Visualisation issues for human systems development: the case of a knowledge sharing support system

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Abstract

The paper starts by discussing the role that Visualisation and Information Visualisation may have in the development of the next generation of user interfaces. An oriented review of issues involved in the creation of systems that take advantage of emergent computer 3D facilities and Virtual Reality systems are presented. Is defended the perspective that visualisation can promote the opportunity to foster user interaction mediated by technology.

The paper ends up with a discussion of the design, architecture, and use of interactive visualisations in a system that allows the creation of a virtual world to assist knowledge sharing. The proposed system uses a 3D interactive visualisation interface to support user exploration and enhancement of the concept space. The concept space is somewhat a 3D semantic map, allowing users to define concepts by listing associated keywords.

The proposed system design is briefly described in order to argue how visualisation, in particular 3D interactive visualisation, can be used for knowledge sharing support and group interaction. Applications of this system include information retrieval and indexing, and group knowledge sharing such as in educational settings.

Keywords: visualisation, information visualisation, human factors, user interaction, virtual environments, knowledge sharing, cooperation and collaboration interfaces.

1 Introduction

We can assume the information management and information flow as critical success factors in human systems [Gouveia 1994], based on the hypothesis that if these factors are handled conveniently it is possible to change dramatically productivity. In order to obtain this kind of advantages, the information system must be improved with technology that enables the information flow and that integrates with existing information systems.

As an emerging discipline, Information Visualisation can offer technologies that improve the way humans perceive and use large and complex data sets, and help manipulate information [Card et al. 1998]. Stuart Card and others, introduce visualisation as the process of transforming data, information, and knowledge into visual form making use of human natural visual capabilities [Card et al. 1998]. Visualisation can also provide an interface between the human mind and the computer.

Virtual Reality technology offers a great potential to represent information and a new paradigm to represent information in 3D. Virtual Reality (VR) can be considered as the delivery to a human of the most possible convincing illusion that they are in another reality [Harrison and Jacques 1996]. This reality exists in digital electronic format in the memory of a computer. Related terms with Virtual Reality (Jaron Lanier) are Artificial Reality (Myron Krueger), Cyberspace (Willian Gibson), and, more recently, Virtual Worlds, Synthetic Worlds, and Virtual Environments [Erickson 1993].

How can we relate Virtual Reality technology and Visualisation? We can consider that the Visualisation goal is to represent data in ways that make them perceptible, and able to engage human sensory systems [Erickson 1993]. As Artificial Reality makes it easier to interact with visualisations, and the user can have its own presence in a 3D space, there are more natural possibilities for manipulating 3D images. This open the way to users to interact directly with the data, to multiple users interact simultaneously with the same visualisation, and also, serve as environments for supporting human/human interaction [Erickson 1993].

2 Motivation

The impact and use of VR technology to visualise information, and knowledge in an education environment along with the possibility to support knowledge management, is currently a viable research subject. Approaches to educational systems based on well-tested and conventional techniques have suffered from limitations due mainly to:

- the complexity resulting from large amounts of unstructured information, and the difficulty of keeping pace with updating, verification, and authoring information. This affects largely human computer interaction.

- the complexity of co-ordinating several information sources when one tries to move to decentralised or distributed solutions does not seem to be reduced as heterogeneity, and interoperability problems arise easily. Further, the user interaction problem remains untouched.

- the shift in information content from pure data to knowledge does not seem to fit well with conventional available systems. Knowledge changes and evolves continuously and needs to be certified, authored, and represented in various supports and dimensions.

One possible approach is to free information and knowledge from conventional and hardware-oriented supports and to easen the user information management [Fairchild 1993]. VR technology seems a promising start as it allows for the following improvements:

- the cost of VR technology is falling, and it is now becoming affordable for even small enterprises

- although the visual quality of a VR system cannot, as of now, compete with traditional display, this is not a drawback in the research context.

- user interaction becomes more intuitive, and presents the possibility of extending routine work, with apparently no losses in productivity.

- VR technology offers new possibilities to build system applications that improve or modify radically productivity.

The described improvements in VR are also valid ones for Computer Supported Cooperative Work (CSCW) systems. The goal of CSCW is to discover ways of using computer technology to further enhance the group work process through support in the time and place dimensions, where the focus of CSCW goal is the social interaction of people, and not the technology itself [Pfeifer 1995].

When considering the use of VR as an enabling technology in CSCW systems, it will be possible to enhance co-operation by synchronising the focus of users attention, the *Do You See What I See* issue [Wexelblat 1993]. With users inhabiting a common world this problem is avoided. The creation of a virtual environment where users can collaborate using VR technology and CSCW principles, introducing 3D representations, user embodiment and enhanced interactivity is referred as a Collaborative Virtual Environment (CVE) [Benford and Greenhalgh 1997].

This brings the essence of a CVE system: make possible to someone to interact with an information space and with other individuals to share, discuss and make as much visual representations of information sets as wanted.

3 Issues to be considered

3.1 Use graphics as dialogue extenders

The need for better ways for representing information and dealing with the increasing complexity and volume of information for a user or a group of users is not a new one. These topics constitute a central issue for many research projects and are part of the expected outcomes for many others. Among these projects is the Engelbart's Augmentation Human Intellect Research Centre, at Stanford Research Institute, which was set up to explore new forms of computer interaction [Engelbart and English 1968].

Some people, like Sutherland, propose new forms of dialogue between users and computers - a graphical dialogue [Sutherland 1963]. Lakin also proposes a performing medium where the focus is on live manipulation of text and graphics [Lakin 1988]. Laurel adds that "*graphical and, by extension, multisensory, representation are to both physical and emotional aspects of directness in interaction. Hence, it is worthwhile to examine the role and contributions of graphic design in interface systems*" [Laurel 1993].

Tufte introduces the roles that graphics and other visuals can have into help visualising information and convey meaning. His well known books are oriented, each one, to a specific topic: the first book focuses in introducing a graphics history and a language for discussing graphics. It also gives a practical theory of data graphics (in particular, statistical graphics) [Tufte 1983]. The second book treats the principles of information design (that are as universal as mathematics, in the author's perspective) [Tufte 1990]. The book is also about escaping flatland, this means, adding more dimensions to be represented and discuss how to represent the rich visual world of experience and measurement knowing that the world is complex, dynamic and multidimensional. The third Tufte's book deals with design strategies for presenting information about motion, process, mechanism, cause and effect [Tufte 1997].

Flatland is a word coined by Abbott, in an 1884 book with the same name, where he describes a two dimensional universe in which all the creatures were flat shapes [Abbott 1986]. The Flatland book also offers a demonstration of the difficulties of breaking out of the mental structures we use to make sense of the world, and serve as reflective model for the use of 3D facilities in actual computer systems. This was best described by Woolley comment about the book: "*How would A. Square make sense of Spaceland, the three-dimensional world occupied by the strange Sphere creature that can be experimented in Flatland as a circle that could make itself large and smaller, and that could appear and disappear at will?*" [Wooley 1993].

3.2 The human side of technology users

When dealing with visual information representation to human use, one first issue to consider must be the human itself, his perceptual limitations and the way he understands visuals. Norman defined humans as thinking, interpreting creatures, that are active, creative, social beings [Norman 1993]. Hutchins [Hutchins 1995], states that cognition is socially distributed. The same author adds that cognitive activity must be analysed in context, where context is not a fixed set of surrounding conditions but a wider dynamically process of which the cognition of an individual is only a part. This means that we must consider cultural factors and explicable effects that are not entirely internal to the individual [Hutchins:pp355 1995] - introducing a sociocultural perspective.

The concept of space and its use has also value to the present study. Human cognition adapts to its natural surroundings and potentially interacts with an environment rich in organising resources. For Hutchins [Hutchins 1995], human cognition is a different cognition when compared with other animals, primarily because it is intrinsically a cultural phenomenon. This way Hutchins refers to three kinds of space: the physical space, the social space and the conceptual space. It is the last one - conceptual space - that will be the focus for the present study.

3.3 Systems to support knowledge share

The main material each individual can use, share, and communicate is knowledge. A percussor system like the Memex system presents as its essential feature the associative indexing which introduces the concept of creating an information space from new material and active links to existing material [Bush 1945]. The Memex was described as an individual appliance to organise and access information. Ted Nelson (who coined terms like hypertext and hypermedia) introduced the Xanadu project in 1962, extending the Memex system and proposing a new type of a publishing medium, where the creation of links between existing and new contents, including its modification which turn possible the creation of new meanings and interpretations by elaborating dynamic structures. This time, the proposed system can be described as a collective appliance.

The system is also described by [Wooley:pp 161 1993]: "*everything within Xanadu project exists by virtue of its links with everything else, and those links are constantly forged and* *broken. Every reader of every text contributes to its meaning by participation in the creation of the structures that place it*". If we consider not the database implementation but an information visualisation representation with an annotation linking system some of the described functionality can be achieved.

Although the Xanadu project has not been accomplished, a distributed hypermedia system - the World Wide Web (WWW or Web) [Berners-Lee et al. 1994] - with client-server architecture has become a global system to access information. The Web is completely unstructured and is continuously changing its content. It links a huge amount of information that is increasing all the time. The Web has three characteristics that make its study challenging for current Information Visualisation research: its information is unstructured; the information is dynamic and complex; and the huge amount of available Web information originate scale problems, even if we considered just partial Web representations.

3.4 The direct manipulation factor

One of the important concepts about interfaces is the strategy of direct manipulation. It was coined by Shneiderman (1982) who listed three criteria for a direct manipulation system: (i) continuous representation of the object of interest; (ii) physical actions or labelled button presses instead of complex syntax; and (iii) rapid incremental reversible operations whose impact on the object of interest is immediately visible [Shneiderman 1987].

Shneiderman argues that the goal of direct manipulation is the creation of environments "*where the users comprehend the display, where they feel the control, where the system is predictable, and where they are willing to take the responsibility*" [Shneiderman and Maes 1997]. He also states that the future direction for direct manipulation is Information Visualisation with the focus on the remarkable human capabilities in the visual domain, under-utilised by current design [Shneiderman and Maes 1997].

The use of 3D visuals, the time and space representation, the ability to detect patterns and the representation of cause/effect relations seems to be some of the issues in the information visualisation field. Other important issues for the current research are interaction and sharing in allowing individuals to deal with information and share its visions of it. Virtual reality systems may play an important role on that, giving way to new forms of interaction with information visualisations and in dealing with the dynamic characteristic of information.

3.5 The importance of a common language

As a functional combination of VR and CSCW systems, a CVE can offer an environment where more than one user is involved with an information space. In a CVE the need for information visualisation still exists and remains as one of the components to be studied, along with others.

To share information we must deal with a common language that specifies and enables the basic communication operations to share meaning by known abstractions. This rises questions about symbols and semantics, that is, communication issues.

Hutchins also proposes that when the manipulation of symbols is automated, neither the cognitive processes nor the activity of the person who manipulated the symbols be modelled. The original source domain of language of thought was a particular highly elaborated and culturally specific world of human activity, that of formal symbol systems [Hutchins 1995]. This way, the boundary between inside and outside became the boundary between abstract symbols and the world of phenomena described by the symbols.

Hutchins [Hutchins 1995], defends that "*people process symbols (even the ones that have internal representation), but those symbols are not inside the human mind, creating a distinction between cognitive and perceptual human activities*". Hutchins [Hutchins 1995], adds that "*the symbols were outside, and the apparatus that fell off is exactly the apparatus that supported interaction with those symbols. When the symbols were put inside, there was no need for eyes, ears, or hands. Those are for manipulating objects, and the symbols have ceased to be material and have become entirely abstract and ideational*".

In cognition, based in Hutchins, we must distinguish between the tasks that the person faces in the manipulation of symbolic tokens and the tasks that are accomplished by the manipulation of the symbolic tokens. The same author presents humans good at detecting regularities in their environment and at constructing internal processes that can co-ordinate with those regularities. Humans spend their time producing symbolic structures for others. Hucthins concludes saying that "*ontogenetically speaking, it seems that symbols are in the world first, and only later in the head*" [Hutchins 1995].

When dealing with representations it's rather obvious that different representations can enhance the understanding level of a particular problem. The form of representation makes a dramatic difference in the ease of the task and their proper choice depends upon the knowledge, system, and method being applied to the problem [Norman 1993].

Why consider information visualisation as the main research topic? We need better tools to deal with complex data sets, ill-structure and dynamic information settings that characterise actual systems Visual representations are more natural for humans and can be used to improve their perception to learn and as an aid for search and computation.

3.6 From abstraction to action

The data-information-knowledge pyramid (figure 1) can provide a starting point to the research discussion. The more higher the level, more symbolic abstraction is on use. Lengel and Collins [Lengel and Collins 1990] designated as educational pyramid, where the information level is referred as ideas level, proposed a similar pyramid. The authors give a description for their educational pyramid: “What education is supposed to do is to get students to see data (facts) in such as way as to inform themselves. The data in their mind are combined into information. Information is then related to other information to produce ideas in the students’ minds - concepts that help explain the world. Some students combine these ideas to produce a wisdom that understands the whys and wherefores of life and truth. The aim of education is to move up the pyramid” [Lengel and Collins 1990].

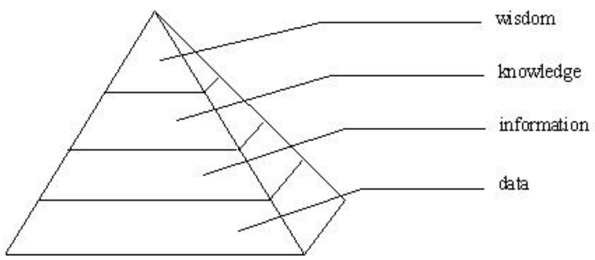

Figure 1: data-information-knowledge pyramid

In the lower level, *data* is considered as the base raw material to represent information [Wilson 1997]. In a more formal definition, data is the representation of facts, concepts, or instructions in a formalised manner suitable for communication, interpretation, or processing by human beings or by automatic means [ANSI 1982].

Information is based on data aggregation and is considered as the material to help and support decision or other action [Wilson 1997]. A formal definition is proposed by [ANSI 1982] as the meaning that a human being assigns to data by means of the conventions applied to those data. For Barnatt [Barnatt 1997], information is the product of filtering and then processing raw data into a potentially useful form.

The knowledge level adds context and purpose orientation to the information level. *Knowledge* stems from the analysis of information within an expert frame of reference so that it becomes attributed with actual meaning. Barnatt [Barnatt 1997] proposes an illustration for the data-information-knowledge progression (figure 2).

Figure 2: data-information-knowledge progression

In the top of the pyramid (figure 1) we propose a higher level - wisdom - as the long term material to a high order structure models for representations of the reality. Wisdom is socially constructed.

The knowledge which is used in a given problem domain could transform itself into wisdom and become a base to the generation of action activity [Coelho 1996]. Cooley proposes a data to wisdom transformation, based in the signal/noise relation (figure 3) [Cooley 1988].

Data combined gives information. Information placed in the appropriate context, form knowledge. And knowledge, combined with experience, judgement and a whole range of other things, gives us wisdom [Weir 1996].

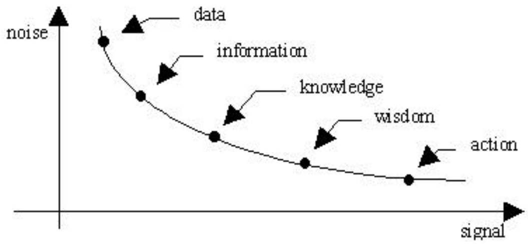

Figure 3: data to wisdom transformation

3.7 Information artefacts

Norman proposes that external representations, especially ones that can be part of a workspace shared with others, require some sort of constructed device to support them: an artefact [Norman 1993]. He also adds that the representations of the representations of thoughts and concepts are the essence of reflection and of higher-order thought. It is through *metarepresentations* that we generate new knowledge, finding consistencies and patterns in the representations that could not readily be noticed in the world [Norman 1993].

As we step on higher levels of abstraction, better cognition artefacts are needed. Engelbart [Engelbart 1963], proposes a useful notion of artefact as part of a four basic classes of augmentation means (the others are language, methodology and training). The proposed cognition artefact differs from the Engelbart notion of artefact because he considers only the physical objects.

This way the proposed cognition artefact is more like the Engelbart's language class from the conceptual framework, defined as "the way in which the individual classifies the picture of his world into the concepts that his mind uses to model that world, and the symbols that he attaches to those concepts and uses in consciously manipulating the concepts («Thinking»)" [Engelbart 1963].

Humans access information in several different ways. If we consider the amount of information available organised into an information space, we can distinguish three access types: search, browsing and reading [Rada 1995].

In the search type access, one concept is key and that concept occurs just once (or a few times) in the information space. In the browsing access, several important concepts relate to several parts of the information space, some are relevant and some not. For reading access, the user takes all the information space to match the required concepts.

If we consider Swets´s definitions of precision (fraction of the retrieved information, which is relevant) and recall (fraction of the retrieved information relevant versus all relevant information) [Swets 1969] together with the amount of information, then we have three-dimensional criteria to evaluate information access.

Search access must need few parts of the information space and should be performed in a system that provides high recall and, at least, medium precision. Browse access needs several parts of the information space, also needs high recall and, at least, medium precision. Any other access that needs greater parts of the information space corresponds to an understanding task. We have an understanding problem when precision and recall are low or when we need to consider large amounts of information [Rada 1995].

These access types works better in small to medium information spaces where to less dimension correspond more structured concepts with a greater number of relations between them. To perform search and browsing tasks in an information space, some understanding tasks must be performed in order to learn about the information space and map the amount of information, precision and recall values.

The understanding problems can be filtered by the use of better and more abstract visualisation schemes. The medium, is important for helping in understanding tasks, like in the case of paper that can be more attractive than computerised information based on its familiarity, tangibility, and portability [Hansen and Haas 1988].

In an alternative perspective, Laura Leventhal defines navigation as "*the cognitive process of acquiring knowledge about a space, strategies for moving through space, and changing one's* *metaknowledge about a space*” [Jul and Furnas 1997]. Furnas and others [Jul and Furnas 1997], proposed a definition of some concepts related with navigation where a distinction between task (search and browse) and tactics (query and navigate) was made. This way, search is considered a task of looking for a known target. The browsing is the task of looking to see what is available in the world. The querying tactic consists in submitting a description of the object being sought to a search engine, which will return relevant content or information. The navigation is presented as moving sequentially around an environment, deciding at each step where to go next based on the task and on the environment seen so far.

Furnas presents *map building* as one of the navigational subtasks and describes it as constructing a representation - mental or physical - with spatial structure to aid multiple routes following and finding task [Jul and Furnas 1997]. Apperley, Carl, Jul, Leventhal and Spence proposed a three level structure to the navigational design where the users cognitive map is based on the user’s previous knowledge, experience and their views of the imposed structure (figure 4) [Jul and Furnas 1997].

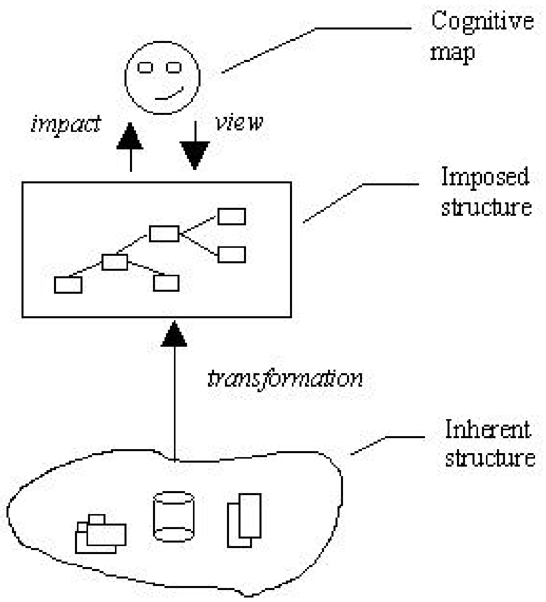

Figure 4: Levels of structure for navigational design

For our purposes, the generation of cognitive map visualisations can be of interest. McAleese [McAleese 1998], suggests that the concept map functions as an aid, helping the learner interpret and organise personal knowledge. The same author proposes the use of concept maps to the representation of knowledge and its application to support learners with external learning space [McAleese 1998].

3.8 Experiential and reflective learning

The way we learn as a cognitive experience can be a result of many kinds of cognition. Norman proposes two modes that are relevant when a discussion of cognitive artefacts is made (in a human centred view); the two modes are experiential and reflective [Norman 1993]. The experiential mode leads to a state in which we perceive and react to the events around us, efficiently and effortlessly. The reflective mode is that of comparison and contrast, of thought, of decision making. The first mode is related with an expert behaviour and efficient performance, and the second, with the creation of new ideas and novel responses.

Human cognition is a multidimensional activity, involving all the senses, internal activities and external structures; this way Norman recognises that the division in only two categories of human cognition is a simplification, although useful for design proposes of human centred systems. Norman [Norman 1993] proposes that experiential thought "*is reactive, automatic thought, driven by the patterns of information arriving at our senses, but dependent upon a large reservoir of experience. (…) it involves data-driven processing*". The reflective mode "*is that of concepts, of planning and reconsideration. (…) tends to require both the aid of external support and the aid of external people".*

Norman suggests that the environments used to aid cognition must be designed accordingly: "*the external representations have to be tuned to the task at hand if they are to be maximally supportive of cognition. Reflection is best done in a quiet environment, devoid of material save that relevant to the task. Rich, dynamic, continually present environments can interfere with reflection: These environments lead one toward experiential mode, driving the cognition by the perceptions of event driven processing, thereby not leaving sufficient mental resources for the concentration required for reflection. In the terms of cognitive science, reflective cognition is conceptually driven, top-down processing* " [Norman 1993]. The focus on designing the action is also proposed by Laurel [Laurel 1993]. Bodker [Bodker 1989], adds that in performing a task, the person has a focus and a goal, this way the attention must be in the task, not upon the tool. Tools must be in the background, becoming a feeling of directly working on the task.

Rumelhart and Norman propose three kinds of learning: accretion, tuning, and restructuring (that extending the experiential and reflective cognition framework). Accretion is the accumulation of facts, adding to the stockpile of knowledge. With the proper conceptual framework, accretion is facilitated and efficient [Norman 1993].

Tuning is based in massive practice. It tunes the skill, shaping the knowledge structures in thousands of little ways so that the skill that in early stages required conscious, reflective thought could now be carried out automatically, in a subconscious, experimental mode. Experimental thought is tuned thought [Norlan, 1993]. Tuning is necessary to reach expert levels of performance, and then essential to maintain them.

Restructuring, is about forming the right conceptual structure. Accretion and tuning are primarily experiential modes and restructuring is reflective. This third way of learning is where new conceptual skill is acquired. It is necessary to use the right tools to reflect, explore, compare, and integrate.

Hutchins proposes learning or conceptual change as a kind of adaptation in a larger dynamically system [Hutchins 1995]. It also states that one scale of learning or changes in the organisation of cognitive systems are the opportunities for the development of new knowledge in the context of practice. Experimental artefacts provide mediation between the mind and the world. Reflective artefacts allow us to ignore the real world and concentrate only on artificial, representing worlds.

4 The use of Semantic Maps

When dealing with representations it is rather obvious that different representations can enhance the understanding level of a particular problem [Tufte 1990]. The form of representation makes a dramatic difference in the ease of the task and its proper choice depends upon the knowledge, system, and the method being applied to the problem [Norman 1993].

This work aims to prove how computer mediated 3D visual representations can be useful in helping the understanding and communication between individuals by sharing conceptual information as proposed by Benedikt [Benedikt 1992]. Application areas include sharing of thesaurus, information maps, complex domain information, and contexts; application domains include information retrieval and visualisation from large data sets (e.g. the Web), and sharing of context information about educational domains.

Visualisation offers advantages and opportunities when we deal with complex data sets, ill-structured and dynamic information, the kind of settings that characterise actual systems where we face understanding and learning problems, info-glut, and information overload [Forrester 1987].

For our purposes, the generation of extended semantic map visualisations can be of interest. The conceptual space as referred by [Hutchins 1995] will serve as initial starting point for the present work. The research can be stated as the use of 3D facilities to improve knowledge sharing by proposing a representation to be used as a collective reflective artefact [Li-Jen and Gaines 1998].

The proposed interface tries to remove the computer as an object of perception, allowing the user to interact directly with the generated environment as discussed by [Hubbold et. al 1995].

Semantic Maps are a strategy for graphically representing concepts. Semantic Maps portray the schematic relations that compose a concept. It assumes that there are multiple relations between a concept and the knowledge that is associated with the concept. Thus, for any concept there are at least these types of associations:

1. class: the order of things the concept falls into;
2. property: the attributes that define the concept;
3. example: exemplars of the concept.

Semantic Maps are used also to identify techniques which describes a variety of strategies designed to show how key words or concepts are related to one another through graphic representations [McAleese 1998].

A general procedure to develop a Semantic Map is by having a group discussion. In a situation like this, it is almost inevitable that the three types of concept associations class, property and example will emerge.

The major purpose of a Semantic Map is to allow students organise their prior knowledge into formal relations and thus provide to themselves a basis for understanding what they are about to read and study. Comprehension can be thought of as the elaboration and refinement of prior knowledge. Semantic Maps provide a graphic structure of knowledge to be used as the basis for organising new ideas as they are understood [McAleese 1998].

One of the first to propose the development of a Semantic Map procedure was [Hanf 1971]. The procedure was designed to improve the teaching of study skills. However, the notion of Semantic Maps is older and based on [Ausubel 1963] who claimed that background information was a necessary prerequisite to the addition of new concepts and vocabulary.

Ausubel defends that when individuals are presented with new concepts, these concepts will not be explicitly understood until they are linked in a meaningful way to pre-existing concepts [Ausubel 1963]. Similarly, reading theorists have likened the process of reading comprehension to relate the new and the unknown [Pearson and Johnson 1978].

Gathering the several uses of Semantic Maps is possible to list them as:

- a technique for increasing vocabulary and improving reading comprehension;
- a means of improving the teaching of study skills;
- a framework for identifying the structural organization of texts;
- a means of teaching critical thinking skills;
- an assessment technique.

5 Concept spaces

Our system uses a 3D visualisation based on a structured description of a domain based in concepts and weighted keywords — defined here as a concept space. For our purposes, keywords associated with a concept define that concept. Figure 5 presents two concepts and their respective keywords; this example shows part of a concept space about the Human Computer Interface (HCI) domain.

Computer	**Interface**
Order, 0.67	order, 0.34
Technology, 0.7	operation, 0.76
Automatic, 0.67	human, 0.8
Processing, 0.8	computer, 0.56
Structure, 0.7	

Figure 5: part of a concept space for the HCI domain

In the above figure two concepts are presented: Computer and Interface. For each one, a group of keywords is listed. Keywords like order exist on both concepts but with different weights, as chosen by the person who created this concept space.

Keyword weights are values between zero and one, and give the degree of membership of a given keyword to the concept. Notice that the sum of all the keyword ratings do not have to be equal to 1 for a given concept. This means that keyword weights are independent and similar to fuzzy sets.

A relation between any two concepts can be established when one or more keywords exist in both concepts. Its also possible to compute a degree of similarity between two concepts by taking into account the existing weights in both occurrences of each keyword. The algorithm to compute a relation between two concepts uses keyword names and ratings and returns a value between zero and one, being the value zero a non similarity result; a value of one means total similarity, although not equality. A relation between two concepts, one being defined by a subset of the keywords of the other has a value of one, although the two concepts are not the same.

6 Visualisation of concept spaces

Based on this structure, the visualisation is rendered. Other information can be included attached to this basic structure allowing for a richer subject domain description. An example can be the use of url references to attach html pages to each concept and even to each concept's keyword.

The system allows concept space sharing and supports user proposals for enhancing the structure. In order to support this functionally, a user with proper rights can propose new concepts and keywords, propose new ratings for existing concept keywords, and propose the elimination of existing concepts and keywords from the structure. Each user proposal is voted by all the group members and if accepted included in the structure. The system uses a voting tool to support the structure enhancement.

Each concept is defined by a number of keywords that characterise it. The exact number of keywords varies for each concept and can always be modified later. Each keyword consists of a name that can be used for search — composing a query — or defining a particular characteristic and an associated weight. Any user can also later modify a keyword weight by proposing a new value to the user group.

Figure 6 presents a screenshot of the concept space visualisation. Note that each concept is represented using a sphere where colour and size takes into account the keyword group. The size is computed as a function of the number of keywords used to characterise the concept taking into account its ratings. The greater the number of keywords and their ratings, the more important is the concept.

The lines between spheres represent a semantic distance, which is colour coded. The semantic distance between two concepts is calculated by a function that uses the ratings of the keywords common to both concepts. With proper controls, a user can navigate in the 3D world by rotating, translating and zooming.

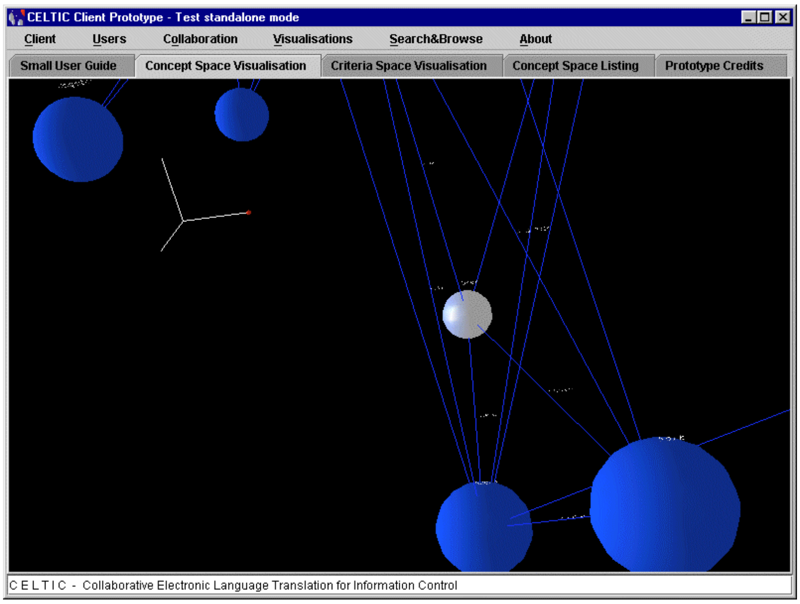

Figure 6: a concept space visualisation

The semantic distance between two concepts is computed as a degree of keyword similarity taking into account keyword weight and the colour used means four levels of similarity:

The first level uses the white colour for a similarity degree of up to 25%; white blue is used for values between 25 and 50%; blue is used for values between 50% and 75%; and red is used for values between 75% and 100%. A label attached to the link gives the precise value for each case. By default, the concept space visualisation displays only the blue and red links. The user has the option to visualise all the relations between concepts.

As soon as the group of users agrees on a common understanding of the concept space, they can start exploring it. In the next section we explain of users can extract useful information from a concept space by projecting it over specified criteria.

7 Working with concept spaces

The system allows each user to interact with the shared visualisation — concept space — and produce a second visualisation from it. The second visualisation is derived from the initial concept space and supports user exploration and organisation of retrieval, search and browse tactics.

The second visualisation is based on the spatial rearrangement of the existing concepts. The user can introduce up to three criteria to project the concepts in a Cartesian space. Those criteria must be chosen from the existing keyword collection in the concept space. The second visualisation is referred as the criteria space. As the criteria space is a 3D space, the user can enter three criteria to determine a spatial position for each concept based on its keywords' weight values.

Thus, the use of the criteria space allows the user to analyse the concept space from its own perspective and information needs, letting the user visualise different combinations of keywords (criteria) for grouping existing concepts.

7.1 The criteria space

The spatial position of each concept in the criteria space is computed by comparing the criteria with existing keywords on the concept and using keyword weight as a coordinate value for the criteria. If the criteria do not exist for a particular concept, a coordinate value of –1 is given to the concept for the corresponding criteria dimension. This negative value places the concept in a different position within the dimension used to represent the criteria.

Figure 7 shows a criteria space example with several concepts (spheres) placed along the three axes.

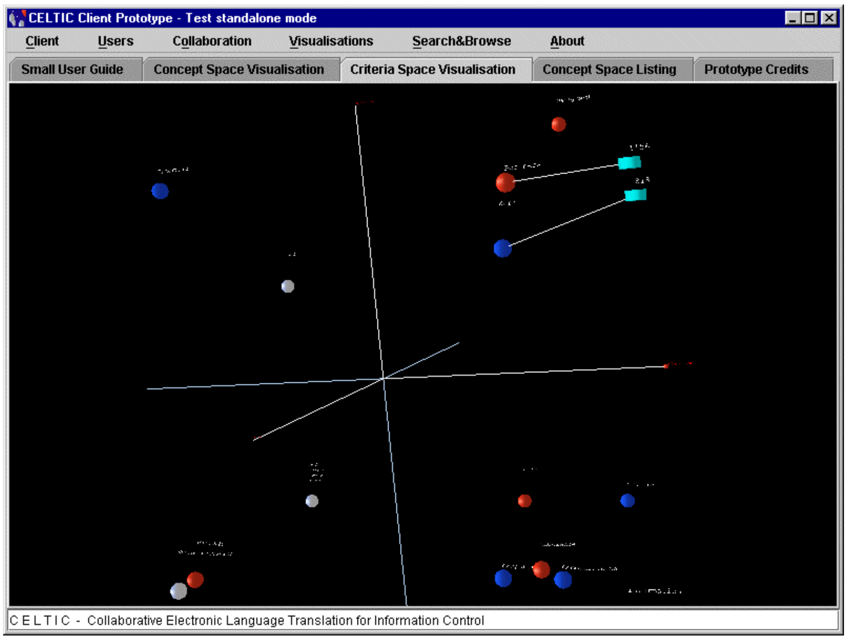

Figure 7: the criteria space

The resulting criteria space produces a visualisation of eight possible quadrants resulting from the three criteria combination of three dimensions. In the criteria space visualisation, each sphere is represented with the same size but remains with original colours, used in the concept space visualisation.

The colour coding for the concepts denotes each concept's relevance within the concept space. Three levels are defined, been the most important concepts coded in red; the base concepts (strong related with the concept space context) are blue and others are coded in white blue (see both figure 6 and 7).

7.2 Services for collaboration

The services for collaboration includes a voting tool to collaboratively decide which proposals to enhance the structure are accepted (add or delete concepts and keywords and alter keywords weights). Another collaborative tool is a chat system that supports user discussion and provides a synchronous communication facility complementing the concept space visualisation. An annotation facility allows the adding of additional information to each concept in the structure. The system also provides basic user awareness support by list system users and current connected user information. These services allow a basic set for collaboration as discussed by [Lea et. al 1997].

In the next section we show how the system can be integrated with a data source, and the operations which are allowed on it.

8 Linking with a data source

The criteria space can be integrated with a data source, as long as one requirement is fulfilled: we must be able to perform textual searching over the data source. The textual search is performed with keywords from the concept space, although other search techniques, such as metadata searching or catalogue searching could be used.

The results are used to generate another information visualisation that is used to compare against the first quadrant concepts of the criteria space. The first quadrant contains all the concepts that satisfy the three criteria (see figure 8).

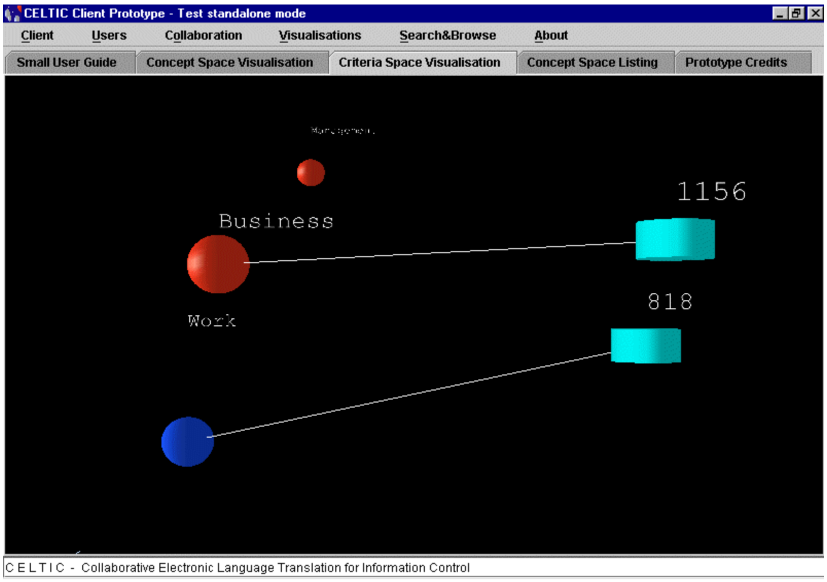

Figure 8: the information visualisation

The resulting visualisation provides information about the data source related with each concept from the first quadrant; data sources are displayed as a green cylinder, and linked to the corresponding concept.

Each cylinder represents the data source, with a label giving the number of occurrences of the concept's keywords in the data source. The position also indicates the keyword occurrences in the data source given the total number of occurrences for all combined existing keywords for a concept. It thus provides information to place the cylinder (data source) as the one that was used to place the sphere.

Having an information visualisation [Card et. al 1999] within the criteria space lead us to the possible integration between the structured knowledge sharing that has been enhanced and built by a group of people, and a given data source, such as the World Wide Web or a library.

This is made possible by populating the criteria space with metadata from the data source [Baeza-Yates and Ribeiro-Neto 1999]. The co-existence of this information allows for the analysis of a given data source, for example if it can potentially have relevant information concerning the subject represented by the structure for knowledge sharing and how well it fits the context represented in the concept space.

9 Concluding remarks

The various research issues described point out the question on how we can use 3D facilities to improve users capacity to deal with information. Information Visualisation can provide a useful way of sharing workable knowledge representations as collective cognitive map constructs, based on an organised set of individuals own visualisation filters.

Applications for workflow support or education, learning and training mediated by computer can be developed to test these ideas. Also, visualisation can lead the way to better content management both for information management and e-business.

The proposed 3D interactive visualisation provides the means for integration between the services needed to allow collaboration for enhancing the structure, and allows for group interaction. It also provides a visual interface for semantic access to information as an independent layer regarding a data source. Any data source can be used, and explored using the concept space and the criteria space (the second visualisation, based on user chosen keywords).

By introducing the criteria space visualisation we allow the users' exploration of the shared concept space by rearranging its concepts based on given criteria.

Additionally the criteria space visualisation allows integration of the structure for knowledge sharing with data source information. In ill-structured or complex domains, this visualisation offers the possibility of discovering relations between given concepts, which define, in a sense, an information context.

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