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ABSTRACT

Hypermedia systems allow for the access of large quantities of information in flexible and interactive ways, facilitating the user's exploration of knowledge and learning. The educational system described in this paper integrates hypermedia with knowledge-based technologies. A hypermedia component in the system allows students to browse through information stored in a domain knowledge base dealing with urban planning and land use. The system is coupled with an intelligent tutoring component that allows students to attempt exercises. User "views" of the hypermedia network are dynamically generated, based on the system's analysis of student problems, misconceptions and learning needs. A representational scheme is described that integrates the components of the system into a coherent object-oriented framework. It is argued that a combination of knowledge-based techniques and hypermedia technology will be important in the development of systems that are flexible and adaptable enough to allow for the full potential of hypermedia in education. (Contains eight references.) (Author/AEF)

A Hypermedia-Based Educational System With Knowledge-Based Guidance

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Abstract: This paper describes an educational system that integrates hypermedia with knowledge-based technologies. The system contains a hypermedia component that allows students to browse through information contained in a domain knowledge base dealing with urban planning and land use. The hypermedia system is coupled with an intelligent tutoring component that allows students to attempt exercises. User "views" of the hypermedia network are dynamically generated, based on the system's analysis of student problems, misconceptions and learning needs. A representational scheme is described that integrates the components of the system into a coherent object-oriented framework. It is argued that a combination of knowledge-based techniques with hypermedia technology will be important in the development of systems that are flexible and adaptable enough to allow for the full potential of hypermedia in education.

1. Introduction

Hypermedia systems allow for the access of large quantities of information in flexible and interactive ways, facilitating the user's exploration of knowledge and learning. In hypermedia systems, users can navigate and browse through linked networks of information nodes consisting of varied media (e.g. text, images etc.). The potential of such systems is considerable and with the growing popularity of interactive graphical user interfaces and technologies such as multimedia, the need for techniques that allow users to access and navigate through large amounts of information will continue to grow. In the domain of education, hypermedia holds considerable promise. However, some basic problems still remain to be resolved. The flexibility that such environments provide the student can greatly facilitate learning and the exploration of knowledge on the part of the student. On the other hand this flexibility can also lead to common problems of disorientation. Thus users of hypermedia systems may find themselves "lost in hyperspace", not knowing where they are, what information is relevant to their current level of understanding and learning needs, and finally, how one can get to that information.

The need for intelligent guidance for users of hypermedia systems has been noted by a number of authors (David, Thiery & Crehange, 1989; Woodhead, 1991). Possibilities include intelligent means to alleviate information overload and reduce the complexity of hypermedia information presented to users to more manageable and meaningful "views". This could be extended to providing such intelligent presentation of information in ways that are tailored to the information needs and level of expertise of particular users. Key to the success of such systems will be the integration of hypermedia with knowledge-based technologies, such as expert systems (Briggs, Tompsett & Oates, 1991; Brusilovsky & Zyrajanov, 1993). A continuum of possible architectures that integrate hypermedia with knowledge-based systems can be conceptualized, ranging from loose coupling where the system architecture consists of separate knowledge-based and hypermedia modules, to tightly coupled architectures, consisting of integrated knowledge-based and hypermedia elements that work in unison, sharing data, knowledge representations and allowing cooperative reasoning (Ragusa, 1994). For example, Wang and Kushniruk (1992) describe a tightly coupled architecture that consists of a hypertext knowledge base that students can browse through, with an embedded intelligent-tutoring system (ITS) component.

In this paper it is argued that rigidly structured hypermedia networks - i.e. networks where all linkages between individual information nodes are "hardwired" or fixed by the system designer will not allow the user sufficient flexibility that will be needed for accessing the increasingly larger educational knowledge bases that are currently being developed. It is further argued that what is needed are schemes and knowledge representations that will allow for both static (fixed) and dynamically generated linkages among information nodes in the hypermedia network. Such dynamic linkage of information contained in a hypermedia network could be based on the student's learning performance and demonstrated level of expertise, resulting in a greater degree of adaptability in educational hypermedia systems. The display of information, the level of detail provided, the highlighting of information and the creation of possible paths (or user "views") through the hypermedia network that the user could access can be based on information contained in and continuously updated in a system model of the student. In previous work (Wang & Kushniruk, 1993), the authors have succeeded in using a student model to select exercises appropriate to the level of the student's learning. In this paper we extend this research to the design of a tightly coupled ITS-Hypermedia educational system. Various forms of information, including hypertext, graphic images, and test questions, can be accessed by students, while a knowledge based component continually monitors student performance and provides intelligent guidance in the presentation of the hypermedia. This paper explores some of these ideas in the context of an example application in the domain of teaching geographical concepts.

2. Overall System Architecture

This section provides a description of the overall architecture of a hypermedia-based educational system for teaching principles of urban planning, known as the "LAND USE Tutor". From figure 1 it can be seen that the system consists of a number of components. The four main components are the following: 1. a domain knowledge base (KB-Domain) 2. a user knowledge base (KB-User) 3. a knowledge base for controlling the hypermedia presentation (KB-Control), and 4. a display module.

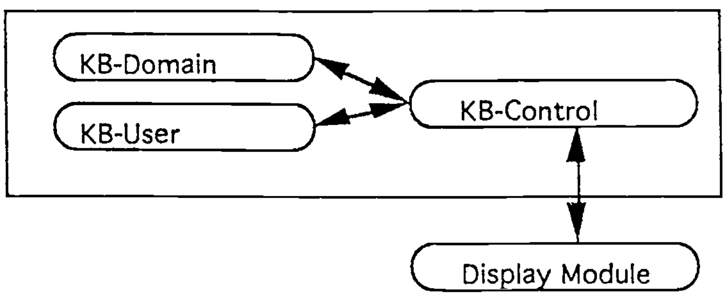

Figure 1. System Architecture

The KB-Domain contains domain specific information, for example information about site selection in planning urban developments. This information is accessed during the student's browsing through the system and consists of information nodes (using an object-oriented knowledge representation scheme described below) in a hypermedia network. The KB-User contains information about the user's interaction with the system and consists of a user model, that is developed by the system, as result of the student's browsing history and performance on exercises. The KB-Control is responsible for providing intelligent guidance by selecting a set of dynamically generated paths through the hypermedia network that the student can access. After every user action (e.g. mouse click, selection of hypertext etc.), one or more objects representing the action are created and asserted into working memory and a forward chaining inference engine is invoked to set one or more dynamic paths. The inference engine can apply knowledge contained in the KB-Domain and KB-User (e.g. information about the user's previous interactions with the system and difficulties) in conjunction with information about the user's most recent action. As a result, certain parts of the hypermedia network contained in the KB-Domain may be made accessible and salient (through the creation of dynamically generated links). The KB-Control also interacts with the Display Module, sending it selected parts, or "views", of the hypermedia network to be displayed.

3. Knowledge Representation and System Operation

Knowledge contained within the LAND USE Tutor is represented, using the object-oriented paradigm, in classes, subclasses and their instances, which are organized into instance hierarchies. In this paper we will describe some examples of classes using C++ format. For example, the hypermedia network is represented using a class hierarchy (a part of which is shown in figure 2) with class Geographical_HyperMedia (a subclass of System_Object) having the following description:

```
class Geographical_Hypermedia : public System_Object
    {
    String title;
    SET <Geographical_HyperMedia> Static_links;
    SET <Geographical_HyperMedia> Dynamic_links;
    ...}
```

This description indicates that all hypermedia information nodes in the system's domain knowledge base (belonging to class Geographical_HyperMedia) have a title (of type String), and two sets of links to other hypermedia nodes: one set of static links (that do not change) to other nodes and another set of dynamic links to other nodes (that can be determined at run-time, as a result of the student's interaction with the system).

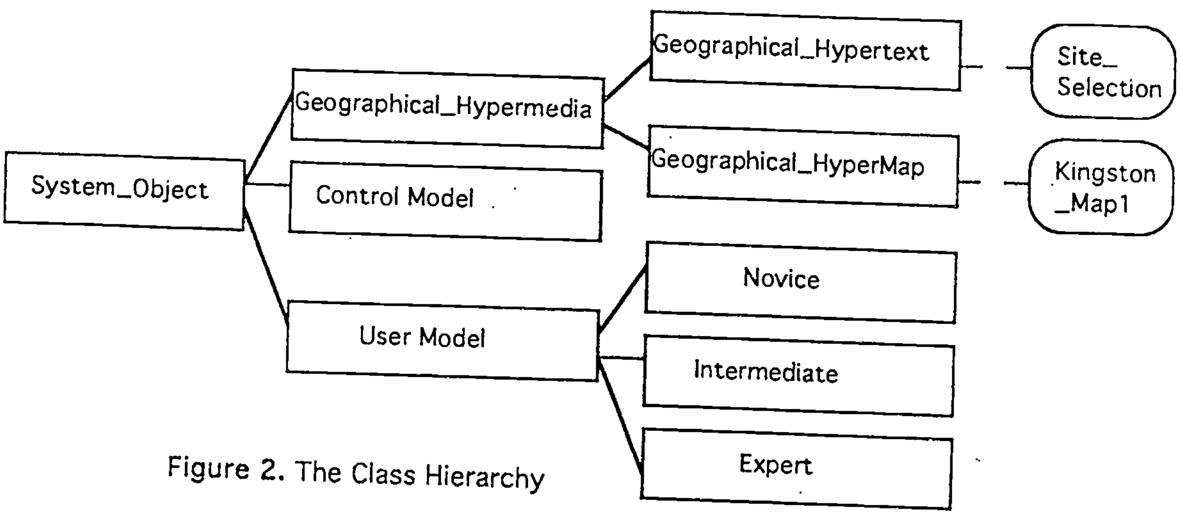

Figure 2. The Class Hierarchy

As can be seen in figure 2, two subclasses of the class Geographical_HyperMedia are the classes Geographical_HyperText (for hypertext information) and Geographical_HyperMap (for graphic information). A partial description of these classes is given below:

```
class Geographical_HyperText : public Geographical_HyperMedia
    {
    TEXT hypertext;
    ... }
class Geographical_HyperMap : public Geographical_HyperMedia
    {
    BitMap map;
    SIZE size;
    ... }
```

In the system, a particular instance of geographical information (e.g. an instance of a hypermedia node containing information about choosing site locations for urban development, such as the node "Site_Selection" in figure 2), will have only static fixed links and no dynamic links to other information nodes at the beginning of a session with a student (i.e. the list of dynamic nodes associated with that node is initially set to NULL). However, based on the results of the student's performance on exercises (see the next section on Student-Tutor Interaction for an example), dynamic links to other parts of the hypermedia network may be established (thereby adding new paths through the network that the student has access to in browsing). The description of a particular instance of geographical hypertext information, containing information about site selection ("Site_Selection"), is given below (note that this instance has a fixed, or static, link to an instance containing information about topography) :

```
Site_Selection InstanceOf Geographical_Hypertext
  {
    title: "Site_Selection";
    text: "Many factors must be considered when selecting
            a possible site for building or land development.
            These factors include:
                1. {\hypertext Topography}
                2. ... ";
    Static_links: {Topography, ...};
    Dynamic_links: NULL;
    chapter: Chapter_3;
    keywords: { "land use", "urban planning", ... };
    }
```

The ITS component of the Tutor is capable of detecting student misconceptions in problem solving (the design of this component is described in Wang & Kushniruk, 1992 and Wang & Kushniruk, 1993). This determination of possible student problems and misconceptions is based on a knowledge-based analysis of the student's responses to exercises. The dynamic linking of hypermedia nodes, based on the existence of student misconceptions, is triggered by the firing of the following generic rule:

```
FORALL $x InstanceOf Geographical_HyperMedia
    IF (established existence of misconception $m)
            AND Find_Related_HyperMedia $m $y
THEN  $x.AddDynamicLink($y)
```

This rule indicates that for a particular instance (instantiated to $x) of a geographical hypermedia node (e.g. containing information about site selection), if a related student misconception (instantiated to $m) is detected and if another hypermedia node (instantiated to $y) is found that contains remedial information related to the misconception, then the two information nodes (i.e. $x and $y) will be dynamically linked. Thus the two nodes will be directly connected at run time in the hypermedia network.

4. Student-Tutor Interaction

When the student first invokes the LAND USE Tutor, information about the student's previous interaction with the Tutor is loaded. A window containing a list of factors to be considered in selecting geographical sites for development is initially displayed from which the student can select. For example, if the student selects information about Topography, this results in the display of another hypermedia window containing hypertext information about the role of topography in selecting a site for building development (keywords in the windows are highlighted for which further information can be obtained). At any point in the student's browsing through the hypermedia network, the student can decide to test his/her knowledge of the information he or she is reviewing by selecting the exercises option from the buttons that appear at the top of each text window. For example, in Figure 3 the student has selected the exercise option while reviewing information about topography. At this point, the Tutor will select an exercise for the student to attempt, based on the system's assessment of the student's level of competence (see Kushniruk & Wang, 1991, and Wang & Kushniruk, 1992 for a discussion of exercise selection based on a student model). In the example interaction, the exercise for the student to attempt is presented in the upper right-hand window in figure 3.

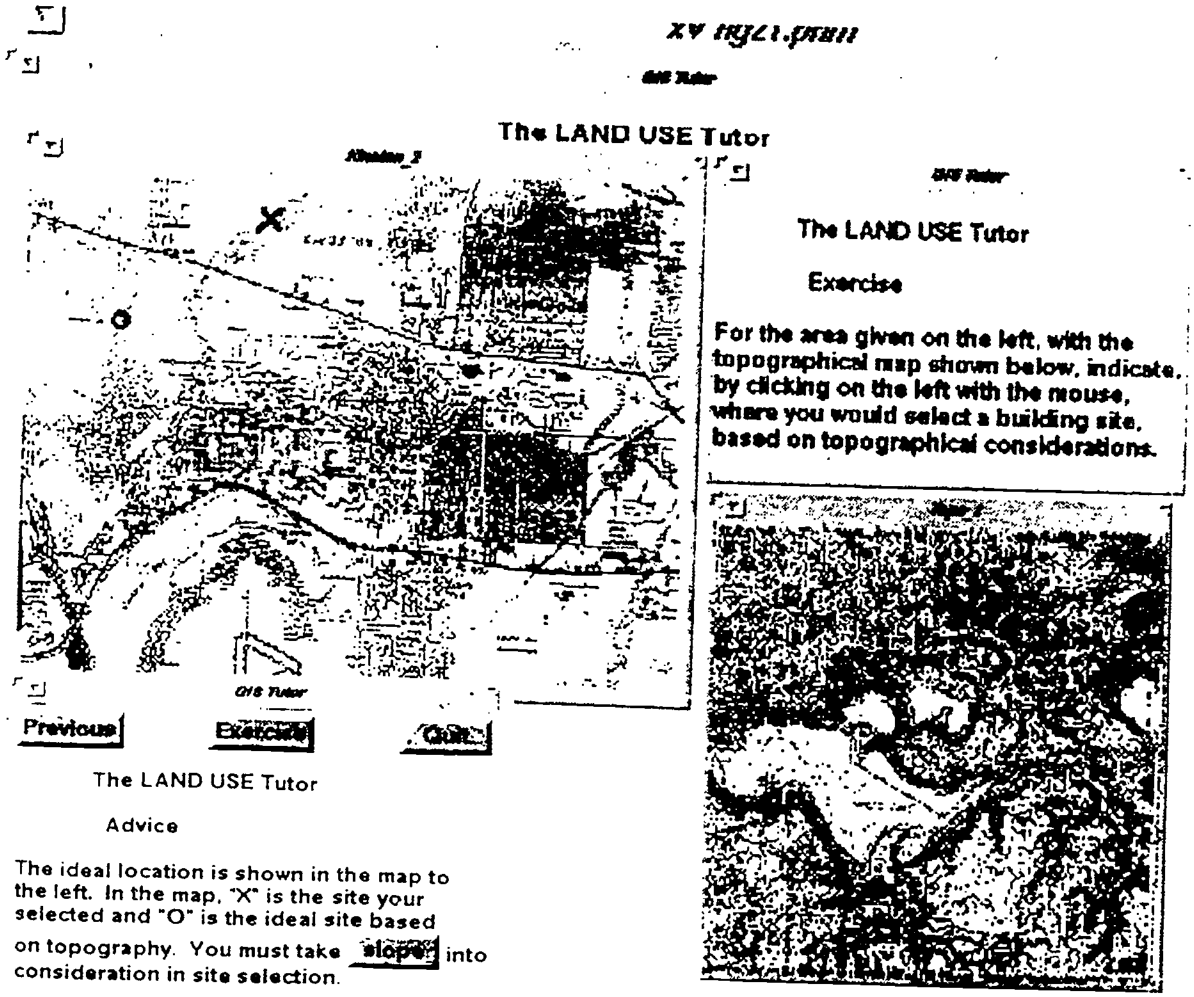

Figure 3. Example of Student-Tutor Interaction

For the exercise in the example, the student is instructed to indicate on the map given in the upper left-hand side of figure 3, where he/she would select a site for a building development. In addition, a topographical map is presented for reference purposes to the student (the map in the lower right-hand side of figure 3). The student selects the site area by clicking the mouse on the desired area of the map in the upper left-hand side of the figure. A knowledge-based expert system component is then invoked to analyze the student's response (i.e. the student's indication of where to locate the site on the map). A set of rules, associated with this particular instance of a student exercise, is invoked to determine if the site indicated by the student matches the ideal location for this particular exercise (i.e. the correct location). If it does not, a rule-based analysis of the student's answer is then invoked (using the techniques described in Wang & Kushniruk, 1993) and hypotheses as to the nature of any underlying student misconceptions are asserted in the Tutor's knowledge base.

The assertion of a hypothesis regarding the existence of a student misconception or misunderstanding may result in the generation of a dynamic hypermedia link to other nodes containing remedial or related information (thus directly linking the current node containing the exercise with other parts of the hypermedia network). In the example, the student had incorrectly located the building site, that is, without proper regard for the slope of the selected site. Upon analysis of the student's answer, an assertion was made that a misconception exits regarding the student's understanding of the role of slope in selecting a site based on topography. Using the generalized rule described in section 3 above (for dynamically generating links between parts of the hypermedia network), a link is made to the part of the domain knowledge base containing an information node about the concept of slope. Thus, in the window that appears in the lower left-hand corner of figure 3, advice is provided to the student, indicating that he/she must take slope into account. Note that the keyword "slope" has now been dynamically associated with information regarding that concept and it is highlighted as being selectable in the window containing advice in figure 3 (i.e. the student may now directly access information about the concept of slope by clicking on that keyword). Thus links within the hypermedia network can be dynamically altered as a result of the student's performance on an exercise and the resulting analysis of student errors.

5. Conclusions

In this paper we have described an educational system that integrates hypermedia with knowledge-based technology, providing user "views" of the hypermedia network based on an analysis of the student's problems and learning needs. It has been shown in this paper that knowledge-based techniques and representations can provide the needed means to achieve a degree of adaptability in hypermedia systems that is both practical and useful. In summary, some of the features of the system described in this paper include the following:

- The LAND USE Tutor integrates both hypermedia and knowledge-based technologies.
- The system incorporates a knowledge representation scheme that allows for the representation of the many types of knowledge required in such a hybrid hypermedia/knowledge-based system, within a coherent and integrated object-oriented framework.
- Knowledge contained within the Tutor is organized as a number of knowledge bases, simplifying the system's operation and the updating and acquisition of new knowledge.
- The LAND USE Tutor incorporates an ITS component that allows the student to attempt exercises related to topics being browsed. This component is also responsible for determining if underlying student problems or misconceptions exist.
- Based on the results of diagnostic processing, links between information nodes in the hypermedia knowledge base can be dynamically generated or modified, adding a level of system adaptability.

In conclusion, we feel that many of the ideas and techniques described in this paper could be extended to the design of a variety of types of computer systems. Furthermore, we feel that the integration of hypermedia and knowledge-based technologies will become increasingly important in the development of hypermedia applications and will be key in the development of future advanced educational systems.

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