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The Construction of Spatial Relations Associated to an urban spatial navigator. Case Study: Mexico City

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Abstract. Population's mobility is a spatial phenomenon that impacts society's development and it depends on individual work organization, family, school or simply leisure time preces; it is related to the spatial structure of each person and the way people build their spatial relations. This paper explores the spatial behavior of a group of individuals through their urban mobility, taking into account indicators such as their spatial perception, the ability they show in reading and interpreting maps and their most commonly chosen search mechanisms in terms of moving from one place to another. Through the interviews to document a case so to explore in a holistic manner the most notable factors in the construction of spatial relations. With the qualitative analysis of these processes, we can establish whether these individuals could easily adopt an urban navigator as a tool for decision making within the context of urban mobility in Mexico City.

Keywords: spatial relations, urban mobility, urban navigator, cognitive map.

Introducction

Spatial mobility is related to the structure that every individual makes about the space and the way in which everyone constructs their own spatial relations. This structure is related to the individual spatial learning or spatial cognition, a topic that in literature has been reviewed under different approaches and diverse disciplines.

In this context, and trough the construction of a conceptual frame, a case study was realized to a group of possible users of a spatial urban navigator in Mexico City. This conceptual frame is based on the physical and cultural issues firstly, and, secondly, on the Cognitive aspects, whose analysis allowed a first approach to spatial relations construction. The group of interviewees does not represent a significant sample in statistical terms, though is very representative because it documents a case to explore in a holistic manner the most relevant factors in the spatial relations construction and allows to test the robustness of conceptual frame. The following model, based on Diesing [1] and modified as shown, makes explicit the process.

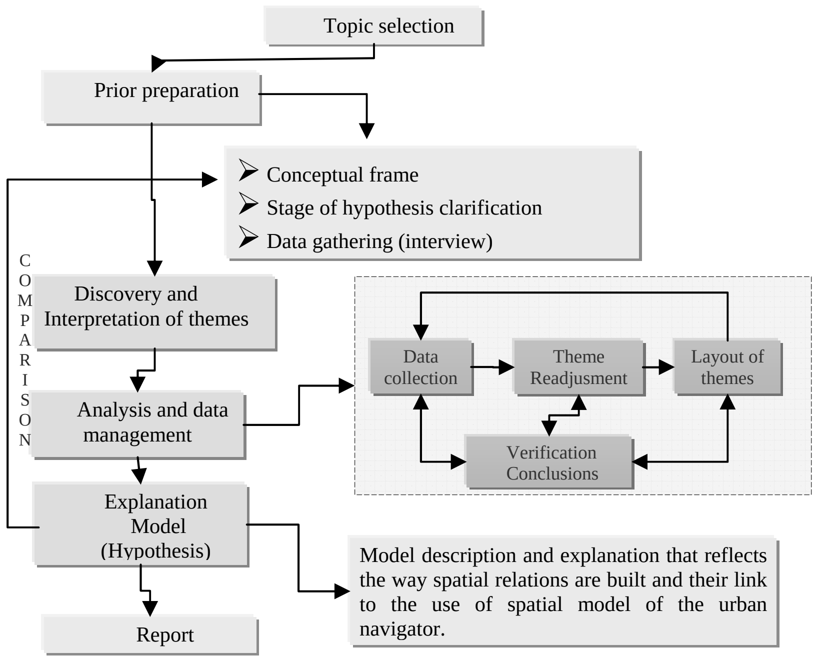

Fig.1. Modified Research Model. From Diesing (1971) & Huberman and Miles (1984).

Analysis:

Interview is the most used method in qualitative research and specially in the participant-observation method. This that was the method that allowed our approximation to the construction of spatial relations based on the spatial mobility of the interviewed subjects. Their answers ware digitally recorded and analysed in a qualitative and holistic manner along with the cognitive maps. This cognitive maps show an abstraction of each individual surrounding environs. The subjects of the interviews were four taxi drivers, four employees, two delivery men and three young students. The analysis is summed up in the following explanation model:

Explanation Model:

The axis of the model is the spatial knowledge, qualitatively evaluated through each subject experiences of their day to day displacements, how they handle space when they are disoriented or when they go to previously unknown places. This is done verbally through their own descriptions on how they reckon their bearings as they move, what is the experience they claim having using maps, and how they build their mental maps. These factors were evaluated qualitatively from their answers and were associated to their corresponding descriptions of each subject environment. The spatial language issue was approached by means of the cognitive map, an expression of the spatial abstraction in paper and by the subject verbal description of a route or trajectory.

The cultural differences were approached through elements such as: place of residence, schooling, frequency of Internet use, leisure time use, personal activities and individual literary preferences; the latter assumes that people who read books that describe space related issues, may establish a better relation with their environment. The leisure time activities, assumes that individuals who travel the most, have a greatest ability to orient themselves and to move through space. The affective links with one's surroundings is associated to cultural differences as much as people were asked to specify what they liked or disliked about their places of residence. In this regard, no association with the time of residence in a place or their personal spatial preferences was detected. The size of the space and the spatial knowledge seem to be strongly related. With this analysis, the final discussion raises some hypothesis.

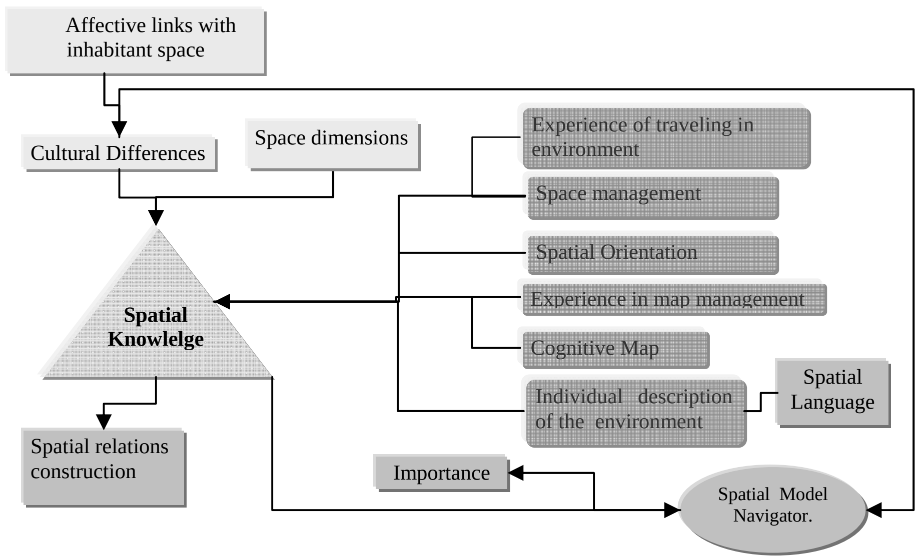

Fig. 2 Explanation Model

Discussion:

a) The spatial knowledge appears to be acquired by means of a process due to individual space mobility needs with a dependency on the motives of the trips from one place to another. This emphasizes that spatial relations construction is undertaken empirically.

b) No explicit relation was found between literary (spatial) preferences and spatial knowledge.
c) The cognitive map only approaches to *procedural knowledge*: representation of a series of actions which show the steps followed for a particular route, basically made by connections between two points. None of the maps represented a *measurement knowledge* which could show the location of the objects and the distances according to a reference system or a conventional map. Neither expression was observed for a *configurational knowledge* which (in accordance with Freundschuh [3]) is a representation of a map, with its geometric uncertainties and its adequate topological relations.
d) The subject dimension of space seems to be related to the hypothesis found in related literature: " to major size for travel long distance, is better the knowledge and moving confidence, for someone who travels bigger distances has therefore more spatial references in the form of objects and probably, a better orientation than those who don’t travel as much”.
e) An urban spatial navigator is compatible with the construction of spatial relations of the individuals. This relation could be more explicit whenever it provides the users an amount of self-confidence in situations of spatial ignorance or disorientation.

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Granularity in Route Directions Generated by Systems and Humans

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Abstract. We address spatial granularity in route directions in relation to information needs in a case study that provides a situation involving different modalities of travel (i.e., walking and travel by public transport). Results reveal that the two sets of route directions investigated (human and web-based) provide the most crucial route elements in hierarchically structured ways that reflect the salient structure imposed by multi-modal traveling. However, human route directions account for the asymmetric information needs assumed for the given scenario in a more flexible and coherent way.[1]

1 Information needs

Theoretical considerations let us expect that the pragmatic information needs of a wayfinder [2] are variable and sometimes asymmetric, especially between start and destination, and then again at complex situations in between. Accordingly recent research has highlighted the importance of variable spatial granularity in generating route directions [3, 4]. We focus here on the identification of pragmatic information needs in a real world scenario, and if and to what extent these varying information needs of wayfinders are addressed by automatically generated as well as human route directions. We compare in a case study two sets of route directions for a particular route involving different modalities, walking and public transport, one set automatically generated and provided by web services, the other provided on request by people with recent experiential knowledge of the route.

Consider this scenario: A lecturer at the University of Bremen is planning a trip to the high school in Ganderkesee, a place about $30km$ away. In this situation, as in many cases of requests for route directions, the information needs involved are asymmetric: the wayfinder is familiar with the start region, but not with the train route and the destination area. Route directions considering this asymmetry would consist of intermediate *destination* descriptions (*Get to Bremen main station*) and subsequent *step-by-step* descriptions (*Then take the NWB on Track 2*) which will also include those types of information that now need to be obtained (often in awkward and cognitively demanding ways) from the environment, e.g., a town map. At points of change of transport

[1] We are grateful for funding by the Volkswagen Foundation and a fellowship of the Hanse Institute for Advanced Studies, Delmenhorst.

mode, the information need can explode in granularity, as opposed to other parts of the journey in which no further information is needed. Furthermore, the complexity of a transfer point is route dependent. These observations indicate a hierarchy of spatiotemporal granularities of the references, and a non-arbitrary, but complex and route dependent navigation through this hierarchy.

2 Web-based services

We investigated how the trip from Bremen University to the high school in Ganderkesee is represented by two public transport planners, `bahn.de` (a web-based service provided by the German railway system Deutsche Bahn AG), and `efa.de` (a web platform for multiple public and private transportation operators in Germany). Both planners (like most others) are by default mono-modal. Searching for a multi-modal travel, or a travel from place to place, requires a range of actions and decisions by the user, such as switching from standard to extended search mode, and then categorizing their departure and destination information as station or stop names, points of interest, or postal addresses. Then the transport planner generates first an overview of alternative travel options, and then more detail for a selected trip (one instruction per transport mode). For the traveler, the diverse transport modes are of different complexity and effort, hence, not equal (walking requires far more spatial information than traveling by train once the correct train has been identified). At this step, the different requirements for each mode are not reflected by the automatically generated information. However, for some of the different transport modes, hyperlinks lead to additional information: Buses, trams, and trains are further specified by their stop lists, and (at `bahn.de`) a walk is specified by a list of verbal route directions and a corresponding map which is zoom- and expandable, hence, for longer walks the wayfinder can access a full overview as well as more detail (`efa.de` provides static maps in portable document format, but no verbal route directions). However, this kind of information is not available for all parts of the route. Where sometimes a desirable level of granularity is lacking, in other instances the provided granularity exceeds the user requirements. For the train, tram and bus legs, one rarely needs to see all the intermediate stops of the trains, in particular where information in the environment (displays, announcements) help to identify the point of disembarkment.

3 Human Natural Language Multi-Modal Route Directions

We collected natural language data describing the same route as before, involving travel on foot and by public transport. Our analysis focused on systematic patterns concerning the choice of, and switches between, levels of granularity. The data were collected during a visit of a class of 11th grade students (around 17 years old) from the high school in Ganderkesee at the University of Bremen (Cartesium) in April 2007. They had met at the railway station in Ganderkesee that morning and traveled together to the university. Their first task (Task I) was to describe—on a blank piece of paper—the way from Bremen University to their school in Ganderkesee, assuming public transport as medium of transportation. Afterwards (Task II) they were prompted to do the same again for the opposite direction.

The data were segmented into informational units, following [1]. Then an intersection of all data sets was accumulated that contains a generalized schema of the spatial information provided in any data set. We distinguished between *crucial elements* (mentioned by nearly all participants), *spatial units*, and *detail units* (which include explanations and sub-actions), yielding a three-level hierarchical structure. Criteria for categorization as a spatial unit (rather than a detail unit) were spatial (a section between decision points) as well as pragmatic. Crucially, no further clear segmentation and order of the detail units can be provided to yield distinct spatial units. The units were annotated according to the generalized schema, i.e., for each item in the schema, it was noted whether the information was contained in the description. This provides the basis for assessing the relative level of detail of each description in general, as well as concerning the particular places at which it provided either no information, or only the most important information (a spatial unit), or further details (detail units).

Our results showed that almost all of the crucial elements also appeared in the opposite direction, at least as a spatial unit but typically as a crucial element. While the spatial units themselves were also astonishingly similar, reflecting a homogeneity concerning the segmentation of the route, there were remarkable differences concerning the distribution of spatial information. These results suggest that there is a general difference according to the direction of traveling which concerns the amount of *details* given in the spatial instructions, but does not affect the choice of main route elements as reflected in the spatial units.

References to public transport appeared regularly and were particularly enhanced by detailed information. In Task 1, more details were provided for the destination than for the starting location. Also, particularly complex decision points (crossings) were accounted for by providing more detail than elsewhere. In Task 2, several participants only started their route description at the train station in Ganderkesee, leading to a complete omission of the route section from the school to the station. This may be due to an enhanced focus on the destination area, mirroring the findings from Task 1. Also, participants provided further details particularly for those route elements that were considered as crucial, rather than distributing details at random places. This result supports the systematic hierarchical nature of the conceptual route representation that is reflected in the linguistic data.

4 Comparison

On a high level of granularity, the most crucial route elements are accessible in all our data, given the present scenario in which the environmental information together with the average wayfinder's procedural knowledge already covers much of the information needed to reach the goal. Also, both sets of route directions exhibit a clear hierarchical structure. As predicted, the various kinds of traveling mode turned out to be particularly salient. Thus, even the coarsest descriptions contain some mention of the train ride between Bremen and Ganderkesee, along with reference to foot paths. Switches of granularity levels typically co-occur with switches of travel mode. This corresponds to our observation that multimodal travel imposes a salient structure of its own.

Both the human and the automatically generated route descriptions provide additional information on various levels of granularity, though with different foci in each case. The web-based services show a range of alternatives of traveling by public transport, which play only a minor role in the human descriptions. In contrast, for people the direction of traveling makes different features relevant; transport planners do not make this distinction. Thus, the human route directions are more flexible concerning functional complexity: finding the exit of a large train station on arrival is easier than finding the correct track on departure. Additionally, to a certain degree the wayfinder's prior knowledge is accounted for by an increased level of detail in the (unknown) destination area. Such adaptivity to actual requirements would presuppose a great amount of implemented world knowledge in any system providing automatically generated route descriptions.

At a more detailed level of granularity, the particular information required and provided differs substantially in the two data sets. For example, switches between granularity levels are potentially disruptive in the web-based systems: specific information about some (but not all) parts of the route may be accessed by user action, but is not integrated coherently. Crucially, the increased information needs identified for the more complex route aspects is not reflected in any systematic way. It seems that the system design in its current form does not allow for a more cognitively adequate presentation of diverse kinds of information, partly due to the fact that the information is derived from various sources.

In contrast, the human route directions constitute coherent and spatiotemporally structured texts, providing various types of information without any apparent discontinuity whenever switches of granularity occur. The instructions contain particularly detailed information for precisely those parts of the route for which a greater need for information was identified, such as when changing travel mode, or in order to identify the correct turn after a lengthy footpath. However, the absence of graphical depictions (in our data set which in this aspect resembles many naturally given route descriptions) may pose a problem with respect to the development of a mental map suitable for current purposes.

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Spatial Revelation and Place Preference

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Abstract. This poster presents an experiment on judgments of 'sense of place' and spatial 'character', based on two experimental environments, created to have the same underlying spatial configuration but varying significantly in their degree of spatial revelation[1]. 32 subjects were shown two movies, each created as walkthroughs along identical paths in the two environments, and were asked to make judgments about the sense of place and character of the environments, as well as selecting one location that they felt particularly captured these factors. The results of the survey and location selection were then compared to measurements of visual revelation. The results were that respondents were shown to favor the stimuli with the greater changes in revelation while all other factors are maintained as constant. This result is consistent with the study's hypothesis that pedestrians are aware of local changes in space and respond to them when considering the 'feel' of a place.

Keywords: Spatial revelation, visibility measures, place and placelessness.

1 Aims

This poster aims to test the hypothesis that pedestrians are quite sensitive to spatial revelation[2] the change in visual isovist [3] properties as a pedestrian moves through space and, furthermore, that this is a contributing factor to forming an overall 'sense of place' [4-6]

A comparative test was devised for this study; the methodology used being a direct extension of that used by [7]. They presented a number of static images (photographs or slides) and asked their subjects to rate the scenes in terms of subjective evaluations of those spaces. This methodology became the core one for a number of environmental psychology studies, with Stamps [8] mentioning more than 20 journal articles using this, or a derivation of this, technique. In the 1990s, Heft [9] criticized this methodology in favor of taking a more ecological or Gibsonian [10] perspective, insisting that it was the temporally-structured, visual information or optical flow that was essential to evaluating a scene as opposed to mere static images. In his paper, Heft provides a number of experimental results that reinforce this view.

2 Method

Two experimental environments were designed, each forming a chain of ten, relatively large, open spaces, invariant in overall size and configuration between the two stimuli. These ten spaces, arranged in a topological ‘ring’, are linked by interstitial spaces: corridors and threshold-spaces. The visual relationship between the thresholds and the open spaces were manipulated in one environment in order to significantly reduce the degree of revelation experienced. See figure 1 for the massing model of the environment and figure 2 for the visibility revelation map.

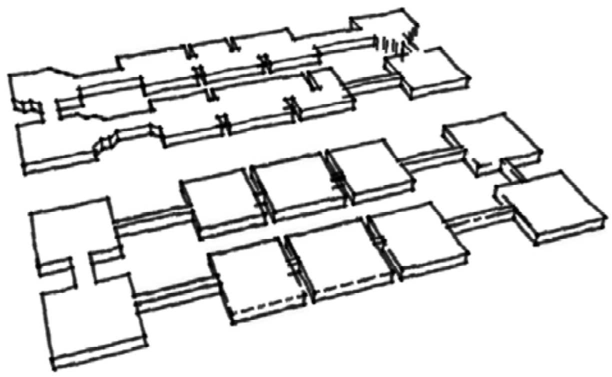

Fig. 1. CAD models for the experimental worlds used

Two identical paths were established, along which the subjects would ‘experience’ each world through the medium of a Quicktime Movie. It was rendered in a minimalist manner, without objects, people or textures, furthermore the walkthrough movie utilized a ‘sketchy’ rendering technique, creating a slightly cartoon-like impression, with strong bold lines for the occluding edges (It was judged that were a more photorealistic rendering to be used, it could begin to engage subjects’ aesthetic judgments) To give a stronger feeling of enclosure the floors and ceilings were coloured dark grey.

The basic experimental methodology was quite simple. Participants were recruited to take part in an online experiment. The experiment was conducted online. Subjects viewed two videos streamed over the Internet (one of each environment; view-order randomized to re-duce any learning effect with subjects permitted to re-view the movies as many times as they required). After watching each movie, they answered a series a series of questions about the environments: they were asked which environment they preferred, which had more character, was more memorable and were more place-like. The results of the survey were then compared to an evaluation of the degree of spatial revelation, derived from an analysis of the original spatial model used to generate the original videos.

3 Revelation Mapping

To facilitate objective correlations of the subjective judgments, maps of spatial revelation were computed. These were produced by flooding the navigable space with an array of points and then performing an '8-radial-direction' revelation calculation and dividing this sum by the number of neighboring nodes (to allow for nodes at the edges that were not eight-way connected). Figure 2 shows the values for the logarithm of revelation (red = locations of high rev., blue = locations of low rev.). As we might expect, in near open space, transition from one point in space to another one gives little change in revelation. Points of high (orange-red) revelation clearly occur near the edges of the doorways or openings. In both buildings, narrow passageways give points of medium to high revelation as one emerges from the passage and enters a space.

Given that the movie-path is known, it is possible to compute 'path revelation': only current and previous points are used (rather than the change in cardinal directions). By computing the sum of absolute changes in isovist area, we can compute the total revelation along a path; for the 'high revelation' route, this value is 34% higher than for the 'low revelation' world (45738 units vs. 34038 units).

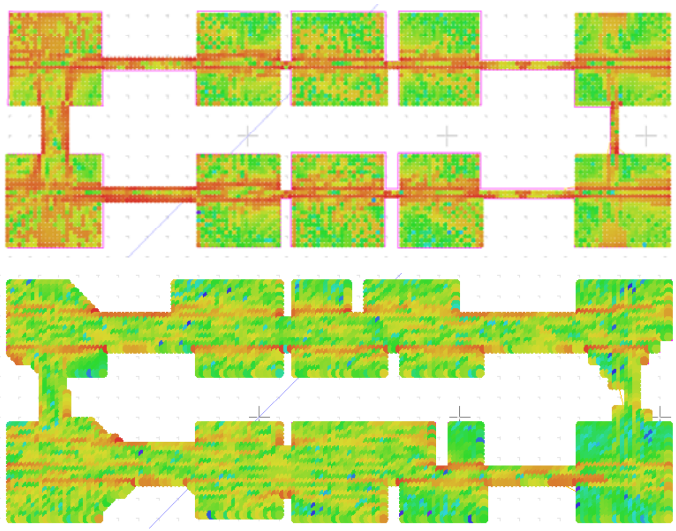

Fig. 2. Revelation maps: high revelation (top) and low revelation (bottom)

5 Results

23 of the 32 participants showed overall preferences for the 'high revelation' environment compared to only 9 for the low revelation environment. This appears to

be a non-random distribution clearly favoring higher spatial revelation. The high-revelation environment was also the preferred option for being more place-like (16 votes opposed to 8 for the other environment and 8 votes for neither). The judgments of 'character' and 'memorability' for the high- vs. low-revelation spaces were 15 vs. 11 and 16 vs. 6 respectively, showing a slight but not significant preference for the high-revelation stimulus. This work reinforces the findings of Franz and Wiener, suggesting that there is a correlation between spatial behavior and visual experience. It also provided evidence consistent with the theory that people are implicitly, but consciously, aware of revelation when assessing the character of a space.

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Proximity based mobile manipulation planning

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Abstract. Autonomous manipulation is a challenging problem for mobile robots. There is a high demand for robots acting within urban scenarios, especially when these are unaccessible for humans. Planning collision free trajectories is necessary for successful operation in such complex spaces. Methods from computational geometry are employed to efficiently generate trajectories that are as safe as possible. A system architecture is implemented and evaluated in a simulation environment as well as on a real world robotic platform.

1 Introduction

Autonomous manipulation is a challenging problem for mobile robots. There is a high demand for robots acting within urban scenarios, especially when these are unaccessible for humans, e.g. for urban search and rescue (USAR) or explosive ordnance disposal (EOD). Closed doors or elevators already constitute difficult obstacles for an autonomous robot. Planning collision free trajectories is necessary for successful operation in such complex spaces.

We utilize a probabilistic roadmap planner for planning collision free paths using proximity queries as collision information. These use, besides static models of the robot, 3D laser scanners for world modelling. Methods from computational geometry are employed to efficiently generate search heuristics and trajectories that are as safe as possible. Proximity Queries are executed on appropriate geometric representations, e.g. tetrahedral volume representations. More specifically we developed an adaptive surface decomposition algorithm for distance computation of arbitrarily shaped objects.

Our system architecture covering spatial planning is implemented and evaluated in a simulation environment as well as on a real world robotic platform.

2 Proximity Queries

In this section, we give an overview of our proximity computation algorithm. This is an extension of the algorithm described in [1] and addresses its main limitation. The algorithm returns the minimum separation distance between a pair of arbitrarily shaped objects.

The algorithm proceeds recursively and can be divided into three stages.

** This research was partially supported by DFG as part of the collaborative research center SFB/TR-8 Spatial Cognition R7

Stage 1: The first stage employs the GJK algorithm [2] to determine a maximally separating plane between the convex hulls (CH) of a mesh pair. If such a separating plane is found, we derive lower and upper distance bounds from the results of GJK and proceed with stage two.

Stage 2: The second stage employs spatial hashing [3] for the efficient culling of mesh primitive pairs with a distance outside the bounds found in the first stage. The minimum distance between the two meshes is found as the minimum of the distances between the remaining primitive pairs.

Stage 3: If the convex hulls of the mesh pair overlap, we do not find a separating plane in stage one. In this case, we utilize information computed by GJK to adaptively decompose the meshes into sub-meshes in stage three and pairwise repeat the process in stage one recursively (see Fig. 1). The overall minimum distance between the object pair is the minimum of the set of distances computed for all the sub-mesh pairs.

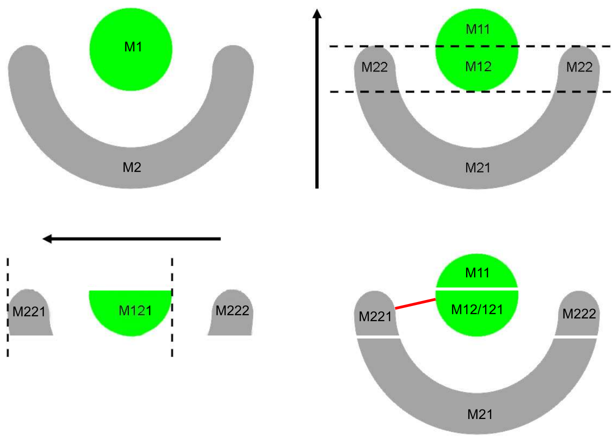

Fig. 1. The convex hulls of two objects(gray and green) intersect (upper left). Results of the support mapping (black arrow) are used to compute splitting planes (dashed lines). Objects are split into sub-meshes (upper right). The convex hulls of $M12$ and $M22$ still intersect. Thus, they are split again (lower left). The red line gives the overall separation distance (lower right).

We have tested our novel distance computation approach on a variety of benchmark scenarios with multiple objects of arbitrary shape and surface resolution and compared the results of the benchmarks with the computation times gathered with the software package SWIFT++ [4]. It decomposes the surface of a non-convex object into convex pieces which are stored in a bounding volume hierarchy (BVH). The query is then executed on the hierarchy of convex pieces.

In comparison, our approach decomposes the objects into pairs of sub-meshes whose convex hulls do not overlap. This is more general when compared to a decomposition into convex pieces. However, it is also more adaptive with respect to the current configuration in the scenario. Depending on the relative position of the objects, the number of sub-meshes that have to be constructed varies, e.g. if the convex hulls of the objects do not overlap, no sub-mesh pairs have to be created. Regarding the recursion depth, we have experienced a maximum of thirteen, even for complex objects. In all scenarios, we achieve a faster computation time on average than SWIFT++. For example, we measure the distance computation time between two cows in close proximity. The cows consist of 6000 surface triangles each. The average computation time with SWIFT++ is 1681 ms, our approach takes 680 ms.

3 Probabilistic Roadmap Planning

Probabilistic roadmap planners are a well suited technique for planning in higher dimensional configuration spaces. The main idea is to prebuilt a roadmap [5], which is a graph, in which randomly sampled nodes correspond to collision free configurations. The roadmap's edges represent collision free paths between these configurations. Edges are constructed by choosing K nearest neighbors for each node and trying to connect these by using a local planner. This local planner is usually chosen to be quite simple, but fast. Once such a roadmap is built planning can then be conducted by simple graph search.

This basic principle can be modified to suit a specific task. Delaying collision tests [6] until an actual plan via an edge is requested gives significant performance improvements. This is especially true on a mobile robot as prebuilt time counts to the planning time in previously unknown environments. By using adaptive dynamic collision checking [7] we can utilize our distance computations in the planning process to improve the planners performance and accuracy.

When implementing such a planning system on a mobile robot world perception has to be considered. A common place for the robot's sensors is at the end of the manipulator. Therefore to acquire a world model the manipulator has to move without knowledge about obstacles. We utilize preprogrammed scanning patterns, which do not extend the manipulator out of the robot's envelope for an initial world model. During operation planning phases precede each robot's movement, which might be a sensing action to acquire a goal position, for example by vision, or executing actions as pressing a button. This procedure ensures, that even in unknown environments, collision free movements can be guaranteed.

4 Results

The planning system has been evaluated in our simulation environment and implemented on a real robot. One example application is the autonomous operation of an elevator, which the robot has shown during the TechX challenge qualification round [8].

In the poster we will present results of our current research in proximity query based mobile manipulation planning. First experiments show the applicability of the distance computation approach into practical motion planning scenarios.

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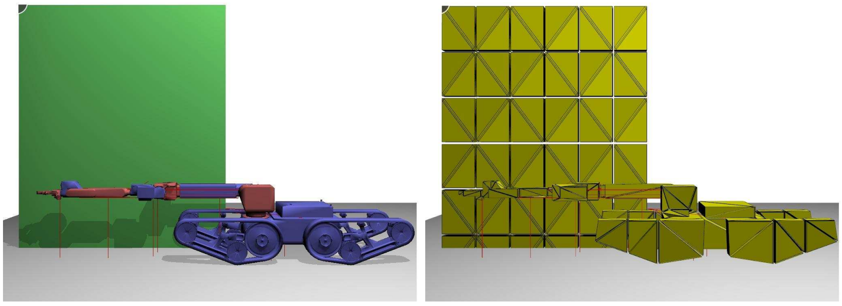
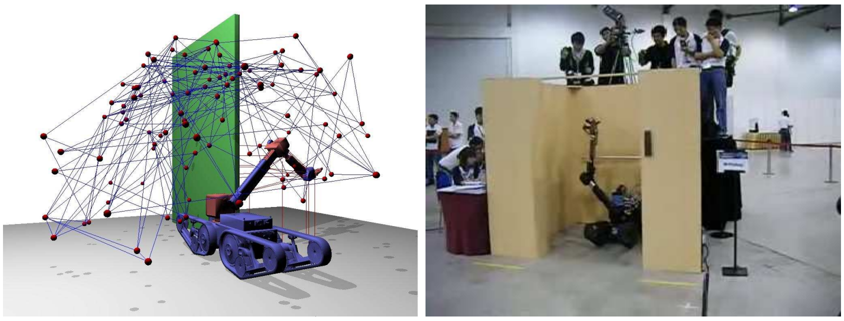


(a) (b)

Fig. 2. (a) The *teleMAX* robot in the simulation environment, (b) the underlying volumetric representation as tetrahedra. Red lines indicate the nearest distance found between objects.



(a) (b)

Fig. 3. (a) A roadmap as generated by the planner, (b) Our *teleMAX* robot executing a plan during the TechX challenge qualification round.

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Where is the Fresh Yeast? The Use of Background Knowledge in Human Navigation

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Abstract. A study conducted in a medium-sized supermarket (approx. 400 m^2) probes for the role of background knowledge in human navigation. Suitable stimuli were derived from the results of a preliminary study investigating similarity judgments by 32 participants and 6 retail store managers. Items are grouped into three categories, with group 'A' incorporating food products placed in a manner congruent with background knowledge. Items stocked in the proximity of products rated as bad neighbors in the pre-study are categorized in group 'B'. Group 'C' consists of items that produced high variances for both, store managers' and participants' ratings, and which might therefore be termed "twofold equivocality". Our hypothesis holds that navigational performance, operationalized through search time and route distance surplus, are higher for groups 'B' and 'C' than for items in group 'A'.

Keywords: Spatial Cognition, Real-World Navigation, Categorization.

1 Introduction

Our objective is to study the effect of domain-specific knowledge (e.g., heuristic rules, default values) about spatial layouts on human spatial cognition and behavior. This relevant background knowledge is not identical to spatial abilities or to former experience with the specific environment. It seems almost self-evident that this knowledge would be applied in navigation. However, the study of this kind of knowledge has been neglected in favor of more purely "spatial" factors: spatial intelligence, spatial long-term and working memory, perceptual factors, etc. Since it is part of common sense, this knowledge has been excluded from the artificial VR environments so prominent in research on spatial cognition (e.g., Gillner, & Mallot, 1998), and has not played a role in existing studies of real-world navigation (although declarative knowledge in general has been named among the knowledge systems in navigation by Montello, 2005).

To conduct our research we decided on a semantically rich indoor environment, the food and drugstore supermarket. Modern supermarkets, by virtue of their sheer size and their vista space limited by shelves, may be considered mazes. In contrast to most mazes used in behavioral research, however, this space is not empty but filled with a multitude of meaningful objects. These objects belong to certain natural (e.g., milk) or artificial categories (e.g., pickles). Heuristic rules link some of these categories with respect to their relative placement. Most supermarkets adhere to categorical placement, with greengrocery and bakery departments, and shelves dedicated to categories. Alternatively, an “episodic” organization may be observed, e.g., putting all things needed for breakfast together. In the delicatessen section, however, many markets in Germany now follow an organization by brand. Categorical organization is also prevalent in memory from about six years of age onward. In younger children, the episodic principle is the dominant one. This implies that at least the two main principles of placement in supermarkets fit with the common organizational principles of human memory.

2 Experiment Methodology

Assessing background knowledge - Categorization Study: To assess the background knowledge people have with respect to the categorization of items found in grocery stores we conducted a pre-study: 32 participants (19 female, 13 male; mean age 36.7 years) were asked to sort 98 plastic cards naming typical food objects into groups of products they thought were similar (see Figure 1). Subsequently they were asked to give their groups captions and compare all the groups with each other using a scale from one (‘groups are very similar’) to seven (‘groups are very dissimilar’).

Fig. 1. Card-sorting task with subsequent application of captions.

These results were compared to those obtained giving the same task to six supermarket managers. Contrasting the dissimilarity matrices through cluster analyses, multidimensional scaling and distance comparisons allowed us to identify suitable items for the main navigation study.

The resulting stimuli are divided into three categories: items that are placed together in the supermarket shelves with items that received high similarity ratings (background knowledge congruity, group ‘A’). Items that are grouped together in the store but which yielded high distances in the pre-study are subsumed in group ‘B’ (background knowledge incongruity). Group ‘C’ pools items that have high variances in their placement, resp. similarity judgments, i.e. in comparison to group ‘B’ there are no real guidelines by the store managers where to place them and the participants’ ratings were inconclusive too. Table 1 gives an overview of the 15 items that are used for the main navigational study.

Group ‚A‘ (congruency):	Group‘ B‘ (incongruency):	Group ‚C‘ (twofold equivocality):
- Yoghurt drinks - Canned corn - Cake decoration granules - Long grain rice - Gravy powder	- Cereal bar - Packaged marble cake - Delicatessen olive oil - Vanilla yoghurt - Pickled herrings	- Salt - Fresh yeast - Tomato puree - Baby food - UHT-milk

Table. 2. The three categories with five products each.

Testing the effects of background knowledge - Navigation Study: In the main study, we intend to use 60 participants: 40 people with varying background knowledge of the store where we are allowed to conduct our experiment and 20 people with no prior knowledge of this supermarket who are allowed to freely explore the layout before being tested.

The sequence is as follows: at first, participants receive experiment instructions and are asked to fill in a German version of the SBSODS-questionnaire (Münzer, Hölscher, & Gramann, 2008). They are then led to the starting point inside the store and subsequently have to find the 15 items. We are able to track the participants' paths by means of a specially prepared shopping cart equipped with a laser range scanner and two RFID antennae's picking up signals from RFID tags scattered throughout the building. Other behavioral measures, such as stop locations, areas of deeper (visual) search, or expected locations, are recorded using the WayTracer technology (Kuhnmünch et al., 2006). A map of the store is depicted in Figure 3 with the 15 items being marked with red stars.

Fig. 3. Floor plan of the supermarket with the location of the items.

3 Expectations & First Results

Our hypothesis is that background knowledge effects navigation performance, i.e. the background congruent placement of objects improves search and navigation performance. On the other hand, layouts that are incongruent with background knowledge hinder efficient accomplishments of such tasks. With respect to the performance measures for our three groups we expect the Items in group 'A' to be found faster and with less exceedance of the optimal path than the group 'B' members. Group 'C' should yield measures in between 'A' and 'B' because there might be some accordance between store managers' and customers' adjacency ratings, so the first guess has a higher probability of proving to be correct in comparison to group 'B'.

An initial pilot evaluation of the data of eight participants corroborates this hypothesis. Considering the optimal path and the total amount of visits to the particular supermarket as covariates, there is a main effect for the time to find objects (in seconds) of the three categories $F(2, 22.634) = 6.341$, $p<0.01$, partial $\eta^2 = 0.359$. Figure 4 shows the means with one standard error of the mean for the search times of the three categories in seconds.

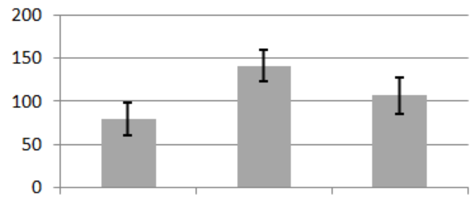

Fig. 4. Means of the search times for the three conditions. Error bars show 1SE of the mean revealing a significant difference between groups 'A' and 'B'.

As the preliminary analysis suggests, our hypothesis appears to hold: Background knowledge does indeed influence navigation performance in that background knowledge equivalent layouts ease navigation while violations of adequacy deteriorate navigation performance. Further evaluations will not only consider the search time as a dependent variable, but also take route length and overshoot of the optimal path into consideration. After completing the real-world navigation study we aim at a replication in virtual reality as this will allow us to induce active variation concerning the placement of products, shelves and aisles.

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Differential Effects of Color on Mental Rotation as a Function of Spatial Ability

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Abstract. We examine whether representations of three-dimensional objects during mental rotation are visuo-spatial or only contain abstract spatial information. Participants performed a mental rotation task in which the figures were colored consistently, inconsistently, or not colored. Performance of low-spatial individuals was facilitated by the added color, but color had no effect on the performance of high-spatial individuals, replicating a previous study [1]. One interpretation of this result is that individuals with high spatial ability have more schematic spatial mental representations whereas individuals with low spatial ability construct representations that include both visual and spatial information.

Keywords: mental rotation, representation, color, spatial thinking strategies

1 Introduction

A hallmark finding in cognitive science is that there is a linear relationship between the time it takes to mentally rotate two objects and the angular disparity between them, suggesting that mental rotation is an analog process [2]. Studies of mental rotation present participants with two-dimensional (2-D) perspective drawings that depict three-dimensional (3-D) objects. What is represented from these 2-D renderings? Does the mental representation consist of abstracted spatial forms or does it also include visual details? This research is concerned with studying what information is represented during mental rotation of 3-D objects and the strategies people use to perform mental transformations of these objects.

1.1 Motivation and Related Work

At least one dominant theory of mental imagery suggests that mental rotation is a visuospatial process in which the content of mental images is represented and transformed in a visual buffer [3]. However, there is evidence that individuals with high spatial ability have schematic mental representations, without much visual detail [4]. With respect to the visualizer/verbalizer dichotomy, two types of visualizers have been identified; those with high and those with low spatial ability. In previous research, low-spatial visualizers interpreted kinematic graphs as pictures, whereas high-spatial visualizers correctly interpreted them as abstract spatial representations [4]. When solving mathematical word problems, low-spatial visualizers represented irrelevant visual details in the problems and performed poorly, whereas high-spatial visualizers constructed schematic spatial representations of the problem-relevant information and had superior performance [5]. In further research participants were given the mental rotation, embedded figures, grain resolution, and degraded pictures tasks; the former depends on spatial transformation ability whereas the latter three are assumed to rely on vivid visual imagery. Low-spatial visualizers performed better than high-spatial visualizers on the tasks that involved vivid visual imagery, whereas the opposite was true for the mental rotation task [6]. The difference in performance was not explained by differences in the ability to process abstract information, as the low- and high-spatial visualizers did not differ on a test of general intelligence.

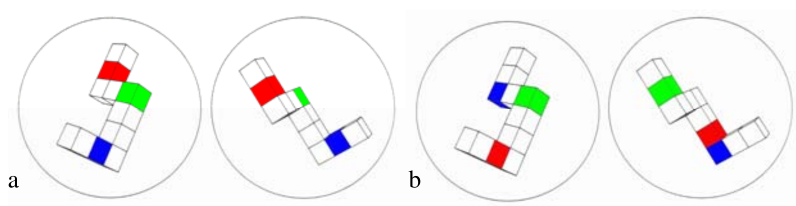

Fig. 1. Monochromatic figures were used in addition to these two colored figure types. a) The color order and spatial position is the same on both consistent figures. b) The inconsistent figures have different color order and spatial position of the hues also does not match.

In order to study the effects of purely visual information on spatial transformations, versions of the Shepard-Metzler figures were created such that some cubes were colored. Although shape, like color, can be perceived through vision and can therefore be thought of as a visual feature, shape can also be perceived through non-visual modalities and therefore is not specifically visual. The shape of the pairs of objects in Figure 1 is the same, but they differ in color (a visual property). In Figure 1a the figures have consistent colors—the colors of the cubes are the same for the two figures. In Figure 1b the shapes are identical but the locations and order of the colors are inconsistent. In our experiments, participants are asked to judge whether the two *shapes* are identical while ignoring the colors of the cubes. Thus the relevant property is shape (a spatial property) and color (a visual property) is irrelevant to the task.

A theoretical information-processing model suggests that the cognitive processes in mental rotation are: encoding the figures, matching corresponding arms, rotating them to congruence, and deciding whether the rotated figures are the same or mirror images [7, 8]. Colored figures might affect performance, especially during the matching process. If the underlying representation has visual information, then we hypothesize that consistent colors will facilitate and inconsistent colors will impede performance. If the mental representation is a more abstract spatial representation, then color should not affect performance in the task.

2 Method

31 participants (11 high-spatial, 11 low spatial) completed 300 mental rotation trials. On one third the figures were monochromatic (similar to those used by Shepard & Metzler, in one third they were colored consistently (Figure 1a) and in one third they were colored inconsistently (Figure 1b). The three types of trials were completed in one (mixed) block. Spatial ability was measured and the sample was divided into high- and low spatial groups (the top and bottom third of the distribution).

3 Results

Both accuracy and response time increased linearly with angle of rotation, $F(1,25)=98.7$, $p<.001$ for response time, $F(1,30)=60.1$, $p<.001$ for accuracy. There was a significant interaction between spatial ability and figure type on both reaction time, $F(2,32)=3.41$, $p<.05$, and accuracy, $F(2,40)=6.2$, $p<.01$. Simple-effects analyses showed that low-spatials were significantly faster and more accurate on the colored figures compared to the monochromatic figures. High-spatials were unaffected by the colors of the cubes and were generally faster overall compared to low-spatials (see Figure 2). Difference scores were computed by subtracting the time taken for colored figures from that taken for monochromatic figures and these were significantly correlated with spatial ability ($r=.37$, $p<.05$), indicating that low-spatial individuals were more affected by color.

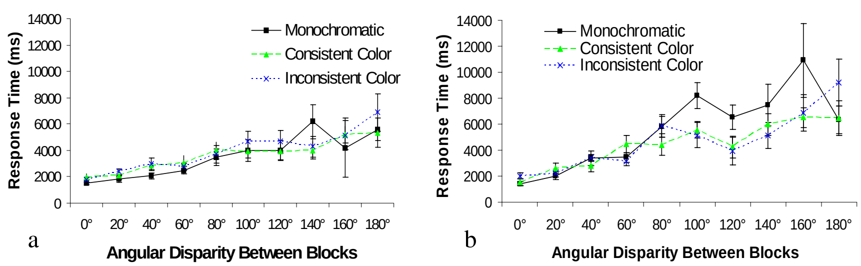

Fig. 2. Response time as a function of angular disparity for the three different types of figures types for a) individuals with high spatial ability and b) low spatial ability.

4 Discussion

The results supported the prediction that low-spatial individuals would be helped by the color information. The results also supported the prediction that high spatial individuals would not be affected by color. A peculiar result is that the low-spatials were not hurt by the inconsistent figures. It is feasible that simply providing a distinctive cue on the arm of the figures, regardless of the position of the color on the arm, is beneficial.

The results, which replicated a previous study [1], are consistent with the account that low spatial individuals but not high spatials represent color during mental rotation. An alternate hypothesis is that the data structures (mental representations) might initially be the same for low- and high-spatial individuals but different algorithms (strategies) might be used by the two groups [9]. Specifically, high-spatial individuals might be flexible information processors who can represent or suppress color information, depending on the demands of the task. A future experiment will change the instructions for the task so that individuals respond 'same' only when both shape and color match. If high spatial individuals never represent color during mental rotation, then they should perform worse on the colored figures in this task than on monochromatic figures. However, if high spatials can adaptively switch strategies then they should perform well even when color is relevant.

Further experiments will utilize a combination of verbal protocol and eyetracking methodologies to study whether high and low spatials look and speak about different aspects of the stimuli. Individuals will first have their eyes tracked while performing a subset of trials and then talk aloud while they complete additional trials. According to the theory that low-spatials represent visual information but high-spatials do not, low-spatials should mention and look at colors more often than high-spatials. Finally, an experiment will test if colors are unique or whether any spatial markers, such as blackened cubes, might benefit performance.

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Animating Trees of Life: How Animation Influences the Perception of Evolution

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Abstract. Cladograms, which depict evolutionary relationships between organisms – are crucial reasoning tools in biology. Yet people's interpretations of them are influenced by many factors. Gestalt principles of perception, the prevalence of historical icons, a penchant for narrative, and the appeal of embodied space may cause or reinforce continued misunderstandings of evolution. Clinical interviews with students suggest that people's perceptions of cladograms and subsequent conceptions of evolution are influenced by animation. Implications are in how evolution is taught with visual representations.

Keywords: animation, evolution, diagrams, interviews.

1 Introduction

Diagrams can be useful for learning and reasoning about science [1]. Professional biologists use *cladograms* that map species' shared characteristics and allow them to hypothesize and to reason about the relations among organisms [2], and educators are urged to teach students such tools of professional practice [3] [4]. However, continued misunderstandings of evolution [5] suggest that interpreting these diagrams is not a simple process. Rather, lingering historical icons [6], a penchant for narrative, Gestalt perception [7], and the appeal of embodied space [8] may cause or reinforce misunderstandings of evolution [9] [6].

The word *evolution*, for example, typically evokes the familiar image of primitive organisms marching toward a sophisticated human being, an idea rooted in medieval notions of a Great Chain of Being [10]. The persistence of this historical icon may colour people's perceptions of cladograms and be linked to certain features of the ladder cladogram, a form of cladogram commonly used in school textbooks [11] (Fig.1). First, people's perception of a continuous diagonal line interferes with correct hierarchical interpretations of the cladogram, a phenomenon referred to in terms of Gestalt perception as *Good Continuation* [7] Second, the tendency for people to read time into diagrams [6] may lead them to interpret that line as a linear progression that culminates in humans. Third, the perceived continuity and temporality of that diagonal line agrees with our encounters of evolution as a story. Through narrative, the complexity of evolutionary routes and relationships among species are trimmed to a single causal sequence of events that neatly maps onto the diagonal line of the cladogram [12]. Finally, the metaphors of graphic space, which naturally correspond to our bodily experiences [13], make the bottom left end of the diagonal line, physically closer to the viewer, interpretable as a beginning; and the upper right end, farther from the body, interpretable as further along in time. The diagonal line is thus intuitively symbolic of a progression from primitive to more sophisticated organisms.

Given the advantages of both diagrams and animations in reducing cognitive load and facilitating learning, animated diagrams should greatly enhance understanding, especially of dynamic processes in which explicitness of information such as change and motion is required [14] [15] [16]. Here, I report on the reasoning patterns observed during clinical interviews with students, who reasoned with the ladder diagram. Specifically, I investigated whether animation had an effect on the narratives viewers constructed of evolution, and on the interpretation of the relationships depicted in the cladogram. Findings from this research may help to describe some conditions under which animation can be useful for learning, and may have implications in the design of diagrams and animations for teaching about evolution.

2 Methods

Three groups of 24 undergraduate students viewed the same cladogram on a computer screen (Fig. 1). The diagram was either revealed from the bottom toward the top (*Bottom-Top*), from the top toward the bottom (*Top-Bottom*), or displayed as a static graphic (*Static*). After the animations, a static graphic identical to the one in the *Static* condition remained onscreen. In individual semi-structured clinical interviews, students were asked to describe, explain, and reason with the diagram. Their responses were audio-recorded, transcribed, and qualitatively analyzed. Information on subjects' prior experiences with cladograms, their science education, and their belief systems was collected in an exit survey.

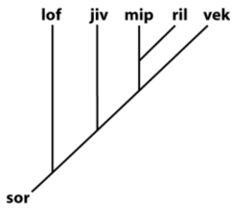

Figure 1. The cladogram presented to subjects during clinical interviews. The three-letter nonsense words ensured that subjects responded based only on the topological features of the diagram, and not on their prior knowledge of familiar organisms.

3 Findings and Discussion

Animation appeared to strongly influence students' perceptions and their resulting interpretations of the relationships depicted in the cladogram. Moreover, their narrative reconstructions of the animations were greatly influenced by their prior knowledge of cladograms and of evolution. Those who viewed the diagram in both the *Static* and the *Bottom-Top* conditions described how a single primitive organism, *sor*, gradually evolved into many diverse organisms. Changes to *sor* occurred along a continuous timeline represented by the apparent diagonal line, until it eventually became *vek.* The vertical lines that stemmed from that diagonal line corresponded to species that had diverged at different points along this timeline. When asked which of two presented subdivisions of the cladogram was the most meaningful, nearly all participants, regardless of condition, preferred the one that preserved the continuity of the diagonal line rather than one that broke it. Many participants in the *Bottom-Top* and *Static* conditions further identified the top-right position of the cladogram (*vek*) with evolutionary superiority in relation to the rest of the positions (e.g., *sor*). These responses suggest that Good Continuation, embodied space, and narrative structure affect participants' conceptions of the cladogram. That there were no clear differences in interpretations of the *Bottom-Top* and the *Static* cladograms suggests that the *Bottom-Top* animation may have simply made explicit the default mental model typically cued by a static cladogram, rather than elicited an essentially different interpretation.

But where subjects in the *Bottom-Top* and *Static* conditions associated organisms toward the top right with more highly evolved and adapted organisms, and organisms toward the bottom left with primitiveness and simplicity, students in the *Top-Bottom* condition did the reverse. As one such student described, the organisms at the top "combine and then eventually they all come together to form *sor*." The contrast between the interpretations across conditions demonstrates the influence of animation on perceptions of cladograms, and on the resulting conceptions of evolution.

However, more than animation, prior knowledge appears to greatly influence interpretations of the cladogram. One student, who had recently learned about cladograms in a course, described how the animation began in the present-day, then "went back through the years to one organism that broke off into all of these, which would be the *sor*." Thus, while less experienced *Top-Bottom* subjects were heavily influenced by the animation, this student's already strong mental model of evolution overcame those effects. In fact, her responses appeared to describe the static image that persisted on the screen rather than the animation she had just viewed.

The effect of the short-lived quality of the animation is evident in other instances. One student in the *Top-Bottom* condition, who initially described a progression from a diversity of organisms to a single one, later changed her mind and said that: "because of the way the video played, I would have assumed we were progressing in a *[downward]* timeline. But I guess it could just as easily have been the other way around." The alternation in her perceptions of the short animation and the static graphic that remained onscreen demonstrates the two competing internal images she constructed as a result of the external one.

These findings have implications for how cladograms should be introduced to novices. Next steps include devising animations to offset the effects of *Good*

Continuation, and comparing with interpretations of the less common tree cladogram, which lacks a conspicuous diagonal line. Another question to pursue involves the effects of first priming students with the idea of evolution on their interpretations of the diagram. To what extent those canonical icons of evolution constrain our interpretations of evolution has implications in the design of images of evolution for education. More broadly, it will have implications for people's literacy of science, which is more often than not a discipline that manifests itself in representations.

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A study into how buildings may provide reassurance to unfamiliar users when wayfinding

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Abstract. This paper introduces wayfinding strategies for people in unfamiliar environments, providing reassurance that the correct route is being followed. Two studies are reported, an observation of route choices made by people walking around an unfamiliar building, and judgements of reassurance given by people on defined routes in an unfamiliar building. The objective of the study is to identify how buildings can be designed to improve wayfinding.

Key words: Wayfinding, Reassurance, Building design

1 Introduction

Wayfinding within any unfamiliar environment places a degree of stress on the people involved [1] [2]. This may compound external stresses present, such as that due to attending a job interview or catching a plane, may distract from the wayfinding task being conducted, which in turn may lead to an error that may cause an even greater level of stress. This situation is likely to escalate if a clear understanding of the environment is difficult to achieve quickly and unnecessary time has to be devoted to information gathering and orientation in order to complete the wayfinding task [2]. Two critical characteristics of human wayfinding are destination choice and path selection [3].

A range of strategies have been identified that relate to path selection in wayfinding behaviour of unfamiliar users at decision points:

- Maintain a straight bearing. If the decision point comprises an option to continue in the same direction, this will be followed in preference to a deviation in direction. This strategy is linked to the Least Angle Strategy [4] [5] and Initial Segment Strategy [6].
- Avoid changes of level. If the decision point permits an option to change vertical level within the building, this will be ignored in favour of remaining at the same level. This may arise from an expectation of confusion on different floors if the floor plans are not consistent [7] [8].

– Choose the wider path. Where the decision points permits two or more exit paths, the wider of these will be chosen. There is some evidence for this from Zacharias [9] and this may be because public routes are associated with greater levels of traffic than private routes and are therefore wider [10].
– Move towards a bright, daylit space. Taylor & Sucov found a preference for walking towards higher light levels [11].

The aim of this research is to identify how the environment influences wayfinding, particularly in unfamiliar buildings, and whether wayfinding behaviour can be anticipated from studying the building design. The possibility of using this information in building design is then investigated. While there are many studies into wayfinding, relatively few relate the findings back to the built environment in this way [5].

In order to identify how a particular strategy or trait influences wayfinding they have been categorised as either 'reassurance' or 'tool'. The 'tool' category includes visual and spatial cues that make wayfinding information easier to obtain. The 'reassurance' category includes visual and spatial cues that reassure the wayfinder that they are heading in the correct direction.

This article describes research carried out to address the reassurance element of wayfinding in unfamiliar buildings, by consideration of the four wayfinding strategies at decision points.

2 Observations of wayfinding behaviour

Two investigations have been carried out in real buildings using test participants who were not previously familiar with the buildings. The first was an observation of wayfinding behaviour, and this provided anecdotal support for the wayfinding strategies. The second was a more rigorous test of wayfinding difficulty, comparing the reported difficulty of the route with a-priori predictions made by consideration of the wayfinding strategies. Both investigations were carried out in University of Sheffield buildings - the Students Union and the St George's Complex.

Two sets of observations were conducted. The first involved participants being asked to walk around the building in accordance with one of three sets of rules; follow a list of directions using named landmarks such as a feature; follow a set of instructions (e.g. turn left when you reach a particular feature); and the (control) third group walked without any directional instructions [12] [13]. The second observation involved participants being taken around the building once then being asked to give directions to various spaces within the building. This aimed to identify elements of the building the participants felt were significant to the wayfinding task and whether there was evidence of the known wayfinding strategies in the routes given.

Analysis of the routes followed by the control group subjects of the first observation provide some support for the wayfinding reassurance strategies. Their routes were analysed to determine the number of decision points at which each strategy was possible. Each strategy was followed on at least 75% of the occasions when it was viable.

Twenty-four volunteer subjects were instructed to follow five routes, in a random order, and report on the perceived difficulty of each route. These routes were within the St Georges building at Sheffield University and the test participants reported that they had not previously entered this building. The difficulty of each route was initially rated by consideration of the four proposed wayfinding strategies.

Test participants initially followed two practise routes, conducted in a separate part of the building to the five test routes. These were chosen as examples of easy and difficult routes, and this was conveyed to the participants to anchor their responses. Following each individual test route, its difficulty was rated using a category rating scale (1=very easy, 2=moderately easy, 3=moderately difficult and 4=very difficult). Four categories were chosen to avoid the potential contraction bias possible when the scale includes an obvious middle (neutral) category [14]. On completion of all five routes, their difficulty was judged by listing them in rank order (1= easiest to 5 = most difficult) with tied ranks not a permitted response. The use of two mechanisms for judging difficulty offsets the bias inherent within each, and this enables more confidence to be placed in the findings. Each participant undertook all seven routes.

	Route A	Route B	Route C	Route D	Route E
Predicted rating	2	3	4	1	3
Recorded rating (mean)	2.29	2.83	3.50	1.25	3.17
Recorded rating (std. dev.)	0.54	0.55	0.5	0.43	0.69
Predicted ranking	2	3	5	1	4
Recorded ranking (mean)	2.17	3.25	4.38	1.08	4.13
Recorded ranking (std. dev.)	0.47	0.66	0.70	0.28	1.09

Table 1. route difficulty and mean rating and rank order of route difficulty recorded in tests

The Friedman test shows that the ratings applied to each of the five routes are significantly different ($p < 0.001$). Subsequent application of the Wilcoxon signed ranks test to individual route pairs revealed significant differences in ratings of difficulty and these differences followed the a-priori predictions. Kendall's W test suggest that the rankings of the five routes are highly concordant ($w = 0.76$, $p < 0.001$) - participants tended to agree on ratings of route difficulty. The Friedman test reveals significant differences ($p < 0.001$) in the rank order of route difficulty and this is again supported by application of the Wilcoxon signed ranks test to individual pairs of routes.

3 Discussion

The two studies reported in this article provide some evidence that when people are wayfinding in unfamiliar buildings they make use of four reassurance strategies at decision points; maintain a straight path, avoid changes of level, choose the wider path and move towards a bright, daylit space. Both studies have limitations. The first was a post-hoc analysis, and does not account for other environmental variables nor for the purpose with which the test subjects were walking in a given direction. The second test considered the four strategies as a group and does not reveal the interaction and weighting of each. Further work in this area will involve studying each of the strategies individually in order to identify whether there is any precedence of choice between strategies. There may be situations where the decision has to be made to adhere to one strategy or another (but both aren't possible), in which case it is felt it would be valuable to know if particular strategies are consistently favoured.

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Timing properties of reference frame selection

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Abstract. Spatial sentences such as "the ball is left of the car" can be interpreted from different points of view. Depending on the frame of reference such spatial relations can be understood from an abstract (cardinal directions) relative (seen from the viewer) or intrinsic (seen from the located object) point of view. In natural communication speakers have to align their frame of reference in order to successfully communicate. Carlson has performed a line of research on sentence-picture verification and reference frame selection. One of the findings is that the sentence serves as a 'recipe' for processing the picture and the reference frames are activated after the picture. However, what happens in a picture-sentence verification task? In this research we investigated when a frame of reference is selected. In a picture-sentence and sentence-picture verification paradigm we tested how much time people need in order to activate and select a reference frame by systematically varying the interval between the two stimuli. Subject were asked to compare a sentence such as "the ball is left of the car" and a picture of a ball and a car. Depending on the orientation of the car the verification could be correct either from an abstract/relative or intrinsic point of view. The results show that sentences activate relative reference frames faster than intrinsic ones and that it takes between 0 and 500 milliseconds to activate these two reference frames. In a follow-up experiment we chose a fixed interval of 500ms and introduced a cue at different moments instructing which reference frame was to be selected, in order to investigate the onset of reference frame activation.

1 Figures

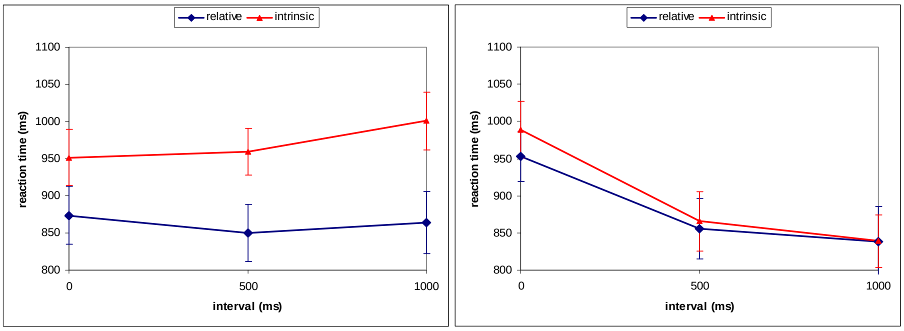

Fig. 1. Left) Sentence-Picture: No main effect of interval, but a significant difference between relative and intrinsic answers. Relative is always answered faster than intrinsic. Right) Picture-Sentence: Responses in the 0ms interval are significantly slower than responses on the 500 and 1000ms interval. There is no significant difference between relative and intrinsic response times.

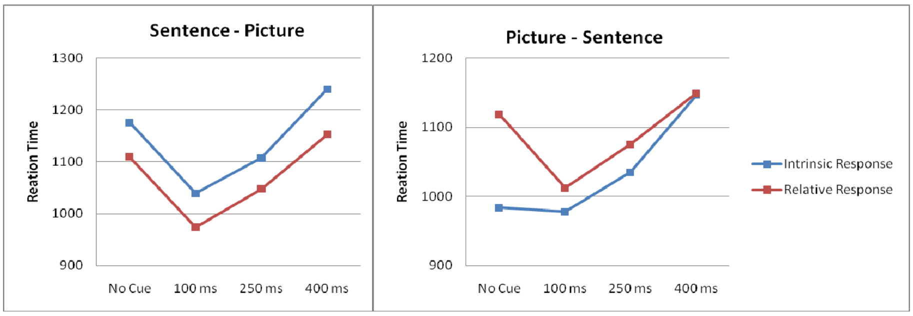

Fig. 2. Mean responses for all participants for all responses. Responses are shown for two different responses, depending on the cue that was shown (relative or intrinsic) at 3 intervals or when no cue was shown. Left) Sentence-Picture: Relative responses are always faster than intrinsic responses. There is a facilitation when a cue is presented at 100ms, compared to no cue. Right) Picture – Sentence: The intrinsic responses were significantly slower when no cue was presented. However, when a cue was presented the difference between intrinsic and relative responses disappeared. Presenting a relative cue at 100ms significantly reduced relative response times.

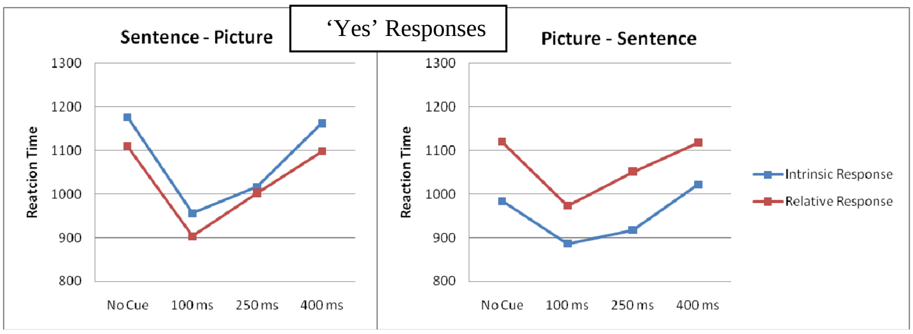

Fig. 3. Mean responses for all participants for 'yes' responses only. Responses are shown for two different responses, depending on the cue that was shown (relative or intrinsic) at 3 intervals or when no cue was shown. Left) Sentence-Picture: Relative response are significantly faster than intrinsic responses. Early and middle cues significantly reduced response times. Right) Picture – Sentence: Intrinsic responses are significantly faster than relative responses. Early and middle cues significantly reduced response times.

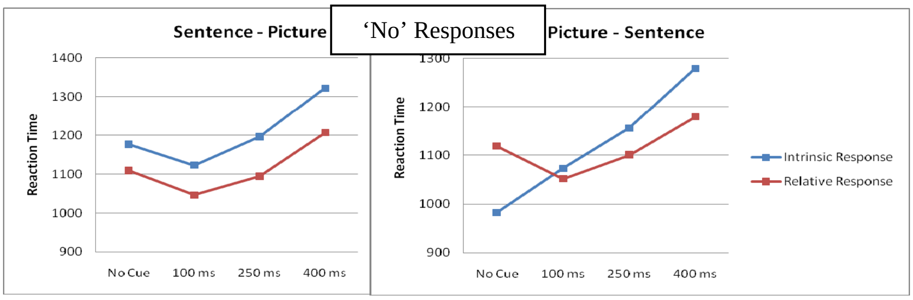

Fig. 4. Mean responses for all participants for 'no' responses only. Responses are shown for two different responses, depending on the cue that was shown (relative or intrinsic) at 3 intervals or when no cue was shown. Left) Sentence-Picture: Relative responses were always slower than intrinsic responses. Responses to the late cues were significantly later than responses to no or early cues. Right) Picture – Sentence: The relative responses were significantly slower in the no cue condition. However, keep in mind that these were 'yes' responses. When a 'no' response was required there was no difference between response times at the early cue. For middle and late cues subjects were faster in responding to the relative cues. Presenting a cue at a later time significantly increased response times to both cues.

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Categorical and coordinate spatial relations from different viewpoints in an object location memory task

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Abstract

Spatial relations between objects can be represented either categorically or coordinately [1, 2]. Categorical relations are more abstract and verbal (above, left of), while coordinate relations concern the metric properties of the relation (10 cm, closer to). Rosielle, Crabb, and Cooper [3] have shown that a change in location of an object in a scene is detected faster when the categorical relations of the object change, compared to a change in coordinate relations.

In the current experiment this effect was further examined in an object location memory task. Subjects studied computerized images of rooms filled with objects. In the testing phase the room was shown without six of the objects, and subjects were asked to choose one of three options as the correct location for each of the objects sequentially.

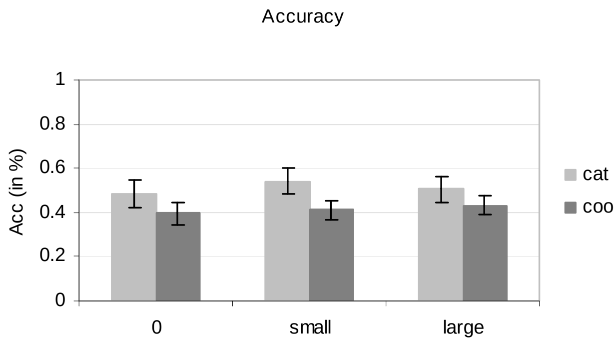
The viewpoint of the room in the testing phase was either the same, shifted with a small angle, or with a large angle. This way, three different object location memory strategies could be dissociated; snapshot, egocentric, and allocentric strategies [4, 5, 6]. All three could be used in the no shift condition, ego- and allocentric in the small angle condition, and only the allocentric strategy in the large angle condition. The three location options in each trial consisted of the correct location, and two distracters which were both either categorically different or categorically the same (only a coordinate change).

59 children (5, 7, and 10 year old) and 40 adult students were tested. Overall performance increased with each sequential age group. All age groups were able to apply all three strategies, but performance increased when more strategies could be used. The trials with categorically different distracters were easier overall for the children as well as adults. The adults showed an interaction of angle and group; performance on coordinate only trials was lower for larger angles. This effect concurs with the stability of categorical relations.

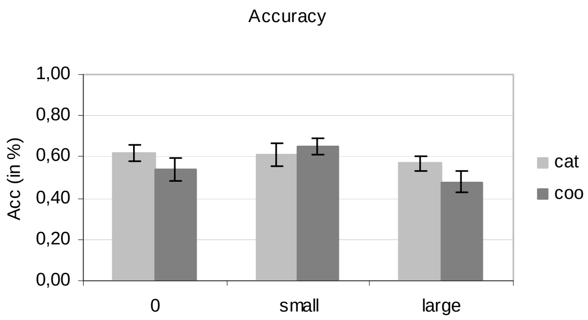
Figures

For all age groups, the accuracy data are presented for both categorical trials (light grey bars) and coordinate trials (dark grey bars). Since there were three response options in all trials, chance level performance was 33 %.

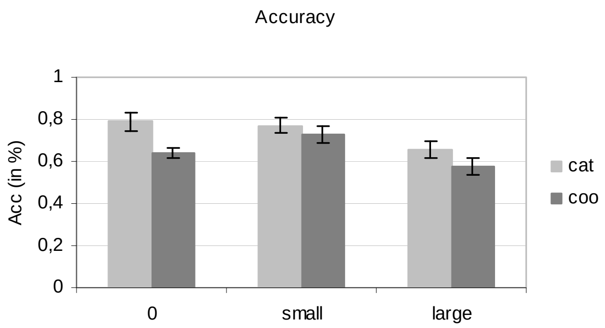
5 year olds



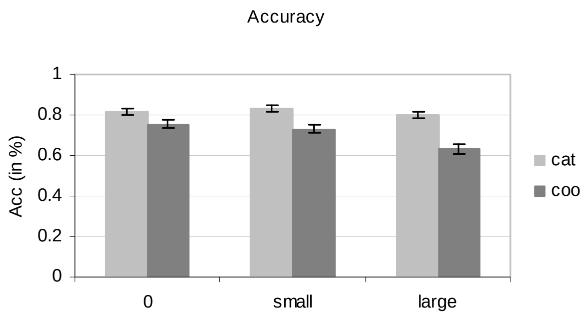
7 year olds



10 year olds



Adults



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A rTMS Study of Planning Using the 3D Maps Task

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Abstract. Navigation is a complex process which includes other cognitive processes, such as wayfinding and planning. We tested the 3D Maps task, a task simulating a 3D environment, aiming to study planning involved in a route navigation. The task is based upon a computerized version of the Travelling Salesperson Problem, in which subjects must collect all the subgoals performing the shortest route in the shortest time. The test has been carried out while inhibitory repetitive transcranial magnetic stimulation was applied on either the prefrontal and the posterior parietal cortices (either right and left ones), aiming at verifying the neural correlates during the task execution. Results showed differential effects on performance depending on gender and stimulated region.

Keywords: Planning, 3D Maps task, rTMS, Associative cortices.

1 Introduction

Spatial navigation entails a large number of sub-processes, such as operating choices, recalling routes when a place is known, or employing strategies to explore an unknown environment. A successful navigation, when constrained by some rules such as finding the shortest, the quickest or the cheapest path, cannot be meraly a blind exploration; thus, it should be based on several processes, particularly on a proficient action planning. This process allows to select the path to follow among several possible trajectories, to organize movements in order to perform actions and to achieve a goal. The creation of a plan within a navigation task is based on the use of heuristics: a group of flexible and dynamic actions aimed to guide subject to achieve the solution of a problem. The most opportunistic combination of heuristics determines a strategy [1].
Visuospatial planning process has been studied using a task, known as the Traveling Salesperson Problem (TSP: [2]), devised to simulate a salesperson which has to find the shortest route across all the cities on his schedule in the shortest time. Basso et al. [3] devised a computerized version of the TSP, the Maps task, to study planning behaviour, that is also used in clinical evaluation of executive functions. This task is

based on a survey view ("an external perspective, such as an aerial or map-like view, allowing direct access to the global spatial layout"); however, in real life people mainly use a route perspective ("knowledge of spatial layout from the perspective of a ground-level observer navigating the environment")[4]. Therefore, the present study is aimed at developing a 3D version of the Maps task: in particular, a TMS paradigm has been used in order to interfere with the processes involved in the TSP, and to evaluate gender differences in the navigation task.
Several data indicate robust gender differences in spatial tasks and in navigation: men are generally faster, more accurate, produce less errors and learn routes faster than women [5]. These differences have been explained by a different employment of landmarks and spatial information: men seem to use a configurational approach in the judgment about distances and spatial relationships, while women treat landmarks as points of reference, localizing other landmarks upon these references and labeling objects either verbally and conceptually [6]. Grön et al. [7] showed a lateralization for spatial processes in females, that seem to use mostly the right hemisphere in spatial tasks, while men are reported to use more the angular gyrus in the left parietal lobe. The functional specialization of associative regions may support these differences. In facts, frontal injured patients show impairments on inhibition, memory and planning processes: Basso et al. [8] reported a decrease of heuristics changes in healthy subjects while the bilateral dorsolateral prefrontal cortex (PFC) was stimulated with Transcranial Magnetic Stimulation (TMS), resembling the impairment found in patients.

2 Methods

Twenty-one healthy subjects, (average age 25.4 years, s.d. 4.7) balanced for gender, gave their explicit consent to participate in the study, and for the video registration of their performance, after the description of TMS risks and attested effects on humans. The procedure was approved by the local ethical committee.

Based on the planning test Maps [3], the 3D Maps test uses a graphic motor (Duke Nukem 3D, by Atomic Edition, 3D Realms, Infogrames). Twenty mazes were created based on a selection of the situations used in the Maps task. The experimental paradigm was divided in 2 days: one day subjects performed 9 maps from the 3D Maps test while rTMS was applied on left and right PPCs; in the other day left and right PFCs were stimulated while administering other 9 maps. Each trial consisted in a survey-perspective map presentation (Fig. 1a), to allow subject to study the situation, create a plan and memorize routes. After the study period, each maze was hidden and the subject could start to execute the task by pressing the arrow keys in order to move the character. In the virtual 3D maps, the starting point was placed in a pending view (Fig. 1b), while the exit-point was represented by two doors placed on the corner opposite to the starting point (Fig. 1d). Subjects were asked to find the shortest path to collect all the seven subgoals (Fig. 1c) and to arrive to the final location in the shortest time. Subjects performances were recorded by means of a tape-videocamera, while variables were collected accordingly to Basso et al. 2006 [8].

A Dantec MagPro (Skovlunde, Denmark) machine was used to produce repetitive (1 Hz) biphasic impulses with an 8-figure coil, 100% of motor threshold. Stimulation was performed in the frontal area over F3 and F4 (respectively left and right BA9), and on the parietal cortex over P3 and P4 (left and right BA40), starting 5 seconds before each trial and ending when the subject reached the final goal.

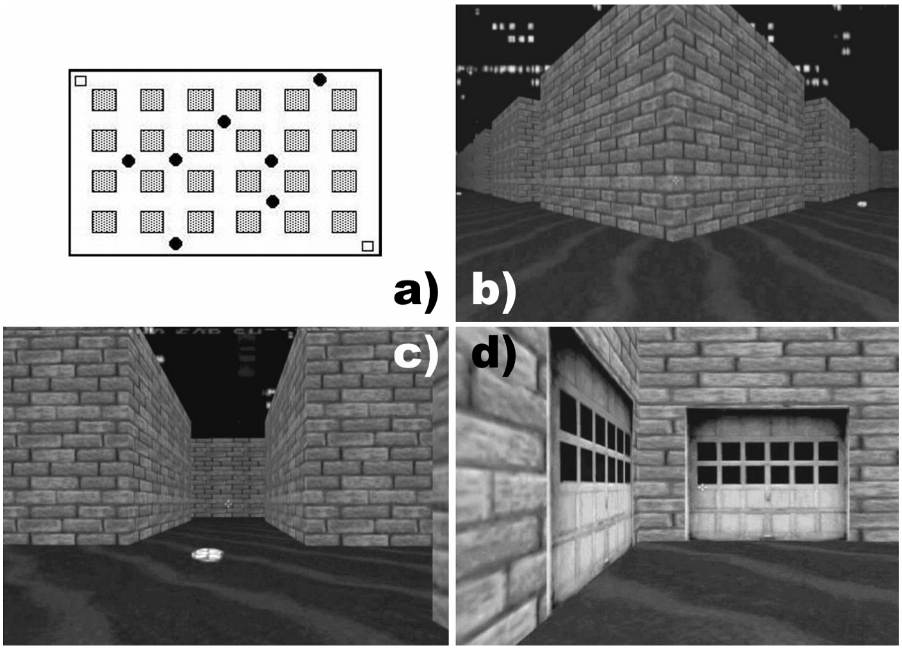

Fig. 1. a) an example of the paper map presented at the beginning of each situation; b) the view presented in the beginning; c) an example of a cross, in which one subgoal is present; d) the doors indicate the final location to be achieved.

Analysis of variance (ANOVA) has been run considering the following factors: gender (2 levels), TMS_site (2 levels: frontal, parietal), TMS_side (2 levels: left or right hemisphere – respectively: LH and RH). Moreover, Chi-square analysis has been used to evaluate the whether strategies depended on stimulation.

3 Results

Results showed a main effect of gender in the initial planning time ($F(1,748)= 108.27$, $p<0.01$) and in execution time ($F(1,860)=113.67$, $p<0.01$), as females exhibited higher values than males. A significant effect of stimulated site ($F(1,860)=5.60$, $p<0.01$, frontal site being faster), and the hemisphere x gender interaction ($F(1,859)= 19.78$, $p<0.01$) were present: males showed increased execution times when stimulating the LH; conversely, females showed longer execution times when stimulating the RH. The number of errors was significant for TMS_side ($F(1,748)=5.34$, $p<0.01$), TMS_site ($F(1,748)=6.99$, $p<0.01$) and their interaction ($F(1,748)=5.23$, $p<0.01$): subjects (both genders) missed more errands when stimulated on the RH, and when stimulated on PFC. The chi-squared analysis evidenced a significant prevalence of constant strategies with respect to the strategies with changes of heuristic, being higher in females ($chi^2(1)=3.92$, $p.<0.05$: 60% against 55% in males).

4 Discussion and Conclusion

Women exhibited longer planning times than men, with stronger effect when right parietal and left frontal lobes were stimulated. This result suggests a selective interference on the creation of a mental representation and its formalization into an action planning. This data is supported also by high execution times, longer trajectories and more errors, when stimulating the right PPC. A reliable representation is fundamental to organize an efficient plan: if this representation fails, the subject cannot base on the initial information and must actively explore the environment. Conversely, the interference to the right PPC in men seem not to affect the environment representation. This process in men seems to be highly automatic (while women have to actively produce it), thus TMS on left PPC seems to affect attention, rather than plan creation.

In conclusion, the 3D Maps test has shown to be a promising ecological way for the evaluation of visuospatial planning process from a route perspective. The results of the experiment showed important peculiarities in the behaviour: the TMS stimulation generated effects depending on gender and on the associative cerebral region.

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Acquiring Route Graphs from Human Instructions

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Abstract. A mobile robot that is given the task to get to a certain unknown location needs to acquire the missing route information in order to achieve the task. It is the goal of this work to use human-robot communication to gain the necessary route information. The robot asks humans for directions and builds a topological route graph from their answers. The robot then follows this route adding metrical coordinates while moving, thus validating the route graph and transforming it into world coordinates.

1 Introduction

An autonomous robot designed to operate in a highly complex human populated environment should be able to find its way to a given goal without previous route knowledge. The robot could get the missing route information from other robots which have already achieved this task or from web based information services or through exploration (which is very time-consuming in a complex environment). Another option is to ask humans for directions. Bugmann et. al. [1] use instruction based learning for a wayfinding problem where the robot translates the instructions into a sequence of motor commands that will lead it to reach a certain goal. When the robot is supposed to really learn a route to be able to follow it again, the human instructions should be included in a route graph (for modelling of navigational knowledge as route graphs, see [2]).

The aim of the Autonomous City Explorer project (ACE) [3] is to have an outdoor robot navigate autonomously to a given goal in the city of Munich without any prior map knowledge or GPS. The robot needs to acquire the missing route knowledge through human-robot communication. Therefore a system is envisioned that uses human instructions to build a topological route graph, verifies it while following it, and transforms it into a metrical route graph.

2 Overview of the Route Graph Acquisition

The robot (with a system as shown in Fig. 1) asks a passer-by for directions to a certain goal. It uses the human answers to build a topological route graph that includes uncertainties (taking into account the sometimes inaccurate human knowledge and possible misunderstanding). The robot will keep asking other humans as long as the route knowledge is not completed and the goal is not reached. When the robot has got a topological route graph, it will follow the route transforming it into a metrical route graph by including the real world coordinates of the nodes (i.e. the crossings).

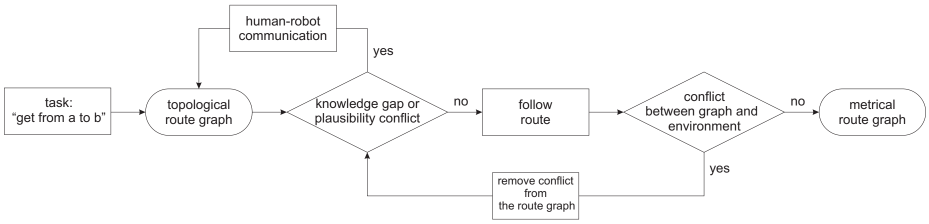

Fig. 1. Overview of the route graph acqusition system

2.1 The Route Graph

The route information is stored as a graph, where the nodes $N_i(x_i, y_i, c_i)$ denote crossings with the coordinates (x_i, y_i), and an additional certainty value c_i. The certainty value ranges from 0 (the coordinates of the crossing are random values, there is no knowledge of the real location) to 1 (the coordinates are correct). Certainty values between 0 and 1 represent information given by humans, the coordinates give relative directions, no absolute coordinates.

The edges denote actions that connect the crossings (e.g. follow the road until the next crossing is reached). The adjacency matrix has values between 0 (no connection) and 1 (certain connection). Values in between 0 and 1 are used to represent uncertainty due to possible misunderstanding or other inconsistencies, such as obstacles the human does not know about.

2.2 From Human Instructions to a Topological Route Graph

The robot starts only with the knowledge of the current position $N_{start}(0, 0, 1)$ and a given goal $N_{goal}(x_{goal}, y_{goal}, 0)$ (the goal coordinates are assigned randomly). The adjacency matrix is a 2x2 zero matrix. The robot will ask a human for a way from the current position to the goal and wait for answers that describe a route that is based on crossings as waypoints and the directions to crossings. The route description given by the human will be translated by the robot into the topological route graph, denoting the directions of crossings relative to the previous ones (i.e. left: x=0, y=-1; right: x=0, y=1; straight: x=1, y=0), the certainty value is set to 0.5. The adjacency matrix is expanded by one row and one column per crossing and the value of the connection between the crossings is set to 0.5.

2.3 From Topological to Metrical Route Graph

The robot has now got topological route knowledge, so it can start following the route towards the goal. If the certainty of the next crossing coordinates c_{next} is 1, it can move exactly to the associated coordinates (x_{next}, y_{next}). If the certainty c_{next} lies between 0 and 1, it follows the street along the given direction until it reaches a crossing. When a crossing is reached, the coordinates are changed from the relative directions to absolute coordinates, the certainty is set to 1 (although a small uncertainty remains due to imperfect sensors). If at some point the robot cannot follow the route in the given direction, e.g. when it gets to a dead end, it will delete the connection to the next crossing from the adjacency matrix and ask another human for directions.

3 Simulation

As a first implementation the robot is simulated in Player/Stage [4]. The robot operates in a maze-like environment (dimensions: 30m x 30m) and is equipped with a laser range finder. The Stage simulation is shown in Fig. 2 (left), the robot (red circle) starts in the upper left, the goal (red square) is in the lower right. The human is shown this map including the robot and is asked to explain the route to the robot. For example:
Robot: Excuse me, how can I get to the red square?
Human: Go straight, then turn left. Take the second turn to the right.
The robot interprets the crossings as nodes $N_2(1, 0, 0.5)$, $N_3(0, -1, 0.5)$, $N_4(1, 0, 0.5)$,

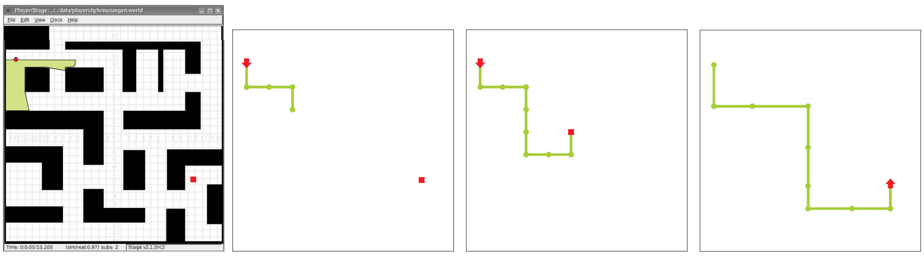

Fig. 2. Left: The environment simulated in Stage with the robot (red circle, laser depicted in green). Center: topological route graph with route knowledge, the edges have unit length. Right: metrical route graph acquired by following the route.

and $N_5(0, 1, 0.5)$ and inserts the connections between the nodes into the adjacency matrix. The route graph is now topological as it includes the directions of the single nodes relative to their neighbors, it contains no real world coordinates. The topological route graph is displayed to the human as shown in Fig. 2 (left center). As the graph is not complete the robot will ask the human again for more information:

Robot: How can I get from there (the last crossing) to the red square?
Human: Follow the street to the second crossing, turn left, go straight until you reach the second crossing, turn left again, and you are there.
The robot includes this new route information analogously into the topological route graph, see Fig. 2 (right center). When the human concludes with the reaching of the goal, the goal coordinates will be adapted to the route graph relative to the previous crossing and the certainty c_{last} is changed from 0 to 0.5.

When the robot has completed the communication with the human, it starts following the route. (It could have as well done this before it had known the entire route. Then it would have had to get back to asking a human at a later point, which is in fact the technique humans use to find their goal in an unknown city.) It turns in the direction given by the next node and moves in that direction until it reaches a crossing, there it sets the coordinates of the node to the measured real world coordinates and the certainty to 1, thus changing the information from topological to metrical. It repeats this behaviour until it reaches the goal where consequently it has got a complete metrical route graph, as shown in Fig. 2 (right).

4 Conclusions

A system is presented that asks humans for directions to a certain goal, includes this information into a topological route graph including uncertainties, and finally compares this graph to the real environment while following the route and transforms it into a metrical route graph. The system was implemented and simulated on Player/Stage.

The system will be implemented on an autonomous outdoor robot (the Autonomous City Explorer) and validated later this year. Also a plausibility check of the different human's answers will be included.

Acknowledgments. This work is supported in part within the DFG excellence initiative research cluster *Cognition for Technical Systems – CoTeSys*, see also `www.cotesys.org`.

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Perceptions of Building-layout Complexity

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Abstract. This poster presents an experiment on judgments of design complexity, based on two modes of stimuli: the layouts of corridor systems in buildings shown in plan view and movies of simulated walkthroughs. Randomly selected stimuli were presented to 166 subjects: 'experts' (architects or students currently enrolled on an architectural course) and 'lay people' (all others). The aims were to investigate whether there were differences between these two groups in terms of their judgments of building complexity, effects of modality of stimuli and if any environmental measures (geometric or complexity-based) correlated with the assessments. The results were, first, there are differences between the judgments of the experts and non-experts, second, the effect of modality was negligible for lay people but evident for the 'experts', third, the judgments of both groups correlated highly with a number of environmental measures.

Keywords: navigation, wayfinding, complexity

1 Aims and Significance

Three aims support the experiment presented in this poster. First is the investigation of the differences in how architects and non-architects view building-layout designs with respect to perceptions of complexity and judged ease of wayfinding. Second is to determine whether the mode of presentation of the design influences such judgment. Third is to determine whether the subject's judgements of design complexity correlate with a set of objective, environmental measures.

This study focuses on two particular types of design-criterion that *may* play a role in the process of architectural design, that of 'design complexity' and the allied judgment of 'ease of wayfinding'. These judgements are of importance, not only to the architect engaged in the process of design, but equally to the end-user of any building. Previous work on judgments of complexity has tended to fall predominantly into one of two groups: those primarily concerned with subjective assessments of design and those focused on computational measures of complexity. This poster attempts to consider *both* the subjective assessments of complexity as well as objective, computational measures and to determine the relationship between them.

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2 Method

The study by Weisman [4] provided the first systematic assessment of floor plan complexity by human judges. He used thirty simplified building layouts that spanned a wide variety of building styles. We opted to use his original materials as the starting point for this study.
Thirty simplified building layouts were used. Our stimuli, both in plan and movie mode, are reduced to corridors, with no indication of the building-envelope, rooms or other spatial subdivisions. The corridor-layouts were then assigned to a number of classes or ‘bins’ from which stimuli could be selected randomly. The layouts were grouped into the bins by attributes of their environmental features. Having established 16 bins based on the number of axial lines, the number of spatial symmetries and O’Neil’s ICD measure [3], it became evident that two additional building layouts were required. These were added to the sample, ensuring that each bin contained between 1 and 3 layouts.
The construction of each walkthrough movie required the selection of navigational paths for each building layout. The paths aimed to traverse the maximally possible distance. This difference between the modalities means that the task for the judge is quite a different one for the plan views versus the egocentric movies (see fig.1 for example stimuli).

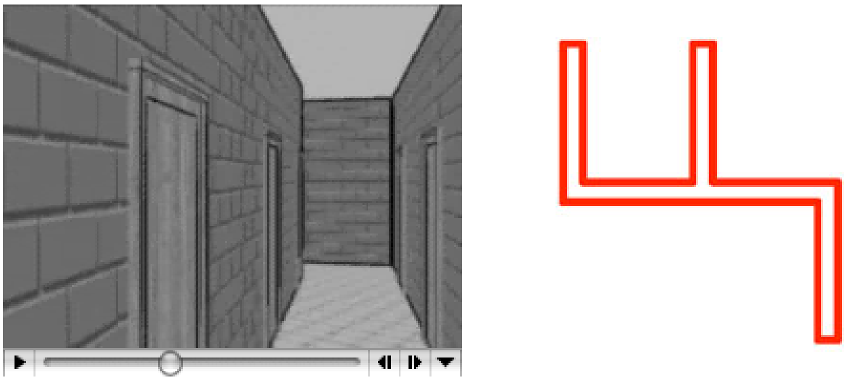

Fig1. Layout-stimuli as Ego-centric Movie (left) & Abstracted Plan (right)

The complexity-judging task was administered in the form of an online questionnaire, which took approximately 20-30 minutes to complete. Each participant is presented with 16 layouts, one from each bin. Each layout is presented both as a movie and as a plan view. Presentation format and order is balanced and randomized into six blocks of 5-6 stimuli, with each block containing either movies or plans.
Subjects were instructed to view each plan or movie and were asked to make two judgments: first, of the complexity of the layout (ranging from ‘simple’ to ‘complex’) and second, of the projected ease or difficulty of finding one's way around a building

with such a plan configuration (ranked between ‘easy’ and ‘difficult’). Both ratings used 9-point, discrete Likert-scales. In total 166 subjects successfully completed all parts of the questionnaire and were included in the following analyses. Of these 52 were architects or had an architectural education and 114 could be considered ‘non-experts’ or laypersons.

A number of measures were calculated to determine if any objective factors of the built environment correlated with people’s subjective judgements of complexity and could thus be used predictively. Many of these were straightforward geometric measures such as a layout’s area, perimeter or its number of walls and polygon vertices. Other measures were included due to evidence in the wayfinding literature that they may play a role in how easily people navigate: the number of symmetries was included (the number of lines of symmetry, rotational symmetries and their sum were evaluated) and the number of axial lines and convex spaces [2] in the layout. Finally, other measures were calculated: the number of ‘topological holes’ in a layout, convexity (a measure developed by Batty [1])) and O’Neill’s measure of ‘ICD’ [3] or *interconnection density.*

3 Results

In this study we find substantial differences between the measures of ‘complexity’ and ‘wayfinding’ when comparing movies versus plans or experts versus laypeople.

The results of this study reveal that the laypeople’s ratings of complexity versus wayfinding differed more distinctly when rating movies, and with smaller differences in rating plan-view images. This can be contrasted to the performance of the experts who appear to perceive greater differences between complexity and wayfinding difficulty in plans rather than movies. Architectural experts judge the same materials as being simpler in plan mode, while laypeople judge the layouts as simpler when presented as movies. A tentative interpretation of this finding is that experts are more familiar with assessing plan views, while laypeople have greater difficulties interpreting plans and thus find movies easier to comprehend. This difference does not extend to rating wayfinding difficulties per se: a further indicator that architects and laypeople interpret the two rating tasks in a different manner.

4 Correlation between Judgments and Environmental Factors

A number of environmental variables are shown to correlate highly with participants’ judgments. Architects react differently to symmetry depending on the presentation modality; they appear to be distinctly critical of the complete lack of symmetry in the low-symmetry group when presented in movie-mode. In plan-view, the high-symmetry, high-number-of-elements stimuli are judged as rather complex and difficult to navigate, while in movie-mode these elements receive relatively positive ratings. For complexity, the pattern is similar: highly symmetric elements are judged as simple and easily navigable in the movie modality, but in plans, the experts attribute high complexity to layouts with many elements, despite high symmetry. In conclusion, the fact that the variables initially identified through factor analysis appear to be particularly relevant for predicting human assessments of complexity and navigability can be taken as an indication that our stimuli covered a considerable range of the potential feature space.

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New Perspectives on Built Environment Models for Pedestrian Navigation

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Abstract. We present a map modelling toolkit that meets the special requirements of pedestrian navigation in intelligent environments. Its central component is a graphical editor, which supports the geometric modelling and visualization of built environments in 3D. Multiple levels and their interconnections, such as ramps and staircases, can be represented through layers. The toolkit also integrates a route finding module for pedestrian navigation applications. The model and the route can be shown as an orthogonal (map-like) projection or from different perspective viewpoints; the allocentric viewpoint shows the model from outside (bird's view), the egocentric viewpoint shows the model from the user's perspective inside the building. Landmark objects can be included and the visibility of signage or public displays can be virtually evaluated using the avatar. Various animations can be created to visualize the route, including transitions between the perspectives.

Keywords: location modelling, pedestrian navigation, intelligent environments

Motivation

Our research aims towards systems that provide ubiquitous navigational aid for pedestrians, with an emphasis on indoor environments. The situation of a pedestrian differs from driving tasks, since the user is not bound to follow paths or streets. Instead users typically cross open spaces, directly following their line of sight. The model has to particularly reflect this and represent places as polygonal objects, in contrast to ordinary street map databases, which usually consist only of line segments in two dimensions. The big providers of navigational maps for mobile systems have recognized the benefit of three-dimensional visualizations, but they are still focused on outdoor environments. As pedestrians spend most of their time inside buildings, indoor environments need to be modelled in 3D with multiple floors and landmarks. Inside, decision points are more complex than outdoors because stairs and elevators add choices. For the same reason, routes can not be depicted easily in a single map, so that indoor wayfinding tasks generally pose a high cognitive load to the user.

Assisting the user with mobile devices however is quite challenging, because no standardized positioning technique like GPS is available for buildings, and electromagnetically noise often hinders the estimation of the user's orientation by a compass. Hence we focus our work on digital media signage because the location of the displays is exactly known to the system. Some of our research questions are: where to place displays, how many do we need, and how to present route instructions.

The Yamamoto Toolkit

Our toolkit, which is called *YAMAMOTO* (**Y**et **A**nother **Ma**p **Mo**delling **To**olkit), see also [2], is positioned between proprietary two-dimensional location models that are typical for ubiquitous and pervasive computing research projects on indoor navigation, and professional three-dimensional CAD (Computer Aided Design) tools for architects. CAD tools require a high level of experience; the designer has to manually cut out windows and doors from solid walls and has to take care about window sills, choices of door handles or steps of a staircase. Such a high level of detail is not required for route finding and presentation purposes. Our approach strives to minimize the modeling effort. By following the motto to keep everything as simple as possible, we have intentionally reduced the degrees of freedom by half of a dimension in order to allow for a simpler and easier to learn user interface.

As the toolkit has been designed with pedestrian navigation in mind, it also includes a route finding module. It is able to generate routes between any two points in a model, which follow the line-of-sight whenever possible and does not require a predefined and restrictive path network.

Understanding the 2½ dimensional model

Now what exactly does this mean, and what are the implications? Rooms of a building are represented only by their outline as flat polygon objects. Each polygon object is defined by an ordered sequence of vertices. Each vertex however is represented through Cartesian coordinates as a triple of (x, y, z) values. The z value allows representing the room's height above ground level, so that multiple floors can be represented. Polygons can have several symbolic attributes, such as name, type, and accessibility for pedestrians. Polygons that are defined by vertices from two different levels represent connections such as ramps, stairs or escalators. Figure F (left) shows an example, where the polygon "Corridor.14021" is defined as sequence of vertices with index (1, 2, 3, 4, 5, 6, 7, 8). In order to allow for route finding it is important to know the semantics of connections between polygons. Thus each edge is attributed by their passability: edges that represent walls or windows are set to be "not passable", in our example edge (8, 1) represents a wall; edge (6, 7) connects the corridor with the adjacent staircase and is annotated to be "passable for pedestrians". On the right hand side in Figure 1, a sample path is shown that has been calculated based on start- and ending points within the 2½ dimensional location model.

Based on the outlines of the rooms and some additional annotation of type and height, *YAMAMOTO* automatically creates the building structure in full 3D. By using the predefined building blocks shown in Figure 2, edges can be visualized in the perspective views as walls, doors, murals or handrails.

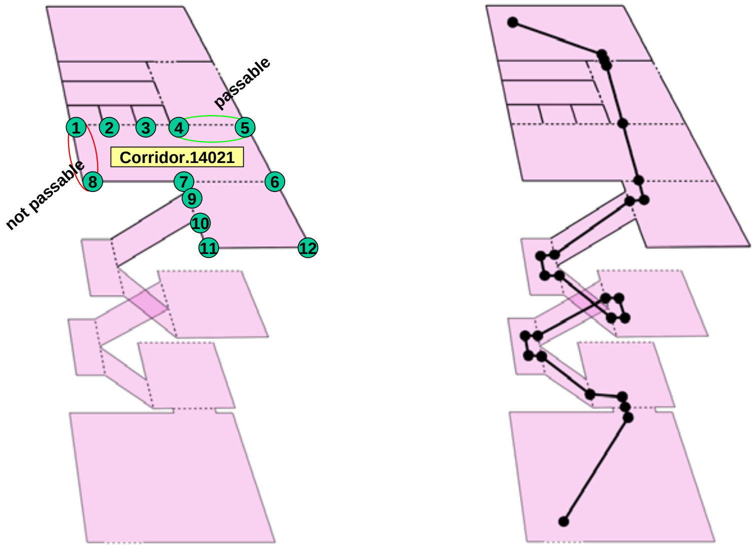

Fig. 1. The 2½ dimensional data model (left) and a route between two points (right).

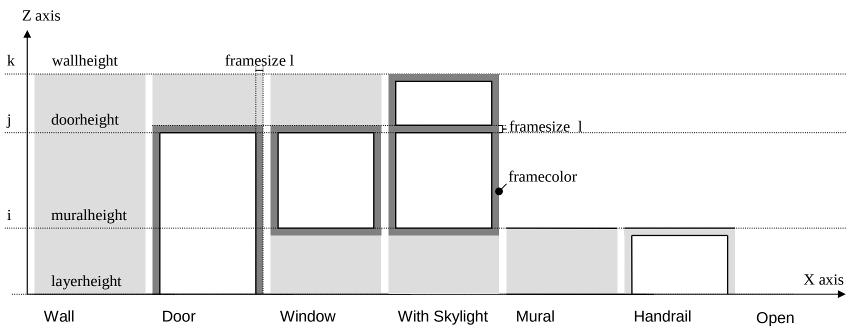

Fig. 2. Set of building blocks, used to automatically create 3D geometry from the 2½D model.

Allocentric and Egocentric Perspectives

One can choose in *YAMAMOTO* at any time among different viewpoints. The orthogonal view shows a top-down projection of the model similar to traditional maps. The perspective view shows the model from an allocentric viewpoint outside the model, as seen in 3a), and allows for free rotation and zoom. The user itself can be virtually represented in the model through an avatar object. The egocentric perspective shows the model from the viewpoint of this avatar, see 3b). It allows for the virtual exploration of the modeled environment. It also creates a demand for interior items that could serve as landmark objects for route descriptions. Rooms can be equipped with predefined 3D objects like shelves, tables or pictures, as seen in 3a) and 3b). Furthermore, one can instrument the environment with pervasive computing artifacts, i.e. beacons used for indoor positioning/navigation and public displays. The avatar view lets the designer virtually examine the visibility of the displays from various positions and helps to identify the best configuration, as described in [3]. In particular the possible interpretation of graphical signage, e.g. an arrow pointing upward, can be ambiguous depending on the actual context of the building. Such situations can be virtually evaluated and resolved before the signs are deployed.

Fig. 3a. Allocentric perspective

Fig. 3b. Egocentric perspective

Results

In order to assist pedestrians in their wayfinding tasks, we have used *YAMAMOTO* to automatically generate visual route instructions for public displays. We have conducted a user study with fourty-eight subjects and compared their performance under three different conditions: (1) floor maps, (2) a sequence of 3D pictures of decision points, and (3) an animation that shows the movement through the virtual building from the egocentric perspective. As a preliminary result, considerably fewer errors have been made by the subjects who saw the animation [1]. Presumably it is easier for the subjects to memorize the turning information through the movement of the virtual camera in comparison to static, symbolical information, such as arrows.

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GQR – A Fast Reasoner for Binary Qualitative Constraint Calculi *

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Abstract. GQR (Generic Qualitative Reasoner) is a solver for binary qualitative constraint networks. GQR takes a calculus description and one or more constraint networks as input, and tries to solve the networks using the path consistency method and (heuristic) backtracking. In contrast to specialized reasoners, GQR supports arbitrary binary constraint calculi, such as calculi for spatial and temporal reasoning, e.g. calculi from the RCC family, the intersection calculi, Allen's interval algebra, cardinal direction calculi, and calculi from the OPRA family. New calculi as well as their combinations can be added to the system by specifications in a simple text format. The tool is designed and implemented with genericity and extensibility in mind, while preserving efficiency and scalability. The user can choose between different data structures and heuristics, and new ones can be easily added to the object-oriented framework. GQR has already been successfully used in various projects.

1 Introduction

Qualitative constraint calculi are representation formalisms for efficient reasoning about continuous aspects of the world. Contrary to numerical or quantitative formalisms, which often rely on undecidable formal systems, qualitative calculi provide an abstraction layer over metrical data, which can be applied for developing efficient reasoning methods. In the past 25 years a huge list of such calculi has been discussed in the literature (see, e.g., [1]). Examples include the point algebra [2] and Allen's interval algebra [3], the various region connection calculi [4], the intersection calculi [5], cardinal direction calculi [6], the OPRA calculi [7], and many more. Qualitative calculi can be applied in the modeling of natural languages, for representing spatial or temporal aspects in human-machine interaction, in high-level vision systems, and in high-level agent control applications. Qualitative calculi can also be used in query rewriting and

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data integrity checks in Geographic Information Systems (GIS) or as an add-on to planning systems to restrict possible state transitions by temporal or spatial constraints.

GQR (Generic Qualitative Reasoner), developed at the Universities of Hildesheim and Freiburg, is a solver for binary qualitative constraint networks. GQR takes a calculus description and one or more constraint networks as input, and tries to decide consistency of the networks using the path consistency method and (heuristic) backtracking. In contrast to specialized reasoners, it offers reasoning services for different qualitative calculi, which means that these calculi are not hard-coded into the reasoner. Currently, GQR supports arbitrary binary constraint calculi; new calculi as well as their combinations can be added to the system by specifications in a simple text format or in an XML file format. GQR is freely usable and distributable under the terms of the GNU General Public License. It can be downloaded from: `https://sfbtr8.informatik.uni-freiburg.de/R4LogoSpace/Resources/GQR`.

2 Related Work

When the development of GQR started, there were only reasoners for particular calculi [8, 9]. In order to reason in a new calculus, one had to develop a new program, modify an existing one for a similar calculus, or encode it in a more generic logic — usually first-order logic, but also propositional modal logic — for which solvers exist.

In the meantime there exist similar research efforts. The qualitative algebra toolkit (QAT) [10] is a Java implementation of tools and libraries for qualitative calculi and constraint networks developed at the Université d'Artois. It features amongst others support for *n*-ary calculi and a solver utilizing various reasoning algorithms for the consistency and minimal network problem. SparQ [11] is developed at the University of Bremen. It provides support for binary and ternary calculi, transformations from quantitative descriptions into qualitative representations, and constraint-based reasoning methods, such as the path consistency algorithm and backtracking search. SparQ is written in LISP with libraries implemented in C.

In contrast to those tools, the main focus in the design of GQR has been to implement a *fast* and *extensible* generic solver, which preserves the efficiency of calculus-specific solvers as much as possible.

3 Qualitative Reasoning with GQR

Reasoning in GQR is based on a purely syntactical definition of qualitative calculi [12]. A *(binary) qualitative calculus* is defined by a non-empty finite set of relation symbols (*base relations*), a converse function for relations, a binary composition function, and an identity relation such that some minimal algebraic requirements are met. The formal language associated to a qualitative calculus (in this sense), then, includes all sets of base relations (referred to as *relations*). A set of base relations is read disjunctively and hence can be used to express imprecise knowledge.

Reasoning problems in qualitative calculi are usually formulated as so-called constraint satisfaction problems. The instances of these problems can be described as *constraint networks*, which are directed finite graphs, where nodes represent objects and each edge is labeled by a set of base relations of the calculus (representing the *constraint relation* between the connected nodes). In GQR these graphs are represented as *adjacency* matrices, where each entry encodes the calculus relation between two nodes in the graph. The constraint satisfaction problem, then, is to determine for a constraint network, whether there exists an assignment to its objects/nodes in a given domain such that all constraints of the network become true (based on a fixed interpretation of the relational symbols on the domain).

A crucial aspect in qualitative reasoning is the fact that the underlying models are typically infinite. Hence, in order to test satisfiability of constraint networks, it is not feasible to enumerate all possible assignments to variables in a model until one finds a satisfying assignment. For this reason, other techniques based on algebraic and semantic properties of the calculus must be applied for testing satisfiability. In particular, the path consistency algorithm manipulates a given constraint network by successively refining the labels $r_{x,y}$ (on the edge from node x to node y) via the operation $r_{x,y} \leftarrow r_{x,y} \cap (r_{x,z} \circ r_{z,y})$, where z is any third variable occurring in the network, until a fixpoint is reached (here $\circ$ denotes the composition and $\cap$ the intersection of relations). Hence, a relation between two objects is refined by the objects' relations to other objects and the composition operation. In GQR Mackworth's variant of the path consistency algorithm is implemented [13], which runs in cubic time in the size of the constraint network.

Since, in general, the path consistency method is not sufficient to decide consistency of constraint networks, GQR uses chronological backtracking, trying out different instantiations of the constraints containing disjunctions of base relations (cf. [3, 9, 8]). Moreover, by using known tractable subclasses of a calculus (i.e., sets of relations closed under intersection and composition, for which the path consistency method decides consistency), one can speed up reasoning: instead of splitting a constraint during backtracking into base relations, one can split it into relations belonging to a tractable subclass, which reduces the branching factor of the search tree considerably (cf. e.g., [9]). Both the path consistency method and the chronological backtracking search may benefit from heuristics about which part of the constraint network is to be processed next. Currently, the weight and the cardinality heuristics [8] are implemented for the path consistency method. For the backtracking search, the cardinality heuristic for variable selection [8] is implemented.

GQR is written in C++. Because of its object-oriented design, users may add their own heuristics quite easily. New qualitative calculi are defined by writing simple text or XML files, which are then read and processed by the reasoner. Furthermore, it is possible to define combinations of calculi such that either a new calculus is obtained or the reasoner works on multiple constraint networks in parallel and propagates information between them. GQR currently includes calculi definitions for: the point algebra, Allen's interval algebra, RCC-5, RCC-8, OPRA-4, and the cardinal direction calculus. Additionally, the program is able to check several algebraic properties of specified calculi.

Finally, it should not go unmentioned that GQR has already been used successfully (a) in a high-level agent control system implementing rule-compliant behavior of agents in sea navigation [14] (where reasoning in a large constraint calculus such as OPRA-4 turned out to be crucial) and (b) for the evaluation of different algorithms for application-specific customizations of qualitative calculi [15].

4 Future Work

We are currently working on the next generation of GQR, which will allow for processing ternary constraint calculi. Also, a module that automatically computes the weights used in the heuristics will be implemented. Furthermore, we plan to compare the performance of GQR to that of other reasoners, especially with respect to larger calculi.

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Which properties define the ‘salience’ of landmarks for navigation? – An empirical investigation of shape, colour and intention

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Abstract. Landmarks represent a very important source of information within the navigation process. However, which parameters define the perceived salience of such objects? We investigated two basic (low-level) visual properties of landmarks, namely shape and colour. We found that shapes revealed significantly higher performance than colours. The data will serve – together with further navigation experiments in virtual reality settings – for the development of an empirically-based landmark salience model.

1. Introduction

Computer-based navigation systems are nowadays very common in Europe or North America, but humans are very good in navigating without such artificial help. Many theories of spatial cognition and navigation assume that objects on our routes, so called *landmarks*, are an important source of information for navigation (e.g., Janzen & van Turennout, 2004; Saucier, Green, Leason, MacFadden, Bell & Elias, 2002; Steck & Mallot, 2000). Landmarks are generally defined as ‘salient’ objects in our environment, which draw our attention and which can be better remembered because they ‘pop out’ from the environment (e.g., Janzen & van Turennout, 2004). Landmarks represent an important part in navigation research, but mostly in computational approaches or theories on city-planning, etc. (e.g., Galler, 2000). But, what exactly makes a landmark a “salient” or “good” landmark? How important are the different visual low-level features of these objects? For example, if you imagine the sign of a famous fast food company, is it important that this sign has the shape of the letter “M” or is it more important, that it has yellow colour in order to pop out from the surrounding? The following studies were conducted to answer these questions. Specifically, we were interested in the basic, low-level properties of shape and colour (bottom-up), how these features affect the processing of landmarks, and how these features are stored in memory during navigation. These simple features are often neglected or just confounded with other variables, such as meaning or famousness (e.g., Janzen & van Turennout, 2004, Pazzaglia & Taylor, 2007).

Another important point, was the question whether attention, which is explicitly paid to a landmark, is able to influence the recognition performance (top-down) in navigation. In order to control for this, we varied the intention of the individuals by using three different task instructions: “remember the landmarks”, “remember the route”, or no specific instruction at all (“just watch the movie”).

2. Method

We conducted two experiments in a virtual maze on a three by four metre projection wall. In the following we refer to the first study as “shape experiment” and to the second as “colour experiment”. We report both experiments together because the only difference between the two studies was that the landmarks varied either in their “shape” or in their “colour”. All other details of the procedure were identical.

2.1 Subjects

We investigated 20 participants (10 females) in the “shape experiment” and 17 participants (8 females) in the “colour experiment”. All were students of the University of Giessen. Their age ranged between 18 and 36 years. All participants had normal or corrected-to-normal visual acuity, normal colour vision (tested with pseudo-isochromatic plates), and all were naive with respect to the experiments.

2.2 Material

The 3D-virtual-maze that we used in the experiment was created with Google Sketch-Up 6.4. It is a ten-by-ten square-shaped maze called ‘Squareland’ (Fig. 1). We created movies with an egocentric perspective of a person walking through this maze (simulated eye-height 170 cm) containing different landmarks. In the “shape experiment” 24 landmarks varied in shape, in the “colour experiment” 24 landmarks in different colours were used. The movies were presented on the projection wall in front of the participants. Superlab 4.0 (Cedrus Corporation) was used for running the experiment and data recording. The design of the experiment is presented in Table 1. The landmark materials and the maze are presented in Figure 1.

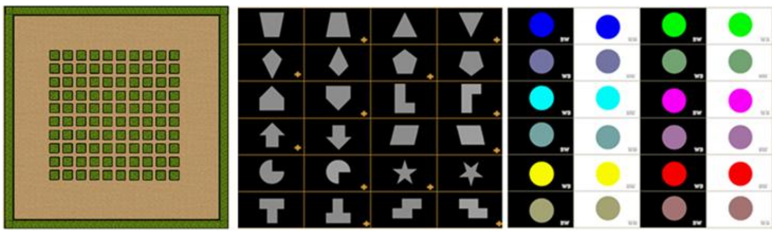

Fig. 1. Maze (left), Materials in the “shape” and (middle) and colours (right) experiment

Table 1. Instructions and distribution of participants per condition

Shape experiment			Colour experiment		
Remember objects n=5	Remember route n=6	No specific instruction n=9	Remember objects n=8	Remember route n=5	No specific instruction n=4

2.3 Procedure

The experiments started with a 2 min. movie, containing either 12 shape landmarks (in front of a low luminance surround; black; indicated with '+' in Fig. 1) or 12 colour landmarks (in front of either high luminance or low luminance surround; white or black), with different instructions (Table 1). Participants were passively led through the maze with a speed of 2 m/s. Subsequently, the landmarks that appeared in the movie were presented on the projection wall together with other twelve colour or shape landmarks that were not seen in the maze (distracters). The participants' task was to judge, whether they had seen the item as a landmark in the maze or not.

3. Results

Analyzing the data with an independent-samples t-test, we found that the shape of landmarks was significantly better remembered than their colour (63% vs. 56% correct recognition; t=2.296; p=.028). In more detail, the colours cyan and yellow differed significantly from chance-level in a positive direction (t=2.416; p=.028) (t=5.215; p=.000), whereas green showed significant differences in the opposite direction (t=-3.043; p=.008) (Fig. 2). There were also significant differences between the shapes (e.g., sign. differences in reaction times between arrow and its distracter; t=-2,173; p=.043).

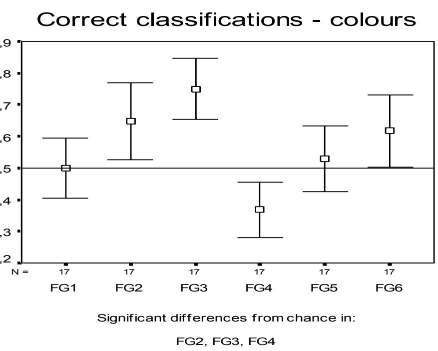

Fig.2. Mean value and standard errors in colour recognition rates including FG1=blue, FG2=cyan, FG3=yellow, FG4=green, FG5=magenta, FG6=red

As a result of these data, we performed a control experiment with a different surround (wall structure instead of hedge) in order to examine whether the bad performance on green objects was due to a lack of colour- and luminance contrast (leading to a weaker pop-out from the greenish hedge background). In this experiment, we tested six participants with the same procedure as described above, but the maze background was changed into a brick stone texture. Here, similar results were obtained for green, but cyan or yellow did not produce as good recognition as they did before.

Analysis for the different instructions did not reveal any significant effects, so these data were pooled in the proceeding analysis.

4. Discussion

We were able to show that the shape and colour of objects have a differential effect on how salient the objects are as landmarks on a route during navigation. Shape seems to be a more important feature than colour. However, we also found, that yellow objects produced better recognition than every other colour in a hedge maze and that green landmarks produced the worst recognition performance. One possible explanation is, that colours like yellow and red, known as so called ‘signal colours’, are better remembered colours for landmarks than typical ‘background’ colours like green. Such colours seem to be no good features for landmarks, independent of surround and contrast (luminance and colour).

In conclusion, the colour of a landmark seems to be less important than its shape, Thus, the big yellow ‘M’ as a landmark could for example probably also consist of the colour blue, since we showed that colour is less important than was assumed so far. Therefore, some of the theoretical and computational models dealing with landmark salience need to be revised using empirical data for improved models.

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Learning of Visual Route Instructions for Indoor Wayfinding

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Abstract. Visitors of complex buildings might be presented with individual visual route instructions shown on ambient displays. Such route instructions can automatically be generated by a modelling software. It was investigated which route instruction format would foster human wayfinding most effectively in a naturalistic wayfinding scenario in a real building. Egocentric, view-based formats (animated virtual walk of the route, sequence of pictures of decision points) were compared to maps with route indication. In each of the three conditions, 16 participants were tested individually. Participants watched the route instruction passively and then walked the route through the real building. Critical wayfinding errors showed a clear advantage of the animated "virtual walk" instruction format. This advantage is explained by the accordance of the virtual walk with the real wayfinding experience. This includes the "analogous" transmission of turning information in the form of movements of the virtual camera.

Introduction

Learning Routes

Studies on environmental learning suggest that qualities of mental representations of the environment differ (Siegel & White, 1975), depending on the learning experience (e.g. Thorndyke & Hayes-Roth, 1982; Shelton & McNamara, 2004). Route knowledge is conceived as associative memory of an ordered sequence of landmarks and directions from egocentric views, such as experienced when navigating. Route knowledge might thus best be learned if a route is presented sequentially from the egocentric perspective.

Empirical studies on route learning in real environments, however, do not consistently support this idea. For instance, first-time visitors of a university campus, which were presented with route instructions at an information desk, preferred maps over a sequence of view-based photographs (Devlin & Bernstein, 1995). Passively viewing a route in a virtual environment did not transfer to wayfinding success in the real building, and virtual environmental training was not superior over studying a map (Farrell et al., 2003). Indoor wayfinding behavior might be affected by a number of factors, including the complexity of the architecture and individual strategies (Hölscher et al., 2006). The present study investigates what route instruction format is most effective for route learning in a complex building.

Wayfinding support in complex buildings

Visitors are presented with individual visual route instructions on ambient displays in the environment. The present approach is based on the modelling software Yamamoto (Stahl & Haupert, 2006). A model of a building includes outlines of rooms and corridors, height data, topology and definition of building levels and staircases, as well as semantic annotations (like ‘this edge represents a door that connects two rooms’). The resulting model represents all structural elements with their function for wayfinding. In conjunction with a routing algorithm, Yamamoto automatically visualizes any path inside the building from egocentric as well as from allocentric perspectives.

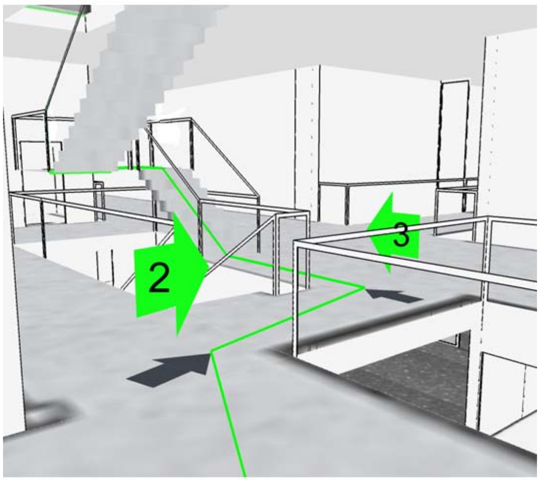
Empricial Study

Materials and Procedure

The new computer science building on Saarland University campus was chosen as the real environment for the present study. The building consists of separate functional areas with different structural features. Two partial routes were selected. The first partial route led through an open gallery system on the first floor to the library’s terrace on the second floor, and the second partial route led from the library to a particular meeting room on the third floor, which comprised a corridor with side-by-side office rooms.

Experimental conditions differed with respect to the visual format of the route presentation: (1) in the map condition, floor maps were shown in which the route was indicated by a line, (2) in the picture condition, a sequence of pictures of decision points along the route were shown (Fig. 1), and in the animation condition, (3) an animation showed the movement through the virtual building from the egocentric perspective.

Fourty-eight participants took part in the study (age M = 23.8; SD = 4.4). In each condition, 16 participants (8 female, 8 males) took part. Each participant was tested individually. Participants did not know the computer science building. They were paid for participation. Participants were shown the route instructions on a tablet PC at the beginning of the route. Presentations were of the same duration in each of the conditions. Participants then navigated to the destination without further assistance. In the present naturalistic scenario, they could also use information given in the environment (e.g., room numbers). The experimenter walked behind the participant and measured critical wayfinding errors (way lost) at decision points.



1.OG

Fig. 1. Example image of the picture condition.

Results

Overall, 62 % of the participants made no critical wayfinding errors on the entire route, while 38 % of the participants made one or more (up to five) critical wayfinding errors. The number of critical errors differed between route instruction conditions (Table 1), non-parametric Kruskal-Wallis test, qui-square (df = 2) = 6.835; p < .05. In addition, the number of participants who made critical errors in the different route instruction conditions was considered. Nine out of 16 participants who had received floor maps made critical wayfinding errors, and seven out of 16 participants who had seen pictures made critical wayfinding errors. In contrast, only two participants out of 16 who had seen animations made critical errors. These numbers differed significantly, median test, chi-square (df = 2) = 6.933, p < .05. The numbers of critical wayfinding errors made by women vs. men did not differ significantly.

Table 1. Numbers of critical wayfinding errors made by women and men in the experimental conditions.

	Maps	Pictures	Animation
Women	10	9	2
Men	9	5	0

Discussion

Results demonstrate a clear advantage for showing the animated virtual walk. About half of the participants who were provided either with (allocentric) maps or with (egocentric) sequences of pictures of decision points lost their ways. The advantage of the animated condition might be explained with the form of information transmission about complex turns. Turning movements on stairs, turns immediate after leaving the stairs, as well as U-turns were critical points at which errors were likely to occur. The animation transmits turning information through the movement of the virtual camera. In contrast, the same information is transmitted symbolically (by showing arrows, Fig. 1) in both of the other conditions. Presumably, participants did not succeed in encoding and memorizing these symbols while passively viewing the picture sequences or the map. In contrast, when viewing the animation passively, the turning information was successfully learned due to the “analogous” transmission of that information by virtual camera movements without active encoding.

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Re-orienting strategies of domestic chicks in a rectangular array of landmarks

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Abstract. To investigate the capabilities of birds to reorient on the basis of the geometrical information provided by a landmark array, we trained domestic chicks in a circular enclosure to find out a reward hidden in correspondence of one out of four landmarks, arranged to form a rectangular configuration. In the first experiment (N=42), the rewarded landmark differed from the other, clearly indicating the presence of the food. After training, a series of non-geometrical transformation tests were administered. The search pattern of the chicks indicated that, even if they had learnt to localize the food using the featural information, they neglected the geometrical cues of the array. In the second experiment (N=12), chicks were trained with identical features. The subjects did not learn to distinguish between the geometrically correct and uncorrect locations. We hypothesized that, in this species, geometrical encoding is done only for highly stable information, typically provided by the global aspects of a visual scene.

Keywords: Domestic chicks, landmark array, re-orientation.

1 Introduction

It has been shown that animals are able to encode the geometrical information provided by the shape of an environment. Rats trained to localize a reward hidden in correspondence of one of the corners of a rectangular enclosure, retrieved the geometrical representation of the environment to partially overcome the spatial ambiguity of the enclosure, focusing their search equally at the geometrically correct corner and its rotational equivalent [2]. Similar results were obtained in humans, primates, birds and fishes [3].

Whether a geometrical encoding also occurs for the arrangement of isolated landmarks has received increased attention recently [1]. An approach designed to investigate this issue is that of using a circular enclosure, where a rectangular configuration of local cues can be located. It has been shown that in these circumstances rats successfully encode the geometrical aspects of the array given by

the distribution of the local cues [5, 8]. In contrast, human infant seems to be unable to distinguish between geometrically correct and uncorrect locations as defined by purely local cues [7, 9].
The literature reports that birds are able to encode relevant position in relation to the surrounding landmarks [4]. However, avian species have not yet been systematically observed in arrays of local landmarks [10-11]. This work aims at fulfil this gap, examining the capability of young domestic chicks to re-orient within a circular enclosure using a rectangular configuration of landmarks.

2 First experiment

We trained 42 domestic chicks to localize a reward buried under sawdust in correspondence of one out of four landmarks, arranged to form a rectangular array (30x60 cm). Three of the landmarks were undistinguishable, whereas the rewarded landmark presented a characteristic visual pattern. The configuration was located within a circular enclosure (Ø 130 cm diameter; 50 cm height), which floor was covered by sawdust. Chicks were trained to ground scratch at reinforced landmark to gain the access to the food. Each training session consists of 3 series of 10 trials. A disorienting procedure between trials was administered. After training, the feeder was removed and the subjects were observed under one of the following experimental conditions: a) with same array as during training (CONTROL); b) with four IDENTICAL landmarks, of the type previously non-rewarded, of the type previously rewarded, or of a new type; c) after having transformed one of the landmark located at the geometrical incorrect position into the type of landmark previously rewarded (SIMIL-AFFINE TRANSFORMATION) d) with a fifth landmark of the type previously rewarded at a new location (EXTERNAL).

2.1 Results

In the CONTROL group, chicks searched consistently in correspondence of the polarized cue without errors (100% correct). Subjects tested in the IDENTICAL conditions, particularly when the cues were of same the type of that rewarded at training, searched randomly among the landmarks, indicating that the residual information provided by the geometry of the array was not encoded at training (**Figure 1**). In the SIMIL-AFFINE TRANSFORMATION and in the EXTERNAL groups, chicks divided their choices equally to the landmarks that presented the feature rewarded at training (**Figure 1**).

3 Second experiment

We trained 12 male chicks in a rectangular array of four identical landmarks, arranged within the same enclosure used in the first experiment. The reward was hidden in correspondence of two landmarks, which occupied equivalent positions as defined by the geometry of the array. As featural information could not specify unambiguously the presence of the reward (the landmarks were all identical), chicks could rely only on the geometry of the configuration to provide a partial disambiguation of the task. Trials were administered following the same procedure describe for the first experiment. After 240 trials, the chicks performance did non differ statistically from chance. Thus, it seems that chicks trained under these conditions were unable to learn to discriminate between the geometrically correct and uncorrect locations provided by the local cues.

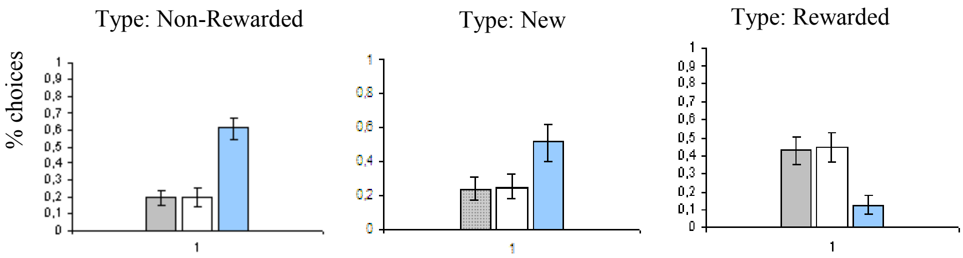

Figure 1 *First Experiment:* Mean frequencies and S.E.M. of choices directed to the geometrically correct (white) and uncorrect (gray) landmarks at the IDENTICAL transformation tests. In blue, mean and S.E.M. of choices directed far from each landmark.

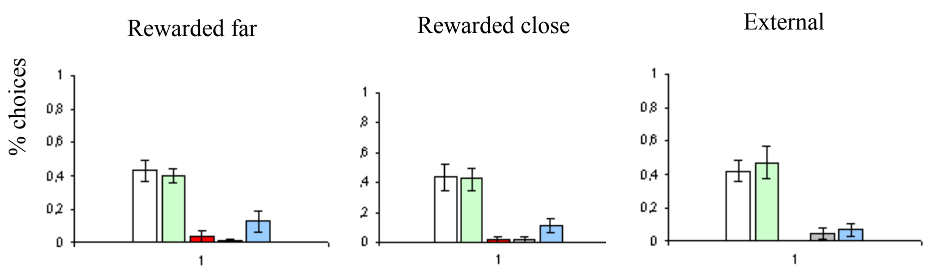

Figure 2 *First experiment* Mean frequencies and S.E.M. of choices directed to the correct landmark (white), to the landmark presenting the same feature at the geometrically uncorrect location (green), to the rotational landmark (red) and to the landmark which was uncorrect either in geometrical and non geometrical terms (gray) in the SIMIL-AFFINE transformation tests (Left and Middle panels) and in the EXTERNAL test (Right panel). In blue, mean frequencies and S.E.M. of choices directed far from each landmarks.

4 General discussion

The results of the first experiment indicated that chicks ignored the information provided by the geometry of the array to overcome the spatial ambiguity presented at the transformational tests. Moreover, the results in the second experiment indicated that chicks were unable to encode this information even when specifically trained. These results contrast sharply with those observed in the same species with the rectangular enclosure test [12], and more generally with the tasks in which the animals were required to localize the goal using both featural and geometrical cues provided by the shape of the enclosure, i.e. using extended surfaces rather than local landmarks. It is possible that in this species (as well as in human infants) geometry is encoded only with reference to extended surfaces, which are typically more stable within a visual scene than small local visual cues. The reason of the discrepancy with data collected in rats is at present unclear. It could be that rats, whose visual capabilities are not comparable to that of birds, would rely preferentially on a specialized mechanism of path integration to esteem distances and direction standing among isolated cues.

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Early experience with angular geometric cues does not facilitate re-orientation abilities in a precocial species

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1 Introduction

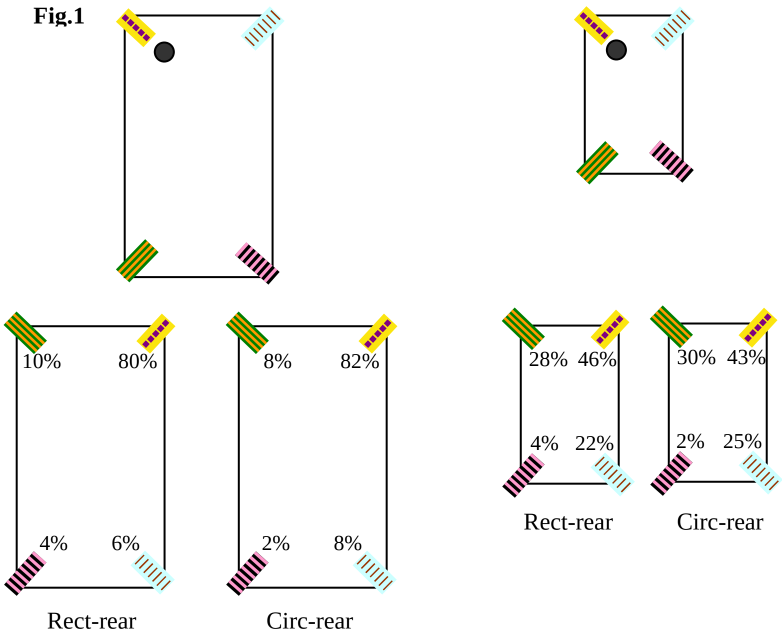
Evidence that vertebrate species are able to orient themselves making use of the shape of an environment (i.e., relying upon metric differences among surfaces and egocentric directional sense of left-right) has been reported in the last decade (see for reviews [1]; [2]). Moreover, it has consistently been shown that this geometric information is spontaneously encoded by the organisms even when trained in the presence of salient visual features that could suffice for successful reorientation (chicks: [3]; pigeons: [4]; fish: [5]). This sort of "primacy" of geometric information makes sense ecologically, since the large-scale shape of the environment does not change seasonally as it happens instead for the non-geometric information such as vegetation. However, a failure in using geometry by a wild-caught species (*Poecile gamboeli*) when feature was present near the target [6] drew researchers' attention on the role of angular and metric information experienced by laboratory animals before solving the task. Brown et al. [7] provided fish (*Archocentrus nigrofasciatus*) with different rearing experience (either in circular or rectangular tanks, i.e., providing direct experience with geometry or lack of it) before testing them in a rectangular environment and showed that growing without geometric information did not affect reorientation performance. Similarly, domestic chicks (*Gallus gallus*) showed no difference in dealing with geometry irrespective of the home-cage experience (circular *vs*. rectangular) ever since the very early phase of training [8]. Results with fish, however, also highlighted that when geometric and non-geometric information was set in conflict, fish raised in a circular tank showed less use of geometric information than fish reared in a rectangular tank: hence, it seems that the rearing environment could affect the relative dominance of features and geometry. Such a control condition was lacking in Chiandetti and Vallortigara [8] study with chicks. Here we show in two separate experiments (in which we provide chicks with conflicting geometrical and non-geometrical information), that there are no differences in the ability to manage geometric information depending on the early experiences in the domestic chick.

2 Methods and Results

2.1 Experiment 1

Soon after hatching under controlled conditions in our laboratory and in complete darkness, male chicks were housed in circular (n=12) or rectangular (n=10) cages. After three days, they were trained to find food in one out of 4 corners of either a large (35x70cm) or a small (12,5x35cm) rectangular environment with discrete conspicuous panels located in each corner (Fig.1 upper). Chicks of both conditions underwent 30 trials a day since they reached a learning criterion of 90% of correct choices in a single session. At test, panels were shuffled according to an affine transformation (see [9]). Since the enclosure's size affects the type of information preferred to reorient - with geometric information much relevant in small enclosures and landmark information much relevant in large enclosures [9] - we checked whether a difference in relying on geometry between circular- and rectangular-reared chicks was evident mostly (if any) in a small rather in a large arena.

Fig.1

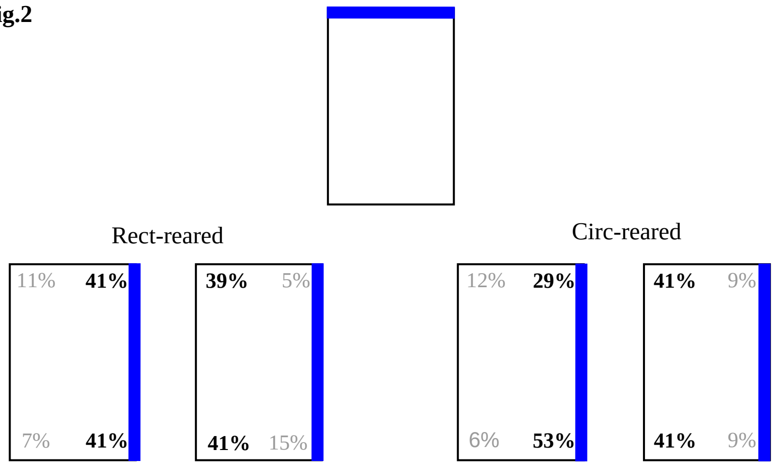


No differences between circular- and rectangular-reared chicks were observed, both groups referring more to the non-geometrical information reinforced during training although located at test in a novel incorrect position. As expected on the basis of a previous work [9], there was a difference due to the enclosure's size: chicks preferred to rely on non-geometric information when in the large enclosure (Fig.1 leftmost) and on geometric information when in a small enclosure (Fig.1 rightmost), however again displaying no differences due to the specific rearing experience.

2.2 Experiment 2

We controlled in this second experiment whether the kind of featural information itself was masking any difference due to early experience: in fact, referring to discrete panels may be different from dealing with an entire wall of a different colour. Hence, we trained circular- (n=18) and rectangular-reared chicks (n=17) in a small enclosure (in which geometry is more relevant) with one blue wall only (the longer or the shorter; Fig.2 upper); chicks could be reinforced to find food either in a corner defined by a junction of a white and a blue wall ("blue corners") or two white walls ("white corners") . Here data are merged together since there were no differences depending on which wall was coloured. Once reached the learning criterion, chicks were tested after a displacement of the coloured wall.

Fig.2



No differences depending on rearing experience were observed: rectangular- (Fig. 2 leftmost) and circular-reared chicks (Fig.2 rightmost) trained on the "blue corners" searched, at test, mainly along the blue wall and chicks trained on the "white corners" searched mainly along the white wall (Fig.2 bold percentages).

3 Discussion

Results obtained with two different species, chickadees [6] and fish [7], the former wild-caught and the latter provided with different rearing experiences in laboratory, proved that some experience with geometry may facilitate the relying to metric information when it is presented together with a salient visual feature, such as a blue wall in a rectangular white environment. However, data collected for another species, the domestic chick, revealed something different: the early experience of living in a home-cage in the presence of geometry did not affect reorientation abilities based on the shape of the enclosure. In Experiment 1, we showed that there was no evidence of any advantage mediated by experience. In fact, it could have been expected that a difference in performance depending on the rearing condition arose especially when animals were tested in small environment (in which chicks have been shown to prefer geometrical information); but this was not the case and both circular- and rectangular-reared chicks proved equally able to resort to the available information in order to correctly reorient. All the animals showed the same pattern of choices (i.e., they all go for the previously reinforced panel although located in a new incorrect position). Also, we confirmed the results obtained with respect to the different size used [9]: in fact, both rectangular- and circular-reared chicks showed a significant preference to rely on featural information when in a large enclosure and on geometry when in a small one. In Experiment 2, we tested chicks after a displacement of a blue wall in a small rectangular enclosure (being the small environment the one in which geometry has a preferred codification). If some differences can be expected, this could be the crucial environment as it was for chickadees and fish. Again, both rectangular- and circular-reared groups displayed the same pattern of results.

In both these experiments, it is highlighted chicks' ability to make use of the metric and sense together with colourful information, a direct proof of the capability to merge available information. The specific ability to deal with geometry seems to depend not on previous exposure to it; also, if necessary, animals have the possibility to conflate information when it is required to solve the task. However, these results pointed out a discrepancy in the role of experience in different species: chicks were not facilitated by living in a right-angled environment in any testing condition demonstrating an innate ability to deal with the available information; in contrast, fish showed that rearing do affect the relative dominance of features and geometry when provided with conflict geometric and non-geometric information at test. This species difference could be explained on the basis that, differently from precocial species such as domestic chicks, altricial species may be more open to external stimulation: hence, fish may be affected by rearing experience. It should be noted, however, that while chicks were reared singly in separate cages, in the experiment by Brown and collaborators [7] fish were reared in groups; this species is characterized by fully visible metric and angular colourful features on the body: living with companions could therefore have directly exposed the experimental fish to geometric information as visible on conspecifics' bodies.

Overall, the present findings support the idea that biological organisms are endowed with largely predisposed cognitive mechanisms to deal with geometrical information in their natural environment. Our data clearly add to the evidence collected in humans that the foundations of natural geometry are far removed from any strictly linguistic and cultural constraint [10].

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Language Systematicity Supports Spatial Mapping

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Abstract. We investigated the claim that relational language promotes the development of relational reasoning [1]. Prior research has shown the benefit of spatial relational language (e.g. top, middle, bottom) in preschoolers' performance in spatial mapping [2], suggesting that spatial relational language invites a delineated relational representation. We generalized this conclusion by testing the benefit of using *non-spatial* relational language in a spatial analogical task. During the task, preschool children heard either a set of systematic terms conveying monotonic structure (1 2 3), or a set of non-systematic terms consisting of names of familiar animals. Both sets of terms are familiar to preschoolers and neither directly denotes spatial locations. Children who heard the 123 labels performed better than those who heard animal names, suggesting that young children were sensitive to the relational structure conveyed by language, and able to apply this structure into a different domain.

Keywords: analogy, language, spatial relations.

How do children acquire the understanding of spatial relations? Previous research has shown that apprehension of spatial relations is not immediate in development; in many spatial tasks, children understand element-to-element correspondences before they understand spatial relational correspondences [3, 4, 5]. Gentner [1] has proposed that the learning and application of relational language is a route to learning domain relations. Indeed, there is evidence suggesting that relational language might foster encoding of relations, for example, children's performance in a search task was correlated with their ability to use the spatial language relevant to the task [6]. Recently, Loewenstein and Gentner [2] found support for this relational language proposal. In a spatial mapping task, preschool children were presented with two identical three-tiered boxes in which they watched an item being hidden in one box and were then asked to search for a similar item in the corresponding location at the second box. The results showed that children who heard spatial relational language (e.g. the terms *on, in, under* describing the three locations of the box) performed better than those who did not hear spatial language, suggesting that relational language fosters an encoding of spatial relations.

Interestingly, Loewenstein and Gentner also found that children who heard the set of spatial terms *top, middle, bottom,* performed significantly better than children who heard the set of spatial terms *on, in, under*. They hypothesized that this difference in performance is due to the advantage of systematicity – the connected system of relations such as *top, middle, bottom* respects the higher-order relation of monotonicity in the vertical dimension (*top* > *middle* > *bottom*), which in turn supports relational mapping. In contrast, *on, in,* and *under* each convey a separate first-order relation between the figure and the ground [7] and do not form an interconnected system. The structure mapping theory predicts that connected systems of relations should be favored over independent relations in analogical processing [8]. Consistent with this prediction, hearing the terms *top, middle, bottom* should provide a deeper structural representation and support the mapping of spatial relations better than the less systematic set *on, in, under*.

The possibility that systematic relational language invites a systematic relational representation offers an appealing learning mechanism that could contribute to the development of higher-order cognition. Loewenstein and Gentner showed that children's encoding of spatial relations is supported by systematic *spatial* language, but can systematic *non-spatial* language also support encoding of spatial relations? The current research tests this possibility via Loewenstein and Gentner's spatial mapping task, wherein two sets of *non-spatial* terms were used. One set of terms (*123*) represents a systematic relation of monotonic structure whereas the other set of terms does not (names of animals: sheep's room, dog's room and pig's room). As neither set of terms is spatial, there is no a priori difference in the clarity of spatial reference. In addition, in order to avoid possible canonical correspondences between our study set up and everyday observations, the three locations of the box were labeled *1, 2, 3* from top to bottom respectively, differing from the usual numbering of floors in buildings. We predicted that children who heard the set of terms *123* would perform better than those who heard names of animals.

It should be noted that our prediction is not at all obvious. Because children are ordinarily familiar with names of animals, one might expect that they will remember them better than numbers, thus, one might well predict better performance with the set of animal names. To fully asses the power of abstraction of systematic relational language, we also compared performance upon hearing non-spatial terms 123 and animal names versus spatial terms *top, middle, bottom.*

2 Experiment

2.1 Participants

Seventy-two children aged 3.5 years (n=37) and 4 years (n=35) participated in the experiment. Within each age group, children were randomly assigned either to the 123, Animal or Top/Middle/Bottom (TMB) condition.

2.2 Materials and Procedure

Two boxes (each measures 15 in. high x 12 in. wide x 7 in. deep), a white Hiding Box and a blue Finding Box, were placed about 2 ft apart on the floor. An identical set of three colored cards (aquarium, earth, pizza) was created for each box. The cards were placed in the box such that matching pictures were in mismatched locations (Fig. 1). One of the cards in each box had a yellow star attached to its back, making it the "winner" card. At all times, there was a card placed at the top, middle and bottom of each box, only one of which was the winner.

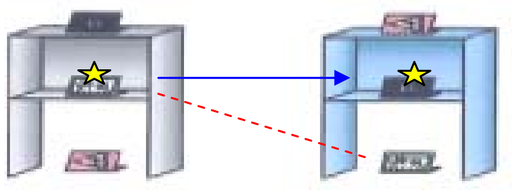

Figure 1: Experimental material. The left box is the Hiding Box, the right box the Finding Box. The solid arrow signifies correct corresponding location. The dotted line signifies an incorrect object match.

During training, the experimenter labeled each location of both boxes, explained the concept of a winner card, and told the child that the winners were always in the same place in the two boxes. At test**,** the child watched the experimenter place the winner at the top, middle or bottom of the box, saying either "I'm putting the winner in the sheep's/pig's/dog's room" (Animal condition) or "I'm putting the winner in number 1/number 2/number 3 room" (123 condition), or "I'm putting the winner at the top/middle/bottom" (TMB condition). The child closed her eyes while the experimenter hid the other winner at the Finding box, while being reminded that the winner at the Finding Box was at the very same place as the winner at the Hiding Box. The child was then asked to search for the winner at the Finding box (Search trials), and afterwards to retrieve the winner from the Hiding Box (i.e., the one they had seen being placed). The child was allowed to search only once, and the experimenter showed the correct location of the card if the child searched wrongly. There were a total of 6 trials (2 for each location) and 1 catch trial (the winner cards were placed *next* to the boxes), to ensure that the child understood the task.

3 Results and Discussion

As predicted, for the Search trials, the 4-year-olds in the 123 condition performed significantly better (M=.69, SD=.3) than those in the Animal condition (M=.44, SD =.28), F (1,22)=4.48 , $p <0.05$. The 123 group performed significantly above chance ($t(11)=4.21$, $p< 0.01$), whereas the Animal group did not (t (11)=1.43, *ns*). This result supports the hypothesis that hearing a set of terms conveying a systematic relational structure invites a representation sufficiently well-structured that the child can maintain a relational mapping even in the face of competing object matches. Furthermore, 4-year-olds are able to abstract this structure into different domains: quite remarkably, we do not see a difference in performance between hearing *spatial* systematic language (TMB group) and *non-spatial* systematic language (123 group), M =.68 and .69 respectively.

However, domain-specificity matters for 3.5-year-olds. Only those who heard the spatial terms *top/middle/bottom* performed significantly above chance ($M_{TMB=}$ .67, $p <$ 0.05), whereas hearing the term 123 (M =.28) or animal names (M = .37) did not lead to insight. There was no significant difference between the 123 and the Animal group, F (1, 24) = .91, p = .35.

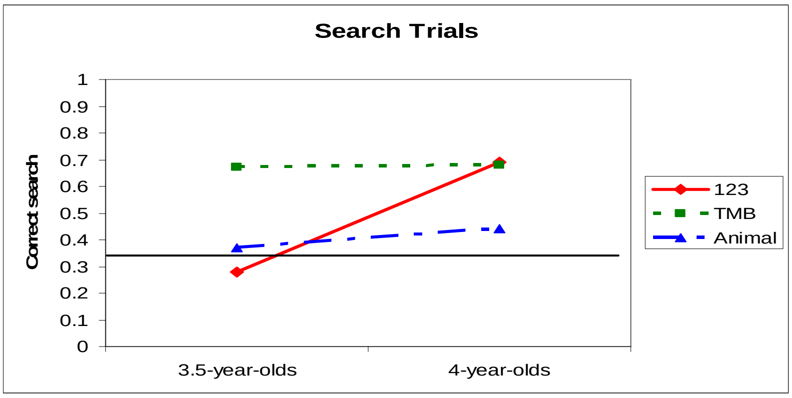

Figure 2. Performance in Search Trials; * $p < 0.05$ against chance (0.33)

In sum, the current results extend our understanding of how language systematicity may contribute to the development of relational cognition. Our results indicate that perceiving and mapping spatial relations can be enhanced not only by spatial relational language per se, but also by non-spatial language that conveys a systematic structure of relations. Learning proceeds from the concrete to the abstract: 3.5-year-olds can map the structure in the language to the structure in the environment only if they are within domain (spatial language to spatial relations), whereas 4-year-olds can project relational structures across domains. This offers a potential path by which well-structured knowledge can help to organize other domains in the course of development.

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Communicating with Navigation Systems about Places

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Abstract. The aim of this research is to investigate the initial phase of route communication with a navigation system: the specification of a route by an origin and a destination. Comparing inputting of a place description to the ways that people communicate about places with each other, we observe gaps impacting the usability and efficiency of navigation systems. From these gaps we identify future research questions. This research only looks at the communication about places, and leaves other phases of the route communication such as the provision of route directions phase and confirmation and closing phase for future work.

1 Problem and motivation

In daily life, people frequently communicate to each other about place. Although they have varying and incomplete descriptive knowledge about their spatial environment, their communication regularly succeeds. Similarly, navigation systems provide interfaces for inputting place descriptions specifying an origin and a destination. A *place description* in the context of this research is an answer to a *where* question [1]. Current navigation systems reveal mismatches between their approaches and their users' cognitive reasoning and verbalization of place descriptions. Firstly, systems use gazetteers for toponym resolution [2]. To ease the burden of natural language processing, system interfaces come with structured input formats. Users have to be adaptive enough to describe their intended places in systems' format, e.g., postal addresses. In this given example, users cannot use the system if they do not know the addresses or their desired places have no formatted postal address. For example, a hospital occupying a block would not have an address with one street number and one street name. Additionally, gazetteers consist of a set of geographic placenames, each georeferenced with a pair of coordinates. This way of georeferencing is not a realistic representation of our world: geographic features have a spatial extent and should be represented by regions rather than a point at the centre position. Also, gazetteers do not store relations between places. Secondly, systems have no awareness that their gazetteers are incomplete and outdated, and the structure and extent of gazetteers are implicit to users. When users look for places names that do not exist in the gazetteers, the systems might offer a close match but would never locate the desired places precisely no matter how users amend input.

Contrary to formatted input in systems, humans describe places in a flexible manner. Winter and Wu [3] studied the route communication with a state-of-the-art navigation system, Metlink's Journey Planner, and observed several gaps in communicating with the system. This research looks at state of the art navigation systems, and identifies fundamental questions relating to the cognitive base of communicating with systems about place in general for future research.

The communication between users and route planning systems consists of three phases: the initial phase where users ask information for directions, the second phase where the systems offer information, and the last phase of confirmation and closing [4]. This research focuses on the initial phase, and proposes a system that allows users' input in a flexible manner as they use in daily life. The hypothesis of this research is that current systems have fundamental gaps in their understanding people's descriptions of place.

2 Experiments

Many navigation systems firstly provide users with an interface to input place descriptions: their current location (or another start place) and their desired destination. To understand how flexibly users can get into contact with systems, the input interface of six state-of-the-art navigation systems are tested (Table 1). The results show that systems have explicit or implicit formats for input, which users have to adapt to. Explicit input format is inefficient for users. For example with Metlink's Journey Planner, it is not clear for users that "The University of Melbourne" is in the category of landmark, stop/station or address. To find out whether systems with implicit input format work better than explicit format, we design the second experiment.

A typical scenario, finding tourist places, is tested. Three of selected state-of-the-art navigation systems serving Melbourne, Australia are further examined on their behavior of matching places. The results are categorized by the following legend: (a) exact match; (b) matched with a list of options where the correct result is found at i/n (i is the index of the correct option; n is the total number of options); (c) failed to deal with input or to match any of the options. The chosen place descriptions are picked up from a widely used tourist guide book [5].

The results (Table 2) show that none of the three systems succeeds in matching all seven places uniquely. In particular, WhereIs only works with addresses, although some places without addresses are labeled on its maps. Google Maps performs best: it identifies all seven places with the most relevant at the top of the result list. Both Google Maps and WhereIs are capable of searching for business services in the vicinity.

Having the best performance, Google Maps is further investigated to determine how adaptable it is to users' input. The spatial reference with the second and seventh places, *cnr Flinders & Swanston Sts*, is tested by varying input in different formats that users would use. The results show that when *Melbourne* is not included in key words, Google Maps frequently locates the place at the

Table 1. Comparison of state-of-the-art navigation systems (T for text; M for click on map; P for public transport, pedestrians or cyclists; C for cars).

	Input types	Input manner	Businesses nearby?	Services	Region
Metlink[1]	station/stop; landmark; address	T, M	no	P	Melbourne (Australia)
WhereIs[2]	address	T	yes	C	Australia
Tomtom Car Navigation	address; landmark; crossing	T	yes	C	Melbourne (Australia)
German Railway[3]	station/stop; landmark; address	T	limited	P	Germany
Sogou[4]	any	T, M	limited	P, C	China
Google Maps[5]	any	T, M	yes	C	Global

intersection of Swanston Street and Flinders Street, Yokine WA 6060. Although it also indicates other relevant options with *Flinders* and *Swanston* within Australia domain, these options are in an arbitrary order with the one in Yokine WA at the top. Additionally, Google Maps does have format constraints: it locates *cnr Flinders & Swanston Sts, Melbourne* at the intersection of Flinders **Lane**, instead of Flinders **Street**, and Swanston Street. It is obvious that Google Maps does not interpret *Sts* as an abbreviation in natural language. In further tests, it is found that some abbreviations can be interpreted properly, e.g., *cnr* and *st.* If searching for *Flinders / Swanston* without specific street types, Google Maps offers 79 options "for **Flinders** / near **Swanston TAS**" as result. The spatial relationship "near" is not appearing in key words but inferred by Google Maps. It also identifies other spatial relationships, e.g., *in.* However there is no reference explaining what and how spatial relationships are defined in Google Maps.

3 Discussion

This research examines the initial phase of the route communication with state-of-the-art navigation systems. Experiments are designed to test whether these systems have constraints and to benchmark the performance of dealing with flexible input. The results show that current navigation systems are inefficient in the specification of a route by an origin and a destination. There are cognitive

[1] www.metlinkmelbourne.com.au
[2] www.whereis.com
[3] www.bahn.de
[4] map.sogou.com
[5] maps.google.com.au

Table 2. Results of searching tourist places in Melbourne, Australia.

	Test input	Metlink[6]	Google Maps[7]	WhereIs[8]
1	Melbourne Museum (Carlton Gardens)	(b)3/3	(b)1/153	(c)
2	Federation Square (cnr Flinders & Swanston Sts)	(a)	(b)1/666	(c)
3	Royal Botanic Gardens	(a)	(b)1/1666	(c)
4	Immigration Museum (400 Flinders St)	(a)	(b)1/121	(a)
5	Queen Victoria Market (513 Elizabeth St)	(a)	(b)1/714	(a)
6	Rialto Towers observation deck (525 Collins St)	(a)	(b)1/29	(b)2/2
7	St Paul's Cathedral (cnr Flinders & Swanston Sts)	(c)	(b)1/68	(c)

gaps between users and systems. In particular, with more format constraints users have to adapt to the systems and have difficulties to express themselves in the process, while with less format constraints the systems have challenges to interpret users' input. Therefore the hypothesis is proved.

From the experiment, unsolved fundamental research questions raise as follows: what is the most natural and effective input model for navigation systems, and how can systems interpret users' input properly and efficiently? As natural language of spatial concepts express everything as place descriptions in principle, further questions are how to locate a place given by a place description, and what is the status of having place descriptions. Additionally, the semantic base in the place description also requires further investigation, such as understanding spatial relations, vernacular names, and context-dependent expressions.

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[6] All inputs are tested by using Landmark input type in Metlink's Journey Planner.
[7] All place descriptions are attached with *Melbourne* in input.
[8] If available, the address is tested instead of place name. All addresses are affixed with *Melbourne, VIC* in input.

Learning to Orient Using a Map Display: Evidence from Eye Tracking

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Abstract. Eight individuals participated in an experiment requiring them to identify the position of a viewer on a map given the viewer's egocentric perspective of the space. Performance data indicated that response times decreased significantly over the course of the experiment, but accuracy did not improve. An analysis of eye tracking data showed that the speedup in participant performance was primarily a reflection of participants shifting attention between the two perspectives of the space less often. This finding suggests that the improvement resulted from reduced efforts to verify the hypothesized relationship between the views, but that identifying corresponding features remained as a significant challenge.

Keywords: Orientation; Frame of Reference; Eye Tracking; Sequence Analysis.

1 Introduction

Maps provide a nearly ubiquitous tool for aiding in navigation and route planning. A substantial literature exists documenting the utility and challenges associated with using maps in a variety of contexts to support human spatial reasoning (e.g., [1], [2], [3]). Practicing using maps to guide spatial reasoning can lead to improved performance in a variety of task contexts, in terms of both accuracy and response time.

In the experiment presented here, we examine learning that takes place as individuals perform an orientation task requiring them to establish correspondence between egocentric visual information about a space and an allocentric map of the same space. In addition to traditional performance measures, we collected eye point of regard (POR) data to evaluate the solution process in detail to identify changes resulting from learning. In the next section, the experiment methodology is described briefly, followed by the results of the experiment, in terms of overall performance and changes in eye movements as experience with the task increased.

2 Experiment Methodology

Participants performed an orientation task requiring them to identify the location of a viewer based upon that viewer's egocentric perspective of a space. In each trial, a circular space containing 10 objects was shown. On the left, a view of the space was presented from the perspective of a viewer standing on the edge of the space facing the center. On the right was a map of the space, which indicated the locations of all 10 of the objects. A small green object indicated the center of the space on both views. Participants responded by clicking on the location on the edge of the map where they thought the viewer was located. A sample trial is shown in Figure 1.

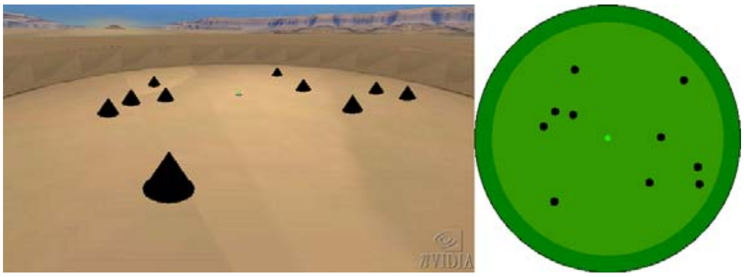

Fig. 1. Sample trial from the experiment. On the left is an egocentric perspective of the space, with a map of the space on the right. Participants were asked to identify the location of the viewer on the map, based upon the egocentric perspective shown. In this trial, the viewer is located in the 30 degrees to the left from the bottom of the map.

Participants completed a total of 576 unique trial conditions, which varied in terms of several factors including the misalignment of the map and factors associated with the arrangement of the objects in the space. A drop-out procedure was used such that if a participant made an error on any particular trial during the experiment (i.e., a response >30˚ from the viewer's actual location), that trial condition was repeated later in the experiment, but with a different randomly-generated set of object locations. There were 8 participants (6 male, mean age 28.5) in the experiment, which was broken into 2 hr sessions, one per day. Participants required from 2 to 4 sessions to complete the study, depending on performance and were compensated for their time at the rate of $10/hr. Calibration of the eye tracking equipment was performed at the start of each session, and opportunities for recalibration were given every 20 trials throughout the experiment. In the results presented next, we focus on the impact of practice on performance, focusing on changes in observed eye movement sequences that can be associated with learning that is taking place.

3 Results and Discussion

Throughout the experiment, data were collected on response time and accuracy for each trial, in addition to the eye POR data. Increased experience with the task did not influence accuracy F(28,196)=0.83, p>.70[1] (p-values are Greenhouse-Geisser adjusted). However, there was a significant speedup in performance across the experiment, F(22,176)=8.24, p<.001, which is illustrated in Figure 2. The decrease in response times is quite large. For the last 100 correct responses, average response time was 9.85 seconds, compared to 18.25 seconds for the first 100 correct responses.

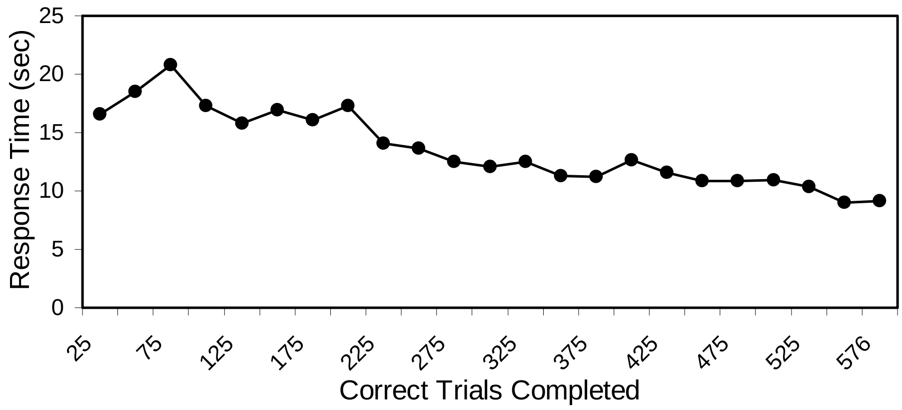

Fig. 2. Performance results for empirical study, showing average response time for sets of 25 correct responses, showing a steady decrease in response times across the experiment.

Although the performance data show evidence of improvement in the participants, they do not provide insight regarding why performance got faster. However, we can add key evidence about what was being learned by examining changes in the sequences of fixations generated by participants as experience with the task accumulated. Figure 3 presents two measures derived from the eye tracking data. The first is the average number of fixations directed to a particular view (the visual scene or the map) during a single period of looking at that view (i.e., consecutive fixations – a "dwell"). The second measure is the average number of such dwells per trial.

The data in Figure 3 illustrate two potential sources of learning in the experiment. The first, fixations per dwell, provides an indication of how difficult it was for participants to (1) extract meaningful spatial information about grouping and organization from one view and (2) identify the corresponding information in the other view. The data indicate that learning had a relatively modest impact on this measure, and the effect was only marginally significant, F(22,154)=2.13, p<.10. Alternatively, the impact of learning on the number of dwells is much larger. Increased practice led to a decline in the average number of dwells per trial, F(22,154)=5.05, p<.01. For both measures, however, the analysis revealed a significant linear trend in the data, F(1,7)=19.55, p<.01 for the number of dwells and F(1,7)=18.51, p<.01 for the average dwell length. A subsequent test of the slopes of

[1] This analysis is based upon the proportion correct for the first 29 sets of 25 trials for each participant. Because of the drop-out procedure, some participants had no data beyond this point. Including data from subsequent blocks would artificially decrease accuracy, since the participants with the lowest error rate would no longer be contributing data to the analysis.

the effects showed that they both differ significantly from zero as well, t(7)=4.42, p<.01 for number of dwells and t(7)=4.30, p<.01 for dwell length.

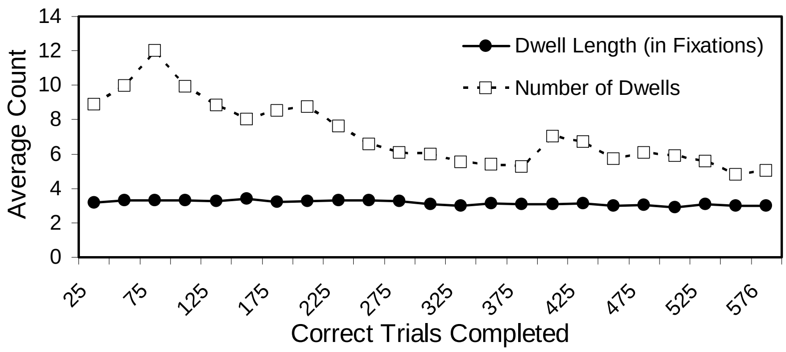

Fig. 3. Eye tracking results for average number of dwells and dwell length for the experiment.

The decrease in the number of dwells provides evidence that participants were becoming more efficient at verifying the correspondence of features between the two views. The small decrease in the average dwell length suggests that searching for features and executing the matching process may have improved, but only to a small degree. Together these results suggest that participants were using the same basic process throughout the experiment (i.e., cycling between views to identify corresponding features and refine an estimate of the viewer's location), but that fewer iterations through the cycle were required with practice. More detailed analyses, follow-on experiments, and computational cognitive modeling will be used to address and validate these conclusions in more detail as the research progresses.

Acknowledgements

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The bipolarity of spatial contrary properties

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Abstract. Three experiments on the pairs of contrary properties high/low, large/small, wide/narrow, and long/short, were carried out in order to verify the validity of the assumption that bipolar scales are unidimensional. In the first experiment, adult participants were asked to look at photographs of various different objects and to estimate the degree to which the eight spatial properties were present. In the second experiment, participants looked at real life objects. In the third experiment, the estimates referred to variations in the eight properties in object-independent conditions. Results from these studies consistently revealed that the contraries high/low, large/small, wide/narrow, and long/short do not lie on unidimensional continua

Bipolarity versus unidimensionality

The studied presented here deal with the question of whether the bipolar structure of contrary properties such as long/short, large/small, wide/narrow etc. corresponds to the unidimensional structure which underlies the reference to, respectively, “length”, “size”, “width” etc. Are bipolar and unidimensional structures mirror images of each other?

The idea that two contraries lie on the same continuum is a kind of default assumption when referring, in general, to contrary properties. It also forms the basis of various different methodologies used in experimental research (think for instance of the semantic differential method or the Lickert scales).

This simultaneous closeness and distance of opposites has been remarked throughout linguistic and semantic analyses of antonymy. “Antonyms name opposite sections of a single scale” (Lehrer & Lehrer, 1982) or opposite poles of the same semantic dimension - e.g., the dimension/scale of temperature in the case of *hot* and *cold* (Cruse, 1986). Yet again in 2005 Kennedy and McNally specified that gradable antonymous pairs “crucially make use of the same dimension and degrees (e.g. both tall and short *map their arguments onto corresponding degrees of height*) but express inverse ordering relations.” (p. 351).

Are we sure that both *tall* and *short* map their arguments onto corresponding degrees of height?

Study 1 - Estimates of photos of objects

In the first experiment we compared estimates of a set of objects on the gradable scales high/low, large/small, wide/narrow, and long/short. The aim of the study was to verify the unidimensionality of the four bipolar scales.

Method

Procedure. Two A4 sheets of paper showing 24 photos (6 x 5 cm) of objects in random order were given to each participant along with eight response sheets. Each response sheet related to one of the eight spatial properties being analyzed (high, low, large, small, wide, narrow, long and short). This was printed at the top of the page and twenty-four 7-point scales followed (one for each object). Participants were asked to rate the extent to which the target properties were present in each of the objects represented.

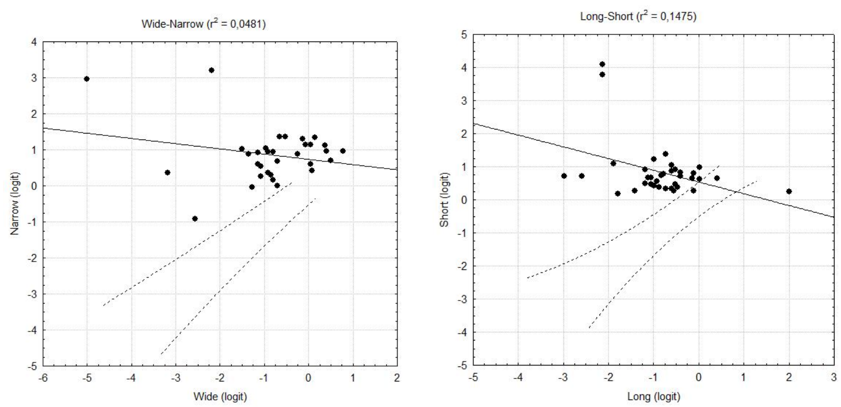
Stimuli: A car, a pair of binoculars, an oak tree, a pair of scissors, a die, a handbag, a motorbike, a park bench, a pair of sunglasses, a cork, a pipe, an umbrella, a phone, a slide, a pencil sharpener, a chair, a stone archway, a rugby ball, a box of matches, a supermarket trolley, a tennis shoe, a laptop, a washbasin, the nave of a church.

Participants. Fourty-three undergraduate students at the University of Verona.

Results

We used the Extended Logistic Model (ELM) (Andrich, 1978a, 1988a) and Bond's (2001) procedure to verify whether the variables under study belong to the same latent trait or not. No identity relationship was found for any of the bipolar scales examined (R^2 high/low = 0.127; R^2 large/small = 0.000; R^2 wide/narrow = 0.048; R^2 long/short = 0.147).

Fig. 1. The relationship between the contraries wide/narrow and long/short (in β–logit). The hatched lines represent 95% confidence interval.



Study 2 – Estimates of real life objects

In study 2, we sought a validation of the findings from study 1 in a task involving the observation of real-life objects.

Method

Procedure: The task and the stimuli were the same as in study 1, except that participants were now asked to express their judgments when directly observing 24 real-life objects.

Participants: Twenty undergraduate students at the University of Macerata.

Results

The results confirmed what we found in study 1 (R^2 high/low = 0.254; R^2 large/small = 0.328; R^2 wide/narrow = 0.357; R^2 long/short = 0.286). Thus, even in ecological conditions, judgments of *high* / *low*, *large* / *small*, *wide* / *narrow* and *long* / *short* do not conform to the hypothesis of an underlying common scale.

Study 3 – Estimates of "extensions" in space

Do our results depend on the discrete nature of the set of stimuli considered? Would they be different whether continuous variations of the properties in question were observed?

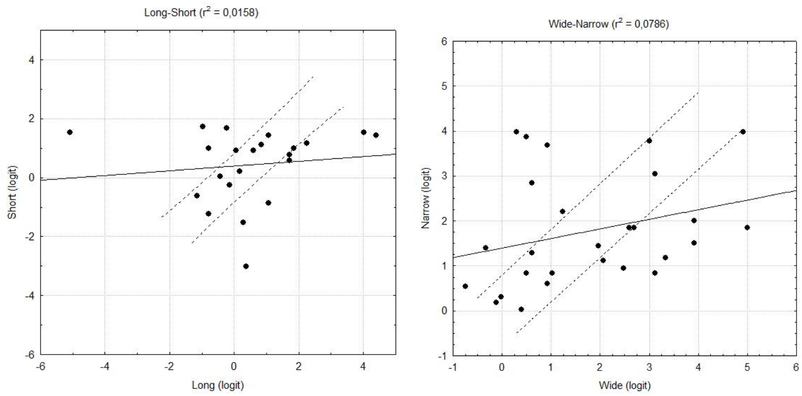
Method

Procedure: The experiment was conducted in the open air. Two small planks of wood painted red (30x10 cm) were used by the experimenter as markers on the ground. One of the two planks (plank 1) remained in the same position, while the other was moved by the experimenter into 24 different positions. Participants were asked to describe how *long/short* and how *wide/narrow* the space between the two planks was using a 7 point scale.

Participants: Thirty undergraduate students at the University of Verona and at the University "La Sapienza" in Rome.

Results: In this condition too, judgments of length and shortness, of width and narrowness did not lie on the same continuum (see Fig. 2).

Fig. 2. The relationship between the contraries wide/narrow and long/short (in β–logit). The hatched lines represent 95% confidence interval.



Conclusive remarks

Following Savardi and Bianchi's approach on opposites (for a review, see Bianchi and Savardi, 2008), which proposes a shift from a linguistic to a perceptual approach to contrariety, we sought an answer to the question of whether psychophysical judgments of opposite properties lie on the same continuum by analyzing the relationship between judgments of high/low, large/small, wide/narrow, and long/short, made by participants observing a set of everyday objects.

The results have demonstrated the non-reducible bipolarity of the spatial contrary properties analyzed.

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Navigation processing influences episodic memory

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Theoretical background

Learning and recalling personal events located in space and time engage the episodic memory [1]. On the other hand, different spatial representations are used to grasp the environment, depending on the action to be done [2]. A link between the efficiency of episodic memory and the spatial representations is then proposed [3,4]. Among the spatial representations, we propose that self-centred navigational processing [5-7] could constrain recollection from the episodic memory. This last one differs from egocentric processing which suppose an active updating of the information due to the permanent subjects' changes in localisation or orientation, and is thus inadequate for episodic memory [8].

The relationship between spatial and mainly allocentric spatial representation on one hand and episodic memory on the other hand ("the cognitive map theory"), is mainly due to the involvement of the hippocampus in both abilities [9-11]. Recent assumptions concerning the episodic memory as a state of awareness [12], as well as the significant findings on visual imagery [13] and spatial memory and navigation [7,14-16] have led us to revisit this functional link.

The present study aimed at distinguishing between "the cognitive map theory" and our new proposal, by answering the following question: Which type of spatial processing of an episode, allocentred or self-centred navigational, is significantly related to encoding and retrieving of an episode in and from the long-term memory? To answer this question we designed an experimental situation allowing the maximization of the navigational as well as of the allocentric processing.

Materials:

Twenty-two undergraduate and graduate students went through three experimental phases: 1) training with the spatial tasks, 2) spatial processing test associated to learning of birds' names and pictures (i.e. episodic learning) and 3) assessment of the episodic memory of birds' names. Each spatial task was tested in a "within-subject" design.

In the navigational task (N), participants had to process space through a route-type navigation (they viewed and simulated navigation in the environment). In the allocentric task (A), participants had to process space through an object relation manner. Conditions did not contain any additional rehearsal time or imagery of items to discard a possible level of processing effect.

Episodic memory was assessed here with a recognition test of the item associated with a Remember-Know-Guess paradigm. The episodic recollection was assessed on previously presented items (names and pictures of a bird), rather than on spatial characteristics.

Results

An ANOVA was conducted on the total number of correctly recognized words, using spatial tasks (N condition vs. A condition) as within-subjects factors. An alpha-level of .05 was used for all statistical tests.

We predicted an effect of the type of spatial task carried out during the study phase on the total number of correctly recalled words. Figure 1 shows means and standard deviations for all variables recorded during the recall test. There was a significant main effect of the task ($F(1, 21) = 17.16$, $MSE = 2.97$, $p = 0.023$; item, $F(1. 27) = 6.52$, $MSE = 2.80$, $p = 0.016$). An average of 10.27 words (SD= 0.56) were correctly recognized in the N task with respect to 8.81 words (SD= 0.38) for the A task. In addition, we expected a significantly higher number of words correctly recognized and categorized as "remembered" in the N condition than in the A condition especially for R responses. This is supported by the significant interaction (see Figure 1) between spatial conditions and RKG procedure responses type: $F(2, 42) = 2.33$, $MSE = 4.30$ $p = 0.10$, item, $F(2, 54) = 5.80$, $MSE = 7.99$, $p = 0.005$. A significant effect is observed for R recognized words $F(1, 21) = 6.23$, *MSE* = 3.50, *p* = 0.02 ; item, *F*(1, 27) = 12.75, *MSE* = 1.34, *p* = 0.001. A mean of 5.72 words (SD= 0.43) is reported following an N task for R responses whereas 4.31 words (SD= 0.63) are reported after an A task. Furthermore, the analysis carried out on the number of K and G recognized words did not provide significant difference between conditions (N vs. A) (*F*<1).

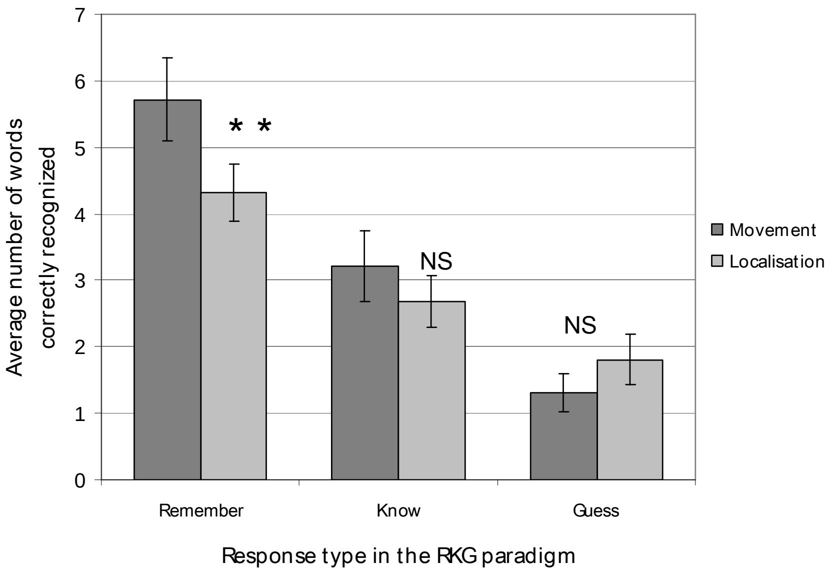

Fig. 1. Recalled word number according to response type in the Remember-Know-Guess procedure.

Discussion

In this study, we explored the relationship between the encoding degree in the episodic memory and the type of spatial representations (self-centred navigational and allocentric) as the episodic memory and spatial processing are intimately linked and depend on the hippocampus. However, episodic memory and spatial processing are in the majority of the research studied into a single perspective that is the “spatial memory” or “memory of spatial information” [17,18]. Instead of focusing on memory of spatial information, we propose to focus on episodic memory. The item to be remembered was not a spatial characteristic, but it was simply an item belonging to one specific time and place (i.e. episodic). Still, this item was learned in a spatially augmented reality emphasizing one or the other type of space processing. The learning condition that maximized self-centred navigational information processing allowed greater performance of episodic retrieval (i.e. event located in a particular space and time).

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Anisotropy of Environmental Awareness Caused by Spatial Changes during Locomotion

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1 Introduction

Environmental perception entails not only the local scrutiny of individual objects but also the global awareness of the environment surrounding the body. The latter is difficult to capture in its natural state because it is susceptible to direct investigation with the use of some cognitive tasks. We have indirectly investigated environmental awareness by using the feeling of oppression caused by the surrounding environment. In our previous study [1], participants continuously rated their feelings while walking along an outdoor route. Analysis of their ratings revealed that they were aware not only of the limited visual field but also of the entire surrounding environment. In this study, we investigate additional details of environmental awareness by using a virtual reality setup in order to test the hypothesis that humans are selectively aware of the direction in which spatial volume changes significantly.

2 Experiment

An experimental route was modeled using computer graphics (Fig. 1). The virtual environment comprised buildings, ground, and sky, each of which was textured with photographs. The route was 700 meters long and had characteristic places in terms of spatial configuration as shown in Fig. 1. In order to create a virtual experience of walking along the route, we used a multi-projection system "D-vision [2]," which had an immersive screen and 24 projectors to provide a 180° field of vision (Fig. 2). Moreover, this system provided stereo viewing through polarized glasses. The viewpoint automatically moved at the speed of 3 m/s.

Eighteen graduate students (7 females and 11 males) individually participated in our experiment. While moving along the route, the participants continuously rated their feelings of oppression caused by the virtual surrounding environment. Their ratings were outputted by sliding a lever in their hand up or down (Fig. 3) and recorded on a laptop computer at the rate of 5 times per second. The temporally recorded data were converted to 700 pieces of data in such a way that each piece corresponded to 700 points at 1-meter intervals along the route. In addition, the converted data were standardized for every participant and then averaged across all participants.

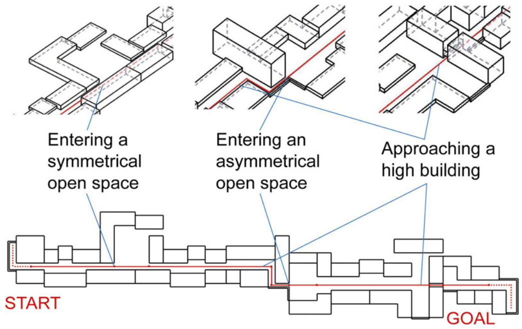

Fig. 1. Experimental route in a virtual space

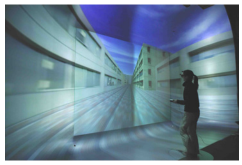

Fig. 2. Experimental setup

Fig. 3. Rating device

To describe the environment along the route, we used a method developed by Ohno [3]. This method views the environment around a viewpoint as a spherical surface consisting of several components (e.g., buildings, ground, and sky) and measures each visible area as a ratio of solid angle. This measurement was inspired by the concept of the "ambient optic array" developed by Gibson [4]. In this experiment, we also measured the average of the horizontal distances to the surroundings, which we refer to as the "spatial extent." This is similar to the "isovist" method developed by Benedikt [5]. All the variables were calculated by using our original computer program. The measurement was conducted at 700 points at 1-meter intervals along the route, and was limited to within a 72-meter radius of each measuring point. In this experiment, the surrounding environment was measured in two ways: together from all directions and separately from four directions (front, right, left, and back).

3 Results and Discussion

3.1 Model *without* Consideration of Anisotropy

First, a simple regression analysis was performed using the following linear model:

$$Fo = \alpha + \beta B_a + \varepsilon , \qquad (1)$$

where Fo is the feeling of oppression, B_a is the visible area of buildings measured from all directions, α and β are the parameters, and ε is the error term. The resultant estimates of α and β were –1.96 and .07, respectively. Figure 4 illustrates the variations in the observed and predicted values along the route (R^2 = .45), and shows that the prediction errors are large in several places. This model assumes that humans are equally aware of the environment in all directions. Given this, it is probable that our participants were, in particular places, selectively aware of the environment in specific directions. We chose such places using the 50% prediction intervals as a criterion, and examined them in terms of spatial volume in the front, right, and left directions (Fig. 5). On the basis of the result, we presumed that the participants' awareness was biased toward the directions in which spatial volume expanded and contracted significantly.

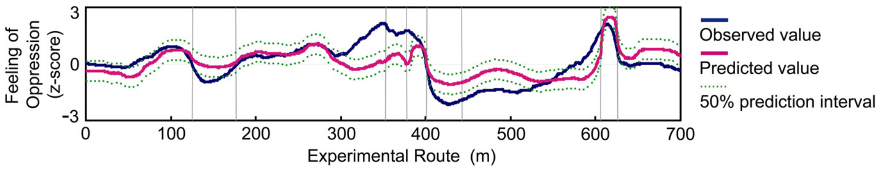

Fig. 4. Observed and predicted values along the route

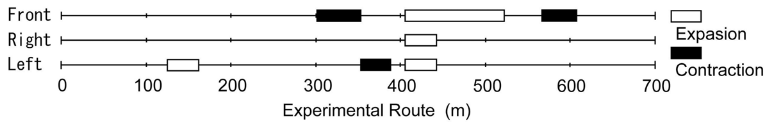

Fig. 5. Changes in spatial volume in each direction

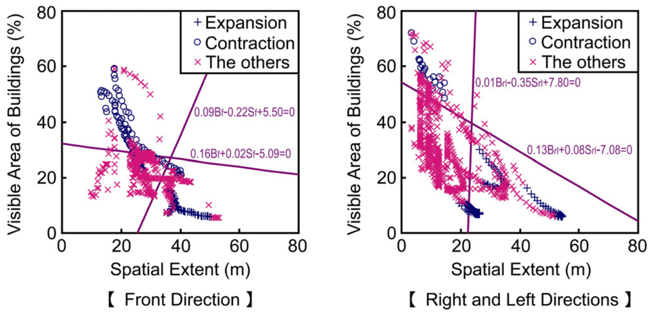

Fig. 6. Prediction of the bias of awareness from spatial measurements

3.2 Model *with* Consideration of Anisotropy

In order to predict the bias of awareness from objectively measured data, we performed discriminant analyses with the chosen places as response variables (Fig. 6). The explanatory variables were the visible areas of buildings and spatial extents measured from each direction. The former (inversely) indexes the longitudinal and latitudinal volume of the space, whereas the latter is the horizontal volume of the space. The right and left directions were analyzed together considering the symmetry. Resultant discriminant functions were statistically valid ($p< .001$ in all cases). This suggests that the bias of awareness can be predicted to some degree from the measurements of spatial volume.

On the basis of the result, we attempted to create a model with consideration of the anisotropy of awareness. In this model, anisotropy is expressed using a weighted mean of the visible areas of buildings measured from each direction as follows:

$$Fo = \alpha + \beta \frac{W_f B_f + W_r B_r + W_l B_l + B_b}{W_f + W_r + W_l + 1} + \varepsilon , \qquad (2)$$

where Fo is the feeling of oppression; B_f, B_r, B_l, and B_b are the visible areas of buildings measured from the front, right, left, and back directions, respectively; W_f,

W_r, and W_l are the weights of the front, right, and left directions, respectively; α and β are the parameters; and ε is the error term. The weights are expressed using the results of the above-mentioned discriminant analyses as follows:

$$\left.\begin{array}{l} W_f = \gamma_f^{P_f} \\ W_r = \gamma_r^{P_r} \\ W_l = \gamma_l^{P_l}, \end{array}\right\} \tag{3}$$

where P_f, P_r, and P_l are the posterior probabilities of belonging to the classes of anisotropy in the front, right, and left directions, respectively, and γ_f, γ_r, and γ_l are the parameters. The probabilities range from 0 to 1. When they are all 0, that is, when there is no anisotropy, all the weights become 1, and Eq. 2 corresponds to Eq. 1. In addition, we set the condition that $\gamma_r = \gamma_l$ by considering the symmetry.

We used the method of least squares with repeated calculations to estimate α, β, γ_f, and γ_r (= γ_l) to be –1.98, .08, 330.36, and 15.90, respectively. Figure 7 illustrates the variations in the observed and predicted values along the route. The fit is better than the previous model (R^2 = .77). This supports our hypothesis that humans are selectively aware of the direction in which spatial volume changes significantly.

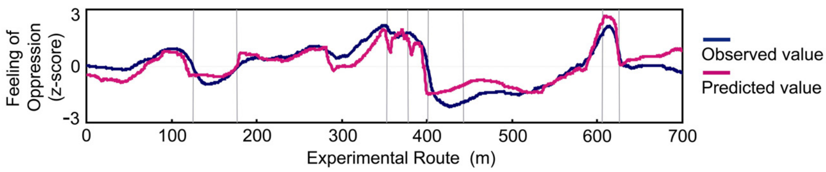

Fig. 7. Result of the prediction with consideration of the anisotropy of awareness

4 Conclusion

Humans are aware of the surrounding environment during locomotion, and when its spatial volume changes significantly, they unconsciously focus the awareness on the direction of change. This anisotropy probably has ecologically significant roles, described as follows: the biases toward spatial expansion and contraction serve as alerts to potential new information and obstacles to locomotion, respectively.

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Route Cognition in Virtual Environments with different Building Height Configurations

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Abstract. This research is addressing the issue of the 3-dimensional scale of the urban environment. The question raised is whether 3-dimensional scale properties affect the navigation, wayfinding and intelligibility in urban environments. In order to investigate these issues an experiment in virtual environments was set up. The experiment is examining participants' performance in navigation, wayfinding and survey knowledge in four environments with exactly the same plan configuration but differences in buildings heights. It is expected that route distance will be overestimated in high buildings environments and navigation will be easier in low buildings environments.

Keywords: three dimensional scale, buildings height, route cognition, virtual environment.

1 Introduction

In everyday life scale is mostly related to affective evaluations. People feel more affectionate towards a low scale, like in a picturesque village, or a high scale, like a downtown area with skyscrapers. However, the question that this research is aiming to address is whether scale is playing any role in navigation and wayfinding, in the intelligibility of the built environment and in the estimation of route distances.
In order to examine this question an experiment in a virtual environment was set up which took place in the VR lab of the Centre for Cognitive Science in Freiburg.
This research is also based on the hypotheses that were created from a previous research in virtual environment on the participants' perception of differences in scale properties. The hypotheses created form that research were that the perception of length of a street is affected by the configuration of form heights along this street and that low height environments are perceived as easier to navigate that different height ones.

2 Aim of the experiment

This experiment is aiming to examine four themes:

1. Whether the estimation of a route distance is affected by the scale of the buildings along the route.
2. Whether navigation in virtual urban environments is affected by the scale of the buildings.
3. Whether there is an effect on navigation of environments where the heights of buildings are correlated to the syntactic integration, according to the Space Syntax term [2] of the street on which these buildings are on.

3 Methodology

3.1 Plan layout and scale configuration

Four different "virtual worlds" were designed for the experiment. The four worlds have all the same layout but each one different buildings' height properties.

- One model with high buildings, 12m, 14m, 16m.
- One model with low buildings, 6m, 7m, 8m.
- One model with heights correlated to the syntactic integration. The height of the buildings is correlated to the integration values of each road. The integrated roads are having higher buildings than segregated ones.
- One model with the reversed correlation: The height of buildings is inversely correlated to integration. Integrated roads have lower buildings than segregated ones.

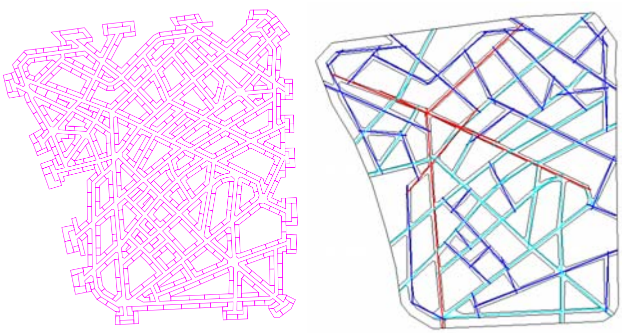

Figure 1 The plan layout of the models and the axial map with the 3 syntactic integration ranges corresponding to 3 different building height ranges.

3.2 Task

The virtual worlds were projected on a 2.6m x 2.0m screen. The experiment consisted of a training phase, a learning of the route phase and the tasks phase. During the training phase there was a distance training and a task training. For the distance training the participants were following a route with distance indication for every 50m. For the task training they had to learn a route and complete the tasks in a world which was different from the worlds of the experiment. After these two training sessions had finished, the actual experiment started. The route learning consisted of a passive navigation first, the participants were watching a video of the route, and then an active navigation, the participants were walking the same route following direction instructions given by the experimenter.

When they reached the end point of the route they were asked to complete the following tasks: They were asked to give an estimation of the route length, of the Euclidean distance (survey distance) from start to end and to point to the starting point. Finally, they were asked to go back to the starting point following exactly the same route. The participants were stopped by invisible barriers and could not move forward if they had taken the wrong turn on a junction. These barriers were giving a feedback to the participants indicating that they are heading away from the correct route and then they had to correct their choice. If the task was not completed within 5 minutes they were asked to stop. After performing all four navigation conditions, the participants were given a questionnaire to fill in. The questionnaire consisted of some questions regarding the level of difficulty of the environments and the navigation and of selected items from the Santa Barbara sense of direction scale questionnaire (SBSOD) [1] and the Questionnaire of Spatial Representation (QSR) [4] .

In order to avoid order & spill-over effects between the four different conditions for each participant, there were four different routes. The routes had all same distance, same start to end survey distance, same number and type of intersections (T type, cross type, 5 streets intersection), same number and type of turns (right angle, obtuse and oblique turns), and same number and sequence of syntactic property changes along the routes. The conditions and routes were counterbalanced across participants.

4 Collected data and expected results

- The route distance estimation. It is expected that the route distances are consistently overestimated or underestimated depending on the heights of the buildings of the models. The buildings are giving a sense of relative scale which affects the measurement of distances. More precisely the distances will be overestimated in high building environments due to the overestimation of traversed to perceived distance [3].
- The survey distance estimation. The survey distance estimation is not expected to be directly affected by the buildings heights given that the routes are equal in angular properties, except of course if the perception of the angular properties are distorted by the buildings height. However, survey distance estimation may be indirectly affected because of the wrong estimation of the route distance; if a route

distance is overestimated by a participant who is very good at detecting angular changes then the survey distance will be expected to be overestimated as well.

- The pointing direction. In Mavridou [3] it was reported that the participants impression was that they were easier oriented in low buildings environments due to the wider field of view and the view of the sky. The case may be that if you can see more of the sky which stays stable and of the skyline of the buildings (edges) when rotating then you can keep a better sense of orientation. It is now examined systematically if orientation is indeed easier in low buildings environments or if it is just an impression of the participants in these environments. Also, it is expected that in the inversed correlation environment, in which the more integrated streets offer better visibility of the back streets, due to the low buildings on these streets, participants can have a better sense of orientation (post hoc hypothesis).
- Detour behaviour. The number of wrong choices per route, the length of the detour and the total time of the detour will be estimated. If people are better orientated in the low height environment then they are expected to perform less wrong choices.
- Total time to complete the task.
- Total distance until the task is completed (metric distance, number of segments, mean length of segments).
- Speed (total distance divided by total time).
- Success to find starting point.

5 Conclusion

This is still an on going work therefore only the set up of the experiment and the expectances have been presented in this paper. This study was designed to systematically test whether differences in building heights affect navigation, wayfinding performance and route distance estimation.

The hypothesis is that the 3-dimensional scale of the urban environment does affect the distance estimation and the navigation performance. In particular, the distances will be overestimated in high building environments and navigation will be easier in low building environments. The expectances and findings will be corrected and enriched by the data analysis which is continuing.

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Projection-Based Models for Capturing Human Concepts of Motions

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Abstract. Projection-based models, which distinguish spatial relations using a frame of spatial reference, can be used as a foundation for modeling human concepts of motions. In this paper, the existing projection-based models are systematized using short code names that symbolize the models' characteristics. Then, through the observation of these code names, we detect some missing types of models that are applicable to the modeling of motion concepts.

1 Introduction

Projection-based models [1] are spatial models that adopt a frame of spatial reference [2], which partitions the space on/around one object (called *relatum*), and distinguish spatial relations based on the set of partitioned fields over which another object (called *referent*) extends. Two sorts of projection-based models can be used as a foundation for modeling human concepts of motions. One is the models whose relatum is represented by a directed line (*DLine*), called *DLine-relatum models*. They can describe where and how a landmark (referent) extends around/on a path (relatum) and, accordingly, they may capture such path-featured motion concepts as "*go toward*" and "*pass by*". Another useful one is *point-referent models*. They can describe where a destination (referent) is located with respect to a landmark (relatum) and, accordingly, they may capture such goal-oriented motion concepts as "*go to the front of*" and "*go to the north of*". Modeling of such motion concepts is important for the development of systems and machines that work together with ordinary people on spatio-dynamic tasks. In the last two decades, a number of projection-based models have been developed. This paper demonstrates that these models are systematized using short code names that symbolize the models' characteristics (Section 2). Then, making use of these code names, we detect some missing types of models that are applicable to the modeling of human motion concepts (Section 3).

2 Coding Projection-Based Models

The existing projection-based models have adopted a large variety of frames. One distinctive difference of these frames is their shapes: +-, ✳-, and ✵-shaped frames can be used when the relatum is represented by a point [1, 3, 4]; †- and ‡- shaped frames can be used when the relatum is represented by a straight DLine or a pair of points [5-7]; and ⌗-shaped frames can be used regardless of the relatum's geometric type [8]. In addition, the frames are categorized by their orientation factors [2]:

- *absolute frame*, whose orientation is determined extrinsically by the environment;
- *intrinsic frame*, whose orientation is determined by the relatum's intrinsic orientation (e.g., facing direction, moving direction); and
- *relative frame*, whose orientation is determined by the direction from the third object (*viewer*) to the relatum.

For instance, "*London is to the north of Paris,*" "*Manhattan is on the left-hand side of Statue of Liberty,*" and "S*phinx sits on the left of the pyramid in my view*" refer to the spatial relations defined by the absolute, intrinsic, and relative frames, respectively.

Table 1 summarizes the existing projection-based models and their characteristics. As this table indicates, these models are characterized by a small number of criteria: the frame's shape, its orientation factor, and the geometric type of the referent and the relatum. Meanwhile, the viewer's geometric type seems not important, because the viewer has been always represented by a point because its function is to specify a viewpoint. Based on this observation, we assigned a code name $\mathsf{XyZ}_{m\text{-}n}{}^{d}$ to each projection-based model in accordance with the following naming rules:

- X: geometric type of the referent—P (point), $\mathsf{P_D}$ (directed point), L (line), $\mathsf{L_D}$ (DLine), $\mathsf{L_{SD}}$ (straight DLine), R (simple region), or A (arbitrary point-set object),
- y: type of frame—a, i, or r (absolute/intrinsic/relative frame),
- Z: geometric type of the relatum—either $\mathsf{P_D}$ or $\mathsf{L_{SD}}$ when an intrinsic frame is adopted (i.e., y = i), and anything (P, $\mathsf{P_D}$, L, $\mathsf{L_D}$, $\mathsf{L_{SD}}$, R, or A) otherwise,

Table 1. Existing projection-based models, together with their code names (*P*: point, P_D: directed point, *L*: line, L_{SD}: straight DLine, *R*: simple region, *A*: anonymous point-set object).

Model	Frame Shape	Frame Class	Referent	Relatum	Viewer	Code Name
Single Cross [5]	†	*relative*	*P*	*P*	*P*	$\mathsf{PrP}_{1\text{-}8}$
Double Cross [5]	‡	*relative*	*P*	*P*×2		$\mathsf{PrP}_{1\text{-}8}{}^{2}$
Double Cross [9]	‡	*intrinsic*	*P*	L_{SD}	–	$\mathsf{PiL}_{SD\ 3\text{-}12}$
Models of cardinal directions [1, 8]	⌗	*absolute*	*A*	*A*	–	$\mathsf{AaA}_{1\text{-}8}$
Dipole Calculus [10, 11]	|	*intrinsic*	L_{SD}×2		–	$\mathsf{L_{SD}iL}_{SD\ 0\text{-}2}{}^{2}$
Ternary Point Configuration Calculus (TPCC) [4]	⊛	*relative*	*P*	*P*	*P*	$\mathsf{PrP}_{1\text{-}24}$
Bipartite Arrangements [6]	‡	*intrinsic*	L_{SD}	L_{SD}	–	$\mathsf{L_{SD}iL}_{SD\ 3\text{-}12}$
Star Calculus [3]	+, ✳, …	*absolute*	*P*	*P*	–	$\mathsf{PaP}_{1\text{-}4n}$
Oriented Point Relation Algebra [12]	+, ✳, …	*intrinsic*	P_D×2		–	$\mathsf{P_DiP}_{D\ 1\text{-}n}{}^{2}$
Ego Orientation [7]	+, …	*intrinsic*	*P*	P_D	–	$\mathsf{PiP}_{D\ 1\text{-}n}$
Orientation Calculi [7]	‡, …	*intrinsic*	*P*	L_{SD}	–	$\mathsf{PiL}_{SD\ m\text{-}n}$

- m/n: number of fields over/around the relatum, respectively, and
- d: number of $XyZ_{m\text{-}n}$ patterns that composes a single relation (omitted if d =1).

The rightmost column in Table 1 shows the code names assigned to the existing models. For instance, Single Cross [5] is assigned a code name $PrP_{1\text{-}8}$, which indicates that this model considers a point-like referent placed in a relative frame, which is centered at a point-like relatum and defines one field over the point-like relatum and eight fields around it. Double Cross [5, 9] has two code names: $PrP_{1\text{-}8}{}^2$ and $PiL_{SD\ 3\text{-}12}$. $PrP_{1\text{-}8}{}^2$ reflects its original definition in [5] where spatial relations are defined as the synthesis of two Single Cross relations ($PrP_{1\text{-}8}$), whereas $PiL_{SD\ 3\text{-}12}$ reflects the reformulated definition in [9] that considers point-DLine relations.

3 Projection-Based Models for Modeling Motion Concepts

As introduced in Section 1, DLine-relatum models and point-referent models are potentially useful for modeling human concepts of motions. Each DLine-relatum model is given a code name like $XiL_{D\ m\text{-}n}$ or $XiL_{SD\ m\text{-}n}$. The model may be used to capture where and how a landmark X extends around/on a path L_D/L_{SD}. We currently have $PiL_{SD\ m\text{-}n}$ (Double Cross in [9], Orientation Calculi [7]) and $L_{SD}iL_{SD\ m\text{-}n}$ (Bipartite Arrangements [6]), while $RiL_{SD\ m\text{-}n}$ and $LiL_{SD\ m\text{-}n}$ are missing. The models of $RiL_{SD\ m\text{-}n}$ and $LiL_{SD\ m\text{-}n}$ may capture path-featured motions concepts that presume the landmark's spatial extension, such as "*go into*" and "*go across*." Thus, these models are particularly useful when handling the motions in a small-scale space (e.g., apartments). On the other hand, each point-referent model is given a code name like $PyZ_{m\text{-}n}$. The model may be used to capture the relative location of the destination P with respect to a landmark Z. We currently have $PaA_{m\text{-}n}$ (Cardinal Direction [1, 8]), $PiP_{D\ m\text{-}n}$ (Ego Orientation [7]), $PiL_{SD\ m\text{-}n}$ (Double Cross in [9], Orientation Calculi [7]), and $PrP_{m\text{-}n}$ (Single Cross [5] and TPCC [4]). Thus, for every geometric type of landmarks, we can consider a point-referent model that adopts an absolute or intrinsic frame (recall that the relatum is limited to P_D or L_{SD} when the intrinsic frame is adopted). On the other hand, as for the point-referent models with a relative frame, $PrL_{m\text{-}n}$ (and its variants $PrL_{D\ m\text{-}n}$ and $PrL_{SD\ m\text{-}n}$) and $PrR_{m\text{-}n}$ are missing. The models of these categories can be used for modeling motion concepts in which the goal is associated with linear or region-like landmarks. For instance, two point-referent models, categorized into $PrL_{1\text{-}4}$ and $PrR_{1\text{-}4}$, may illustrate whether the goal is located on the left, right, front, or back of a linear landmark (e.g., a station platform) and a region-like landmark (e.g., a park) as seen from the mover's start point, respectively.

4 Conclusions

DLine-relatum models and point-referent models, both subsets of projection-based models, are useful for qualitative characterizations of spatial movements using landmarks. This paper demonstrated that these models are systematized by short code names that reflect the models' prominent characteristics. The comparison of the code names leaded to the identification of four missing types of models—$RiL_{SD\ m\text{-}n}$,

$\mathsf{LiL}_{\mathsf{SD}\ m\text{-}n}$, $\mathsf{PrL}_{m\text{-}n}$, and $\mathsf{PrR}_{m\text{-}n}$—that are potentially useful for modeling motion concepts. Currently we are developing a series of models that belong to $\mathsf{RiL}_{\mathsf{SD}\ m\text{-}n}$ and applying these models to the modeling of a number of motion concepts that concern region-like landmarks in an effective way [13]. The exploration of the other potential models that belong to $\mathsf{LiL}_{\mathsf{SD}\ m\text{-}n}$, $\mathsf{PrL}_{m\text{-}n}$ or $\mathsf{PrR}_{m\text{-}n}$ are also desirable for enriching the foundation for handling human concepts of motions computationally.

Among the models reviewed in this paper, TPCC [4] introduces a new concept of projection-based modeling—*near-far* distinction. Although nearness is a subjective concept, TPCC expediently defines *near* and *far* fields based on the viewer-relatum distance, as this yields some nice properties in its calculus [4]. It is an interesting topic to apply such a *near-far* distinction to other projection-based models and analyze how it improves the calculus, as well as the modeling capability of spatial concepts.

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Computational Modeling of Control in Spatial Cognition

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1 Control and Spatial Cognition

Spatial cognition, the ability to process spatial information, reason about space, and communicate about it, is crucial in various domains of human endeavor. For instance, without this ability people would not be able to navigate their environment, plan city or building layouts, exchange knowledge about dangerous or attractive places, plan vacations, execute directed movements, etc.

Another crucial aspect of human cognition is *control*. A common assumption in the cognitive sciences is that the human mind can be viewed as being composed of distinct entities / components. Each of these entities serves a certain function. For example, one component might be important for doing arithmetic, another for language, and a third for moving ones right arm. Almost any cognitive ability is presumed to draw on more than one entity. As a result, for successfully performing a task the different relevant entities have to be appropriately coordinated. Control, roughly speaking, is the means by which the entities of the human mind are organized and orchestrated. Without control coherent and coordinated activity seems impossible, because there would be no guarantee that the workings of the different entities involved in cognition would reasonably complement each other. Thus, to fully understand human cognition it is essential to know and understand the control mechanisms involved.

2 Control in Spatial Cognition

Due to the importance of spatial cognition and control for human cognition, both have been investigated intensely in the cognitive sciences. Yet, apart from few exceptions (Allen, 1999; Cheng & Newcombe, 2005), research in the fields of spatial cognition and control has so far proceeded virtually in isolation from each other. While investigations in spatial cognition normally do not broach the issue of control, researchers examining control have done so mostly considering only tasks which are not very informative regarding human spatial cognition. As already said, any kind of mental activity, that is, also spatial cognition, requires some form of control to be successful. Neglecting control when investigating spatial cognition therefore neglects an essential aspect of the object of investigation. Consequently, there is need for a more thorough examination of control in spatial cognition.

The work presented in this contribution constitutes first steps towards such examination. More precisely, the remainder of this contribution will be concerned with the computational modeling of a certain aspect of control in spatial cognition, namely the control of reference frame selection.

3 Reference Frame Selection in Spatial Cognition

3.1 Reference Frames

Reference frames (RF) are hypothetical constructs presumably employed by humans to partition space. More concretely, a reference frame can be characterized as a three dimensional coordinate system with a defined origin, scale, direction, and orientation (cf. Logan & Sadler, 1996). Depending on the precise specification of these four characteristics, space can be partitioned differently. For example, if the origin of a RF is placed on the height of the ceiling of a room, the space of the room is partitioned differently into above and below than if the RF's origin is placed on the height of the floor.

Mast and Zaehle (2008) point out that "No meaningful processing of spatial information is possible without a frame of reference." Due to this importance of RF in spatial cognition, considering control aspects related to RF addresses a core issue of control in spatial cognition.

3.2 RF Selection in Various Spatial Cognition Abilities

The selection of RF plays a crucial role in various spatial cognition abilities such as spatial term use, imaginal perspective taking, (mental) image reinterpretation, and spatial reasoning. In this contribution we will focus on the former two.

As a number of studies by Laura Carlson have shown (see, e.g. Carlson-Radvansky & Irwin, 1994), the selection of RF is important to apprehend spatial terms such as "above", "right", etc. Before such terms can be produced or understood, a suitable RF has to be selected which allows to partition space to assign a reasonable verbal label to different parts of space.

Imaginal perspective taking (see May, 2004) refers to the ability of humans to judge spatial relations between objects of a previously seen configuration without having sensory access to the configuration at the time of judgment. To be able to perform such judgment a RF has to be imposed on the memory representation of the relevant spatial layout. Since often more than one RF is potentially available, one of these has to be selected to successfully take the imaginal perspective.

4 Computational Modeling of RF Selection

Given the importance of RF selection the question arises how the selection of RF is achieved: What are the mechanisms underlying RF selection? To address this question we developed a computational model of RF selection. In the following we will briefly describe the model before presenting results of fitting the model to pertinent experimental data.

4.1 The Model

The developed model is a connectionist model which essentially consists of two layers. The units in the first layer, called competing units, each represent a possible value for one of the RF parameters proposed by Logan and Sadler (1996). The units in the second layer, called shunting units, are realizations of the shunting models as proposed by Grossberg (1982). The number of competing units is equal to the number of shunting units and each competing unit c_i excites exactly one shunting unit s_i and inhibits all other shunting units. Moreover, each shunting unit s_i positively feeds back to its corresponding competing unit c_i.

This connection structure establishes indirect lateral inhibition between the competing units via the shunting units. As a result, when different values for RF parameters activate different competing units, each competing unit will tend to increase its own activation and decrease the activation of all other competing units. During this competition the shunting units accumulate the net activation exchanged between the competing units which gives rise to priming effects: Previously selected RF parameter values become easier to select and previously not selected RF parameter values become harder to select after competition. The competition between the units stops when one of the competing unit's activation is sufficiently higher than the activation of all other competing units. The parameter value finally selected results from the combination of all competing values weighted by their activation at the time competition stops.

Due to its design the model has been termed *competitive shunting model* (*CSM*). It has been applied to modeling both the apprehension of spatial terms and imaginal perspective taking.

4.2 Spatial Term Use

In their study Carlson-Radvansky and Irwin (1994) had participants judge the adequacy of spatial terms used to describe visual scenes. In doing so, Carlson-Radvansky and Irwin (1994) systematically varied the number of different values available for the orientation and direction parameter of the RF. Overall 20 different experimental conditions resulted. For each of these conditions reaction times needed by the participants to judge the terms were recorded. By estimating only a single parameter the CSM was fit to these 20 data points resulting in a correlation of 0.81 between model and empirical data.

4.3 Imaginal Perspective Taking

The second data set the model was applied to was taken from May (2004). In the relevant experiment participants were asked to first memorize a configuration of objects which surrounded them. After sufficient learning subject had to close their eyes and were asked—without changing their bodily position or orientation—to point to certain objects as if they would be positioned or oriented differently from than they were. One dependent variable which was recorded was the time participants needed to execute the pointing response. Due to the experimental manipulations, reaction time was measured in 24 different experimental conditions. Again fitting only one parameter the CSM achieved a correlation of 0.91 to the experimental results.

5 Conclusion

Previous research on control and spatial cognition has proceeded virtually in isolation of each other. This contribution presents first steps to explicitly consider both areas together, that is, control in spatial cognition. To this end a computational model of the control of reference frame selection, the competitive shunting model (CSM), was developed. This model nicely and parsimoniously accounts for empirical data regarding various spatial cognition abilities. In doing so, the CSM not only indicates the importance of control for understanding spatial cognition abilities, but also highlights commonalities between abilities which so far have been considered only separately from each other.

6 Acknowledgements

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Is there a geometric module for spatial orientation? Insights from a rodent navigation model

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1 Introduction

Throughout the history of research on animal learning there have been conflicting views concerning the fundamental issue of what animals learn during training in a spatial task. Cognitive theorists such as Tolman proposed that animals acquire knowledge of the environment layout, or a cognitive map [1], whereas other theorists proposed that animal learning consists of the formation of stimulus-response (S-R) habits [2]. Recent behavioral and lesion data suggest that animals are able to use both the map-based and S-R navigational strategies when solving spatial tasks; these strategies are mediated by distinct memory systems, and hence may be learned in parallel and compete for control of behavior [3].

Further evidence suggested that external sensory cues are used differently depending on the current strategy. The map-based, or *locale*, strategies, seem to favor distal (e.g landmarks attached to a maze walls) over proximal (e.g. intramaze objects) cues [4]. Moreover, configurations of distal cues are preferred over individual landmarks [4]. In contrast, the S-R (or *taxon*) strategies preferentially use proximal cues, when they are available, as beacons that signal the goal location [5]. In the absence of proximal cues, they fall back to distal-cue configurations [6].

A particularly striking evidence for the control of behavior by configural cues has been observed during reorientation experiments in rectangular rooms [7]. In a typical experiment, a food-deprived animal is first shown the location of a food source in a rectangular room with distinct landmarks in the corners. The animal is subsequently disoriented and is allowed to re-locate the food source. Under these conditions the animals exhibit systematic rotational errors, i.e. they often go to the location that is diagonally opposite to the correct location. Since the correct and the diagonally opposite locations are indistinguishable with respect to the rectangular shape of the room, this data suggest that the geometric layout of the room, but not the identities of the corner landmarks, have been used by the animals during goal search. Preference for the geometric cues in this and similar experiments gave rise to the idea of a 'geometric module' [7] which is considered by many cognitive psychologists as a separate subsystem of the (vertebrate) animal brain, responsible for reorientation in a familiar environment [8, 9].

A challenge to our understanding of mechanisms of spatial navigation is to explain such behavioral data using available knowledge on anatomy and neurophysiology of neuronal networks mediating spatial memory and goal learning. In our work we addressed this challenge by proposing a computational neural model of navigation which provides a unifying point of view on the behavioral data described above and links this data to underlying neuronal properties. The model implements locale and taxon goal-navigation strategies and focuses on the influence of configurations of distal cues, represented by visual snapshots of the environment. Such combination allows for a direct comparison between the model and animal behavior in navigational tasks where the location of a hidden target can be learned by different strategies. Moreover, reorientation behavior described above can also be analyzed using the same model.

2 Results

In our model, presented on the poster, the simulated rat moves through a virtual arena surrounded by walls. At each time step, the visual input is given by a snapshot of the environment processed by a large set of orientation-sensitive visual filters, while the self-motion input is represented by the speed vector corresponding to the last movement. The motor actions are generated in the model by two separate pathways (Figure 1). The first, taxon navigation pathway, associates visual input directly with motor actions and represents anatomical connections between the cortex and the dorsal striatum (caudate-putamen in the rat). The second, locale navigation pathway, generates actions based on a representation of space learned in a simplified model of place cells in the CA1 area of the hippocampus. The activity of model place cells encodes location of the animal and is further associated with motor actions, presumably encoded by the nucleus accumbens (NA) of the ventral striatum. The place cells receive feed-forward input from a population of simulated grid cells, similarly to CA1 cells that receive direct input from grid cells in the in layer II of the dorsomedial entorhinal cortex (dMEC). Motor actions are encoded in two separate populations of hypothetical *action cells*, which represent motor-related activity of the caudate-putamen and nucleus accumbens for the taxon and locale strategies, respectively.

The model was tested in three sets of tasks. The first set of tasks examined the firing properties of modeled place and grid cells in rectangular environments with varying lighting conditions (i.e. light/dark), during visual cue manipulations, and during changes in the geometric layout of the environment (i.e. stretching and shrinking of the environment in one dimension). The second set of tasks tested the ability of the model to reproduce animal data in the circular water maze experiments with hidden platform. The starting position of the simulated

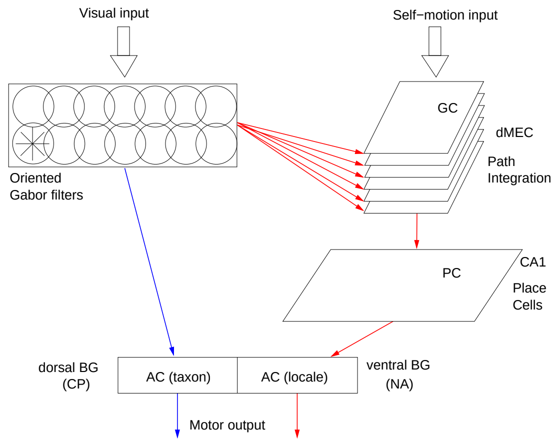

Fig. 1. Model overview. dMEC – dorsomedial entorhinal cortex, GC – grid cells, PC – place cells, BG – basal ganglia, CP – caudate-putamen, NA – nucleus accumbens, AC – action cells (see text). Blue (red) arrows represent taxon (locale) action generation pathway.

animal in the maze was either varied from trial to trial (variable-start task) or fixed (constant-start task), such that different navigational strategies could be used in these tasks [10, 6]. In the last set of tasks, the model was used to reproduce Cheng's data on reorientation in rectangular environments [7].

Results of our computer simulations lead to three main conclusions, illustrated on the poster by a number of figures. First, our model, in which visual input is represented exclusively by snapshots of the environment, was able to capture a number of neurophysiological properties of grid and place cells. These include, e.g., location-sensitive firing in light and dark conditions, rotation of firing fields following a rotation of visual cues, stretching/doubling of place fields in stretched environments, and shrinking/disappearance of place fields in shrunk environments [11, 12]. Hence, extraction of landmark or wall information from visual input, suggested by most of the present models of place cells, is not necessary to reproduce much of the related experimental data. Processing of raw visual information contained in the snapshots of the environment might be sufficient.

Second, the model reproduced rat behavior in variable-start [10] and constant-start [6] versions of the watermaze task (including lesion studies). The modeling approach proposed in this work is novel and permits to study taxon and locale navigation strategies (and their interaction) in environments with complex visual features.

The third and main conclusion concerns the effects of environmental geometry on the activity of spatially selective cells and goal-oriented behavior. Our results suggest that the influence of geometry of space, observed in experimental data, is a byproduct of visual information processing [13, 14]. Rotational errors, reproduced by the model during reorientation in rectangular rooms, were caused in the simulations by the structure of visual inputs, rather than by room geometry. In environments in which the arrangement of walls is symmetric, the edges of walls represent ambiguous cues, whereas visual patterns attached to the walls (e.g. landmarks) represent non-ambiguous cues. Behavioral decisions made on the basis of the ambiguous cues may *appear* to be caused by the room geometry, but could in fact be based on sets of local features, arranged in a symmetric and hence ambiguous configuration.

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Towards an Implementation of the Qualitative Trajectory Calculus to Analyze Moving Objects

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Abstract. Due to technological advances in position-aware devices, data about moving objects are becoming ubiquitous. Yet, it is a major challenge in Geographical Information Science and Systems to offer tools for the analysis of motion data, thereby evolving from static to dynamic frameworks. In spite of the already large volume of theoretical and fundamental research available in this field, much of this knowledge is not as ready-to-use as it seems, leaving a notable theory-practice gap to be filled. This research aims to contribute in this area by focusing on the implementation of the Qualitative Trajectory Calculus (QTC) in GIS.

Key words: Qualitative Trajectory Calculus, moving objects, GIS

1 Introduction

Nowadays, omnipresent position-aware devices such as GPS and mobile phones supply large amounts of raw data about moving objects. While GIScientists from multiple disciplines have already created a sound theoretical basis regarding the analysis and the extraction of knowledge from motion data, this work is not well reflected in the tools offered by current GIS. Among others, one of the research fields which, until now, has remained largely theoretical, is the domain of qualitative spatial and temporal reasoning.

In the past decades, several qualitative spatial and temporal calculi have been worked out in order to deal with specific spatial and temporal issues. Yet, the usefulness of these reasoning tools often remains questionable and needs to be evaluated in terms of suitability, relevance and scope of its applications.

A qualitative calculus of particular interest to the domain of moving objects is the Qualitative Trajectory Calculus (QTC) [1]. The aim of this research is to assess the applicability of QTC by implementing it in a GIS in order to represent, analyze and query data about moving objects. Section 2 gives a short introduction to QTC and an overview of its subtypes. Section 3 provides a résumé of work in progress. Finally, section 4 discusses future key interests and outlooks for the proposed research.

2 The Qualitative Trajectory Calculus (QTC)

QTC is a qualitative calculus to represent and reason about moving objects [1]. The QTC formalism defines relations between two disjoint moving point objects (MPOs). These objects are assumed to evolve continuously in space and time. Due to the consideration of different spaces and frames of reference, the following types of QTC have been elaborated:

- Basic type – QTC_B [1], [2]
- Double-Cross type – QTC_C [1]
- Network type – QTC_N [3]
- Shape type – QTC_S [4]

QTC-Basic and QTC-Double-Cross both deal with MPOs having a free trajectory in an *n* dimensional space. In QTC_B, relations are determined referring to the Euclidian distance between two MPOs (Fig. 1a), while QTC_C relations refer the double cross between them (Fig. 1b), as introduced by Zimmerman and Freksa [5].

QTC-Network focuses on the special case of MPOs which trajectories are constrained by a network, such as cars in a city. Since both the Euclidean distance and the double cross concepts ignore the spatial configuration of a potential underlying network, they or not well suited for QTC_N. Therefore, QTC_N relations rely on the shortest paths between MPOs in the network (Fig. 1c).

Finally, QTC-Shape is a calculus to represent and compare trajectory shapes, making abstraction from the actual MPOs.

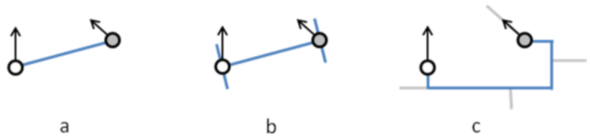

Fig. 1 Two MPOs represented in a typical QTC_B (a), QTC_C (b) and QTC_N (c) setting.

3 An Implementation Prototype for QTC

As a first step, a basic implementation of the QTC-Basic calculus is developed in AutoCAD 2008 using the Visual Basic 6.5 programming environment. This CAD environment was preferred above a conventional GIS because of the efficient and fully supported use of three dimensions as well as the flexible and ad hoc design tools creating manifold visualization opportunities. In addition, only a few typical GIS tools were required and solutions can easily be found within the CAD system.

This basic implementation starts from a given set S of 2D trajectories T, each of which is described as an ordered sequence of n spatiotemporal sample points T_i of the form (x_i, y_i, t_i). In order to obtain unambiguous continuous geospatial lifelines, the implementation further relies on several assumptions:

- All time poins t_i are positive and increase as time progresses.

- All trajectories in a given set are sampled at the same consecutive time points t_i (concurrent observation).
- In between two sample points, an MPO moves along the straight line segment connecting both points.
- In between two sample points, an MPO has a constant uniform acceleration, and thus a persisting linear increasing, decreasing or constant speed.

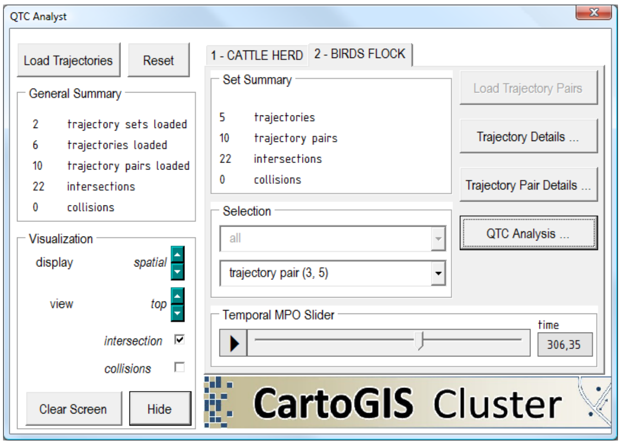

Fig. 2. The main user window offers possibilities to load (top left), visualize (bottom left) and to analyze (right) data as well as some summary information (top left and centre).

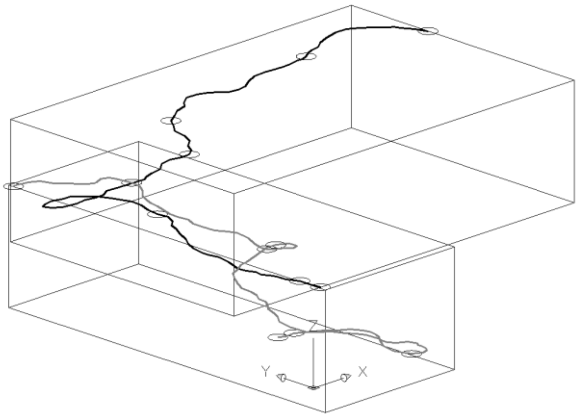

Fig. 3. A pair of MPO trajectories represented in their conventional space-time cubes where the z-axis corresponds with time. Circles represent event points where the movement of the second object (grey trajectory) changes with respect to the first object (black trajectory) in QTC_B.

The GUI of the implementation allows for a user to input a trajectory set, to perform QTC_B analysis on the loaded set, and to visualize and export the analysis results (see Fig. **2** and Fig. 3). Until now, the input trajectories have been automatically generated in a constraint random way. In its most basic form, QTC_B analysis implies the translation of a pair of MPO trajectories into a set of QTC_B relations and/or transitions.

4 Future Perspectives

First of all, we identify two fundamental key issues to receive special attention prior to further implementations. The first is the transformation of MPO trajectories consisting of discrete spatiotemporal sample points – as tracked by a device – into a continuous geospatial lifeline as assumed by QTC. The second is to find objective and sound methodologies to compare non-concurrent trajectories.

Concerning the actual implementation, obviously, the basic prototype of section 3 needs to be further extended in terms of supported QTC calculi. On the one hand, an extension to QTC_C is rather straightforward since the double cross concept relies on the Euclidean distance and both calculi deal with unconstrained MPOs. On the other hand, extending to QTC_N is more complex due to the unique network structure to which all trajectories need to be matched. Since QTC_S abstracts from the actual moving objects, its implementation is initially skipped as a direct perspective, although there seem to be promising applications, e.g. in the field of trajectory similarity measurement.

Further, several improvements can be made concerning the input, the analysis and the output of the data. Possibilities for interactive ways of data input, such as query-by-sketch, should be studied in depth. New intuition-based tools should allow for more specific analysis tasks such as pattern recognition. Consequently, this improved analysis unit impels to be supported by advanced, intuition-based visualization and communication means, such as animations.

Finally, we aim to test and evaluate QTC implementations with real MPO data in order to identify concrete and specific applications and thereby determine the added value of the QTC formalism.

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Do you know your way? A mixed-method study on the use of virtual environments in wayfinding research

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Abstract. This poster compares wayfinding behavior in virtual and real environments in order to reveal the theoretical basis for comparison while simultaneously producing applicable implications for designers and architects. The constructed virtual environment was modeled using standard design tools available for most practicing architects and mimicked the parallel real environment upon which it was based. Methodologically the study builds on existing research on wayfinding in both real and virtual environments, implementing both previously used and new methods.

Keywords: wayfinding, orientation, virtual environments, design evaluation

1 Background

Spatial behavior is not a new topic in the social sciences. Tolman [1] introduced the term “cognitive map” to describe a mental construct of routes, paths, and environmental relationships which, in his research, determined animals’ responses to the environment. Some time later, Kevin Lynch [2] coined the term “wayfinding” in his well-known book The Image of the City. The phenomenon was “a consistent use and organization of definite sensory cues from the external environment in order to find one’s way in it” which is “fundamental to the efficiency and to the very survival of the free-moving life” (p. 3). Wayfinding is different from following a known route. As the term implies, in wayfinding the route is not known, even though the origin and/or destination points are. The term wayfinding is used both for traveling to novel and known destinations, as long as it involves finding the way to it. It is different however from exploratory movement, which involves surveying, without any particular spatial goal [3] [4].

Research on movement through space found that wayfinding behavior is partly influenced by design decisions [5] [6]. What is more, authors who tackle the issue agree that facilitating people’s wayfinding involves more than signage since placing signs cannot overcome flaws in the architecture that cause confusion and make orientation difficult [7]. It is therefore important to study the mental processes of orientation as well as wayfinding behavior in the context of the structured environment putting particular emphasis on designed features of the environment.

2 Rationale for the study

The underpinning assumption for this research is that today various forms of virtual environments (VE) are widely used in the architectural practice and could perhaps serve beyond presentational purposes. The aim of this study was to research if a particular type of VE could be used for testing the building's wayfinding systems, including both architecture and the signage. In other words, the study aimed to reveal whether one could assess the building in terms of its wayfinding characteristics in the design phase before the building is actually built. If the wayfinding behavior and navigation in virtual and real environments was shown to be similar, one could conclude that VEs can be used for assessing the future building's wayfinding system.
A number of studies have undertaken the issue and demonstrated that the patterns of movement could be comparable between virtual and real environments [8] [9]. However, a literature review revealed two strong tendencies in the research on wayfinding in virtual settings. One possible limitation of the existing research, often acknowledged by authors, is that environments do not consider salient characteristics of the environment such as ambient light and landmarks (see for example [8] [10]). Often the VEs do not fully account for signage, focusing instead on the structural elements of the environment. Another possible limitation emerges from a review of studies on wayfinding in VE [11] showing that a bulk of the research employs quantitative approach, and only a few studies take a qualitative approach. The study presented here constitutes an attempt of embracing the above-mentioned issues by including more physical characteristics in the VE that have been shown to be relevant to wayfinding along with employing a mixed method approach.

3 Research Design and Metrics

The virtual environment used was a simulation of one floor of CUNY Graduate Center building. It included such elements of the environment as textures, colors and signage and was modeled in a standard architectural software – Autocad and 3ds Max Studio. The three dimensional model was next imported to and edited in an Unreal Game Engine, which allowed for game-like movement in the modeled space. On the basis of existing research, implying that patterns of movement are consistent between desktop and immersive environments [9] as well as the need for the research to be easily applicable for designers, it was decided to use a desktop, non-immersive VE, presented on a computer monitor and operated through a mouse and a keyboard.
The first phase of the study was conducted in a form of experiment. Half of the participants (17 people) were asked to find an elevator in the actual physical space (one floor of a university building) and the other 17 people were asked to find it in the VE. The participants assigned to the VE group had a training session, in which they had unlimited time to learn and get used to move through a different virtual setting, by operating a mouse and a keyboard. Every participant started his/her task from the same point in space and had their wayfinding efforts videotaped. The second, qualitative phase of the study consisted of analysis of the video recording that the investigator co-conducted with each participant: as they were watching their

performance, the participants were asked comment on their thoughts and behavior. This method allowed for getting detailed information on the process of wayfinding, without impeding their performance, which is often pointed to as a limitation of a traditional think aloud protocol method. This was followed by an interview about their experience of wayfinding in the building.

Following Ruddle and Lessels' [11] classification of metrics used in wayfinding research this study yields data on all three levels, allowing for a thorough comparison between the two conditions. The performance level (1) is evaluated based on the time taken to complete the task. The physical behavior level (2) is assessed by cumulating paths taken in both environments into two composite maps. The qualitative methods allow for comparison of the cognitive rationale level (3) behind the wayfinding behavior in both real and virtual environment.

4 Findings

The preliminary findings are partly consistent with existing research. The performance measures indicate that the time taken by the users in VE was significantly longer than in real environment. The cumulative paths yield from both conditions differ diametrically, which contradicts the studies demonstrating that movement patterns in virtual and real conditions correlate [8].

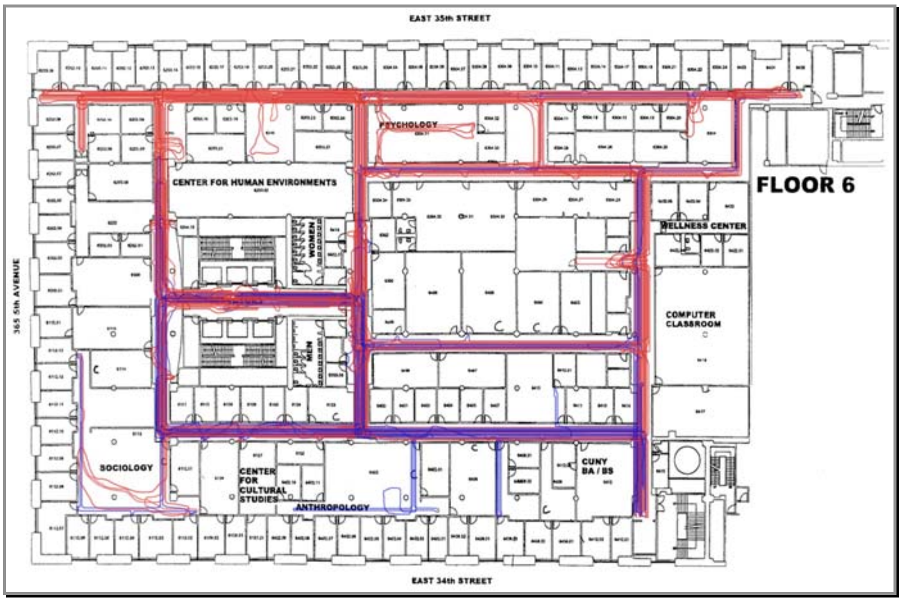

Fig1. Movement patterns in the real (blue) and virtual environment (red). All participants started in the elevators lobby. Their goal was to find the 7th elevator, located in the bottom right corner of the plan

Movement in this study was task oriented while Conroy's research looked at a non-task oriented. This might be one possible reason for the differences in the findings between the two studies, yet further investigation of this issue is necessary. The comparison of aggregate paths along with the qualitative findings suggests the critical role of body in experience of wayfinding and movement in complex environments, which has been also recently pointed out by other researchers [3]. The results are also consistent with other studies showing that in a VE, people tend to travel in paths that are generally straight [12], a pattern that is not persistent in RE navigation.
Finally, the qualitative analysis of think aloud protocols and interviews demonstrates major similarities in the cognitive rationale behind the wayfinding in both conditions. These findings allow for a tentative implication that the VEs could be used for assessing wayfinding systems of future buildings. Although the virtual environments might not prove to be useful in predicting wayfinding performance and movement patterns in quantitative terms, qualitative data that can be gained through using VE in the architectural programming phases of a project seem to be sufficient for evaluation purposes and useful for redesigning buildings before they are constructed. It remains to be seen if this will be the case in more interesting, differentiated environments.

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Configurational features and wayfinding: approaching visibility and angular incidence.

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Abstract. This work aims to approach the influence of two different configurational features of the urban space on wayfinding behaviour. In particular, the study targets the influence of two environmental features: visibility (the number of elements that can be perceived by participants when they have to choose how to continue their route) and angular incidence (the angle with which any possible options crosses a node from which subjects have to take their decisions). A software to propose a navigation task in a real environment by pc represented the tool of the study. The results showed a significant influence of the two parameters on participants' behaviour.

Keywords: Wayfinding, Visibility, Angular Incidence.

1 Introduction

Literature on spatial cognition suggests that spatial configuration of the environment can be related on mental representation of space and on spatial behaviour. To organize their own mental representation of these spaces, people have to consider the multiplicity of salient elements that constitute the setting with which they are interacting. In particular, when humans have to move on their navigation space (B. Tversky et al, 1999**,** they build and utilise a mental representation of the various constituents of this space (i.e. streets, buildings and landmarks). Works in this field have tried to highlight the constituents of the space that are at the basis of human movement. The different typologies of environmental information sources influence differently navigation behaviour, developing a spatial image based on environmental properties and on the information that these properties can offer to the individuals. The perception of the environmental elements and properties is not unambiguous, but depends from what they offer, in terms of spatial information, to the perceiving subject (Gibson, 1979)**.** People, when retrieving the information about the space, have the need to economise their cognitive resources, and this can lead them to consider only a part of the whole paths that link an origin to a destination. From this point of view, these routes seem to move together in a limited framework, as a

strategy to simplify the environmental complexity (Wineman, Peponis & Conroy Dalton, 2007).
This study targets, in particular, the influence of two environmental features individuated through a pilot study (Nenci & Troffa, 2007):
- least angle incidence, intended as the angle of incidence among different streets. Lower is the angle, higher will be the possibility of the street to be passed through.
- visibility, intended as the portion of space that can be perceived by participants when they have to choose their route.
Coherently with literature and with the results of the pilot study previously carried out, the hypotheses of the study were:
H1 – The manipulation of visibility influences subjects' choices. It is expected that an high angular option can be chosen more frequently when the level of visibility is experimentally raised.
H2 –The manipulation of visibility acts in different manner depending on the level of familiarity.
H3 – Subjects choose more frequently the paths characterised by the least angular incidence. This result is expected to be observed also when it implies a longer route.

2 Method

Participants: The study involved n=60 inhabitants of the city of Cagliari (age mean =29 years). The sample was balanced for as regards the gender variable. In any experimental condition, the subjects were equally divided according to their level of familiarity with the setting (high vs low).
Materials and apparatus: A software was developed to stimulate a goal-directed navigation in a real environment by means of a computer. This software, called FINDyourWAY , reproduces the experimental setting with photos and movies collected in a real neighbourhood. It allows a navigation through the use of mouse, or of mouse and keyboard together, to change the point of view and choose the direction. The experimental setting was divided into nodes and streets. Any street was reproduced in a film segment, that was subsequently saved in a movie. Any node was replicated by means of the photos representing any street departing from the crossroad. Photos and movies were obtained in the same moment of the day, to avoid possible influences of light and weather. The resolution of the images was kept at a fixed level to control the effect of quality.
The experimental setting: The results of the pilot study showed how this kind of wayfinding task can be disturbed by the effect of the presence of landmarks, panoramic points and identitarian elements. So, the neighbourhood chosen as adequate for our study was a modern quarter of the city of Cagliari (Sardinia - Italy). It was selected by virtue of his structure and nature, that allow to control the influence of the possible intervening variables individuated by means of the pilot study. In fact, it is a modern neighbourhood, with no monuments or panoramic points. All possible paths linking the origin point to the destination one are defined homogenously by :

- panoramicity
- identitarian value
- landmarks.

Procedure: Data were collected through the software FINDyourWAY. Participants had to reach, starting from an origin point "A", an arrival point "B". 40 of them had to complete the task in a route perspective using FINDyourWAY, while the rest had to indicate the route in a survey perspective. Subjects that were committed in the route perspective task were divided in two groups and then assigned to the two experimental conditions (low and high visibility).

Due to the particular structure of the neighbourhood, participants had to take a fixed number of choices in reaching their destination: five. Any node proposed two typologies of choice: high and low angular incidence. By virtue of the setting's structure, the path obtained by choosing the highest number of least angle options was also the longest one, whereas the route characterised by the highest number of highest angular incidence was, instead, the shortest one.

The software was structured in order to allow an experimental manipulation of the visibility for the highest angular incidence options. In the first experimental condition (high visibility), participants perceived completely all the possible options (as if they were in the middle of the node, turning their head to have a frontal view of the entrance of any street); in the second experimental condition the node was presented in a partial way (from the visual perspective of a person who is reaching the node from the origin street).

Visibility was kept as fixed (maximum) in the case of the straight options, since participants can perceive the whole elements that constitute the subsequent part of the street. Before the task, the subjects received instructions explaining how to use the software. There was no time limit to complete the navigation: all the subjects took between 4 and 9 minutes to reach the destination.

4 Data analyses

Data were analysed through a log linear analysis to investigate the associations among participants' choices and the categorical environmental variables (low vs high visibility; low vs high angular incidence).

5 Results

In any experimental condition an association between low angular incidence and high frequency of choice was observed ($z_{(1)} = 7.26$, $p < .01$). Participants chose in an higher way the lowest angular incidence options. This association emerged also from the analyses of the data collected through the survey perspective task ($z_{(1)} = 3.047$, $p < .01$).
The manipulation of visibility showed different effects depending on the level of familiarity. A significant effect of the manipulation emerged in participants with a low level of familiarity: an high level of visibility is significantly associated to high frequencies of choice for the options with an high angular incidence, and a low level

of visibility is significantly associated to low frequencies of choice for the options with an high angular incidence ($z_{(1)}$=1.98 p <.05). No significant effect appears for the manipulation of visibility in participants with an high level of familiarity ($z_{(1)}$= n.s.).

Such results move to the planning and realization of a new study to further analyse these effects, by involving a larger number of participant in new studies and including the consideration of the role of individual cognitive abilities.

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