A COGNITIVE PERSPECTIVE FOR DESIGNING MULTIMEDIA LEARNING ENVIRONMENTS

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ABSTRACT

This paper discusses cognitive and cybernetic theories of human learning and how these can influence the design of multimedia learning environments. We first briefly outline the formalised theories of cognitive flexibility, discourse, activity and conversation from the perspective of the way in which the hypermedia may be semantically structured to facilitate learning. Two instances are then presented: Conceptura, as an environment here being introduced to the literature for adaptive concept visualisation, teaching and assessment in complex domains based on the Conversation Theory of Pask (1975); and InterBook (Brusilovsky, Schwarz & Weber, 1996a) which offers adaptive navigation support in an information space structured through a domain model of pre-requisite and outcome concepts, based on Discourse Theory (Hobbs, 1979; Reichman, 1979; Grosz and Sidner, 1976). Both environments use a network of concepts to represent knowledge about the subject domain, although the implementation and visualisation of this network differs.

KEYWORDS

Cognitive, adaptive, multimedia.

1. A BRIEF SURVEY OF COGNITIVE THEORIES

It has been suggested (Jonassen, 1992; Spoher, 1994; Eklund, 1995) that hypermedia is particularly useful in facilitating learning because hypertext structures reflect a map of knowledge in the human brain according to a cognitively based theory. In schema theory for example, learning is the accumulation and organisation of knowledge structures. These knowledge structures are a representation of the organisation of ideas in our semantic memory. Each knowledge structure exists as an object, idea or event as well as a set of attributes, which link it to other knowledge structures. As we learn, we gain new structures and links, adding information to existing structures (also known as accretion), or alter existing structures through a process of restructuring. Restructuring also involves grouping knowledge structures into procedures, or coarser-grained schemas. Our knowledge thus exists in a semantic memory, which is a network of interrelated concepts.

1.1 OCTR

These ideas are formalised in a cognitive model proposed by Chan *et al* (1993) called OCTR, which suggests four stages in human learning: orientation (relating prior knowledge), coaching (apprenticeship learning), tuning and routinisation (practice with gradually more student autonomy). This model emphasises the constructivist view and also assumes knowledge consists of units and links. The distinction is made between strong and weak links. The four stages in learning involve the creation of weak and strong links between ‘proper old knowledge’ (p. 259) and new material. The stages in the learning model are qualitatively explained in cognitive terms through processes of connection (weak links are created between old knowledge and new knowledge), accretion (knowledge is expanded with many new weak links created), articulation (links are strengthened while some are deleted), and solidification (units and links are strengthened). Chan *et al* (1993) demonstrate the links in the design of a computer system through a tree diagram of the knowledge architecture, represented as a learning goal hierarchy. Each node in the hierarchy possesses a ‘cluster of episodes’ (p. 262) which is essentially a small unit of related material from the domain.

1.2 COGNITIVE FLEXIBILITY

The interrelationship of hypermedia nodes as concepts is also reflected in Cognitive Flexibility Theory (Spiro & Jehng, 1990; Spiro *et al*, 1992) which is the belief that examining a concept from more than one perspective increases comprehension of the concept itself and also the ability to transfer that understanding to other domains. This means that presenting material in a variety of forms, examples, case studies, interactive exercises, is likely to have a positive effect on learning. Likewise, examining different concepts from the same perspective can also lead to new insights. This holds true especially in ill-structured domains. Multiple representations are a primary aspect of this theory and implementing multiple teaching strategies in a learning environment supports this. Coming to an image or idea from several directions reinforces both the new idea and the concept from which one came, since the link forms a new bond between two otherwise unconnected concepts.

1.3 ACTIVITY THEORY

Work is being currently undertaken at The Human Communication Research Centre in Leeds, UK spent in examining the idea of multiple linked representations. This group decided that cognitive flexibility theory to be inadequate or incomplete, and that a combination of ideas from Salomon and Activity Theory were promising (Brna, 1988, 12 May). Salomon, Perkins & Globerson (1991) write about the cognitive effects of the intellectual partnership between intelligent machines and humans, that “...technology, activity, goal, setting, teacher’s role, culture...” (Salomon *et al*, 1991 p. 8) have the combined effect of enhancing intellectual performance (Salomon & Perkins, 1988), and this has been shown to be the case with learning a programming language (Salomon & Perkins, 1988). “Activity theorists argue that consciousness is not a set of discrete disembodied cognitive acts (decision making, classification, remembering), and certainly is not the brain; rather, consciousness is located in everyday practice: you are what you do. And you do is firmly and inextricable embedded in the social matrix of which every person is an organic part. This social matrix is composed of people and artifacts. Artifacts may be physical tools or sign systems such as human language.” (Bonnie, 1996; p. 7). Activity Theory emphasises an object oriented approach in that it mediates interactions between subjects and objects. Activity is not achieved in isolation, as we live in an objective reality, which determines and shapes the nature of subjective perceptions. Accordingly the theory differentiates between internal and external activities, those that are unseen and largely unquantifiable mental operations taking place in the subjective human mind, and those that are identifiable, objective and directly alterable. Activity Theory is a holistic, emergent view of learning based on the idea that human learning is mediated through practical activity; activity is mediated by cultural signs: language, tools, media, and conventions; and these technologies are themselves the artifacts of practical activity. As the artifacts change, activity changes along with the consciousness of the participants in a continuous, evolving cycle of learning. Activity is fundamental to learning as it precedes knowledge and there is no understanding apart from it.

1.4 DISCOURSE THEORY

The idea of a transaction between object and subject is also espoused in Discourse Theory. This is a generally under investigated research area which is directly relevant to navigation in hypertext systems (Inder & Oberlander, 1994 [HREF2]). Theories of discourse structure are designed to model the construction and evolution of the structures underlying extended dialogues. Drawn from the field of natural language processing, the focus has been on the creation and analysis of coherent discourse (Hobbs, 1979; Reichman, 1979; Grosz and Sidner, 1976; Mann & Thompson 1987). Theories have been offered which attribute hierarchical structure to discourse, and relations of various types between the discourse segments. The theories attribute certain characteristics to links between the segments: both in terms of the user's 'reasons' for making the connections and how these connections make some individual meaning to the user. These theories help to determine which structures and knowledge sources are relevant in either interpreting or generating a connected discourse which is meaningful for an individual – a user's discourse with the knowledge is defined by the particular path they take through it, and this is facilitated by navigation tools which acknowledge the individuality of those paths. For example, static navigation features such as 'next' or 'continue' provide one path through the hyperspace and thus present a static discourse. Adaptive link annotation, on the other hand, recognises an individual's path through the learning space as their 'learning context' or discourse with that knowledge.

As learners may construct a great number of varying paths through a hypertext system, they have different interactions or discourses with the knowledge. The choice of navigation may be influenced by task and document structure (Wright & Lickorish, 1990), as well as the prior knowledge and intent of the learner. Because of the individuality of paths through hypertext, the notion of 'Next' is somewhat redundant, 'next' for one learner can be very different from 'Next' for another. This also brings in the notion of context: Books have a well-defined structure with chapters, sections, indexes, etc. This structure is chosen by author to help the reader integrate the information effectively, on the assumption that the text will be encountered in a linear order, and readers can be assumed to know what they have just read. Hypertext authors cannot generally rely on any such order effects – they cannot assume that a node will be read after the ones that come before (Neilsen, 1990).

1.5 CONVERSATION THEORY

Conversation Theory (Pask, 1975) is a generalised cognitive theory which characterises learning as transaction between, in the case of computer assisted learning, a computer and a human. Conversation theory is of particular interest because there are direct parallels between the structuring of hypermedia as a conceptual network of knowledge is represented as a semantic network of interrelated concepts, a 'concept mesh', with the learner's ultimate task to attain concepts at the top of the hierarchy. By exteriorising the learning paths that a user may take through the concept mesh, making the concepts and their interconnections immediately obvious to the learner, it allows the learner to form a cognitive map of her progress through the material. Dependency between concepts and therefore prerequisite information is implicit, allowing the user to freely navigate any particular path in the learning style-neutral manner; the learner builds her own relational network of concepts from a number of possible paths.

The second focus of Conversation Theory is on the exchange of information between the participants of what is termed a 'learning conversation', where the learner is paired with a teacher (in this case a computer system). This technique, employed in the works of Piaget since the mid 1920's as well as numerous others, seeks to exteriorise conversation on two different levels, what Activity Theory refers to as external (L1) and internal (L0) learning processes. Pask argues that cognition in the present and broad sense of the word is a general process, biological cognition (internal process) is a specialised example of it. As Laurillard (1993) outlines this conversational framework – on one level, the teacher and learner interact directly on the task to be accomplished (real world action) and on another level, the two reflect on the actions and concepts needed to perform the task. By differentiating the two distinct levels of interaction between the participants in the learning conversation, we are able to more effectively utilise teach-back – a learner's cognitive model of an artifact is compared with the teacher's on the L1 level (indicating that the learner has the concept), and then an L0 level conversational exchange is carried out where the learner proceeds to demonstrated how the concept was realised.

2. COGNITIVE THEORIES AND THE DESIGN OF MULTIMEDIA

Brown (1990) and other writers (Anderson, 1992; Corbett & Anderson, 1990; Swan, 1989) have explained how current theories and architectures in intelligent systems have impacted upon learning theories, and vice-versa. Brown makes the distinction between explicit cognition (practice) and implicit cognition (theories), and draws parallels between the ways that students learn outside school (by experience, demonstration, problem solving in practical situations), and in school (through formal reasoning and abstraction). The analogy is extended further to everyday cognition (typically those types of processes in which one would engage in the course of ordinary living, often achievable by rote learning) and expert cognition (the ability to abstract problems in order to solve them). Brown's assertion that theories of learning and intelligent system design are related is supported by Anderson (1989), who argues that there is considerable research in cognitive psychology which can be used as a guide to the development of computer based learning environments. He states that the success of an environment can depend on its ability to achieve 'task decomposition', a process of simplifying learning, and the monitoring of student's belief by generating production rules (task analysis) for a restricted knowledge domain.

Inherent in implementations of hypermedia there is an author/expert defined structure of the material, simply in the sequencing of the nodes and the availability of associative links (permissible progression paths) between them, and this has been the predominant approach to structuring educational hypermedia to date. It is based on the idea that an expert's sequencing and linking of concepts (depicted as nodes), combined with a domain referenced design of interface ergonomics, will provide a knowledge structure which reflects the way learning typically takes place in the content area. However, a fundamental limitation of this approach is that not all students are typical. The sequencing of the material and the links are fixed, and not dependent on the individual user's responses or actions. Unlike intelligent systems, hypertext-based systems are most often a static, non-adaptive learning medium. They have been described as 'user-neutral' (Brusilovsky & Vassileva, 1996) because they know nothing of the characteristics of the individual user. They do not teach, but instead provide students with an excellent opportunity to learn of their own accord, and have been described as a non-pedagogical technology (Duchastel, 1992).

It has been suggested that organising the hypermedia using a concept map (or cognitive map) as a semi-formal means of knowledge representation (Gaines & Shaw, [HREF3]; Jonassen & Wang, 1993) provides a means of internally structuring (Eklund & Zeiliger, 1996) the hypermedia according to a model of cognition for the domain (see also Spoher, 1994). The partitioning of courseware into concept-related nodes, or logical pages (Hekmatpour, 1995) in which the concepts are logically ordered and linked by an expert who imposes her understanding of how learning can be sequenced in the domain, reflecting the cognitive structures of the learner, is a technique for adding internal structure to a hypermedia system. Asking students to generate concept maps has been shown to be effective as an instructional technique in that it encourages them to organise and systematise their knowledge, identify gaps and be explicit about relationships between ideas (Novak & Gowin, 1984). Further, this structural knowledge has been shown to be highly individual (Jonassen & Wang, 1993).

Whether the knowledge structure is imposed on the hypermedia in an informal way or developed through a cognitively based theory (Recker *et al*, 1995), the environment remains passive, ignorant of the individual knowledge state of the user. The hypermedia is static, inflexible, and presents in an identical manner for each user. This is overwhelmingly the case with the educational hypermedia on the Web. Further, empirical studies have underscored weaknesses in learning from internally or semantically structured hypermedia, and strengthen the case for a more dynamic external structure to be applied to the hypermedia, which accounts for the specific knowledge and tasks of an individual user. This has led to the development of adaptive systems.

Clearly the models of cognition upon which adaptive educational systems are explicitly based as well as aspects of student versus system control are important issues in the design of these systems. More critical is the way the hypermedia is structured to reflect the knowledge of the expert as well as that of the student. Spoher (1994, p.77) suggests that an important reason why much instructional hypermedia systems exhibit difficulties is that they are based on new technology which has not been designed on a cognitively-based theory. "The design issue goes well beyond issues of navigational tools and screen layout. For if cognitive science is correct about the characteristics of effective conceptual neighborhood structure, then hypermedia design must also incorporate an appropriate structure for the corpus itself". An expert may thus define the precedence relationships between knowledge elements, while the environment allows freedom of navigation for the learner to construct individual networks of cognitive links (within those defined precedence boundaries).

In the following sections we describe two adaptive educational systems and the cognitive theories on which they are based. These systems have approached the issue of user-centric learning through two visually differing methods, with the intent of providing navigation paths through the system that is user-definable.

3. INTERBOOK

InterBook (Brusilovsky, Schwarz & Weber, 1996a) is a system for authoring and delivering textbooks on the Web using adaptive link annotation as a form of navigation support (Brusilovsky, Eklund & Schwarz, 1997). It is based on a suite of systems known as ELM-ART (Brusilovsky, Schwarz & Weber, 1996b) which were developed at The University of Trier in Germany. Its main departure from the ELM-ART system was domain independence: a total package for authoring and delivering adaptive electronic textbooks on Web with any suitable content, using the Common Lisp Hypermedia Server [HREF1] (CL-HTTP) (Mallery, 1994). It also used slightly different annotations than ELM-ART, and offered new features such as 'teach this page'; an idea attributed to Schwarz. As a Web-based computer mediated courseware delivery tool it has no conferencing facilities, and may be best described as an environment in which structured textbooks could be presented in a multiply navigable interface. Any knowledge base that contains reasonably specific and identifiable knowledge elements that can be organised hierarchically into sections, subsections and indexed in detail is suitable for delivery through the InterBook system. Technical and software manuals are an excellent example of suitable material. InterBook takes the structures commonly found in such a textbook (such as tables of content, indexes and glossaries) and delivers them on the Web with navigation support, providing individualised assistance to each learner.

All InterBook-served electronic textbooks have a generated table of content, a glossary, and a search interface. In InterBook, the structure of the glossary resembles the pedagogic structure of the domain knowledge in that each node of the domain network is represented by a glossary entry. Likewise each glossary entry corresponds to one of the 'domain concepts'. All sections of an electronic textbook are indexed with 'domain-model concepts'. These are what are commonly termed attributes in other systems (Eklund & Sawers, 1996); they are basic knowledge elements. For each section, a list of concepts related with this section is provided (called the spectrum of the section). The spectrum of the section also dictates the role of a concept in the section (each concept can be either an outcome concept or a background concept). The knowledge about the domain and about the textbook content is used by InterBook to serve a well-structured hyperspace. In particular, InterBook generates contextual links between the glossary and the textbook. Links are provided from each textbook section to corresponding glossary entries for each of the involved background or outcome concepts. Similarly from each glossary entry, which describes a concept, InterBook provides links to all textbook units that can be used to learn this concept. This means that an InterBook glossary integrates features of an index and a glossary. These links are not stored in an external format but generated 'on the fly', in other words dynamically, by a special module that takes into account the student's current state of knowledge represented by the user model.

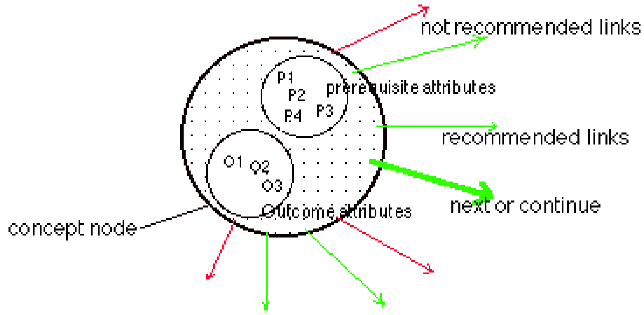

Figure 1: Pre-requisite and outcome attributes at a concept node in the InterBook tool

InterBook uses coloured bullets and different fonts to provide adaptive navigation support through link annotation (Figure 2). Annotations are evident in the individual section of the text (in the textbook window, as below) as well as in a local overview map (on the navigation bar).

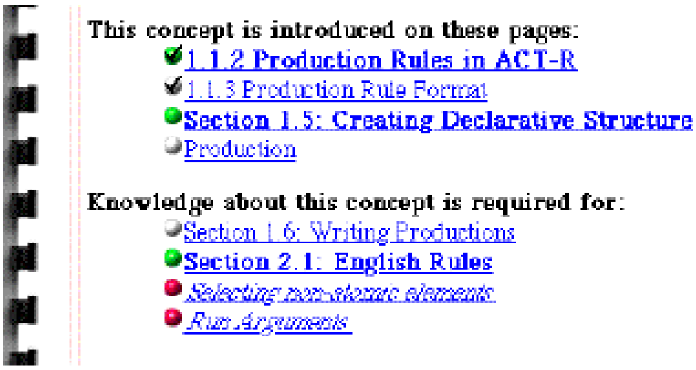

Figure 2: Adaptive link annotation in InterBook

There are clear parallels in the design InterBook and Discourse Theory. InterBook structures a knowledge space in a conceptual network, with nodes represented as chunks of knowledge in the textbook window. InterBook emphasises the individuality of user paths through an information space, their 'discourse context' [HREF2], and adds the 'intelligence' to the transaction between subject (the user) and object (part of the conceptual network) to assist in traversing that space. InterBook offers a highly structured information space in which a user may have many possible discourses. The semantic structure of knowledge in InterBook represents the author's discourse context. The linear reading of the text, as the user presses the 'continue' or 'next' button means that individual will have the same discourse with the material. Books are meant to be read in a linear manner, although this does not always occur. Hypertext offers multiple discourses with the material, and the purpose of the link annotation as navigation support is to suggest an author-defined context – a preferred path through the information space. Inder & Oberlander [HREF2] make it clear how the navigation features of hypertext systems can effect a user's discourse context – generally learning material is structured in a linear manner with nodes in a author specified sequence and certain features allow the user to move around the current node, gaining insights into the knowledge at that node via pop-ups and so forth. In the case of InterBook the knowledge in the node was represented in the textbook window, and the toolbar, navigation bar and concept bar provided additional information associated with that node. A clash between the author's and the user's discourse context does not occur until the user makes a jump to another non-sequential node.

4. CONCEPTURA

Conceptura, under development at Griffith University in Queensland, Australia was conceived with a brief of providing a means of delivering interdisciplinary subject material in a non-trivial problem space, namely enterprise engineering methodology. It comprises three main components: adaptive concept and link visualisation; explanatory material for each concept; and a system of teach-back assessment, and is primarily based on Gordon Pask's formalisation of Conversation Theory (1975).

As with InterBook, adaptive link annotation is used, providing visual feedback of the current state of nodes and links. However, the underlying network of concepts which both systems use to describe learning-order prerequisites, and therefore the entailment structure of the cognitive mesh of concepts, is exteriorised to the learner. By making explicit the interconnection between concept nodes and therefore the number of permissible methods of learning any given concept, the learner always has at her disposal a visualised cognitive map of goals and subgoals, as well as immediate feedback on progress through the mesh. This addresses many of the problems related to the concept of 'global coherence' (Thuring, Hannemann & Haake, 1995).

The concept mesh developed for Conceptura (Figure 3) is initially assembled from a number of expert-prescribed learning paths through the problem domain. While (as with hypermedia systems) the user is free to navigate along a path according to her own preference and learning style, the system is also able to visually indicate a given path through the material based on the user's background and learning requirements. Although similar to previously constructed systems such as SEPIA (Streitz *et al*, 1992) in that mesh visualisation is made explicit, Conceptura does not follow a true 'tree hierarchy'. Concepts may be learnt in a way which could impact upon the paths taken through the mesh and the way other concepts are thus developed, and through a series of abstraction and generalisation, a circular path may be in fact developed (Pask, 1975). In addition, Conceptura can suggest a progression path based on two factors: firstly from an initial survey of the learner's background and ultimate learning objective, and secondly recommend a path to continue based on the concepts already learned.

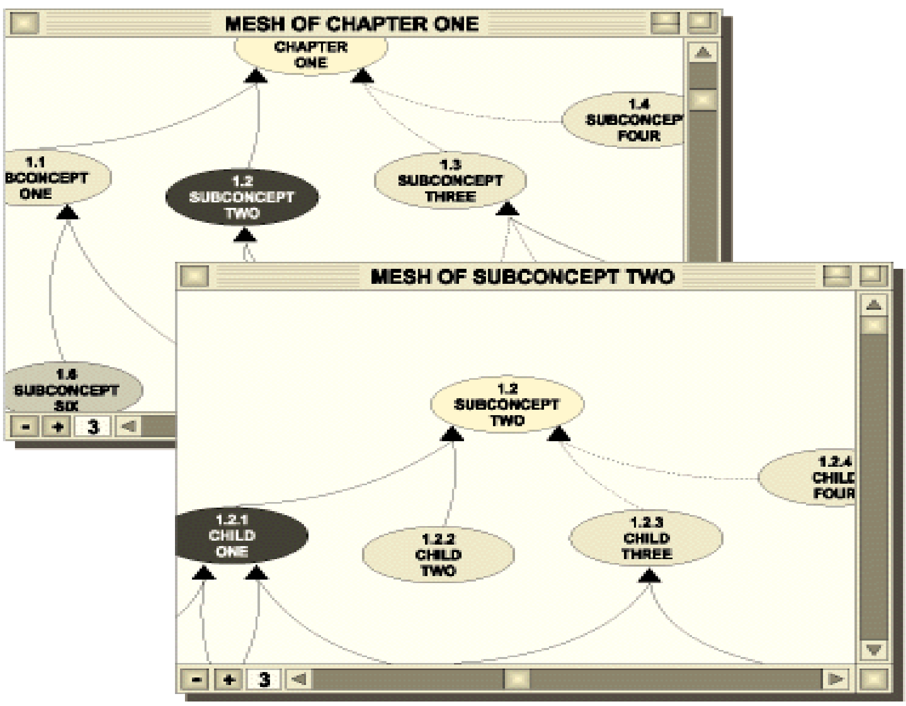

Figure 3: Domain structure of Conceptura

This view of the concept mesh is the main interface to the system. We make the distinction between two types of concept nodes in the system, (a) ‘derived’ nodes similar to InterBook’s outcome concepts and (b) ‘base’ nodes or background concepts. Each derived node has one of three possible states: Explained (the explanation window had previously been displayed to the user and the user has studied the explanation), Tested (where the user has undertaken the assessment for that concept), and Understood (where the user has successfully completed assessment for the concept). Assessment for each derived node is conducted on both L1 and L0 cognitive levels (effectively the ‘can do’ and ‘deep understanding’ levels as explained previously), while assessment on a base node only covers the L1 level.

Once again, the use of coloured fonts, nodes and links indicate the state of each node, as well as system-recommended paths. The learner does not have to necessarily follow the recommended path, but it is present and fully navigable by the learner.

5. CONCLUSION

Both these hypermedia systems offer adaptive link annotation. From the perspective of educational theory, the adaptive navigation support technique of link annotation offers a middle ground between a more directive, behaviourist approach to instruction and the free-browsing constructivist approach of common static hypermedia based systems. Environments which offer link annotation show a complete and fully navigable hyperspace, and use a soft didactic to individually and intelligently suggest to the learner the best path to proceed. Along the continuum of the locus of control, they acknowledge both the importance of the individual as a learner, and the value of the teacher as expert.

These systems are inherently grounded in cognitive theory (Mayes, 1993) as they are ‘knowledge-based’, they have a formal knowledge structure imposed upon them which reflects the construction of knowledge in the human brain according to the cognitive theories described in this paper. Both the domain and the student model are expressed as a network of interrelated concepts or knowledge elements, and these structures reflect both a generalised knowledge structure for content and an individual model of cognition for the student. Adaptive educational systems recognise the importance of the knowledge of an individual, through history-based mechanisms and the use of a user-model, and that a learner’s particular discourse with the knowledge space is in effect a map of their understanding of it.

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