

Embodying cognition: a proposal for visualising mental representations in virtual environments

Á Sánchez, J M Barreiro and V Maojo

Laboratorio de Inteligencia Artificial, Facultad de Informática, Universidad Politécnica de Madrid
Madrid, SPAIN

alvaro@delicias.dia.fi.upm.es, jmbarreiro@fi.upm.es, vmaajo@infomed.dia.fi.upm.es

ABSTRACT

This paper examines the possibility of visualising the most abstract knowledge in virtual environments: mental representations that are involved in the basic cognitive processes. Metaphorisation is a key tool for creating virtual environments capable of embodying what is in the mind. The aim of these environments is to improve the learning and rehabilitation of users with cognitive disabilities. We propose to design symbolic environments in which concepts are converted into a bodily experience by means of the metaphorical projection from the abstract to the physical domain. Our proposal is illustrated by the description of a case study: the representation of categories in a virtual environment for blind children.

1. VISUALISATION OF COGNITION: A NEW CHALLENGE FOR VIRTUAL REALITY

Ever since it appeared on the scene, the aim of virtual reality technology has been to build synthetic worlds capable of simulating, representing or recreating the different facets and sides of reality. The virtual environments developed so far can be classed according to the sort of visualisation they provide. In this paper, we use the term “visualisation” in the broadest sense as a multi-sensory experience in an artificial environment. Although immersive virtual reality systems theoretically can provide different sorts of perception (visual, haptic, auditory, kinaesthetic), vision is usually the most important or only type implemented. So, as employed here, the term “visualisation” represents all the senses, that is, the possibility of touching, picking up and handling objects, listening to sounds or moving around in a virtual environment rather than just the ability to see.

In the following classification we propose below, virtual environments are divided into three major groups according to the type of objects and contents they can visualise:

- (a) Visualisation of things, objects, activities, scenarios or persons in virtual environments aiming at imitating reality; for example, buildings or architectural spaces for virtual walkthroughs, flight simulators, systems of telepresence for long-distance face-to-face communications, etc.

Significant examples of this type of environments are Street World and Object World, two applications developed by the University of North Carolina for autistic children. The first simulates an urban scenario: a street lined with buildings and a pavement, a car and a stop sign. The child can safely walk along this virtual street and learn how to cope with a range of different situations. The second scenario, Object World, serves to stimulate learning in a classroom containing objects that can be identified by their shape, colour or the use to which they are put and which the student can handle directly (Youngblut, 1998).

- (b) Visualisation of information: text and documents, data and information bases, including hierarchies, networks, frameworks and systems; for example, virtual environments as information spaces, in which users can explore, retrieve, organise and browse a collection of references to information sources located on the Web or elsewhere.

A possible example of a system belonging to this group is proposed by researchers from the Argentine University of La Plata and the University of Chile: a framework for adapting graphical hypermedia interfaces for blind users (Lumbreras et al., 1996). Using this framework, they have been

able to develop a hypermedia system with 3D sound that can be used without the need for any visual information.

- (c) Visualisation of knowledge is concerned with exploring information in such a way as to gain an understanding and insight into the data. This is a fundamental goal of much scientific research. It can be used to understand and solve scientific problems, look for regularities or connections, find hidden patterns in data and create new models. Scientific visualisation in virtual environments is the art of making the unseen visible: torsion forces inside a body, heat conduction, flows, plasmas, earthquake mechanisms, botanical structures or complex molecular models.

A representative project is VESL (Virtual Environment Science Laboratory). Its ultimate goal is to build a virtual sciences laboratory that can be used by any student, including users with cerebral palsy or other motor disabilities by means of different mechanisms and interfaces, including verbal orders (Nemire, 1995). Students can use the current prototype to explore the world of atoms and learn concepts and laws from atomic physics.

Our work aims to go one step further: to design and develop virtual environments that provide visualisation of cognition. Visualisation of cognition means the externalisation of mental representations embodied in virtual worlds. We are interested in how to map mental contents into sensorial representations and experiences in a virtual environment. Mental representations are the internal system of information used in cognitive activities (perception, language, reasoning, problem solving, etc.). Cognitive processes are essential in any activity demanding intelligence: recognising a voice, understanding a poem, learning a new concept, remembering a route, putting an object into a set or category, etc. All these activities involve people applying certain operations to mental content. We have to represent the things that the mental content is about in our minds. Different disciplines, like cognitive psychology, philosophy (logic, epistemology), cognitive science or artificial intelligence, are concerned with how things and processes outside minds can be represented inside minds (so that they can be dealt with by brains or machines).

These representations cannot be observed directly. However, we believe that their embodiment in virtual environments could help users with cognitive disabilities (learning or linguistic problems) to experience them through the senses and thus to understand them better. Such environments could be fully explored, allowing users to (re)build their own cognitive model and enhance learning by means of the sensory interaction with the virtual model.

The first problem that arises is how to transfer a mental representation –which is invisible to the senses, abstract, devoid of physical profiles- to a virtual environment based mainly on sensory perception. Is it possible to visualise mental contents in a virtual reality system?

2. THE ROLE OF METAPHOR IN VIRTUAL ENVIRONMENTS

Metaphor is much more than just a linguistic medium, it is also a mechanism of thought, an instrument capable of conveying new cognitive contents (Radman, 1997). Metaphors are a guide to the discovery of invisible things and abstract notions. If we want to learn or discover something new, we have to be able to imagine it first. Thanks to metaphorisation, it is possible to gain new knowledge. The analogies or similarities established by metaphors generally follow the same pattern: the use of the known, the familiar and the concrete to express the new, the unknown and the complex. Metaphor is usually employed in scientific research to structure and understand a new domain in terms of a known field. For example, Niels Bohr used visual metaphor to describe atomic processes in 1913: the atom behaves as if it were a minuscule solar system

Metaphor is also a key element in the design, construction and use of virtual environments. Firstly, the user interface of any virtual environment calls for the design and elaboration of metaphors that symbolise the different forms of navigation and interaction with the artificial world. On the other hand, if the end users of a virtual environment have any sort of sensory disability (like blindness or deafness), the creation of kinaesthetic metaphors that ease perceptual transposition is a must. For example, a virtual environment for blind users would require metaphors capable of representing the visual information and converting it into tactile or auditory information. Besides, metaphorisation is essential for representing the concepts or contents furthest removed from material reality: as the complexity of the type of visualisation becomes more complex and abstract in the virtual environment (objects-information-knowledge-mental representation), metaphor plays a more significant and central role.

We have claimed the metaphorical design of virtual environments for education elsewhere (Sánchez et al., 2000). The main component of our design is what is termed metaphorical projection. The metaphorical projection can be viewed as a mapping between the source knowledge of the real world (what is to be taught) and the virtual environment (what is to be designed). The purpose of this transfer is to develop a network of metaphors that define both the structure of and the forms of learning, navigating and interacting with the virtual world, that is, the metaphorical projection acts on four interdependent planes: the structural plane, the learning plane, the navigation plane and the interaction plane. The most important is the structural plane, whose metaphors establish the architectural principles of the virtual scenario, which will determine its ultimate form and structure. The goal is to create an isomorphism or structural correspondence with a domain with which students are already familiar, thereby easing understanding and learning of didactic contents. The learning plane metaphors are used to design the educational strategies (the activities to be performed by the student in the virtual environment, the role of the teacher, etc.). The navigation and interaction planes are composed of the metaphors that define how users can move about in and interact with the virtual environment. These four planes of metaphorical projection form a systematic set of metaphors, which provide the guidelines for designing and building the entire virtual world.

In our opinion, only through metaphor is it possible for users of a virtual environment to visualise and physically experience the abstract. The imperceptible, the mental, the complex thus becomes accessible to users, something that they can understand and interpret. We, therefore, propose to address the design and construction of metaphorical virtual environments specifically directed at users with some sort of cognitive impairment or retardation. These artificial worlds would embody the mental representations and models mainly to strengthen user rehabilitation or learning. In the next section, we will briefly examine a case that will serve as an example of our proposal: a virtual environment directed at blind children for stimulating and improving their ability to classify.

3. REPRESENTATION OF CATEGORIES IN A VIRTUAL ENVIRONMENT FOR BLIND CHILDREN: A CASE STUDY

There is nothing as essential as categorisation for human perception, thought, action and language (Lakoff, 1987). Every time we see something (as a class of thing), every time we reason (about classes of things: countries, diseases, emotions, etc.) or intentionally take any action or talk about anything, we are employing categories. Categorisation is central to our cognitive abilities. It is vital for us to have an understanding of how we categorise to be able to comprehend how we think and work as human beings. We have categories for everything that can be thought about and perceived: categories of biological species, physical substances, artefacts, colours, emotions, words, etc. Category learning is the most general form of cognition.

3.1 Main Concepts of Categorisation

Some basic concepts of categorisation, taken from the classic work of Eleanor Rosch (1978), will be used throughout this section. These are taxonomy, basic level, attribute and prototype.

Taxonomies are systems in which the categories are interrelated by relationships of inclusion. A conceptual hierarchy (e.g., *animal – bird – sparrow*) has different levels of generality or abstraction, depending on category inclusiveness.

A taxonomy is divided into three levels or category types: generic or supra-ordinate categories, specific or subordinate categories and basic categories. This basic level always comes between the more general and more specific category, at an intermediate level of inclusiveness. For example, if *table* and *bird* are basic categories, the supra-ordinate categories are *furniture* and *animal* and the subordinate categories *kitchen table* and *sparrow*.

A category can also be considered as a series of traits or attributes that are shared by most of the members of the category in question. For example, the category *chair* would be composed of attributes like *seat*, *legs*, *back*, etc. Prototypes are the specimens with a definite air of family within a category. So, the prototype acts as the category reference point.

3.2 Categorisation by Blind Children

Generally, blindness complicates the process of categorisation, as visual perception is one of the main sources for acquiring knowledge about the world. But, exactly how is category learning affected in blind children? According to Perais et al. (1992), blind children face two basic problems for categorisation:

Firstly, a deficit in the generalisation and structuring of categories. Sight impairment prevents blind children from inducing or abstracting the most important characteristics of a class to form a general representation. Generic classes do not have a concrete referent, hence their difficulty. The process of generalisation calls for experience with many concrete specimens. Young children have little knowledge of supra-ordinate and subordinate classes or of taxonomic organisation, whereas the basic level is the most significant and best characterised.

Secondly, an alteration or delay in language learning. A distinction has to be made between the lexical level (lexical label) and the conceptual level (the mental representation) in a child's (blind or otherwise) process of language learning. The child must learn to establish the right connections between these two levels. Development of the referential function is a necessary condition for the process of naming and conceptualising reality. When the absence of visual information interferes with the process of identifying the referents of words (lexis), the "mental lexicon" may also be disturbed.

Language learning is delayed, especially in the early childhood of the blind, because they have no visual stimulation. "Verbalism", the use of meaningless words and expressions that have no particular sensory referent, is a common phenomenon; that is, blind children tend to learn and use some lexical labels without an associated mental representation.

3.3 Acquisition and Representation of Categories according to Lakoff: an Experientialist View

Lakoff's main thesis (1987) is that we organise our knowledge by means of structures called idealised cognitive models or ICMs. Each ICM is a complex structured whole, a gestalt. The structure of thought is characterised by cognitive models and the categories of the mind correspond to elements of these models.

Cognitive models derive their fundamental meaningfulness directly from their ability to match up with pre-conceptual structure. Some experiences are structured pre-conceptually because of the way the world is and the way we are. At least two forms of pre-conceptual structure exist:

- (a) Basic-level structure: Basic-level categories are defined by the convergence of our gestalt perception, our capacity for bodily movement and our ability to form mental images. Water, wood, stone, dog, cat, chair, table... are basic-level concepts, that is, directly meaningful concepts. (Note on imagery in blind people: some papers, e.g. De Beni and Cornoldi (1988), show that impaired vision does not eradicate mental images. The blind can form images that possess many of the essential characteristics of objects, like texture, shape and others that are not based on visual perception).
- (b) Kinaesthetic image-structure: Image schemas are simple structures that constantly recur in our everyday bodily experience (containers, paths, links, forces, balances) and in various orientations and relations (up-down, front-back, part-whole, centre-periphery, etc.). The consideration of certain patterns in our experience (our vertical orientation, the nature of our bodies as containers and as wholes with parts, our ability to sense hot and cold, etc.) suggests that our experience is structured kinaesthetically in a variety of experiential domains.

These two structures are directly meaningful, because they are directly experienced owing to the nature of the body and its mode of functioning in our environment. Given basic-level and image-schematic concepts, it is possible to build up complex cognitive models. Image schemas provide the structures used in those models. Some schemas (like container, link, part-whole, centre-periphery, up-down, front-back...) can structure our experience of space. Lakoff claims that the same schemas structure concepts themselves. When we understand something as having an abstract structure, we understand that structure in terms of image schemas. According to the spatialisation of form hypothesis (Lakoff, 1987):

- Categories are understood in terms of container schemas
- Hierarchical structure is understood in terms of part-whole schemas and up-down schemas
- Relational structure is understood in terms of link schemas.

The spatialisation of form hypothesis requires a mapping from physical space into a "conceptual space". Thus, spatial structure is mapped into conceptual structure. Specifically, image schemas (which structure space) are mapped into the corresponding abstract configurations (which structure concepts). The spatialisation of form hypothesis thus maintains that conceptual structure is understood in terms of image schemas, plus a metaphorical mapping.

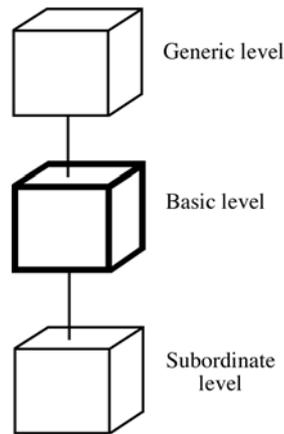


Figure 1. *Cube network*

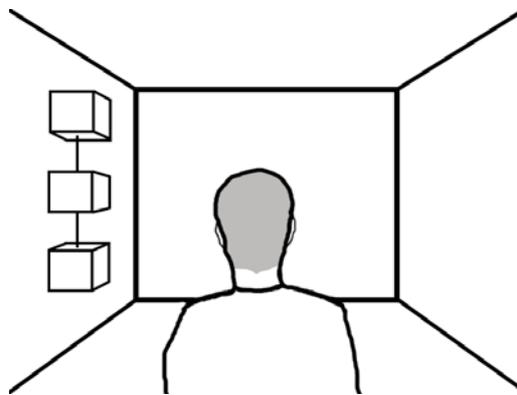


Figure 2. *Room-container*

3.4 Preliminary Design of a Virtual Environment for Blind Children

In this section, we present a preliminary design of a virtual environment that will serve as an example of category representation. Preliminary design means a simplified (and, therefore, incomplete) and idealised (not taking into account implementation difficulties) design.

Its potential users are blind children with categorisation and linguistic labelling problems. The content is focused on a three-element taxonomic hierarchy: *furniture – chair – fold-up chair*. We will follow Lakoff's theory for the representation of this taxonomic hierarchy, according to which each taxonomy is an idealised cognitive model, a hierarchical structure of categories, in which each category is structurally represented by a container schema and the complete hierarchy by part-whole and up-down schemas.

The virtual environment must be designed in accordance with natural metaphors, that is, motivated by the structure of bodily experience (for Lakoff, human categorisation is partly based on the nature of human bodies). The metaphorical projection guiding the design of the virtual environment is carried out on four different planes: the structural plane, the learning plane, the navigation plane and the interaction plane.

(a) Structural plane. The goal is to convert the conceptual space (the hierarchy) into a physical space, establishing a structural correspondence between Lakoff's schemas and a similar virtual scenario. We propose to design two virtual environments. The first will represent the conceptual hierarchy and the second, each category.

- Cube network. The hierarchy is represented as a network of cubes ordered vertically at three spatial levels (see Figure 1). Each cube-container represents a category of our example: *furniture* (generic level), *chair* (basic level) and *fold-up chair* (subordinate level). The full network symbolises the taxonomy. The scale or size of this environment must be very small so that the child can explore the cube network using its hands (equipped with data-gloves or a similar device).

- Room-container. Each category is symbolised by a 3D scenario, a life-size cube-shaped room (see Figure 2). Two items are arranged inside the room. Firstly, the above-mentioned cube network is located at one side of the scenario and within the user's reach. This network acts as a map or guide, letting the child know what room it is in (the cube in use can be marked by means of a distinctive tactile or auditory characteristic: shape or size, texture, sound or verbal message). Secondly, there is one or more objects representing the category, which can be handled and explored by the user, in the centre of the room.

The creation of two virtual environments, the network and the room-container (which is really only one spatial scenario: the room, that always contains the cube network) is justified because human categorisation is understood as a two-fold process. On the one hand, categorisation answers to the identification of perceptual and functional attributes by sensory interaction (by means of which specimens of each category can be identified and distinguished). On the other hand, categorisation is also based on theoretical or mental constructs of the subject (by means of which to generalise, induce and classify elements in a conceptual hierarchy).

(b) Learning plane. The selection of activities that will guide the child's learning in the virtual environment can depend on many factors (age, pupil's background knowledge, type of impairment concerning categorisation, etc.), but the following are advanced as a suggestion. Each level, each room-container, could call for different sorts of activities or exercises:

- Basic level (room containing chair). This should be the starting point, the first room visited by the child. Remember that basic categories are especially important, as they are the first categorisations made by the child (have similar external forms and develop similar motor programs). This room would contain a virtual chair, which would represent all the chairs of the basic category. This would be a prototype chair, with all its definitional components: seat, back and four legs. The activities of this level would be committed to understanding the component "parts of" or "part-whole" of the basic concept (linguistically expressed by expressions like "*has...*", "*its parts are...*"). The virtual chair could be explored and handled in ways that are out of the question in a real environment: the child could take apart and reassemble the chair, each component could speak and identify itself when the child touches it ("*hello, I am a seat*") or give additional information ("*I am shaped like...*", "*I am made of...*"), the (animated) chair could fall over or be positioned differently for the child to stand it up correctly, etc.
- Subordinate level (room containing fold-up chair). As soon as the child is familiar with the basic category chair, it is ready to learn about different types of chairs (in this case, the subordinate category fold-up chair). The activities at this level are focused on learning to distinguish the evaluative or rateable component (linguistically expressed by expressions like "*is used to...*", "*is + adjective*", "*is used as...*") and on understanding what similarities and differences it has with the prototype chair of the basic level by directly interacting with a virtual fold-up chair (or several different types of fold-up chair).
- Generic level (room containing furniture). This level would aim to stimulate the process of generalisation and abstraction (e.g. "*a chair is a piece of furniture*"). The room could reproduce a real setting, like a dining room (or a kitchen or lounge) with different sorts of furniture, like chairs, a table, a cupboard, shelves. By exploring the virtual scenario, the child would be able to get to know different specimens of furniture, know how they are arranged in a given setting and learn how to recognise the common characteristics of all the pieces of furniture.

(c) Interaction and navigation planes. The child would not need to move to go from one room to another or to reach objects. Either a verbal order or a given hand movement or manual indication on the cube map would suffice to move up or down a level. All it would take is a spoken instruction or a predetermined gesture to reach objects, and the things would move in front of the child or be placed directly into its hands. The objects could feature magical properties useful for supporting learning: they could break up into parts, talk, move, change size or shape, etc. A teacher or instructor-guide could accompany the child, especially during its first visits to the virtual environment.

A virtual environment like this one is beneficial in many ways: the blind child can broaden its experience and enter into contact with many elements of a class (thus making it easier to generalise). The virtual environment promotes activity based on gestures and manipulation and allows the child to experiment directly with objects, while establishing the respective linguistic expressions (which are associated with their referents). All this takes place in a safe environment that is completely harmless for the child.

The example of the environment described above is very simple but could be extended in several ways: enlarging the taxonomy by including more elements at each level; changing the conceptual domain (animals, vehicles, plants...) without modifying its structure; creating a visual or graphical version of the environment for children with remaining sight or sighted users with other categorisation-related cognitive problems (aphasia, mental retardation, autism), etc.

4. CONCLUSIONS

As shown in our case study, embodiment in virtual environments provides a link between cognition and experience (abstract concepts are based on bodily experience). The cognitive models and concepts that represent the taxonomies are embodied in a virtual environment that reproduces the same patterns and schemas that we use in everyday categorisation: categories as containers and hierarchies as spatial structures.

Much of our technology, -telescopes, microscopes, photography, television-, has provided ways of extending basic level perception in the visual domain. Virtual reality technology has two other benefits: firstly, it extends perception to other sensory domains (tactile, acoustic, movement) and, secondly, it is capable of creating semantic spaces, where the abstract can be represented metaphorically in a physical scenario. By building virtual environments, we can actually create perceptual worlds that embody mental models created entirely in the mind. These artificial environments can externalise and represent the inner landscape of our mind, thus enhancing the learning process. We believe that virtual reality can make a great contribution to the study of the ideas, concepts, theories and methods developed by cognitive science and pedagogy. In the near future, virtual environments are likely to become an indispensable tool for these sciences and the main results could be applied to the rehabilitation of some cognitive disabilities.

Acknowledgements: We would like to thank Rachel Elliot for her help in correcting the English and to Ignacio Sánchez for preparing the 3D figures.

5. REFERENCES

- R De Beni and C Cornoldi (1988), Imaginary Limitations in Totally Congenitally Blind Subjects, *Journal of Experimental Psychology: Learning, Memory and Cognition*, vol. 14, n° 4, pp. 650-655.
- G Lakoff (1987), *Women, Fire, and Dangerous Things: What Categories Reveal about the Mind*, The University of Chicago Press, Chicago.
- M Lumbreira, M Barcia and J Sánchez (1996), A 3D Sound Hypermedial System for the Blind, *Proceedings of the 1st European Conference on Disability, Virtual Reality and Associated Technologies*, P M Sharkey (Editor), Maidenhead, UK.
- K Nemire, (1995), Learning in a Virtual Environment: Access by Students with Physical Disabilities, *Proceedings of the Tenth Annual Conference on Technology and Persons with Disabilities*, H J Murphy (Editor), Northridge: California State University.
- H Peraita, R Elosúa and P Linares (1992), *Representación de categorías naturales en niños ciegos* (in Spanish, "Representation of natural categories in blind children"), Editorial Trotta, Madrid, Spain.
- K Radman (1997), *Metaphors: Figures of the Mind*, Kluwer Academic Publishers, Dordrecht, The Netherlands.
- E Rosch (1978), Principles of Categorization, in *Cognition and Categorization* (E Rosch, B B Lloyd, Eds.), Lawrence Erlbaum Associates, Hillsdale, N. J.
- A Sánchez, J M Barreiro, V Maojo (2000), Design of Virtual Reality Systems for Education: A Cognitive Approach, *Education and Information Technologies*, special issue on Virtual Reality in Education (forthcoming).
- C Youngblut (1998), *Educational Uses of Virtual Reality Technology*, Institute for defense analyses, IDA Document D-2128, Alexandria, Virginia.