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AUTHOR	Purchase, Helen
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ABSTRACT

Coded experience and effective semiotic systems, organizations of patterns of signs that comprise a system of meaning, have proved essential for the propagation of knowledge. In education, communication via semiotic systems forms an important role in guiding children toward the effective use of information and techniques, and it is important that children be able to decode a given representation competently. As semiotic devices, computers have additional power in that not only can they externally present representations, but they can also internally manipulate them. Three areas have been identified where their use may enhance learning: the representation of complex structural domains, the navigation of a lexical space depicting the relationships between words, and the display of a hypertext structure in an authoring tool. Three systems were designed to investigate the use of interactive schematic representations for these learning activities and include browsing the representation of a structured domain, navigating the lexical space, and accessing the structure of a story in an interactive fiction authoring tool. The aspect of these systems that distinguishes them from other computer educational systems which use schematic representations is the fact that what is represented is declarative subject matter, rather than the basis for a simulation tool or a procedural exercise. (Contains 14 references.) (AEF)

Computers as Interactive Representational devices for Declarative domains

HELEN PURCHASE

Computer Science Department, University of Queensland, Australia

Abstract: This paper reviews semiological theories in relation to the use of computers for enhancing learning activities, concentrating particularly on the use of graphical (or *schematic*) texts in declarative domains. Relevant semiological and educational issues are discussed, and three areas where the use of schematic representations in computer learning environments may be investigated are proposed: representing a complex structural domain, depicting the lexical relationships in a thesaurus, and assisting the authoring of an interactive fiction system. Three existing systems which address the associated learning activities are also described.

Introduction

Literacy is a primary aim of education: subject matter is usually taught 'out of context' with the use of various forms of text, and it is considered essential that children learn the skills to decode represented experience competently so that the information and techniques which form part of a culture may be propagated. Emphasis is therefore placed on reading, numeracy and the interpretation of diagrams and film. The computer is a significant addition to this list: its power as a representational device is greater than other media because of its interactive and processing nature. This paper considers the use of computers in education from the point of view of representational semiotic devices. First, relevant semiotic terminology is defined and appropriate educational issues addressed. Three projects which entail the design and development of computer educational systems which use an interactive representational method are then described. The aim of each of these systems is to investigate the suitability of using schematic representational methods for the depiction of declarative subject matter in an interactive device. They are each related to a particular learning activity: envisaging the structure of a complex domain, discovering the relationships between words in a lexicon, and authoring a hypertext system.

Semiology: terminology and classifications

Definitions

Semiology was defined by Saussure in 1915 "*A science that studies the life of signs* within society...[to] show what constitutes signs, what laws govern them..." (Saussure, 1959). While his emphasis was primarily linguistic, Peirce's analysis of signs (which he termed *semiotics*) was more general and concentrated on the characteristics of all signs (Peirce, 1977). Terminology differs between Saussure's and Peirce's definitions of signs and symbols, and for the purposes of this document, Peirce's definitions and categorisations will be used; that is, a *sign* is an intimate relation between an object (*term*) and an interpretant (*concept*). While the nature of the bond between the two components of a sign is irrelevant, a *symbol* is a particular category of sign, where the relationship between its object and interpretant is arbitrary. A *semiotic system* (*code*) is an organisation of patterns of particular signs (usually rule- and convention-based) that comprises a system of meaning, and a *symbolic system* is a type of semiotic system. A semiotic system thus consists of a *syntax* which defines the manner in which terms may be organised, and a *semantics* which indicates how meaning can be attributed to a syntactically correct pattern of terms. A *statement* is defined as a syntactically correct and meaningful combination of terms in a semiotic system, a *message* as a semantically coherent sequence of statements, and *text* (*representation*) as the physical realisation of a statement or message. A *representational system* (or *medium*) is an abstract term that refers to the physical realisation of the rules and conventions that comprise a semiotic system, and a *device* is a physical object used for communication via a semiotic system. *Communication* takes place when text is created according to a particular code, and transmitted via a device. The receiver of the text decodes it to extract meaning, choosing to impose a particular code on the text to enable interpretation.

For example, music is a *semiotic system* comprising *signs* (notes), where each note consists of a *term* (*eg* E flat) and a *concept* (the sensation produced by the corresponding sound wave). A figure from Beethoven's ninth symphony is a *statement*, the whole symphony is a *message*, the score is a *text*, an orchestra is a *device* for communicating it, and musical notation is the abstract term denoting the corresponding *representational system*.

A distinction may be made between *non-interactive* communication devices, which do not allow the receiver of a text to interact with then (*eg* televisions), and *interactive* communication devices, whose flexibility allows text to be altered and manipulated by the receiver. The most obvious example of an interactive communication device is a computer: its flexibility allows for dynamic transmission and manipulation of signs and texts.

Classifications

Bruner identifies three different types of semiotic systems: *enactive*, *iconic* and *symbolic*, with the corresponding signs *action*, *image* and *symbol* (Bruner, 1966). The enactive system is based on physical movement and the learning of responses (*eg* riding a bicycle), the iconic system depends on imagery and perception (*eg* looking at a picture), and the symbolic system uses symbols which do not have a perceptual relationship with the objects they signify (*eg* reading a sentence in natural language). For the purposes of this document, symbolic systems are further classified into *schematic* and *linguistic* categories, the main difference between them being the way in which the symbols are physically organised. Schematic systems use spatial indicators to show the structure of the subject matter (*eg* circuit diagrams, flowcharts), while linguistic systems place the symbols in a purely sequential manner (*eg* formal logic, morse code). In both systems, the way in which the symbols in a text are organised is important: linguistic systems have a linear syntax which determines how the meaning of the separate symbols unite to produce the semantics for the whole statement. Schematic systems tend to be graphical in nature, the overall structure of the subject represented and the relationships between the individual symbols being interpreted according to a conventional code (*eg* straight lines in circuit diagrams represent physical connections which are not necessarily straight). The physical realisation of a statement or message in a schematic system is here termed a *diagram*. Schematic representations are exceptionally useful. Some concepts cannot be captured by icons or individual symbols alone and the holistic nature of diagrams ensures structure and relationships are made explicit, often making a simple diagram more effective than the equivalent linguistic form.

Semiotic skills and the educational use of computers

The use of semiotic systems is mankind's most distinctive characteristic; coded experience and effective semiotic systems have proved essential for the propagation of knowledge. In education, communication via semiotic systems forms an important role in guiding children towards the effective use of information and techniques, and it is therefore important that children be able to decode a given representation competently; they should know the appropriate code well enough to both understand the text as well as manipulate and use it. For this reason, the development of literacy in various semiotic codes is the primary concern of much formal schooling.

Subject matter is usually taught to children 'out of context' by the use of a (usually symbolic) medium. Olson and Bruner make a clear distinction between the knowledge represented in a text and the skills required to decode the text. They consider that, regardless of whether the medium is enactive, iconic or symbolic, a common invariant 'deep structure' of knowledge can be created. However, the skills used for extracting and utilising this knowledge in each medium differ greatly, and they recommend that this should be considered when a representational system for instruction is chosen:

> The choice of a means of instruction, then, must not depend solely upon the effectiveness of the means for conveying and developing knowledge; it must depend as well upon its effects on the mental skills that are developed in the course of acquiring that knowledge (Olson and Bruner, 1987).

The choice of medium for encoding subject matter for educational purposes is therefore an important issue on two counts. Firstly, the ability of the intended users to understand the code in order to perform the required task should be considered. This is related to the cognitive development of the children and their previous experience with similar systems. Secondly, the suitability of the medium for the subject matter embodied and the intended learning activity ought to be addressed: inappropriate use of a medium may result in the creation and use of unsuitable and confusing mental models of the domain.

Both of these issues are made more complex when the computer is chosen as the medium of instruction. As semiotic devices, computers have additional power in that not only can they externally *present* representations, they can also internally *manipulate* them. Educational studies regarding the semiotic nature of the computer tend to be concerned with the cognitive benefits accrued from programming (*eg* understanding random numbers, recursion, variables *etc*) (McDougall, 1990). They have concentrated on the symbolism afforded by programming languages (Papert, 1980; Pea, 1987), and have not addressed the computer's potential as a semiotic interactive device for the explicit representation and manipulation of information, where no enactive (*ie* simulation or program) counterpart exists. The emphasis in the practical educational use of computers is usually on the subject matter embodied within the software, or on the computer skills re-inforced by computer use, rather than on the nature of the medium used.

Three interactive schematic systems

In focusing on the semiotic nature of the computer as a representational device, educational researchers and practitioners ought to consider whether its interactive nature contributes in any way to the learning activities that the user is engaged in (or indeed, whether it inhibits them). The research reported here considers interactive declarative schematic representations in particular, and three learning activities have been identified as potential areas where their use may enhance learning: the representation of complex structural domains, the navigation of a 'lexical space' depicting the relationships between words, and the display of a hypertext structure in an authoring tool.

Three systems have been designed to investigate the use of interactive schematic representations for these learning activities: they are described briefly below, with particular emphasis given to the nature and use of each the schematic representations used.

Schematic hierarchical knowledge base structures

KREEK is an educational learning environment which embodies an interactive schematic representational method for the portrayal of structured declarative domains (*eg* the solar system, an animal taxonomy), using a network syntax where *nodes* represent objects and *links* represent relationships. Relationships between the main objects in a text are made explicit by forming links between them, while attribute (or 'property') information associated with the objects are encapsulated within *frames* at the nodes (Minsky, 1975). In addition, each node may have associated with it a *layer*, which is itself a syntactically valid diagram and covers the entire computer display. Thus KREEK texts may consist of any number of layers organised in a hierarchical structure, allowing the knowledge-base to be structured so that subordinate layers provide more specific information about an object.[1] The dynamic environment offered by the computer is therefore used in order to incorporate structural conventions: not all of the information is made available at once, and the parts of the text that are not initially visible (either in frames or in layers) may be selected by the user for further perusal. KREEK may be used for both browsing and creating these hierarchical schematic texts: the intention is that the inherent structure of a knowledge base may be better envisaged by making it explicit in an interactive schematic text.

Qualitative preliminary evaluation of this system with nine-year old children revealed that their ability to recognise and use appropriately the structural conventions embodied within a KREEK text varied with the mode they were in. They had little difficulty in understanding the fact that the positioning of the facts within the hierarchy provided additional information when they were *browsing* a KREEK text, but only the higher-ability children used these structural conventions appropriately in *authoring* mode (Purchase, 1992). Further experimentation needs to be done to supplement these observations with a more rigorous qualitative analysis, encompassing a larger sample size, and focusing more particularly on the structural envisagement aspect of text browsing and creation, and its support of the learning activity.

Depiction of 'lexical space'

GLOSS is currently under development: it is intended to be a language tool which portrays the highly-linked information in a thesaurus graphically, providing the means for easy and efficient access of the entries for the words cross-referenced by a particular lexical entry, and displaying these relationships between the entries in a graphical manner. Hypertext type implementations of thesauruses have implicit links between the entries: the system proposed here will make these relationships graphically explicit, thus allowing the user to visualise the 'lexical space' in which the word is situated. Thus the 'lexical area' defined by a word and its lexical associations will be depicted in a graphical manner (using a node-arc notation similar to Quillian's 'semantic

[1] This idea is similar to Quillian's linking together of planes (Quillian, 1967), without the condition that links between planes be restricted to relationships between concepts and their corresponding instances.

memory' representation (Quillian, 1967)), in order to allow the relationships between the words and their cross-references to be perceived visually. A lexical entry will be visually depicted as a 'focus' node representing the word, which is joined by graphical arcs (indicating lexical or semantic relationships) to the relevant cross-referenced words. The display is made more complex by the further arc-node depiction of words associated with these cross-references. User selection of any word which is displayed on the screen in one lexical entry would change the graphical display so that the newly selected word forms the focus of the display. The new focus node, its cross-referenced words, and further lexical or semantically associated words would now be displayed. By appropriate selection of words, the user can browse through the thesaurus, following relationships through the lexical space. A system like this may have many uses in education, in learning about the structure of the lexicon (either for children or for people learning English as a second language), or for discovering the semantic relationships between concepts. In addition, the graphical aspect of GLOSS provides any user with a new way of visualising words, semantic and lexical relationships and lexicon structure.

Schematic structures for interactive fiction

STORYTIME is a creative writing authoring tool, which allows non-sequential stories to be both read and written. It maintains a hypertext type implementation of events in a story, with the links between the events relating to choices that the reader makes when decision points are reached in the narrative. The non-sequential nature of the stories is what is of most interest from both a reading and an authoring perspective, and this underlying structure of highly-linked nodes allows many stories with different conclusions to be explored and created. STORYTIME is intended to be used by primary school children in both reading and authoring mode, and it provides a simple interface for both activities.

Readers of STORYTIME stories suffer from the problems that users of hypertext systems are prone to: not knowing where in the linked structure they are currently located, and having no prior knowledge of the scope of the story (in terms of both size and possible events in the narrative).[2] When creating stories, authors may experience the same problems, but these may be exemplified by errors or omissions that they may have made (*eg* forgetting to ensure that all pages are accessible, associating the wrong page with a link, or losing sight of the overall structure of the story, and the various narratives that it may entail.)

STORYTIME has been partially extended in an attempt to address these problems by including the facility for the overall structure of the story to be viewed as a schematic display of a directed graph. Thus the internal hypertext representation of nodes and links is made visible to assist the reader in knowing something more about the structure and entent of the story. In addition, the author will be able to get an overview of the possible paths in the story, and ensure that all pages are accessible and the created structure correctly represents their intention. Further implementation is necessary to provide graphical authoring facilities.

Like the thesaurus implementation discussed above, these extensions to STORYTIME require the use of a suitable automatic graphical display algorithm which will display the structure of the highly-linked internal representation of nodes and links. Graphical tools which implement algorithms which enable the perspicuous display of graphs (*eg* the 'spring' algorithm (Kamada, 1989)) will be used.

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[2] A reader of a book may get some idea of its scope by seeing how thick it is, or by "flicking though" to get some preliminary notion of the nature of the language and events that can be expected. There is no similar equivalent in STORYTIME.

Conclusion

The three systems described above are intended to be used to investigate the potential for the use of schematic representations in an interactive device for three particular learning activities: browsing the representation of a structured domain, navigating lexical space, and accessing the structure of a story in an interactive fiction authoring tool. The aspect of these systems that distinguishes them from other computer educational systems which use schematic representations is the fact that what is represented is declarative subject matter, rather than the basis for a simulation tool (Cheng, 1993), or a procedural exercise (Levonen and Lesgold, 1993). Successful use of these systems (*ie* the enhancement of the respective learning activities) would demonstrate the suitability of this choice of medium, and would indicate that the interactive nature of the computer can indeed be exploited with schematic representations for the effective depiction of declarative subject matter.

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