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Posters (alphabetically ordered by first author):

Describing routes with incomplete spatial knowledge

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Route descriptions can be viewed as a way of accessing speakers' current spatial representation of an environment. Typically, analysis in this area centers on concrete turn-by-turn directions, given by speakers who are fully familiar with the environment they describe. Our aim was to gain insights on the process of accumulating a cognitive map. In our explorative study set in a complex University building, we collected spatial descriptions by speakers who were not necessarily sufficiently familiar with the building to provide a concrete path description. We were interested in the linguistic representation of their cognitive strategies of dealing with this problem. 30 experts (people working in an office within the building) and 63 novices with very limited building-specific knowledge (e.g. first-time exposure), located at five different starting points, were asked to describe the shortest way to a) the next exit and b) the Cafeteria. Afterwards they were asked to walk to one of these goals while thinking aloud. The collected rich corpus of verbal data were analyzed with respect to their linguistic structures, and related to the behavioral data (route choice and performance). Results show that the elicited descriptions range from general strategies via building specific and central point–oriented strategies to specific turn-by-turn directions using the shortest path. The various degrees of spatial knowledge were reflected by the behavioral data as well as by the linguistic features of the descriptions.

Supporting Joint Human-Computer Reasoning and Problem Solving: Blueprint of an Architecture

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Abstract. This contribution focuses on the development of a tiered computational architecture for supporting human-computer collaboration in spatial reasoning and problem solving. The aim is to improve human spatial task performance or the performance of a human-computer pair through better adapting the actions of the computational part to the human's individual and current cognitive and perceptual processes. A key challenge for improving the quality of human-computer interaction lies in not only employing general findings about spatial cognitive and perceptual parameters (loads, preferences, ability levels) but in also being able to match and adapt these to the specific, live interaction situation. Reasoning with spatial problems in diagrammatic formats is taken as a sample domain, in which current behavior of the human reasoner is registered through tracking eye movements. The architecture addresses issues of general and individual (spatial) ability levels and (spatial reasoning) preferences, and of situation-dependency. Overarching methodological and technical challenges lie in (a) establishing computational routines to robustly, reliably and live interpret and react to the reasoner's actions, and (b) in finding adequate operationalizations of selected cognitive and perceptual processes and that can be easily made available to standard approaches in HCI design outside the spatial cognition community. I argue that, while still being hard problems overall, it may be relatively easier to address both challenges for spatial task domains than for many other domains, due to specific representational and procedural properties that the modeler can exploit. The current state of the architecture's development is discussed, as are planned developments.

What is That Thing and Where is it Located? Effects of Strategies and Aging on Visuospatial Working Memory

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Abstract: We examined the relationship between object location and identity memory in visuospatial working memory and how this relationship may change with normal aging. We also investigated metacognitive accuracy, or the ability to monitor one's own cognitive processes, for spatial information. In Experiment 1 older and younger adults saw up to 5 objects in a 5x5 grid and were instructed to attend to either object identities, object locations, or both. In Experiment 2, older and younger adults were instructed to pay attention to all information. After studying a grid, participants made a Judgment of Learning (JOL) and then completed a yes-no recognition test assessing object identities, locations, or both in combination. Recognition trials were either blocked by question type (Experiment 1) or randomized (Experiment 2).

Results from Experiment 1 suggest that participants had the most difficulty remembering combined location and identity information, followed by identity information alone. They had the best memory for location information. Further, while memory for identity alone and combined information declined as array size increased, memory for location remained stable across array size. Finally, older adults' JOLs were less well calibrated with recognition performance as compared to younger adults. Experiment 2 eliminated the ability to use strategic processing, i.e. when aware of what information will be tested. Results suggest memory differences relevant to strategic processing of specific grid information. Results will be discussed in the context of automaticity of spatial processing (e.g., Hasher and Zacks, 1979) and the role of strategy in visuospatial working memory.

Key words: Spatial Working Memory, Aging, Metacognition

Individual Differences in the Gesture of Abacus Experts
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Gesturing while speaking has been shown to be beneficial for numerous cognitive processes, including learning (Broaders et al., 2007), linguistic fluency (Krauss, 1998), and working memory (Goldin-Meadow et al., 2001; Wagner, Nusbaum, & Goldin-Meadow, 2003). However, the mechanisms underlying the relationship between gesture and thought are not well understood. Some researchers have suggested that gesture plays numerous roles in cognition, perhaps interacting with different systems depending on the task. However, studies relating gesture to specific cognitive processes, such as working memory and mental imagery (see Wesp et al., 2001) suggest that in some cases, gesture use may be tied to individual differences in these processes.

The present study explored the gestures of children who are expert abacus users. These children solve addition problems quickly and accurately by imagining operations on a "mental abacus" (Stigler, 1984; Barner & Frank, in press). We examined gestures produced while solving abacus problems, while explaining these problems to an experimenter, and while explaining an unrelated spatial problem. We also measured participants' decline in performance when they were not permitted to gesture on an abacus task and a novel spatial task. Measures of working memory were obtained for all participants. Our study had three main goals: 1) to compare gesture produced in nonverbal, non-communicative contexts to more well-studied co-speech gestures 2) to examine individual differences in gesture production and gesture dependence across a variety of spatial tasks; and 3) to explore the relationship between gesture use and working memory at an individual differences level.

Orientation after floor changes in regularly and irregularly shaped parts of a staircase

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Abstract. The study investigates how a regularly and an irregularly shaped part of a staircase affects direction knowledge after floor changes. Horizontal direction judgments were less accurate after floor changes in the irregular part than in the regular part. Also, females were stronger affected by this than males. For vertical direction judgments only relative, but not absolute pointing errors were affected. The results are discussed in a framework of spatial information processing also with respect to implications for 'design for wayfinding'.

Keywords: cognitive psychology, orientation, regularity, staircases, floor change

1 Introduction

Being oriented means knowing one's own position in relation to a known location. Orientation has been assessed by several authors through direction estimations, e.g. [1][2][3][5], also for the vertical dimension [4]. Disorientation in wayfinding occurs either when two or more places look alike (spatial ambiguity) or when spatial updating is interrupted e.g. when turns which were actually executed are not integrated in the mental model of the environment. In architectural space floor changes may cause disorientation [6]. Vertical translations have to be integrated in addition to horizontal translations and rotations compared to movement within the plane. This additional processing load may lead to the neglect of some of the executed actions when integrating them into the mental model. In addition, the structure of the environment itself may influence integration performance. On a fairly regular motion path not every single movement needs to be integrated. Instead a single movement can be inferred from previous movements. On an irregular motion path every single movement has to be integrated in the mental model and the neglect of a movement may lead to an incorrect mental model of the environment.

The current study investigates how floor changes affect spatial knowledge assessed by direction estimations. The regularity of the environment was varied within participants. In particular, participants were first led along a regularly shaped part of a staircase followed by a part with an irregular structure.

2 Methods

Forty-four participants (23 of them female) between the ages of 18 and 52 years (M=25.4, SD=6.6) were recruited through postings on the campus of Concordia University and local classified ads. The study lasted about 90 minutes and participants were compensated for participation with CAD$ 15. The study consisted of four parts though due to limited space, here only the first part will be reported. This first part took about 15 minutes.

The reported data was gathered in a staircase of the Hall building of Concordia University in Montréal. The staircase had a very uniform finish with exposed concrete from the inside and no visual access to the outside of the building. Direction estimations were recorded with an angle meter. It consists of two legs being connected by a hinge. The enclosed angle is measured with an accuracy of 1° and can be read from a display on the tool. Participants were instructed to hold one leg straight in front of them (parallel to the floor plane) and were then asked to move the other leg until it points in the direction they think the target is located. Horizontal (azimuthal) and vertical direction estimations were recorded separately with the horizontal estimation being asked first, followed by the vertical estimation. For vertical pointing participants were allowed to turn towards the assumed horizontal direction of the target.

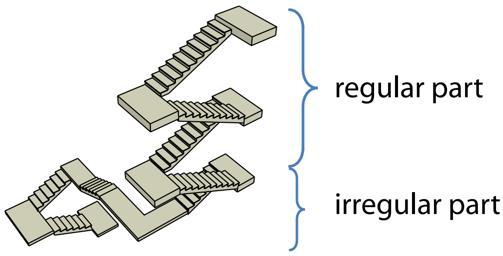

Fig. 1. Schematic drawing of the staircase. In the experimental setting both, the regular and the irregular part covered four floors each.

Participants were met at the main entrance and then brought to the lobby on the 2nd floor. They were instructed how to use the angle meter for both horizontal and vertical pointing. After two test trials in which they had to use the tool to point to a visible target in front of them and a non-visible target behind them, the experiment started. Participants were brought to the 10th floor with an elevator. At a location close to the staircase they were asked to point to the location where the instruction had taken place (2nd floor, lobby). First, the horizontal estimation was recorded, then the vertical. Participants were then led along the regularly shaped part of the staircase (eight flights of stairs with a 180° turn between each flight of stairs) down to the 6th floor (cf. Fig. 1). At a location close to the staircase they were asked to point again (horizontally and vertically) to the same location on the 2nd floor. After that they were led along the staircase down to the 2nd floor. This part of the staircase was shaped irregularly (cf. Fig. 1): six flights of stairs with a 180° turn between each flight of stairs, followed by a 90° horizontal turn, another flight of stairs, a 90° turn and two other flights of stairs with a 180° turn in-between). In the staircase they were asked to point to the location on the 2nd floor again. There was no visual access from the pointing location to the target location, though they were only about 8 yards apart from each other. After pointing participants were also asked to guess which floor they were on.

3 Results

Repeated measures ANOVAs with floor level as a within-, and gender as a between-subjects factor were conducted for horizontal and vertical pointing separately with absolute pointing error as the dependent variable.

For horizontal pointing there was no main effect of gender [$F(1,42)=.014$, $p=.908$, $\eta_p^2<.001$] though a main effect of floor level [$F(2,84)=21.82$, $p<.001$, $\eta_p^2=.342$] and an interaction of gender and level [$F(2,84)=4.17$, $p=.048$, $\eta_p^2=.090$]. The descriptive data shows a small but not significant improvement in pointing accuracy between the 10th and the 6th floor (the regular part) for both, males and females. However, there is large drop in accuracy between the 6th and the 2nd floor (the irregular part); although at this point participants are just a few yards away from the target (with no visual access to it). The interaction of gender and floor level shows that males are less strongly affected than females.

For vertical pointing there was no main effect of gender [$F(1,41)=2.259$, $p=.140$, $\eta_p^2=.052$], no significant main effect of floor level [$F(1.736,82)=3.20$, $p=.053$, $\eta_p^2=.072$] and no interaction of the two [$F(1.736,82)=1.217$, $p=.298$, $\eta_p^2=.029$]. The small effect sizes show that the absolute pointing error in the vertical dimension was not affected by the irregularity of the staircase. Inspection of rose diagrams (circular plots of the distribution of pointing direction) and the relative pointing accuracy, however, reveals that on the 10th floor participants' accuracy is quite well with a small tendency to underestimate the angle. On the 6th floor they are still quite accurate with a tendency to overestimate the angle. On the 2nd floor, however, there is strong dispersion indicating that participants are not aware of which floor they are on. While on the 10th floor 54% of the participants estimated the direction of the target within a range of +/- 15°, on the 6th floor 49% of the participants' estimates were in that range, on the 2nd floor only 20% of the participants' estimates were within the range. At the final pointing location participants were also asked to guess which floor they were on. Only 21% guessed correctly being on the 2nd floor. 58% thought they were on a higher floor. 21% thought they were on a floor lower than the second.

4 Discussion

We find participants' horizontal pointing performance to be affected by an irregular geometry of the environment, but not by the preceding regular part. Here, males seem to be less affected than females. For vertical pointing the absolute pointing error is not affected by the irregular geometry, neither for males nor for females. However, relative pointing performance and the informal question about the floor level reveal that most participants were not aware of which floor they were on. The results indicate that the regularity of the environment is a key factor in orientation. A regular geometry can be represented parsimoniously helping people to remain oriented, while irregularities can cause severe disorientation.

The observed difference in performance between male and female participants confirms earlier results on gender effects in spatial information processing. A detailed analysis of the mechanisms causing these differences, however, is beyond the scope of this paper.

With respect to architectural design we conclude that regular structures are important to support the building user's orientation, especially during floor changes. However, excessively regular environments involve the risk of spatial ambiguity, i.e. structures in which different parts are difficult to distinguish from each other. This in turn can lead to disorientation again. Thus, a careful balance of regular and irregular structures is necessary to support a building user during wayfinding.

In addition to the results presented here, the poster will contain rose diagrams with a circular histogram, the direction of the mean pointing vector and pointing dispersion indicted by the length of the vector for each pointing location.

5 Acknowledgements

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Wayfinding architectural design criteria for complex environments in ordinary and emergency scenarios

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Abstract. This study analyzes human wayfinding strategies in relation to the perception of the building's environment. Wayfinding strategies in complex buildings (by floor plan complexity, type of users, etc. ...) are put in relation to the user's behavior and the quality of the environment around her/him, expecially in emergency situations. The preliminary results of a case study concerning wayfinding in a supermarket in northern Italy will be presented in order to understand efficient wayfinding design criteria, especially in emergency situations. The study concerned a cognitive mapping test in which the person had to recall emergency exits inside the building. Almost 80% of elderly and adults (who are routine clients of the supermarket) were unable to recall exits or have identified themselves as behaving ineffectively in an emergency. This is considered as an important consideration for properly designing wayfinding systems and highlights the importance of understanding human perception in order to design safer buildings.

Key interest: wayfinding, architecture, complex environments, human behavior in fire, environmental psychology, design criteria, cognitive mapping

1 Motivation of the study and related work

Weisman [1] found that the most serious disorientation problems occurred in buildings judged as being the most complex and difficult to describe. He found that visual spatial features of the environment (such as simplicity and good form) and familiarity with the building are the most important key elements for good human wayfinding performance.

Nowadays, most buildings are very complex and most of the designers think that sing are a sufficient solution for poorly designed buildings. It has been argued several times, for example by Arthur and Passini [2], that signs do not fix the problems related to the bad design of a building.

In addition, most of the early researchers of human behavior in fire have demonstrated that wayfinding tasks difficulty increases significantly in emergency scenarios [2,3,4]. A frequently observed phenomenon reported in the literature [3],

termed “movement towards the familiar”, refers to the intuitive way that people exit buildings by their familiar exit even in emergencies. This intuitive egress behavior is not always problematical but in some cases it could prove lethal, for example, when the familiar route is untenable.
McClintock et al. [6] also been reported by that under everyday conditions occupants tend not to notice or recall the location of emergency exit signs.
As suggested by Ozel [7], in order to understand how to design efficient wayfinding especially in emergency situations, it is important to know how people perceive the environment. Cognitive factors are a key element in influencing wayfinding performance.
In this paper, the authors turned their attention to the visibility of the egress route as an important performance factor in assuring the safety of occupants in buildings.
They decided to conduct a cognitive mapping test on emergency exits in a supermarket. Clients in a supermarket are never involved in fire drills and may not be aware of emergency exits location, or how to behave efficiently in emergency.
Supermarkets, as suggested by Norman [8], are known as being complex environments also because of visual merchandising techniques that tend to easily disorient customers.
Research on cognitive maps and cognitive mapping is by now quite extensive. The bulk of research has focused on people’s memory representations of large-scale environments [9,10]. Many of these studies have tried to determine what people remember about the environment.

No studies, to the knowledge of the author, have analyzed cognitive mapping capacities of recalling emergency exit in supermarkets or malls. Understanding how people perceive the environment is, therefore, the most important thing in order to predict human wayfinding behavior and consequently design the building [2].

2 Methods

The research method involved case studies of human wayfinding behavior in two malls in northern Italy. The data collection technique used was post-occupancy verbal interviews with a set of pre-defined questions with single individuals. People involved in the test are both clients and workers.
Participants were asked to:
1 - indicate a certain route to a person who had never been inside the supermarket
2 - recall emergency exits, otherwise indicate what evacuation procedures he/she would have followed in the event of a real emergency.

3 Preliminary results

In this paper we report preliminary findings (Table 1) on a cognitive mapping abilities test about recalling emergency exits, as the emergency scenario is considered to be the most difficult one for wayfinding.

The study was conducted on February 27th 2010 in the “IperCoop Meduna” supermarket in Pordenone (Figure 1), northern Italy. There were 106 people interviewed (male 48%, female 52%).
The cognitive mapping test was necessary to highlight the critical elements of architectural design of the building.

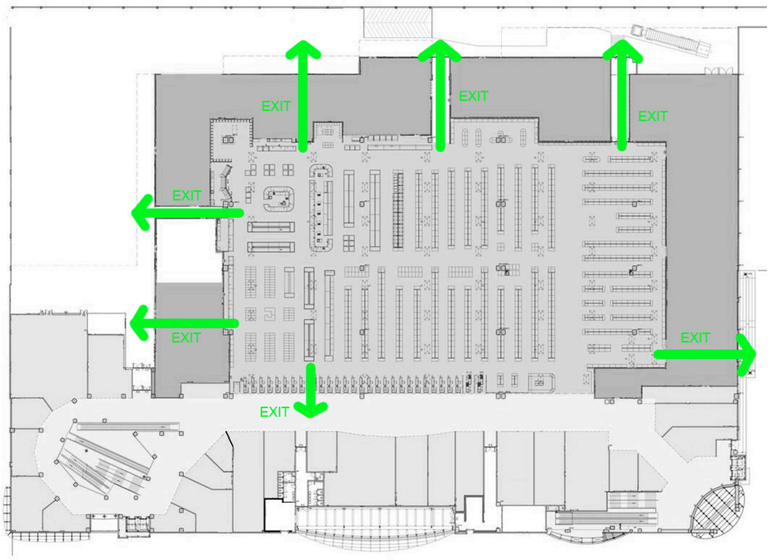

Figure 1. Supermarket’s layout with individuation of emergency exits

The first consideration relates to the identification of a vivid distincion of responses related to the different age groups: particularly important, also, the fact that only 18% of all respondents were able to give an effective indication of the location of at least one emergency exit.
Also significant the halving of effectiveness in indicating emergency exits between adults and elderly people: 10.71% of elderly respondents, compared to 22.22% of adults have shown real ability to indicate exits.
Respondents, who were unable to recall emergency exits (32,08%), have proposed, as an alternative for escaping, to head towards pay desks or entrance, simply proposing the paths habitually engaged in ordinary conditions.
Paydesks and entrance are, therefore, critical design elements. In case of an emergency they can impede rapid people flow: this is due to the narrowness of paydesks lanes and the presence of crowds in their close proximity.
About 16% of participants said that they would seek signs or emergency exits. This is an efficient attitude in emerency situations, but it could be completely vain if the sign systems and location of emergency exits are not really effective in that particular situation.

Table 1. Answers the question: "Can you recall emergency exits? Otherwise, how would you exit the supermarket if an emergency occurs?”. Age classification.

Answers	**Young 15 (14,15%)**	**Adults 63 (59,52%)**	**Elderly 28 (26,45%)**	**TOT 106 (100%)**
Absolutely not	3 (20%)	12 (17,46%)	6 (17,86%)	19 (17,92%)
Effective response	2 (13,33%)	14 (22,22%)	3 (10,71%)	19 (17,92%)
Pay desks/Entrance	5 (33,33%)	18 (28,56%)	11 (39,29%)	34 (32,08%)
I will follow the flow	2 (13,33%)	9 (14,28%)	3 (10,71%)	14 (13,21%)
Signs/Exits	3 (20%)	10 (15,87%)	4 (14,29%)	17 (16,04%)
General information	0	1 (1,59%)	2 (7,14%)	3 (2,03%)

The fact that almost 80% of elderly and adults (who are routine clients of the supermarket) were unable to recall exits or have declared that they would have ineffective behavior in an emergency, is as an important consideration for properly designing wayfinding systems.

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Active And Passive Components Of Spatial Learning

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When arriving in a new city, it seems that actively walking around would lead to better spatial knowledge than passively riding in a taxi, yet the literature is mixed. We tested the contributions of four components to spatial learning: visual information, vestibular information, motor/proprioceptive information, and cognitive decisions. Twelve groups of participants learned the locations of 8 objects in an ambulatory virtual maze, and were then tested on their graph or survey knowledge of object locations. Three information conditions were crossed with two decision conditions: (a) *Walk* – participants walked in the maze, providing visual, vestibular, and motor/proprioceptive information. (b) *Wheelchair* – participants were pushed through the maze in a wheelchair, providing visual and vestibular information. (c) *Video* – participants viewed desktop VR displays, providing visual information. Decision conditions: (1) *Free* – Participants freely decided which paths to take during exploration. (2) *Guided* – Participants were guided along paths matched to participants in the Free Walking condition. In the test phase, participants were wheeled to object A and instructed to walk to the remembered location of object B: (i) *Survey task* – the maze disappeared and participants took a direct shortcut from A to B. (ii) *Graph task* – participants walked from A to B within the maze corridors, with detours. Results suggest that participants in the Walk conditions have lower variable errors, implying an important role for active motor/proprioceptive information. We also observed large individual differences in spatial learning.

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The Role of Map Alignment in Performance on Mapping Tasks

A key requirement for map use is linking the representation to its referential environment, a link supported by physically or mentally aligning map and space. Three studies addressed participants' success in indicating locations or directions on a campus map in relation to map alignment. Study 1 (college students) and study 2 (10-year-old children) provided correlational data showing that participants who spontaneously aligned the map with the environment performed better on mapping tasks. Study 3 (college students) provided an experimental test of the impact of alignment by randomly assigning students to one of three groups: *uninstructed*—not instructed regarding alignment; *cued alignment*—informed that alignment might be helpful for the task; and *explicit alignment*—given and asked to maintain alignment during the task. Data showed significantly better performance in the explicit than in the cued group, and in the cued than in the uninstructed group. The former contrast is another instance of the well-known finding that performance is better with map alignment. The latter contrast demonstrates a significant benefit even when participants must rely on their own alignment skills to implement the suggested strategy. Additional data collection is underway to examine performance in relation to participant sex and individual differences in spatial ability as measured by a battery of paper/pencil spatial tasks. The present findings indicate the utility of providing instruction on physical map alignment as part of map-skills education for both children and adults.

Wayfinder: A Spoken Dialogue System for Indoor Navigation

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Abstract. We present a spoken dialogue system that aims to help users for navigating in buildings that are generally recognised as presenting significant navigational challenges to both new and infrequent visitors. Our system automatically generates—visual and verbal—indoor route instructions when asked about locations, using speech-based natural language input and output (in English and German). This system is an extension of a text-based dialogue system [1], and is presented with five main modules: natural language understanding, dialogue management, route instruction generation, natural language generation, and schematic map visualization. First, the user interacts with a graphical user interface by asking questions about route directions using speech-based natural language. Second, the language understanding module applies parsing and keyword spotting to the user utterance in order to extract a user dialogue act. Third, the dialogue management module specifies the system's behaviour by mapping dialogue states (extracted from the knowledge base) to dialogue acts such as 'request', 'clarify' or 'present info'. Fourth, the route instruction generation module extracts the content to be presented to the user, e.g. graph route and landmarks. Fifth, based on the selected content, the language generation module produces high-level route instructions, which in turn outputs text to be synthesized in syncronization with the schematic maps. Finally, the knowledge base maintains the history of the interaction. In this demonstration we focus our attention to the route instruction generation module in order to frame the generation of adaptive route instructions as an optimization problem. For such a purpose, we provide a proof-of-concept of the machine learning approach proposed by [2], and show that it is promising for its application in online user-machine interaction and that it can be used for inducing adaptive behaviour in in-situ navigation assistance.

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Spatialized Audio for Remembering Auditory Target Azimuths

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Abstract. The efficiency of virtual spatialized audio has been studied for real-time route guidance, but its utility for presenting information that is integral to spatial learning is still unclear. Here we evaluate the efficacy of spatialized sound for use with auditory displays by comparing participants' performance on basic spatial tasks when auditory targets were presented through headphones (virtual audio) versus speakers (external audio). Our findings show that using virtual audio elicits more accurate orientation toward auditory targets than external audio, and that both modes yield equivalent recall of auditory target azimuths. These findings demonstrate that virtual audio is at least as efficient as traditional external sound sources for providing information that assists in the representation and recall of object locations. These results have important implications for the development of virtual auditory displays, which could be used with navigation systems and nonvisual spatial interfaces.

Keywords: spatialized audio, spatial learning, functional equivalence

1 Introduction

While people learn unfamiliar environments through multiple sensory modalities, vision has an advantage over other senses as it allows a traveler to integrate both proximal and distal information into a global spatial representation while navigating. The motivation of this study is to examine the usability of virtual 3D spatialized audio (virtual audio), in which sounds are heard as emanating from a specific distance and direction in space, as part of an interface for an indoor navigation system. Virtual auditory displays can be used to effectively present distal environmental information because, similar to visual displays, they allow for spatial information to be perceived directly rather than undergoing cognitive interpretation [1]. This form of 'direct' presentation has been shown to significantly improve performance on a wayfinding task [2], likely because it minimizes the amount of information that must be communicated to the user, and reduces the errors caused by cognitive processing [3].

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Functionally equivalent behavior has been shown for learning from external 3D spatialized audio (external audio), in which speakers are placed at actual locations in the environment, and other modalities, such as vision and spatial language. However, while virtual audio delivered through headphones has been successfully employed for real-time route guidance, its equivalence for learning and recalling location information has not yet been compared to external audio. The purpose of this study was to compare the ability of participants to orient toward and then remember the azimuth of a target sound that was presented either through speakers or headphones. Performance on these tasks will help determine whether participants can use virtual audio, which is necessary for a mobile navigation system, to create accurate spatial representations (e.g., spatial images or cognitive maps).

2 Encoding and Recalling Audio Targets

Ten women and eight men participated ($M_{age} = 26$, range 20–42). Target sounds were presented once at each of 12 azimuths. Participants completed 2 blocks in each auditory presentation mode (speakers or headphones) for a total of 48 trials.

At the beginning of each trial, participants faced an initial heading. The target sound was presented until the participant turned in place to orient toward its location and pressed the response button, which measured the *perceived target location*. The participant then turned back to the initial heading and was instructed to reorient toward the same target location from memory. Once the participant was satisfied that they were facing the remembered target location, they pressed the response button, indicating the *recalled target location*.

2.1 Results and Discussion

Heading error (Figure 1) was calculated as the absolute difference between the actual target location and the perceived target location. Encoding error (Figure 2) was calculated as the absolute difference between the perceived target location and the recalled target location. Heading and encoding errors were analyzed with separate 2 x 12 (mode, target location) repeated measures ANOVAs.

A main effect of mode was found for heading error ($F(18, 1) = 29.34, p < 0.01, \eta_p^2 = 0.63$). Orienting toward sounds presented using virtual audio produced smaller errors ($M = 4.28, SE = 0.44$) than orienting toward sounds presented using external audio ($M = 8.38, SE = 0.71$; $t(17) = 5.42, p < 0.01$).

For encoding errors, there was a main effect of target ($F(18, 11) = 4.98, p < 0.01$, $\eta_p^2 = 0.23$), which was expected because participants took more time to reorient and respond to rearward targets due to the larger turn angles. This behavior is likely to result in accumulated error and thus poorer recall [4]. Confirming this expectation, a paired samples t-test of forward (azimuths $\leq \pm 75°$) and rearward (azimuths $\geq \pm 105°$) targets demonstrated that rearward targets were more difficult to recall accurately ($t(17) = 3.37, p = 0.004$).

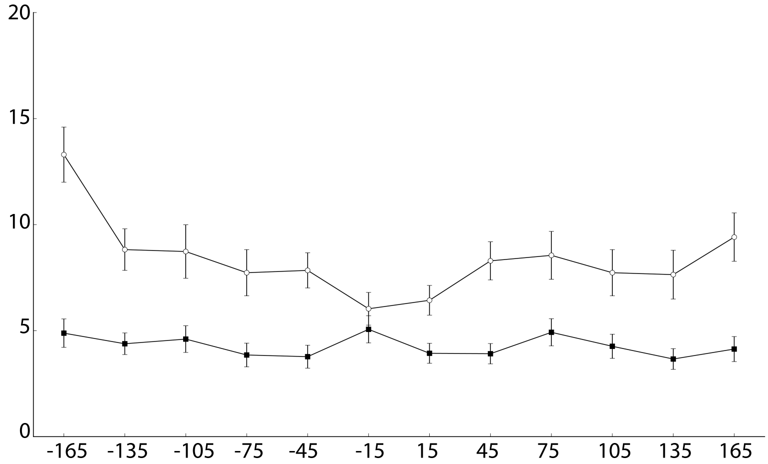

Fig. 1. Mean unsigned heading error (degrees) for virtual audio (*filled squares*) and external audio (*open circles*) by target azimuth. Bars represent ±1 standard error of the mean.

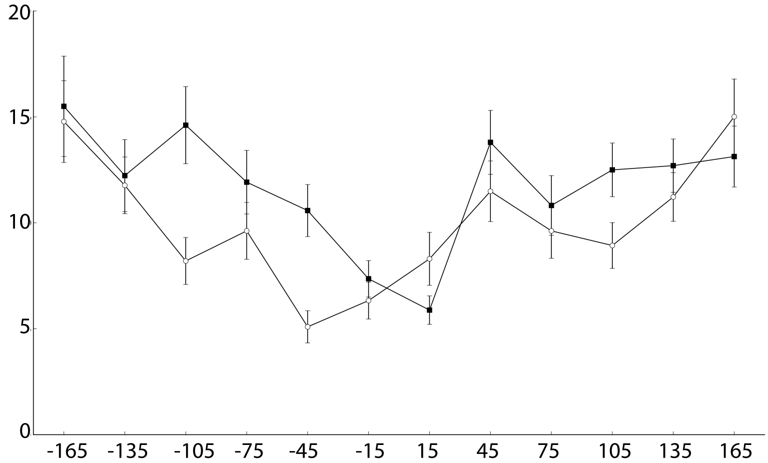

Fig. 2. Mean unsigned encoding error (degrees) for headphones (*filled squares*) and speakers (*open circles*) by target azimuth. Bars represent ±1 standard error of the mean.

Most importantly, there was no significant main effect of mode for encoding errors, indicating that virtual audio signals yield recall of target locations that is equivalent to external audio. This result suggests that virtual and external audio engender similar spatial representations. These data provide strong support for the use of virtual audio for presenting distal information.

Additionally, the differences between the heading and encoding errors in each condition were analyzed using a 2 x 12 (task, target location) repeated measures ANOVA. There was no main effect of error type for the speaker condition ($F(18,1) = 0.99, p = 0.43$). In comparison, there was a main effect of error type for the headphones condition ($F(18,1) = 48.31, p < 0.01$, $\eta_p^2 = 0.74$). These results show that when using virtual audio, participants oriented toward targets significantly better ($M = 4.28$, $SE = 0.44$) than they oriented toward the remembered target locations ($M = 10.91$, $SE = 0.74$), whereas there was no such difference with the same tasks when using external speakers. Therefore, although participants perceived and oriented toward targets more precisely with headphones, the memory of that location was not more accurate than locations encoded using external audio.

3 General Discussion

This study examined the utility of virtual audio for use with an auditory display interface that is being designed for an indoor navigation system. Our results demonstrate that virtual audio is effective for relaying high precision, perceptually mediated, distal information to the user. The application of these findings has important implications regarding the design of future navigation systems that employ spatialized audio displays. Smaller heading errors indicate that virtual audio elicits more accurate target localization compared to external audio. In addition, the absence of significant differences in encoding error for remembered targets suggests that there may be functional equivalence between audio conditions for facilitating spatial learning and the development of spatial representations. Taken together, our data support the efficacy of virtual audio for use with a mobile navigation system.

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Collaborative Orientation Task Performance: Effects of Communication Medium and Relative Spatial Abilities

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Abstract. Pairs of dispersed individuals often must communicate information about spatial configurations in order to solve orientation tasks. This study investigates how collaborative orientation tasks of varying difficulty are solved using one of three communication media (text, audio, video). Within each pair, individuals played two distinct roles during task performance, depending on the information they possessed. Pairs in the audio condition outperformed those in the text and video conditions in complex tasks. We found strong relationships between pairs' performance levels and pair members' spatial abilities, and found that the relationship strength depended upon the relative abilities of each role within a pair, as well as on task difficulty.

1 Introduction

Certain spatial tasks demand that individuals align their personal perception/view of the environment with that of an external navigational aid (e.g., using a map to orient oneself). Because the map frames the environment in a perspective independent of the reader's point of view (Klatzky, 1998), individuals must use various processing strategies (e.g., mental rotation) to align their frame of reference with that of the map (Gunzelmann, Anderson & Douglass, 2004). Orientation tasks are often distributed across geographically separate individuals, each with their own frame of reference, and each with information crucial to solving the task but insufficient on its own (e.g., a lost driver can call a friend for directions rather than study a map). Such communicative partners must actively discuss their pertinent spatial information in order to resolve the orientation issue, calling into question the way in which information is communicated (i.e., what medium is used), as well as the spatial abilities of each communicating individual and the relations between their individual spatial abilities. Our study examines how individuals solve *collaborative orientation tasks* (tasks in which two individuals receive different task-relevant information and must communicate to solve an orientation task) using different communication media (Text, Audio, and Video). We investigate how individuals' spatial abilities impact task performance, especially with regard to the role each individual plays during collaborative orientation tasks. In our tasks, individuals' roles (i.e., *Instructor*, *Responder*) were dependent upon the type of task-relevant information they possessed (please see *Measures* in the *Method* section, below).

2 Method

Participants. 48 participants over the age of 18 were recruited from Champaign, IL. Participants were randomly assigned to pairs. Data from one pair (Audio condition) was not included in the analysis due to a failure to perform tasks. Of the remaining 46 participants (mean age=24.6; mean years of education=15.7), 29 were female.
Measures. Participants' ability to mentally rotate objects was measured with the Mental Rotation Test (MRT; Vandenberg and Kuse, 1978). The Perspective Taking/Spatial Orientation Task (PTSOT; Kozhevnikov & Hegarty 2001) was used to assess participants' ability to imagine a scene from a different location in space. Orientation tasks were adapted from Gunzelmann, Anderson, & Douglass (2004). Each collaborative orientation task contained two separate displays with object configurations that needed to be reconciled to solve the task. The Responder's display showed a target's location relative to other objects while the Instructor's display showed certain objects and a cardinal direction arrow. Pairs needed to discuss their displays (e.g., orientation and relative positions of objects) to enable the Responder to deduce and report a target's direction relative to an X in the center of his display (see Fig. 1 for examples). Stimuli were on two levels of complexity: In simple tasks, each icon on the Responder's display was unique; in complex tasks, it contained multiples of the two icons present on the Instructor's display.
Procedure. Roles (Responder, Instructor) were randomly assigned, as were pairs to communication conditions. Individuals completed demographic and spatial tasks prior to the orientation tasks (1 practice task; 20 actual tasks: 10 complex, 10 simple).

3 Results

8 pairs participated in each condition; however, one pair in the Audio condition was later excluded (see above). Our previous analysis (D'Andrea & Fu, 2010) examined the effect of communication media (video, audio, text) and task difficulty (simple, complex) on overall accuracies. Findings indicated that in complex tasks only, pairs in the Audio condition outperformed pairs in either Video or Text conditions. Please see D'Andrea & Fu (2010) for an analysis of why communication media spurred differing performance.

For this contribution, we assessed the relationship between task performance and relative spatial ability of each role (i.e., Responder vs. Instructor) within a pair. To first examine the impact of pair members' relative abilities on pair performance, we correlated the latter (overall; simple tasks; complex tasks) with maximum and minimum spatial ability scores (MRT, PTSOT) from each pair. A prior assessment of the average difference between max and min scores found that both differed reliably (overall: *MRT*: avg. diff.=9.0, possible task range of 36; *PTSOT*: avg. diff.=21.0° of 360°; similar results for all condition pairs). Results showed a reversed relationship between performance and relative mental rotation ability across simple and complex tasks. The *min* MRT score within each pair was much more predictive of *simple* task performance than was the pairs' max MRT score, while *max* MRT was more predictive of *complex* task performance. Perspective-taking ability did not correlate with task performance as strongly as did mental rotation ability. However, it was predictive of performance, as min (better) PTSOT levels predicted performance more strongly than max (worse) levels in both simple and complex tasks. All significant correlations ranged from 0.47-0.67; all $p<0.05$.

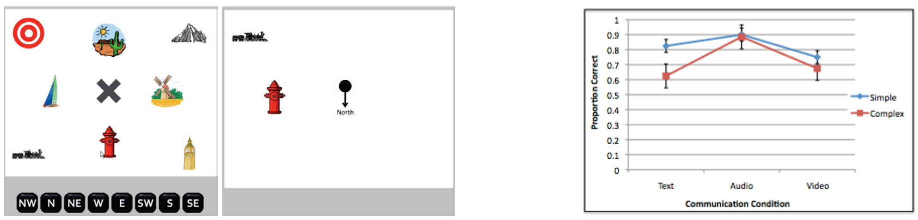

Fig. 1. a *(left):* Sample trial displays for a simple task. The left is a display seen by a Responder; the right is a display seen by an Instructor (correct response=Southwest). **b** *(right):* Average proportion of trials correct by communication medium, as a function of trial complexity.

We next examined relative abilities in light of the role (Instructor, Responder) of the pair member responsible for each level. For both MRT and PTSOT, we selected: 1) max score was the Instructor (i.e., Instructor had higher ability than Responder); 2) max score was the Responder (i.e., Responder had higher ability than Instructor). We generated correlations between performance (simple tasks; complex tasks) and spatial ability (max, min scores) for both groups. The pattern of MRT score correlations indicates that *simple* task performance is highly related to *Responders'* ability to mentally rotate objects; Instructors' ability is relevant only when they have the lower MRT score of the pair, and even then it holds less weight than Responders' ability. On the other hand, *complex* task performance related to MRT scores only when the *Instructor's* ability to mentally rotate objects is better than that of the Responder, in which case performance is more strongly related to Instructors' ability than Responders'. All significant correlations ranged from 0.55-0.88, $p<0.05$. With regard to PTSOT, results suggest that perspective-taking ability predicts task performance only for the Responder, as correlation coefficients with performance are consistently higher than for the Instructors (though only with statistical significance when the Responders' PTSOT scores are better than the Instructors'; significant correlations were 0.60, 0.72, $p<0.05$).

We assessed whether relative spatial abilities had differing relationships with task performance depending upon the communication medium utilized. Results indicate that our previous findings regarding relative spatial abilities and task performance were not an artifact of combining individual communication media effects. Rather, the impact of relative spatial abilities appears to exist through levels of communication.

4 Discussion

We described results of a study aimed at situations during which information about spatial configurations must be communicated between two human partners who possess different (incomplete) information. In the study, they either acted as Instructor or Responder, used different communication media (text, audio, video) and simple and complex tasks. We found strong effects of communication medium (audio > text, video) and of spatial abilities (e.g., for mental rotation) on task performance, with interesting differential effects for role-ability combinations. Where performance in easy tasks was found to more strongly depend on mental rotation abilities of the Responder, performance for more complex tasks (e.g., for tasks that require successfully disambiguating spatial interpretations) depends more strongly on the Instructor's mental rotation abilities.

We propose that the varying relationship between task performance and relative spatial abilities of Responder vs. Instructor is rooted in differing task demands imposed by our simple and complex tasks. Responders could solve simple tasks with little input/information from the Instructor; the major bottleneck for task performance thus lay with Responders' abilities. In complex tasks, Responders needed Instructors to communicate more extensive information (e.g., on relationships between objects) and to anticipate or resolve potential conflicts that were due to the ambiguous configurations. As a result, Instructors need to take on a much more active role, and their abilities constituted the most important factor for pair task performance. We argue that the fact that only Responders' PTSOT scores predicted performance (and this only in some conditions) likely reflects a use of perspective taking before Responders gave their answers; Instructors on the other hand could perform just as well with using mental rotation strategies only.

We suggest that the presented data has rather direct implications for a number of practical applications, such as for selecting and training emergency response personnel based on spatial ability profiles of their respective tasks.

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Measuring Configural Spatial Knowledge: Techniques for Directly Comparing Pointing Tasks and Sketch Maps

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Abstract. Pointing tasks and sketch maps are widely used to measure configural spatial knowledge, the map-like or quasi-geometric spatial memory representation of the layout of a natural or virtual environment usually obtained from direct environmental experience. Pointing tasks typically have people make judgments of relative direction. The pointing data use absolute angular error scores, the absolute value of the angular differences between the pointing responses and the correct angles, to quantify acquired configural spatial knowledge. Sketch map tasks have people hand draw a plan view map of an experienced environment. However, a variety of different scoring methods are used to evaluate configural spatial knowledge from maps, such as subjective goodness ratings and the number of critical features included in the drawing. Consequently, the scoring of pointing and sketch maps can result in disparate measures which may be sensitive to different aspects of memory knowledge. This is not because the information people use to point or sketch is not inherently spatial, but because the scoring methods may generate an index of different types of spatial information. Here we describe how we obtain analogous absolute angular error scores from pointing tasks and sketch maps. We illustrate the angular error sketch map scoring technique, additional techniques for scoring maps and making pointing judgments, and we present supporting data from our laboratory. With these procedures, cognitive processes underlying both pointing tasks and sketch maps can be directly compared. Theoretical implications for the measurement techniques will also be discussed.

Keywords: Spatial Cognition, Configural Spatial Knowledge, Sketch Maps

The Visual Properties of Spatial Configuration

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Abstract. This research is a first step in understanding how spatial information is used during navigation, by identifying elements of the spatial structure that represent spatial configuration. The study seeks to uncover the visual properties of spatial configuration. A novel method for approximating the pedestrian visual experience uses a series of 360 degree photographs taken along three routes in the City of London. Six image properties are identified that are held to be representative of spatial configuration: visual connectivity; percentages of visible sky and floor areas; ratio of sky to floor area; the maximum road centre line and the maximum depth of view. Each variable is correlated with several space syntax measures. The results show that these variables do represent properties of spatial configuration, and that accessibility, permeability and visual connectivity, as interrelated variables, are particularly relevant.

The influence of external landmarks on learning a non-Euclidean wormhole environment

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Department of Cognitive and Linguistic Sciences

Participants learned a non-Euclidean hedge maze in a virtual environment containing two "wormholes" that seamlessly transport them between locations by means of virtual maze rotation. Previous experiments revealed that participants rely on topological graph structure (route knowledge) when navigating, and exhibit violations of global Euclidean structure (rips and folds in space). In the present experiment, we added four distal (~120m) landmarks outside the maze; they provide information about the maze rotation, indicating that its internal Euclidean structure is preserved. Participants learn the locations of nine places (objects) during free exploration in one of three conditions: (1) no external landmarks (control), (2) external landmarks rotate with the maze, and (3) external landmarks remain fixed in the laboratory. We then probed their spatial knowledge using a shortcut task, in which they walked from the Home location to object A, the maze and landmarks disappeared, and they walked directly to the remembered location of object B. In all three conditions, participants took shortcuts in the direction of the wormhole, rather than to the Euclidean location of the target. The results are consistent with learning the graph of the environment, even with distal landmarks that should reveal the maze rotation. Primary spatial knowledge appears to have a topological structure with some coarse metric information, but is not integrated into a globally consistent Euclidean map.

The Long and Short of it: Development of Spatial Scaling Abilities

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Spatial scaling is an integral aspect of many spatial tasks that involve symbol-to-referent correspondences (e.g., map reading, navigation, drawing, etc.). It is also relevant to geometrical or mathematical reasoning that involves proportional thinking and comparisons of magnitudes. Although a fair amount is known about the development of spatial scaling skills, this knowledge has yet to be brought to bear on the emergence of individual differences. In the present study, we investigated 3- to 6-year-olds' ability to scale distances, with the objective of developing an assessment tool that will allow us to investigate the emergence of this integral aspect of spatial thinking. We asked children to determine the location of hidden objects in a two-dimensional spatial layout using information provided by a second spatial representation (map). By presenting different layouts and different maps, we examined which factors of the map and the hiding location (scaling factor, landmarks, boundary information) affect the emergence of early understanding of spatial scaling. Results showed a clear developmental progression of spatial scaling abilities from 3 to 6 years of age. The roles of boundary information, scaling factor, landmarks, and gender will be discussed.

The construction of cognitively-adequate tactile maps

Christian Graf

Diagrammatic representations, such as maps, have proven to be successful aids in navigation, i.e. to gain some survey knowledge about the world. In the case of visually impaired people, tactile maps have become an option to supply geographical knowledge. Due to the low resolution in the tactile modality, tactile maps cannot be populated that much (tactile entities are rather large compared to graphical entities and they need a larger gaps to be regarded as separate entities). I want to investigate the usage of tactile maps and define an inventory of tactile entities that en ensemble convey non-arbitrary clues about the underlying map concepts. The aim is an ease in the acquisition of survey knowledge from tactile maps to support self-dependent navigation in formerly unknown environments.

How to Measure the Brain Dynamics
Underlying Embodied Spatial Cognition

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Human cognition is embodied in the sense that cognitive processes are based on and make use of our physical structure while being situated in a specific environment. Brain areas and activities that originally evolved to organize motor behavior of animals in their three-dimensional (3-D) environments also support human cognition (Rizzolatti, Fogassi, & Gallese, 2002), suggesting that joint imaging of human brain activity and motor behavior could be an invaluable resource for understanding the distributed brain dynamics of human cognition. However, due to technical constraints of traditional brain imaging methods there is a lack of studies investigating the brain dynamics underlying actively behaving subjects. This imposes a fundamental mismatch between the bandwidth of recorded brain dynamics (now up to 10^6 bits/second or more) and allowed behavior (typically, minimal button presses at ~1/second).

To better understand the embodied aspect of human (spatial) cognition, we have developed a mobile brain/body imaging (MoBI) modality to allow for synchronous recording of EEG, eye movement and body movements as subjects actively perform natural movements in 3-D environments (Makeig et al., 2009). Simultaneous recording of whole-body movements and brain dynamics during free and naturally motivated 3-D orienting actions, combined with data-driven analysis of brain dynamics, allows, for the first time, studies of distributed EEG dynamics, body movements, and eye, head and neck muscle activities during spatial cognition *in situ*. The new mobile brain/body imaging approach allows analysis of joint brain and body dynamics supporting and expressing natural cognition, including self-guided search for and processing of relevant information and motivated behavior in realistic environments.

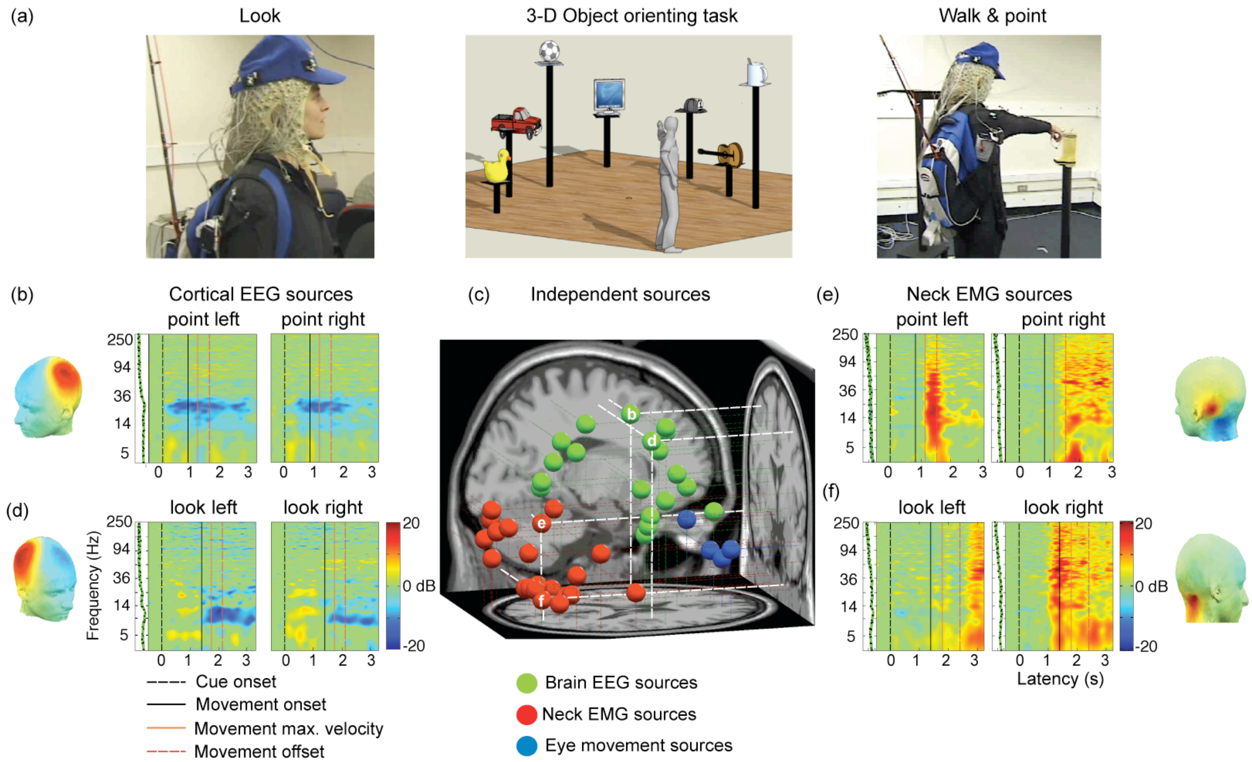

Figure 1. Pilot mobile brain/body imaging data. (a) A pilot 3-D object-orienting MoBI experiment. Wearing a lightweight battery-powered 256-channel EEG system (Biosemi, Inc.) and motion capture suit (Phasespace, Inc.) incorporating 30 infrared emitters whose positions are captured at 480 Hz by 12 cameras, the participant turns his/her head to look toward (left), point to (center), or walk and point to (right) one of several displayed objects as cued by instructions displayed on a task screen (center). Custom (DataRiver) software synchronizes the high-density EEG and full-body motion capture data, stores it, and simultaneously makes it available across a local area network (LAN) for online computation, allowing interactive stimulus control based on current body position or movement and/or EEG measures. The synchronized EEG and behavioral data allow assessment of functional links between brain dynamics and behavior. Independent component analysis (ICA) separates the EEG data into a number of temporally and (often) functionally distinct sources that may be localized, e.g., via their equivalent model dipole(s), as illustrated for one subject in (c). For example, (b) an independent component (IC) source localized to in or near left precentral gyrus (BA 6) exhibits blocking of high-beta band activity following cues to point to objects on the left or right, while another right middle frontal (BA 6) IC source (d) exhibits mean theta- and beta-band increases followed by mu- and beta-band decreases during and after visual orienting to the left or right. (e) An IC source accounting for activity in a left neck muscle produces a burst of broadband EMG activity during left pointing movements, and while maintaining a right pointing stance, while (f) a right neck muscle IC source exhibits an EMG increase during right head turns and during maintenance of left-looking head position (from Makeig et al., 2009).

Abstract for Spatial Cognition 2010, Poster Session

Authors: Michelle D. Greenwood, Teenie Matlock, Michael J. Spivey, Justin L. Matthews
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Title: How Agent Presence and Verb Agency Influence Perspective-Taking in Spatial Scenes

People commonly take an egocentric perspective when describing spatial scenes, where spatial relationships among objects are described from the viewer's perspective. Sometimes, however, we take an alternative (allocentric) perspective to add meaning or reduce ambiguity in a situation. In a series of experiments, participants were asked to view a photograph and describe the spatial relationship of objects pictured on a table. Results showed three main findings that all increased the probability of an allocentric response. First, when a toy robot was present in the spatial scene and facing the viewer, people were twice as likely to take an allocentric perspective over an egocentric response. Second, when an action-oriented verb such as "placed," was included in the question (with scenes that had the toy robot present), participants responded with the allocentric perspective twice as often than they did with the egocentric response. Third, when an object (such as a chair) is present, that provides motor affordances consistent with an agent potentially being present, and facing the viewer, people once again are twice as likely to take the allocentric perspective over the egocentric perspective. Individuals tend to choose the allocentric perspective when there is an agent-like entity in the scene to use as an anchor (even one that merely hints at agency, such as a toy robot). Although the egocentric perspective is often used, the embodied approach of using affordances in visual scenes to cue action can prompt individuals to take another perspective.

Key Words: Perspective-taking, embodied cognition, agency, affordances, viewpoint

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Title: Does language support spatial cognition concerning routes and maps?

Recent theories of embodied cognition suggest that verbal representations are given meaning by "simulation" processes performed in non-verbal, sensory-motor representations. This theory seems to suggest that non-verbal representations alone would be sufficient to generate functional behavior. Another perspective claims that action and language are interwoven in the way of „grounding language in action". Language has been recognized as playing an influential role in establishing concepts about objects or events.
In a series of recent experiments, we have tested this (alternative) hypothesis that language-based representations do support spatial behavior even in monologic situations. Subjects were trained to find goals in virtual environments comprising an iterated Y-maze with clearly nameable landmark information at each decision point. In three conditions, subjects were either allowed to explore and learn on their own (baseline condition), or were instructed at each place to select from a list either a suitable name (word condition) or an icon summarizing the gist of the landmarks presented at each place (icon condition). The experiment was performed for a route and for a map learning task. Together with studies of Meilinger et al. (2008 and submitted) here we provide first results of a supporting function of language in wayfinding.

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Spatiomotor Routines as Spontaneous Gestures

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Abstract. The spontaneous gestures that accompany spoken language are particularly suited to conveying spatial information. The current work uses gestures with spatiomotor semantics to sharpen requirements for models of language production.

Keywords: gesture, spatial language, knowledge representation, language production

1 Introduction

Because hand gesture is spatial in medium, it can express spatial information directly and thereby enhance accompanying speech. Among the spontaneous gestures that accompany speech, *iconic* gestures are those which present "images of concrete entities and actions"[1]. Iconic gestures have been shown to be effective at communicating basic spatial information such as direction, speed, and size [2]. In this work we focus on gestures that present concrete actions, in the form of spatiomotor routines associated with simple manual tasks. We survey the range and limits of their use within a single corpus, and use close observation of their relationship to context as a basis for drawing preliminary conclusions about possible models of language production. Gestures with spatiomotor semantics thus provide a unique periscopic view through spoken language and into spatial cognition.

2 Spatiomotor Routines in the Truffles Corpus

"Gestures originate in the tactile contact that mindful human bodies have with the physical world. In other words, …", write LeBaron and Streek. "the knowledge that the human hands acquire … in these manipulations is realized and brought to bear upon the symbolic tasks of gestural representation."[3]

The Truffles data set is a reference corpus for dialogue in context with intonation and gesture. The subjects were twelve pairs of University of Chicago undergraduate and graduate students, who were familiar with each other and had some cooking experience. They were videotaped while performing a 30-45 minute cooking task. They were also recorded when replaying the videotaped session and queried about their communicative intentions at various points in the task. Some elements of the task include locating ingredients and equipment, dividing the labor, choosing flavorings, and activities such as measuring and washing up. A survey of spatiomotor gestures is ongoing, and has yielded several exemplars to date.

The spatiomotor gestures illustrate the use of various tools and materials, albeit with empty hands. Functionally, they serve purposes such as

- explaining an event that happened in the past
- requesting that an action be performed in a different manner
- teaching a new way to perform an action
- rehearsing actions to be performed in the future

Consider a representative exemplar. The actions of the left hand (lh) and right hand (rh) are described below the co-occurring speech. The gesture is initiated at the leftt bracket, has its main force during the stressed bold text, and is completed at the right bracket. Neil and Jeff are rolling chocolate into truffles, but they are chatting about other topics while doing so. Jeff states that he cut his hand recently and is asked how.

Jeff: My can opener disintegrated.
(lh) using spoon to dig into chocolate ganache
(rh) steadying bowl

Jeff: [My little **hand can** opener disintegrated] right in my hands.
(rh) releases spoon, lifts, twists, twists, retracts falling outward
(lh) releases bowl, lifts, grips handle, retracts falling outward

Illustration 1: Closeup of holding the can opener

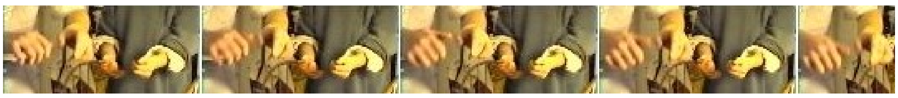

Illustration 2: Right hand (far left) rotates forward to twist the rotating grip with the thumb.

During the first utterance, Jeff's hands are busy with the truffle task. He describes what happened. Then he decides that a better explanation is required. This time, he not only augments the verbal description (with 'little' and 'hand'), but also frees both hands from the task and enacts use of a can opener. He does this by positioning the left hand as if it were grasping the twin handles of the can opener, simultaneously positioning the right hand at the putative rotating grip, and rotates the hand and thumb sharply forward by roughly 30 degrees, twice. The filmstrip shows the progress of one such rotation (follow the leftmost thumb and knuckles.) The twists are synchronized with the stressed “hand can” in the text. Then the hands fall away from each other and return to the truffle rolling task.

3 Observed Relation of Gesture to Speech

The most striking property of spontaneous gesture is the way in which it intertwines with the accompanying spoken language, sometimes expressing concepts explicit in the text and sometimes presenting additional information [2, 4, 5]. In this gesture, the two hands coordinate to show the literal, manual *use* of the can opener. This is a compact, cohesive gesture. Its spatiomotor enactment is abstracted in that it does *not* show the phase of locking the opener onto the can, nor sufficient twisting to remove the lid.[1]

Although size information is presented both in speech and in gesture, it is not at all the focus in either modality of this communication. Rather, the size information merely helps us to understand that the can opener is a particular type (old fashioned manual can opener with poor ergonomics, as opposed to a modern electric or ergonomic one.)

It is tempting to classify this easily recognizable (though *very* brief) can opening gesture as a kind of gestural lexical item. In the absence of speech, it could stand on its own to mean 'can opener', deriving its meaning from familiar behavior. However, this still leaves several architectural possibilities as to where the gestural lexicon logically resides:

1. in the model of Krauss et al.[8], the gestural attributes are derived from long term memory, via working memory, by a motor system that is independent of the communicative pipeline (though the attributes do facilitate verbal lexical retrieval);
2. in the de Ruiter model[9], the 'gestuary' is an adjunct of the communicative conceptualizer but precedes verbal message generation;
3. in a generic computational linguistic model, the gesture may be taken as a structured attribute of a lexical item such with lemma “can opener”;
4. in an equally generic computational model, the gesture may be taken as an attribute of a conceptual entity that also has a lexical attribute, with lemma “can opener”; or, finally,
5. as an attribute of a specialized child (particular kind of can opener) of the entity with the lexical attribute with lemma “can opener”.

Although it is also tempting to conclude that the 'little hand can opener' gesture does have a role in lexical retrieval, that role is not the obvious one of Krauss et al.'s target phenomena. The gesture isn't used as the equivalent of a specific lexical item. Rather, it participates in an effort to convey *more* detail than the term 'can opener' and even more spatial detail than the expanded “little hand can opener”. It may aid the speaker in constructing a more detailed description, but it is also of value to the hearer in constructing a detailed model of the original event. The spatiomotor gesture

1 See [6, 4, 7] for discussions of abstraction in American and Dutch Sign Language.

conveys information that is difficult to articulate in speech, even with extra effort. (Note that this also favors option 3 or 5 over option 4).

6 Conclusions and Future Work

The work thus far suggests that spatiomotor gestures are sometimes better associated with concepts than directly with the verbal lexicon[2] Further work is needed to establish the scope of this trend.

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[2] Though see[10] for parallels between verb typology and gesture, for manner of motion.

Formalizing Diverse Spatial Information with Modular Ontologies
– Extended Poster Contribution –

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Abstract. Space can be described from different perspectives, with different granularity, for different purposes, and with different formalization details. A spatial system that describes these different aspects formally thus has to take into account their spatial diversity. We propose to formalize these aspects by using thematically different ontologies, each of which describing the spatial aspects from a particular perspective. The resulting modular structure not only provides an adequate representation of the thematically different aspects of spatial information but also allows the use of application-specific ontologies as necessary, while hiding information and reducing complexity in terms of the represented spatial knowledge and reasoning practicability.

1 Introduction

One of the oldest representations of spatial information is most likely geometry [7] that has been used and applied within computations systems dealing with space. Together with numerical information available from systems' input data and the use of three or other dimensional coordinates, a system can build an internal structure of its spatial environment. However, this kind of representation is less applicable for capturing the way humans deal with space and thus how cognitive agents are supposed to deal with space. In particular, cognitive and ontological considerations show that space is represented by a huge variety of different kinds [1]. As a consequence, an ontological formalization of spatial information has to take these different aspects into account.

In general, ontologies provide tools for organizing and contextualizing knowledge [3]. They are widely used in different fields as a method for making explicit what is already known implicitly. Their terminology is supposed to work as a basis for communication between a group of agents or between agents and humans. Ontologies are defined as "a shared understanding of some domain of interest" [18]. They also have a predefined structure with an inherent meaning. Their structure consists of a taxonomy, that defines the categories of a domain, relations between these categories, and axiomatizations of categories and relations.

As space is a fundamental component (such as time) it is often abstractly formalized in upper-level or foundational ontologies. They formally describe entities and properties, such as physical objects, spatial relations and properties, movement, dimensionality, granularity, or spatial vagueness. Ontologies have also been developed specifically for the spatial domain and applied to a variety of spatial systems, such as geographical information systems (e.g., user- and context-specific map visualization), vision and image recognition systems (e.g., embodied agent or object classification), human-computer interaction by using natural language (e.g., route instructions), robotics (e.g., localization scenarios), design (e.g., architecture or arts). General information, such as topology, orientation, distance, size, shape, morphology, or spatial change, however, also describe highly important aspects of space, and thus have to be taken into account by ontological formalizations.

In this paper, we propose that these thematically different spatial aspects are most appropriately described by using ontological modules. Each module formalizes selected spatial aspects and their combinations can be defined to build more expressive representations. Each module also describes space from a specific perspective. We analyze what has to be taken into account to categorize these perspectives, i.e., we structure the different aspects involved and illustrate example applications accordingly.

2 Perspectives on Space

Thematically distinct ontology modules not only describe particular types of information about the environment. Each module also describes the domain from a certain perspective on a more general level, i.e., the way an ontology describes space not only depends on its selected thematic aspects but also on its selected perspective. These perspectives vary according to the different types of spatial information they describe. They can mainly be divided into four types. First, an ontology may describe space on an abstract or general (and re-usable) level, such as basic locations as specified in *foundational* ontologies. Second, *terminological* aspects specify particular characteristics of space, e.g., for a specific application. Third, an ontology may analyze space from a formal perspective, e.g., by abstract formalizations as in *spatial calculi*. Finally, space can be defined from the perspective of *multi-modal semantics*, for instance, spatial natural language or gestures. The four different groups categorize possible perspectives from where space can be described.

2.1 Foundational Ontologies

Ontologies of this group define space often as physical locations of physical entities. The foundational ontology DOLCE [14], for instance, defines these locations as a physical quality of endurants. The spatial location can be described by a physical region, that can, for example, be axiomatized by conceptual spaces. Other general purpose ontologies, such as Cyc [13] and SUMO [15], formalize a variety of spatial theories. The base ontology of SUMO, for example, defines several general spatial categories. One of them is *SpatialRelation*, which represents spatial relations based on mereology and topology. Subcategories of this type include *WhereFn*, a function that maps an object to its position in time and space. [19] introduces a formal theory of space that analyzes locations of entities according to their mereotopological relations between the entities and locations.

Ontologies that describe spatial information from a foundational perspective mainly provide guidance for the further development of ontologies. Approaches for design decisions of (spatial) ontologies are introduced, for instance, by [20, 14]. If different ontologies re-use the same foundational ontology for their top categories, mappings between them can be defined more easily.

Systems are thus able to re-use foundational ontologies for general considerations of space. Any kind of application independent of its purpose or task can apply the definitions and types given by foundational ontologies.

2.2 Terminological Ontologies

Ontologies of this group are often developed for specific purposes or applications. They specify and axiomatize the domain in more detail and less general than the previous group. They can, however, be based on findings from the previous group. In many cases, they are used for particular tasks or data analyses.

In the context of geographic information systems, for instance, [5] provide a geographic ontology with topological spatial information. A similar approach is provided by [11] with a focus on topographic and environmental information, i.e., hydrology, administrative geography, buildings and places. In the context of visual recognition systems, for instance,

[16] have developed a room ontology to recognize indoor scenes. Here, a domain ontology re-uses DOLCE and refines particular categories and relations to describe the scene domain. In [10], modular ontologies are developed in order to precisely cover information about architectural design and the different modular aspects involved. Here, qualitative, quantitative, and conceptual spatial information is modularly designed and combined in order to represent the thematically distinct aspects of architectural environments. It also uses ontologies from the next group for region-based spatial information.

2.3 Spatial Calculi

Ontologies of this group define formal calculi by specifying space in an axiomatic and rather abstract way. They do not define terminological aspects of space but abstract entities, such as points, lines, or polygons. An overview of different spatial calculi is given by [4].

A calculus can be re-formulated as an ontology [6, 5]. These ontologies specify space, for instance, according to region, orientation, shape, distance, origin, or property-specific criteria. In particular, spatial calculi provide composition tables in order to calculate combinations of relations. As spatial calculi are often highly axiomatized, their specification in an ontology is often not directly accessible. Particular reasoners for certain spatial calculi are, however, available [6].

2.4 Multi-modal Semantics

Ontologies of this group characterize space from a certain (multi-)modal perspective. An example of such an ontology is the formalization of space from a linguistic perspective motivated by the way natural language categorizes the domain. They are used as an interface for natural language interaction, and they act as an intermediate between the terminological representation and lexicogrammatical information. An example of such a linguistic ontology is presented by [2]. Different ontologies of linguistic semantics may also be specified, for instance, to provide semantics for different languages.

Spatial applications that interact with human users by natural language can thus re-use ontologies of this group to describe, e.g., linguistic semantics of space. In [9, 8], for instance, a linguistic ontology is connected with a spatial calculus providing the flexible interpretation between natural language and spatial logics in a given situation. Context information is available through terminological ontology modules.

3 Summary

The four groups presented provide a general distinction between spatial perspective that can be instantiated by an ontology module. Hence, if an ontology is newly developed or refined, it can be developed with regard to a certain perspective. In order to achieve the full and flexible interpretation and combination of the different perspectives, the ontology modules can be combined or connected and exchange information. Techniques have been developed and discussed that provide this combination and integration [12, 17]. We present different terminological spatial ontologies that follow the perspectival distinction above, particularly applicable for spatial indoor systems, at `http://www.informatik.uni-bremen.de/~joana/ontology/SpatialOntologies.html`.

In summary, a perspective determines how the domain is described and which aspects have to be taken into account. Applications can then use those ontologies that satisfy their requirements. An application providing HCI may need to apply an ontology from the *multi-modal semantics* group, an assisted living application may define and re-use different ontologies for space from all groups, etc. Terminological ontologies, in particular, can be applied on the basis of their application-specific descriptions of the domain, may they be influenced by architecture, indoor or outdoor environments, geography, physics, or astronomy.

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Individual differences and eye movements during mental imagery

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Abstract

In this study eye movements were recorded for participants in two different experiments: *fixed-free* (N=20) and *free-fixed* (N=20). Additionally, all participants performed a working memory capacity test (OSPAN) and were tested for individual differences in object imagery, spatial imagery and verbal cognitive styles (OSIVQ).

All conditions in both experiments consisted of a perception phase followed by a mental imagery phase. Both experiments started with a control condition, in which participants looked freely at a complex picture. The imagery task was afterwards to orally describe the picture while looking freely at a blank screen.

In the fixed-free experiment participants looked at a complex picture and listened to a scene description while maintaining fixation at the center of the screen. The imagery task was afterwards to orally describe the picture or retell the description while looking freely at a blank screen.

In the free-fixed experiment participants looked freely at a complex picture and listened to a verbal scene description while looking freely at a blank screen. The imagery task was afterwards to orally describe the picture or retell the description while maintaining central fixation at the screen.

Results confirmed previous results that eye movements during mental imagery reflect those from perception, and revealed that despite central fixation during perception participants' eye movements reflected spatiality from the picture or scene during imagery. Furthermore, analyses from the verbal data, the OSPAN-test and the OSIVQ-test suggest that the reported eye movement effect is dependent on task difficulty, cognitive style (spatial imagery) and working memory capacity.

Topology in Composite Spatial Terms

anon and anon2

somwhere
someplace

1 Introduction

People often refer to objects by describing the object's spatial location relative to another object, e.g. *the book on the right of the table.* This type of referring expression is called a **spatial locative expression**. Spatial locatives have three major components: (1) the **target** object that is being located (*the book*), (2) the **landmark** object relative to which the target is being located (*the table*), and (3) the description of the spatial relationship that exists between the target and the landmark (*on the right of*).

In English spatial relationships are often described using **spatial prepositions**. The set of English prepositions that describe static relationships between a target and a landmark can be divided into two sets: (1) those that denote **topologically** defined relationships, e.g. *at*, *on*, *in*, and (2) those that describe directional relationships, e.g. *left of*, *right of*, *front of.* Interestingly, the topological and directional spatial prepositions are often combined into **composite spatial terms**: *at the right of*, *on the right of.* This raises the question of what motivates the uses of one topological preposition over another in the planning of composite spatial terms.

Contribution: This paper describes an experiment that investigates the semantic distinctions marked by the use of different topological prepositions in composite directional spatial terms.

2 Related Work

Previous psycholinguistic work on directional spatial descriptions [5, 3] has focused on the semantics of the directional prepositions; for example, *above*, *below*, *left of*, *right of.* This work has found a consistent relationship between the directional preposition used and the region around the landmark that can be acceptably described using that preposition. The term **spatial template** is often used to describe these acceptability regions. There are three regions of acceptability in the spatial template of directional prepositions: good, acceptable and bad. These regions are symmetric around the canonical direction described by the preposition with acceptability approaching 0 as the angular deviation from the canonical direction approached 90 degrees. Topological prepositions, by contrast, are often defined in terms of functional [1] or topological [4] relations (e.g., **disconnted**, **externally connected**, etc., see [2]). The difference in the semantics

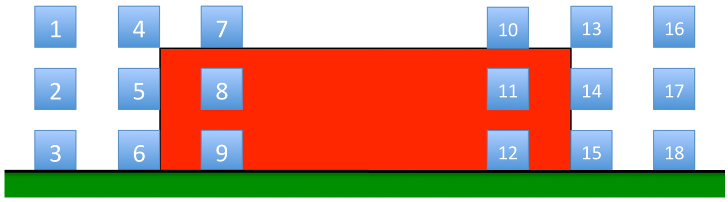

Fig. 1. The positions of the 18 locations where the target object (small blue box) appeared relative to the landmark object (large red box).

of regionally defined directional and topological prepositions is problematic in so far as it is not clear how the two types of semantics should be integrated when modeling composite spatial terms.

3 Experiment

The experiment examined how people's judgment of the appropriateness of composite spatial terms in describing a spatial configuration changed as the topological preposition in the composite spatial terms changed. A trial consisted of a participant being presented with an image containing two objects and an English sentence of the form *the blue box is X the Y the red box*. The *X* was replaced by one of the topological prepositions *at*, *on*, *in*, *to*[1] and the *Y* was replaced by one of the directional prepositions *left of*, *right of*. For example: *the blue box is at the right of the red box*. Each trial image contained a small blue box and a large red box. In all trial the blue box was used as the target object and the red box was used as the landmark. In each trial image the target object was positioned in 1 of 18 locations. The possible target locations are illustrated in Figure 1. These locations were chosen so that the topological relationship (e.g., **disconnected**, **externally connected**, etc.) between the target and the landmark object varied depending on the target position. The target positions 1 through 9 were used in the trials where the directional term used in the linguistic stimulus was *left of* and the target positions 10 through 18 were used in the trials when the directional term used in the linguistic stimulus was *right of*. This resulted in 72 trials: 4 topological relations * 2 directional terms * 9 target positions.

In each trial the sentence was presented under the image. Subjects were instructed that they would be shown sentence-picture pairs and were asked to rate the appropriateness of the sentence to describe the image on a 7-point Likert scale: with 1 denoting not acceptable, 4 denoting neutral, and 7 denoting perfectly acceptable. Trials were presented in a random order to control for sequence affects. Trials were self-paced and the experiment lasted about 10 minutes in total. 19 participants took part in the experiment.

[1] Traditionally *to* is not considered a topological prepostion. Our results, however, indicate that its semantics does have topological semantics.

Table 1. Mean acceptability ratings for the 18 target positions for *at*, *on*, *in*, and *to*.

Preposition	Target Positions					
at	5.000	5.091	2.500	2.357	5.125	5.250
	5.091	5.692	2.636	2.545	5.583	5.385
	5.500	5.750	3.091	2.917	5.538	5.467
on	5.091	4.769	2.750	2.000	4.923	5.067
	5.500	5.438	2.636	2.769	5.417	4.929
	5.300	5.500	1.846	2.545	5.083	5.333
in	2.545	2.385	1.583	1.143	2.500	3.000
	3.300	2.929	4.900	4.917	2.444	2.231
	3.556	2.000	5.000	4.462	2.917	2.667
to	5.667	5.125	1.909	2.667	5.200	5.667
	5.833	5.231	1.778	1.778	5.636	5.706
	6.000	5.692	1.286	1.800	5.875	5.786

4 Results

In analysing the results we assume that the semantics of the directional terms *left of* and *right of* are symmetric. This assumption is backed up by previous research on directional terms [5, 3]. Under this assumption we merged data for trials that only differed in the directional term used. Following this, we computed the mean acceptability rating for each target position and topological preposition. Table 1 lists the mean acceptability ratings for each of the 18 target positions for each of the topological prepositions.

5 Analysis and Conclusions

The results presented in Table 1 show that toplogical prepositions when used in composite descriptions do generally follow their paradigmatic topological uses, as reported in [4]. Specifically, the topological preposition *in* is sensitive to inclusion: its acceptability increases in target positions 8, 9, 11, and 12. And, the topological preposition *at* is sensitive to contact: generally, its acceptability is high in the target position where contact with the landmark occurs, namely positions 4, 5, 6, 7, 10, 13, 14, and 15. Interestingly, however, these topological meanings are deviated from in a number of ways. If we examine the acceptability ratings as a function of relative distance from the landmark center, see Figure 2, it is evident that the acceptability of *in* and *at* does not decrease in the same way with distance from the landmark as would be the case for their purely topological counterparts. In particular, the acceptability of *in* increases slightly as distance from the landmark increases, while the acceptability of *at* does not notably decrease. One possible cause for this is that as distance increases the place picked out by the preposition as its anchor ceases to be a portion of the landmark, but rather becomes a newly construed area that is disjoint from the landmark.

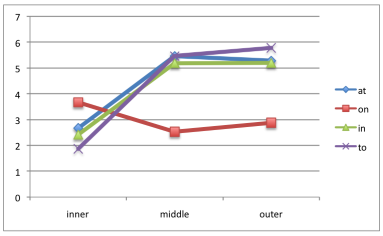

Fig. 2. Mean acceptability ratings by column by distance from landmark center.

In general, such devivations from the core toplogical meaning are also observed in the case of the term *on*. From the results, we see that contrary to a purely topological interpretation, the acceptability of locations 7 and 10 (i.e., directly above and touching the landmark) are rated poorly. A likely cause for this could be that prepositional phrases such as *on the right of* can be interpreted as having an idiomatic meaning that is equivalent to *to the right of*. In this case, it is possible that the more conventional purely topological use of *on* is being superceeded by this idiomatic use. However, while this may be the case, it is also notable that the ratings assigned to *on* in the extreme positions are less than those given for *to* and *at*. One possible reason for this situation could be that the more conventional topological interpretation of *on* interfers with this idiomatic directional usage. Lastly, we note that *to*, while not traditionally treated as a topological preposition, does demonstrate topological features in that it is sensitive to landmark boundary in a similar fashion to *at*; namely, its acceptability increases notably once the target is no longer contained within the landmark.

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An Active Role for Gesture in Spatial Problem Solving

Gestures often contain action information not present in speech, and thus can influence problem solving. Gestures may also affect problem solving simply because they are actions themselves. We asked how gestures differ from epistemic actions in terms of their impact on spatial problem solving. Participants (n=20) solved the Tower of Hanoi (TOH) (Pretest), explained their solution to someone else (Explanation), and solved TOH again (Posttest). During Pretest, all participants used a set of disks whose size and weight were positively correlated (smallest disk was lightest / could be lifted with one hand). For some participants (*No-Switch* group), Pretest and Posttest disks were identical. For others (*Switch* group), Posttest disk weights were reversed (smallest disk was heaviest / could not be lifted with one hand). Previous work has shown that one-handed gestures about the smallest disk hurt subsequent TOH performance when the disks are switched. We replicate these results. The *No-Switch* group improved their solution time more than the *Switch* group ($t(18)=2.8, p=.01$). We then ask whether acting on the physical disks has the same effect as gesturing about them. A second group (n=20) proceeded as above, with one difference. Rather than explaining their solution and gesturing, they demonstrated their solution using the Pretest disks. There was no improvement difference between the *Switch* and *No-Switch* groups in this action condition ($t(18)=0.1, p=.91$). Gestures impact one's representation of TOH differently than explicit experience.

Grounding an agent-based model of human physical behavior with thousand of hours of video.

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We have developed a microscopic agent-based model of human physical behaviour in buildings which captures goal-directed behaviors observed in a large corpus of video ground truth. A series of high-resolution ceiling-mounted cameras were installed in two real-world retail environments, and have captured several thousand hours of video of the operation of these settings. Coupling this video data with anonymized transactions, we postulate the roles and likely goals of users, and correlate these goals with behavior. Since the agent-based model is calibrated against the observed longitudinal data, it can serve as a tool to evaluate and optimize interventions to both observed and unbuilt spaces.

Studies of behavior in the built environment largely fall on one of two ends of a spectrum ranging from the microscopic and rich in detail (as with ethnographic observational studies) to the aggregated, macroscopic and often longitudinal (e.g. cost/patient/day, operational efficiency, survey studies). In the middle of this spectrum currently exists a gap: data and analysis microscopic in nature as with ethnographic studies, but driven by very large datasets. Very large datasets make human annotation uneconomic or impossible, but the rapidly decreasing cost of data storage, coupled with new techniques in data-mining, make possible for the first time the illumination of these hidden traces.

The preliminary results of this study show the promise of longitudinal, autonomous extraction of microscopic features from video, and demonstrate the capture of behavior in an agent-based model suitable for use by designers.

Spatial Constraint Satisfaction Using SAT

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Abstract. In this paper, we present a SMT approach that augments regular SAT with a theory of Diagrams. Diagrams represent space as collections of points (regions) while preserving their overall geometric character. This representation allows reasoning to be performed over (far fewer number of) regions instead of individual points.

1 Introduction

The inclusion of domain-specific knowledge into the satisfiability process is captured under the umbrella of Satisfiability-Modulo Theories or SMT [2]. Quantifier Free Integer Difference Logic (QF-IDL) is one of the theories commonly used for reasoning about space in the SMT approach. However, while OF-IDL is efficient in capturing the relationship between point objects, expanding their use to capture the representation of 2-D shapes has at least two drawbacks - One, the number of inequalities needed to represent a shape increases as the complexity of the shape increases. Two, if an object (even a simple one such as a rectangle) is allowed to rotate, the relationship between its vertices change and inequalities have to be written for each possible rotation of the object. In this paper, we propose and evaluate the use of diagrammatic models as the appropriate theory for representing and reasoning about space and show how the SAT approach can be augmented to use diagrammatic models as appropriate during solving.

2 A Theory of Diagrams

1. Region Object - Given a square grid of side N_g, a region object r is defined by its extent $E(r)$ where
   - $\forall_{x,y}(x,y) \in E(r) \Rightarrow \exists_{x_1,y_1}((x_1,y_1) \in E(r)) \wedge (\mid x - x_1 \mid = 1 \vee \mid y - y_1 \mid = 1)$ where $1 \leq x, y \leq N_g$.
2. Point Object - A point object p is a special case of a region object where $\#E(p) = 1$
3. Maximum and minimum x and y coordinates - Given a grid of side N_g and an object o, we define
   - $E_{x_{min}}(o) = x | (x,y) \in E(o) \wedge \forall_{(x_1,y_1) \in E(o)} x \leq x_1$

   We define $E_{x_{max}}$, $E_{y_{min}}$ and $E_{y_{max}}$similarly.
4. Object width and object height - Given an object o, we define the width $W(o)$ and height $H(o)$ of the object as

- $W(o) = E_{x_{max}}(o) - E_{x_{min}}(o)$ and $H(o) = E_{y_{max}}(o) - E_{y_{min}}(o)$

5. Object Rotation - Given an object o with its extent $E(o)$, we define $Rotate(o, d)$, o rotated by d degrees as
   - $Rotate(o, d) = o'$ where
   - $E(o') = \{(x', y') | \forall_{(x,y) \in E(o)} x' = (cos(d) \cdot x - sin(d) \cdot y),\ y' = (sin(d) \cdot x + cos(d) \cdot y)\}$
6. Minimum/Maximum object width/height - We define $W_{min}(o)$ the minimum width of o over all possible orientations of o as
   - $W_{min}(o) = min\{W(o') | \forall_{i=1}^{360} o' = Rotate(o, i)\}$

   and similarly for $W_{max}(o)$, $H_{min}(o)$ and $H_{max}(o)$.
7. Given a grid of size N_g and objects a, b, a constraint c holds between objects a and b iff one of the following hold
   - $c = Left\ and\ E_{x_{max}}(a) < E_{x_{min}}(b)$

   and similarly for $c = \{Right, Above, Below\}$.

Definition 1. *Possibility Space*

A possibility space is a set of points that satisfy some set of spatial constraints. Given a grid of side N_g, an object o, a spatial constraint c and a truth value i, we define

1. $P_s(c(o))$, the possibility space of a spatial constraint $c(o)$ as follows
   - $c = Left$, $P_s(c(o)) = \{(x_i, y_i) | 1 \leq y_i \leq N_g;\ x_i < E_{x_{min}}(o)\}$

   and similarly for $c = \{Right,\ Above,\ Below\}$.
2. $P_{s_1} \cap P_{s_2}$, the intersection of two possibility spaces as follows
   - $P_{s_1} \cap P_{s_2} = \{(x_i, y_i) | (x_i, y_i) \in P_{s_1},\ (x_i, y_i) \in P_{s_2}\}$
3. $P_s(o)$, the possibility space of object a as follows
   - $P_s(o) = \bigcap_{i=1}^{|C(o)|} P_s(c_i)$ where $C(o) = \{c_1, ..., c_k\}$ is the set of spatial constraints on o.
4. $E_{x_{min}}(P_s(o))$, the minimum x-coordinate of the possibility space $P_s(o)$ as follows
   - $E_{x_{min}}(P_s(o)) = x | (x, y) \in P_s(o) \wedge \forall_{((x_1, y_1) \in P_s(o))} x \leq x_1$

   and similarly for $E_{x_{max}}$, $E_{y_{min}}$ and $E_{y_{max}}$.
5. $Inside(o, P_s)$, an object o is inside a possibility space P_s as follows
   - $Inside(o, P_s) \Leftrightarrow \forall_{(x,y) \in E(o)} (x, y) \in P_s$
6. $W_{min}(o, P_s(o))$, the minimum width of an object o given its possibility space $P_s(o)$ as
   - $W_{min}(o, P_s) = min\{W(o') | \forall_{i=1}^{360} o' = Rotate(o, i) \wedge Inside(o', P_s(o))\}$

Definition 2. *Maximal Possibility Spaces*

1. Given a grid of side N_g, an object o with its possibility space $P_s(o)$ and a constraint $c(o)$, the maximal possibility space $P_{s_{max}}(c(o))$ that satisfies $c(o)$ is defined as

– $c = Left$, $P_{s_{max}}(c(o)) = \{(x, y)|1 \leq x \leq E_{x_{max}}(P_s(o)) - W_{min}(o, P_s(o));$ $1 \leq y \leq N_g\}$
and similarly for $c = \{Right, Above, Below\}$.
2. Given an object o with constraints $C(o) = \{c_1, \ldots, c_n\}$, $P_{s_{max}}(o)$, the maximal possibility space of object o is defined as
   – $P_{s_{max}}(o) = \bigcap_{i=1}^{n} P_{s_{max}}(c_i)$

Definition 3. *Diagram*

A diagram d is a 5-tuple $< N_d, O, T, C, I >$ *where* N_d *denotes the side of the diagram (for the purposes of this paper, diagrams are considered to be square),* $O = \{a_1, a_2, \ldots, a_k\}$ *is a set of diagrammatic objects,* $T = \{Left|Right|Above|Below|Near\}$ *is a set of relation types, C is a function from O to* $\{T \times O \times O\}$ *that returns the set of constraints on the objects in O and* $I : C \rightarrow true|false$ *is an assignment of truth values to the constraints in C*

Definition 4. *Satisfaction of spatial constraints in a diagram*

A diagram d satisfies a set of spatial constraints C iff for each $c(o_1, o_2) \in C$ *and* $o_1, o_2 \in O$*, the constraint c holds between* o_1 *and* o_2 *in d.*

2.1 Satisfiability with Diagrams

In order to combine the best of both SAT and diagrammatic reasoning, we introduce a version of SAT called SAT-S, that allows for the representation of spatial information using diagrammatic models. Formally,

A problem specification in SAT-S is given by the 6-tuple $S_s =< \phi, P, O, T, C, M >$ *where* ϕ *is a SAT formula in CNF form, P is the set of variables in* ϕ*, O, T and C are as described above for diagrams and M is a mapping from the set of variables P to the set of spatial constraints.* A solution (model) to a problem in SAT-S is an assignment of truth values, I to the variables in P and a diagram D. A valid model in SAT-S is an assignment I such that every clause in the ϕ evaluates to true and $[(\forall p \in P) I(p) \neq unknown \wedge M(p) = c(o_1, o_2)] \Rightarrow D$ satisfies $c(o_1, o_2)$ $(\neg c(o_1, o_2))$ if $I(p) = true$ $(I(p) = false)$, i.e., if there are spatial variables that have been assigned $true$ or $false$, then the diagram D satisfies the constraints corresponding to these variables. The diagram D represents one possible configurations of objects in O given the spatial variables that have been assigned values.

3 DPLL-S - An algorithm for solving problems in SAT-S

The main difference between DPLL-S (our approach) and the standard DPLL algorithm is as follows: When DPLL-S encounters a constraint where the diagrammatic representation cannot be satisfied given the current assumptions of where objects are located, instead of backtracking and trying other locations randomly, it tries to modify the diagram to satisfy the constraint. If it is successful, the system continues without having to backtrack. [4] gives a detailed explanation of how DPLL-S modifies the diagram to satisfy the constraint.

4 Evaluations

We compared the performance of our system to that of yices2 [3] and cvc3 [1] on the following problem - Given a grid of size N and a set of constraints C, find locations for all objects such that C is satisfied. Figure 1 shows the results of two evaluations - increasing the number of objects while keeping the diagram size constant, and increasing the diagram size while keeping the number of objects constant.

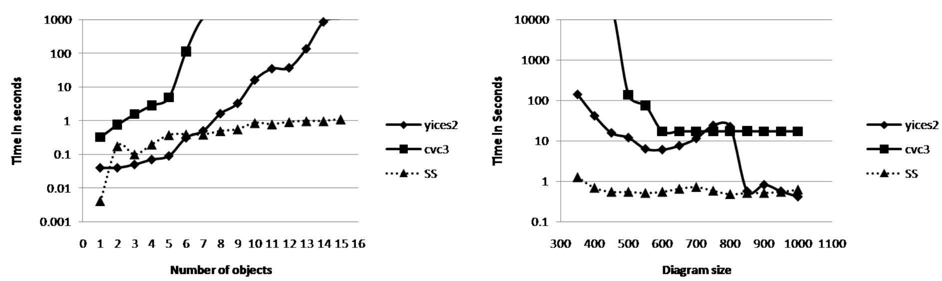

Fig. 1. (a) Solution time vs increasing number of objects with constant diagram size. (b) Solution time vs increasing diagram size with constant number of objects.

5 Conclusion

Current SMT theories perform poorly due to the lack of a good representation for space and inefficient backtracking routines for search. In this paper, we have shown how a DPLL algorithm integrated with a theory of diagrams can be beneficial when representing and reasoning about space.

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Improving Understanding of Ruler Measurements of Children from Low-Income Families

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Abstract. Understanding measurement is important in mathematics and science. However, elementary students from low-income families perform substantially worse in measurement than their counterparts from higher-income families (Lubienski, 2003). The present study carried out a training study aimed at improving understanding of ruler measurement of 2nd grade students from low-income families. We hypothesized that comparing two objects different in length – a long object which is aligned with the start of a ruler and a shorter object which is not aligned with the start of a ruler but has the same rightmost number as the longer one – will improve children's understanding because it highlights the fact that length of an item cannot be determined by merely reading off the rightmost number on a ruler. The results revealed that the intervention significantly improved performance from pre-test to post-tests. In contrast, the control condition which was similar to the activities employed in typical mathematics curricula - measuring aligned ruler measurements and measuring with discrete units - did not significantly improve performance. Our findings indicate that comparing unaligned and aligned ruler measurements with the same rightmost number, which is not typically done in mathematics classes, is critical in promoting learning of units of measure.

Keywords: linear measurement, socio-economic status

Adult gesture-speech mismatch predicts learning on a mental rotation task

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When children explain their answers to tasks that they have yet to master, some children spontaneously produce hand gestures that include additional information that is not found anywhere in their speech. Children who produce such gesture-speech mismatches are more likely to learn than children who do not produce mismatches. Here we investigate whether the gesture-speech mismatches produced by adult novices predict which adults are likely to benefit from instruction in a task involving organic chemistry. On each pretest problem, naïve subjects were asked to attempt to draw a stereoisomer, which is an alternative spatial arrangement of a given molecule that is non-superimposable on the original. Mastering this task requires visualizing and mentally rotating the given spatial arrangement of a molecule and then drawing the alternative spatial arrangement (if done correctly, a stereoisomer). Mental rotation (MR) tasks such as this are ideal for studying the effects of gesture on learning, given that motor system activation has been shown to affect MR task performance (Wexler, Kosslyn & Berthoz, 1998). We coded the problem solving strategies that subjects expressed in both speech and gesture during explanations of their drawings to see which adults produced problem-solving strategies in their gesture that they did not produce in speech. After instruction, subjects who produced gesture-speech mismatch on the pretest performed significantly better on the posttest than subjects who did not produce mismatches. This suggests that gesture-speech mismatch is a general index of transitional knowledge that can be useful in determining which adults are ready to learn.

The differences of space syntax methods on explaining wayfinding behaviors: A preliminary comparison[1]

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Abstract. The purpose of this study is to use an exploratory experiment to validate two popular methods of space syntax that have been used to provide formal descriptions of environments and explaining wayfinding behaviors. A frame consisting of elements (Lynch, 1960) and legibility (Weisman, 1981) of environment are used to compare differences between these methods for explaining wayfinding behaviors. Future directions to improve space syntax on predicting wayfinding behaviors are suggested at the end.
Keywords: space syntax, wayfinding, formal description

1 Introduction

Space syntax has been widely used to assess the characteristics of built environments and to explain human wayfinding behaviors. These characteristics were suggested to be correlated with wayfinding behaviors in many studies (Haq & Girotto, 2003; Hölscher & Brösamle, 2007; Montello, 2007). Different methods of space syntax have been used to address specific aspects of human wayfinding behaviors. So far a comparison between these popular methods of space syntax is not yet available. Consequently it is the purpose of this study to evaluate two popular methods of space syntax on explaining wayfinding behaviors. A frame is built on the five elements of environment (Lynch, 1960) and the legibility of environment (Weisman, 1981).

2 Inter Connection Density (ICD)

The concept of ICD is to calculate the average number of connections of all nodes that an environment possesses (O'Neill, 1991). The legibility of an environment mediates the development of mental representations and subsequently influences wayfinding behaviors. Nodes and paths of environment are clearly stated as the

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elements n representing environments. And the legibility of the environment ICD represents is layout complexity.

It is important to point out that one aspect of the library floor plan was neglected. That is, the end of book stacks is an important decision point but not considered in the original method. Hence we suggest nodes and connectivity formed by the book stacks should be considered in calculating the ICD for library environments.

3 Visibility Graph Analysis (VGA)

VGA represents environment in terms of visual areas wayfinders can see. Turner *et al.* (2001) extended the representation of isovists in visibility graph. An example of VGA is given in Figure 1. The most important role VGA plays is showing locations of different degrees of visibility (Penn, 2003). Out of the elements of enviornment, districts and boundaries of the enviornment are represented in this method. VGA accounts for the visual access of legibility in built environments.

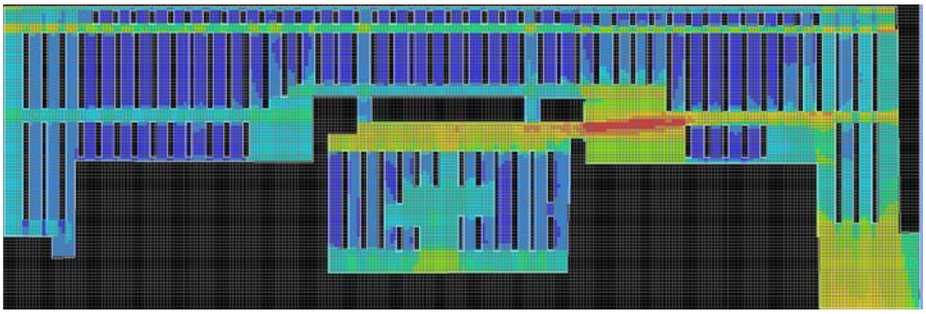

Fig. 1. Visibility Graph Analysis of a library floor. Areas in red and orange represent good visibility and areas in blue and purple represent poor visibility.

VGA has been used to explain the general preference of hiding places (Wiener & Franz, 2005) and wayfinding strategies (Hölscher & Brösamle, 2007) in built environments. However, the role of effectiveness of using VGA to explain orientation is limited (Davies*, et al.*, 2006). Additional measures could be considered to address broader aspects of wayfinding behaviors.

4 Behavioral experiment

In the exploratory experiment, 4 participants had limited experiences with the environment and 4 had no experiences. Each of them was asked to locate 2 books in each of three library area (Paterno Library, Central Stacks, and West Pattee). At the end of finding both books in each area, each participant was asked to give horizontal estimation of direction to the main reference desk. A summary of both methods of space syntax is in Table 1 and wayfinding performances by participants are shown in Table 2.

Table 1. ICD and VGA output of three libraray areas

Methods	Paterno Library	Central Stacks	West Pattee
ICD (density)	**3.21**	**3.33**	**2.84**
VGA (visibility)	**High(319.468)**	**Low(79.99)**	**High (293.80)**

Table 2. Wayfinding performances in each library area by groups

	Familiarity	Paterno Library	Central Stacks	West Pattee
Time (min)	Limited	**9.80**	**14.08**	**7.96**
	No	**16.66**	**14.30**	**13.38**
Distance (m)	Limited	**132.24**	**179.95**	**144.11**
	No	**179.45**	**217.60**	**142.07**
Estimation Errors (^{o})	Limited	**45.00**	**70.00**	**23.75**
	No	**78.75**	**75.00**	**95.00**

5 Conclusion

The output of space syntax seems to be related to different aspects of wayfinding behaviors. At first, ICD seems positively correlated with the time participants spent in each area. Second, VGA seems positively related to the distances that participants additionally walked in each library area. Third, directional estimations do not show a simple relationship with any space syntax method. The estimations made by paraticipants who have limited familiarity are positively correlated with the results of VGA. However, to those of no familarity, the area with highest ICD is related to the lowest error of estimation, and vice versa. It is noticable that layout complexity and familiarity have different powers on influencing wayfinding behaviors. This finding is different from earlier suggestion that familiarity plays a more important role on wayfinding performance than layout complexity (O'Neill, 1992). Further assessments are needed to verify the differences.

It is noticeable that the differentiation of environment in legibility was not addressed. The effectiveness of landmarks in human wayfinding has been favorably suggested (Raubal & Winter, 2002), hence assessment of landmarks can contribute to a fuller account of differentiation of environment in legibility. Visual, structural and semantic properties of landmarks (Sorrows & Hirtle, 1999) have been used in studies to carry out saliency measurement (Klippel & Winter, 2005; Raubal & Winter, 2002). Approach from different perspective has also been suggested for the same goal (Caduff & Timpf, 2008). Implementation of these approaches is valuable supplementation to space syntax methods.

It is important to acknowledge that although the methods of space syntax do not cover all elements of environment and legibility, they serve the roles for specific purposes. Supplementing existing methods seems to be a feasible way to conduct formal descriptions of environment. In addition, improvement of measuring landmark saliency serves an important role to shed light on how environments can be differentiated by salient objects.

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Describing Spatial Locations from Perception and Memory:
The Effect of Spatial Reference Directions on Reference Object Selection

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Word counts: 246

Abstract

Speakers may describe an object's location by spatially relating it to a nearby reference object. Previous research within spatial language has shown a preference to select reference objects that are vertically or horizontally aligned. In the spatial memory literature, inter-object relations are organized and encoded with respect to a spatial reference direction. Here we connect these two literatures, asking whether the spatial reference direction used to perceive and encode a layout biases the selection of particular reference objects in a reference object selection task. In Experiment 1, participants selected a reference object to complete the frame "The <target> is by the ___" while standing in front of a perceptually available display. The results show a bias to select objects along the spatial reference direction used to organize the display. Experiment 2 replicated this result using a nonverbal measure. In Experiments 3 and 4, after learning a display, participants completed the reference object selection task with the display out of view. A judgment of relative direction task was used to verify the spatial reference direction used to encode the display. The results show a bias to select objects along the spatial reference direction. In Experiment 5, participants learned the display from one viewpoint, but described it from another, setting up a conflict. Results show an influence of both viewpoints on reference object selection. This research suggests that the spatial features underlying reference object selection may be the spatial reference frames used to perceive and encode the displays.

Spatial Learning Mechanisms that Underlie Encoding Strategies,
Memory Performance, and Navigational Preferences

In human spatial cognition it is clear that individuals prefer different explicit strategies to navigate familiar environments. However, anecdotally, most people have stories about ending up somewhere unintended because they were "driving on autopilot" or walking "out of habit." Animal models of spatial learning might provide a framework for understanding both the explicit and implicit strategies at play in human navigation. In the rat, *place learning* is considered a fast, flexible system for learning locations relative to the allocentric cues of the environment, whereas *response learning* is considered a slow, rigid system for learning a specific pattern of responses for navigating to a goal location (e.g., Restle,1957). The neural mechanisms that support this dichotomy between place and response learning in rats (hippocampus and caudate, respectively; Packard & McGaugh, 1996) are the same regions that differentiate explicit and implicit memory in humans. Using behavioral tasks analogous to rodent paradigms, we provide evidence for place and response learning in humans. In a dual solution paradigm, participants learn an environment in a way that supports either type of learning. Results from both brain and behavior suggest that different people are differentially engaging place- and response-like mechanisms. In a task that varies encoding to require either place- or response-like learning, we observed learning curves that link these tasks to place and response but also support the availability of both systems for any given individual. Together, these results provide a framework for how explicit strategies might arise from a combination of implicit and explicit mechanisms.

Verbally assisted navigation through a virtual environment: what benefit from inspecting a map or reading a survey description before navigation?

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Abstract. With the advent of advanced information technologies, devices equipped with GPS (Global Positioning System) receivers are increasingly used for assisted navigation. However, one criticism levelled is that assisted navigation impedes people from forming an adequate mental representation of configural information. The present study aims to test whether presenting a schematic map or a survey description of a route to people before verbally assisted navigation helps them construct a cognitive map.

A sample of 90 (45 males) participants navigated throughout a route in a virtual environment following verbal directions ("assisted navigation"). They were split into three groups of 30: before effective navigation, one group was presented with a schematic map (MAP group) and a second group received a short survey description of the route (DESCRIPTION group); the third group (CONTROL group) received no aids before navigation. Navigation was followed by a testing phase in which participants (a) re-performed the same route without assistance, (b) performed a direction-estimation task and a map-drawing task. A series of spatial measures were also administered. As expected, no differences were found between the three groups in navigation errors; instead, differences were found in the other two tasks: the MAP group outperformed the DESCRIPTION group in map drawing, and outperformed the CONTROL group in both direction estimation and map-drawing. Moreover, the pattern of significant correlations of spatial measures with tasks changed as a function of condition. Overall, these results indicate that verbal directions during navigation can be usefully integrated to facilitate cognitive map construction.

Spatial Cognition 2010 – Poster Submission

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Finding Your Way Around the Environment: Differences and Similarities Across Countries in Self-Reports

Self-reported sense of direction, wayfinding strategies, and competences can be reliable and valid predictors of spatial behavior in the real world. Several self-report instruments have been developed in the last decade to measure aspects of environmental spatial cognition. Although instruments often include similar questions (e.g., knowing cardinal directions, remembering routes, forming mental maps), they may differ in dimensionality, and items may tap different constructs when translated into another language. Reasons for these differences can be manifold: The conceptual meanings of central constructs may differ across languages, countries may differ in the environmental experiences that they provide, and goals and methodologies for instrument construction may differ across investigators. The goal of the present research is to clarify these issues. In an international collaboration, parallel English- and German-language versions of a questionnaire on environmental spatial cognition were constructed. The 74 items included were based on (1) items from existing instruments from different countries, and (2) new items selected to address additional constructs not well-represented in prior measures (e.g., use of maps and other navigation aids, type of environment, common means of transportation). Data were collected in Germany (Saarbrücken, Freiburg, Augsburg) and in the U.S.A. (Pennsylvania) and analyzed with the same methods. Results of exploratory factors analyses show a similar structure for both data sets. The structure is multi-dimensional and separates sense of direction from allocentric competencies and strategies (cardinal directions, maps and mental maps). Perspectives for further development of an international measure and research across countries and types of environments are outlined.

Factors Influencing Children's Map Based Orientation in an Unknown City

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Abstract. 328 third, forth and fifth graders had to find their path in an unknown city. The path was presented on a detailed city map. A map based orientation index was calculated from children's performance in path decision making, map reality transformation and reality map transformation. Effects of age, sex and alignment on this map based orientation index were found. Apparently no incidental survey knowledge had developed accompanying map use. Survey knowledge was measured by a pointing task in which children had to point to the starting point and to several points on their path. Only the alignment effect indicates that map use is involved in the pointing process.

Keywords: Map based orientation index, survey knowledge, school children, alignment effect

1 Introduction

Even in times of GPS based navigational help systems map based orientation in real space is not obsolete. Map reading and map use in real environments are considered as the most important goals in geographic eduation at school by German public representatives (Hemmer et al., 2010). Path planning and way-finding decisions need map reading competencies (Ishikawa et al., 2008). Map based orientation includes core components such as path decisions at crossings and map reality transformations which work in both directions: transformation of map symbols into the representation of real landmarks and routes and identification of environmental variables' representation in a map. All three components are also needed in way-finding based on GPS map interpretation.

Survey knowledge is configuration knowledge which provides analogous information and hence enables mental connections between landmarks not previously connected. It is acquired from maps (e.g. Münzer, et al., 2006) and may also be

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developed after excessive direct experience. When moving through macro spatial environments dead reckoning occurs which is a continuous process to update the position relative to home (e.g. Etienne, 1992). Dead reckoning uses internal and external information about velocity and direction.
School children's map based navigation skills in an unknown urban area are investigated as a pre-condition to teach adequate map reading competencies. Another goal of our study was to develop a practical instrument to measure map based orientation performance (mbo index). It should be simple, yet reflect the important components of map based orientation: path finding decisions, transformations map – reality, and transformations reality – map. Sex differences favoring boys (e.g. Mathews, 1987) as well as age related differences are expected for this mbo index. An aligned map condition is supposed to yield better mbo index results than a non-aligned map condition (e.g. Liben, 1993). These replications intend to establish mbo index quality.

Our study aimed to answer the question if map survey knowledge develops incidentally in children as it was shown for adults (Münzer et al., 2006) and if it is related to mbo index.

2 Method

2.1 Participants and Design

325 children from 24 German schools participated in our study, 111 third graders, 108 forth graders and 106 sixth graders. 163 participants were girls and 162 were boys. Boys and girls were equally spread within grades.

This study was part of a larger investigation program on children’s map based orientation in an unknown city which is described in detail in Hemmer et al. (2010).

2.2 Procedure

The children were picked up at school in groups of six. They were then brought by car to Muenster, a city at least 30 kms from their respective schools. In Muenster they were asked to find a given path already plotted into a. The map can be classified as a "detailed map" according to Münzer et al. (2006). Path length was about 2 kms. Children were tested individually. Half of the children started at the northern end of the path (not-aligned condition), the other half at the southern end of the path (aligned condition). They had to stop at several points on route and had to fulfill one of the following tasks: (1) point to the symbol in the map representing a real object (e.g. building) they were shown in reality (four objects); (2) point to the real object in their physical environment represented by a symbol indicated in the map (four objects) (3) decide where to go next at a crossing (15 crossings); (4) point to the starting point or to the destination point of the route with outstretched arm and index finger (four pointing occasions). None of these points nor any surrounding landmarks could be seen at the moment of pointing. Children had to rely on survey knowledge derived from map use and on dead reckoning to infer the correct bearings: Pointing performance to the destination can only reflect map based survey knowledge. Pointing to the starting point combines dead reckoning and survey knowledge.

Sum of correct reality map transformations ((1), max=4) plus sum of correct map reality transformations ((2), max=4) plus weighted sum of correct turns ((3), max=15, adjusted to a maximum of 8) were summed up. This sum was taken as mbo index for theoretical as well as for statistical reasons (for further explanation see Hemmer et al. 2010). Pointing sum (4) was calculated separately. Pointing was counted as correct if the absolute difference between children's pointing and correct GPS bearing was less than 30°.

3 Results

In a 2 (sex) x 3 (grade) x 2 (alignment condition) ANOVA with mbo index as dependent variable all three main effects were significant ($p < .01$) with a small effect for sex ($\eta^2 = .04$, $F(1,313 = 14.3)$) and alignment ($\eta^2 = .02$, $F(1,313 = 7.3)$) and a medium effect for age ($\eta^2 = .15$, $F(2,313 = 28.1)$). No interaction effect was significant ($\eta^2 < .01$). As expected boys performed better than girls, fifth graders better than third graders and children walking toward north, i.e. in alignment with the map had better mbo indices than those walking toward south.

Pointing sum was not related to mbo index in general or in any of the sub-samples if split up by age, sex or alignment condition. In a 2 (sex) x 3 (grade) x 2 (alignment condition) ANOVA with pointing sum as dependent variable only alignment proved to be significant ($p < .01$, $\eta^2 = .03$, $F(1,313 = 10.8)$). No other main effect and no interaction effect was significant ($\eta^2 < .01$).
Interestingly, the group walking toward south had better pointing results: In a 2 (alignment) x 2 (pointing direction: towards starting point vs. towards destination, repeated measures factor) ANOVA a small but significant main effect for pointing direction ($p < .01$, $\eta^2 = .02$, $F(1,319 = 9.2)$) favouring pointing to the starting point as well as a significant medium interaction effect ($p < .001$, $\eta^2 = .14$, $F(1,313 = 51.8)$ was found (see fig. 1). No significant main effect for alignment was demonstrated in this analysis.

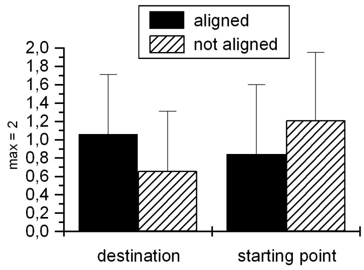

Fig. 1. Interaction of path direction (north: aligned, south: not aligned) and pointing direction (towards destination or towards starting point). Colums represent mean pointing performance values, bars represent standard deviations.

Figure 1 clearly indicates that the interaction effect is in reality a hidden alignment effect: Pointing to the destination in the alignment condition as well as pointing to the starting point in the non-alignment condition yield better pointing results because both times pointing has to be performed in alignment with the map.

3 Discussion

The mbo index which takes into account map-reality transformation as well as correct turning decisions has proven to be an adequate and valid instrument to measure map based orientation: The expected effects of sex, age and map alignment could be demonstrated.

Processes based on map use could only be shown rather implicitly in pointing tasks by revealing the clear map alignment effect underlying the interaction effects of pointing direction and path – map alignment.

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Distinguishing Location Memory Based on Allocentric and Egocentric Spatial Systems

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Abstract. Separating between location memory performance based on egocentric and allocentric spatial systems is challenging. The Northumberland Gallery Task was developed to allow for such a separation by taking into account critical features of the egocentric/allocentric distinction. Here, we introduce the task and present results of task performance based on limited prior knowledge of the task environment. The presence of an alignment effect in the intended allocentric representation motivated the in-progress implementation of a more focused training regime to precede the task. By increasing knowledge about the environment, we expect to eliminate the alignment effect, and thus cleanly separating between the two spatial systems.

Keywords: Spatial memory, reference frames, allocentric, egocentric

1. Introduction

Evidence is accumulating in support of a basic distinction between allocentric and egocentric spatial systems. In practice, however, no consensus has emerged regarding how to best separate these spatial systems empirically. The importance of such a separation is highlighted by evidence showing that healthy individuals, who have access to both systems, differ in the strategies spontaneously used to solve the same spatial problem [1]. In addition, an empirical separation has the potential to increase our understanding of deficiencies in spatial memory in clinical populations.

2. Dissociating the Allocentric and Egocentric Spatial Systems

In order to arrive at an uncontaminated measure of spatial performance, it is critical to distinguish between the allocentric and egocentric systems [2]. To this end, the differential effect of a change in observer position on allocentric and egocentric representations is commonly utilized. Specifically, whereas an allocentric representation is independent of such a change, an egocentric representation is not [3]. In several studies, however, the change is achieved by physical movement of the participant around the spatial array [4], or a gradual and in-view change of viewpoint [5]. The match between the perceptual input and the change in position or viewpoint allows for a continuous updating of the egocentric representation [6], which in turn prevents the assessment of the intended allocentric representation. An instantaneous change in observer position, by which all perceptual information relating to the change is avoided, is therefore necessary although not sufficient for ensuring the use of an allocentric representation.

The terms *allocentric* and *viewpoint-independent* are often used interchangeably [1], but in practice viewpoint-independence is rarely assessed. In fact, the common finding in spatial memory tasks is not an equivalent accessibility of novel and familiar views but a positive linear relationship between the angular distance between the familiar and novel views and response latencies [7]. This is often interpreted as evidence of an alignment of the novel and familiar views, which in turn indicates a viewpoint-dependent strategy [8]. However, only if the alignment effect can be greatly reduced or eliminated can an allocentric representation be inferred. It has been suggested that allocentric representations develop when spatial information is acquired through direct experience of several viewpoints [9], highlighting the fact that a specific training regime may be necessary to encourage such a representation.

To allow for a direct comparison of the two spatial systems, the use of an egocentric representation also needs to be ensured. In a modified version of the egocentric spatial updating paradigm [10], the position of an external cue has been manipulated, in addition to the usual manipulation of the spatial array and the observer [11]. Because the allocentric system is dependent on stable external cues, solving the task will depend on the egocentric system.

In summary, a task that aims to dissociate and compare spatial performance based on the allocentric and egocentric systems should involve instantaneous and independent manipulation of observer position *and* external cues. The Northumberland Gallery Task incorporates such features in a desktop set-up. Below, we provide a description of the task and two training regimes, and present results based on task performance preceded by limited knowledge of the environment.

3. The Northumberland Gallery Task

The Northumberland Gallery Task takes place in a virtual circular room with seven environmental cues [12] rendered within identical picture frames on the walls, equidistantly. The task commenced immediately after a training regime (described below). At the beginning of each trial, participants appeared in a peripheral position of the arena. After one second, a pole appeared for three seconds (Fig. 1a). After a five second delay, participants had to indicate in which of two possible locations they recalled the pole as being previously presented. All experimental manipulations occurred during the delay and out of participants' view. An instruction presented at the delay informed the participant of which manipulation that applied to each trial; 'none' indicated that nothing had changed (control condition), 'you' indicated that the peripheral view of the participant had changed (allocentric condition) and 'wall' indicated that the walls had rotated (egocentric condition). Participants completed 72 trials in each condition in a random order. The magnitude of rotation was varied between 45°, 90° and 135° in the egocentric and allocentric conditions.

In order to vary the qualitative learning of the environment, either a limited or a focused training regime preceded the task. In the limited regime, participants studied a small-scale cardboard replica of the room for two minutes. Memory for cue locations was tested with a second model, in which all picture frames were empty, by asking participants to place a cue in its correct location relative to a cue placed by the experimenter. In the focused regime, participants passively view navigation from one picture frame to another in the virtual arena for two minutes. At any given time, cues are present only in the picture frames relating to the start and goal of navigation, and navigation never occur between adjacent picture frames, thus preventing serial learning. Memory is tested by asking participants to navigate, in an arena with empty picture frames, from a known peripheral position to the cue location being tested. In both regimes, additional study sessions were given until cue locations could be remembered sufficiently. 35 participants completed the limited training procedure. Data collection is currently underway for the focused regime.

4. Results: Limited Training Regime

Reaction times for correct trials were found to differ significantly between the three conditions, $F(2,68)=251.90$, $p<.001$, with the allocentric condition producing longer reaction times ($M=2463$, $SD=458.75$) than the egocentric condition ($M=1493$, $SD=385.57$), $t(34)=16.51$, $p<001$, which in turn produces longer reaction times than the control condition (M=1260, $SD=232.60$), $t(34)=5.52$, p<.001. A 2x3 ANOVA was conducted with condition (allocentric, egocentric) and angle (45°, 90°, 135°) as within-subject factors. There were significant main effects of both condition, $F(1,34)=290.13$, $p<.001$, and angle, $F(2,68)=33.17$, $p<.001$, and the interaction between condition and angle was also reliable, $F(2,68)=25.81$, $p<.001$ (Fig. 1b). Participants had an average exposure of 3.0 minutes to the cardboard model.

A B

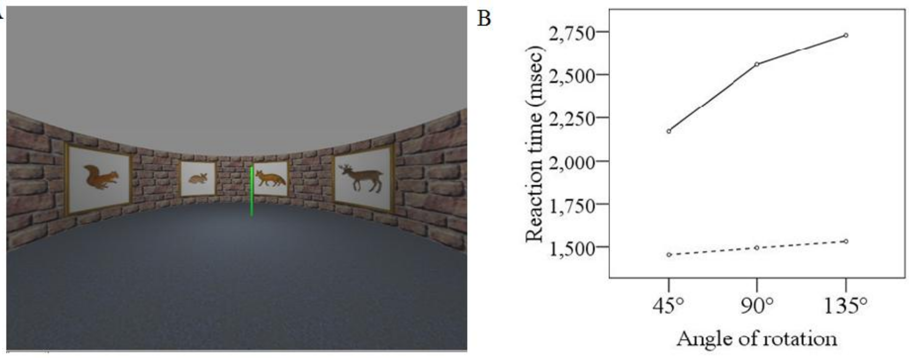

Fig 1. A screen shot of the Northumberland Gallery Task at pole presentation (A) and mean reaction times in the egocentric (dashed line) and allocentric (straight line) conditions for three magnitudes of rotation (B).

5. Discussion

The results derived from the Northumberland Gallery Task when participants received the limited training regime support the presence of an alignment effect in the 'allocentric' condition, which indicates the use of a viewpoint-dependent strategy [8]. The restricted knowledge of the environment prior to the task is suggested to explain participants' reluctance to use a viewpoint-independent strategy. The focused regime has been designed to oppose such reluctance and encourage the use of a true allocentric representation. Because adjacent cues are never visible simultaneously, the environmental cue locations cannot be learned serially and participants must encode a more complete set of spatial relations, extending beyond adjacent cues. Furthermore, the continuous movement is expected to discourage an egocentric updating strategy. The focused regime is thus predicted to encourage a viewpoint-independent over an alignment strategy. This expected contrast of limited and extensive knowledge of the environment prior to the task, and its implications for the separation between the egocentric and allocentric spatial systems, will be the focus of the proposed poster.

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Implications of Eye-Tracking and Other Studies for Learning in College Science Courses

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To promote learning in introductory college science courses, instructors deploy a blend of textbook information, online activities, homework problems, lab and field-trip exercises, and in-class lectures and activities. There is little evidence, however, about how students interact with these materials and what they are seeing, thinking, and learning. We have used eye-tracking technology and other studies to document student behaviors and learning in an introductory geoscience course. Our eye-tracking studies are examining (1) the role of distracters in geologic photographs, (2) how students observe geologic illustrations and animations, and (3) how students interact with a traditional textbook versus a cognitively designed textbook with tightly integrated figures and text. We are using annotated (concept) sketches in teaching and as assessment, supplemented by interviews, to investigate how students envision the evolution of landscapes, the origin of tectonic features, and processes involved in complex geologic systems. Our results highlight the need for figures that are relatively distractor free and that contain the feature of interest near the center of the view, for 3D cues in cross sections and other figures depicting the subsurface, and for explicit instruction about how to learn from a textbook and how to observe geologic photographs and illustrations. Our studies indicate that instructors need to consider the role of cognitive load, which limits learning from long lectures, especially those that use bullet lists detached from figures, from traditional textbooks with weak text-figure integration, and from mixed-mode assessments that try to simultaneously assess breadth and depth of knowledge.

An Empirically-based Model for Perspective Selection in Route-Finding Dialogues

No Author Given

No Institute Given

1 Introduction

In this work we aim to computationally model the extent to which certain empirical factors affect spatial perspective selection as used in route-finding dialogues. In such dialogues, both interlocutors need to adopt a spatial perspective in which to describe movement direction. In map-based tasks such as the one we are concerned with, two perspective choices are typically available, i.e., route perspective, where projective terms are defined with respect to the perspective of the route follower themselves, e.g., "go to your right", or survey perspective, where projective terms are defined with respect to a global or allocentric perspective, e.g., "go down", or "go toward the top of the screen". Addressees must be able to assign perspectives to a given spatial term in order to correctly interpret the utterance it is contained in. However the most frequent directional terms, i.e., left and right, can be used in either route or survey perspective, and perspective is not typically marked explicitly at the lexical level. Generally addressees do correctly assign perspective to projective terms, even when perspective is not indicated explicitly in language, but misunderstandings may occur and clarification is often necessary[1].

To develop computational systems which can adequately assign perspective to spatial terms which do not describe perspective explicitly, we need computational models which account for the factors which influence perspective choice. Physical orientation of the instructee and the intended direction of movement described by a spatial term are two such potential factors. However, while orientation and instruction direction would seem to be important factors in perspective use, it is well known that people are far from consistent in their use of perspective, and that a great many other factors can influence perspective use. For example, Watson et al found that partners tend to align reference frames in dialogue, both within and between spatial axes in a task where they describe locations to each other [1]. Such an influence of recent perspective on current perspective can also occur between utterances in monologue i.e., with a speaker's own earlier contributions [2]. Moreover, perspective choice may also be influenced by discourse function, i.e., current or previous dialogue acts; for example, Striegnitz et al show that perspective use in gesture is related to the type of linguistic dialogue acts communicated in current and preceding turns [3]. Goeschler

[1] In the corpus presented later in the paper, perspective-querying clarification requests composed 14.29% of all clarification requests for the whole corpus.

et al have also observed that for a data set similar to the one which we consider in our own work, the mean percentage use of survey perspective shows a weak positive correlation with the number of times participants perform a basic route instruction task [4].

2 Data Collection & Annotation

To empirically estimate the influence of spatial and discourse factors on perspective choice, we annotated a human-human route instruction corpus with respect to a number of features. The corpus we used was collected for a scenario in which two humans interact via a chat box while observing a screen which depicts a shared environment and the location of one participant within that environment. One participant, the route giver had knowledge of the goal location and could see the location of the route follower at any given point in the interaction, but could not directly move the route follower. The route follower on the other hand had a joystick to move their avatar around the shared map, but had no knowledge of the final location. In total there were 15 dyads and each dyad performed a basic route instruction task up to 11 times. We retained the first 6 of 11 trials for each dyad for annotation. The resultant corpus contained a total of 693 utterances, 339 of which (48.91%) indicated spatial perspective. Full details of the corpus collection procedure, samples of the interactions, and a basic analysis of the language used in that corpus has been provided in Tenbrink et al [5]. For our current work, the corpus was annotated for perspective use as well as a number of empirical factors predicted to play a role in determining perspective, i.e., orientation of the avatar, the intended direction underlying a given instruction, previously used perspective for both speakers and dialogue act. Part of the data-set was coded by a second annotator to assess the reliability of annotation. Cohen's Kappa scores (κ) of 0.77, 0.86, and 0.57 were found for the features perspective, orientation, and instruction direction respectively.

3 Data Analysis

Since our goal is to produce computational models which describe the factors which affect perspective use, we first assessed the effect of individual factors on perspective choice. For this analysis, we considered only utterances in which a perspective was identified. From this set we eliminated all cases of mixed (e.g., "on your right, that's up") and unclear perspectives, resulting in a data set consisting of 290 utterances of which 15.86% were conflated (i.e., the same linguistic expression maps to the same spatial direction for both perspectives), 67.59% were route, and 16.55% were survey. We then assessed the independence of perspective choice with respect to predictor variables. Chi-square and Fisher tests for independence showed that a null hypothesis assuming independence of perspective and predictor value should be rejected at the 95% confidence threshold for orientation (p=9.836e-27), instruction direction (p = 3.307e-10), previous perspective of the same speaker (p = 1.139e-06), the dyad (p = 2.315e-05), and

Model	Type	Predictors	Accuracy	κ
1	MLR	Ori*Dir+PPSS+TN	80.69	0.57
2	MLR	Ori*Dir+PPSS	79.65	0.55
3	MLR	Ori*Dir	77.24	0.43
4	NB	Ori Dir PPSS TN	82.41	0.62
5	NB	Ori Dir PPSS	82.65	0.62
6	NB	Ori Dir	77.57	0.42

Table 1. Results of model evaluation.

trial number (p = 3.918e-06). Independence of other predictor factors with respect to perspective choice, i.e., dialogue role (p=0.49), dialogue act direction (p = 0.21), and the previous perspective of the other speaker (p = 0.65), could not be rejected however.

In order to arrive at a classifier which enables us to predict perspective given the annotated empirical factors discussed above, we trained and evaluated both a Naive Bayes classifier [6] and a classification model based on Multinomial Logit Regression [7] for a range of predictor combinations. Multinomial Logit Regression (MLR) is a statistical regression technique which generalizes logistic regression to more than two levels of response variable, while a Naive Bayes (NB) classifier is a machine learning technique based on the Bayes Theorem. Both MLR and NB may be applied to data consisting of mixed predictor variables and a (categorical) multinomial response variable, and as such are well suited to the perspective use data. However, both models also make a number of additional assumptions which must be considered. The main assumption of the Naive Bayes classifier, and an assumption of MLR to a lesser extent, is that predictor variables are independent of each other. The MLR technique also presupposes that response categories are mutually exclusive (i.e., that the independence assumption holds).

Each classification technique was trained and evaluated through 10-fold cross validation. Table 1 shows accuracy and Kappa scores calculated from the confusion matrices for a selection of MLR models and NB classifiers trained on our corpus for combinations of significant perspective predictor variables. The terms used for describing predictive models include: *Ori*, the annotated orientation of the speaker; *Dir*, the intended instruction direction; *PPSS* the previous perspective of the same speaker; and *TN*, the trial number. For MLR models, individual factors can either be considered independently or we can consider the interaction between factors. This is noted in the model description through the use of the addition symbol (+) for the addition of independent items to the model and the multiplication symbol (*) for interactions of factors. It should be noted that we started with a fully interacting model of all predictor variables and refined that model through stepwise elimination of non-significant predictor variables to the set of models shown in Table 1.

Results show that Naive Bayes based methods slightly outperformed the Multinominal Logit Regressions models for all investigated models; this is likely due to former's better handling of noisy data. As can be seen in the best performing models (models 4 and 5), turn number does not significantly influence model accuracy and can be removed from the predictive model. It should also be noted that due to inter-dyad variability, dyad was also shown to significantly increase model performance, but we omit this factor in our models as we are interested in producing models which are easily generalized to new dyads. Finally, all models perform better than a simplistic *route-always* predictive model (Accuracy=67.59,κ=0).

4 Conclusions and Future Directions

The main contribution of this work is an empirically based method for spatial perspective selection in natural language dialogues. Our approach to this problem involves the determination of the effects of various factors of dialogic and spatial context on perspective disambiguation and selection. Orientation, intended direction, and previous self perspective were found to correlate with particular perspective choices, and predictive models based on these factors achieved higher predictive power than the selection of one perspective only.

Determining perspective from a corpus can easily be influenced by noisy data as well as inconsistent speakers. In order to verify the significance of the factors presented here, we are currently running controlled empirical studies to estimate single variable effects on perspective selection under controlled conditions. We also aim to annotate the rest of our data and re-run our classifiers on a larger test-set to see how this affects our results. Moreover, since our ultimate goal is to improve the quality of spoken interaction with situated spatial applications, we are also planning to incorporate these perspective choice models into dialogue system applications and evaluate whether using such empirically derived models do indeed provide any benefit to human-computer interaction.

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Chunking in Spatial Memory from Route Experience

Jesse Q. Sargent & Jeffrey M. Zacks

In exploring a new environment we store visual and other sensory information that describes the particular route followed. In order to then use that route information to support flexible, adaptive (e.g., navigational) behavior, we must make spatial inferences, about object-to-object relationships for example, based on that stored route information. The current study examines this inferential ability by testing survey perspective spatial knowledge learned from a route perspective. Participants viewed a video shot by someone walking around the circumference of an outdoor park during which nine target objects were named in a voice over. Immediately afterwards, participants arranged icons of the objects on an overhead line drawing of the path walked in the video. We examine individual differences in performance measures including Euclidean error, and the degree to which certain object locations appear to be chunked together in spatial memory. Results show that 1) tendency to chunk and Euclidean error are negatively correlated, and 2) Euclidean error and age are positively correlated. These findings suggest that the fidelity of inferred survey perspective representations was largely a factor of the influence of categorical information, i.e., the grouping of the target objects into discrete chunks.

Children's reasoning with logic diagrams

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1 Introduction

Over the past few decades, many researchers have shown an interest in formal and cognitive properties of diagrammatic reasoning (e.g. Glasgow, Narayanan, & Chandrasekaran, 1995). In particular, logic diagrams such as Euler and Venn diagrams have been intensively studied using the method of mathematical logic (e.g. Shin, 1994), and based on such logical analyses the efficacy of diagrammatic reasoning has been explored in the context of cognitive science (e.g. Shimojima, 1996). Currently, however, there seem to be few attempts to apply these logical and empirical findings to the study of the development of children's reasoning, and in particular, little attention has been paid to the cognitive efficacy of diagrams in children's deductive reasoning.

In our previous work (Sato, Mineshima & Takemura, 2010a,b), we studied the efficacy of diagrams in adults' deductive reasoning, by comparing the effects of Euler and Venn diagrams in syllogistic reasoning. In Euler diagrams, set relationships are expressed by inclusion and exclusion relations between circles (see the diagrams in Fig. 2). By contrast, Venn diagrams have a fixed configuration of circles and represent set relationships by stipulating that shaded regions denote the empty set (see the diagrams in Fig. 3, which deliver the same semantic information as the corresponding Euler diagrams in Fig. 2). In the experiments

P_1 : *All A are B*
P_2 : *No C are B*
Therefore, *No C are A*

Fig. 1. Syllogism

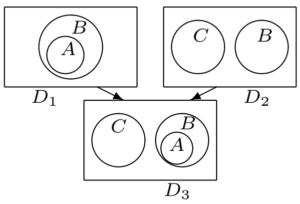


Fig. 2. Euler diagrams

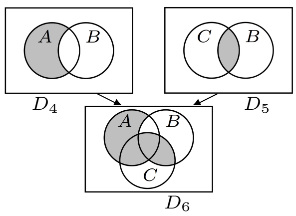


Fig. 3. Venn diagrams

of Sato et al. (2010a), the subjects (undergraduate students) were divided into two groups, called the Euler group and the Venn group. The subjects in the Euler group were presented with two sentential premises such as P_1 and P_2 in Fig. 1 together with the corresponding two Euler diagrams D_1 and D_2 in Fig 2, and asked to solve the syllogism (similarly for the subjects in Venn groups, where diagrams D_4 and D_5 in Fig. 3 were presented instead). Generally speaking, deductive reasoning requires a task of combining information in premises.

We expected that such a task would be easy if it could be realized as a concrete syntactic manipulation of diagrams. In the case of Euler diagrams, such a manipulation was expected to be easily available even to untrained subjects. For example, when presented with the Euler diagrams D_1 and D_2 in Fig. 2, one would be able to construct the unified diagram D_3 by exploiting the intuitive understanding of topological relationships between circles, and extract the correct conclusion "No C are A" from it. By contrast, Venn diagrams were expected to be more difficult to manipulate syntactically. For example, it would be difficult to combine diagrams D_4 and D_5 of Fig. 3 in a direct manner so as to obtain the conclusion diagram D_6. To test this point the subjects were provided with an instruction on the basic meaning of diagrams but not with any instruction on how to manipulate diagrams in solving syllogisms. The results showed that the performance of the Euler group was significantly better than that of the Venn group, which in turn suggested that the syntactic manipulations of diagrams were available to the Euler group but not to the Venn group.

Based on these findings, the present study compares children's performance in syllogistic reasoning tasks externally supported by Euler and Venn diagrams. Our study differs from other research where children were provided with substantial training in using diagrams (e.g. Morgan & Carrington, 1944). We hypothesize that Euler diagrams are *self-guiding* in the sense that the syntactic manipulation of them could be available even to subjects without substantial training of the rules or strategies of manipulations, while Venn diagrams are not. We focus on whether diagrams could have efficacy in inferential processes, rather than in sentence interpretations (cf. Agnoli, 1991, where it is reported that logic diagrams could help children avoid misunderstanding of linguistic materials). We expect that even in the case of untrained children's reasoning, the performance would be better when using Euler diagrams than when using Venn diagrams. If this would be the case, it could count as evidence for the existence of syntactic manipulation of diagrams in children's reasoning. This in turn would give a partial explanation of the efficacy of diagram use in children's deductive reasoning.

2 Experiment

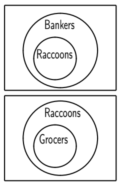
Participants. Eighty-six children in a Japanese public elementary school took part in the experiment. (i) 29 children were in the fourth grade (9- to 10-years-olds) and were divided into the Euler group (15 children) and the Venn group (14 children). (ii) 31 children were in the fifth grade (10- to 11-years-olds) and were divided into the Euler group (15 children) and the Venn group (16 children). (iii) 26 children were in the sixth grade (11-years-olds) and were divided into the Euler group (13 children) and the Venn group (13 children).

Materials and Procedure. The experiment was conducted in a booklet form. Children were first provided with an instruction on the meaning of diagrams and then required to solve syllogistic reasoning tasks with diagrams. The instruction and tasks were given in Japanese. The premises and conclusions of the syllogisms are universally quantified sentences of the form either *All A are B* or *No A are*

B, where concrete terms appeared in A and B. Before the syllogistic reasoning tasks, a pretest was conducted to check whether the children understood the instructions correctly. The highest possible score on the pretest was four and the cutoff point was three. The Euler group was required to solve syllogisms with Euler diagrams (see Fig. 4). The Venn group was required to solve syllogisms with Venn diagrams (see Fig. 5). The children were presented with two premises and asked to select a correct answer from a list of three possibilities: *1. All A are B*, *2. No A are B*, and *3. Neither of 1 and 2*. Both groups were presented with twelve syllogisms, out of which five syllogisms had a valid conclusion and seven had no valid conclusion. Each task was presented in a random order.

All Raccoons are Bankers.

All Grocers are Raccoons.

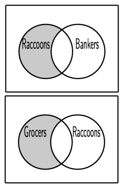


1. All Grocers are Bankers.
2. No Grocers are Bankers.
3. Neither of 1 and 2.

Fig. 4. An example of a reasoning task of the Euler group (correct answer: 1).

All Raccoons are Bankers.

All Grocers are Raccoons.



1. All Grocers are Bankers.
2. No Grocers are Bankers.
3. Neither of 1 and 2.

Fig. 5. An example of a reasoning task of the Venn group (correct answer: 1).

Result: pretest. At the fourth-grade level, twelve in the Euler group and one in the Venn group passed the pretest. At the fifth-grade level, eleven in the Euler group and four in the Venn group passed the pretest. At the sixth-grade level, ten in the Euler group and five in the Venn group passed the pretest. These results indicate that for all grade levels, Venn diagrams are more difficult to understand than Euler diagrams. Since so few of the fourth-grade children could understand the meaning of Venn diagrams correctly, the following statistical analysis of the Venn group begins at the fifth-grade.

Result: syllogistic reasoning tasks. The results are given in Table 1, where valid means syllogism with valid conclusions and invalid means syllogisms having no valid conclusion. At the sixth-grade level, the difference in the performance of valid syllogisms between the two groups was significant: 70.0% for the Euler group and 36.0% for the Venn group (F (1, 14) = 4.950. $p < .05$). At the fifth-grade level, the performance of valid syllogisms in the Euler group was better than that of the Venn group, although the difference was not statistically significant. At all grade levels, the performances of invalid syllogisms in both groups were lower than the chance level.

Table 1. The average accuracy rates of syllogistic reasoning tasks (the bold-types refer to the significant difference between the sixth-grade groups at the level of $p < .05$.)

	The fourth grade		The fifth grade		The sixth grade	
	valid	invalid	valid	invalid	valid	invalid
Euler group	48.3%	11.9%	56.3%	29.8%	**70.0**%	17.1%
Venn group	—	—	35.0%	26.4%	**36.0**%	22.8%

Discussion. Our results showed that the difference between Euler and Venn diagrams had significant effect on the performance of the children in the six grade with respect to the valid syllogisms. This could be interpreted to suggest that the syntactic manipulations of Euler diagrams could be naturally triggered for them, facilitating the processes of combining information in premises. The overall results present evidence for the claim that Euler diagrams do help children solve syllogisms. By contrast, in the case of Venn diagrams, even the performance of the children who passed the pretest was not so higher than the chance level. This could be explained by supposing that syntactic manipulations of diagrams were not available to the children in the Venn group, and hence they had to rely on usual processes of linguistic inferences, resulting in poor performance in syllogisms. Regarding the invalid syllogisms, the results indicate that the diagrams did not improve the children's performance. This shows a striking contrast to adults' performance reported in our previous study, where the performance in the invalid syllogisms was significantly improved when subjects were presented with Euler diagrams (see Sato et al., 2010a, b). This might be related to the fact that invalid syllogisms usually involve some kind of indeterminacy with respect to the information contained in premises. In the case of reasoning with Euler diagrams, unless some special convention is introduced, such an indeterminacy usually requires enumerating the possible configurations of circles and thus multiplying the conclusion diagrams. In neuroimaging studies, Goel et al. (2007) reported that the predominant activation in the right prefrontal cortex (PFC) was observed in the case of reasoning with indeterminate forms. Shaw et al. (2006) reported that the PFC matures late in development. Children might have an inevitable disadvantage for judging invalidity even when using diagrams. These issues and other are left for future work.

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Towards a Comprehensive Computational Model of Spatial Term Use

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1 Spatial Term Use

When you want to communicate the location of a certain object to someone else you may employ spatial terms such as "above", "left", "near", etc. For example, you may say "Your glasses are to the *left* of the notebook" to help another person to locate their glasses. Producing and comprehending spatial terms requires a mapping between the objects described in the utterance and the objects and relations in perceived space. This mapping can be assumed to involve the following steps: Indexing the objects, identifying the reference object, selecting a spatial reference frame to impose on the reference object, and computing a goodness of fit, that is, an assessment of how well different locations around the reference object correspond to the given spatial term (Logan & Sadler, 1996).

A detailed computational account of the representations and mechanisms underlying spatial term use is currently not available. Computational models for some of the above mentioned steps have been proposed, but these have so far addressed different stages in isolation. The work presented in this contribution aims at developing a more comprehensive computational account of spatial term use by combining two existing computational models: Specifically, the competitive shunting model (Schultheis, 2009) that accounts for reference frame selection and the attentional vector-sum model (Regier & Carlson, 2001) that accounts for goodness of fit thereby encompassing multiple processes. We show that the model combination accounts for pertinent experimental data that neither model alone is able to explain.

2 Existing Models

2.1 The CSM

The competitive shunting model (CSM) is a connectionist model of the selection of a reference frame to define the spatial term. Multiple reference frames exist that can be used to define spatial terms (Levinson, 2003), including the absolute, relative, and intrinsic frames. The absolute frame defines spatial terms based on environmental features (e.g., gravity). The relative frame defines spatial terms based on bodily features (e.g., body orientation). The intrinsic frame defines spatial terms based on object features (e.g., top side of an object). These different frames are represented by units (called competing units) within the CSM. The connection structure of the CSM establishes indirect lateral inhibition between the competing units. As a result, when different available reference frames activate different competing units, each competing unit will tend to increase its own activation and decrease the activation of all other competing units. Selection stops when the activation of one of the competing units is *crit* times higher than the sum of the activations of all other competing units. Once selection stops, the selection result is computed as the weighted linear combination of the competing reference frames, with the activation values of the competing units when selection terminates being used as the weights. Accordingly, the magnitude of crit modulates the strictness of selection: The higher one chooses *crit*, the more will the result of the selection resemble only one of the possible reference frames.

2.2 The AVS

Given a scene containing a reference object, the attentional vector-sum model (AVS) computes a value corresponding to the goodness of fit for the mapping around the reference object. One main source for computing this goodness of fit value is an angular component. The angular component is based on the angle between a reference vector and a vector sum of all vectors that are rooted at points along the reference object and pointing to a certain location. These vectors are weighted by the amount of attentional focus allocated at the root of the vector. Attentional focus is assumed to be centered at the point on the reference object closest to the location in question, with a gradient that diminishes with distance. In this way, each point on the reference object receives attention of a certain strength. The resulting vector-sum is compared to the reference vector; the larger the angle, the lower the goodness of fit will be.

2.3 Combining CSM and AVS

The CSM exclusively models reference frame selection. The AVS exclusively models goodness of fit, assuming a given reference vector. In combination, the output of the CSM in the form of a selected reference frame can serve as the input of a reference vector into AVS. Such a combination has the advantage of accounting for a more diverse set of situations, including the case in which there are competing reference frames, which neither model can account for on its own. We refer to the combination of the two models as CSM-AVS.

3 Assessing CSM-AVS

For a first evaluation of the CSM-AVS we chose to simulate rating data of experiment 1 in Carlson-Radvansky and Logan (1997). This study is particularly well suited, because it is one of the few investigations that measures goodness of fit values for a large number of locations in situations with reference frame competition.

3.1 Data

In experiment 1 of Carlson-Radvansky and Logan (1997), each trial started with the presentation of a sentence such as "The square is above the tree". Following the sentence subjects saw a display containing a square and a tree. The tree was always in the center of the screen and the square was located in one of 48 positions surrounding the tree. Participants had to rate how well the location of the square fit the spatial term "above". For half of the trials the tree was displayed upright on the screen and in the other half of the trials the tree was displayed as rotated by 90 degree. In particular, displays containing the rotated tree produced reference frame competition, because "above" could be defined with respect to the absolute reference frame using the top side of the display or with respect to the intrinsic reference frame using the top side of the tree. Thus, trials using a rotated tree were of particular interest for assessing the CSM-AVS, and we focus the simulations on these trials.

Carlson-Radvansky and Logan (1997) reported considerable interindividual variability in preferences for selecting the different reference frames. For the mixed group (N = 7), there was no clear preference for either of the two competing frames. For the absolute group (N = 5), there was a preference for using the absolute frame. For the intrinsic group (N = 10), there was a preference for using the intrinsic frame. Given these large individual differences we simulate spatial term use for these three groups separately.

3.2 Simulation

Simulation of one trial proceeded as follows: First, the initial activations of the competing units of the CSM were set. Second, the CSM simulated reference frame selection resulting in one particular reference direction for "above". This reference direction was employed in the AVS as the reference vector, and was used to determine the goodness of fit value for the location of the square for that trial. To fit the resulting ratings to the human ratings we estimated two parameters. The first was the selection criterion *crit* of the CSM. We chose to estimate this parameter, because (a) it can notably impact the produced reference direction and (b) previous simulations using the CSM had not yielded clear evidence for this criterion value. The second estimated parameter was the probability with which the reference frame based on the intrinsic frame was selected. Given the interindividual variation observed in the data it was necessary to estimate this parameter to account for performance across the three groups of participants. All other parameters of the AVS and the CSM were set at the values used in previous simulations (Schultheis, 2009; Regier & Carlson, 2001). Simulation results for the three groups and estimated parameter values are shown in Table 1. As can be seen, the CSM-AVS explains the observed human data very well for each of the three groups.

Table 1. Simulation results and parameter values for the three groups of Carlson-Radvansky and Logan (1997)

Group	*crit*	Probability	Correlation
mixed	107.95	0.5	0.95
absolute	90.5	0.09	0.97
intrinsic	75.92	0.95	0.97

4 Conclusion

This contribution presents a first step towards a comprehensive computational account of spatial term use. Two existing models addressing separate aspects of spatial term use were combined to yield a computational model, the CSM-AVS, with an extended explanatory domain. An initial evaluation of the CSM-AVS suggests its utility. Additional simulations are underway to further corroborate the cognitive plausibility of the CSM-AVS.

5 Acknowledgements

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Preferred Solutions in Human Spatial Planning

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The way humans deal with planning tasks differs in central points from formal approaches and algorithmic planning. Humans do not compute full computation trees and they do not use applicable operators equally. Instead, the planning is mostly based on heuristics which leads to the preference of certain solutions. Despite differences in plan sequences, single actions might be conceptually equivalent for reaching specific subgoals. An experiment based on Rush Hour tasks was conducted where subjects had to generate plans. The experiment results were integrated in a graph structure to analyze the subjects behavior. Implications of the obtained results are discussed with respect to a preferred planning theory. The results support the assumption of preferred planning paths when people solve sufficient complex planning problems. We will present results with respect to application of heuristics and subgoals.

Concrete Models as Aids to Representational Translation of Molecular Diagrams

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Abstract. Chemists use many different types of diagrams to represent molecules and, to be successful, must develop skills to accurately translate between these diagrams. Such translations can be accomplished by manipulating an internal 3-d representation of the molecule, a spatially demanding task, or by executing analytic strategies. We hypothesized that performance would be improved when concrete models, external 3-d representations, were used. In a series of studies, we present students with external 3-d models to facilitate the formation and manipulation of internal 3-d representations as they perform 2-d diagrammatic translations. Students' model use were videotaped and coded for behaviors, such as moving, holding, reconfiguring, pointing to, or gesturing about the molecules. Results showed a great diversity in whether and how students used the models and demonstrate that active, directed manipulation of concrete models is strongly predictive of translation accuracy.

Exploring Regional Variation in Spatial Language – A Case Study on Spatial Orientation with Spatially-stratified Web-sampled Documents

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Abstract. How does spatial language differ regionally? Spatial language contains expressions that characterize static and dynamically changing spatial relations. It has long been noted, that a) different languages refer to the same spatial information differently [1, 2] and that b) differences can occur within the same language across different regions [3, 4]. Collecting data has primarily been accomplished by individuals via time consuming manual methods [3]. With the advent of methods and tools developed in computational linguistics and in geographic information retrieval (e.g., geo-referencing), new opportunities arise and allow for collecting and analyzing large amounts of both qualitative and quantitative data efficiently.

The WWW is an ideal data source to sample data with extensive geographical coverage. To source spatial language documents from the World Wide Web, we developed a spatially-stratified data collection schema (see Figure 1). Starting with a postal code based web crawler, we used a machine learning-based document classification approach [5] to identify web documents that contain route directions across 3 English-speaking countries: U.S., U.K., and Australia (see Figure 2 for an illustration of data source for the continental U.S.). The corpora are organized by states (U.S.) or postal regions (U.K and Australia) after sorting out documents with multiple postal codes from different regions (location validation). As a result, corpora of spatial language documents (with more than 10,000 web documents) obtained from places across the three countries have been built to investigate regional variation in spatial language. Visual analytics text processing tools we developed (Term Tree Tools [6]) are used to assist analyzing spatial language usage from region to region for the large quantity of text data.

As a case study employing our corpora, tools, and analysis scheme, we address the often raised question of the usage of cardinal versus relative directions in route directions both to indicate actions as well as static spatial relations (detailed semantic categories are defined in Table 1). Linguistic variances on both national and regional levels are observed (illustrated in Figures 3 and 4). On a national level, all three country shares similar semantic categorical usage of relative directions; while the cardinal direction used for “change of directions” seems to be extremely rare in the U.K. comparing to the others. The regional linguistic analysis results are also mapped (Figure 5) to provide insights into the variation in spatial language usage. Figures 5 shows that certain regions stand out as patterns with similar relative and cardinal direction usages (e.g., in Figure 5c, 5d, 5e, 5f: the states from SD to KS, WY to IA (blue-circled) sees to differ from surrounding states). A possible explanation for this observation (that we have not yet tested in greater depth) is that it derived from two factors, regional linguistic preference and physical characteristics of the places.

This case study offers a novel perspective on performing linguistic studies at the geographic scale. The research presented on design and implementation of a geo-referenced, large-scale corpus derived from Web documents offers a methodological contribution to corpus linguistics, spatial cognition, and the GISciences.

Figures

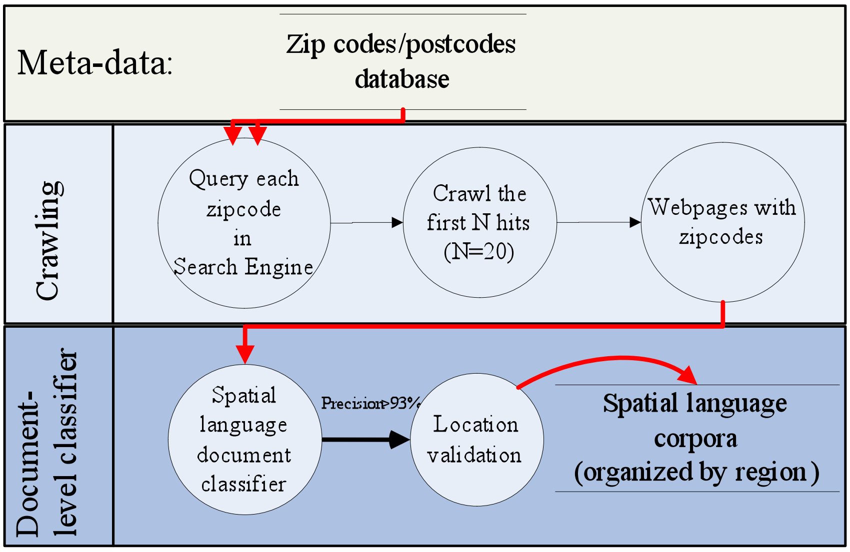

Figure 1. Data flow chart for building spatial language corpus in the U.S.

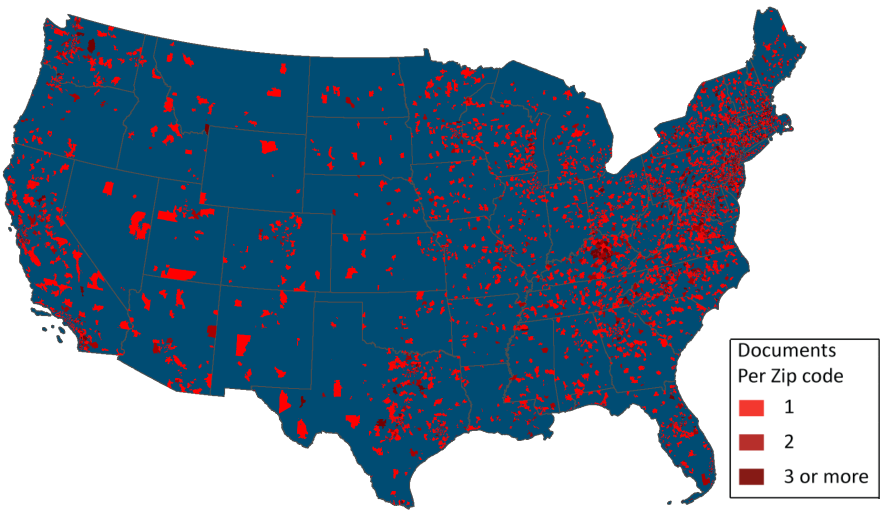

Figure 2. Data source of motion-descriptive language corpus in the continental U.S.–by postal codes

Table 1. Semantic categories for Cardinal Direction and Relative Direction

	Semantic Categories	**Examples**
Relative Direction	**1. Represent change of direction**	take a left, bear right
	2. Represent static spatial relationship	destination is to the left of ...
	3. Represent driving aid	keep to the left lane, merge right
Cardinal Direction	1. Represent traveling direction	head north, traveling south
	2. Represent change of direction	veer southwest on US-24, turn north
	3. Represent static spatial relationship	2 blocks east of the hotel
	4. Indicate general origin	from north, if coming from south of ...
	*used in POI names	North Atherton Street, West Street

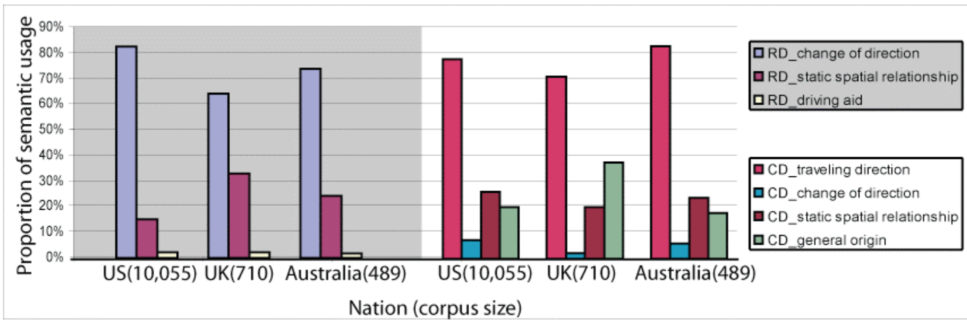

Figure 3. National-level histogram of Relative Direction (RD) and Cardinal Direction (CD) usage.

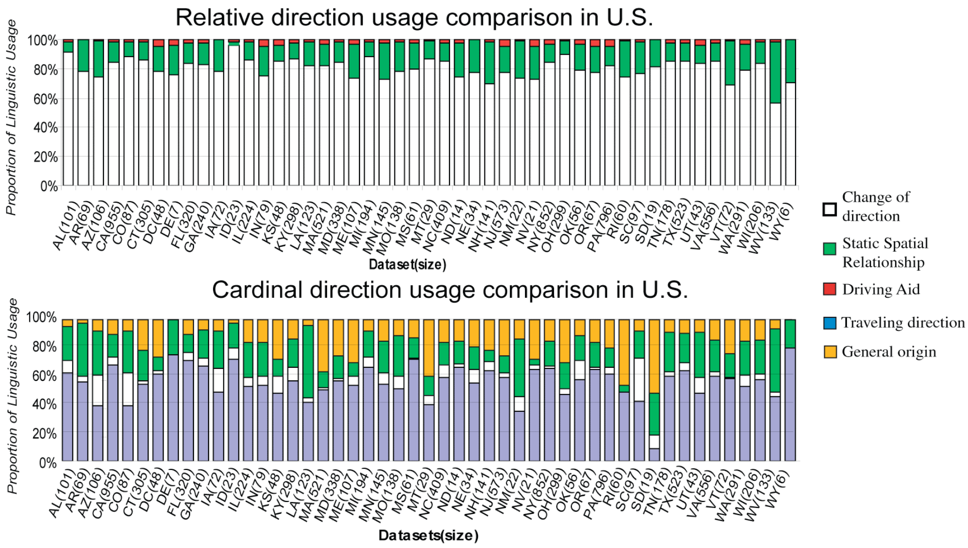

Figure 4. Cardinal vs. Relative direction usage (proportional) comparison among States in continental U.S.

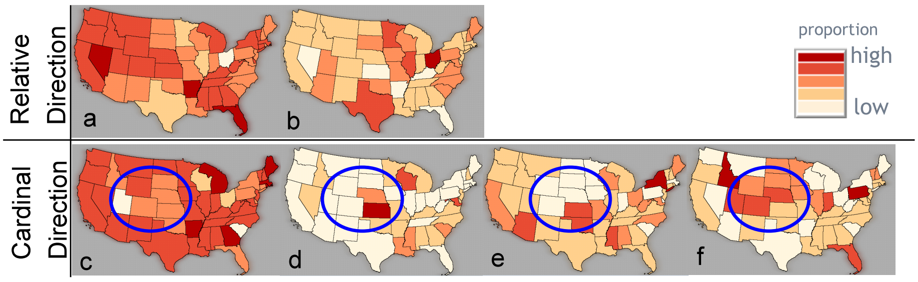

Figure 5. Regional-level map visualization of Relative Direction (RD) and Cardinal Direction (CD) usages in the U.S. For RD used as "change of direction" (a), "static spatial relationship" (b); For CD used as "travelling direction" (c), "change of direction" (d), "static spatial relationship"(e), "general origin" (f).

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Assessing the Cognitive Adequacy of Topological Calculi in Scaling Movements[1]

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Introduction

Movement patterns of individual entities at the geographic scale are central to research in spatial sciences. Among these, translation, scaling, and rotation are identified as three major kinds of movement patterns (Egenhofer and Al-Taha, 1992). At the Human Factors in GIScience Lab, a series of experiments have been conducted to access the cognitive adequacy of topological calculi in translation movements with different scenarios such as a hurricane moving across a peninsula (e.g., Klippel and Li, 2009). This paper focuses on the assessment of scaling movement patterns, specifically: a lake extending and shrinking. To this end, nine topologically distinguished ending relations of movement patterns were derived from the two most prominent topological calculi, the region connection calculus, RCC (Randell et al. 1992), and the 9-intersection model (Egenhofer and Herring 1991).

Methods

Materials. 72 animated icons (eight icons for each topological equivalent class, Figure 1) were created using Adobe Flash, depicting a lake extending and shrinking (scaling) after heavy rainfall and a house placed at the lake's shore. The icons are 120 by 120 pixels in size. The location of the house was restricted to a 40 by 40 pixels area in the center; the starting lake position was always disconnected from the house (DC) and coordinates were randomized within the margins of the icons. The (cardinal) directions from which the lake approached the house were counterbalanced. The ending position was chosen from the nine topological equivalence classes (Figure 1). The velocity of scaling movements is identical for all icons. Moreover, the coordinates of the lakes and houses are selected to ensure that each scaling movement lasts for at least three seconds.

Participants. 20 students (9 female, average age: 21.4) were recruited for the experiment. None of them had any background in Spatial Information Science.

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Procedure. The experiment took place in a GIS lab at Department of Geography. 24-inch Dell widescreen monitors were provided to all participants. The experiment consisted of two tasks: First, participants were asked to sort the animated icons into groups based on their self-assessed similarity. No pre-defined number of groups was provided. Second, participants had to provide linguistic labels for the groups they created.

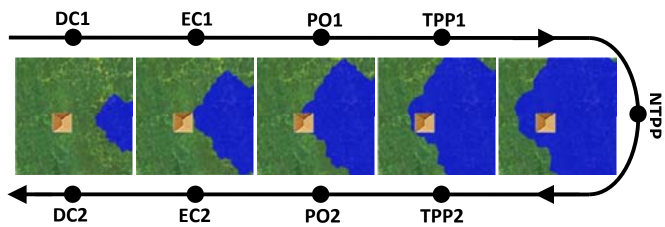

Figure 1. At the starting point, all the lakes were always disconnected from the house (DC). Nine topological ending relations were distinguished, for example: DC1 – the lake never 'touched' the house, or DC2 – the lake extended and completely immersed the house and retracted such that it became disconnected again.

Results

The following information was collected: background information, number of groups created, linguistic descriptions for each group, and a similarity matrix.

Cluster Analysis

Average linkage, complete linkage, Ward's method were applied to the similarity matrix, the resulting dendrograms were cut at the nine-cluster level. Distinguishable clusters of DC1 and EC1 were found using Ward's method (Figure 2), all DC1 icons and 7 out of 8 EC1 icons formed a 'natural' cluster. Similar clustering structures were found using average linkage and complete linkage. This suggests the high similarity between DC1 and EC1, which supports the cognitive adequacy of RCC-5 (Cohn and Hazarika, 2001) and results by Lu and Harter (2006). However, the similarity between DC2 and EC2 was not prominent in the clustering structure. Likewise, other topologically defined ending relations did not surface as clearly as in experiments using translation (e.g., Klippel and Li, 2009). The main aspect distinguished related to topological information seems to be: flooded or not flooded.

To shed more light on the actual grouping behavior of the participants, we re-labeled the icons to reflect the cardinal directions that were chosen for the lake's starting position. Four possible directions exist taken the house as a referent: northwestern, northeastern, southeastern, and southwestern. Reexamining the clustering structure in Figure 2 focusing on the direction information reveals that the direction factor was chosen as a main grouping criterion. For instance, the bottom most cluster only consists of SE icons and the second bottom most cluster only consists of SW icons. Similar structures surfaced using average linkage as well as complete linkage.

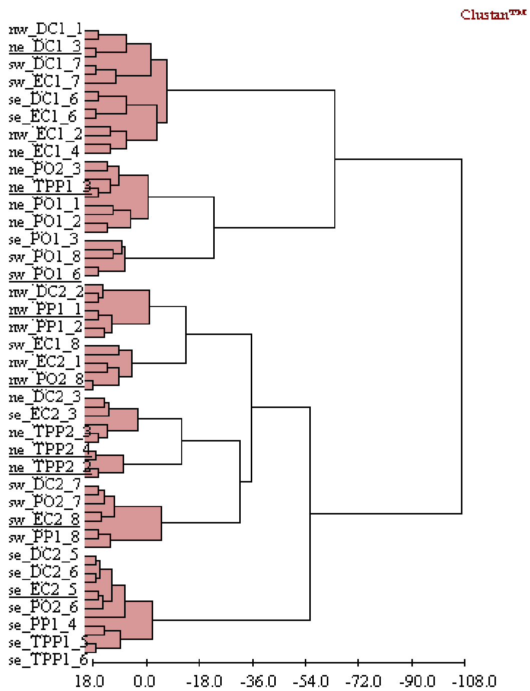

Figure 2. Dendrogram of Ward's method.

Linguistic Descriptions

The linguistic descriptions from the participants were explored in KlipArt (Klippel, Hardisty, and Weaver, 2009). Focus was placed on the descriptions from those participants who placed all icons of a specific ending relation into the same group. Samples of descriptions for DC1 and EC1 are listed below:

DC1: Flood warning; No risk; Minimal flooding; Not flooded; Small lake; Safe.
EC1: Just a touch; Not flooded; Close call flood; Possible risk; Not covered object.

Participants' descriptions focus on domain semantics (e.g. safe, no risk, and no flooding), which explains why there is high similarity between DC1 and EC1 in the clustering structure. The explicit use of spatial language is rather the exception.

We additionally follow up on the aspect that participants used location as a grouping criterion. To this end, we analyzed the short linguistic labels participants provided: 61.4% of a total of 114 short labels used a direction term.

Conclusions

Three conclusions can be drawn from the results of this experiment. First, for adequately modeling the cognitive conceptualization of geographic movement patterns, the nine topologically distinguished ending relations may need to be aggregated. Second, for ending relations that show some kind of overlap the main distinction made is based on the location (direction of movement). Last, the similarity and salience of topological relations may vary across different scenarios (compare Klippel and Li, 2009).

For future research, the animated icons will be revised in two aspects: (a) extending and shrinking velocity of the lake will be shortened to reflect movement times of previous experiments; (b) the location factor will be controlled to reveal topology's role in conceptualization of scaling movements. In addition, different scenarios will be targeted to test if the similarity of topological relations changes across scenarios.

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Are Path Integration and Visual Landmarks Optimally Combined in Spatial Navigation?

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Both path integration and visual landmarks could be used to guide homing during spatial navigation. While the interaction of these cues during animal navigation is extensively investigated, how humans use multiple sources of information is poorly understood. We tested two hypotheses about how humans combine path integration and visual landmarks during a homing task in an virtual environment: (1) The Bayesian integration hypothesis predicts that behavior will be determined by a weighted combination of cues, with the weights based on their individual reliability (Cheng et al., 2007). (2) The multiple-system hypothesis predicts that different cues will dominate under different environmental conditions (Shettleworth & Sutton, 2005). Participants performed a triangle completion task in the presence of three visual landmarks, which were increasingly shifted prior to the home-bound leg (by 15^0 to 135^0). With local landmarks (5.5 m from home) participants followed the landmarks completely up to a 90^0 shift, and then switched to rely on path integration at 135^0: a bimodal response was often observed around 90˚. With distal landmarks (500m from home), by contrast, most participants primarily relied on path integration and ignored the landmarks. Although some individuals appeared to integrate the information in the distal condition, they also switched to path integration beyond 90^0. These findings are consistent with previous animal navigation studies, indicating that path integration not optimally combined with visual landmarks during human navigation. Instead, it may serve as a back-up or reference system when external visual landmarks become noticeably unreliable or are absent.

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The Role of Gesture in Learning Mental Rotation Tasks

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Mental Rotation (MR) involves mental transformation of spatial stimuli and is one of key cognitive skills that underlies performance in math and science (Humphrey et al., 2003; Casey et al., 1995). Differences in children's performance in a MR task emerge very early in life (Erlich et al., 2006; Levine et al., 1999). Gesture has been shown to improve learning in a variety of spatial tasks (Church & Goldin-Meadow, 1986; Ping & Goldin-Meadow, 2008) and may be especially helpful as an early intervention strategy for mastering an MR task. We conducted a training study among 5-year-olds to examine the role of specific gesture in a mental transformation task when it is observed versus performed by the child. In a 2x2 factorial design (Teacher: Point, Move vs Child: Point, Move) we found that only a child's gesture (or lack of it) affected learning significantly ($t(157) = -4.37$, $p < 0.001$). We conclude that when children are asked to perform relevant gestures they learn to MR better than those children who are not asked to gesture. Current projects explore the role of spontaneous gestures in children's learning and whether gesture differs from action in understanding MR.