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ICSC 2000

International Conference on Spatial Cognition: Scientific Research and Applications

Proceedings

Lectures, Symposia, Sessions

Demonstrations and Posters

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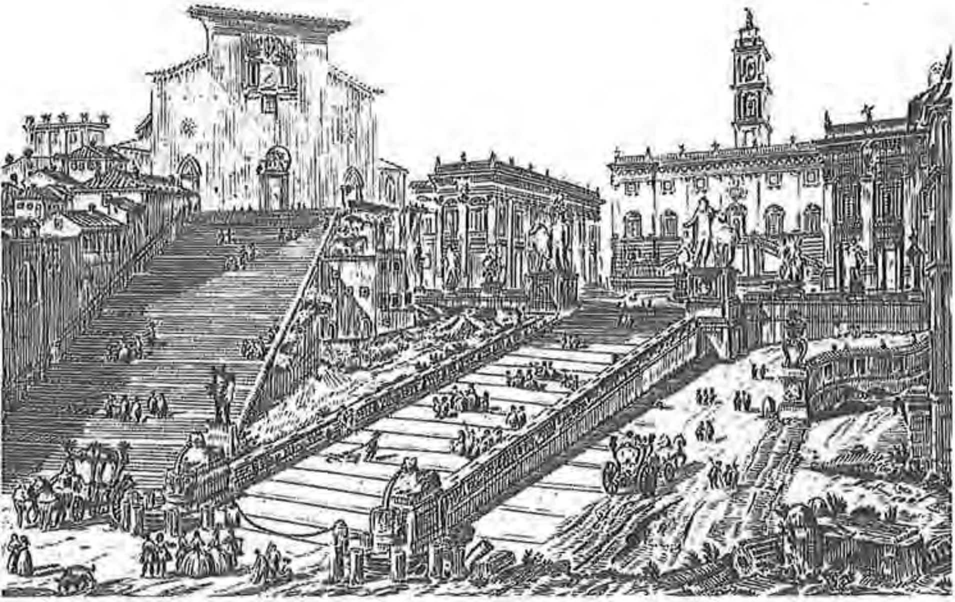
ICSC 2000



Rome, December 14-16, 2000

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PABST

COGNITIVE PROCESSING
International Quartely
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ICSC 2000
Program

Thursday, December 14, 2000

Session on *Verbal labeling of spatial information*
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Symposium on *Communicating spatial relations*
Convenor: H.D. Zimmer
H.D. Zimmer, H. Speiser, J. Baus & T. Krüger (Saarbrücken, Germany); J. Baus, A.Butz, C. Kray & T. Krüger (Saarbrücken); J. Grabowski (Heidelberg); R. Klabunde (Heidelberg); M. Raubal (Vienna).

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Invited Lecture - *Language and space: How to convey directional information in spatial discourse* by M. Denis (Paris).

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Symposium on *Perceptual space organisation processes relevant to visual arts and architecture*
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Symposium on *The neurocognitive foundations of spatial memory*
Convenor: A. Postma
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Poster and Demo Session
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Invited Lecture - *Mechanisms of spatial cognition in man and machine* by H.P. Mallot (Tübingen).

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Session on *Spatial cognition and modeling*
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Symposium on *Spatial attention as a motor-perceptual integration process*
Convenor: F. Ferlazzo
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Session on *Spatial cognition and virtual environments*
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C. Thinus-Blanc & S. Gouteux (Marseille); C.R. Menzel, E.S. Savage-Rumbaugh & E.W. Menzel jr. (Panthersville, USA); P. Potì (Rome).

Invited lecture - *Brain-computer interfaces for communication and control* by J. Wolpaw (Albany).

INVITED LECTURES

COGNITIVE PROCESSING
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Language and space: How to convey directional information in spatial discourse?

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Université de Paris-Sud, Orsay, France

Communicating about space is one of the primary forms of communication in the human species. The case under consideration here is the situation in which a person requests another one to provide him/her with assistance in an unfamiliar environment. An interesting feature of this situation is the variety of modes in which people communicate spatial information to one another.

A straightforward way of assisting another person's navigation consists for the person who knows an environment in guiding the person in need of assistance along the intended route. The significance of this procedure is clear. It offers to the assisted person an opportunity to perform the very same sequence of steps as the guiding person, this ensuring a secure way to reach a distant target in the environment. However, this form of assistance has a cost, both in terms of energy and time, for the person who escorts the person in need of assistance. But it seems to be an appropriate form of assistance when more sophisticated means of communication cannot be used (e.g., when the assisted person is a young child, or a foreign visitor). The solution to the navigational problem is then achieved by inviting a person to mimic one's own navigational performance on line.

If the person who provides assistance cannot accompany the other person for some reason, other solutions must be found. Some are based on highly analog communicating systems. For instance, pointing by hand to an intended goal may be useful. Its value is that the pointing gesture directly applies onto the metric structure of the environment. But its limitations are obvious. Pointing is usually accomplished in the direction of visible objects, which in general do not require any special assistance to be reached. Pointing may be directed to more remote places, but the informational value of such pointing is limited when it applies to out-of-sight objects or places.

Other symbolic devices can be used to convey spatial information to people in need of assistance. Mostly useful are maps, which provide people with survey views of environments. The value of maps is to offer an integrated perspective on large-scale spaces, including parts of space that are distant from the point where an observer stands. Another valuable feature of maps is that they are structurally analogous to the environments they refer to, which is generally considered to be cognitively advantageous. However, maps also include a number of more abstract pieces of information, which require decoding capacities on the part of the map user. Note that some maps include directional information (typically, in the form of arrows), but more usually they offer survey views of environments, without any reference to navigational procedures.

Language can also be used to help people in need of navigational assistance. Language is of special value when no graphic device is available. It is a highly available, flexible, ubiquitous mode of communication. Like maps, language-based route directions can be used on the spot, but also in places that are distant from the described environment. Language is useful to describe static scenes in an environment, either from a frontal or a survey view. Spatial discourse can also be used to make an addressee adopt the perspective he/she will have while navigating through the environment. Route descriptions convey information that matches the sequence of local views that will be encountered during navigation.

Route directions belong to the well documented class of procedural discourse. They consist in delivering instructions on how to navigate between specified points of an environment. However, they are not just sequences of instructions, such as "Make a left", or "Go straight". They include numerous references to visual landmarks of the environment. Most of these landmarks are targets for specifying actions ("Walk towards the ice-cream shop"). A number of them are also introduced as references to views that will be encountered while the person proceeds along the route ("In the middle of the square, there is a statue"). Studies conducted in our lab indicated that up to 80% of statements in route directions refer to the visual environment traversed by the travelling person. This contributes to our conception that route directions are not limited to prescribing navigational procedures. They are to a large extent intended to provide a person with an advance visual model of the environment where navigation will take place. Route directions are more than "directions". They make it possible to create internal representations of visuo-spatial configurations of the environment in which actions will be implemented.

Route-giving is of interest on both sides of the communication process. On the speaker's side, it is important to understand the mechanisms by which only a limited subset of landmarks present in an environment is selected to be included in route directions. Another interesting feature is the variety of descriptions that a sample of participants typically give when describing the very same route. It is a valuable task for researchers to discover the common structure that underlies the many variants of route directions given by several participants. These issues have elicited a number of empirical investigations that I will report in my talk. Results will also be reported from studies on the comprehension side. In particular, experiments have investigated the amount of cognitive resources allocated to the various parts of route directions, and the components of the visuo-spatial working memory that are involved in the processing of the prescriptive and the descriptive parts of route directions. These investigations provide data that are relevant for the design of user-oriented computer-based navigational systems.

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Mechanisms of spatial cognition in man and machine

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Eberhard Karls Universität Tübingen

Abstract - The simplest representation of space allowing for spatial cognition in biological and artificial systems is a graph; the nodes of this graph contain local position information (views) characterizing certain places while its links are labeled with movements or actions leading from one view to the next. In this paper, we review recent theoretical and psychophysical work on view graph representations. Results indicate that the view-graph approach is well suited both for modelling human navigation performance and for implementing spatial memories in robots.

1. Spatial behavior

Spatial behavior includes a wide variety of competences that can be classified based on the type and extend of memory they require; for reviews see Trullier et al. (1997), Mallot (2000) and the papers collected in Mallot & Hauske (2000).

Without memory (no remembered goal). Simple tasks like course stabilization, efficient grazing and foraging, or obstacle avoidance can be performed without memory. Traditionally, memory-free orientation movements (and some simple movements requiring memory) are called "taxes" (Kühn 1919).

Working memory of a home position. This is required for path integration. Current ego-motion estimates are vectorially aelded to an egocentric representation of the start position thus that the current distance and direction of the start point are always available. This vector to the start point is a form of working memory. Long-term memory of places visited along the path is not required (see Maurer & Séguinot, 1995, for review).

Long-term memory. This is involved in landmark-based mechanisms, which use a memory of sensory information characteristic of a given place ("local position information") . In *guidance*, motions are performed such as to achieve or maintain some relation to the landmarks. For example, a so-called snapshot taken at the target position is stored in memory. By comparing the current view to the stored reference view, a movement direction can be calculated that leads to an increased similarity of current and stored snapshot (Cartwright & Collett, 1982; Franz et al. 1998b).

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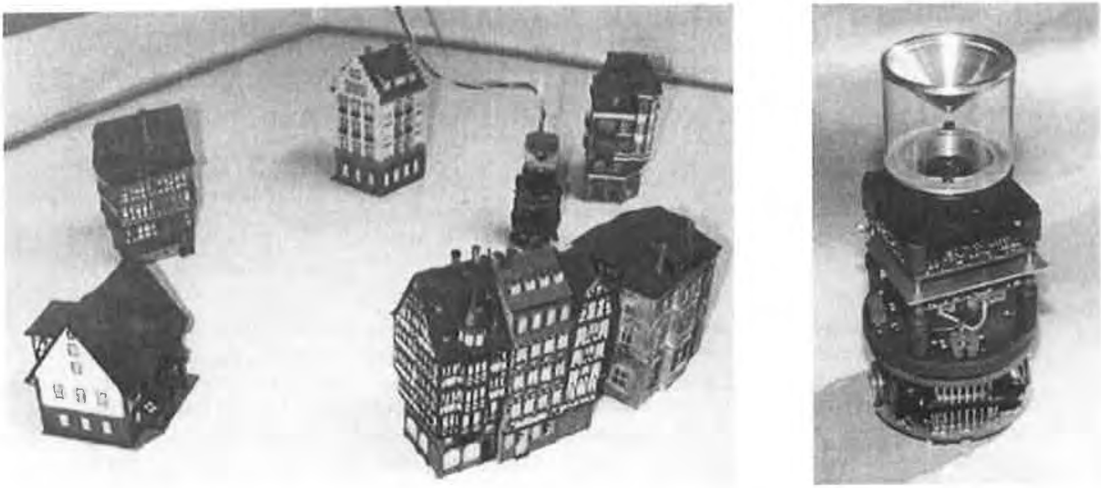

Fig. 1. *Left* Arena for robot experiments using toy houses. *Right* Close-up of modified Khepera robot with a vertically mounted camera facing a conic mirror. (Franz et al. 1998b)

A second type of landmark based navigation uses a slightly richer memory. In addition to the snapshot characterizing a place, an action is remembered that the observer performs when recognizing the respective snapshot. In the simplest case, these actions are movements into specific directions, but more complicated behaviors such as wall following could also be attached to snapshot recognition (e.g., Kuipers 2000). We will refer to this mechanism as "recognition-triggered response" (Trullier et al. 1997). Chains of recognition-triggered responses allow the agent to repeat routes through a cluttered environment.

Declarative memory. This is required to plan and travel different routes composed of pieces and steps stored in the memory. At each step, the movement decision will depend not only on the current landmark information, but also on the goal the navigator is pursuing. Following O'Keefe & Nadel (1978), we use the term cognitive map for a declarative memory of space; a cognitive map in this sense does not necessarily contain metric information nor does it have to be two-dimensional or "map-like" in a naive sense. A framework which is able to accommodate most findings on spatial declarative memory is that of a "cognitive graph", i.e. a graph composed of recognized landmarks, views, or places (the nodes of the graph), and actions leading from one node another (the edges of the graph); see Kuipers (1978, 2000) and Schölkopf & Mallot (1995). A single node with one outgoing edge corresponds to a recognition-triggered response.

2. View-graphs in robot navigation

Using view-graphs as spatial memory is most intuitive in maze-like, or channeled, environments, which have discrete decision points and strong movement restrictions. In order to apply the view-graph approach to open environments, two problems have to be addressed: First, discrete points or centers have to be defined based on sensory saliency and strategic importance (e.g., gateways). Second, a homing mechanism has to be implemented that allows the agent to approach the centers from a certain neighborhood or catchment area.

2.1. *Snaptshots*

View-based solutions to both problems have been presented by Franz et al. (1998a,b). An agent starts the exploration of an open environment (arena) by recording the view visible from its initial position. During exploration, the agent continuously monitors the difference between the current view of the environment and the views already stored in memory. If the difference exceeds a threshold, a new view is stored; in the view-graph, this new view is connected to the previously visited one. The second problem, approaching a familiar view, is solved by scene-based homing: The agent starts by comparing the current and the stored view. From this comparison, the agent calculates a direction in which to move in order to increase the similarity between stored and current view. During exploration, this second mechanism is also used for "edge verification": if the agent encounters a view similar to one stored in its memory, it tries to home to this view. If homing is successful, i.e. if stored and current view get sufficiently similar, a link is added to the view-graph. The mechanism has been tested with a robot using a panoramic vision device navigating an arena with model houses.

At first glance, the view-graph approach might not seem natural for open environments. However, in a view-based scheme, the manifold of all pictures obtainable from all individual positions and viewing directions in the arena (the "view manifold") cannot be stored completely. The sketched exploration scheme is an efficient way to sample the view-manifold and represent it by a graph whose mesh size is adapted to the local rate of image change, i.e. to the information content of the view-manifold. The threshold for taking a new snapshot has to be set in a way to make sure that the catchment areas of adjacent nodes have sufficient overlap.

2.2. *Depth signatures*

Local position information is any information that can be obtained from a given observer location. So far, we have studied pure image, or texture information. However, there is strong evidence both from rodent and human studies that depth information is also used and may even override texture information. For example, Cheng (1986) showed that rats remember the corners of a rectangular box by the geometric configuration (e.g. "long wall to the left") rather than by the pattern information given at the corners and therefore confuse diagonally opposing corners.

We designed a panoramic stereo camera with a bipartite conic mirror (see Stürzl & Mallot, 2000, for details). In experiments with the panoramic stereo camera mounted on a Khepera robot, we were able to show that depth signature can be used for homing to places where depth signatures had previously been recorded. Further experiments with improved stereo algorithms and integration of depth signatures and snapshots are under way.

2.3. *Metric information in graphs*

Strictly speaking, graphs contain only neighborhood information such that mirror images or scrambled version of a given drawing of a graph are completely equivalent. In the view-graphs developed by Franz et al. (1998a,b), some metric information is implicitly incorporated in the panoramic views stored for each node. In the homing algorithm, the current view is compared to the stored target view and a movement direction is computed so as to reduce the difference between the stored and current views. For three stored views connected in a row, the angle subtended by the first and the last views, when viewed from the central node, can be estimated by the same algorithm. Another form of local metric information easily accessible to the observer is the distance between two connected views.

If the known nodes in an environment are connected in a chain, the estimation of global metric information from local measurements is accomplished by path integration (cf. Mallot 2000, Maurer and Séguinot 1995). If, however, a true graph is available, much better estimates may be obtained from multidimensional scaling (MDS; see for example Mardia et al. 1979). Hübner & Mallot (this meeting) developed a MDS algorithm using both distance and angle information by minimizing a common cost function. The resulting representation is again a graph whose nodes are associated with coordinate values. That is to say, the graph is metrically embedded.

The behavioral relevance of metric localization of nodes rests on three advantages:

1. Perceptual aliasing, i.e. the problem of similar landmarks occuring at different nodes can be broken.
2. Path planing can be performed by minimizing path lenght.
3. Shortcuts across meshes of the graph can be found even if the according link does not (yet) exist.

3. Mechanisms of human spatial behavior

We have tested the view-graph approach to cognitive maps in a series of behavioral experiments using the technology of virtual reality (see van Veen et al. 1998). The basic structure of the experimental environment, called Hexatown, is depicted in Fig. 2 (Gillner & Mallot 1998, Mallot & Gillner 2000). It consists of a hexagonal raster of streets where all decision points are three-way junctions. Three buildings providing landmark information are located around each junction. Subjects can move through the environment by selecting "ballistic" movement sequences (60 degree turns or translations of one street segment) by clicking the buttons of a computer mouse (see Gillner & Mallot, 1998, for details). Aerial views are not available to the subjects. In the version appearing in Fig. 2, the information given to the subjects is strictly view-based, i.e. at any one time, no more than one of the landmark objects is visible.

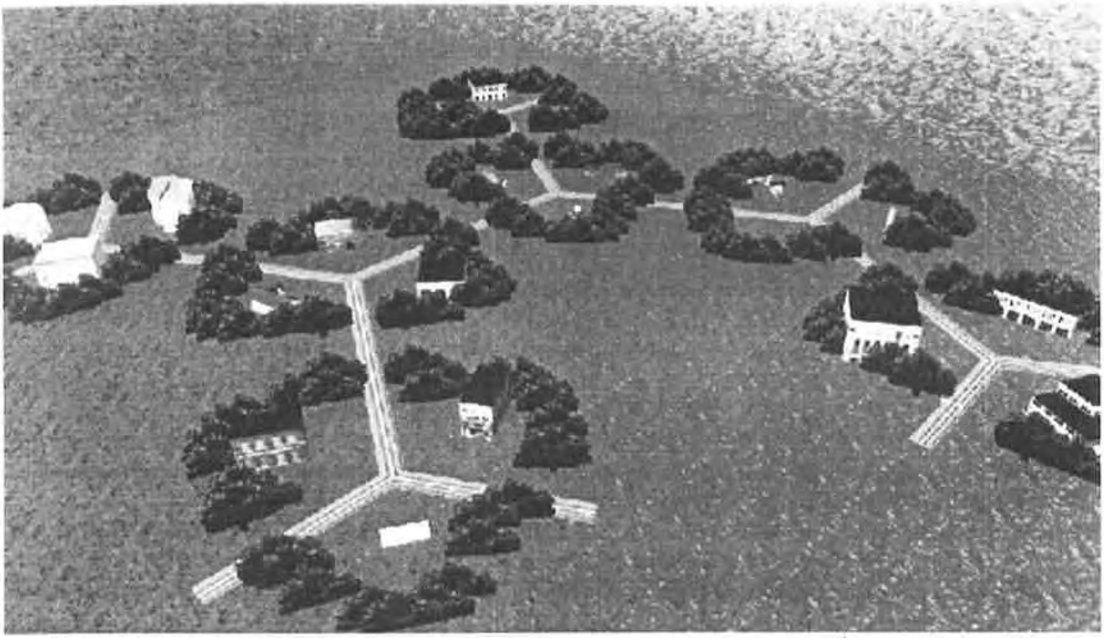

Fig. 2. Aerial view of Hexatown. The white rectangle in the left foreground is view 15, used as "home"-position in our experiments. The aerial view was not available to the subjects.

The landmark information in Hexatown is strictly confined to the buildings and objects placed in the angles between the streets. Tlle geometry of the street raster does not contain any information since it is the same for all places and approach directions. This is important since geometry has been shown to play an important role in landmark navigation (Cheng 1986, Hermer & Spelke 1994). Hexatown does also provide one other type of information, i.e. egomotion as obtained from optical flow.

The most important results obtained with the Hexatown environment are the following:

Place vs. view in recognition-triggered response. In systematic experiments with land-mark transpositions after route learning, we could show that recognition-triggered response is triggered by the recognition of individual objects, not of the configurations of objects making up a place (Mallot & Gillner 2000). After learning a route, each object together with its retinal position when viewed from the decision point (left peripheral, central, right peripheral) is associated with a movement triggered by the recognition of this object. When objects from different places are recombined in a way that their associated movement votes are consistent, no effect in subjects' performance was found. If however, objects are combined in inconsistent ways (i.e. if their movement votes differ), subjects get confused and

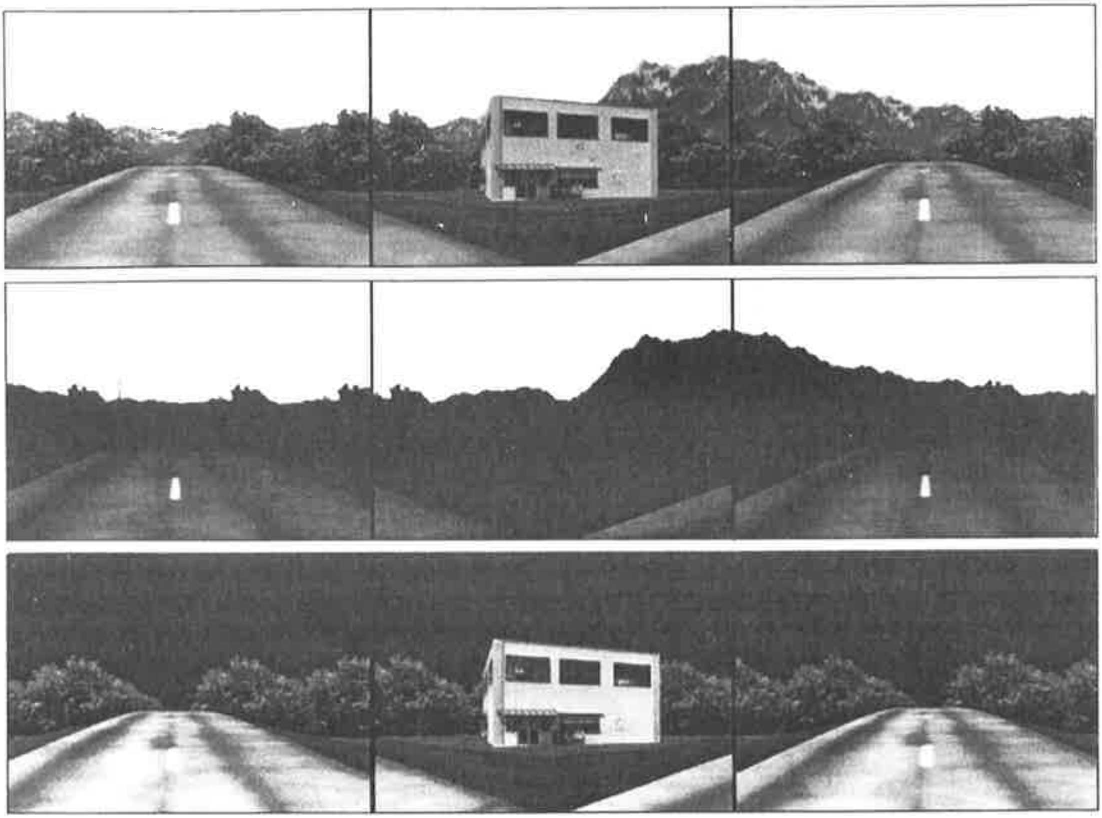

Fig. 3. Panoramic views of Hexatown used in the interaction experiments. *Top*: Training condition: both distant (mountain peak, distant tower in the left panel) and local landmarks (building) are visible. *Middle*: "Dawn" condition. Only the silhouette of the landscape and tower (distant landmarks) are visible. *Bottom*: "Night" condition. Only local landmarks are visible. Subjects who ignored one landmark type (distant or local) in a landmark transposition experiment with cue conflict, were still able to use the previously ignored landmark type in these environments.

the distribution of motion decisions approaches chance level. It is interesting to note that this result is different from findings in guidance tasks (Poucet 1993, Jacobs et al. 1998), where the configuration of all landmarks at a place seems to be stored in memory.

Stereotyped behavior. Recognition-triggered response is not restricted to pure route behavior. In order to study map behavior, subjects were asked to learn twelve different routes in Hexatown (Gillner & Mallot 1998). While map knowledge has been acquired during that experiment (see below), stereotyped associations of views to movements could also be demonstrated in this situation. By evaluating the sequences of views and movement decisions generated by the subjects when navigating the maze, we found a clear tendency to simply repeat the previous movement decision when returning to an already known view. This implies that subjects use the strategy of recognition-triggered response, which is a stereotyped strategy useful in route navigation.

Map knowledge. Subjects can acquire map knowledge in a virtual maze. In a series of search tasks where subjects were released at some position and had to find a landmark shown to them as a print-out on a sheet of paper, subjects were able to infer the shortest ways to the goal in the later search tasks (Gillner & Mallot, 1998). Each individual search corresponded to a route learning task; the advantage for later search tasks indicates that some goal-independent knowledge was transferred from the known routes to the novel tasks, which is an indication of map knoledge in the sense of O'Keefe & Nadel (1978). Other indications of map knowledge were the subjects' ability to estimate distances in the maze and the sketch maps drawn as the last part of the experiment.

Interaction of cues. In order to study different types of landmark information, we added distal landmarks to the environment, placed on a mountain ridge surrounding Hexatown (Steck & Mallot 2000). In this situation, various strategies can be used to find a goal: subjects could ignore the distant landmarks altogether, they could rely on the distant ones exclusively, or they could use both types in combination. We tried to identify these strategies by replacing the distant landmarks after learning, so that different patterns of movement decisions can be expected for each of the above strategies. We found that different strategies are used by different subjects and by the same subject at different decision points. When removing one landmark type from the maze after learning, subjects who had relied on this landmark type earlier were still able to use the previously neglected type. This indicates that both types of information were present in memory but one was ignored in the cue-conflict situation (see Fig. 3).

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Brain computer interfaces for communication and control

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Abstract - Over the past decade, many laboratories have begun to explore brain-computer interface (BCI) technology as a radically new communication option for those with neuromuscular impairments that prevent them from using conventional augmentative communication methods. BCI's provide these users with communication channels that do not depend on peripheral nerves and muscles. Current BCI's use electroencephalographic (EEG) activity recorded at the scalp or single-unit activity recorded from within cortex to control cursor movement, select letters or icons, or operate a neuroprosthesis. The central element in each BCI is a translation algorithm that converts electrophysiological input from the user into output that controls external devices. BCI operation depends on effective interaction between two adaptive controllers, the user who encodes his or her commands in the electrophysiological input provided to the BCI, and the BCI which recognizes the commands contained in the input and expresses them in device control. Current BCI's have maximum information transfer rates of 5-25 bits/min. Achievement of greater speed and accuracy depends on improvements in signal processing, translation algorithms and user training. These improvements depend on increased interdisciplinary cooperation between neuroscientists, engineers, computer programmers, psychologists, and rehabilitation specialists, and on adoption and widespread application of objective methods for evaluating alternative methods. The practical use of BCI technology depends on the development of appropriate applications, identification of appropriate user groups, and careful attention to the needs and desires of individual users.

Introduction

Brain-computer interfaces (BCIs) give their users communication and control channels that do not depend on the brain's normal output channels of peripheral nerves and muscles. Current interest in BCI development comes mainly from the hope that this technology could be a valuable new augmentative communication option for those with severe motor disabilities- disabilities that prevent them from using conventional augmentative technologies, all of which require some voluntary muscle control. Over the past five years, the volume and pace of BCI research have grown rapidly. In 1995 there were no more than six active BCI research groups, now there more than 20. They are focusing on brain electrical activity, recorded from the scalp as electroencephalographic activity (EEG) or from within the brain as single-unit activity, as the basis for this new communication and control technology. This review addresses the major aspects and issues of BCI research and development.

Definition and essential features of a Brain-Computer Interface (BCI)

Since the EEG was first described by Hans Berger in 1929 [1], people have speculated that it might be used for communication and control, that it might allow the brain to act on the environment without the normal intermediaries of peripheral nerves and muscles. In the 1970's, several scientists developed simple communication systems that were driven by electrical activity recorded from the head. Early in that decade, the Advanced Research Projects Agency (ARPA, which also sponsored the initial development of the internet) of the U.S. Department of Defense became interested in technologies that provided a more immersed and intimate interaction between humans and computers and included so-called "bionic" applications. A program proposed and directed by Dr. George Lawrence focused initially on autoregulation and cognitive biofeedback. It sought to develop biofeedback techniques that would improve human performance, especially the performance of military personnel engaged in tasks that had high mental loads. The research produced some valuable insights on biofeedback, but made minimal progress toward its stated goals. A new direction, under the more general label of "biocybernetics," was then defined and became the main source of support for bionics research in the ensuing years. One of the directives of the biocybernetics program was to evaluate the possibility that biological signals, analyzed in real-time by computer, could assist in the control of vehicles, weaponry, or other systems. The most successful project in this area was that headed by Dr. Jacques Vidal, Director of the Brain Computer Interface Laboratory at UCLA. Using computer-generated visual stimulation and sophisticated signal processing, the research showed that single-trial (i.e., not averaged) visual evoked potentials (VEPs) could provide a communication channel by which a human could control the movement of a cursor through a two-dimensional maze [2].

Vidal's studies and other less well-controlled early work brought out the importance of the distinction between control systems that use actual EEG activity and those that use EMG (electromyographic) activity from scalp or facial muscles. Because scalp-recorded EMG activity can be much more prominent than EEG activity at the same locations, EMG-based communication can masquerade as EEG-based communication. To the extent that EMG-based communication is mistaken for EEG-based communication, it can hamper the latter's development. Careful spectral and topographical analysis may be needed to distinguish one from the other. The early work also served to bring out the fundamental distinction between EEG-based communication that depends on muscle control (e.g., visual evoked potentials that depend on where the eyes are directed), and EEG-based control that does not depend on muscle control.

These distinctions shape the definition of the term brain-computer interface (BCI): *"A brain-computer interface is a communication system that does not depend on the brain's normal output pathways of peripheral nerves and muscles"*. This definition also reflects the principal reason for recent interest in BCI development — the possibilities it offers for providing new augmentative communication technology to those who are paralyzed or have other severe movement deficits. All other augmentative communication technologies require some form of muscle control, and thus may not be useful for those with the most severe motor disabilities, such as late-stage amyotrophic lateral sclerosis, brainstem stroke, or severe cerebral palsy.

Several different true BCIs, that is, communication systems that do not appear to depend on nerves and muscles, have been achieved (e.g., [3]-[9]). These systems use either EEG activity recorded from the scalp or the activity of individual cortical neurons recorded from implanted electrodes. While these are exciting developments, with considerable theoretical significance and practical promise, they are relatively low bandwidth devices, offering maximum information transfer rates of 5-25 bits/min at best. Furthermore, improvement is likely to be gradual, and to require continued careful and laborious investigation.

BCI development requires recognition that a "wire-tapping" analogy probably does not apply- that the goal is not simply to listen in on brain activity (via EEG, intracortical recording, or some other method) and thereby determine a person's intentions. A BCI is a new output channel for the brain, and, like the brain's normal output channels of peripheral nerves and muscles, is likely to engage the brain's adaptive capacities, which adjust output so as to optimize performance. Thus, BCI operation depends on the interaction of two adaptive controllers, the user's brain, which produces the activity measured by the BCI system, and the system itself, which translates that activity into specific commands. Successful BCI operation is essentially a new skill, a skill that consists not of proper muscle control but rather proper control of EEG (or single-unit) activity.

Like any communication and control system, a BCI has an input, an output, and a translation algorithm that converts the former to the latter. BCI input consists of a particular component (or components) of brain activity and the methodology used to measure that component. BCIs may use frequency-domain components (such as EEG mu or beta rhythms occurring in specific areas of cortex) [6]-[14], or time-domain components (such as slow cortical potentials, P300 potentials, or the action potentials of single cortical neurons) [3]-[5], [12], [15]-[18]. The methodology includes the scalp electrode type and locations, the referencing method, the spatial and temporal filters, and other signal-processing methods used to detect and measure the components. The distinction between a component as a reflection of a specific aspect of nervous system physiology and anatomy and a methodology as a technique for measuring the component is more clear for some components (e.g., the firing rate of a single cortical neuron, which is presumably the same however it is measured) than for others (e.g., autoregressive parameters, which depend on the details of the analysis algorithm). Nevertheless, the distinction is important because attention to components as reflections of nervous system anatomy and physiology, rather than as merely products of particular analysis methods, helps guide improvements in BCI technology, and also encourages continued attention to the problem of artifacts such as EMG activity (which can, for example, affect autoregressive parameters).

Each BCI uses a particular algorithm to translate its input (e.g., its chosen EEG components) into output control signals. This algorithm might include linear or nonlinear equations, a neural network, or other methods, and might incorporate continual adaptation of important parameters to key features of the input provided by the user. BCI outputs can be cursor movement, letter or icon selection, or another form of device control, and provides the feedback that the user and the BCI can use to adapt so as to optimize communication.

In addition to its input, translation algorithm, and output, each BCI has other distinctive characteristics. These include its On/Off mechanism (e.g., EEG signals or conventional control); response time, speed and accuracy and their combination into information transfer rate; type and extent of user training required, appropriate user population; appropriate applications; and constraints imposed on concurrent conventional sensory input and motor output (e.g., the need for a stereotyped visual input, or the requirement that the user remain motionless).

Because BCI operation depends on the user encoding his or her wishes in the EEG (or single-unit) components that the system measures and translates into output control signals, progress depends on development of improved training methods. Future studies should evaluate the effects of the instructions given to users, and analyze the relationships between user reports of strategies employed and actual BCI performance. For example, some BCI protocols ask that the user employ very specific motor imagery (e.g., imagery of right or left hand movement) or other mental tasks to produce the EEG components the system uses as control signals (e.g., [7], [9]). Others may leave the choice of imagery, or the decision to use any imagery at all, up to the user (e.g., [3], [8]). Analysis of the similarities and differences between acquisition of BCI control and acquisition of conventional motor or nonmotor skills could lead to improvements in training methods. The impacts of subject motivation, fatigue, frustration, and other aspects of mental states also require exploration. Users' reports might help in assessing these factors. At the same time, the value of such reports is not clear. Users' reports of their strategies may not accurately reflect the processes of achieving and maintaining EEG control (e.g., [19]).

Because BCIs differ greatly in their inputs, translation algorithms, outputs, and other characteristics, they are often difficult to compare. While it is likely that different systems will prove most valuable for different applications, a standard performance measure would be useful as a general purpose benchmark for following BCI development. A standard measure of communication systems is bit rate, the amount of information communicated per unit time. Bit rate depends on both speed and accuracy [20], [21]. Thus, for example, the information transfer rate of a BCI that can select between two possible choices with 90% accuracy is twice that of a BCI that can select between them with 80% accuracy, and equal to that of a BCI that can select between four possible choices with 65% accuracy. The enormous importance of accuracy, illustrated by the doubling in information transfer rate with improvement from 80% to 90% accuracy in a two-choice system, has not usually received appropriate recognition in BCI-related publications. While the effectiveness of each BCI system will depend in considerable part on the application to which it is applied, bit rate furnishes an objective measure for comparing different systems and for measuring improvements within systems.

The continuation and acceleration of BCI development and application does not depend solely on scientific and technical advances. It depends also on attention to important practical issues. At present, the pace of development is limited by the small number of people involved and the relatively modest funding available. Increased collaboration and increased numbers of refereed publications in high-quality journals should encourage more funding from public and private agencies worldwide. At the same time, major funding increases, particularly for development of specific applications, depends on generating interest from industry and on securing approval for reimbursement from medical insurance companies. Industrial interest depend in large measure on the numbers of potential users. Expansion beyond the relatively small numbers of people who are locked-in, for example, to include individuals with high-level spinal cord injuries or severe cerebral palsy, could draw much greater commercial interest. Furthermore, widespread application of BCI-based communication systems will depend also on cost, ease of training and use, and on careful attention to user satisfaction.

Matching the BCI and its input components to the user

Matching the user with his or her optimal BCI input component(s) is essential if BCIs are ever to be broadly applied to the communication needs of users with different disabilities. Most BCI systems use EEG or single-unit components that originate mainly in somatosensory or motor areas of cortex. These areas may be severely damaged in people with stroke or neurogenerative disease. Use of components from other CNS regions may prove necessary. For EEG-based BCIs, comprehensive multielectrode recording, performed initially and then periodically, can reveal changes in the user's performance and/or the progression of disease, and can thereby guide selection of optimal recording locations and EEG components. Some brain areas may not prove to be useful: slow potential control is poor over parietal areas [22], and mu rhythms are largely limited to sensorimotor cortex. BCI systems should be flexible enough to use a variety of different EEG components as control signals. A system that can use slow potentials, mu rhythms, or P300 potentials alone or in combination is under development. Such flexibility could provide a considerable practical advantage.

At present, only limited clinical data are available on BCI use by those with severe neuromuscular disabilities. The Thought Translation Device (TTD) [3], which uses slow cortical potentials (SCPs), and the Wadsworth BCI, which uses mu and beta rhythms [8], have been evaluated in small numbers of users with amyotrophic lateral sclerosis (ALS), stroke, spinal cord injury, cerebral palsy, or amputation. Controlled clinical trials in various user groups will be required to determine which BCI methods might be best for each group. These studies should compare the performances of different BCI systems and different electrophysiological inputs in comparable user groups. While a double-blind design is generally not practical in such work, comparable training procedures should be used and controls for placebo effects (e.g., [23]) should be incorporated. Because such studies are time consuming and costly, especially when they involve users with severe disabilities, they are likely to require the joint efforts of several centers.

The most obvious application of BCI technology in its present state of development is to locked-in patients. Totally locked-in patients should be differentiated from those who retain some minimal voluntary muscle functions, such as eye or eyelid movement or some facial muscle control. For the TTD, early training of ALS patients, before they lose all or most voluntary functions, has proved valuable because problems in learning SCP control from scratch can appear as the disease progresses. In addition, it may be necessary to change the feedback modality used by the BCI to accommodate the sensory capabilities of the user. Because the visual system may be compromised in certain user groups, BCI systems should be able to use other sensory modalities. Locked-in patients with poor control of eye movements might achieve better communication when tactile feedback is substituted for the standard visual feedback.

In addition to its use in locked-in states associated with brainstem strokes, ALS, or other degenerative diseases, BCI technology has been proposed as a possible communication system in autism, aphasia, and other severe communication disorders [24]. By bypassing compromised language areas in temperofrontal cortex, it could conceivably provide slow but less deviant or redundant communication. In patients who cannot master the alphabet, a pictorial system might prove an effective alternative.

With the exception of systems that depend on muscle control [2], [10], [25], and the possible exception of the P300 BCI [4], current BCIs depend on EEG or single-unit control that is acquired through operant conditioning procedures. Thus, thorough behavioral analysis of the learning phenomenon and environment is important. Such analysis requires extensive knowledge of learning theory, experience in its clinical application, and understanding of how a specific neurological impairment might influence learning. However, most current BCIs have been developed primarily by engineers and other technically oriented groups with limited expertise in behavioral principles and methods. High-level intellectual and cognitive functioning is probably not essential for successful BCI usage [26]. Nevertheless, issues such as optimal response selection, optimal reinforcement types and schedules, and optimal stimulus-response conditions, which are essential for successful shaping of any behavior (in this case, EEG or single-unit control) need much greater attention than they have received, and well-controlled clinical trials are essential. BCI development requires extensive interdisciplinary cooperation, between neuroscientists, engineers, psychologists, programmers, and rehabilitation specialists.

In addition to controlling the chosen electrophysiological components, users must simultaneously select the message to be communicated (e.g., specific letter or cursor movement direction) and observe the actual output from the system. This requires some division of attention, and might compromise control of the input components. Several studies indicate that such division is possible [27], [28]. Nevertheless, it may turn out that the capacity for automatization of brain responses such as slow cortical potentials or mu rhythms is limited. This problem could conceivably be overcome by switching to subcortical responses or by reducing the size of the cortical regions that produce the input used by the BCI system.

Signal analysis

The goal of signal analysis in a BCI system is to maximize the signal-to-noise ratio of the EEG or single-unit components that carry the user's messages and commands. To achieve this goal, consideration of the major sources of noise is essential [44]. Noise has both non-neural sources (e.g. eye movements, EMG, 60-Hz line noise) and neural sources (e.g., EEG components other than those used for communication). Noise detection and discrimination problems are greatest when the characteristics of the noise are similar in frequency, time or amplitude to those of the desired signal. For example, eye movements are of greater concern than EMG when a slow cortical potential is the BCI input component because eye movements and slow potentials have overlapping frequency ranges. For the same reason, EMG is of greater concern than eye movements when a beta rhythm is the input component. In the laboratory particularly, it is important to record enough information (e.g., topographical and spectral distributions) to permit discrimination between signal and noise. Non-neural noise such as EMG is of particular concern because a user's control over it can readily masquerade as actual EEG control. Non-neural noise produced by reflex activity may occur even in users who lack all voluntary muscle control. In this case, the non-neural noise will not support communication, but can degrade BCI performance by reducing the signal-to-noise ratio. It is also important to distinguish between different neural components. The visual alpha rhythm is a source of noise when the mu rhythm is the component being used for communication. While appropriate temporal and spatial filtering methods can help make such distinctions, signals from different sources might well have similar frequency spectra and similar spatial distributions (e.g., [45]). If non-neural and neural noise can be detected online, in the course of BCI operation, its impact on operation can be greatly reduced or eliminated. For example, in a BCI driven by slow cortical potentials, input contaminated by eye movements can be rejected [3]. This approach can also induce the user to reduce the production of such noise.

Numerous options are available for BCI signal processing. Ultimately, they need to be compared in on-line experiments that measure speed and accuracy. The new Graz BCI system [46], based on Matlab and Simulink, supports rapid prototyping of various methods. Different spatial filters and spectral analysis methods can be implemented in Matlab and compared in regard to their online performance.

Autoregressive (AR) model parameter estimation is a useful method for describing EEG activity, and can prove valuable for BCI applications (e.g., [7]-[9]). The AR model typically assumes a Gaussian process [15]. Because very small non-Gaussian residuals can markedly influence AR parameter estimation, these residuals should be assessed. When additive outlier contamination is present, a generalized robust maximum likelihood estimate (GM) can be valuable. This method is based on a modified Kalman filter. GM methods produce results similar to the typical AR estimate for Gaussian data, but perform better for non-Gaussian data. Bayesian algorithms, which can assess the certainty that the system's interpretation of the user's intention is correct, may also prove useful (e.g., [9]). They can arrest communication when this certainty falls below a criterion level, and thereby reduce errors in BCI performance.

Signal processing methods are important in BCI design, but they cannot solve every problem. While they can enhance the signal-to-noise ratio, they cannot directly address the impact of changes in the signal itself. Factors such as motivation, intention, frustration, fatigue, and learning affect the input components that the user provides. Thus, BCI development depends on appropriate management of the adaptive interactions between system and user, as well as on selection of appropriate signal processing methods.

BCI translation algorithms

A translation algorithm is a series of computations that transforms the BCI input components derived by the signal processing stage into actual device control commands. Stated in a different way, a translation algorithm takes abstract feature vectors that reflect specific aspects of the current state of the user's EEG or single-unit activity (i.e., aspects that encode the message that the user wants to communicate) and transforms those vectors into application-dependent device commands. Different BCIs use different translation algorithms (e.g., [3]-[9]). Each algorithm can be classified in terms of three key features: transfer function, adaptive capacity, and output. The transfer function can be linear (e.g., linear discriminant analysis, linear equations) or non-linear (e.g., neural networks). The algorithm can be adaptive or non-adaptive. Adaptive algorithms can use simple handcrafted rules or more sophisticated machine-learning algorithms. The output of the algorithm may be discrete (e.g., letter selection) or continuous (e.g., cursor movement). The diversity in translation algorithms among research groups is due in part to diversity in their intended real-world applications. Nevertheless, in all cases the goal is to maximize performance and practicability for the chosen application.

Current consideration of alternative translation algorithms focuses primarily on those applicable to scalp-recorded EEG activity, because it is at present the only widely available BCI option for human users. As invasive technologies (e.g., the cone electrode [5] or intracortical or subdural arrays [16], [30]) evolve, extant algorithms will require additional evaluation and new algorithms will probably arise. EEG activity reflects the integrated activity of large populations of cortical neurons. If the input components extracted from this activity are to provide effective communication, they must have two or more discernible states that reflect the user's intentions and are accommodated to the domain and constraints of the application. The BCI might employ a single simple component (e.g., amplitude in a specific frequency band at a specific scalp location), or a combination of multiple time and/or frequency domain components (e.g., slow cortical potentials, mu rhythms) produced by multiple physiological processes. The demands of the chosen application will help guide selection of a translation algorithm that provides an acceptable combination of speed and accuracy. Because the human brain is a highly adaptive controller that relies upon both predictive methods and feedback information, it is desirable and perhaps essential that BCI translation algorithms also be adaptive. One current algorithm adapts continually to the mean amplitude and/or variance of its EEG input components [44].

Whatever the nature and the computational power of a translation algorithm, it will not succeed without a comprehensive development and application strategy. Without such strategies, BCI development programs may degrade into optimizations of very abstract performance measures without real-world relevance. Thus, for example, the accuracy and speed of BCI-controlled curosr movement is meaningful only in the context of its performance in a specific target-selection protocol. While BCI research involves important theoretical issues and has important implications for the understanding of brain function, the primary impetus for it is the potential benefit to those with severe motor disabilities, and for this reason real-world relevance and success are extremely important.

Objective methods for comparing different translation algorithms are important for fostering further development and for synchronizing the multinational collaborative research programs that have arisen over the last several years. At present, such comparisons are often difficult, even for one specific application or within the same BCI system. This unsatisfactory situation could be improved by adoption of specific benchmark applications, uniform data sets, or standard procedures that would support comparisons between translation algorithms and between entire BCI systems, and would be accessible to all research groups (e.g., use of bit rate to measure performance, see above). Furthermore, because of the adaptive capacity of the brain and individual differences in this capacity, evaluation of translation algorithms should adopt appropriate statistical approaches (e.g., bootstrapping, cross-validation, forward prediction) and apply them in a sufficient number of users and in relevant applications. Particular algorithms may prove unsuitable for particular applications, and even the most sophisticated algorithms may fall short of expectations.

BCI development has begun to address real-world applications. Continued progress in development of these applications will require the combined effort of different laboratories and professions. Training protocols should be standardized within each laboratory and perhaps across laboratories. In addition, even the most sophisticated signal processing methods and translation algorithms are unlikely to be successful without involvement of neuroscientists, psychologists, physicians, and rehabilitative specialists who work with those who will be using BCI-based communication and control devices. Their guidance is essential to ensure that BCI technologies are not only theoretically effective but are also actually used by people for significant purposes in the real world.

Invasive BCI methods

Invasive methods for obtaining BCI control signals will be appropriate only if they are safe and if they provide significant improvement in function over noninvasive methods. The issue of invasive methods focuses on seven important questions.

First, what are the possible locations of implanted electrodes and what signals *will they record*? The motor cortex is an obvious choice for recording and should be considered in most cases because of its direct relevance to motor tasks, its relative accessibility compared to motor areas deeper in the brain, and the relative ease of recording from its large pyramidal cells. Other sites that might be considered include the supplementary motor cortex, subcortical motor areas, and the thalamus. Functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG), and other functional imaging techniques could help identify appropriate areas for implantation. In addition, for some electrode types, neural recording during implantation can confirm that the sites selected are appropriate. The information in the recorded signals will depend on the location of the electrodes, and may be modified by sensory inputs to the recording area. Furthermore, the information will depend in as yet unknown ways on the functional use that is made of the signals, and this dependence may change with continued use. These factors all require further research. One issue of particular interest is how many cells need to be recorded simultaneously in order to get a meaningful signal. Estimates range from the expectation that one or two cortical neurons can provide useful information from an otherwise locked-in brain [29] to the belief that 50 to100 neurons will be needed to provide an information transfer rate that justifies an invasive procedure [18], [30]-[32]. These differing views lead to somewhat different research approaches.

Second, what are the options for obtaining stable recording capability over months and years? In small-brained animals such as rats and guinea pigs, stable single-unit recording has been maintained for long periods [30], [33]-[35]. In non-human primates stable recording has been maintained over months, and in selected instances over years [18], [36]-[38]. Recent results indicate that the cone electrode may provide stable recording in primates, including man, for periods of years [36]. Other promising microelectrodes include microwires and micromachined microelectrode arrays [30], [33]-[35], [39]-[40]. Further electrode development, combining the multi-site capability of micromachined electrodes with the long-term stability of the cone electrode, is essential.

Third, which user groups might be best suited, by disability and/or need, for implanted electrodes? Patients who are locked in (e.g., by ALS) might benefit from invasive BCI technology if it is both safe and effective. Selected individuals with stroke, spinal cord injury, limb prostheses and other conditions might also benefit. Apart from the issues of safety and efficacy, the stigma sometimes associated with brain implants must be addressed and overcome. Individual preferences will play a significant role in decisions about implantable systems. To be justifiable, an implanted system must offer the individual a substantial functional advantage over conventional augmentative technologies and over noninvasive BCI methods. For example, a recent preliminary study describes noninvasive EEG-based operation of a neuroprosthesis that provides hand grasp [11].

Fourth, to what extent will the control provided by recorded neurons be able to be independent of the presence of normal feedback from other CNS areas? Implanted microelectrodes have been likened to a wiretap where the microelectrodes listen in to a normal conversation between cells. For users who are paralyzed or have other severe neuromuscular disabilities, it might be more appropriate to say that the implanted array of microelectrodes is a wiretap into a conversation in which one party has hung up. An effective BCI must provide feedback to the user and thereby substitute for the missing part of the conversation. The nervous system's ability to change so as to respond effectively to the new feedback provided by a BCI will have a major role in determining how well the communication system works. Studies indicate that the firing rates of individual neurons in motor cortex can be controlled using visual and auditory feedback [41]. Auditory prostheses research has shown that large populations of cells in the auditory system will modify their tuning specificity in response to electrical stimulation [42]. While the plasticity of the brain makes it difficult to predict the precise nature of the communication code, the expectation is that this plasticity will enhance communication efficiency.

Fifth, what other improvements in recording technology might help BCI development? Progress in several research areas is needed to make invasive methods a viable approach for a BCI. One area is signal acquisition, which includes recording methods, electrode design, artifact elimination, telemetry, and biomaterials. Other important research areas are the nature of information coding in the nervous system, the changes that occur with learning, and other aspects of integrative and cognitive neuroscience. Interdisciplinary cooperation is essential for this research. The research agenda includes further experimentation in primates, feasibility studies in humans, continued improvements in microelectrode design and telemetry, and studies of specific neuron populations and their ability to support BCIs with high information transfer rates.

Sixth, are other recently developed technologies such as MEG, fMRI, and positron emission tomography (PET) of possible use for BCI purposes? These technologies can have a significant role in patient evaluation and in preliminary identification of sites for implantation of invasive BCI recording electrodes. At the same time, given current understanding and equipment, it is not clear that these technologies could replace EEG or single-unit activity as the input for a portable and effective BCI. Nevertheless, in the future these and other imaging techniques, such as near-infrared photonic imaging, might support noninvasive BCI systems.

Seventh, what are the ethical issues that must be considered in implanting recording electrodes in human volunteers? Patients must be informed of the risks and potential benefits of any intervention, especially an invasive procedure with uncertain benefit to the individual and possibly serious risks. Volunteers with severe disabilities may tend to greatly overestimate the potential benefits, so that risks and uncertainties must be clearly and forcefully explained. On the other hand, many people may want to volunteer for research that provides no direct benefit to themselves beyond the knowledge that they are participating in a research project that might help others with similar conditions in the future. They should not be denied this opportunity. The Belmont Report [43] enunciates three basic ethical standards for the conduct of human research. The first, respect for persons, incorporates the idea that individuals are autonomous agents and should be free to make their own choice regarding participation after being given a full understanding of the risks and benefits. The second, beneficence, obligates the investigator to act in a way that will maximize benefit to the individual volunteer and/or the greater society while simultaneously minimizing the risk of harm. The third standard, justice, obligates the investigator to design studies so that the benefits and burdens of research are shared in a just way. An ethicist should be involved in the earliest phases of any human research developing or testing invasive BCI methods.

Applications of BCI technology

As an essential prelude to addressing the potential practical uses of BCI technology is the difference between BCIs and the applications to which they are applied. This is the difference between a tool, in this case a BCI, and its applications. A tool in the present context is a device that performs a specific function and can be applied to a wide variety of applications. A tool is specified by the manner in which it performs its function, and it is evaluated by the ease and effectiveness of its performance. The screwdriver, that most prototypical of tools, is designed to turn screws either clockwise or counter-clockwise. This function remains the same, whatever the purpose served by the screws turned. In contrast, an application is a system that uses the tool to achieve some practical purpose. While an application may be described in terms of the tools it employs, its primary description focuses on the purpose it serves, and its evaluation focuses on how well it serves that purpose.

The BCIs described to date are tools that record and analyze EEG or the activity of single cortical neurons. These tools can be used to move a cursor, select from among two or more possible choices, control a neuroprosthesis, etc. Discussions of the design and development of these tools inevitably focus on these possible applications and on the efficiency, reliability, and cost of specific tools in specific applications. Issues such as “How do we best move a cursor” or “How fast can we choose one of 26 characters?” are of primary concern. With satisfactory answers to these questions in hand, attention can turn to the real-life purposes the tools might serve.

Present BCIs can be classified into two groups according to the nature of the signals they use as input. Some depend on user control of endogenous electrophysiological activity, such as amplitude in a specific frequency band in EEG recorded over a specific cortical area (e.g., mu or beta rhythms recorded over sensorimotor cortex [6]-[9]). Others depend on user control of exogenous electrophysiological activity, that evoked by specific stimuli (e.g., amplitude of the P300 potential produced in response to letter flash [4]). Endogenous BCIs provide a better fit to a control model because the trained user exercises direct control over the environment. On the other hand, these BCIs often require extensive training. Exogenous BCIs may not require extensive training, but do require a somewhat structured environment (e.g., stereotyped visual input). For example, an endogenous BCI may enable a user to move a cursor to any point in a two-dimensional space, while an exogenous BCI may constrain a user to the choices presented by a display.

BCI tools have potential applications spanning at least five different areas: verbal communication, activities of daily living, environmental control, locomotion, and exercise. In choosing among these areas, the needs and priorities of the anticipated user should be the primary concern. Developers must guard against the tendency to approach the parameters of the tools and their applications as an abstract design exercise. A BCI and its applications should be optimized for each individual user or user group. At the same time, the optimization process should be as objective and standardized as possible. For each user, the BCI and its application(s) should be embedded in a behavioral program with well-defined objectives. A thorough behavioral analysis that addresses the needs, desires, and primary motivators of the user and/or her or his caregivers is essential. BCI development should incorporate not simply technical and electrophysiological principles, but well-defined learning principles as well.

One approach to application development would begin with a matrix that lists the tools (i.e., the different BCIs) on one axis and their characteristics (e.g., speed, accuracy, training needed, demand on attention, etc.) on the other axis. A second matrix would list applications on one axis and their requirements (e.g., speed and accuracy needed, attention required, etc.) on the other. The rows and columns of these two matrices could be combined to produce a BCI-to-application mapping matrix that would aid developers in designing applications and providing them to individual users. This matrix might also aid clinicians in exploring collaborative development, or integration, of several different BCIs to better serve particular applications [47]. In addition, users with a progressive disorder such as ALS might be provided with a BCI that matches the characteristics of an existing conventional augmentative communication interface. Then, as disability progresses and the conventional interface loses its usefulness, the user might make a smooth transition to the BCI.

The recent development and commercial application of the Freehand Functional Electrical Stimulation system (FES) at Case Western Reserve University illustrates the conditions necessary for success (e.g., [48]). These conditions include: stabilization of all aspects of design and documentation, a well-defined user population, standardized training protocols, demonstration of the feasibility of the specific application, well-defined outcome measures that document successful usage and performance, regulatory assessment, multicenter assessment, and identification of manufacturing partners and commercialization strategy. Satisfying these conditions requires collaborative interactions with the users, who must know how to use the technology and be persuaded that the technology is both useful and safe. Also essential is the cooperation of the relevant health care professionals, who must be persuaded that the risk/benefit ratio is favorable, that the technology is safe and useful, and that it is equal or superior to available alternatives. Finally, whoever is paying the bill (usually an insurance company) must be convinced that the long-term savings will offset both the initial costs and the operating costs of the system.

Among the factors that impede development of BCI applications are: that the essential neuroscientific and psychological foundations of the field are not sufficiently developed, that current EEG recording methods are somewhat cumbersome and susceptible to noise from various sources, that current BCIs have limited resolution (e.g., binary selection is a weak substitute for continuous or multilevel selection), that close interdisciplinary collaboration (i.e., engineering, neuroscience, psychology, computer science, rehabilitation) is still rare, and that access to appropriate users with substantial interest in obtaining improved function is as yet inadequate. Access to a sufficient number of appropriate and motivated users is a particular challenge.

Although a prototype application would allow objective comparison between BCI systems, the choice of application would place an arbitrarily high priority on specific performance characteristics while downplaying others that might be of equal or greater importance for other applications. A better alternative would be a standard set of benchmark applications that would together quantify the different performance characteristics of each BCI, including accuracy, speed of operation, etc. The results of such a standard and comprehensive evaluation would help in matching BCI to application to individual user.

Support for BCI research and development

Further development of BCI technology will depend on both basic and applied research. Basic research efforts that elucidate the mechanisms underlying and controlling EEG rhythms, cortical single-unit activity, and other electrophysiological phenomena, that develop processing methods that improve signal-to-noise ratio, or that provide other insights into the physiological, psychological processes and engineering principles involved in BCI operation will be an essential element in future progress. Public and private entities that support basic biomedical and engineering research are likely sources of support for this work. Of particular interest in this context is the new initiative on bioengineering research at the National Institutes of Health (NIH) [49] (e.g., [50]). This program emphasizes interdisciplinary research and is thus particularly well-suited for BCI research efforts.

Applied research — the development and evaluation of particular BCIs in particular applications — is also essential. At present, the primary impetus for this work is the need of those with severe neuromuscular disabilities, those who lack the voluntary muscle control needed to use conventional augmentative communication systems. While their need is great, their numbers are small. As a result, BCI development is as yet of limited commercial interest and depends for support mainly on public and private non-profit entities. Because these institutions traditionally focus on basic research, support for applied BCI research has been difficult to obtain. In recent years, the National Center for Medical Rehabilitation Research of the NIH has recognized this problem and has begun to provide support for research programs that are primarily applied rather than basic. The NIH Small Business Innovation Research Grant Program [51] also provides support for applied research that has as yet only limited commercial potential. The National Institute of Disability and Rehabilitation Research is another potential source of support. Other NIH grant mechanisms and the specific interests of the different institutes at NIH are described on NIH's home page (www.nih.gov). In Europe, the European Union and national agencies (e.g., the Deutsche Forschungsgemeinschaft (DFG) in Germany) have also begun to provide support for such applied research. In the future, if and when the speed and accuracy of BCI technologies increases enough to make them useful for larger populations with less severe disabilities, private industry is likely to display greater interest and to provide substantial support.

Conclusions

A brain-computer interface is a communication and control channel that does not depend on the brain's normal output pathways of peripheral nerves and muscles. At present, the main impetus to BCI research and development is the expectation that BCI technology will be valuable for those whose severe neuromuscular disabilities prevent them from using conventional augmentative communication methods. These individuals include many with advanced amyotrophic lateral sclerosis (ALS), brainstem stroke, and severe cerebral palsy.

Current BCIs record electrophysiological signals using noninvasive or invasive methods. Noninvasive BCIs use scalp-recorded EEG rhythms or evoked potentials, while invasive BCIs use single-unit activity recorded within cortex or EEG recorded subdurally. They have maximum information transfer rates of 5-25 bits/min and are being used to control cursor movement, select letters or icons, or operate a neuroprosthesis.

Like other communication and control systems, a BCIs have inputs, outputs, and translation algorithms that convert the former to the latter. BCI operation depends on the interaction of two adaptive controllers, the user's brain, which produces the input — the electrophysiological activity measured by the BCI system S and the system itself, which translates that activity into output — specific commands that act on the external world. Successful BCI operation requires that the user acquire and maintain a new skill, a skill that consists not of muscle control but rather of control of EEG or single-unit activity.

BCI inputs include slow cortical potentials, P300 evoked potentials, mu and beta rhythms from sensorimotor cortex, and single unit activity from motor cortex. Recording methodologies seek to maximize signal-to-noise ratio. Noise consists of EMG, EOG, and other activity from sources outside the brain, as well as brain activity different from the specific rhythms or evoked potentials that comprise the BCI input. A variety of temporal and spatial filters can reduce such noise and thereby increase the signal-to-noise ratio. BCI translation algorithms include linear equations, neural networks, and numerous other classification techniques. The most difficult aspect of their design and implementation is the need for continuing adaptation to the characteristics of the input provided by the user.

BCI development depends on close interdisciplinary cooperation between neuroscientists, engineers, psychologists, computer scientists, and rehabilitation specialists. It would benefit from general acceptance and application of objective methods for evaluating translation algorithms, user training protocols, and other key aspects of BCI operations. Evaluations in terms of information transfer rate and in terms of usefulness in specific applications are both important. Appropriate user populations must be identified, and BCI applications must be configured to meet their most important needs. The assessment of needs should focus on the actual desires of individual users rather than on preconceived notions about what these users ought to want. Similarly, evaluation of specific applications ultimately rests on the extent to which people actually use them in their daily lives.

Continuation and acceleration of recent progress in BCI research and development requires increased focus on the production of peer-reviewed research articles in high quality journals. Research would also benefit from identification and widespread utilization of appropriate venues for presentations (e.g., the Society for Neuroscience Annual Meeting). For the near future, research funding will depend primarily on public agencies and private foundations that fund research directed at the needs of those with severe motor disabilities. With further increases in speed, accuracy, and range of applications, BCI technology could become applicable to larger populations and could thereby engage the interest and resources of private industry.

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SYMPOSIA

Spatial attention
(as a motor-perceptual integration process)

Chair-person: FABIO FERLAZZO
Organization: ALESSANDRO COUYOUMDIJAN
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Keywords: spatial attention, human error, psychophysiology and attention, representations of space.

Cognitive sciences have been witnessing relevant changes during the last few years. Perhaps, such changes have been particularly influential in spatial attention research. As a result, several issues are now going under an intense debate, especially regarding the nature of spatial attention, and its relationships with the perceptual and motor systems, which have important consequences for the application of research results to everyday life tasks, such as driving. Indeed, a number of findings suggests that goal-directed actions modulate the activity of the attentional system. Evidence come from studies on the deployment of attention across the 3D space, which also suggest that attention orienting occurs within different frames of reference according to the action that should be performed. It is worth noting that such a view may also represent a theoretical basis for our understanding of the mechanisms underlying human errors, at least insofar as action slips are concerned, giving an important contribution to Cognitive Ergonomics. Some light upon the relationships between spatial attention and action is shed also by the electrophysiological and behavioral studies that address the question of whether spatial attention is served by a supramodal system or by separate systems. In fact, in the latter case the question rises of how many separate systems exist and how they are linked one each other and to any action system. To this regards, the Premotor Theory of attention is one of the most influential models which assume an action-based attention. In conclusion, a many-sided research community is pursuing a new challenge in spatial attention, which is not important only for the progress of knowledge, but also for the view that it is going to impose to Cognitive Sciences. In this Symposium, presentations will address most of the issues shortly described above, giving a contribution from a multidisciplinary point of view.

The role of inhibition in the control of gaze: a hierarchical theory in support of the motor theory of attention

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Keywords: Control, eye movements, saccades, cortex, frontal eye field, basal ganglia, motor learning, motor imagery.

I will summarise data concerning the neuronal mechanisms of eye movement control which support the idea that inhibition plays a crucial role in blocking execution at severeal levels of the brain. A first level is the brain stem with the pause neurons which block execution with a temporal gating. A second level is the superior colliculus whose discharge can only trigger saccades if the inhibition from the substantia nigra is itself inhibited by neurons from the caudate nucleus. A third level is the frontal areas themselves which exert inhibitory control on several of the downstream levels. This points to the fact that the brain can internally organise shifts of attention and simulate saccades without executing them overtly. Therefore it supports the motor theory of attention and also supports the idea that there is not a simple dichotomy between imagined and executed movements but that there can be a hierarchical gating of movement execution by these cascades of inhibitory mechanisms.

Time-based spatial control of the motor vehicle

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Keywords: motor-vehicle driver, speed, time sharing, time margin, time-to-contact, time-to-line-crossing.

The last decay or two have witnessed major efforts in search for time-based mechanisms which drivers use in controlling their vehicle in the road environment. The two popular measures, also applied in intelligent vehicle systems, include the time-to-collision and time-to-line-crossing. They refer to the time margin until the point where a driver crashes an obstacle or the rear-end of the car ahead or, respectively, crosses either of the lane boundaries if he/she continues at the present rate. Such time-basedmeasures imply a quality of availability, that is, a driver has time at his/her disposal which he/she can control and also share between different activities. Low speed and a wide and straight road simply mean more time, and the time which can be used for in-car tasks is directly related to speed. Functional time margins however change abruptly and may deceive the driver when he/she attends to targets that are away from the roadway, either inside or outside of the car, because of increased thresholds for detection of critical targets in the retinal periphery. Driving speed also modifies drivers' visual search strategies in a way that actively masks critical targets at less probable spatial locations. This paper reviews relevant experimental work, outlines a theoretical overview, and discusses safety implications.

Event related brain potentials and functional imaging in the investigation of spatial attention in humans

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Keywords: event-related potentials, attention, cross-modal, functional neuroimaging.

In this talk, I will review data from recent event-related potential and functional imaging experiments in spatial attention paradigms to illustrate the power of these techniques. Examples will include:

- several studies on cross-modal spatial attention;
- studies revealing plasticity of auditory spatial attention in the early blind and in professional music conductors;
- studies that combine electrophysiological and neuroimaging techniques to construct a spatiotemporal map of spatial attention.

Automating by cues: errors, space, and schemata

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Keywords: errors, schemata, frames of reference, attention.

In some of our recent works we proposed a theoretical perspective on the genesis of the action slips which are derived from some considerations related to the spatial nature of the action. We proposed a model able to account for the errors that occur in interacting with the 3D space. In a series of experiments, we showed how action slips can be related to failures in the human cognitive representation(s) of the 3D space. Particularly, we showed that an error may occur whenever different representations of the space conflict with each other. The spatial representations we use to locate objects in the world could be considered as low-level behavioral units. They should also be active all at the same moment, and then triggered by the attended location. However, the question arises of whether such behavioral units or schemata may be triggered only by the object of action or also by different objects at the same attended location. We consider this issue as very relevant because demonstrating the existence of a pre-activation effect would provide a stronger evidence of that fallacy in the system we hypothesized. In order to investigate this aspect we ran a stimulus-response spatial compatibility experiment in which visual targets were delivered at 8 different spatial locations, arranged in a 3D scene comprising the peri-personal and the extra-personal spaces. In half of the trials, a visual cue occurred 300 msec before the visual target at the same spatial location. Results suggest that a spatial frame of reference may be automatically triggered also by stimuli which are not the object of an action. These results support our view of a system composed of spatial schemata interacting with the environmental stimulation in order to optimize performance. Such a system would be sensitive to the stimulation in any portions of the 3D space, always being captured independently of the nature of the stimulus.

Head-centered meridian effect on auditory attention

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Keywords: auditory orienting, sounds localization, head-centered meridian.

The interest in auditory selective attention, especially with regards to the mechanisms of auditory covert orienting to spatial locations has grown up in recent years. By means of a cueingparadigm in some previous experiments we provided evidence of a head-centered meridian effect on reaction times to pure tones that is independent of a visual meridian effect. On this basis we concluded by suggesting that two modality-specific attentional systems exist as separate entities and that each of them is associated with a different representation of space, at least insofar as visual and head-centered meridians are concerned. The presence of a head-centered meridian effect on orienting to auditory targets is in fair agreement with the Premotor Theory of Attention, as the theory holds that spatial selective attentional processes are embedded within the same cortical areas involved in programming motor actions related to specific sets of effectors. However, the question arises of whether the auditory cues to spatial location (e.g., the time of arrival of the sound to the two ears and the different intensities of the sound at the two ears) interact with the head-centered meridian effect. In order to investigate this hypothesis, we are running a further experiment in which auditory stimuli are delivered with multiple auditory cues to and from different spatial locations. Expected results are that 1) a head-centered meridian effect should appear also in these conditions, confirming our previous findings; 2) different effects of the considered auditory cues may be isolated.

Spatial attention allocation in the peripersonal and extrapersonal spaces

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Keywords: 3D spatial attention, rappresentation of space, visual attention.

The question of how spatial selective attention is deployed across the three-dimensional space has been scarcely addressed in literature. Only a few studies investigated how visual attention orients in depth, reporting both benefits and costs in 3D spatial cueing paradigms (e.g., Atchley et al., 1997, *Psychon. Bull. & Rev.,* 4, 24). However, it should be observed that extending the general models of attention to the third dimension may not be straightforward, and may have several theoretical consequences. For instance, several models make a main action-based distinction between representations of the peripersonal and the extrapersonal spaces (e.g., Previc, 1998, *Psychol. Bull.,* 124, 123). Accordingly, if attention had to be shifted from one representation to another, it should be possible to observe that performance decreases during such a transition. Aim of this study was to show that the attentional system allocates resources also in depth and that such a process is likely based on the different functional representations of the 3D space which are supposedly encoded in the human brain. To test this hypothesis, we run a number of experiments where participants performed a cued detection task on target stimuli which were displaced in depth across the peripersonal and extrapersonal spaces. Besides a cueing validity effect, we observed higher RT when attention was shifted across the two spaces than when it was shifets within the same space, distances being equal. The implications for action-oriented models of attention will be discussed.

Perceptual space organisation processes relevant to visual arts and architecture

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Keywords: emotion, illusion, incongruity, mental schema, visual space.

From ancient times up to now the knowledge of perceptual space organisation processes and phenomena has greatly influenced architecture, painting and theatrical techniques, and later on also experimental psychology, psycho-physiology and related disciplines. This broad field has seen an impressive amount of observations, systematic research, theoretical work and practical applications. It may be interesting to look into the differing scientific views, to assess the concrete empirically based results, and to criticize the less productive approaches. An analysis of this kind, focusing on psychic dynamics notably involved in the perceptual organisation of space, shows the usefulness of considering the reality of stimulating situations, the perceptual phenomenology with even its counter-intuitive aspects, as well as the role of mental shemata, emotions, motivations and related expectations of the ordinary observer, or that of special groups of observers, according to an in-depth approach. The four contributions presented in the Symposium, together with their visual supports, aim to enrich reflection, experimental methodology and possible applications in the above-mentioned direction. All the invited speakers have achieved well-recognised results in their fields. The first paper will present a detailed analysis of a series of relevant visual processes that are triggered in relations between people and pictorial or environmental spaces. The second paper will summarize systematic observations involving the perception of buildings constructed according to very recent international trends in design techniques. The third paper deals with space depiction and visual perception, expecially in relation to the motivations, emotional experiences and techniques of painting landscapes in the XV century. The processes in organising classical and modern illusory visual spaces, depending on the above mentioned special devices, are described in the fourth paper also with reference to cognitive styles and dynamic factors.

Space in landscape paintings

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Keywords: emotion, landscape, mental schema, painting, perception.

The landscape background of several paintings made in Italy in the second half of the fifteenth century reveals a new commitment of artists in constructing space illusions. Mountains, valleys, villages, rivers and lakes, illuminated by clear light or veiled by winter hazes, constitute the setting for holy or mythological recallings.

According to Gombrich, the Italian beginning of this pictorial genre, which will later be established as proper landscape, may have been influenced by visual stimuli, comparisons and suggestions derived from Flemish paintings, as well as from narratives and literary models inspired by Plinius' or Vitruvius' ancient treatises.

Particularly relevant landscape situations and images are found in paintings by Domenico Veneziano, Mantegna, Beato Angelico, Piero della Francesca, Giovanni Bellini, Ghirlandaio, Benozzo Gozzoli, Vinenzo Foppa, Antonio Pollaiolo and Pinturicchio. These landscape pieces could be considered as configuration systems produced in a cross phase of several topics. When examined with reference to art historian experience, they carry and communicate late-Gothic conventions, North Europe echoes and novelties coming from perspective research. The latter find greater development in the following periods, making use of theoretical precepts by Leon Battista Alberti, and of naturalistic investigation and indications by Leonardo da Vinci.

The present author develops Baxandall's considerations and studies on influences that fifteenth century culture had on the pictorial style of that time, and perhaps on visual perception too. Moreover, following indications by Goodman and Freedberg, and taking into account that clients of that period demanded depictions of countries able to induce happiness and pleasure, she tries to evaluate emotional components animating the artistic experience of painters of landscape backgrounds, as well as the client's experience.

Classical and new illusions in visual space organization

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Keywords: expectation, illusion, incongruity, perception, space.

Different kinds of phenomena that appear relevant when studying spatial environmental visual perception are briefly presented with the help of appropriate images and with reference to underlying psychic processes. The list is as follows:

a) Assimilation and contrast of environmental structures and properties.
b) Amodal and modal completion of environments.
c) Masking, simulation and salience.
d) Constancy, subconstancy and overconstancy.
e) Adaptation phenomena and alternation of visual solutions.
f) Overt or latent conflicts in environmental perception.

Among the experimental investigations whose short report enriches the presentation, it is worth mentioning the research on phenomenal spatial properties of the so-called "Distorted Room", the classical experimental tool proposed by Ames more than half a century ago and later discussed by several researchers and commentators (Mooney, 1950; Wittreich, 1952; Massucco Costa, 1956; Minguzzi, 1956; Kilpatrick, 1961; Van de Geer & De Natris, 1962; Bonaiuto, 1991; Bartoli, Giannini & Bonaiuto, 1996, and many others).

A tridimensional model of a distorted room on a reduced scale (cm 44 x 57 x 56) has been used. Two experimental groups composed of individually examined young adults (both genders) have been employed. In order to produce unequivocal quantitative data, each participant evaluated the phenomenal shape of the inside back wall, which is a trapezium with acute angles of 72 degrees. Participants used seven-box comparison scales (method of limits). Results confirm that: 1) Ambiguous perceptual conditions, that is, monocular observation by the central hole, on average favour shape regularization. This is due to assimilative influences of viewer expectations, conforming his/her normal tendencies to regularity and congruence. 2) Unambiguous perceptual conditions, that is, binocular observation without visual field limitations, favour a significant emphasis effect, expressed by overevaluation of the anomalous trapezoidal shape. This is due to proactive contrast with respect to desired and expected model shape.

These phenomena and related processes are compared with those occurring with other classical and new anamorphoses, among which models of tilted or deformed buildings, used by our research groups.

A comparison between normal and paradoxical architectures

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Keywords: building, mental schema, norm, paradox, perception.

A normal appearance or, on the contrary, a paradoxical one, with different intensity degrees, is grasped when dealing with real buildings, or building models and depictions, depending on confirmation or contradiction with respect to commonly shared mental schemata. Paradoxes affect spatial properties such as position, shape, size, composition, density, other perceptual properties such as colour, texture, consistency; and, depending on the previous one, expressive qualities and meanings.

Over the last 20 years some research groups have worked at the Psychology Department, 1st University of Rome, following research methods and criteria established by Paolo Bonaiuto, and taking advantage of his coordination. The following other researchers have taken part in the investigations from time to time: Anna Maria Giannini, Marino and Flavia Bonaiuto, Margherita Miceu Romano, Valeria Biasi, and, more recently, Gabriele Bonaiuto, Martina D'Ercole, Chiara Latini, Erika Balestri and Marina D'Angeli. Field observations and systematic research have been carried out on leaning buildings, such as the famous Leaning Tower of Pisa, the Garisenda Tower in Bologna, the Leaning House of the Holy Wood in Bomarzo. Studies have also considered buildings with leaning walls, with vertical obtuse or acute edges, or with breaks, slidings and other anomalies.

Recently the comparison between normal and very incongruous buildings has included the so-called "deconstructive" architecture buildings, like some examples designed by Frank O. Gehry and located in Europe (Prague, Bilbao, Weil am Rhein) or in the United States; moreover, other very astonishing buildings such as the U.F.A. multiscreen cinema in Dresden, designed by Wolf Dieter Prix, Helmut Swiczinsky and associates; or several works by Peter Eisenman, Zaha Adid, Bernard Tshumi and others. Continuity and novelty aspects, with respect to previous relatively incongruous buildings, have been carefully evaluated.

The main verified psychic phenomena and processes include: attenuation or even masking of the building incongruities when observed in ambiguous perceptual conditions; their emphasis in the opposite conditions; effective influences of verbal and non-verbal messages on the above-mentioned phenomena; reduction of both incongruity and anxiety arousing power following fitting and appropriate explanations; special reverberations of conflict overloading, with perceptual defence phenomena; gradual adaptation over time; contrasting aesthetic and emotional evaluations by very incongruity-intolerant or very incongruity-tolerant people.

The virtual spaces of anamorphoses and "trompe l'oeil" depictions

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Keywords: anamorphosis, completion, contradiction, illusion, trompe l'oeil.

Anamorphoses are bidimensional or tridimensional devices that, when normally observed (for example, from a frontwise position), appear strongly deformed or even incomprehensible depictions, while observed from other positions (for example, slantwise) favour well recognizable, plausible and harmonious images. Contributions to anamorphosis knowledge come from investigations by Baltrusaitis (1969), and, in Italy, by Bonaiuto (1971), Massironi & Savardi (1991), Bartoli, Giannini & Bonaiuto (1996), Caterina & Guerra (2000).

The so-called "trompe l'oeil" situations are, on the other hand, strongly realistic paintings that utilize visual effects of depth, relief, and sometimes continuity beyond the environmental boundaries, generating remarkable space illusions in the average observer. Pertinent comments were made by Musatti (1976).

According to our psychological approach, there are interesting and deep analogies between anamorphoses (classical or modern) and "trompe l'oeil" situations, as they are known in art history: also if one deals with apparently different devices. In both cases, indeed, artists make use of viewer's recognition and completion processes, taking advantage of tendencies, expectations and mental schemata that are already present in the average beholder and that in this way are confirmed further on. The adherence to schemata, and so to perceptual habits, coexists with contradiction and conflict features. Actually, the beholder becomes aware simultaneously, or in an alternating way, that perceived spaces, structures, objects and environments are merely virtual. On the whole, an articulation of contrasting processes is obtained. Effects come out of complexity, wonder, cognitive and emotional richness, contributing to aesthetic satisfaction. Knowledge of such dynamics makes the interest, attention, attraction and success that these art works have obtained, since ancient times, understandable.

Several anamorphosis or "trompe l'oeil" real situations were investigated by our research group, contributing to demonstrate that in both cases the proactive assimilation of visual images to the observer's mental schemata favour their full regularization; while deformation, destructuration and derealization phenomena turn out to be even emphasized when proactive contrasts with respect to mental schemata take place.

By experiencing immersion in virtual spaces created by illusion processes or, alternatively, by discovering and controlling reality, one practices cognitive and emotional excursions. The extent of the change is related to observation conditions predisposed by the artist and to autonomous activities of the beholder, whose personality components play relevant roles.

The neurocognitive foundations of spatial memory

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Keywords: spatial memory, neurocognitive techniques, temporary storage of locations, longer lasting representations.

Spatial memory concerns the ability to remember the spatial layout of our environment. It enables us to learn the route between two locations in our neighbourhood, to know where things are, and know where we are ourselves in relation to relevant landmarks and objects. The behavioral functions of spatial memory vary from wayfinding, to visual search, to spatiomotoractions like grasping. In addition, the effective time span of a given spatial memory can range from a few seconds to several decades.

The foregoing description makes it clear that spatial memory is not an unitary concept, but rather should be viewed as a multicomponential construct. In turn, it is not restricted to a single area of the brain. Important circuits are found in the hippocampal formation, parietal lobes, and the prefrontal cortex. In short, there are many ways to code space, used for different behavioral purposes, and this coding is done in distributed neuroanatomical circuits.

The aim of this symposium is to discuss recent neurocognitive studies on a variety of spatial memory tasks. We will start with a preliminary taxonomy of spatial memory types. In the subsequent presentations of this symposium specific forms of spatial memory will be dealt with in more depth. A diversity of neurocognitive techniques will be discussed: patient studies, transcranial magnetic stimulation, fMRI. The second paper of this symposium (Zimmer & Mohr) focuses on the temporary storage of locations when searching through space and counting locations, and neuropsychological dysfunctioning. Next, the role of the parietal cortex in spatial working memory is illustrated by a rather new technique: transcranial magnetic stimulation (Postma et al.). Magnetic stimulation allows for transient interventions in circumscribed cortical areas.

In the last two papers of this symposium we will make a shift from spatial working memory to longer lasting representations of spatial memory. Kessels et al. provide an overview of selective impairment in components of object location memory. Their findings further support the notion of a multicomponential spatial memory construct. Finally, Berthoz will present fMRI and PET data on different ways to code spatial information during route versus survey navigation.

Taxonomy of spatial memory processes

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Keywords: types of spatial memory, brain circuits.

Spatial memory is required whenever one needs to store information on spatial features, such as location, orientation, distance, or interobject relations, for some period of time beyond the direct perceptual input. Different forms of behavior rely upon spatial memory: navigation, visual search, grasping, remembering object locations etc. In addition, the time span of the memories can range from a few seconds to many years. Working from the notion that multiple different types of spatial memories can be distinguished, this presentation will attempt to give a preliminary overview of the most relevant distinctions and of the presumed underlying neuroanatomy. To start with, there is the difference between allocentric, cognitive coding of locations versus egocentric coding, used for spatiomotor actions. Ventral and dorsal pathways of the posterior cortex are thought to be involved. Related to this, there is the concept of spatial working memory, relying upon parietal and prefrontal areas. Spatial working memory involves the transient maintenance of positional information, for which movement codes might be crucially important (e.g. eyemovements or attentional search movements). More stable, cognitive representations of space are associated with the hippocampal formation. Recently, Berthoz (1999. Hippocampal and parietal contribution to topokinetic and topographic memory. In: Burgess N., Jeffery K.J., O'Keefe J. (eds.) *The hippocampal and parietal foundations of spatial cognition*. Oxford University Press, Oxford, pp. 381-399) has suggested that in navigation tasks also more dynamic 'topokinetic' spatial codes are formed.

Functions of visuo-spatial working memory: behavioral and neurpsychological data

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Keywords: visuo-spatial working memory, selective impairments, experimental findings.

We will tackle three different functions of visuo-spatial working memory: (a) a passive storage of visuo-spatial input in order to detect changes in the visual environment; (b) a workbench for assembling of visual images; and (c) a device for spatial marking, i. e. transient memory for spatio-temporal information that is not supported by environmental cues. We will present data from classical psychological experiments with healthy participants and from two patients with a visual short-term memory deficit which support the assumption that these three functions are different components of visual working memory.

Transcranial magnetic stimulation at the parietal cortex and spatial working memory

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Keywords: spatial working memory, transcranial magnetic stimulation, parietal cortex.

Recent neuroimaging studies underscore the role of the posterior parietal cortex in the temporary storage of positional information in working memory. Furthermore, there is abundant evidence that spatial working memory is highly lateralized. In the current study high-frequency repetitive magnetic stimulation (rTMS) was employed as a 'virtual, reversable lesion technique' at the right and left parerial cortex. Eight subjects performed a spatial working memory task in which three dots were shown for 500 ms. After a 1000 msec delay, a test circle appeared around one of the memorized dot locations or somewhere else. rTMS was applied during the 1000 ms delay at the right or left parietal cortext or in a sham condition (frequency 25 Hz, trains of 200 msec). Reaction times turned out to be significantly slower with right-parietal stimulation than with left-parietal stimulation. This provides converging evidence for recent theories on the role of the right parietal cortex in spatial processing. The potential additive value of the rTMS technique to the patient lesion method and correlational neuroimaging techniques will be elaborated.

Spatial memory dysfunction in patients with anterior or posterior cerebral lesions

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Keywords: object location memory, cerebral lesions, selective impairments.

Recently, a distinction has been proposed within object-location memory between 1) processing of precise, metric information, 2) binding objects to locations, and 3) a possible integration mechanism. In the current paper, the neuroanatomical substrates of these processes have been studied. Fifty non-acute stroke patients participated, as well as 40 healthy volunteers (age- and education-matched). A computer task was used in which subjects had to remember the positions of everyday objects within a frame (focusing both on immediate and delayed recall after 3 minutes). To assess object-location binding, ten different objects were shown, of which the positions were pre-marked by dots in the relocation phase. Next, ten identical objects were presented to measure positional memory, which had to be relocated in an empty frame (without pre-marked dots). Finally, ten different objects were presented that had to be relocated in an empty frame in order to measure the integration mechanism. Lesion localization was done on the basis of CT or MRI data. The results show that patients overall performed worse than healthy subjects (p = 0.006). Post-hoc analyses showed that patients with anterior lesions performed at control level on all tasks. Posterior lesions produced deficits on object-location binding only (p = 0.03), and patients with anterior and posterior lesions were impaired at object-location binding (p = 0.03) and positional memory (p = 0.02). No hemispheric specialization was found on any of the spatial-memory tasks. These selective findings provide converging evidence for the previously mentioned distinction within object-location memory. In addition, it appears that especially the posterior cortices are specialized in spatial processing. Moreover, spatial-memory impairments are not limited to right-hemisphere damage, but can occur in patients with lesions in either hemisphere.

Neural basis of spatial memory during route versus survey navigation

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Keywords: topokinetic memory, topographic memory, neuroimaging data, navigation, brain circuits.

During navigation the brain uses different cognitive strategies (for instance route versus survey) for guiding locomotion and for storing information concerning the memory of routes. Although a abundant litterature suggests that the brain uses "cognitive maps" we have been interested by the possibility that the brain, in addition to a map like representation of environmental space, may use dynamical memories of the movements and of the relations between the body and various kinds of landmarks. We have termed this spatial memory "topokinetic" or "topokinesthetic" instead of "topographic" memory. We shall give a number of examples of experimental results using psychophysical methods with virtual reality or blind locomotion tasks which indeed suggest that the brain can simulate active navigation using dynamic processes. We shall also present some results from brain imaging (fMRI and PET) which allow the identification of the respective role of the parietal, hippocampal, and frontal lobes in these various cognitive tasks and which support the idea of distinct processes associated with different mental strategies using for example either egocentric or allocentric reference frames.

The physiologist meets the philosopher Kant. How subjects build and construct space. Analysis of psychophysiological process on the relation among spatial experience, time organization and emotion

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Keywords: spatial experience, time organization, emotion, philosophy, psychophysiology.

Researches about visual decodification examined how stimuli placed in space are perceived presupponing that "space" be a physical phenomenon absolutely independent from the perceiving subject. Many researches studied the perception of depth and tridimensionality, but all consider space only as an objective external situation. On the contrary, the philosophical discussion about space, in particular in the previous centuries, examined space in relation to the subject and his mental activity. Starting from a new psycho-physiological point of view we think that the so called "real space" exists in the framework of the subjective experience of space. This conception requests an active processing from the perceiving subject. In other words, subject, in real perception, would actively build "the space". We hypothesize two levels of activity in organizing perception. The first, the central nervous system, like the hardware of a computer, organizes and creates the space through a particular form of elaboration of the stimuli. The first process is realized through a mechanism of abstraction that we have re-written, in physiological term starting from the research on perception of Hubel and Wiesel. In this way the physiologist meets the philosopher Kant. Then in organizing experience of space the subject synthesizes the flux of bodily information (proprioceptive stimuli etc.). So the experience of space is a product of synesthetic activity of the subject. It is a special form of elaborating stimuli. When the space is actively formed, subjects decodify stimuli placed in space. This activity represents the second level of visual perception, like the software of a computer. The temporal organization of so called visual stimuli plays a central role in this process. In this symposium we will discuss this thematic examining also the relationship between experience of space and individual psychological differences and development.

Personal space as real concrete measurable phenomenon

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Keywords: personal space, narcissism, posture, psychophysiology.

We considered from an experimental point of view the hypothesis of the existence of a personal space suggested from the literature on nonverbal communication. We define personal space not only in terms of interpersonal distance and in relation to attention, but as a psycho-physiological characteristic like a personality trait of the subject that defines parts of his personal territory. Personal space is a concrete physiological phenomenon organizing the relationships with the spatial environment, strictly related to the organization of bodily concrete experiences of the ego structure. By asking subjects to modify their postural attitude, we also observed the presence of relevant modifications of personal space. We asked 30 undergraduate psychology students, males and females, to indicate if they could perceive and define space around themselves. They were also asked to indicate the dimensions and the shape of their space. When subjects gave positive responses, the experimenter measured the dimensions of the perceived space with a centimeter tape rule. The subjects were considered as center of eight spatial directions: anterofrontal, posterior, right and left lateral, and 4 obliques. The eight dimensional axes were placed immaginatively in horizontal plain perpendicular to the subject at the level of the xifoid apophysis of the sternum. Results seems to confirm the hypothesis. 24 subjects (80%), perceived a well defined and measurable personal space. For each subject a graphic representation of the area of the perceived space is given. Therefore the phenomenon of the personal space has been connected with the problematic of narcissism, examining the relationship between personal space and normal dimensional narcissistic development studied through the Questionnaire of Scilligo. Interesting relationships between shape and extension of personal space and some Scales of narcissistic development (Assertivity, Projectivity and Creativity) appeared.

Role of auditory timing experience on the perception and the estimation of spatial dimensions

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Keywords: spatial distance, rhythm, psychophysiology.

This research hypothesizes the influence of the rhythmic experience on perception and evaluation of spatial distances. In our experiment, the rhythmic experience is elicited by listening to different acoustical tempos produced by a metronome. For the evaluation of the spatial distance three independent groups of 60 males and females were formed by undergraduates psychology student. The three groups were differentiated on the basis of the evaluation of spatial distances. The evaluation of spatial distances was made asking subjects to reproduce by means of the distances between their own hands the estimated distances of the stimuli. The experimenter measured in cm the distance between the hands of each subject. The real evaluable distances were respectively of 30-60-90 cm. The speed frequencies were 66, 144, 192. Subject listened to each of the three frequencies, randomly presented for 15 min. At the end of each rhythmic acoustical experience, subjects were asked to evaluate the spatial distance of two vertical rods placed in a frontal plane at a distance of 1.50 from the subject. Results confirmed the hypothesis. For each stimulus situation, subjects showed a strong contraction of the evaluated distances, in relation to the increasing of the listened metronomic frequencies.

About spatial visual imagery

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Keywords: depth, imagery, tridimensionality, experience of space, psychophysiology.

On the basis of a previous research, we hypothesize that the experience of tridimensionality would be different between perception and imagery. We examined the differences in spatial experiences of visual representation between perception of a "real" stimulus and the imaginative representation of the same stimulus with closed eyes in 72 undergraduate psychology students, males and females. The stimulus was a building placed at the distance of 50 m. from the experimental subjects. Between building and subjects a railing was placed at the distance of 10 m. from the subjects; the railing was composed by 6 rectangles (10x30 cm). Subjects received the following instructions: "Look at the railing and the three windows on the build, trying to perceive both structures simultaneously with a perceptual operation like making a photo." Then subjects, closing their eyes, were asked to recall imaginatively the previous perceived image while indicating if the two representations (real and imaginative) were identical or different. In particular they had to observe if they have seen simultaneously figure (railing) and back (windows) considering also the dimensions, the distances between the structure, the dimensional relationships between the structures. During imagery subjects showed two different forms of response: 1) impossibility to have simultaneous representation of figure and background or 2) when figure and background are simultaneous present important modification of the relative dimensions of the stimuli (railing and windows) appeared. In conclusion we think that spatial imagery is bidimensional one. A discussion about this concept will be made.

Communicating spatial relations

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Keywords:

In a mobile world humans often have to orient themselves in an unknown spatial environment. In order to solve their way finding problem, we inform the visitors about the locations and we describe them their way to the aimed location. For this purpose we have different possibilities. We can give them pictures of landmarks, a map, a verbal description, an augmented map, we can take them on a virtual travel through the environment, we can indicate directions by pointing, etc. All these possibilities are only partially equivalent in respect of the given information, and all of them have their advantages and disadvantages. Hence, if we want to use these possibilities in a sophisticated manner, we have to understand how these different media are cognitively processed. For example, if an artificial agent has to generate verbal spatial descriptions, we have to know what the meanings of spatial prepositions are in order to select the correct one. Similarly, we have to decide about a specific visualization if we want to present a trajectory through a depicted surface map. At a higher level, we finally have to plan which of these different spatial aids we want to select because it is under these circumstances the most efficient one. The contributions to this symposium should bring us a bit closer to a solution of these problems.

PABST

Symposium on spatial relations

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Critical features for the selection of verbal expressions for path relations

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Keywords:

In three experiments we examined the spatial characteristics which are critical for the selection of spatial prepositions to describe path relations. We investigated the conditions for using 'vorbei' [past] and 'entlang' [along] in a production experiment. Subjects saw pictures on which a reference object (RO) and a trajectory (T) of a movement were depicted. The spatial relation between RO and T was manipulated. T was either parallel to the nearest edge of RO, or it violated this feature to a different degree. Additionally, the distance between T and RO, the starting and target positions, and the outline of RO were varied. The selection of verbal descriptions was mainly influenced by the degree of parallelism between RO's surface and T in the critical area, i.e., the area bounded by the perpendicular on RO's nearest edge in the corner which was nearest to the starting position of the path, and the perpendicular in the corner which was nearest to the target position. In contrast, distance and shape of RO had only minor effects.

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Visualization of path relations in multimodal route descriptions

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Keywords: spatial cognition, route description, path relations, visualization.

We investigate the design of a resource adaptive navigational help system with the ability to adapt to various restricted resources during the generation of multimodal route descriptions. The resource adaptive generation of graphics/animation for different classes of output devices ranging from a high-end 3D-graphics workstation down to a personal digital assistant implies dealing with limited technical resources on one hand, and taking into account a user's limited cognitive resources to decode and understand the presentation on the other hand.

Based on experiments reported by (Hubert Zimmer et al.) investigating the characteristics of path relations described by the german path prepositions (e.g. vorbei (past), entlang (along)), we developed a computational method, which uses a 3D model of the environment, to find an appropriate path relation for a given situation. At this point we are able to verbalize the selected path relation using a mapping between relations and prepositions.

In addition we generate and present a virtual journey through the environment to visualize the different path relations/prepositions adequately. The experiment rose evidence that there are protoypical characteristics of trajectories for different path relations depending on the reference object's shape. Reference objects are apparently 'attracting' or 'bending' the path taken by the moving objects and as in reality, where people tend to cut corners, the trajectories for example bend smoothly around the reference objects.

Our idea is to assign a force field to every reference object used to modify the progression of the trajectories. By means of a physical simulation the trajectories are modified by the force field which in turn is derived from the object's shape. Parameters such as strength and decay of the force field can be adjusted in order to approximate the modified trajectories to the prototypical trajectories form the experiment. Our hypothesis is that the modified trajectories visualize the different characteristics of the path relations most adequately by adhering to the prototypical path as far as possible.

Spatial intelligence and the cognition of spatial dimensions

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Keywords: frame of reference, spatial intelligence, spatial communication.

The interpretation of dimensional spatial expressions depends on the hearer's selection of a frame of reference (Carslon-Radvansky & Irwin, 1993). Particularly with "in front of" and "behind" relations, there are cases where the object-centered (or intrinsic) and the observer-centered (or deictic) frame of spatial cognition lead to just opposite choices of places when interpreting prepositional phrases. So far, five classes of determinants for the selection of a frame of reference in a discourse situation have been described: (a) orientedness of the reference object (Miller & Johnson-Laird, 1976); (b) social context (Grabowski & Miller, in press); (c) statics vs. dynamics of the described situation (Wunderlich, 1981); (d) discourse context (Ehrich & Koster, 1983); (e) prepositional inventory of a particular language (Grabowski & Weiß, 1996). Still, however, a significant portion of variance remains unexplained, particularly for the interpretation of German and Dutch dimensional prepositions.

We will report on experiments that investigate the role of individual spatial intelligence for the predicition of deictic vs. intrinsic interpretion of spatial expressions. This also involves the basic question whether the dimensional conception of space — which is inter-individually clearly non-uniform — is intra-individually uniform or not across situations of the same type. Previous evidence in favor of such a consistency, as presented with the assumption of personal styles (Levelt, 1982), shows some methodical flaws.

Three important results emerged: (1) About half of the people behave intra-individually non-uniformly on successive trials of interpreting dimensional descriptions of spatial situations. (2) Those subjects who interpret all items within a class of object constellations consistently, show significantly better spatial IQ scores than those who perform non-uniformly across same-class items. (3) It can not be predicted from the high spatial IQ subjects whether they will interpret dimensional expressions uniformly intrinsicially or uniformly deictically.

The are three major conclusions: (1) Spatial intelligence is a further determinant of spatio-dimensional cognition and interpretion with respect to frame of reference selection. (2) The frequently found inter-individual variation in the interpretation of dimensional prepositions does also hold intra-individually. (3) The assumption of cognitive styles in spatio-dimensional cognition appears to be a methodical artefact (set effect); considering spatial intelligence allows for a theoretically deeper explanation of frame of reference selection.

Conditions for the choice of projective terms

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Keywords: spatial communication, projective terms, natural language generation, lexical choice.

German projective terms can be divided into two classes: projective prepositions and adverbs. Items of both classes require a spatial frame of reference, providing a system of axes and directions to refer to a spatial relation that holds between the reference object (RO) and a primary object (PO).

For each projective preposition a number of morphologically related adverbs exist whose meanings differ in several respects from the meaning of the corresponding preposition. For example, the preposition *über* (above) refers to a vertical axis-based region. The corresponding adverbs *oben* (at the top), *darüber* (over that), *obendran* (lit.: at the top+there+at) etc. refer to regions that are principally based on the same axis, but their use in spatial communication is restricted by means of several semantic and pragmatic factors.

The semantic differences between the various projective terms are the localization of the PO in a region that is external vs. internal to the RO and — in case of adverbs like *darüber* — reference to the RO vs. refernce to the region the RO occupies. Pragmatic differences are based on the identifiability of the RO by the listener and its status in the discourse model.

In natural language generation, the mapping of a concept onto a situatively appropriate lexical item is called lexical choice. In my talk, I will present a model of the choice of projective terms that takes into account the mentioned semantic and pragmatic factors in using these terms. I will propose a decompositional approach to the choice problem where features of the reference object and its kind of textual embedding are collected in order to receive an unambiguous mapping. Technically, this feature collection is realized as abductive reasoning.

Human wayfinding in unfamiliar buildings: a simulation with cognizing agents

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Keywords: spatial perception and cognition, agent design, human wayfinding, information needs, affordances.

Researchers in the areas of human wayfinding, spatial cognition, computer science, and artificial intelligence have developed cognitively based computer models for wayfinding. These models focus primarily on learning a spatial environment and on the exploration of mental representations rather than the *information needs* (Gluck, 1991, *Behav. and Soc. Sc.*, 63, 117) for wayfinding. It is important to consider information needs because people trying to find their ways in unfamiliar environments do not have a cognitive-map-like representation but depend on external information. To simulate such wayfinding behavior in a cognitively plausible way it is therefore necessary to integrate structures of information perception and cognition in the underlying model.

In this work we use a cognizing agent to simulate people's wayfinding processes in buildings. The wayfinding model integrates an agent's cognitive schema and perceptual structures within an SPA (Sense-Plan-Act) approach. It focuses on external knowledge to explain actions of the agent performing wayfinding tasks. We use the concepts of information and affordances to describe the kinds of knowledge agents derive from the world by means of visual perception. Affordances (Gibson, 1979, Houg. Mifflin Co., Boston.) are possibilities for action with reference to the agent. Information (such as from signs) is necessary for the agent to decide upon which affordances to utilize. An internal cognitive schema (Neisser, 1976, Freeman, New York.) guides the agent's processes of perception, decision, and action during the wayfinding task. This schema includes information about the task and goal, and a minimum of wayfinding strategies and commonsense knowledge necessary to perform the task. The task description directs visual perception in such a way that the agent samples only task-relevant information and affordances. The wayfinding model concentrates on the actual information needs during wayfinding and does not focus on learning a spatial environment. Its fundamental tenet is that all information must be presented at each decision point as "knowledge in the world" (Norman, 1988, Doubleday, New York).

The proposed formal specification of the agent-based model within a functional programming environment can be used to simulate people's wayfinding behavior in spatial information and design systems. We employ the specific case of wayfinding in an airport to demonstrate the proposed model. The result is a test of the signage in the airport.

ORAL PAPERS

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Spatially structured situation models in narrative comprehension: Spatial distance effects revisited

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Keywords: text comprehension, spatial situation model, spatial distance effect, spatial gradient, mental model.

Spatial distance effects (increased accessibility of object concepts with decreased spatial distance between the object location and the reader's current focus of attention within a narrative's setting) are regarded as evidence of the spatial structure of situation models formed during narrative reading (e.g., Morrow et al., 1989, *Journ. of Memory and Lang., 28*, 292; Rinck et al., 1995, *Journ. of Memory and Lang., 34*, 110). In three experiments, the hypothesis was tested that spatial distance effects are not only controlled by the spatial structure of the situation model but also by the representation of the text's surface structure. In all experiments, participants first learned the layout of a building and then read 12 narratives about a protagonist's motions and actions within this building. Reading times of undistingiushed target sentences were measured that referred to objects (a) in the same room as the protagonist (location room), (b) in the room the protagonist had just gone through (path room), (c) in the room where the protagonist started (source room). Source room sentences referred to objects in close, medium distant, or far source rooms. Rinck and Bower's (1995) spatial gradient (increasing reading times from location over path to source room sentences) was not replicated. Instead, reading times were controlled by mentioning the target room name in the sentence preceding the target sentence. Selective priming of target rooms even inverted the spatial gradient (increased reading times with decreased spatial distance). However, holding surface-based priming of target rooms constant, consistently produced weak spatial distance effects among sentences referring to close, medium distant, and far source rooms. The results contribute to specifying the spatial situation model construct and are discussed in terms of multi-level theories of text and discourse comprehension.

Directional adverbs and cognitive spaces. The case of analitical verbs in friulan language

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Keywords: adverb, analysis, direction, verb.

Analitical verbs are binary verbal constructions that result from the union of a spatial adverbial element, with directional value and modificatory function, and a verbal basis. They are called "analytical", because the semantic load of the locution is distributed on both verb and adverb. In this contribution some considerations are set forth on the general criteria governing the selection of the proper adverb in forming these binary verbal locutions, selection that seems to show a clear preference for certain spatial determinations rather than others.

From a typological point of view, it is possible to notice a loss of functionality of prefixes as verbal modifiers — that is conspicuous in passing from Latin to Romance languages, especially concerning directional values — and to point out their lesser productivity in verbal composition. On the other hand, we have a remarkable increase in using adverbs to build *analitical verbs*. Moreover, we eventually get the impression that adverbs, and not prefixes, can be really considerated — in Friulan, and in Romance languages in general — the verbal modifiers *par exellence*. The spreading of that use and the expansion of the category of analitical verbs, in Friulan, are the direct effect of the function's strengthening of the adverb as verbal modifier and directional indicator. That suggests, for his general implications, a greater attention for these binary locutions in the other Romance languages too. In this way, it could be verified, also for verbal modification, the substantial unity of typological evolution from the model *Modifier + Head*, proper of classic Latin, to the model *Head + Modifier*, typical of Romance languages, but already present in vulgar Latin.

Another interesting problem concerns the selection of modificatory adverb in forming analitical verbs. From a well defined and tested corpus of analitical verbs, it is possible to suppose that the high prevalence of some directional indicators — in comparison with other ones, and with reference to their frequence and their compositional flexibility — could be related to the anisotropies of psychological or perceptual space. An analysis of the language along this perspective can show that an adaptive behaviour is revealed by the frequency with which spatial specificators are selected.

Angle size schematization in on-line visual processing and short term visual memory

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Keywords: visual perception, visual memory, psychophysics angle, perception linguistics.

The 45°, 90°, 135° angles and the straight line play a special role in long term spatial and linguistic memory. As shown, e.g., by Hayward & Tarr (1995) and Tversky (1996) memory for object location is better at these angles from the line of sight than at other angles. And, as shown, e.g., by van der Zee (1999, forthcoming) and van der Zee & Nikanne (in preparation) the meaning of curvature verbs like the Finnish verb *kiemurrella* corresponds more closely to path curvatures centered around some of the above mentioned angles than other angles. This raises the question of why the above mentioned angles are more special in our long term memory than other angles. We carried out two experiments to answer this question. In experiment 1 participants compared the angle size of two simultaneously perceived angles and in experiment 2 participants compared the size of an angle with another angle from visual memory (in both experiments the two presented angles differed by 7° or less than 1 jnd). In our experiments participants made more mistakes when distinguishing the 45°, 90° and 135° angles from other angles, compared to other angles that also differed by 7° but did not contain any of the 'special' angles. Participants made less mistakes when distinguishing the straight line from angles, or angles from the straight line, compared to angles that also differed 7° in angle size. A differential verbal labeling of the stimuli had no effect on mistakes or reaction times. Participants carried out no mental rotation to compare angles. The results found are compatible with an angle size detection mechanism (Regan, Gray & Hamstra, 1996) in which angles are represented in a viewer independent fashion. The results are also compatible with on-line angle schematization and angle schematization in short term visual memory.

Ocular movements and visuo-spatial working memory

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Keywords: visuo-spatial working memory, oculomotor processes, visual cache, inner scribe.

The purpose of this experiment was to study the distractions created by different eyes tracking tasks, executed during a delay left between presentation and reconstruction of shapes. The shapes were black angular patterns, which were created by filling in 10 cells in 4 x 5 grids. The shapes were successively displayed on a computer screen for 10 seconds. After the presentation of each shape, the subject had to wait 10 more seconds before using the mouse to reconstruct it on the screen. Subjects performed this reconstruction task, response times and errors rates were recorded. There were 3 conditions. The subjects of the control group had no task to perform during the delay. The subjects of the "random group" visually followed a point randomly displayed on the screen. The subjects of the "imitation group" visually followed a point successively and clockwise displayed at the different places, where the angles of the removed shape appeared. We made 2 hypotheses: First, the performances of the random group subjects will be worse than those of the control group subjects, secondly, the performances of the imitation group subjects will be better than those of the control group subjects. The results confirmed the first hypothesis: The random group subjects were slower and made n-ore errors than the control group subjects. But the main result is that both responses times and errors rates of the imitation group subjects were similar to those of the control group subjects. In other words, when the ocular movements are no longer randomly executed, but imitate a visual exploration of the removed shape, the performances are then no more damaged by the eyes tracking task. These data suggest that the refreshing process of a visual image in the visuo-spatial working memory is linked to oculomotor processes.

Interference during the encoding and during maintenance of visuo-spatial material

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Keywords: visuo-spatial, Working Memory model, interference paradigm.

Recent work by the authors (e.g. Quinn & McConnell, 1996) has indicated that words learned under the pegword mnemonic technique is susceptible to selective interference by an irrelevant dynamic visual noise display. Moreover, additional research (McConnell & Quinn, 1996) has further indicated that a particular type of irrelevant interference, line drawings of common objects, differ in the nature of the interference caused depending on when it is presented. When the presentation is timed to coincide with the presentation/encoding of the word, interference is not selective but affects the words under both verbal and visual processing instructions. In contrast, when the drawings are presented during a maintenance period, the interference is selective for visual processing. Against this background, experiments were conducted using a dynamic visual noise technique and asking whether the timing of the interference is crucial for the interference to occur. Preliminary indication are that timing is crucial to interference with the visual noise having its selective effect exclusively during encoding. Interference is not effective during maintenance.

Previous results of the series of experiments have been interpreted in terms of the two-part architecture of visuo-spatial working memory: selective noise interference has its effect through the passive visual store rather than through the active spatial rehearsal mechanism. However, although a two-part architecture remains consistent with a variety of behavioural and neuropsychological investigations, the restriction of the effect of irrelevant noise to the encoding stage suggests that the relationship of the two-part architecture to the current concept of the Central Executive within the Working Memory model should be reconsidered.

The role of ANN in investigating the cognitive processing of target tracking

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Keywords: attention, alertness, oscillatory neural network, visual motion detectors.

Tridimensional spatial cognition is mainly based on the possibility of discriminating objets from a structured background, exactly identifying their contours and estimating their mutual distances. As firstly (at least at our best knowledge) it was pointed out by von Helmholtz in 1866, these tasks can be achieved by motion parallax. Since we are dealing with a *relative* motion, it is evident that many situations can arise (e.g. only the observer is moving with respect to the whole scenery that is standing, also objects and/or background exhibit some kinds of relative motion, the observer can only see a twodimensional picture of the reality, etc.) that requires that a time-varying signal is processed. Many researchers investigated in great detail such a processing procedure by both behavioral and alectrophysiological techniques. However many questions are still unexplored. Among these we may identify two key subjects: attention and alertness. The first is the ability of concentrating the majority of the processing resources on that part of the incoming signal that vehiculate the most relevant information, while the latter is the ability of detecting any sudden change of the observed scenery. Artificial Neural Networks (ANN), due to their capability of simulating cognitive processing, can be a powerful tool for investigating the role of attention and alertness in the process of spatial cognition. In our paper we will concentrate our attention on a typical problem of spatial cognition, namely the visual target tracking, and we will show the results that can be obtained by using special kinds of neural networks (ANN's with oscillating neurons and time-varying synapses and Cellular Neural Networks) and appropriate algorithms (PCA and ICA).

The processing of an irrelevant stimulus location

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Keywords: Simon effect, sequential effects, spatial attention, sensory-motor integration.

In a typical Simon task, a red or a green stimulus is presented to the left or right of the fixation cross and subjects have to react with a left or right response key on the colour of the stimulus. The irrelevant stimulus location influences the reaction time (RT) in at least two ways. It is a standard finding that if the stimulus location corresponds spatially with the response location that the RTs are faster than when both do not correspond, this is called the Simon effect. With a sequential analysis of 3 Simon tasks, we demonstrate that the direction of the attention shift towards the stimulus is responsible for the Simon effect. If two successive stimuli are presented on the same location, there is only a Simon effect if there was ample time to shift attention towards the fixation cross during the response-stimulus interval. The irrelevant location of the stimulus influences the RTs in a second way. RTs are fast when both the location and the response (colour) repeat or alternate, but when only one of the dimensions changes, RTs are slow. This means that complete alternations are faster than partial alternations. We introduce a Simon task with 4 colours mapped on 2 response keys in order to dissociate stimulus and response repetition effects and demonstrate that the interaction is caused at response level. This suggests that the interaction is not caused by the integration of the stimulus features (location and colour), but rather by a link between the irrelevant location and the response. This link does not seem to be caused by the dimensional overlap between the two dimensions since a similar interaction is observed for irrelevant shapes as well.

The use of spatial cognition for behavioural simulation of autonomous pedestrians and car drivers evolving in virtual cities

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Keywords: behavioural model, virtual reality, spatial cognition, city life simulation.

Urban traffic simulation has a high complexity, as it requires interactions between cars, trucks, cyclists and pedestrians, and also public transportation systems. 3D modelling tools are very useful for the visual realism of virtual urban environments but they are not sufficient due to the lack of life of these digital mock-ups. Realistic behaviours of autonomous actors evolving in complex and structured environments can be obtained if and only if the relationship between the actor and its surrounding environment can be simulated. In accordance with Gibson's ecological theory, components of the virtual urban environment should be informed (Gibson, 1986, Lawrence Erlblaum Ass.).

]. M. Relieu (Coll. VILLES, 1998) has defined the notion of positive and negative affordances for a pedestrian who is using the urban discrimination to focus his attention, to select pertinent information for his actions inside the current region, while he maintains a secondary task to observe what is happening in regions close to its circulation area. Synthetic actors should exhibit the appropriate looking or attending behaviours relevant to the activities they are engaged in. All pedestrians do not have the same assessments capabilities neither potential speed. In this way, behaviours variety comes from variations in the gap acceptance; this is conform to sociological studies (1992, *Perc. and motor skills*, 75(2), 432).

Social variety can be reproduced thanks to the notion of temperament and the parameterization of the Goffman's oval security zone (Goffman, New York : Basic Books, 1971).

In this paper, we present how spatial organization is taken into account for the pedestrian attending behaviour, and how it is possible to produce more realistic behaviours by using a city model affordant to autonomous actors. To describe realistic human behaviours, we have defined a formal model (Moreau, 1998, Thèse de l'Université de Rennes; Moreau 1998, Proc. of the Eurograph. Workshop on Computer Animation and Simulation) based on Hierarchical Parallel Transition Systems (HPTS), which is compliant with most of the paradigms specified by Alan Newell in its Unified Theory of Cognition (Newell, 1990, Harvard Univ. Press).

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Egocentered and allocentered pointing

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Keywords: spatial updating, pointing, egocentric coordinates, allocentric coordinates, and spatial representation.

When we move in our environment, it is crucial to keep track of the things around us, considering both the objects-to-subject and the objects-to-objects spatial relations. Literature about spatial updating has focused on the first aspect; our purpose is to investigate and to compare both kinds of spatial processing. We hypothesised that updating the objects-to-objects spatial relations is more difficult than updating the objects-to-subject spatial relations. In fact, in the first case people are supposed to rely on egocentric coordinates, whereas in the second case on allocentric coordinates which are known to require an effortful and complex cognitive processing. Participants were asked to study 8 common objects, displaced along a circle. Next, half of participants had to indicate the position of an object in relation to the position where they imagined to be (egocentric condition) and the other half the position of an object in relation to a second one (allocentric condition). Pointing responses were given by means of an angular pointer. Response time and accuracy were recorded. The results showed that spatial updating took longer and was less accurate as the self-to-object and object-to-object angular distances increase. In line with previous evidences, there was a drop in both response time and errors at 180°. Finally, the allocentric condition did not take longer than the egocentric condition, but it was less accurate. The findings suggest that when the body is the centre of the individual-environment spatial network, updating spatial information is facilitated. Moreover, the special status of the 180° position emerges in both egocentric and allocentric conditions. In the first case it corresponds to the front/back axis of the spatial framework model (Franklin & Tversky, 1990); in the second case it matchs the line linking the north/south positions of objects.

Ego-reorientation on mental representations of rooms

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Keywords: spatial cognition, ego-reorientation, mental rotation, 'sawtooth' pattern, room shape.

When imagining yourself standing in a remote room facing first one direction, e.g., the window, subsequently facing another direction, e.g., the door, yet keeping your mental stand point fixed, you have performed a mental ego-reorientation. How is such an orientation-transformation achieved? The standard assumption is, that mental rotation is employed (Rieser 1989, Easton & Sholl 1995). However, the mental rotation approach faces theoretical as well as empirical problems (Hintzman et al. 1981).

An alternative approach is proposed here. Similar to what Easton & Sholl (1995) suggest, the building up of an ego-orientation is proposed to be a process of anchoring the ego on a perspective-free representation of the room. In contrast to Easton & Sholl (1995) however, reorientation then is modeled as a two-step process of dissolving the old connection between the room representation and the ego, subsequently anchoring the ego directly in the new orientation. Furthermore, the model proposes that mental axes — either room or ego axes — are represented and that it is easier to reorient toward the directions of these axes than to any other direction.

Two experiments were conducted, where participants were required to imagine themselves standing in the center of a previously learned room, being surrounded by an array of regularly spaced objects, first taking one orientation, then mentally changing to another orientation in that room. In experiment 1, the ground floor of the room was circular, thus providing no symmetry axes of the room, in experiment 2 the room had a square ground floor, thereby inducing symmetry axes. In both experiments no increase of reaction times over increasing reorientation angles was found. Instead, there were only two groups of reactions times: short ones and long ones, like in the '*sawtooth*' pattern of Hintzman et al. (1981). In experiment 1, where no inherent room axes were given, people reoriented fast toward directions, which were directions of the body axes in the previous trial. Thus, people derived axes from the ego and used them in the reorientation process. In experiment 2 people reoriented fast toward the directions of the room axes. Thus, in both experiments no evidence for mental rotation was found. Instead, the shape of the represented room plays a critical role. The proposed model can explain the '*sawtooth*' pattern reported by Hintzman et al. (1981), for which no explanation existed so far.

Reconciling precise and erroneous spatial behaviors

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Keywords: spatial cognition, mental models, memory errors, cognitive maps, wayfinding, rationality, selection, working memory, information processing.

Spatial judgements are notoriously biased and error-prone. People erroneously believe that Rome is south of Philadelphia and Rio west of Boston. In contrast to these biased judgements are finely-tuned precise spatial actions such as those entailed in playing tennis, performing surgery, and playing the violin.

Those finely-tuned precise spatial actions are highly learned and practiced in environments that provide feedback on performance and cues to guide it. Again, by contrast, the spatial judgements that are biased are performed on hypothetical rather than actual spaces. In order to make the judgements, a representation of the relevant environment must be constructed in working memory; the judgement is performed on this representation in working memory. Because working memory is limited, the representations constructed are schematic, local, and ad hoc. They contain only the information relevant to the judgement. Because the representations are schematic, they are prone to bias; because they are local, there is no guarantee of global consistency. In hybrid cases, such as way-finding, that integrate spatial judgements with spatial actions, environments provide cues and guidance that reduce error.

Switching perspectives of a real spatial scene

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Keywords: spatial perspectives, task-switching, mental rotation.

The perspective adopted in conceptualising a spatial scene has been found to be a major determinant of the decision time for spatial judgements of the relative location of objects in the scene (e.g. Bryant, Tversky & Franklin, 1992). Where more than one perspective can be adopted, there is conflicting evidence as to whether subjects adopt a single perspective or multiple perspectives (e.g. Franklin, Tversky and Coon, 1992; Maki & Marek, 1997). If multiple perspectives are adopted, this would require switching between perspectives, potentially slowing judgement times (i.e. producing a switch cost) for the judgement involving the switched-to perspective. This proposition was investigated in three experiments employing methodology from the task-switching literature (e.g. Monsell and Rogers, 1995). Placed in a room with several objects, subjects were required to verify statements about the location of the objects relative to either themselves or to model heads facing in directions different to that of the subject. The results indicated that in two of the three experiments, switching to a judgement relative to self incurred no switch cost, whereas switching to a judgement relative to a model head incurred a switch cost, particularly when the judgement involved the locations to the left or right of the head. Angular deviation of the direction faced by the head from the direction faced by the subject was not linearly related to response times, arguing against a mental rotation account of perspective switching. The results were interpreted as consistent with switching between internal perspective computation and intrinsic computation (Bryant and Tversky, 1999) rather than the transformation of an internal perspective.

Comparing cognitive maps for wayfinding tasks in the real world and the web

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Keywords: navigation methods, cognitive maps, ontology, classification of errors.

A travel-related decision making process is highly based on the individual's spatial knowledge of the environment (Bovy and Stern 1990). The knowledge of the environment can be represented in cognitive maps (Tolman 1948, Tversky 1993). In this paper we want to explore the transfer of knowledge from real world navigation to web navigation. We propose that a web navigation process is based on a cognitive map. We compare the structure of cognitive maps in the domain of a street network and the web, fundamental differences between these two types of cognitive maps will be shown. These differences make a direct mapping of navigation methods from the world to the web difficult, even when using spatial metaphors (Kuhn 1996, Dieberger 1998) in the web, which should enable inclusion of familiar navigation methods of the real world. Furthermore, we give a classification of potential errors in both types of cognitive maps, those which are used in the web navigation and those used in the real world navigation.

A mental representation of the environment is needed for the real world wayfinding process if

- the traveler navigates towards a novel destination (which excludes use of habitual locomotion) and
- the novel destination cannot be perceived directly by the traveler and
- no external navigation aids such as routemarks (Krieg-Brückner, Röfer et al. 1998) or reference directions (Rossel and Wehner 1986, Wiltschko and Wiltschko 1995), are given.

Web space and web domains are not spatially structured, except when using spatial metaphors for the user interface. Therefore, navigation in the web requires a mental, semantically based representation of objects in the traveler's mind in form of an entity model, which allows the estimation of semantic distances between objects. For modeling this approach, an artificially created ontology, e.g., taken from WordNet (Miller 1990, Miller 1995), can be implemented. A semantic representation of objects is based on the navigator's previous life experience. This representation is not directly connected to its environment (the web), in contrast to the cogntitive map which is constructed during a real world navigation process. Potential problems in the web navigation can be caused by differences in the web designer's and the web traveler's ontology of the world.

Self-motion and allocentric criteria in spatial vision

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Keywords: active vision, spatial vision, structure from motion.

In studies of spatial vision, the role of observer movement has usually been overlooked. In the study of the perception of 3D structure from motion, for example, the so-called rigidity assumption plays a central role. The rigidity assumption has been motivated by the fact that much of optic flow is generated by an observer moving with respect to a stationary objects in an environment; if self-motion is overlooked and the situation is considered from a retinal point of view, this is equivalent to a non-moving observer seeing rigidly moving objects.

We demonstrate that, on the contrary, self-motion can play a crucial role in spatial vision: active (moving) and passive (non-moving) observers that experience the same optic flow (i.e., the same retinal stimulation) perceive different 3D structure. We use a depth cue conflict paradigm, in which motion parallax is pitted against conflicting perspective cues to 3D structure. In a first experiment, we found that active observers make much more use of motion cues than do passive observers. Thus, extra-retinal information relating to observer self-motion (pre-motor or motor signals, or vestibular or proprioceptive information) is integrated in the recovery of 3D structure. In a second experiment we showed that the active/passive difference disappears if the 3D object perceived is not stationary in an allocentric, earth-fixed reference frame. Thus, the visual system uses self-motion information in a specific way, in order to code the spatial configuration of objects in an allocentric, rather than egocentric, frame of reference. Consequently, it is false to suppose that an observer moving with respect to a stationary object sees the same thing as a non-moving observer with equal-and-opposite motion of a rigid object. The rigidity assumption therefore must be modified to take self-motion into account.

PABST

Spatial cognition and modeling

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A neural network approach to synaptic development of labyrinth

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Keywords: space perception, labyrinth, synaptic development, neural network.

Space perception is a complex task which living beings achieve by the cooperative action of many perceptual and control systems: The integration of information coming from visual, oculomotory, auditory, balance, muscular systems allows a complete control of movements in space. The information coming from different perceptive systems is coded according to their specificity. In three previous papers, I have developed a Perturbative Neural Network (PNN) able to code information in terms of principal component analysis of the correlation matrix of input vectors. In this way some synaptic weights of the visual system have been correctly reproduced, namely retinal ganglion cells for chromatic coding, cortical cells performing space frequency analysis of visual patterns and disparity cells in striate visual cortex allowing binocular stereovision, the most precise visual way for space perception.

The aim of this paper is to describe by the same PNN the labyrinthine system for balance, physically equivalent to a number of accelerometric devices, sensitive to translational and rotational stimuli as well: More precisely, the neural network describes the development of synaptic weights connecting the labyrinth to cortical units under the influence of accelerations. Such a system, coupled to visual and oculomotory systems, provides the necessary information for self control and perception in space.

In the simplified model I want to present the PNN consists of two (right and left) subsystems, each composed of three rotational (semicircular canals) and two translational (sacculum and utriculum) accelerometers: therefore, stimuli produced by different accelerations may excite up to ten neuronal units in the first layer of PNN. Since six parameters are sufficient to characterize translational and rotational accelerations, the ten components of the stimulus are not independent, because the two subsystems are rigidly connected: Therefore, only six of ten coding units in the second layer of PNN are related to nonzero eigenvalues of the correlation matrix; the remaining four units provide information about anomalous or pathological behaviours of the labyrinthine system, such as spontaneous or induced excitation of neurons or loss of rigidity in the crane.

Synaptic weights have been obtained by numerical simulations with different configurations of the system, characterized by the relative orientation of the ten accelerometric units. Different distributions of accelerations have also been selected for the learning phase (purely translational, purely rotational, mixed, isotropic, anisotropic). Results are compared to the available neurophysiological information.

Balancing equilibrium deficit using spatial models: Strategies and applications

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Keywords: equilibrium, balance, context, cognitive model, intelligent interactive tool.

Movement in human beings may take place: Having equilibrium; Having lack of equilibrium, f. i. because of illness, such as to require, use of proteases as extension of the body; ability to USE context as a source of equilibrium.

In the last case subjects must create *projects of movement* by considering: reliability of supports; emergency actions in case of failure; designs of paths of supports. That's in case of availability of light and of no blind subjects.

Considering subjects that are able to see, in case of lack of light they must: Remember and process the scenario, modeling it, hypothesizing how to use it; use tactile redundancy.

In case of blind subject additional balancing information must be considered, such as acoustic ones. A system, human or artificial, may have two different goals: To move to know the context; to use the context to be able to move, creating hypotheses and learning about it, if context is not known in advance. The two goals are usually combined by the system.

In the last framework it's interesting to know the *amount of information processing* required to balance the lack of equilibrium, modeling the context and adopting a *dynamic use of models.*

Illness typically creating this situation in human subjects is Multiple Sclerosis (MS). Subjects having more processing power and many cognitive models available, have more ability to walk.

Applications in medical care are related to teaching MS patients how to compensate lack of equilibrium and to take advantage from rehabilitation. To compensate by using Cognitive Models must not replace physiotherapy, to avoid focus only on mental processes.

To support both the usability of the context and rehabilitation processes intelligent interactive tools (proteases, shoes, crutches, wheelchairs, etc.) able to adapt, to learn, to correct and to track (registering detected information, available on demand both on line and off line) patients behavior, may be designed. Thanks to recorded information, cognitive models of the perceived space may be assumed.

Examples of Artificial Intelligence applications and simulations for robotics are explorations of unknown contexts and mines removing.

Integrating landmark and metric information in a cognitive graph

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Keywords: topological navigation, survey navigation, multidimensional scaling, cognitive graph, autonomous agent.

The kind of spatial knowledge an agent has about its environment mainly determines the repertoire of spatial behavior the agent is capable of. Topological knowledge could be modeled within graphs, where the nodes are identified with landmarks and the edges describe how to get from a node to a linked neighbor. Although graphs are efficient in terms of memory usage and computational effort they limit the agents navigation capabilities in several ways. The set of possible movement decisions is for example limited by the topological structure. One possibility to overcome these limitations is to combine topological graph structures with metric information which could be achieved by path-integration. We present a method based on "multidimensional scaling" (MDS) which calculates from locally perceived distances and angles the position of the nodes in a global coordinate system. MDS generalizes path integration along chains of landmarks to landmark networks. The algorithm will be examined with respect to the following points:

1) Its numerical robustness and the ability for on-line learning during exploration.
2) The influence of topological features such "bridges", "circuits" and the graph regularity on noise reduction. This effect is mainly based on recalibrating the path-integration system by recognissing nodes.
3) The ability to extrapolate metrical relations on untravelled paths.

All calculations are done within a simulation approach where a virtual agent has to reconstruct the metrical relations within given sample graphs. The simulation is part of a larger navigation system, which will be used later on to control real robots.

Testing hypothesis of animal spatial behaviours using adaptive mobile robots

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Keywords: adaptive robotics, animal behavior, embedded model, neural networks.

Modelling animal behaviour using adaptive mobile robots is a well stabilised methodology that permits to test, in an extremely controlled setting, hypothesis, constrains and assumptions about how organisms orient themselves. We apply this methodology to simulate experiments with rats in open field box. Animal psychologists have used open field box settings in order to empirically show the formal structure of cognitive maps used by rats in navigation tasks. In these experiments, rats that have been shown the location of hidden food in a rectangular box are able to navigate towards and dig at that location (or at the rotational equivalent location) in a second identical box. These results lead researchers to state that (a) rats use a cognitive map of the environmental shape, and (b) the cognitive maps can be described in terms of Euclidean geometry. We studied an adaptive mobile robot in a similar experimental setting. The robot was controlled by a simple perceptron (two layered neural networks) with no capability of constructing internal maps. The robot, despite its sensory-motor limitations, learnt the same behavioural indexes as rats in the open field box experiments. The results show that the open field box experiments are not sufficient to conclude that the rats construct cognitive maps. Other task solutions based on no explicit knowledge of the environment are theoretically possible. The results show that the geometrical properties of the environment can be assimilated in the sensory-motor schema of the robot behaviour without any explicit representation. More in general, trying to simulate animal spatial behaviour on real robots could be extremely useful for both cognitive and computer scientists. The first one are constrained to embedded their hypotheses in hardware machines, the others could be inspired by real organisms to build more adaptive and flexible robots.

Spatial knowledge acquisition in virtual environments

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Keywords: spatial knowledge, large-scale virtual enviroment, active/passive exploration, survey representation.

Past studies have demonstrated that configurational knowledge of an environment can be acquired from computer-simulated navigational experiences (O'Neill, 1992; Regian, Shebilske, & Monk, 1992), with the quality of this knowledge varying in relation to a variety of factors, including goal specificity (Sweller & Levine, 1982; Counclelis, Golledge, Gale, & Tobler, 1987; Ferguson & Hegarty, 1994) and type of exploration. Some studies have shown the superiority of active exploration (Christou & Bulthoff, 1998; Peruch et al., 1995; Tong et al., 1995), but discrepant results have also been found (Satalich, 1995; Arthur, 1996; Wilson et al., 1997). At present, whether spatial knowledge gained through active exploration is qualitatively different from the one gained from passive one remains unclear.

In our hypothesis an active exploration enhances a survey type organization of knowledge as individuals plan their paths in order to infer spatial relations between landmarks.

A large-scale, close and empty environment was designed, sufficiently complex to allow to experience and integrate multiple paths.

Two experimental conditions were created:

i.) passive exploration: participants had to follow an *avatar* in order to reach specific areas of the VE that they were invited to freely explore.
ii.) active exploration: participants were invited to freely explore the entire VE.

Participants were assigned the spatial goal to find target flags, positioned all over the environment. The global time allowed for the exploration was the same for both groups.

The subjects were evaluated on two tasks: 4 sessions of pointing, one session of shortcut finding (survey criteria).

No differences were found among the experimental groups in the pointing tasks ($F = 0.23$, $p = 0.69$), a significant difference was found in the shortcut individuation: active subjects were more accurate (chi-square $= 5.05$, $p = 0.029$). These results will be discussed in the light of some basic methodological problems and suggestions for further investigation will be presented.

Using virtual reality in cognitive research

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Keywords: spatial representation, virtual environments, experimental setting, virtual reality design.

Virtual reality is a very promising technology that can be used in many different experimental researches. Researches on cognitive representation of space could exploit at best facilities provided by virtual reality and, on the other hand, can better evaluate pros and cons, limits and capabilities of the new medium.

In natural context, to test hypotheses concerning the cognitive representation of an environment it is necessary to face many practical problems: experiments have to be carried out into buildings never explored before, buildings must be large and complex enough to require a non trivial representation and, during experimental sessions, they have to be uninhabited. Other problems arise during experiments: Movements and actions of the subjects can not be precisely recorded, and data has to be rewritten in a computer format to compute quantitative and statistical analysis.

In spite of it's drawbacks, virtual reality could offer the solution of many of the just exposed problems. Experimenters can create ad hoc buildings — including the desired furnishings and landmarks — the subjects can navigate, explore and perform activities within; the software can directly log movements and record actions with the desired spatial and temporal resolution. Researchers can create types of interaction that in real world can not be realized.

Our research team uses virtual reality to experimentally test the effect of different kinds of exploration (i.e. passive vs. active) on spatial representation. We have created a virtual large-scale close environment, we have designed different kinds of interaction (using a virtual puppet able to guide subjects along different paths); furthermore we have created a script able to register subjects' movements in each experimental session with a very high spatial and temporal resolution; finally, we have developed a simple java applet that reads the log files so generated and renders them on a bidimensional graph that allows us to view in a glance each subject's movement.

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Learning strategies when navigating virtual mazes

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Keywords: human, virtual maze, navigation strategies, route knowledge.

This study investigated the development of adults' spatial knowledge when they attempted to learn the layouts of virtual mazes through repeated, direct navigational experience. Head-mounted and desk-top (monitor) displays, irregular and regular mazes (paths intersecting at oblique and 90 degree angles, respectively), and the effects of a defined perimeter were compared. Participants searched for the same target objects several times and, in some sessions, made estimates of direction and distance for unseen targets. Performance was assessed through participants' navigation (distance travelled and time taken) and direction and distance estimate errors.

In Experiment 1, participants navigated irregular mazes using head-mounted and desk-top displays. With both types of display, participants' spatial knowledge improved during the navigation sessions but, contrary to the findings of an earlier study that used a regular building layout, there were no significant differences between the two displays. Analysis of the paths that participants followed revealed two distinct navigation strategies: participants either first tried to find the targets near the centre of the maze ("centre-first" strategy) or first followed the border walls before looking for targets near the centre ("border-first" strategy). Participants using mainly a border-first strategy performed better.

In Experiment 2, participants navigated irregular and regular mazes using a desk-top display. In both types of maze the perimeter walls were distinguishable by their colour. This increased the frequency with which participants used a border-first strategy and, compared with Experiment 1, significantly improved navigational performance.

In conclusion, with both types of display and environmental structure, a border-first strategy produced more rapid spatial learning. The reasons, however, remain open to question. Border-first may be more compatible with the development of route (topological) spatial knowledge, considered particularly important in irregular environments. Alternatively, the border strategy may have been beneficial because it helped participants establish a framework around which to base their spatial learning.

Imagine getting lost when you walk round a cluttered room

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Keywords: navigation, virtual environment, small-scale space, field of view, disorientation.

The navigation of virtual environments (VEs) relies on and is associated with cognitive processes that are similar to those that people employ in real-world settings. For example, in both types of environment people form similar spatial representations, ultimately learn to wayfind efficiently (e.g., travel by the shortest route) and develop accurate survey (map-type) knowledge. However, it is also well-known that people's rate of spatial learning is much slower in VEs than in the real world.

This reduction in the rate of learning could be caused by any one (or combination) of the many differences that exist between real and virtual navigation. Examples include changes in people's field of view (FOV), the method used for locomotion, the amount of visual detail that is present and the lighting conditions in the environment.

The present study set out to investigate the effect that different interfaces had on people's ability to navigate in small VEs (10m x 10m) that contained obstacles, for example, a cluttered room. The experimental task was to search a VE for targets that were in known, possible locations. The locations could be seen from anywhere (the VEs were small-scale spaces that participants could see the whole of if they stood in one place and turned around) but the targets themselves were only visible from 0.75 m.

Three experiments were run, investigating a head-mounted display (HMD) and a desk-top (monitor) display, different methods of locomotion, and normal and wide FOVs (48 and 103 degrees, respectively). Unexpectedly, and in all the experimental conditions, participants often had great difficulty finding the targets. Participants were easily disoriented and, in effect, became "lost".

The trivial real-world task used in the study highlights a basic problem with current VE systems. In itself, a large increase in participants FOV was not sufficient to prevent the problem from occurring, and neither was the use of physical movements for changes of direction (the HMD). Understanding and finding a solution to the problem of disorientation in small VEs presents a useful opportunity to investigate human spatial learning, and may lead to methods of improving spatial learning in large-scale VEs.

From cinematography to spatial cognition in virtual environments: Cognitive binding during camera cut

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Keywords: cinematography, camera cut, perspective change, cognitive binding, spatial cognition.

Navigation in virtual environment (VE) can be performed in two ways: Either under the continuous control of the traveler (e.g., with joystick, 6DOF devices, etc.), or semi-automatically. In the latter case, the user specifies the destination or object of interest, and an automatic camera control system will manage to bring the user towards his/her goal. Accordingly, there have been several attempts to apply the principles of filmmaking to the problem of camera control in interactive video game. These implementations are based on a variety of assumptions about VE user cognitive skills. The present work is a first step toward testing the cognitive validity of the directing rules underlying virtual camera control. Among those rules is the so-called “180-degree rule” or “axis of action”. This rule proposes that an imaginary line of action be drawn between two characters discussing together, or along the direction of a moving character or object. Once the line is determined, a working space of 180 degrees is established on one side of the line. For any scene or sequence, only camera positions within this working space are permitted. The result is that the screen direction of any shots obtained from one side of the line will be consistent with each other. The assumption is that if the line of action is crossed during a camera cut (sudden perspective change) the observer will be lost. Two experiments investigated the cognitive processes (cognitive binding) involved during camera cut in a VE, with respect to the line of action. The role of a priori knowledge on the spatial organization of the environment where the camera cuts are performed is also examined.

The encoding of geometry in primates. A comparison with children

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Keywords: spatial cognition, geometry, monkey, children.

Geometric features of surfaces and local information are constituent elements of spatial representations. A number of studies in animals (rats) and human children (24 month-old) have evidenced that in a rectangular environment with a reward hidden in one of the corners, geometric properties predominate over local cues. In contrast, human adults are able to take into account both types of information (geometric and local) to reorient.

On the basis of these data, Hermer & Spelke (1996) made the hypothesis that language would be necessary for taking jointly into account and using both types of spatial information.

We will present data on monkeys tested in the locomotor space, that do not confirm Hermer & Spelke's hypothesis. In contrast, date recorded with children (from 3 to 5 years) using a table-top model of a rectangular room show that taking jointly into account geometry and local cues emerges at only 5 years, when language is fully developed.

Other data from monkey and children studies point to the importance of the salience of the stimuli that are used to disambiguate spatial symetrical geometric situations, and question the well-established notion of a modular organization of the encoding of geometry.

Primate geometry

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Keywords: primate, chimpanzee, maze, spatial cognition, geometry.

To navigate a forest, open field, or maze with high efficiency, primates must solve a common task: They must judge the shortest available path from their starting point to a goal location. Primates' judgments of shortest path were studied in simulated, digital spatial tasks, including two-dimensional maze tasks and open field tasks. Rhesus (N = 2), orangutans (N = 2), bonobos (N = 4), common chimpanzees (N = 5), human children (N = 18) and human adults (N = 6) were presented with 167 novel maze patterns of increasing complexity. Participants manipulated a joystick to move a cursor from start point to end point. The participant could see the entire maze pattern throughout a trial. The nonhuman participants had not previously worked complex maze tasks. For each maze, the participant's path of responding on Trial 1 was compared on a pixel by pixel basis to the optimal routing. Group differences in movement efficiency were large and reliable and were not simply attributable to differences in motor control. Human adults were clearly the best, and human children were predictably less skilled on the task. The nonhuman participants were suprisingly efficient. All chimpanzees were more efficient than the bonobos and orangutans, and all apes outperformed the rhesus. It has long been assumed that judgments of shortest path are more difficult and more intellectual in a maze than in an open field. However, determination of shortest route in even a simulated open field is surprisingly complicated, and rhesus, chimpanzees, and human adults appear to make different assumptions about the importance of straight-line movement. The findings raise the possibility of fundamental differences in how primates conceptualize space and distance. The relevance of these issues to real-life travel and foraging problems will be discussed.

The organization of spatial knowledge in cebus monkeys

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Keywords: spatial representation, reference frames, search tasks, capuchins.

A previous study on capuchins dealt with search tasks in a small-scale space. The capuchins observed a reward being hidden under one of two containers placed on a round platform; the reward was then displaced by rotating the platform out of sight; capuchins were then allowed to retrieve the reward. In one experimental condition the baited container was always the one closer to a landmark (cylinder) placed on the platform. Capuchins learned to solve the task in this condition by associating the successful position of the reward to the landmark. However, they also strongly tended to rely on egocentric coordinates. In another experimental condition the baited container was either the closer to or the farther from the landmark. In this condition capuchins failed. It was argued that they failed because they were not able to code two detached simultaneous spatial relations. However, it was also hypothesized that capuchins may have not been able to solve the task because they relied on external cues other than the landmark on the platform, such as distant landmarks in the room. Therefore, capuchins would have been successful had the transformations been the consequence of their movements rather than of the platform. A new experiment was then designed where capuchins deal with perceptual transformations of the reward's positions analogous to those of the second condition of the previous study; however, now these transformations depend on capuchins' movements. If capuchins used external landmarks to solve the search task, either at the small-scale level or at the large-scale level, then they would be successful. In this new experimental condition capuchins can also take advantage of the dead-reckoning mechanism. First coming results will be illustrated.

POSTERS and DEMO

Route spatial representation of decisional problems: Application of TOGA framework to the modeling of cognitive agent

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Keywords: spatial cognition, decision advisor, agent.

The use of a software agent metaphor to the realization of route based navigation/reasoning in a spatial world-of-objects representing physical and abstract decisional domains, has been investigated. Our main objective has been to demonstrate and test how an IPK cognitive agent (Pestilli, Gadomski, Olivetti Belardinelli, 1999), based on the TOGA (Top-down Object-based Goal-oriented Approach) theory (Gadomski, 1993), is able to suggest decisions in such reconceptualized problems.

The growing interest in spatial cognition research focused on the distinction between route and survey spatial representations, promotes a hypothesis of an unified representation of extremely different decisional domains within an unified cognition theory (Olivetti Belardinelli, 1998; Meyer, Kieras, 1999). On the other hand, generic object-oriented/based and agent-oriented conceptualizations are nowadays strongly investigated by numerous scientific disciplines from system engineering to modern philosophy. Therefore, our work deals with a symbolic representation of cognitive agent's intervention domains in the form of worlds-of-objects. The TOGA knowledge-ordering theory has been employed to the representation of spatial environment for route description. Problem-independent IPK (Information, Preference, Knowledge) agent architecture enables planning, learning and goal-modification. It has been applied to the development of the IPK cognitive agent prototype, called FRANK (Pestilli, 2000). The rational or emotional reasoning of FRANK on information, preferences and knowledge are performed using domain independent graph-based representation what has enabled the implementation of the same spatial reasoning model.

A few simple test cases illustrate functioning of the FRANK prototype of IPK agent.

The quest for sound spatialization in contemporary music: Planephones, sound projectors and holophones

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Keywords: auditory space, displacement of sound sources, sound spatialization.

One of the most prominent needs in the performance of Contemporary music is the achievement of some degree of control on the deployment and displacement of sound sources during public concerts. In today's musical composition views, auditory space is seen as a counterpoint factor, used either to segregate or melt voices, or to enhance dramatic action. This goal can hardly be achieved by actually moving the sound sources, either for practical reasons or because many sound sources are today of an electronic nature. Several sounds are synthesized, or reproduced from a recording medium, or else they are electronically processed as they are produced by acoustical instruments actually played on stage.

To make matters worse, traditional music halls are far from being adequate for such purposes. Moreover, most contemporary music concerts take place in sites or premises absolutely not conceived for public performances.

For these reasons, sound spatialization is one of the main issues in contemporary musical research. To this purpose, several tricks taken from the scarce and yet empirical knowledge of the operation of human auditory system have been used. They include filtering with Head Related Transfer Functions, precedence effect, and so on. The resulting constant struggle against the usually destructive interference of the acoustic environment — be it a concert hall or an open air site — has convinced several composers that the use of loudspeakers as the main way of auralizing contemporary music is nowadays to be considered as doubtful.

The experimental work here presented is therefore an attempt at gaining control of auralization by the return to purely physical means. Holophones (of which Sound Projectors are a component) are here seen as a mean to control the wavefront, in this way reproducing the physical conditions in which our spatial auditory systems works, instead of giving it the illusion of space — as virtual reality techniques do. The key-idea is to deal with approximately plane fronts. To do this, an ancient device has been re-discovered: The focusing acoustic mirror, used so far only for demonstrations in Science & Technology museums.

Construction of these devices ended a few months ago. In the meantime, the experimental use of these devices in several public concerts — always in acoustically harsh environments — has supplied proof of the fact that the idea can work.

Spatial representations in a navigational task: Are there any gender differences?

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Keywords: spatial representations, gender differences, navigation.

A very controversial topic in the field of spatial cognition concerns gender differences. Different studies have found an advantage of males compared to females in spatial representation tasks. These results are still object of discussion; in fact, some authors show results in which these differences seem to disappear after a training period, while others do not seem to confirm any differences of gender in spatial ability. The aim of this study is to investigate whether there are any gender differences when subjects are involved in a navigational task which requires to use environmental spatial representation.

Sixty subjects, thirty males (mean age 40) and thirty females (mean age 38), took part in this study.

Two plywood pathways of different length and complexity were built. The pathway named "A" was 10.55 metres long and was created by using four straight lines and three right angles. The pathway named "B" was 14.47 metres long and it has six straight lines and five right angles. So, the pathway "A" was considered easier than the "B" one. Both pathways were 0.30 metres high.

Each subject was blindfolded and tested individually. Prior to the trial, each subject had to go along a 15-metre-long pathway with three angles in order to practice with the task. The experimental setting required two phases: In the first one the subject has to deal with the simplest pathway (A), then in a second phase s/he has to deal with the more complex pathway (B). The subject's task was to walk along the two pathways and answer to different questions asked by the experimenter. The questions concerned directions between some specific points, and required the subject to use spatial representations to be able to answer.

Statistical analysis on subjects errors pointed out that, in the most complex pathway, males' performance was better than females' one (ANOVA for repeated measures; $F = 9{,}444$ $p < .01$). No gender difference was found in the simplest pathway (A).

Gender differences seem to emerge in spatial representation but only in sufficiently complex tasks. This observation could explain why some research did not found any gender difference in simple spatial tasks. Moreover, our results seem not to confirm the hypothesis that gender differences disappear after a training period since all our subjects made all the training pathway before the "A" route and they all performed the "B" route as last trial.

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Representational neglect impairs generating mental spatial representations from verbal descriptions

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Keywords: representational, neglect, memory, visual imagery.

Background. Previous studies have demonstrated that patients with representational neglect find difficulty in reporting details from one half of the imagined scene when accessing long-term stored visual and spatial knowledge from a particular viewpoint. One possible interpretation is that such patients show impairments in their visuo-spatial working memory system. However we are aware of no studies in which representational neglect patients have been asked to generate mental visuo-spatial representations from non-visual input such as aurally presented verbal descriptions of scenes or object layouts.

Methods. We will report an experiment contrasting perceptual reports with immediate recall of object layouts with 11 patients who showed clinical and psychometric evidence of neglect, nine of whom had representational neglect, 15 healthy controls, and 6 right hemisphere-lesioned control patients with no evidence of neglect. On each trial four objects were presented as pictures. The experimental procedure comprised four conditions: Visual Perception, Memory following Visual Perception, Memory following Verbal Description, Verbal Memory only.

Results. Neglect patients reported fewer items on the left in conditions one, two and three. None of the error patterns of both healthy and patient controls were lateralised. The three groups did not differ in condition four.

Conclusions. (i) Representational neglect also appears for recently visually perceived information. (ii) It is quite distinct and does not depend on the presence of perceptual neglect. (iii) Representations of neglect patients can be impaired when built from auditory verbal descriptions, that is, without any recent or more remote inputs from visual perception. Patients with representational neglect do not appear to compensate for their deficit by using verbal codes, despite showing no verbal memory deficits.

Our data support the view that mental representation and perception are quite independent, although similar patterns may be found in the ways they operate.

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Poster

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Individual differences in spatial mental representation formats: Cognitive correlates

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Keywords: individual differences, spatial mental representations, cognitive correlates.

An idea that has become commonplace is that individuals may differ qualitatively in spatial mental representation formats. The first aim of this work is to briefly report results on clustering individuals on the basis of a self-assessed inventory on spatial mental representation (principally eterocentric or egocentric format). The inventory detected the presence of subjects that *prefer* one representation on the other in every orientation task, moreover it identified subjects who adjust their representations according to the format of the task to face or according to the format of previous knowledge. The main goal of this study is to demonstrate that differences in spatial mental representation are, in some extent, dependent on *lower level* spatial factors accounted by different spatial tasks. Different groups are considered into two discriminant analyses. Results of the first analysis demonstrated that *preference* for eterocentric spatial mental representation format, is predicted by better performance in different spatial tasks (especially spatial scanning and map reconstruction). The second analysis, which is more explorative than the former one, detected differences between the two modality of representational *congruence*: According to the format of the task or according to the format of previous knowledge. That is, subjects *congruent* to the task seems to be more effective in spatial tasks characterized by simple and immediate processing than subjects *congruent* to the knowledge. Simple spatial factors seem to be able to predict differences in spatial mental representation formats.

Visual and spatial simultaneous memory: Two different components?

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Keywords: visuo-spatial memory, spatial simultaneous memory, working memory.

Visuo-spatial working memory has become an interesting research issue, in particular the distinction between visual and spatial memory, made within the visuospatial sketchpad. In this research we have assumed that a simultaneous component can be distinguished from a sequential one within a specific spatial system. The simultaneous component involves the processing of spatial relationships presented simultaneously. For this reason some authors have argued that it is part of the visual rather than spatial system. Our research examines whether it is possible to consider the visual and spatial simultaneous memory as two different, although complementary, cognitive systems. To study these processes we used the selective interference paradigm, in which we suppose that a visual primary task would be disrupted more by a visual than a spatial simultaneous secondary task and that a spatial simultaneous primary task would be disrupted more by a spatial simultaneous task than a visual one. The visual primary task asked the subject to look closely at an abstract picture and then recognize it among other similar pictures after a very short time. The visual secondary task required deciding if some closed lines, that looked like clouds, were different from each other. The spatial primary task consisted in looking at some dots on a piece of paper and trying to recognize the same pattern of dots among three similar configurations. Finally, the spatial secondary task required the subject to decide if some patterns of dots were different or not. The secondary tasks were run for about 15 seconds on a PC, after presentation of the target picture or pattern of dots and before the recognition. The outcomes show selective interference that depends on the type of task.

Galvanic vestibular stimulation on seated and head fixed subjects modifies the accuracy of manual pointing toward memorised visual targets

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Keywords: galvanic vestibular stimulation, manual pointing, egocentric reference frame, target localization, human.

The ability to reach or grasp objects in our immediate environment involves appropriate coding of the position of those objects with respect to our body. This "egocentric" encoding is dependent on the position and orientation of the body in space. Many studies have highlighted the contribution of vestibular signal in detecting changes in the body-in-space position (e.g. Blouin et al:., 1995; Israël & Berthoz, 1992; Mergner et al., 1991). In the present study, we verified whether the arm motor system interprets a change in the vestibular signal as a change in body-in-space position during pointing at a memorised visual target while the body is maintained stationary. Subjects (N = 5) were instructed to point manually toward memorised visual targets in otherwise complete darkness. The subjects were seated head fixed. Two targets were located 18° on either side of body midline and one target was located straight ahead. In half of the trials, a 3 sec, bipolar binaural galvanic stimulation of variable polarity was triggered by the movement onset. Prior to the movement, subjects received visual feedback of their hand positioned near their belly. The subjects were not informed prior to the movement about the forthcoming target and vestibular stimulation conditions. Results revealed that movement accuracy was significantly affected by the galvanic vestibular stimulation. As compared to the movements that unfolded without stimulation, movements with the anode on the right mastoid were deviated to the right (mean = 0.84°) and movements with the anode on the left mastoid were deviated to the left (mean = -1.29°). In unrestrained subjects, galvanic vestibular stimulation gives rise to a tilt of the head and/or body to the side of the anode (Day et al., 1997). Since the head is kept fixed, it may be inferred that subject's internal representation of the head posture is shifted toward the opposite side. Constant errors in pointing are attributable to a change in the egocentric reference due to vestibularly induced misrepresentation of the head posture.

Movement span in ballet dancers: The effects of a secondary motor task and dynamic visual noise

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Keywords: memory span for movements, motor memory system, visuo-spatial working memory.

The aim of the present study was to investigate memory span for movements in ballet dancers. In order to minimize the contribution of visual mental imagery, and unlike Smyth and Pendleton (1989, *Quart. Journ. of Exp. Psych., 41A*, 235) who presented the movements to be remembered visually, in the present study the list of movements was presented orally. Subjects were asked to perform an articulatory suppression task in order to prevent any kind of verbal coding while the experimenter was reading aloud the list of ballet moves. In a pre-experimental test the effects of articulatory suppression were evaluated in order to make sure this task didn't interfere with the memory span for movements. In the main experiment the effects on movement span of two different interfering tasks were tested.

Twenty eight ballet dancers studying at the *Accademia Nazionale di Danza*, subdivided into 2 groups, participated in this study. While the experimenter was reading the list of movements the first group (n = 14) was asked to perform, in addition to the verbal suppression task, an "arm movement task" in which the head, shoulders and hips are touched in succession (Smyth & Pendleton, 1994, *Intern. Journ. of Sport Psych., 25*, 282). The second group of subjects (n = 14), while performing the articulatory suppression task, was also watching a dynamic visual noise on a monitor, according to a technique devised by Quinn and McConnell (1996, *Quart. Jour. of Exp. Psych., 49A*, 200). Immediately after having listened to the list of movements, subjects of all groups had to perform a serial recall memory test by performing the ballet moves.

Results showed that the motor interference task ("arm movement task") significantly decreased memory span while dynamic visual noise had no effect.

In conclusion, results suggest that when the movements to be encoded are not presented visually, encoding seems to be performed by a specific motor memory system rather than by a visual or visuo-spatial working memory.

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Attenuating banner blindness through the manipulation of banner characteristics

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Keywords: banner blindness, human computer interaction, attention, banner format.

Recently, Panero Benway and Lane (1998) observed that web searchers often miss the banner contents in that observers learn to ignore all information that is perceptually separated from everything else in the web page. This phenomenon is known as "Banner Blindness". In the present work we explored whether and, if so, under which conditions specific characteristics of the banner can attenuate the effect. We manipulated the shape of the banner (squared or rectangular), the presence of target information (presence or absence) and the type of perceptual attractor (flashing or static). The experimental task was to find a specific information in a web page. The information could be present in the text or in the banner. In general, the banner was ignored by participants. However, when the information was not present in the text, participants attended the banner only if it was flashing. On the other hand, if the information was included in the text, participants detected more frequently the presence of a banner with a squared format. These results stand at odd with those reported by Panero Benway and Lane (1998). They demonstrate that blindness for banners can be easily attenuated through simple manipulations.

Functional neuroimaging of place learning in a computer-generated space

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Keywords: spatial cognition, fMRI, hippocampal formation, hippocampus, computer-generated arena.

We used functional magnetic resonance imaging (fMRI) to examine patterns of brain activation during place learning in humans, guided by the prediction that hippocampus is involved in learning to locate a place in space. Place learning was tested in the Computer-Generated Arena (C-G Arena), which has been successfully used to study spatial navigation and place learning and memory in humans. Thomas, Hsu, Laurance, Nadel, and Jacobs (1999) reported that participants learned the spatial layout of the C-G Arena, and locations within it, simply by watching others search for and find appropriate targets in the computer-generated space.

Consistent activity was found in parahippocampal gyrus, posterior parietal cortex, premotor cortex, and motor cortex during the visible- and invisible-target conditions, but there was highly variable activity during the visible-target condition and stable activity during the invisible-target condition. Incidental spatial learning may account for the variable activity during the visible-target condition.

The hippocampal formation, along with motor areas and the posterior parietal cortex, appears to constitute a *fronto-parietal-hippocampal* network, indicating that perception, memory, motivation, and action in the spatial domain are closely related at the neural level.

Investigating distance knowledge using virtual environments

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Keywords: Distance cognition, feature-accumulation-hypotheses, virtual environments.

More recent research on spatial cognition has used computer-simulated three dimensional environments to create appropriate laboratory settings to examine processes of spatial orientation. One way to evaluate "virtual environments" is to successfully replicate results of experiments which were formerly conducted in real word settings.

The Experiments, which are reported in the following, investigate the role of features in the cognition of distances in space. The design follows an earlier experiment by Sadalla & Magel (1980). Their participants explored the paths marked with tape on the floor through active walking. The hypothesis to be tested was that the number of turns determines the estimated length of the route. A route with a higher number of (7) turns was estimated longer than a route of the same length with less (2) turns, confirming the feature-accumulation-hypotheses mentioned above.

In our experiments participants had to explore the routes in a desktop virtual environment navigating through it by means of a joystick. In a first experiment, the estimation of the route length was investigated using a ratio-estimation and a reconstruction method. In a second experiment, a reproduction-technique was used: Participants walked along a straight route until they thought that they had walked the length of the previously explored route.

The investigated distance estimations confirmed the feature-accumulation-hypothesis: A route with 7 turns was estimated longer than a route with 2 turns. The results of the second experiment extend the results of Sadalla and Magel: The route with 7 turns was overestimated, the other route was underestimated in relation to the objective length, allowing a precise statement about the ratio between objective and subjective distances.

Overall, our results reveal that desktop virtual environments are a reliable and economic tool for the investigation of knowledge about distances in space.

Spatial memory across realities

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Keywords: computer generated space, performance of humans, real space.

In recent years scientists studying spatial cognition have turned to computer generated (C-G) space to study phenomena in spatial memory and navigation. The advantages of C-G space include ease of administration and the small amount of actual lab space required. This study was designed to test the performance of humans in both a C-G and a real space version of the same task. The task requires the person to choose the correct one of four possible targets. The correct target was green in the familiarization phase, the other three were blue. In the test phase all four targets were blue. The person had to pick the target that was green in the familiarization phase. A disorientation procedure was used between the familiarization and test phases. In the C-G task the person was teleported from the room and returned to it facing a pseudo-random direction. In the real space task the person turned in place with their eyes closed between the familiarization and test phases. The results showed that adults treat the C-G space in the same way they treat a real space. However, in the real space some people found small imperfections and used them to increase accuracy. When those who reported finding imperfections in the real space were removed from the analyses, performance in the computer and the real space were very similar. Preliminary analyses show no differences between the computer task and the real task in the number of correct responses ($t(18)=.321$, $p=.75$), the number of error responses ($t(18)=-.113$, $p=.91$). Nearly one third of the subjects in the real space were discarded from these analyses because they reported using some small cue. The analogy created within the computer does function like a perfect version of imperfect real space.

The influence of two partial incongruent color naming training sessions of the stroop effect: Is the reading conflict really the explanation for the interference effect?

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Keywords: Stroop effect, implicit learning, working memory, color naming.

Since 1935, the Stroop effect has been considered as the reflection of the interference of the automatic reading process on the controlled process of naming (Cohen, Dunbar & McClelland, 1990; Morton & Chambers, 1973; MacLeod, 1991, for a review).

Withouth calling into question the incidental reading of the incongruent word on the color naming task, we rather consider that the increasing of the naming RTs from neutral or congruent items to incongruent items would be due to an implicit will of learning of the incongruent association links color/word.

Implicit learning would be not only incidental and unconscious process but also a stimulus driven processing limited by the working memory capacities (WMc) (Cleeremans, Destrebecqz & Boyer, 1998; Perruchet & Vinter, 1998; Serger, 1994, for a review). As the number of incongruent items was 12 in the incongruent naming condition (overlapping the WMc), the implicit learning could not be evidenced in classical protocol.

So, by limiting the number of incongruent items to name (in partial color naming training sessions), we suggest that interference effect would disappear.

After two partial color naming training sessions, the interference effect disappeared. These data permit us to consider implicit learning as an new issue of Stroop effect explanation

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Perception and cognition of urban spaces

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Keywords: environmental perception; urban spaces; environmental cognition.

In classical psychological literature perception and cognition are two different concepts. As far as Environmental psychology is concerned, Ittelson (1973) maintains that it is not possible to clearly distinguish between perceptive and cognitive processes, according to the following arguments: "Environmental perception" is defined as a "molar" or "total" experience given by a set of information coming from all the senses; environment is to be explored rather than seen according to temporal sequences; information, both central and peripheral, is always more than it is possible to process, thus the subject is forced to select information and formulate validity judgements on what he/she is acting out; to perceive an environment means not only to consider its physical and spatial characteristics, but also its social use and its affective/emotional qualities; environmental perception is directed to action, in the sense that an environment is perceived and known so that it may be used according to the subject's goals and/or characteristics in that particular moment: As goals change, so does perception.

On the grounds of these assumptions a great deal of research has been developed on the subject of the cognition and representation of urban spaces, and its results give fresh proof of the ample articulation between physical, spatial and social variables in environment perception (Bonaiuto, Bonnes, 1999; Nenci, 1997).

Physical features influencing performance in a cube comparisons task

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Keywords: visuo-spatial abilities, visuo-spatial representation, mental rotation, visuo-spatial task analysis, cube comparisons task.

Because of stimuli complexity, the physical features influencing task difficulty are barely detectable in visuo-spatial tests. Nevertheless, research on visuo-spatial task difficulty has been more concerned with subject internal psychological features than physical task features.

The aim of the present work is to establish the physical factors influencing the mental spatial rotation. This analysis may be very useful for detecting different visuo-spatial ability components and, therefore, to constructing more predictive and sensitive tests.

The present experiment is a computer version of the cube comparisons tasks widely used in the literature. Items consist in a pair of cubes rotated each other of 90°, 180° (two 90° rotations on the same axis or on two different axes) and 270° in space. Two types of cube stimulus are used: "surface cubes" (with different uniformly coloured visible faces) and "figure cubes" (with different coloured circles in the centre of visible faces). In both cases, the number of distinctive (not white) response cube faces is controlled (2 or 3).

Subjects (N = 88) are asked to decide if the cube on the right (response cube) is the same as the one on the left side of the screen (demand cube), with the constraint that all the hidden faces of the demand cube are white.

We hypothesize that 1) both task difficulty and latency time increase enlarging degree or complexity of rotations; 2) response time is slower for expected negative response items than for expected positive response items; 3) males perform better than females.

In general, Analysis of Variance confirm the hypotheses. Nevertheless, some anomalous results are explained by Rasch Analysis. In particular, the axis on which the second 90° rotation occurs in 180° items seems to be relevant in determining task difficulty. Some interesting remarks on experimental data are discussed.

The role of geometric and local cues in orienteering in a computer-simulated environment

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Keywords: human, spatial orientation, virtual reality, geometry, local cues.

The components of mental representations that are used for orientation have not been clearly established. Several studies have tried to investigate which environmental cues are used for spatial orientation. In particular it has been shown that even in the presence of local cues, the geometrical properties of an environment predominate in animal and in children, whereas adult humans are able to use both cues if necessary.

This study investigated whether geometric and/or local cues are used by adults to orient (or reorient) themselves in a simple computer-simulated environment. Participants were shown a target object before it was hidden in their presence in one corner of a rectangular environment. After being disoriented the participants were required to find the target.

First, in common with real situations, in the absence of local cues all the participants oriented themselves by using geometric cues; when present, local cues were employed if they allowed participants to resolve ambiguity in a symmetrical environment. Second, if the participants were forced to choose between conflicting geometric and local cues, there was no consistent preference: Both kinds of cues may be used. Third, providing feedback on the position of the target in a forced choice between conflicting geometric and local cues had no effect: Feedback appeared to be useful only if the target location could be easily identified.

Relationship between spatial experiences, narcissistic dimensional, development and posture

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Keywords: space, posture, narcissism, psychophysiology.

This research examines 55 undergraduate psychology students, 30 female and 25 male, in order to study the relation among three psychological processes.

a) The first one refers to individual differences in spatial experiences centered on the relationship between subject and environment. This aspect has been studied trough a list of bipolar adjectives defining emotional psychological-connotative aspects of space. For example adjectives utilized were: Definite/indefinite, wide/thight, stable/changeable ... Results of the chek-list indicated interesting individual differences in emotional and connotative perceiving space. Then we have examinated through a videotape the postural attitude standing in the space. Video recording showed two different forms of attitude: 30 subjects had active gesturing performance with a tendency to occupy the environmental space, while 25 subjects had a more static attitude.

b) The second psycho-physiological examined activity refers to the narcissistic process considered as a dimension present in all subjects, strictly related to the psycho-physiological normal development of the Ego. To measure the narcissistic level we used Patton, Connor and Scott's Dimensional Narcissistic Questionary, adapted to Italy by Scilligo. The questionnaire presents six scales: Assertivity, Creativity, Projectuality, Realization, Individuation and Admiration.

c) The third psychophisiological process refers to different forms of standing measured through an instrument (Baro-podo-meter) that measure the pressure of the feet on a platform.

The study of relationship of three considered phenomena showed interesting interactions between narcissistic individuation and postural experiences of space. In particular subjects that presented an dynamic spatial attitude showed an higher level of "Individuation". In conclusion subjects with a dynamic spatial posture seem have a more differentiated form of individuation.

The aggressive behaviour modulation style and spatial gesturing experience

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Keywords: space, gesture, aggressiveness, emotion, psychophysiology.

Clinical experiences showed that many subjects have difficulty in producing a particular gesture of the upper limb and of the hand: When the subjects are asked to break through an active concrete aggressive gesture, using the hand as cutting an imaginary plane placed in front of them. We hypothesized that the difficulty in producing this gesture is related to the habitual style of modulating aggressive behaviour and emotions, linked to the organization of spatial experience. Spatial experience is examined considering the ability to break ideal planes placed around oneself. The gesture is an aggressive one: The hand breaks the imaginative plane through a rapid aggressive movement of the hand's edge. Research participants were 62, undergraduates psychology students, 31 male and 31 female. The style of modulation of aggressive behaviour has been measured by the Picture Frustration Study (Rosenzweig). The gesture was registered by a videotape. The experimenter consider the concrete phenomenology of gesture in breaking the frontal plane and the subjective feeling related to this experience, explored through a self-report scale. Results indicated interesting statistically significant relationship between gesture modality, ego-defence and obstacle-dominance scales. Subjects that have subjective and objective difficulty in breaking the frontal plane have higher scores in the ego-defence and in the obstacle-dominance scales.

Requirements for accomodative stability in observation of stereoscopic images

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Keywords: stereoscopic, accommodation, vergence, super multi-view, display.

In the observation of old stereoscopic images, the accommodative state of the eye is not corresponded to the vergence. To solve this problem, the super multi-view (SMV) stereoscopic display was developed (Kajiki et al., 1997, SPIE Proceedings #3012, 154-166). The display can generate an image with parallax in 45 directions horizontally, and the parallax interval is within 0.25 degrees. Therefore, even if the head is moved horizontally, a natural solid image can be reproduced in the horizontal viewing range which is of a visual angle 11.25 degrees, and some parallaxes on the pupil can be presented. Since the parallax interval is extremely narrow, ray aberration of the image becomes small in horizontal direction, and stability of accommodation is expected in observation of the display.

Employing the SMV display, we measured vergence and accommodation under old stereoscopic conditions and under SMV conditions. In under old stereoscopic conditions, the images on the left side from center of 45 parallaxes had the same disparity and the images of the right half were all the same but different in disparity from the left. Under SMV conditions, the image of 45 parallaxes simulated the disparity of the solid object. The stimuli were a vertical line and a radial pattern with the upper and lower parts presented at different distances from the observer: 1.75 and 2.13 diopters, respectively. The subjects alternately observed the stimuli of both parts.

In general, change in vergence and accommodation corresponding to distance was caused by all conditions. However, under old stereoscopic conditions, the accommodative distance was unstable in the transition phase when the subject moved the gaze point to the different depth although the distance was relatively stable under SMV conditions. These results suggest that accommodative stability of the eye in viewing stereoscopic images requires SMV parallax images for both eyes.

Spatial order effects on the recall of various kinds of categorial items in pre-school children

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Keywords: conceptual organization, preschool children, orderly spatial arrangement.

Scientific research has shown that there are various ways to link events. Specifically, children have shown they are able to form concepts that use relations that are thematic (dish-soup,) slot-filler (egg-jam,) and taxonomic (dog-cat). In addition, the literature highlights that in doing memory tasks, pre-school subjects are able to use cues and spatial ordering.

In the study we are introducing, we analyse the role of the spatial order of stimuli.

These stimuli, which are thematic, slot-filler, and taxonomic items, are used in a recall task, which is either free or guided.

The experimental design is a factorial 3 (material) x 2 (conditions) x 2 (tasks).

The differential frequencies of the free and guided recall of the various categories used, in conditions with and without spatial support, have been checked.

The results of the study clearly show that the variables "way in which the task is introduced" and "kind of task" influence the mnemonic performance.

Interaction between evolutive levels and experimental contexts are discussed in order to increase the knowledge of the conditions that enable people to approach and use various relations among categories.

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Central executive interference in a spatial working memory task

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Keywords: central executive, spatial working memory, interference.

The aim of the study was to examine the role of central executive processes in a serial spatial working memory task. We used the Corsi-Block task together with different types of interfering secondary tasks, mainly focusing on the executive functions. Furthermore we were interested in subsystem-specific components of different central-executive secondary tasks. Our subjects had to perform interference tasks during the presentation of the spatial sequences of the Corsi Block task. No retention interval was given.

We compared secondary tasks that demanded to maintain a serial order of elements with such tasks where the same elements had to be randomized. In both conditions (serial and random) three modalities were contrasted: Tasks with verbal elements (numbers), with spatial elements (locations) and with motor elements (hand movements).

Results showed that random generation generally effected performance in the Corsi span procedure. However the strength of this effect was not independent on the modality of the secondary task.

Our results can be interpreted as a support for a strong central executive demand during the encoding of serially presented spatial information. Due to the modality effect in our study, we propose a careful selection of central executive secondary tasks, i.e., take into account that all central executive secondary tasks have modality specific components.

Spatial drawings and other sculptures

PAOLO CAMIZ

Paolo Camiz, professor of Nuclear Physics at università di Roma “La Sapienza”, has been involved in sculpture since the seventies. Among many poor materials he favored one is iron (old and rusty iron, found anywhere). In this occasion, works are exhibited which are representative of Camiz's research on dimensional fights in space: One-dimensional iron rods are bent (by hand) in such a way to surround a volume while suggesting surfaces, flat surfaces invade 3-D space by means of 1-D cuts, identical pieces of metal are weld together by almost geometrical or chemical links (Monomanie), suggesting a crystal growth. Works by P.C. are present in a number of private collections in Italy and USA. Exhibitions have taken place in Rome, Cori del Lazio, Sestriere, Spoleto, L'Aquila, Lecce.

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