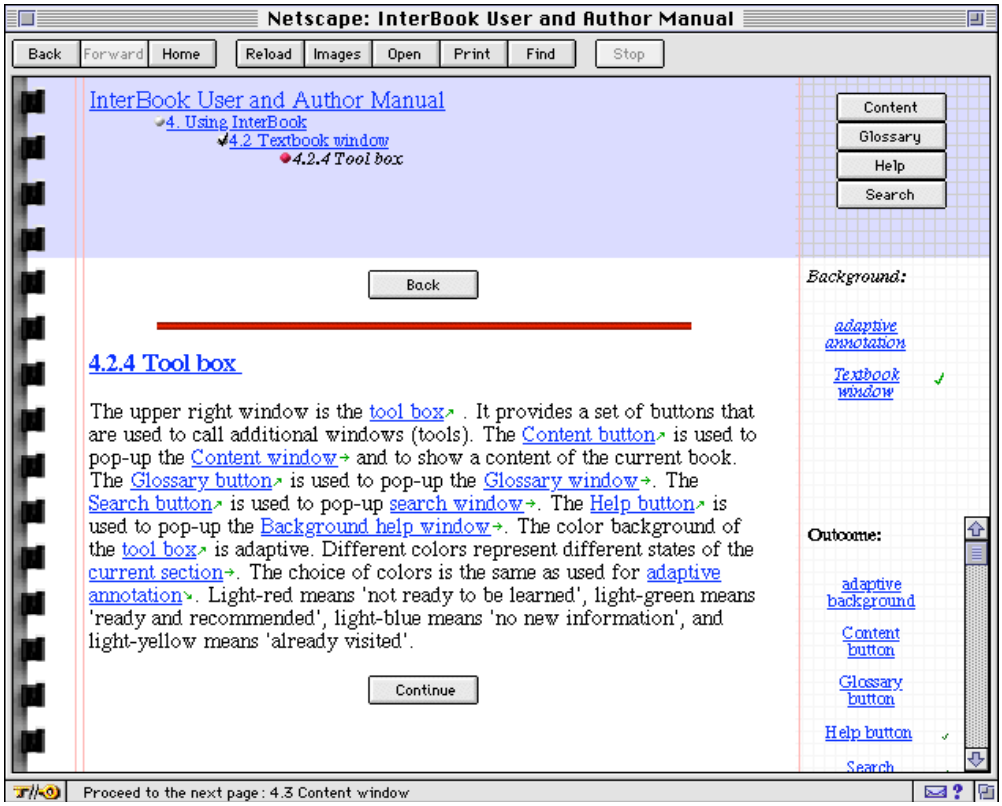

Figure 1: The main window of the textbook. The index is visualized at the right-hand side.

Student modeling

To represent individual user's knowledge InterBook uses an *overlay student model*. For each domain model concept, an overlay model stores a value which is an estimation of the user knowledge level of this concept (for example, unlearned, learned, and well-learned). This type of model is powerful and flexible: it can measure independently the user's knowledge of different topics. Student model and spectrum of a unit can be used to determine an educational state of the unit, for example, is it not ready to be learned (if it has unlearned concepts among its background concepts), ready to be learned (if all its background concepts are learned), or "nothing new" (if all its outcome concepts are well-learned).

The spectrum of a unit is also used to update the student model. When the user completes a unit (either a presentation or testing one) the "knowledge levels" for all concepts of the unit's spectrum are updated. The overall score of total knowledge is computed by adding factors like pure reading experience and passing or failing tests. Structure and algorithms for doing that are not important at this point and will not be discussed here.

Conventional navigation tools

InterBook provides a student with several popular navigation tools such as table of content, search, or navigation bar. These tools are used in a number of electronic textbooks. A specific feature of InterBook is that no authoring of these tools is required: everything is generated by the system. Each navigation tool presents some structured list of unit names which can be user for navigation (naturally, all names are clickable links). Table of content represents a hierarchy of units. Search tool lets a student find all units which contains a specific text.

Navigation bar [Fig. 1] shows names of all direct predecessors and all brothers of current unit. It provides an orientation support ("where am I?") and an easy way to move "up", "left", and "right" within the three of units.

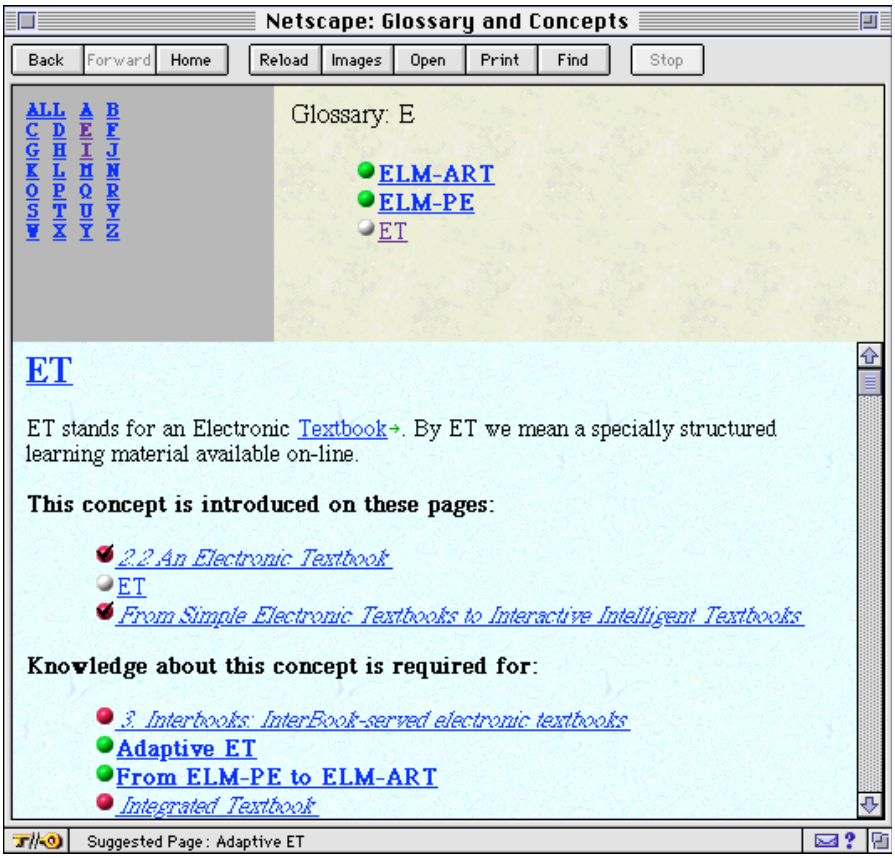

Figure 2: The glossary window displays a short description of the referred concept. Below this description pages and concepts are listed which either require or teach the current concept.

Concept-based navigation tools

In addition to regular navigation tools InterBook provides some concept-based tools. First of all, InterBook is able to construct a glossary of all domain concepts. Glossary is shown in a special Glossary window [Fig. 2] which contains an interface for locating a concept by its name. For each concept InterBook shows its description (if provided by an author) and generates links to all units, which has this concept in its spectrum either as a background or outcome concept. In this sense, glossary in InterBook unifies the features of two classic tools glossary and index.

Second, InterBook generates a concept bar for each unit [Fig. 1]. Concept bar shows clearly all background and outcome concepts for the unit. For a terminal unit, these concepts are taken from its spectrum. For a higher level unit, the list of background and outcome concepts is generated from the respective lists of its subunits. The outcome of any subunit is the outcome of the section, whilst prerequisites are only inherited from the subunits, if they are not taught within another subunit of the same section. This mechanism ensures that a student is always able to see the real educational closure of a section. We decided to show background and outcome of a section in two different parts or frames. Outcome and background are scrollable independently to assure fast access of both of them.

Additional links from the text of a unit to glossary concepts are generated based upon the concept names. These automatically generated links point to the glossary window, where the student, as described, has access to other units

which deal with that concept. Links to concepts from the text of a unit are annotated according to their role on the current page. Each link indicates whether the marked concept is an outcome concept, part of the background or just a reference to some concept without a certain role. Further InterBook allows for references to other pages, that might appear within the text.

With concept-based indexing, InterBook can build a naturally structured and tightly interlinked hyperspace of educational material, which supports advanced navigation. For example, a student can start from a unit which describes several concepts, then move to a glossary page which describes one of these concepts. If the student still cannot completely understand the concept, he or she can navigate to one of the units presenting this concept (i.e. having the concept as an outcome concept in the spectrum), which provide some example for the concept. Then the student can select one of the problems related with the concept to test the obtained knowledge. If the problem appears to be hard, the student can analyze the list of background concepts in the problem spectrum and move from a problem to the another concept which is not clear yet (and which can be far away in the network from the starting concept). Thus the user has many ways of navigation and many paths going from the current node to related nodes.

Navigation support

With its overlay student model, InterBook can provide additional help to a student in a form of adaptive navigation support [Brusilovsky 1996]. InterBook uses three main ways of adaptive navigation support. First, InterBook shows an educational status of each unit by marking each link to the unit with a colored icon. Each link to the unit is annotated in that way in all contexts where this link is shown: in the table of content, in the search list, in the navigation bar, etc. Different colors and icons represent different educational status. For example, "red" means not ready-to-be-learned and "white" means nothing new. Checkmarks indicate visited pages. The same color is used to indicate the status of the current unit page either by colored bars or colored backgrounds for concepts. Second, InterBook can provide background help on demand by showing an adaptively sorted list of pages, which introduce background knowledge of the current unit. These two ways of adaptive navigation support described in more details in [Brusilovsky, Schwarz & Weber 1996].

Third, InterBook shows the user's knowledge level for each concept represented in the concept bar by attaching icons of different size to concept names. No annotation means "unknown", small check mark means "known" (learning started), medium check mark means "learned", and big check mark means "well-learned". Red exclamation marks indicate concepts on which the student recently failed in solving a problem. In fact, what is shown to the student is the state of the student model. Such a technique is usually called visible student model. A specific feature of InterBook is that visible student model is used for orientation and navigation support.

Discussion: Benefits of Concept-Based Navigation

Visualization of indexing

We consider the visualization of indexing as an important technique. Our philosophy of books, chapters and sections having their own internal didactic structure, which should not be broken without any significant reason, lead us to visualize not only the content of the current page, but the content of the current section as well. InterBook provides navigation support not only for terminal pages, but also for books, chapters, and sections. This enables students not only to select page-by-page their own individual learning paths, but also to select larger units like section and chapter that will bring him to his individual learning goal.

We decided to implement some textual visualization in an old-fashioned hypertext style [Fig. 1]. We took into account that those interfaces are less transparent for novices, but the advantages exceed this problem: textual representation in lists take much less space than graphical one. The required space can be even collapsed, since it a quite easy to generate scrollable lists, which, of course, demand some basic skills on the user‘s side. Additionally textual representation can be easily extended with adaptive visual cues. Last but not least, old-fashioned techniques like hyperlinks are more transparent in usage and better known to more users.

Visualizing state of knowledge

It is important that in InterBook an implicit feedback about the state of each unit in adaptive hypermedia is represented by adding visual cues to links to that unit. A student that is looking for a strong support will work perfectly with such summarizing cues. For more advanced users this could be unsatisfying, because the navigation aids on a higher level of InterBook do just provide suggestions, but can't help with reasons for these suggestions. A page may be suggested because it introduces some very basic completely new concepts to the student or because it just talks about some concept of minor interests, whilst all other concepts are already well-known.

By annotating all concepts with adaptive checkmarks the student can gain an overview about the content of each page quicker [Fig. 1]. He or she can notice by looking at the annotations which are the missing concepts for a page or what really new can be learned on that page and why it might be unnecessary to read it, because almost all concepts are already known.

Visualizing Relationships between Units and Concepts

The logical next step of visualizing indexing information is taken by showing information about the current educational relationships between units and concepts. Some approaches use orientation maps, which are represented by a graph. These maps show pages as nodes and one or several concepts as edges [Capell & Dannenberg 1993]. Because these graphical ways of visualizing use a lot of space on the screen, they become completely insufficient in very complex learning environments with many sections and relationships.

Again we decided for some old-fashioned way of common hypermedia pages with simple hypermedia links. We put each of the edges and the nodes of the graph on a single page. As we did see in the last section, nodes are given by the text pages itself with visualized adaptive index. By showing the links in the visualized index the student can reach a concept page in the glossary [Fig. 1]. Such a concept page can be considered as an intelligent copy of an index entry in a common printed textbook. It shortly introduces the concept the page refers to and gives links to all pages where the concept can be learned, i.e. it is an outcome of the page, and for which pages it can be useful, i.e. it is part of the background [Fig. 2]. From this page the student can understand how the information flows through this concept. By this two-way navigation system implemented in InterBook the student is not provided with a general overview like in graphical representation, but he or she can follow information flow forward and backward in his or her textbook to understand the didactic relationships of current page and its conceptual environment. We get away from simple visualization of relationships towards real understanding of them, which should be the final goal of any teaching operation.

Concept-based navigation extends functionality of educational hypermedia systems. This approach is based on concept-based indexing and student modeling which show to be relatively cheap and useful technologies for authoring "more intelligent" hypermedia systems. We have described an implementation of concept-based navigation in our InterBook system for authoring Web-based hypermedia and argued for several benefits of this approach. We hope that our ideas will be useful for researchers in the field of educational hypermedia and that our tool will be useful for practitioners who are interested to extend their hypermedia systems with advanced way of navigation and adaptive navigation support.

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