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Cognitive Media Types as Indices for Hypermedia Learning Environments

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Abstract

In this paper, we propose a theoretical framework for designing indices for educational hypermedia systems. In this theory, we argue that the design of these systems and their and indices are best thought of in terms of "cognitive media types." Specifically, we argue that systems should not be characterized primarily in terms of the kinds of physical media types that can be accessed. Instead, the important aspect is the content that can be represented within a physical media, rather than the physical media itself. Cognitive media are based on a cognitive theory of the inferential and learning processes of human users, and encapsulate different methods or strategies for problem solving and learning. These strategies rely on specific media characteristics that facilitate specific problem solving actions, which in turn are enabled by specific kinds of physical media.

Introduction

Recent advances in computing technologies have made it possible to incorporate many types of physical media (e.g., video, sounds, text) into the design of new interactive, hypermedia environments. When building systems targeted for educational settings, designers must address important issues in how novices can gain access into a potentially large database of interconnected media types. In particular, designers need to address the kinds of indices that support access and learning in media-rich environments.

There has been little research has been conducted into how people actually use such systems, what kinds of usage improves learning and under what conditions, and what types of educational materials such systems should provide. A cursory review of the research literature reveals several approaches to the problem in which access and structure of a hypermedia system is determined by various "physical" properties of the information contained in the system. In one common approach, indices provide access into various physical media types. This means that the learner can choose to view text, video, sound, etc. However, research that compares learning from different media types are inconclusive in showing advantages of one physical medium over another. Research on what kinds of media types and materials facilitate learning is confusing and contradictory (Kozma 1991).

The lack of conclusive evidence demonstrating the superiority of one physical media over another reflects the fact that many factors, above and beyond simple media, affect a student's learning process. These factors include, for example, students' background knowledge, their motivation and interests, their learning strategies and goals, and the overall learning context (Recker & Pirolli in press). Therefore, rather than base the design of a hypermedia system on the physical properties of the information contained in the system, we propose that the indices and structure of the system should be based on cognitive aspects of the *users* of that information. By this, we mean that the access methods in a hypermedia systems should be "cognitively relevant" to the learning and information seeking goals of the user.

In this paper, we present a theoretical framework for designing indices for educational hypermedia systems. In this framework, we argue that their design and indices are best thought of terms of what we call "cognitive media types." Specifically, we argue that systems should not be characterized primarily in terms of the kinds of physical media types that can be accessed. Instead, the important aspect is the content that can be represented within a physical media, rather than the physical media itself. Moreover, the content and means of access to the content should structured so as to be cognitively-relevant to the user's goals.

Text is an example of a physical media type. It can be used to represent several cognitive media types. For example, text can be used to present abstract, general instructions. Text can also be used to display instantiations of these concepts within examples, or to provide explanations and annotations. Animations and pictures are other examples of physical media types. Animations can be used to exemplify general or specific instantiations of dynamic displays of processes. Pictures can be used to display graphical relations among concepts. Each of these cognitive media facilitate different learning inferences.

Cognitive media are characterized in terms of the inferential processes of the human user rather than physical properties of the computer representation. Cognitive media encapsulate different kinds of problem solving information which might, in turn, be composed of many different physical media.

We believe that it is essential to focus on cognitive media in order to understand how best to design multimedia systems that can support novices in learning or training situations as well as aiding experts in on-the-job situations. We are developing a theory and taxonomy of cognitive media types that we believe are useful in learning situations. In addition, we are attempting to specify at which point during learning they may prove to be more advantageous. For example, is a general principle more useful at the beginning of a learning session, or after the student has gained some experience in a domain? Finally, we are interested in determining the physical media types that can best represent the different cognitive media types.

In the next section, we present our theory of cognitive media types. We then describe an educational system that we are building within a hypermedia authoring environment, called MMEDS (Li, Gallant, & Stasko 1994). This system will be used to evaluate our theory and to determine general guidelines for the design of hypermedia learning environments.

Cognitive Media Types

In our theory, multimedia information can be thought of as composed of three layers. At the lowest level are media types, for example, text, video, animation, etc. They are defined by characteristics of the physical (on-screen) media used to represent different kinds of information. Although often distinguished based on perceptual modalities (for example, visual vs. aural), they may be also characterized by the types of inferences that they facilitate. For example, figures (or diagrammatic representations) can facilitate spatial inferences (Larkin & Simon 1987) Thus, media types can be classified based on "cognitive" distinctions that depend not on physical characteristics of media but on the reasoning processes of users.

For example, consider the following example from Boden (Boden 1991). A 20-foot rope is tied to and hanging between two buildings that are some distance apart. Given that the lowest point of the rope is 10-feet below the tethered ends, how far apart are the buildings? In this example, most people tend to draw a diagrammatic representation of the problem showing the two buildings and a rope hanging in some sort of arc between them—this representation enables all kinds of fancy mathematical (geometric) reasoning which in this case is absolutely the wrong way to solve the problem. Boden points out that mathematically-inclined people tend to take a long time to solve this problem because they usually start by drawing a picture of the hanging rope, whereas less math-sophisticated people find it easier to solve because they do not rely on diagram-based geometric reasoning. The point is that a type of physical media—here, a diagram—can affect the course of problem solving by facilitating certain kinds of inferences and making others harder.

At the next level are the media characteristics (Kozma 1991). These are a characterization of the kinds of problem-solving actions that people might perform during a task. For example, *zooming* is a problem-solving action that focuses attention on and highlights the details of a problem situation; such an action is easier in a diagrammatic representation than in a symbolic one.

Finally, at the level above media characteristics, are cognitive media types. For example, *zooming* is a particular problem solving action—more precisely, a particular schema for a problem solving action which results in certain inferences—whereas at the higher level one might have schemas for problem solving strategies as a whole. So, for example, one may resort to case-based reasoning (Kolodner 1993), go back to first principles using basic definitions and equations, or reason using constructive simulations (Soloway *et al.* 1992).

A case is a type of media (characterized at the cognitive level) that facilitates the former (case-based reasoning) problem solving strategy. Using a case requires (among other things) zooming into the differences between the case and the problem situation so that the differences can be characterized and the case suitably adapted. Zooming in and adaptation are specific problem solving actions that are facilitated by different media characteristics; these characteristics, in turn, are enabled by specific physical media.

To take another example, consider *Emile*, a multimedia environment in which subjects learn physics by constructing physics simulations (Soloway *et al.* 1992). While the physical media characteristics—animations—are similar to those of many other animation-based learning environments, the crucial difference lies in the reasoning processes used by the student—here, constructive experimentation rather than passive observation.

We are developing a taxonomy of the kinds of cognitive media types used in learning and how these are best represented within of physical media types. We are also interested in determining the kinds of learning inferences they facilitate. Table 1 shows a partial taxonomy and examples of types of physical media we are using, and the kinds of cognitive media that can be represented within each physical media.

It is important to note that physical media types and media characteristics can be defined without a strong appeal to a cognitive theory of reasoning and learning. This is not true of cognitive media types—the structure, content, and use of cognitive media types is a function of the researcher's theory of cognition. This has two implications. First, the design of effective hypermedia environments must take into account

Examples of Physical Media	Examples of Cognitive Media Types
Text	Abstract principles Specific instructions Annotated cases or examples Explanations Annotations
Animations	Dynamic display of process
Pictures	Graphical display of relation among processes Examples Diagrams
Sound	Voice-over of text Warnings Summaries

Table 1: Partial taxonomy of physical media and cognitive media types

a cognitive theory of how the user interacts with the environment. In particular, the design must be based on considerations of how the user will think, use, interact with, and learn from the environment. The second implication is that such cognitively-based hypermedia environments are not just likely to be more effective, but in addition might be used to test the validity of the cognitive principles on which they are based.

Evaluating the Theory

We are currently designing and implementing a hypermedia learning environment based on our theory of cognitive media types. In this section, we describe our authoring environment, the courseware we are developing, and our plans for empirically evaluating how students use and learn within the environment.

Overview of MMEDS

In our implementation, we are using the "MultiMedia Education Delivery System" (MMEDS), as a multimedia authoring tool. MMEDS runs on workstations under X-Windows and Motif. It provides a set of tools for authoring and presenting multimedia-based courseware. These tools enable the author to create, organize and synchronize educational information within an open and extensible architecture. Authored course modules utilize a hypermedia, networked organizational model and support the presentation of text, audio, still graphics, animations, and other arbitrary programs (Li, Gallant, & Stasko 1994).

Using the MMEDS authoring environment, we are designing an educational module targeted for introductory computer science and engineering classes. The module, called AlgoNet, will allow students with minimal background to learn about basic algorithm concepts, such as graphs and sorting. AlgoNet consists of a collection of information nodes, which are linked together to create one large educational document. These nodes are analogous to sections of a book in that they each cover one specific subsection of the entire module. However, unlike a book, the nodes do not have to be viewed in any particular sequence. Moreover, the nodes within the module can contain a variety of different information types such as text, pictures, animation, buttons, and sound. Each node can be activated (or played) many times. In addition, the AlgoNet module is an active document. Many nodes are interactive, requiring active student input, construction, and involvement.

Planned Studies

We are planning a set of empirical studies to evaluate our theory of cognitive media types, and to determine general guidelines for designing hypermedia learning environments. The studies will involve beginning computer science students and will use the AlgoNet courseware on basic computer and engineering concepts and algorithms.

The studies will investigate the effects of providing different indices into the multimedia courseware. Our particular focus is on how different media indices may affect student learning and the kinds of information seeking strategies that students employ.

To evaluate our theory of cognitive media types, we are currently implementing two versions of the AlgoNet courseware. In the first system, access is provided via physical media types. For example, students can click on buttons to view animations, pictures, or text, etc. In the second, contrasting system, access into the courseware is via indices that specify particular cognitive media types. For example, students can view definitions of concepts, examples of concepts, or case studies that use the concepts, etc.

In addition to manipulating index types, we are interested in determining how these indexing schemes may interact with student learning goals. To examine this possibility, groups of students within each experimental conditions will be provided with focused questions that they must answer through interacting with the course module.

We plan to examine student interaction patterns and strategies in order to determining how these learning goals are supported by the multimedia indices. Student interaction patterns and strategies will be analyzed by examining the log files that record how students choose to browse and interact with the courseware. Learning outcomes will be determined by analyzing students' performance on a post-test.

Conclusion

The indices and structure of hypermedia systems are typically based on the physical properties of the information contained in the system, and on the structure of the actual content or subject matter of that information. In this paper, we have argued that the design of hypermedia systems should be based on cognitive considerations of the users of the information. We have presented a theoretical framework for designing indices for educational hypermedia systems based on what we call "cognitive media types." Cognitive media are based on a cognitive theory of the inferential and learning processes of human users, and encapsulate different methods or strategies for problem solving and learning.

We believe that the design of effective hypermedia systems must be based on a functional theory of human cognition that specify these strategies in sufficient detail to allow the system designer to understand how precisely they might be facilitated. In particular, problem solving and learning strategies rely on specific functional media characteristics that facilitate specific problem solving actions, which in turn are enabled by specific kinds of physical media.

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