Poster Session I, September 6th, Thursday 2:00-4:00pm

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3. Biologically Inspired View-Based Navigation with Place Fields Constituted Through "Micro-Snapshots"
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4. Weak radiofrequency fields rather cancel than only modify the magnetic navigation of insects
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5. Cognitive Maps in the Real World and the Laboratory
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6. Does Interest Influence Landmark Selection?
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8. Where did I park the car? Influence of landmark's permanency on navigation
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9. The effect of concurrent task load on the acquisition of local and global landmark knowledge
   Sascha Credé, Tyler Thrash and Sara Irina Fabrikant

10. Evaluating Working Memory Demands in Visualization Decision Making
    Lace Padilla, Spencer Castro, Ian Ruginski, P. Samuel Quinan and Sarah Creem-Regehr

11. Foraging in Heterogeneous Environments
    Ketika Garg and Chris Kello

12. Spatial Memory and Smartphone Use: Navigation by People with Different Levels of Sense of Direction
    Masashi Sugimoto, Noriko Nagata and Toru Ishikawa

13. The ways of looking for ways on maps: wayfinding and navigation in a virtual city
    Török Zsolt Győző

14. Route Planning and Situated Navigation in a Collaborative Wayfinding Task
    Crystal Bae

15. The (un)familiar city map: Navigation behavior in unknown environments is influenced by background knowledge about urban structures
    Julia Frankenstein and Stefan Münzer

16. Research on Scene Sketches Interpretation
    Ming Tang

17. Reconceptualizing Affordance as a Cognitive Construct Dependent on Emergent Spatial Multi-Model Contexts:
Daniel Ness and Min Wang

18. Exploring human processing of 3D perception with using compatibility paradigm
Satoko Ohtsuka

19. Performance discrepancy between left-handers and right-handers reveals multisensory integration in the mental rotation of hands
Lilian You Cheng, Mary Hegarty and Elizabeth Chrastil

20. Can Navigation Ability be Trained? Growth Mindset and Navigation Ability
Chuanxiuyue He and Mary Hegarty

21. Collaborative vs. Individual Problem Solving
Adamantini Hatzipanayioti, Marcel Bechtold, Betty Mohler, Heinrich Buelthoff and Tobias Meilinger

22. On the relation between body and movement space representation: an experimental investigation on spinal cord injured people
Michele Scandola, Rossella Togni, Massimo Brambilla, Renato Avesani and Valentina Moro

23. Illuminating disorientation in Alzheimer's disease through the use of functional, structural and metabolic neuroimaging
Gregory Peters-Founshtein, Tahel Nave, Liran Domachevsky, Amos Korczyn, David Groshar and Shahar Arzy

24. Is the structuring effect of environment elements on route learning absolute or relative? Comparative study of Alzheimer's and healthy elderly subjects
Christel Jacob, Constant Rainville, Alain Trognon, Reinhard Fescharek, Isabelle Clerc-Urmes and Thérèse Rivasseau Jonveaux

25. Semantics of Urban Space (Poster)
Asya Natapov

26. Placing Abstract Concepts in Space: Quantity, Time and Emotional Valence
Greg Woodin and Bodo Winter

27. Spatial semantics of 16 concrete and abstract categories
Alex Miklashevsky

28. Preferences and Space in Everyday Activities
Holger Schultheis and Jasper van de Ven

29. An auditory display for representing two-dimensional space
Holger Schultheis and Tim Ziemer

30. Spatial Cognition in Time Expressions: Speech and Gesture from Large-scale Multimodal Data
Cristóbal Pagán Cánovas, Javier Valenzuela and Daniel Alcaraz Carrión

Neural Coding of Landmark and Self-motion Cues in the Human Hippocampal-entorhinal System

Xiaoli Chen[1], Paula Vieweg[2], and Thomas Wolbers[1]

[1] Aging & Cognition Research Group, German Center for Neurodegenerative Diseases (DZNE), Magdeburg, Germany
{Xiaoli.Chen, Thomas.Wolbers}@dzne.de
[2] Institute of Psychology, University of Leipzig, Leipzig, Germany
paula.vieweg@uni-leipzig.de

Abstract. This project investigated how the human hippocampal-entorhinal formation supported landmark-based navigation and path integration, and how sensory noise affected spatial representations. Participants learned a target location and judged relative positions of test locations to the target location. The uses of landmark cues and self-motion cues were dissociated, and cue reliability was manipulated separately for each cue. The results showed that in general the hippocampal-entorhinal formation was engaged in successful navigation. Multi-voxel pattern analysis revealed that activation pattern of the anterior-lateral entorhinal cortex contained valid spatial information when reliable landmarks were used for navigation, in that representational dissimilarity in activation pattern increased as the distance between locations increased. The anterior-lateral entorhinal cortex encoded reliability information for landmarks as well, in that its neural coding contained greater spatial information with reliable landmarks than unreliable landmarks. The posterior-medial entorhinal cortex, on the other hand, contained valid spatial information when self-motion cues were high in reliability. These findings lead to a new conceptualization of how the hippocampal-entorhinal formation supports sub-components of spatial navigation and advance the scientific understanding of how sensory noises influenced neural representations of spatial information.

Keywords: navigation, landmark, path integration, hippocampus, entorhinal cortex, fMRI, multi-voxel pattern analysis.

Bidirectional interactions between place-cells and grid-cells in the vision- and self-motion driven spatial representation model*

Tianyi Li, Angelo Arleo, and Denis Sheynikhovich

Sorbonne Université, INSERM, CNRS, Institut de la Vision, 17 rue Moreau, F-75012 Paris, France

Abstract. Hippocampal place cells and entorhinal grid cells are thought to form a representation of space by integrating internal and external sensory cues. Experimental studies show that different subsets of place cells are controlled by vision, self-motion or a combination of both and that there is a bidirectional interaction between grid cells and place cells. In particular, while grid-cell representations are reset by visual input upon entry to a familiar environment, self-motion input is sufficient for place cells to fire. Moreover, under various type environmental manipulations coherent changes in both grid- and place-cell activity patterns has been observed. However, the computational nature of this bidirectional interaction remains unclear. In this work we present a neural network model that receives visual and self-motion input to learn vision-based place cells as well as self-motion driven place cells based on grid-cell input. A third place-cell population is driven by both vision- and self-motion input and forms a recurrent loop with the grid cell population. The model was tested in light and dark experimental conditions, during environmental manipulations and in double-room experiments, in which two visually identical environments are connected by a corridor. It is shown that receptive fields of the model cells reproduce basic features of visual- and self-motion based place cells. Dynamics of place- and grid-cell interaction in double-room experiment is explored and experimental predictions are formulated with respect to the changes in receptive fields of place cells driven by vision, self-motion, or a combination of both.

Keywords: grid cells · place cells · self-motion · vision · Bidirectional interactions.

* This research is supported by ANR-Essilor SilverSight Chair ANR-14-CHIN-0001.

Biologically Inspired View-Based Navigation with Place Fields Constituted Through "Micro-Snapshots"

Tristan Baumann, Gerrit A. Ecke, and Hanspeter A. Mallot

Cognitive Neuroscience Unit, University of Tübingen,
Auf der Morgenstelle 28, 72076 Tübingen
tristan.baumann@student.uni-tuebingen.de

Abstract. Models for spatial navigation in biological systems have a long standing history of relying on scene familiarity and topology [1–3]. One of these concepts, the view-graph model, states that an agent may record a chain of snapshots when exploring its environment. This chain might later on guide the agent to follow the same route again. Recognizing a view previously seen enables the chain of snapshots to be linked up to a graph, so that a graph search allows to calculate new routes between arbitrary nodes. Numerous implementations for robot navigation have been realized [4–6], as well as human navigation was modeled in the same vein, using a rather high-level interpretation of snapshots [7].

Navigation with discrete snapshots has been a matter of concern. It seems legit for high-level navigation like in humans to select discrete views at sparse, decisive locations and connect these views by the rule to follow an obvious route (e.g. a street). Low-level view-graphs however usually span a grid of arbitrarily chosen snapshot positions. It is not obvious how to choose where to record a view in the first place, and there is a lack of evidence for the utilization of such discrete way-points in studied animals. Tackling this problem, Baddeley et al. [8] suggested that direction commands based on holistic scene familiarity can explain route following of ants. In this model, a route is learned by labeling Haar-features detected in a scene with the associated direction of movement. The course of the route can later be reproduced by moving into the average direction in which detected features are labeled.

In our model, we attempt to merge the continuous nature of navigation based on motion-labeled features with a view-graph that allows to calculate new and optimal routes between arbitrary positions. SURF-features [9] are treated as micro-snapshots, embedded in a graph where edges are labeled with a direction of movement. Measuring the similarity between detected features and recorded snapshot-features as a function of the position of the agent yields view-dependend activities comparable to place-fields. Motion labeled graph edges are then recorded at the transition between overlapping place fields. Note that the view dependency of place fields is in line with evidence from rodents [10] as well as from primates, including humans [11, 12].

Routes are planned by graph search between all features detected in a current view and all features recorded at a goal location. The agent then moves in a

consensus direction obtained from the *several* plannend routes. The model was tested in a virtual environment of the inner city of Tübingen. Simulations run in realtime and generally show good performance. The agent is able to always find a reasonable route with distances which are on average no more than 20% above optimum.

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Weak radiofrequency fields rather cancel than only modify the magnetic navigation of insects

Radek Netusil[1], Tomas Pecka[1] and Martin Vacha[1]

[1] Masaryk University, Faculty of Science, Brno, Czech Republic
netusil@mail.muni.cz

It has been known for decades that broad range of animals, such as birds, fish, mammals and even insects, use geomagnetic field as a cue for navigation in space. Mechanism of reception is unknown but convincing evidences of so called radical-pair mechanism based on Cryptochrome protein have been shown. It also has been shown that magnetoreception was influenced by, even a remarkably weak anthropogenic (10000x weaker than Earth-strength magnetic field) radiofrequency (RF) fields and innate navigation was lost in several species. The mechanism of RF impact is not very clear. We wandered if magnetoreception mechanism is only modified, or completely cancelled by RF fields. May the background RF noise become a part of natural magnetic environment and may proper navigation still be achieved after some time of training by the animal?

We developed a conditioning behavioral assay on firebug *Pyrrhocoris apterus* where rotation of magnetic field was followed by „punishment“ by a hot air stream during the training. In the test, if only magnetic field rotation was presented, the animals „freezed“ (decreased their activity) expecting unpleasant stimulus.

Preliminary data suggest that insect magnetoreception is sensitive to Larmor frequency (1,4 MHz, 4nT) and that magnetoreception was completely canceled even if RF was presented all the time during the training and the test. Interestingly, only males, not females, reacted successfully to magnetic stimulus.

This work shows that the loss of animal navigation due to the anthropogenic RFs is likely not due to the transient modification of perception only but due to fundamental disruption of the Cryptochrome signaling. Considering the role of Cryptochromes in control of circadian rhythms, such a finding may not only be important for animal navigation but it may concern human health as well.

Keywords: Magnetoreception, Conditioning, Insect.

Cognitive Maps in the Real World and the Laboratory

Jennifer E. Sutton[1,2], Nicole Youngson[2], and Chantelle Cocquyt[1]

[1] Brescia University College, London, ON, N6G 1H2, Canada
[2] University of Western Ontario, London, ON, N6A 5C2, Canada
jennifer.sutton@uwo.ca

Individual differences in spatial microgenesis appear similar in real-world and virtual environments, with some individuals integrating spatial information into a survey representation, or *cognitive map*, early in the learning process, while others fail to form a cognitive map at all [1, 2]. Though such studies specifically focus on learning and remembering the layout of a novel environment, are they also assessments of the mental representations of familiar, real world environments? That is, do individuals who are unable to create a cognitive map of a virtual environment also hold a weak cognitive map of their everyday, familiar environment?

In the current study, 98 participants (48 females) explored the virtual environment *Silcton* and searched for eight target buildings. Afterwards, they completed direction estimation and building arrangement tasks based on memory of the buildings' locations. In addition, they provided 4 – 10 regularly-visited locations in their home city of London, ON and then estimated the directions between the four most-frequently-visited of these locations and also drew a sketch map. We predicted that accuracy would be greater for cognitive maps of the real world than for Silcton, but that cognitive map accuracy in Silcton and the real world would be related. We were also interested in whether there were sex differences in the pattern of results.

As shown in Fig. 1, we found a significant Environment x Sex interaction for the direction estimation tasks. Simple main effects analyses confirmed that where males were more accurate on Silcton tasks than in the real world but females showed the opposite pattern. In addition, males and females did not differ on estimations of real world directions, but males were significantly better than females for directions based on Silcton. A similar pattern was also found for map creation. Finally, performance across the two environments was correlated for males on both direction estimation and map tasks but females showed only a weak correlation for the direction estimation tasks. It will be important to determine how the novel and virtual aspects of laboratory tasks interact to affect performance, especially of females.

Keywords: cognitive map, virtual reality

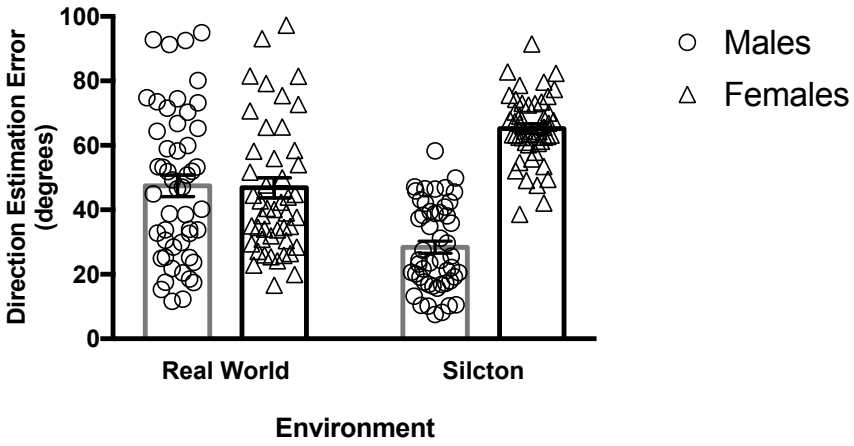

Fig. 1. Direction estimation error based on memory for the real world home environment and the Silcton virtual environment. Circles and triangles show individual scores. Error bars show standard error of the mean. Horizontal spread of individual scores is for clarity of presentation only.

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Does Interest Influence Landmark Selection?

Eva Nuhn[1][0000−0003−2443−8122] and Sabine Timpf[1][0000−0002−7964−4110]

Geoinformatics Group, University of Augsburg, Alter Postweg 118, 86159 Augsburg, Germany
eva.nuhn@geo.uni-augsburg.de, sabine.timpf@geo.uni-augsburg.de

Keywords: Landmarks · Personalisation · Interest.

In contrast to the prevalence of uniform points-of-interests given in digital maps or tourist apps, research shows that travellers prefer their own landmarks for orientation and wayfinding. Certain landmarks are more consciously perceived than others while navigating. This results from the fact that attention is guided by interests [7]. Thus, the personal interests of a pedestrian must be considered for landmark identification [3]. Furthermore, landmarks matching the traveller's interests should be contained in wayfinding aids [6].

Landmarks have been researched intensively over the past decades (for an overview see [8]). The role of personalisation and different landmarks for different travellers has been of growing interest in the last years (i.e., [1] [2], [9]). Currently, the salience models needed to differentiate and to adjust landmarks to a person's interest are not available.

In [4] a multidimensional model that helps to select personal salient landmarks is proposed. Specifically, authors take the existing landmark salience model by [5] and add personal attributes. In this work, we extend the multidimensional model for personalised landmarks to include the personal interests of a traveller.

To test the extended model we will perform a study. The participants will rate their interests in different topics and select landmarks from a pool of potential landmarks. We then predict landmark selection using a conventional model without personal interests [5] and, in addition, using our model based on salience calculations. We ask the following research questions: *does a landmark salience model considering personal interests predict more selected landmarks than a 'conventional' landmark salience model?* And if so: *are the differences in the outcomes of the models statistically significant?* The results will help us to draw conclusions if personal interests should be included in future landmark salience models.

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Using Landmarks in Pedestrian Movement Simulation

Gabriele Filomena and Judith A. Verstegen

Institute for Geoinformatics, University of Münster, Münster, Germany
gabriele.filomena@uni-muenster.de, j.a.verstegen@uni-muenster.de

Keywords: Landmarks · pedestrian simulation · wayfinding

In *The Image of the City*, Kevin Lynch [1] unearths the role played by specific environmental features in assisting wayfinding processes: people decompose the city in elements - landmarks, nodes, routes, edges and districts - that facilitate the acquisition and organisation of spatial knowledge. In particular, landmarks are elements that stand out from the environment and are used as point of references [1].

The idea that landmarks may support navigation has become stronger in the last 20 years: while local landmarks suggest what a walker should do at a specific junction, distant landmarks organise the spatial knowledge and offer confirmation to the explorer. To include landmarks in automatic navigation systems, several attempts to formalise the concept of landmark salience have risen. Furthermore, researchers have advanced routing algorithms where landmarks are incorporated in the computation of optimal paths.

Here a novel approach to landmark routing is advanced. Differently from previous research, the current work does not seek to formulate best path for automatic route-description. The intent is to provide a tool for better understanding and simulating pedestrians movement.

A methodology for ranking buildings in a specific study area by cognitive salience was devised, following Sorrows and Hirtle's [2] approach: the *global landmarkness* of an edifice is viewed as the combination of visual, structural, pragmatic and cultural components. Our effort is focused on employing the salient elements to adjust algorithms commonly used to represent humans route-choice criteria, based on Euclidean distance or angular-change minimisation. Landmarks cognitive functions are here formalised distinguishing *on-route markers* and *distant landmarks*, and incorporated in a primal graph representation of the street network. On-route markers are defined as landmark relevant at the junction level. Their local score results from the combination of local salience and advance 2d visibility (see Fig. 1 a) and b)). Nodes are weighted with the highest landmark-local score at the junction, depending upon the direction of movement. Additionally, each node is rewarded with a visibility score, computed based on 3d sight lines (see Fig. 1 (c)), to include the role, so far neglected, of distant landmarks. These two components are used as additive inverse costs along edges.

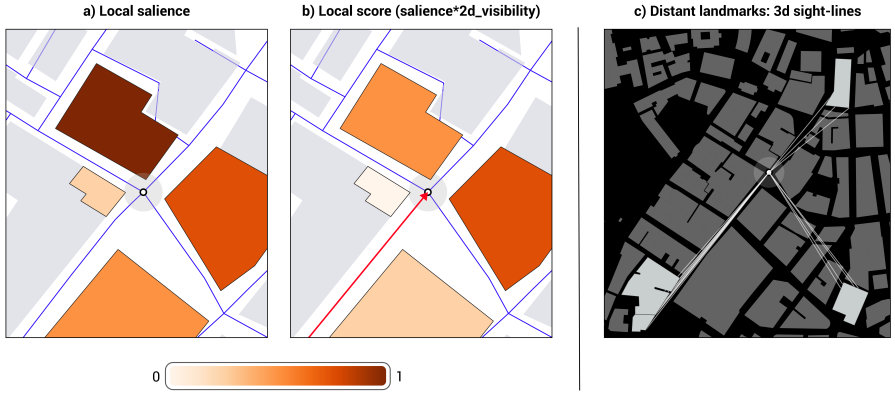

Fig. 1. Local landmarks at a street junction, coloured by local salience before and after 2d visibility computation, and distant landmarks

In an ABM environment, agents route-choice criteria algorithms were manipulated to compare patterns emerging from shortest Euclidean and least-angular paths with the ones resulting from a combination of the first and the landmark network weights. The central area of London was used as case-study. Differences in the most traversed street segments emerged: while some major roads were used regardless the inclusion of landmarks in the algorithms, others were completely avoided in the landmark condition. In the latter, agents tended to choose routes featured by higher visibility, as along rivers or parks, as well as minor roads featured by high local salience. Feature research will be dedicated to validate the method with qualitative data.

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The effect of concurrent task load on the acquisition of local and global landmark knowledge

Sascha Credé, Tyler Thrash, and Sara Irina Fabrikant

University of Zurich, Department of Geography, Geographic Information Visualization and Analysis, Winterthurerstrasse 190, 8057 Zurich, Switzerland

Abstract. Global landmarks can be defined as stable objects that can be perceived from many different locations within a large-scale environment. Previous research has demonstrated the benefits of attending to global landmarks for spatial knowledge acquisition [6] and displaying distant off-screen landmarks on mobile map devices [7, 9,11]. However, the relative (dis)advantages of global and local landmarks with respect to the integration of these landmarks into a common survey representation during navigation are still unknown. Previous research has demonstrated that information presented simultaneously (rather than sequentially) is easier to encode and represent in working memory [1,2,5]. The present study transfers these findings from the basic experimental psychology literature to the domain of navigation through large-scale spaces. In one virtual reality experiment, we investigated whether the mental integration of highly visible global landmarks, which can often be viewed simultaneously, is more accurate than the mental integration of local landmarks, which are acquired sequentially over different views in working memory [3,4,8,10]. To investigate the extent to which the mental integration of global and local landmark configurations relies on working memory resources, we manipulated the mental workload of one group of participants during navigation.

Participants navigated predetermined routes in a large-scale virtual environment from an egocentric perspective. Their task was to navigate through cities with either local or global landmark configurations highlighted (Figure 1) and either with or without concurrent task demands. All participants were instructed to reach the destination as quickly as possible and learn the highlighted landmark configurations as accurately as possible. After each of two navigation trials, participants' survey knowledge was assessed with judgments of relative direction (JRDs). For the treatment group, concurrent task demands (i.e., a spatial tapping task) aimed to load the processing capacity of participants' working memory. We expected the low availability of working memory resources in these participants to adversely affect survey knowledge acquisition. However, we expected the integration of global landmark configurations to be more resilient to this detrimental effect of the spatial tapping task on spatial knowledge acquisition.

Fig. 1. Screenshot of the same virtual city during the navigation phase with (a) showing a viewpoint in the local condition and (b) showing the the same viewpoint in the global condition. In both conditions, there were 4 landmarks highlighted (only local or only global).

Our preliminary results show that global landmarks were mentally integrated more accurate than local landmark configurations. These findings support the empirical results from more applied studies that have shown orientation advantages after attention was guided to global landmarks. Also in accordance with our expectations, participant's knowledge of landmark configurations was less accurate when acquiring knowledge under constant secondary task demands. These findings raise questions about the generalizability of empirical results which investigated spatial knowledge acquisition under no concurrent task demands. Finally, we could not find stronger detrimental effects of multi-tasking stress on the acquisition of local as compared to global landmark configurations.

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Evaluating Working Memory Demands in Visualization Decision Making

Lace Padilla[1], Spencer Castro[2], Ian Ruginski[2], P. Samuel Quinan[2], and Sarah Creem-Regehr[2]

[1] Northwestern University, Evanston, IL 60208, USA
[2] University of Utah, Salt Lake City UT. 84112
lace.m.k.padilla@gmail.com

Abstract. At their best, visualizations of data effortlessly reveal the true nature of information. Working memory consists of multiple mental components that maintain a limited amount of information for a finite period, and allow the viewer to engage attention in a controlled manner to suppress automatic responses and maintain the most task-relevant information. While many studies assert both that a critical purpose of visualizing information is to reduce dependence on working memory and that some visualization techniques minimize working memory demands, few visualization studies test working memory directly. Researchers from cognitive science have established widely used procedures for evaluating working memory demands. However, surprisingly few studies in the field of information visualization have employed these methodologies to assess their claims about working memory reduction. The goal of this work is to provide clear, practical, and empirically validated methods for evaluating working memory during visualization tasks. As a case study, we present multiple methods for assessing working memory demands in a visual-spatial aggregation task with geospatial data. The task consisted of making relative average height judgments between various areas in digital elevation maps. The digital elevation maps were continuously encoded with grey scale. Participants compared the average height of either two or four regions in the maps. The manipulation of increased number of regions to compare was intended to increase the working memory demands of the task. In addition, we implemented a dual-task in which participants remembered a string of numbers while performing the average height comparison task, and reported the remembered numbers after each trial. We utilized pupillometry, reaction time, accuracy, and individual differences measures to demonstrate converging techniques for evaluating how task difficulty increases demand on working memory in the context of visualization decision making.

Keywords: visualization decision making · working memory · visual-spatial aggregation · geospatial data

Foraging in Heterogeneous Environments

Ketika Garg[1][0000-0003-0915-7314] and Chris Kello[2][0000-0003-1588-9474]

[1] University of California Merced, Merced CA 95340, USA
kgarg@ucmerced.edu
[2] University of California Merced, Merced CA 95340, USA
ckello@ucmerced.edu

Abstract. Several studies have shown that human and animal foraging movements follow a Lévy flight [1]—a power law distribution comprising of many short path segments with increasingly rare longer movements, where the probability of observing a given path length is inversely proportional to the length, with an exponent near two:
$P(l_j) \sim l_j^{-\mu}$, where the length of step j is l_j, and the power law exponent μ is bounded, $1 < \mu \leq 3$.

Lévy flights maximize foraging efficiency under a set of simplifying assumptions, most notably that foraging is a memory-less search process and resources are sparsely and randomly distributed in an isotropic environment [2]. These assumptions are useful for making the model tractable to analyze, but they do not hold true in natural mammalian foraging conditions. Foragers have memory and strategy, and environments are heterogeneous regarding movement costs, field of view, and resource distributions. Foraging theories should explain how these factors and processes give rise to Lévy flights, but collecting relevant data is often difficult in natural environments, and experimental manipulation is usually prohibitive.

The present study introduces a real-world foraging environment simulated in a 3D virtual environment to capture several critical factors in human foraging and make them amenable to experimental manipulation. A terrain patch from the foothills of the Himalayas was extracted from Google Earth and replicated into a Unity3D environment. The undulating landscape of the terrain simulates the heterogeneity that real-world foragers encounter in terms of their field of view and movement cost, the latter expressed as higher "energy" expenditure with the increase in uphill slope, based on a prior study of human energy expenditure as a function of gradient [3].

The items to find are ancient temples tagged through Google Earth that were historically used as waypoints and shelters for the nomadic tribes of the region as they would navigate across the Himalayas on foot. Individual players are positioned at a home-base and instructed to navigate through the terrain using six keys and find as many temples as possible. Efficient foraging in the virtual environment requires navigational decisions that weigh climbing up to vantage points against energy expenditure in a realistic way, and require memory because foragers had to relocate the home base to report the found temples back to their hypothetical community.

Preliminary results were collected from twenty participants in an online version of the game hosted through Amazon's Mechanical Turk services. Results showed a consistent power law distribution for each participant in terms of path segment lengths in distance (Fig. 1), in time (Fig. 2), and energy expenditure (Fig. 3). Subsequent analyses with much larger numbers of participants will examine foraging factors and strategies that correlate with greater foraging success, including but not limited to power-law path segment analyses. This initial study may serve as the anchor for subsequent experiments in which environmental factors can be manipulated to study how foraging behaviors adapt, and the extent to which Lévy flights generalize across conditions.

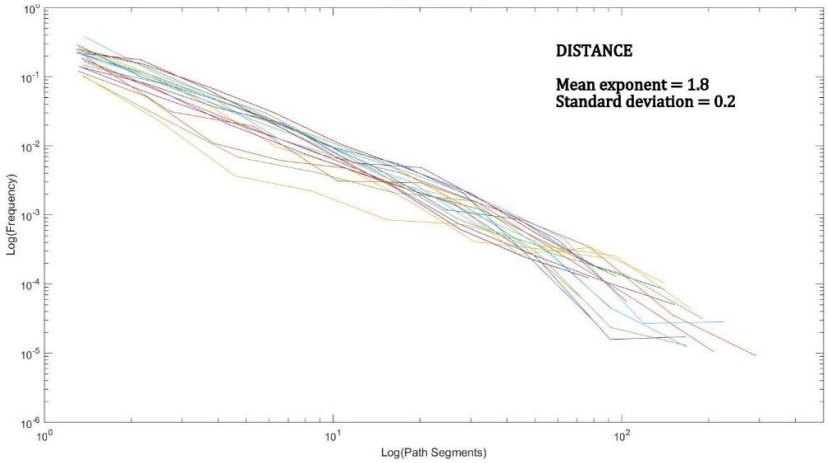

Fig. 1. The length of path segments follows a power law, with an exponent of ~2.

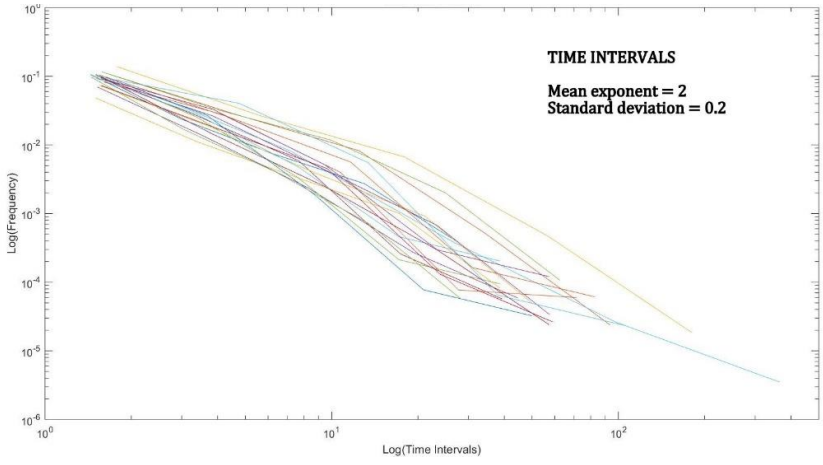

Fig. 2. The time intervals of walking follow a power law, with an exponent of ~2.

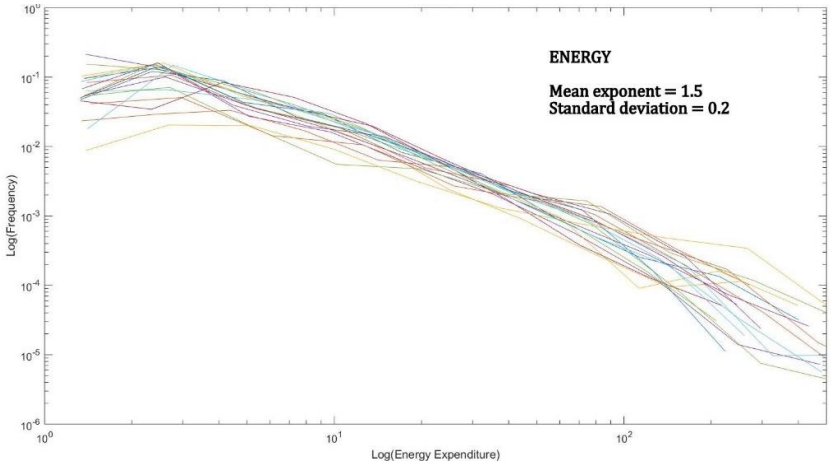

Fig. 3. The amount of energy expenditure follows a power law, with an exponent of ~1.5.

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Spatial Memory and Smartphone Use: Navigation by People with Different Levels of Sense of Direction

Masashi Sugimoto[1[0000-0002-6040-8046]], Noriko Nagata[1[0000-0002-2037-1947]], and Toru Ishikawa[2]

[1] Kwansei Gakuin University, Gakuien 2-1 Sanda Hyogo, Japan
[2] The University of Tokyo, Hongo 7-3-1 Bunkyo-ku Tokyo, Japan
sugimoto.masashi@kwansei.ac.jp

Recently, digital maps on a smartphone have been used widely, oftentimes more widely than paper maps. Smartphone maps provide the user with information about where they and their destinations are, and which route to take. These navigation functions presumably allow the user to feel confident without the fear of getting lost. However, past studies pointed out that navigational assistance provided by smartphones, including GPS-based navigation tools, have a negative effect on the user's spatial cognition. In particular, these studies showed that the use of navigation tools deteriorated the user's spatial learning in terms of their memory for traveled routes.

The present study examined how people with different levels of sense of direction use smartphone maps. In particular, it looked at possible differences in the use of (or interaction with) smartphone maps and their navigation functions depending on users' sense of direction, and the relationships between the manner of interaction and users' learning and behavior in the environment.

Twenty-two students participated in a behavioral experiment of wayfinding and navigation. The participants were divided into two groups based on their scores on the Santa Barbara Sense-of-Direction scale: a good sense-of-direction (G-SOD) group (n = 8, MSBSOD = 4.3) and a poor sense-of-direction (P-SOD) group (n = 14, MSBSOD = 2.9). They participated in a real-world navigation task using a digital map shown on a smartphone, having been instructed to reach a predetermined destination (whose location was shown on the smartphone map) using any navigational function freely. During the navigation, their uses of the smartphone map (e.g., which functions they used) and the routes that they took were recorded. After reaching the destination, they completed spatial tasks concerning the traveled route: distance estimation, direction estimation, scene recognition, and map recall.

Both groups showed nearly perfect performance on the navigation task. All participants reached the destination by themselves, and they self-assessed the difficulty of navigation as very low. In contrast, the two groups differed in the use of the smartphone map and the accuracy of spatial memory. While a majority of the G-SOD group did not use a navigation function (route directions) and chose their own routes to the destination, the P-SOD group tended to use the navigation function and followed the route directed by the smartphone. Also, the manner in which they interacted with the smartphone map affected participants' performances on some spatial tasks. The G-SOD group showed nearly perfect performance on map recall regardless of the

use of the navigation function, but the P-SOD group did worse when they used the function.

These results indicate that people with differing levels of sense of direction use smartphone maps differently and the interaction with smartphone maps affects spatial memory. Participants in the P-SOD group are likely to rely on smartphone maps during navigation due to their low wayfinding ability, and this reliance may cause them to passively follow directed routes, leaving the task of spatial thinking in navigation to the smartphone, somehow finding their way to the destination but having their spatial memory impaired.

The ways of looking for ways on maps:
wayfinding and navigation in a virtual city

Ágoston Török[1][0000-0002-1550-7969], Zsolt Győző Török[2][0000-0002-6447-1499]

[1] Systems and Control Laboratory, Institute for Computer Science and Control, Hungarian Academy of Sciences, Budapest, 1111, Hungary
[2] Department of Cartography and Geoinformatics, Faculty of Informatics, Eötvös Loránd University, 1117 Budapest, Pázmány Péter sétány 1/a, Hungary
zoltorok@map.elte.hu

Abstract. Since ancient times humans use maps as cognitive tools to visualize complex spaces. In the modern age maps are routinely used to help wayfinding and navigation in geo-space. Despite the long history of cartography, little is known about why and how maps help cognitive processes. To explore spatial cognition processes in geovisualization, especially map-based navigation in virtual environment (VR) we established a Cognitive Cartography Lab, and designed the Virtual Tourist experiments to study and better understand map use during navigation. In this paper we present preliminary results of our recent study that explored the use of a static, north-oriented city map during navigation in an interactive, 3D town. Participants explored the virtual environment and completed spatial tasks while their spatial behavior of subjects, their verbal reactions were recorded, and also eye tracking data from 62 participants was collected. The experiment was designed by a multidisciplinary research group, including students and was supported by the Talent Support Grant of Eötvös Loránd University.

Keywords: Spatial Cognition, Virtual Environment, Navigation, Cartography, Eye Tracking.

1 Summary of methods

In our research paradigm the participants sitting in a chair in front of a 21" LCD screen (with the resolution 1080 (horizontal) by 1920 (vertical) pixels). On the upper half of the vertically placed monitor they could see the 3D reconstruction of the fantasy town 'Szegvár'. Below the interactive, virtual environment, in the lower part of the screen a static city map was presented. It was based on an old, instructional topographical map of an imaginary region (Major, 1963), and was designed in the style Google maps (Google 2018). A remote eyetracking device, placed under the screen, served to track and record eye movements during the navigation experiment.

Adopting the concept of gamification, participants were first guided in the streets of the unknown town to explore its attractions. Next in the storyline they were given some free time and, standing in front of the cathedral at the main square (a salient landmark),

they were verbally instructed how to find the locations of different specialty stores in the town by remembering the verbal descriptions and, whenever it was needed, using the map. Clues in the spatial narrative included relevant directional (both geocentric and egocentric reference frame), landmark and/or beacon information.

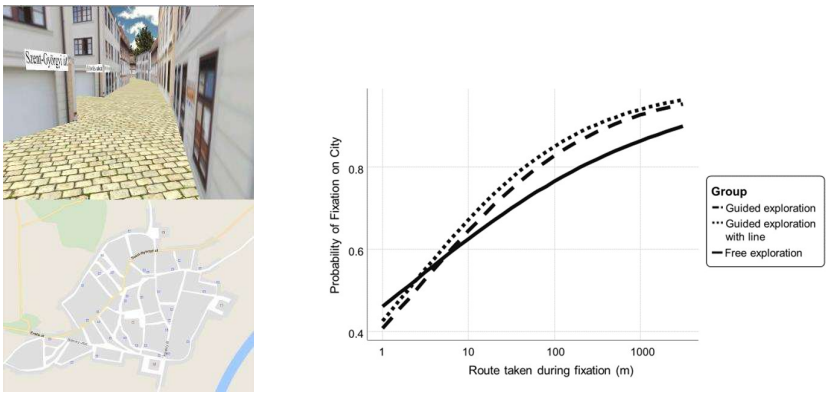

Fig. 1. The layout of the display of the VR experiment (left) and the probability diagram of the fixations of the participants in the three spatial learning groups on the town (right).

The statistical analysis in progress includes general, linear mixed effects modelling of data for the proportion and frequency of map use (and spot) throughout the different target finding tasks; task order and gender are used as independent variables.

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Route Planning and Situated Navigation in a Collaborative Wayfinding Task

Crystal Bae

Department of Geography
University of California, Santa Barbara, CA
cbae@geog.ucsb.edu

1 Extended Abstract

Much prior work in spatial cognition has taken an individual approach to the study of wayfinding, isolating the planning and decision-making process of a single person as the unit of study. This study expands our understanding of navigation as it unfolds in a social context, as often occurs in real-world scenarios. Support has also been shown for a difference in situated and prospective planning, wherein participants often modify their route-following *in situ* [1]. I investigate properties of both prospective route planning and situated navigation by pairs of people (dyads) in an unfamiliar, real-world environment.

Participants collaborated on a task to both plan and execute a route between a given origin and destination point. In the planning phase of this study, each dyad was given start and end points between which they had to devise and agree upon a route to take. From coded interactions of these route planning interactions, I employ a Conversation Analytic approach to propose explanations for successful route planning [2, 3]. In the second part of the study, each dyad was taken to the study site where they navigated together between those same origin and destination points, while being video-recorded and GPS-tracked. Participants were video-recorded by the researcher during both the planning and navigation phases. Using this rich repository of video-recorded interaction alongside collected data on participants' navigational planning and execution, I investigate strategies of social role-taking (such as leading and following), the collaborative use of environmental cues and references, and the communication of uncertainty in wayfinding.

This poster communicates preliminary findings from my study and invites additional feedback on further analysis and next steps. I will present my analysis of where and when dyads deviated from the route as previously planned, and a summary of interactions recorded at critical decision points. Additionally, I suggest where social role-taking between the participants during the route planning and situated navigation phases either inhibited or supported successful navigation. This research agenda furthers our understanding of collaboration during navigation, and additionally illuminates the impact of social roles on decision-making and interaction in a wayfinding task.

Keywords: navigation · collaborative wayfinding · route planning · social navigation · social interaction.

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The (un)familiar city map: Navigation behavior in unknown environments is influenced by background knowledge about urban structures.

Julia Frankenstein[1] and Stefan Münzer[2]

[1] Centre for Cognitive Science, TU Darmstadt, Alexanderstr. 10, 64283 Darmstadt, Germany
[2] Mannheim University, A 5,6, 68159 Mannheim, Germany
julia.frankenstein@cogsci.tu-darmstadt.de
stefan.muenzer@uni-mannheim.de

Abstract.

Introduction

Humans use background knowledge to efficiently navigate buildings. As historically grown European cities frequently share an underlying structure of their respective city centers, we tested in Experiment 1 whether European inhabitants have background knowledge about the structure of street layouts of cities. Particularly, we tested how participants infer where particular buildings and places might typically be located. In Experiment 2, we tested if these inferences based on background knowledge guide actual navigation behavior.

Experiment 1

In Experiment 1, participants were asked to mark supposed positions of three buildings and places (an "ancient castle", the main station, a gas station) on one out of four German city maps (maps of Krefeld, Aachen, Mainz, Radebeul). These maps depicted the street layout only. Furthermore, we asked participants to rate their confidence about their judgement. Results show that participants did not select the target location randomly. Especially for the castle's location they agreed on a small number of typical locations in the maps of Krefeld and Radebeul. In particular, two target locations for the "ancient castle" were preferred on the map of Radebeul, which was used to construct a virtual city used in Experiment 2.

Experiment 2

In Experiment 2, we tested whether the background knowledge about urban structures as assessed in Experiment 1 guides actual navigation behavior. For that, we built a virtual city based on the city map of Radebeul. Another group of participants freely navigated the VE to find the ancient castle. During navigation, they were provided with a virtual version of the city map used in Experiment 1, depicting only the street layout. The castle was located either at the most likely location (as found in Experiment 1) or at an alternative location. Even though the alternative location was closer

to the starting point and required the same number of turns to be approached, results revealed longer search times and longer trajectories in this condition.

Discussion

Participants inferred similar positions particularly for the castle, which in European cities often determined the historical development of the city and its structures. However, this effect was more apparent in smaller and less complex maps (Krefeld and Radebeul), while the other maps may have offered too many possibilities and geometrically equivalent locations. To test actual navigation behavior, a virtual city based on the relatively small map of Radebeul was used. Despite that the alternative location was closer to the starting point (with respect to number of turns and distance), participants showed shorter trajectories and were faster in finding the castle if the castle was located at the typical place identified by participants of Experiment 1. This observation indicates that participants utilized common background knowledge about the cities' structural layout to navigate to the target location.

Reconceptualizing Affordance as a Cognitive Construct Dependent on Emergent Spatial Multimodal Contexts

Daniel Ness[1] and Min Wang[2]

[1] St. John's University, Queens NY 11439, USA
[2] St. John's University, Queens NY 11439, USA

Abstract. As a psychological construct, affordance generally refers to the meaning of an object in terms of meaning and function for the user [1]. More recently, the authors have suggested that the greater the affordance, the less creative fluency and use of spatial skills. In this paper, the authors considered how affordance as a cognitive construct in multiple spatial environments either enhance or impede cognitive development. The authors posit that greater affordance provides more ease and speed for the learner, and thus possibly more experience with surface knowledge and less experience with deep knowledge and higher order thinking. It may be more beneficial to conceive of affordance as a more dynamic construct that is dependent on the context in which something occurs.

The term affordance made its way into the research corpus of numerous related disciplines, which include, but are not limited to, linguistics (particularly new language acquisition [2], cognitive science [3], sociology [4], and even fields in the natural sciences [5]. When considering spatial affordances, we oftentimes think of what the addition of a certain spatial feature offers the individual. Thus, more affordance is often construed as a good thing because it is seen as applicable to provision of attributes for better living.

Affordance is essential in characterizing and analyzing visuospatial constructive play objects (henceforth, VCPOs), such as blocks, bricks, and planks used for building structures, because it allows the investigator to tap the individual's uses and intentions for use of a particular object in question.

In connection with spatial thinking and intelligence, it is important to clarify that the authors' use of the term "affordance" is only tangentially associated to the Gibsonian position. That is, the definition of affordance that Gibson has presented clarifies the way we refer to objects in our everyday lives, including VCPOs. However, the authors challenge the putatively held position that the greater affordance an object possesses, the more it positively influences our way of life. The authors' argument in using affordance for the purpose of studying spatial thinking as it relates to multimodal contexts is to determine to what extent affordances of objects, in the present case, VCPOs, may influence levels of complexity of spatial thinking and reasoning.

For the purpose of this paper, the authors call attention to how the diversity of affordance levels of VCPOs affects conceptual knowledge. The authors re-

considered one meaning of affordance based on findings from children's engagement in activities involving VCPOs. Results from naturalistic observation in the constructive play environment suggest that the greater the affordance of a VCPO, the easier it is to use in construction, and therefore, the more it impedes creative processes, problem solving, spatial thinking, and cognitive development in general. VCPOs with higher levels of affordance generally lead to more constraints on creativity-relevant aspects of performance. Thus, the authors proposed the existence of an inverse relationship between the level of affordance of a particular VCPO and spatial-related cognitive skills.

Word count: 485

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Exploring human processing of 3D perception with using compatibility paradigm

Satoko Ohtsuka[1]

[1] Saitama Institute of Technology, 1690 Fusaiji, Fukaya, Saitama 3690293, JAPAN
satoko@sit.ac.jp

Abstract. Psychological compatibility refers to effects on human response of the response-irrelevant information. For example color response performance is better when a color-word (ex. "red") is painted with the corresponding color (red) than with different color (green). This well-known Stroop effect can be called the stimulus-stimulus (S-S) compatibility effect. As another effect, the response, to color for example, is better when the stimulus appeared on one side (ex. left) should be manually responded with the same side (left) than when with the opposite side (right). This is the Simon effect, and is stimulus-response (S-R) compatibility. In the previous study we found that the two compatibility effects are clearly discriminated by introducing the Stimulus Onset Asynchrony (SOA) between the response-relevant and irrelevant properties (Kogure, 2015). That is, the S-S effect are highlighted at negative SOAs (the irrelevant property appears before the relevant property) in addition to zero SOA. The S-R effects, on the other side, are so at positive SOAs (the irrelevant after relevant). This difference can be explained that the S-R effect contain spatial processing to response whereas the S-S effect does not. In the present study we applied the SOA paradigm in compatibility experiment in exploring human processing of depth information to perceive three-dimensional space. In experiments the response-relevant property of color was assigned to the stimuli which also contained the response-irrelevant depth information defined by various depth cues. The stimuli were presented on the identical position in two-dimensional plane, while was suggested to be appear at nearer or further from observers by binocular disparity (Experiment 1), pictorial depth cues (Experiment 2), or words of "front" and "back" (Experiment 3). The observers responded to the color with two keys arranged so that one is near and another is far from themselves. Here, the SOAs between the color (response-relevant) and depth information (irrelevant) properties are modified from -400 to +400 ms. The experiments are under progress now, however the data could suggest how the depth cue information is processed to yield response via 3D perception. The depth cues employed here generate relatively clear depth impression. If some depth cues yield the similar pattern of results as the S-R effect, these cues can provide the spatial information to human directly to lead the corresponding manual spatial response. If other cues yield the S-S effect like pattern, they can provide weaker spatial information. Thus our study can discriminate various spatial representations established with various depth cues.

Performance discrepancy between left-handers and right-handers reveals multisensory integration in the mental rotation of hands

Lilian (You) Cheng[1], Mary Hegarty[1], Elizabeth R. Chrastil[1]

[1] University of California-Santa Barbara, Santa Barbara, CA 93106-9660, USA
you_cheng@ucsb.edu

Abstract. In mental rotation tasks, people show a remarkably different pattern of responses to hand stimuli compared to geometric 3D objects, but it remains a conundrum whether motor simulation (an automatic activation of the motor system that guides the intended action) can account for these effects. Here, we contrasted two hypotheses: a) the Sensorimotor Recalibration Hypothesis, the match of the spatial representation of the felt hand (the hand making the response) and the seen hand (the image of a hand on the screen) as the motor system requires a consistent internal representation of body position, and b) the Multisensory Hand Binding Hypothesis, the match of spatial representation of hand of different sensory modalities: visual representation of the seen hand and proprioceptive representation of the felt hand. In this task, both left-handed and right-handed subjects performed a modified Shepard & Metzler task using pointer (hands in a pointing gesture) and palm hand stimuli. All hand stimuli were shown with the inside of the hand facing the viewer (palm-up). Given that people are expected to have better performance to their dominant hand stimuli because of their embodied experience, we can make two predictions. Under the Sensorimotor Recalibration Hypothesis, a match between the felt hand and the seen hand will improve performance. Thus, left-handed subjects will have better performance on left hand stimuli than right hand stimuli and right-handed subjects will have better performance on right hand stimuli. Under the Multisensory Hand Binding Hypothesis, a 'wrong-hand effect' will be expected, whereby the match of spatial configuration ('shape') of the seen hand and the felt hand, is preferentially processed. The shape of a right palm-up hand on the screen resembles a left palm-down hand, and the felt hand in this task was in a palm-down position. Thus, this hypothesis predicts that right-handed subjects will have better performance on left hand stimuli than right hand stimuli and vice versa for left-handed subjects. We found a wrong hand effect when the stimuli were palms. This finding supports the hypothesis that the integration of different sensory modalities, not motor simulation, is important for the mental rotation of hands. However, the 'wrong hand effect' was diluted when the stimuli were pointers. This pointer result raises the possibility that the match of one's own hand gesture and the gesture seen on the screen potentially facilitates motor simulation in the mental rotation of hands. In sum, this study reveals that the performance discrepancy between left-handers and right-handers for palms, but less so for pointers, demonstrates multisensory integration in the mental rotation of hands.

Can Navigation Ability be Trained? Growth Mindset and Navigation Ability

Chuanxiuyue(Carol) He[1[0000-0002-5819-7171]] and Mary Hegarty[1[0000-0002-7777-8844]]

[1] University of California-Santa Barbara, CA, 93106-9660, USA
c.he@psych.ucsb.edu

Abstract. Growth (versus fixed) mindset in navigation ability refers to a person's implicit theories that their navigation ability can (or cannot) be improved. This study aims to investigate the relations between this mindset, self-reported sense of direction, everyday navigation behaviors, and people's actual navigation abilities, including perspective-taking, constructing survey knowledge, and navigation efficiency. In Study 1, 123 (74 females and 49 males) participants self-reported their growth or fixed mindset in navigation ability, dependence on GPS in everyday navigation, tendency to explore new places and self-evaluation of their "sense of direction" and spatial anxiety. The results indicated that people with a growth mindset are more likely to report a good sense of direction, feel less anxious during navigation, and are more likely to explore new places. They also have better performance in perspective-taking tests. People who report a good sense of direction are less likely to rely on GPS, whereas those with high anxiety during navigation are more likely to rely on GPS. In terms of gender differences, the results of perspective taking tests replicate the prior findings favoring males. In addition, females are more likely to report a poor sense of direction and high spatial anxiety, replicating previous research. Females are also less likely to explore new places or use new routes, and more likely to rely on GPS. In Study 2 (in progress) we are studying the relations between growth mindset, dependence on GPS, tendency to explore new places, and two measures of real-world navigation: ability to point to non-visible landmarks in a familiar environment and ability to take shortcuts in navigating this environment. After being led on a specific "learning" route, participants are asked to take shortcuts from place to place (5 places in total). Experimenters track their routes using a GPS tracker on a tablet. At each place, participants are also asked to point to 5 non-visible places on the previous learning route. Pointing directions and angular errors are recorded and computed. Then participants return to the lab complete a computer-based imaginary pointing task. The performances on the real-world navigation tasks, computer-based imaginary pointing task and perspective-taking tests will be combined to indicate participants' individual differences in navigation ability and these will be related to measures of mindset about navigation and navigation preferences. The results of this study will be reported at the conference. These studies inform questions of how navigation ability can be improved and suggest that changing people's mindset about navigation ability might be a preliminary step in a training program.

Keywords: Navigation Ability, Growth Mindset, Real-word Navigation.

Spatial Cognition, Germany 2018

Collaborative vs Individual Problem Solving

Adamantini Hatzipanayioti, Marcel Bechtold, Betty Mohler, Heinrich H. Buelthoff, Tobias Meilinger

In everyday life we come across numerous problem solving situations that we either resolve alone or in collaboration with another person. The aim of the present study was to examine the underlying cognitive mechanisms that are involved in collaborative problem solving using virtual reality technology. Participants worked either individually or in pairs (collaborative condition) to solve a virtual rubik's cube type puzzle task. The puzzle-task included 9 cubes with different colours on different sides and a solution space with 4 empty cube positions. Participants were instructed to choose the correct cubes among the distractor ones and arrange them within the solution space such that each side of the solution space displayed a single color. In the collaborative condition participants stood opposite to each other, allowing for communication, and each person was represented within the virtual world by a virtual head and a virtual controller. Results showed that participants were faster in solving the task when they were working in pairs compared to individually. Moreover, they employed a strategy of dividing the cube space according to their physical position in space. Our conjecture is that pairs, given their location in space, had access to all relevant information of the problem at a single point in time, compared to individuals. That is, together they could view all sides and all colors of the cube space, whereas individuals had to remember the color of cubes that were not visible from their perspective (i.e. the back side of the solution space).In this interpretation access from multiple perspectives at once, as in the collaborative condition allows for better problem solving. In a follow up experiment, we are currently testing whether collaborative problem solving from adjacent problem solvers is similar to individual performance.

On the relation between body and movement space representation: an experimental investigation on spinal cord injured people

Michele Scandola[1[0000-0003-0853-8975]] , Rossella Togni[2[0000-0002-5812-3762]], Massimo Brambilla[2], Renato Avesani[3], Valentina Moro[1[0000-0002-7119-7264]]

[1] NPSY-Lab.VR, Department of Human Sciences, University of Verona, Italy
[2]Neurorehabilitation Department - Spinal Cord Unit, A.S.S.T. Valtellina e Alto Lario, Hospital of Sondalo (Sondrio), Italy
[3]Neurorehabilitation Department - Spinal Cord Unit, "Sacro Cuore – Don Calabria" Hospital Negrar (Verona), Italy
michele.scandola@univr.it

Abstract. Body Representation (BR) and Movement Space Perception (MSP) are fundamental for human beings in order to move in space and interact with objects and other people. Both BR and space representation change after spinal cord injuries in complete paraplegic individuals (CPP), who suffer from lower limbs paralysis and anesthesia.
To date, the interaction between BR and MSP in paraplegic individuals remains unexplored.
In two consecutive experiments, we tested I) if the individual's wheelchair is embodied in BR; and ii) if the embodied wheelchair modifies the MSP.
For the first question a speeded detection task was used. Participants had to respond to visual stimuli flashing on their trunk, legs or wheelchair. In three counterbalanced conditions across participant, they took part to the experiment while: 1) sitting in their wheelchair, 2) in another wheelchair, or 3) with the LEDs on a wooden bar. To indicate the embodiment, there was no difference in the CPP's responses for LEDs on the body and personal wheelchair while these were slower in other conditions After this, while sitting in their or another wheelchair, CPPs were asked to judge the slope of a ramp rendered in immersive virtual reality and to estimate the distance of a flag positioned over the ramp. When on their own wheelchair, CPPs perceived the flag closer than in the other wheelchair.
These results indicate that the continuous use of a tool induces embodiment and that this impact on the perception of MSP.

Keywords: body representation; tool embodiment; movement space perception; extrapersonal space; wheelchair embodiment; spinal cord injury;

Illuminating disorientation in Alzheimer's disease through the use of functional, structural and metabolic neuroimaging

Gregory Peters-Founshtein [1][0000-0001-6874-1807], Tahel Naveh[1], Liran Domachevsky[2][0000-0001-8038-8161], Amos Korczyn[3][0000-0003-0125-2579], David Groshar[2][0000-0002-4675-0750], Shahar Arzy[1][0000-0001-6500-8095]

[1] Hadassah Hebrew University Medical Center, Jerusalem, Israel
[2] Department of Nuclear Medicine, Assuta Medical Center, Tel-Aviv, Israel
[3] Department of Neurology Tel Aviv University, Tel-Aviv, Israel

Abstract. As Alzheimer's disease (AD) is increasingly gaining recognition as a health-and social-care priority, lengthy non- and minimally symptomatic stages of AD are explored as opportunities for disease modifying interventions. These early stages are generally regarded through a dual perspective: 1) identification of markers predictive to AD-related neurodegeneration at early and minimally symptomatic stages; 2) investigation of the mechanisms allowing patients to maintain healthy-level performance during these minimally symptomatic stages.

In the current work we drew from both perspectives, as well as from our own previous findings (Peters-Founshtein et al, 2018, Peer et al, 2015), to establish a comprehensive experimental design incorporating multiple neuroimaging modalities as well as a previously validated orientation paradigm in the domains of space, time and person. Specifically, subjects across the AD spectrum performed the orientation task while undergoing functional magnetic resonance imaging (fMRI), followed by a set of extensive structural MRI, and metabolic positron emission tomography (PET) sequences.

Examination of a set of parietal and medial temporal regions, preferentially recruited by the orientation task, revealed that the accumulation of pathological neuroimaging markers (glucose hypometabolism, cortical atrophy) correlated to the clinical severity of AD, while the orientation-evoked fMRI signal exhibited an increase in a set of non-demented yet cognitively compromised patients with mild cognitive impairment (MCI), followed by a stark decline in activity in patients with fulminant AD. Interestingly, orientation performance, while highly disturbed in ADs, was only mildly compromised in MCIs, Leading us to consider the up-regulation in brain activity as a compensatory mechanism that allows patients to maintain orientation performance on a similar to control level.

In the context of recently published works, these results suggest that while up-regulation of activity allows patients at early stages of AD-related neurodegeneration to maintain control-level performance, it is potentially a part of the Alzheimer's pathological cascade rather than merely its result.

Keywords: Alzheimer's disease, Orientation, MCI, PET, MRI, fMRI

Is the structuring effect of environment elements on route learning absolute or relative? Comparative study of Alzheimer's and healthy elderly subjects

Christel Jacob[1,2][0000-0003-1273-6659], Constant Rainville[3], Alain Trognon[1], Reinhard Fescharek[4], Isabelle Clerc Urmes[5], Thérèse Rivasseau Jonveaux[1, 2, 6].

[1] Université de Lorraine, Laboratoire InterPsy, EA 4432, Groupe de Recherche sur les Communications, Nancy, France
[2] CHRU de Nancy, Centre Paul Spillmann, Nancy, France
[3] Centre de Recherche, Institut Universitaire de Gériatrie de Montréal, Montréal, Canada
[4] Fescharek Sculpture & Design, Pfingstweide 11, 35043 Marburg Lahn, Germany
[5] CHRU de Nancy, Plateforme d'Aide à la Recherche Clinique, Unité de Méthodologie, Datamanagement et Statistiques, Vandœuvre-lès-Nancy, France
[6] CHRU de Nancy, Centre Mémoire de Ressources et de Recherche, service de gériatrie, Vandœuvre-lès-Nancy, France
christel.jacob@univ-lorraine.fr

Keywords: Route Learning, Alzheimer's Disease, Landmarks.

1 Introduction

To memorize a path and then be able to retrace its steps in a new environment, one of the strategies consists in memorizing a succession of landmarks associated with a given direction. It has been shown that Alzheimer's disease (AD) leads to a deficit in route memory, from the early stage of the disease [1-2]. However, health care facilities in which the studies are generally conducted have been described as poor in terms of landmarks and may thus increase disorientation.

The purpose of this comparative study was to assess the structuring effect of the elements of a real environment, rich in landmarks, on route learning (forward and return trips), in a population of AD and healthy control (HC) subjects.

2 Methodology

Thirty subjects at mild to moderate stage of the disease and 30 matched HC underwent route learning: after 1 learning route (forward trip), they were asked to reproduce it in the same direction 2 times, then a third time in the opposite direction (return trip). The task was carried out in the healing garden "art, memory and life" of the CHRU of Nancy, designed to contribute among others, to mitigate spatial disorientation [3].

3 Results

As expected, subjects with AD committed significantly more errors than the HC, regardless of the trip. However, contrary to the literature data, the AD subjects did not make more mistakes in the return trip than in the forward trip, which is a more complex task [4-5].

In addition, the analysis of the location of the errors along the route showed that they were not located in the same areas of the route in forward and return trips. According to the qualitative analyzes, the salience of the elements of the environment but also their "perceived affordance" [6] (their possibilities of action) have influenced the directional choices and this in a different way according to the trip (forward-return) and the group (AD-HC).

4 Discussion

After several trials, the subjects with Alzheimer have thus acquired some knowledge of the "route" type. The nature of the environment, rich in landmarks, seemed to favor this acquisition.

To reproduce a route requires, at least, memorizing a direction associated with a given place / landmark. This association was favored by the "perceived affordance" of the elements which depended on: 1) the point of view of the subject and thus, varied according to the direction of the trip: backward/return; 2) cognitive control abilities, and so, varied by group: HC/AD.

This study shows that the elements of the environment have a structuring effect on learning performance that is not absolute but relative to these 2 factors: direction of the trip and the cognitive control abilities of the subjects.

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Semantics of Urban Space

Asya Natapov [1]

[1] Centre for Advanced Spatial Analysis, UCL
a.natapov@ucl.a.uk

Poster Abstract
Any city can be represented as a street network overlayed with various activities distributed within. Urban activities are origins and destinations of people's travel in the city; navigation between activity locations lies at the heart of our cities and social milieu.
Open space between buildings within the street network can be seen as a syntactic element of the city, while activities carry semantic and pragmatic information. (Semantic information refers to the meaning conveyed by an urban feature while pragmatic information refers to the action it incites). It is known that topological structure of the street network influences wayfinding (Javadi et al., 2017). However, it remains unclear how and when people process semantics of urban locations. In this poster we lay out our ongoing investigation into the effects of semantic and pragmatic information on urban navigation. We develop a cognitive-architectural description of urban space to assess potential relations between urban meanings and human spatial behaviour. First, we encode two main elements of urban environments - street network and activity locations - by a mathematical graph, using their mutual visibility (Natapov et al., 2013). Then, based on this mapping, we systematically modify these environments to create variant semantic readings by rendering semantic and pragmatic content variable in an identical street structure. A behavioural experiment in virtual reality takes place: individuals are exposed to visual stimuli that convey varying semantics and their route decisions are recorded. Results of this study will help to understand how people interpret urban semantic and pragmatic information. In a long term such understanding will assist to planners, architects, and stakeholders in the design for user friendly built environment.

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Keywords: Navigation and wayfinding; Spatial concepts and representation; Visibility graphs, Virtual reality, Urban activity location.

Placing Abstract Concepts in Space: Quantity, Time and Emotional Valence

Greg Woodin ✉ ORCID: 0000-0001-7992-4991
University of Birmingham, Birmingham, UK
gawoodin@gmail.com

Bodo Winter
University of Birmingham, Birmingham, UK

Research has discovered that quantity, time and valence are often conceptualised along horizontal and vertical axes [3, 5, 8, 11]. However, there are mixed results concerning which axis is preferred for which type of conceptual domain [1, 4, 10]. For instance, it has been suggested that the vertical axis is preferred for quantity in tasks using linguistic stimuli (e.g., 'more', 'less'), whereas numerals (e.g., '1', '2', '3') may be more prone to horizontal conceptualisation [2, 6-7, 11]. Moreover, evidence suggests that these axes are compatible with each other, and so may become co-activated [9]. In this study, we used a task with free response options based on the methodology employed by Tversky and colleagues [8] to see where participants would place quantity words ('most', 'more', 'less', 'least'), numerals ('2', '4', '7', '9'), time words ('past', 'future', 'earliest', 'earlier', 'later', 'latest') and valence words ('best', 'better', 'worse', 'worst') on a piece of paper. We found that for quantity words, the vertical axis was preferred; whereas for numerals, participants preferred the horizontal axis. For time, participants preferred the horizontal axis; whereas for valence, they preferred the vertical axis.

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Spatial semantics of 16 concrete and abstract categories

Alex A. Miklashevsky[1,2]

[1] National Research Tomsk State University, Tomsk, Russia
[2] University of Potsdam, Potsdam, Germany
armanster31@gmail.com

This work was supported by the Ministry of Education and Science of the Russian Federation (the RF Government Grant No. 14.Y26.31.0014).

Abstract. Some words refer to objects with typical localization in vertical space (e.g., sun or bird are up-words; grass or shoe are down-words). A number of experimental studies revealed an automatic and unconscious activation of this spatial semantics during language processing (Dudschig et al., 2012, 2013; Estes et al., 2008; Tsaregorodtseva & Miklashevsky, 2015), suggesting spatial localization to be an important semantic feature. However, there are no studies systematically describing this feature for a reasonable sample of linguistic units.

In the present study, vertical spatial semantics was collected for 506 Russian nouns by using 7-point Likert scale (1 – the lowest position, 7 – the highest; with the order counterbalanced for the half of the participants). Importantly, data for both concrete (e.g., eatable plants, animals, tools, transport, sounds) and abstract (e.g., actions and processes, emotions, mental states) 16 sematic categories were collected.

The analysis revealed that concrete concepts in average are localized lower in space than abstract ones ($p < .001$). In line with abstract concepts, names of sounds also are "located" significantly higher than names of tools, food or names of landscape elements and surfaces. Differences also were found within the group of abstract concepts: mental states ale "located" higher than actions and processes. Within the group of emotions, a positive correlation was found between the level of positivity of the emotion and the "height" of its location, thus supporting previous findings from conceptual metaphor theory ("good is up, bad is down") and experimental studies (Taylor et al., 2015).

These results are discussed in context of embodied cognition theories, including conceptual metaphor theory, mental simulation theory, Words As social Tools (WAT, Borghi & Binkofski, 2014) and cultural representation of a body scheme.

Keywords: Spatial Semantics, Embodied Cognition, Rating Study, Abstract Words, Concrete Words.

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Preferences and Space in Everyday Activities*

Holger Schultheis[1][0000−0001−6892−1656] and Jasper van de Ven[1][0000−0001−9790−4708]

Bremen Spatial Cognition Center, University of Bremen, Bremen, Germany
schulth@uni-bremen.de

Humans perform a wide range of everyday activities (e.g., preparing a meal, setting the table) frequently, with ease, and often without thinking, although everyday activities require a complex set of abilities and mechanisms to be completed successfully. One major aspect of successful performance of everyday activities is the order in which actions are performed. To be successful the action order has to satisfy a number of constraints that may arise, for example, from the current task's goals. While much previous research on everyday activities has focused on how sequences of actions are controlled to satisfy such sequencing constraints, research has so far devoted little attention to (parts of) action sequences that are not subject to sequencing constraints essential for task success.

For many everyday activities, performing certain actions is crucial, but the order in which actions are performed is not. When setting the table, for example, any order of putting the required items on the table will be fine as long as all necessary items are on the table eventually. Despite the commonality of weakly constrained sequence in everyday activities, little is known about how humans deal with such sequences: Do humans treat these sequence as completely arbitrary in the sense that each possible sequence is acted upon with equal probability? Do humans consider all possible sequences and then decide for one of these? If yes, what factors are considered during decision making. If not, what determines the sequence that humans eventually employ?

In this contribution, we argue that humans do not order weakly constrained actions arbitrarily, but exhibit systematic patterns of orderings, which we term ordering *preferences*. Specifically, we argue that the task environments spatial layout and its mental representation are key factors in determining such preferences.

We introduce the concept of preferences and review existing evidence that supports the assumption that human behavior and cognition is governed by preferences both generally and, in particular, with respect to everyday activities. In addition, we highlight three lines of research, which suggest that the spatial state of affairs and its mental representation give rise to action order preferences in weakly constrained sequences: (i) Intelligent use of space; (ii) Representation and reasoning preferences; and (iii) Regionalized representations of space.

* The reported research has been (partially) supported by the German Research Foundation (DFG), as part of project P3 (Spatial Reasoning in Everyday Activity) of the CRC EASE, University of Bremen (http://www.ease-crc.org/). We thank Alexander Wich for his help in data acquisition.

As an initial empirical assessment of this idea, we collected data from a single participant, who was naive with respect to the purpose of the experiment, repeatedly performing the everyday task of setting the table for breakfast. In a kitchen VR environment, the participant set the table for a breakfast of cereals and a glass of juice 39 times. Analyses of the observed action sequences revealed that their ordering was highly systematic showing clear spatial preferences. Specifically, the observed preferences seem to be based on a regionalization of space and the distances between the regions.

Spatial preferences appear to play an important role in structuring human everyday activity. The preferences we observed give rise to an efficient ordering of actions, when actions could be ordered arbitrarily with respect to task success.

An auditory display for representing two-dimensional space

Holger Schultheis[1 [0000−0001−6892−1656]] and Tim Ziemer[1 [0000−0001−6821−7327]]

Bremen Spatial Cognition Center, University of Bremen, Bremen, Germany
schulth@informatik.uni-bremen.de,ziemer@uni-bremen.de

Most research investigating spatial cognition has focused on spatial information conveyed through vision. Accordingly, little is known about (a) how to precisely present spatial information auditorily and (b) how auditorily presented spatial information is represented and processed in the human mind. Addressing these issues not only helps shedding further light on human spatial cognition, but also has the potential to complement or replace visuo-spatial information in domains where this may be desirable (e.g., in minimally-invasive surgery or in piloting).

Against this background, the aim of our work was to develop an auditory display that allows presenting arbitrary locations in two-dimensional space. A major difficulty in devising such a display is to identify physical sound characteristics that allow mapping the two orthogonal dimensions of space onto perceptually orthogonal sound features. Finding such characteristics is difficult, because physically independent aspects of sound may interact perceptually. For example, the perception of the loudness of a pure tone does not only depend on the volume level at which it is presented, but also on its frequency (e.g., a tone around 4 kHz sounds much louder than a tone around 16 kHz when presented at the same volume level of 60 $\mathrm{dB_{SPL}}$). When representing the two orthogonal spatial dimensions auditorily such perceptual interactions have to be taken into account to achieve an accurate and precise mapping of space.

Based on an in-depth psychoacoustics review, we implemented an auditory display that allows presenting locations in 2D space. This display presents space as organized by a horizontal and a perpendicular vertical axis. The horizontal axis is mapped onto a Shepard tone cycle (i.e., a tone that gives the perceptual impression of ever rising/falling pitch). If the displayed location is to the left/right of the users current position, the tone is falling/rising. The speed with which the tone's pitch changes indicates distance from the target. The vertical axis is mapped onto beating (loudness fluctuation) and roughness. If the user is below the target, the tone has a beating such that the beating gets quicker the farther the user is from the target. If the user is above the target, the tone becomes rougher and rougher with increasing distance.

We evaluated the auditory display in an experiment (N=18) comparing the performance in moving a mouse cursor to 20 invisible target locations employing the auditory display to moving the cursor to the same 20 targets presented visually on a rotated screen. Despite the short familiarization with our display (30 Min.), participants found the targets based on auditory information more

slowly, but as accurately and as directly (length of trajectories) as in the visual condition.

Consequently, our display allows accurately conveying spatial information by sound. As such it constitutes an innovative way to (a) further investigate the nature of human spatial cognition and (b) support spatial cognition by complementing or replacing visual spatial information.

Spatial Cognition in Time Expressions: Speech and Gesture from Large-scale Multimodal Data

Cristóbal Pagán Cánovas,[1] Javier Valenzuela[1] and Daniel Alcaraz Carrión[2]

[1] University of Murcia, Plaza de la Universidad s/n, 30071, Murcia, Spain
[2] Lancaster University, FASS Building, Lancaster University, LA1 4YD, Lancaster, United Kingdom
cpcanovas@um.es

Keywords: Spatial Construals of Time, Co-speech Gesture, Multimodal Corpora.

The co-occurrence of linguistic expressions with patterns from other modalities, especially gesture, is producing very important insights into the interplay between spatial cognition and language production (McNeill, 2000). However, quantitative studies of gesture co-occurring with specific linguistic expressions are practically non-existent, since it is hard to obtain a large sample of authentic utterances of the same linguistic expression.

To bridge this gap, we extracted our data from NewsScape, a dataset of television broadcasts from over 50 networks, with around 400,000 hours of video and totaling 2.5 billion words of aligned closed-captioning in 17 languages. NewsScape is developed by the Red Hen Lab, an international research consortium (Steen et al., 2018). The search tools for NewsScape's vast repository of subtitles (Uhrig, 2018) render hits in the shape of video clips where a speaker is uttering the linguistic structures searched, thus allowing for the examination of the multimodal information accompanying the production of specific utterances.

To study how time phrases are associated to gestural patterns (Casasanto & Jasmin, 2012; Núñez et al., 2012; Núñez & Sweetser, 2006; Walker & Cooperrider, 2015), we examined over 8000 video clips with four types of time expressions in English (as classified by Núñez & Cooperrider, 2013): sequential (e.g., earlier/later than), deictic (back in those days, in the distant future), and demarcative (from beginning to end). Most cases included gesture directly linked to the semantics of the time expression. We also examined the correlation between sagittal, lateral, or vertical gesture and the types of time expressions, as well as the congruity between the spatial information provided by language and gesture.

The high frequency of co-occurrence between verbal and gestural patterns and the nuanced semantic connections found suggest: a) that some kind of spatial simulation or mental imagery, which might be acquired alongside a particular linguistic structure, plays an essential role in the construction of the temporal meaning, b) that time meanings are adjusted according to context and goals, with spatial knowledge not directly projected on a target time concept but rather selected and adapted to fit the specific purposes of the situation at hand, and c) that a transfer or grounding model positing

fixed, unidirectional projections from spatial to non-spatial concepts cannot account for the complexity of the data: a hybrid, non-unidirectional model is required, which should include integration, a network of input concepts, including spatial and non-spatial knowledge, and emergence of ad-hoc meanings (Fauconnier and Turner, 2008).

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Poster Session II, September 7th, Friday 2:15-4:15pm

1. Mental rotation below age 4: Evidence from a new mirror-image discrimination task
   Salome Pedrett, Rahel Tschachtli-Heiniger and Andrea Frick

2. Spatial Training, Computational Thinking, and Math Performance in Elementary School Children
   Steven Moore, Gary Scott, May Ling Halim, Adeline Wolfe and Mary Moore

3. Movement and art experience, spatial abilities, and familiar environment representations in 9-10 year olds
   Erica Barhorst-Cates, Cheryl Wright, Sarah Creem-Regehr, Jeanine Stefanucci and Elizabeth Cashdan

4. Learning space through cooperation: a study of spatial expressions by sighted and visually impaired children
   Agnieszka Kolodziej, Christophe Jouffrais and Valérie Tartas

5. Does a free range childhood improve spatial cognitive abilities? A look at children among the Tsimane of central Bolivia
   Helen Davis and Elizabeth Cashdan

6. Cognitive and Motivational Changes in Adolescents' Spatial Thinking: Effects of the Geospatial Semester
   Bob Kolvoord, Emily Grossnickle Peterson, David Uttal and Adam Green

7. Age-related preference for geometric cues during real-world navigation: behavioral and neuroimaging correlates
   Marcia Bécu, Guillaume Tatur, Denis Sheynikhovich, Stephen Ramanoel, Catherine Agathos and Angelo Arleo

8. Aging and spatial performance: Searching for Culture-free Diagnostic Markers of Mild Cognitive Impairment in the Tactile Domain
   Leandra Bucher, Kateryna Nural, Henrike Nagel, Roja Palma de Figuireido, Frank Zobel and Markus J. Hofmann

9. Do age differences affect performance in 2D sketching based on a first-person perspective (3D) route learning task in differently-designed virtual environments?
   Ismini Eleni Lokka and Arzu Çöltekin

10. Mechanisms of Visuospatial Thinking in STEM
    Mike Stieff, Mary Hegarty, Steve Franconeri, Stephanie Werner, Dane Desutter, Peri Gunlap, Zoe Rathbun, Nicole Jardine and Hauke Meyerhoff

11. Practising Spatial Reasoning using a Qualitative Descriptors and Computer Games
    Zoe Falomir

12. Navigation in a 360-degree Virtual Environment: Recall of Spatial Relations
    Priyanka Srivastava, Anurag Rimzhim and Sushil Chandra

13. The Induced Roelofs Effect Presented in a Virtual Environment
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14. Where Am I, in Terms of My Physical and of My Perceived Body, When Using Different Virtual Reality Setups
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Mental rotation below age 4: Evidence from a new mirror-image discrimination task

Salome Pedrett[1], Rahel Tschachtli-Heiniger[1] and Andrea Frick[1]

[1] University of Fribourg, 1700 Fribourg, Switzerland
salome.pedrett@unifr.ch

Abstract. Recent evidence has suggested that infants are able to differentiate objects from their mirror images in different orientations, suggesting an early onset of mental rotation abilities. On the other hand, many children at the age of about 4 to 5 years seem to have major difficulties with mental rotation tasks that require mirror-image discrimination. To narrow the gap, we tested 70 preschoolers between 3½ and 5½ years of age using a simplified mental rotation task. Children were presented with two boards, each of which supported a stimulus in the shape of a flag as well as a counterpart. The counterparts on the two boards were identical, but the flags were mirror images of each other. Thus, only one of the flags would fit the counterpart when rotated around a pivot point in the center of each board. Across 16 trials, four different flag shapes were presented at 90°, 120°, 150°, and 180° angular difference from the counterparts. The children were asked to choose and rotate the flag that would fit the counterpart. We expected this task to be less demanding than mental rotation tasks used in previous studies, because the rotation axis was clearly defined, and no additional horizontal or vertical motion was necessary. By using a mirror image task, the likelihood that children used strategies other than mental rotation was minimized. Results showed that children under four years of age clearly performed above chance level, choosing the correct flag in 81% of the trials if the flags were presented at 90° angular difference from the counterparts, and in 75% of the trials even with a disparity of 150° ($p < .001$). Yet, success rates still improved significantly between 3½ and 5½ years of age ($p < .001$). Consistent with mental rotation studies in adults, response times increased with increasing disparity ($p < .001$). These findings indicate that mental rotation is possible below the age of 4, but still improves markedly until 5½ years of age. This novel task opens up new possibilities for research on mental rotation abilities in young children.

Keywords: mental rotation, cognitive development, preschoolers, visual imagery.

Spatial Training, Computational Thinking, and Math Performance in Elementary School Children

Steven Moore[1][0000-0003-1563-3217], Gary Scott[10000-0003-2987-3764], May Ling D. Halim[2][0000-0002-8944-1472], Adeline Wolfe[2][0000-0002-7297-5443], and Mary Moore[1][0000-0003-3850-6042]

[1] University of Redlands, Redlands, CA 92374, USA
[2] California State University, Long Beach, CA 90840, USA
steven_moore@redlands.edu

Abstract. During 2016-2017, the Spatial STEM+C project conducted research to see how spatial thinking training in grade K-5 classrooms would impact students' spatial thinking skills, computational thinking abilities, and math performance. Two treatment classrooms in each K-5 grade at Inland Leaders Charter School in Yucaipa, California, implemented spatial thinking activities for approximately 30 minutes each day during a school year; two control classrooms in each grade did not do the designated activities. The spatial activities included creating designs with manipulatives, mapping classrooms and schoolyards, using a map to find treasures, and providing directions with coordinate systems. At the beginning and end of the school year, all students completed spatial and mathematics assessments. A computational thinking assessment was also piloted with K-2 students. Qualitative feedback from teachers indicated that the spatial activities increased students' interest and engagement with spatial thinking, as well as the children's confidence and persistence in solving problems. Quantitative analysis revealed that, on five of ten measures of spatial thinking, the treatment classrooms showed significantly better spatial skills than control classrooms across time. However, both treatment and control classrooms improved significantly during the study period. Significant improvement in computational thinking skills was noted in both treatment and control classrooms. Path analysis models revealed correlations among various dimensions of spatial thinking ability and math performance. A bidirectional relationship between computational thinking and math performance was noted. The results indicate a need for spatial and computational assessments that better measure near transfer of skills acquired in the classroom.

Keywords: Spatial Thinking, Computational Thinking, Math Education.

Movement and art experience, spatial abilities, and familiar environment representations in 9-10 year olds

Erica M. Barhorst-Cates[1], Cheryl Wright[2], Sarah H. Creem-Regehr[1], Jeanine K. Stefanucci[1], and Elizabeth A. Cashdan[3]

[1] University of Utah Department of Psychology, Salt Lake City, UT 84112, USA
[2] University of Utah Department of Family and Consumer Science, Salt Lake City, UT 84112, USA
[3] University of Utah Department of Anthropology, Salt Lake City, UT 84112, USA
lncs@springer.com

Abstract. Spatial abilities are malleable and can be improved via experience and training of different types. This finding is important because spatial abilities underlie many important skills such as navigation and success in Science, Technology, Engineering, and Mathematics (STEM) fields. The current study has several aims to examine effects of experiential factors on spatial abilities in middle childhood. First, we aimed to measure the effects of dance and other extensive arts training as a means of improving spatial thinking skills in 9-10-year-old children from two elementary schools, with and without required additional arts and dance classes. Second, we aimed to document sex difference in spatial abilities in this age group, to address the question of when in the developmental cycle sex differences may emerge. Third, in an exploratory manner, we aimed to measure the relationship between standard tests of spatial ability and mental representations of familiar environments through a map drawing task. 121 participants completed a selection (that testing time allowed) of the following battery of spatial tasks in a classroom setting: two tests of mental rotation (standard paper and pencil task and computerized bodies mental rotation task), water level, real-world triangle completion, two versions of Corsi block-tapping, and filled out a spatial activities questionnaire. Thirty-six participants also completed a map drawing task in which they drew their neighborhood.

For Aim 1, we did not find strong differences between children's performance in the schools with and without additional arts and dance training. This will be further addressed in analysis of individual differences in spatial activities measured via the spatial activities questionnaire. For Aim 2, we observed a male advantage on water level and bodies mental rotation accuracy, but on no other task. It is interesting that the well-documented male advantage on standard mental rotation tasks was not observed in this age group, suggesting that males gain additional advantage (e.g., possibly through exposure, experience, or hormonal factors) after middle childhood that allows them to excel at this type of mental rotation. The male advantage on the bodies mental rotation task was surprising but could be explained by greater involvement in sports and movement-related play. For Aim 3, we coded children's drawn neighborhood maps in terms of frame of reference of the neighborhood: (a) containing allocentric, or top-down components only, (b) egocentric components only, or (c) a mix. We explored the hypothesis that participants who incorporated survey components may possess en-

hanced spatial-cognitive abilities compared to participants who incorporated egocentric components only. We expected this because prior research has suggested that participants who use allocentric, survey-based perspectives for navigation also perform better on small-scale spatial-cognitive tasks. We found support for our hypothesis on the water level task, such that those who used allocentric-only components performed significantly better than those who used egocentric-only components. Taken together, this ongoing study highlights an important intersection of spatial activity experience, spatial-cognitive abilities, and mental representation of environments in middle childhood.

Keywords: Middle childhood, arts training, spatial abilities.

Learning space through cooperation: a study of spatial expressions by sighted and visually impaired children.

Agnieszka Kolodziej[1 2], Christophe Jouffrais[1 3], Valérie Tartas[2]

[1] CNRS et Université de Toulouse, IRIT, Toulouse, France
[2] Université de Toulouse et CNRS, CLLE-LTC, Toulouse, France
[3] CNRS, IPAL, Singapour
agnieszka.kolodziej@univ-tlse2.fr

Abstract. The developmental studies of sighted children are numerous and they differ on the hierarchical steps (changes from the egocentric to the allocentric perspective) and timing of acquisition of spatial skills (Nys et al., 2015). The recent studies show that there is rather a parallel development of these ability (Boccia et al., 2017). Results of studies about the effects of visual impairment on developing spatial cognition have been conducted largely on blind adult's person (Millar 1994; Thinus-Blanc & Gaunet, 1997) and there is a lack of developmental data in blind children (Ochoita et al., 1991, Edwards et al., 1997). Moreover, many studies deal with spatial abilities measured through an individual spatial task but not a collaborative task (Catteano et al, 2008; Pasqualotto & Proulx, 2012) whereas it has been shown that sighted children who cooperate to solve spatial tasks are better than when they solve it independently (Viana et al., 2016). There is no work that has addressed the effects of cooperation on spatial performances of VI children. In this study, we aimed to address different skills of spatial cognition (navigation, path and space description) in spaces of different scale (Montello, 1993) with blind children and blindfolded-sighted. Two complementary spatial tasks (route walking task, instructions task) are proposed to examine how visually impaired (VI) children achieve and collaborate with adult or peer. We examine how children use the spatial expression to describe a space and a path familiar alone and in dyad. Also, we study a hypothesis about the relevance of cooperative situations for efficient construction of spatial representation of space. Children from 6 to 11 years old participated to this study. Children with VI (congenitally blind) attend a school for the visually impaired and the children with sight attend mainstream state schools. They are match by age and sex and they are divided into three age groups: 6-7, 8-9 and 10-11 y. o. Each child is tested in two sessions, second is one week later. The first task is a route walking task in a real space where a child is guided by an experimenter and then his become a guide in turn. It is expected that analysis of verbalizations would allow to identify how the spatial expressions of child are used according to the difficulties encountered during the two types of guiding. In the second task, the subject is asked to describe a familiar place (classroom) or a route within their school (route from entrance to classroom), first individually and one week later in dyad. We expect that the situations of cooperation with adult or peer will promote children's use of spatial terms and clarify spatial representation for all children no matter their ages. The practical and theoretical

implications for acquiring and construction of spatial cognition by sighted and visually impairments children will be discussed.

Keywords: spatial language, spatial cognition, visual impairment.

Does a free range childhood improve spatial cognitive abilities? A look at children among the Tsimane of central Bolivia

Helen Davis[1] and Elizabeth Cashdan[2]

Harvard University, Cambridge, MA 02138, USA
University of Utah, Salt Lake City UT. 84112, USA
helenelizabethdavis@gmail.com

Abstract. Gender differences in range size and spatial ability are widely reported, but there is disagreement about the age at which these differences emerge, and little is known about the emergence of spatial ability and mobility in traditional and transitioning societies. Variation in ecology, patterns of mobility, freedom to explore, and modes of learning may be critical to spatial cognitive outcomes. This project seeks to determine the developmental processes that underlie spatial learning in a non-Western society, the Tsimane of Bolivia. We focus on two main questions: 1) What is the age and gender patterning of spatial abilities among children and adolescents in a non-Western population? 2) How do novel socioeconomic changes in subsistence, modes of mobility, and education shape these differences? We collected data on daily mobility (GPS), navigational ability (dead reckoning and perspective taking tasks), computerized mental rotation, and interviews to measure variation in reported harm avoidance, spatial anxiety, and lifetime mobility. Prior work among Tsimane and Twe adults found women to be more spatially anxious than men (t88=-3.32, p=.03) in both populations. However, there was no observed sex difference in wayfinding and perspective taking between Tsimane men and women (t88=2.00, p=.22), but one existed among the Twe (t94=-2.31, p=.01). Preliminary analysis of Tsimane child data suggests that gender differences in range size and spatial ability are small to nonexistent. Our initial findings suggest that environmental and social variation play a significant role in the degree of difference found between sexes within both populations, and that generalizations based on Western populations should be made with caution.

Keywords: spatial ability · gender differences · GPS · development · education

Cognitive and Motivational Changes in Adolescents' Spatial Thinking: Effects of the Geospatial Semester

Bob Kolvoord[1], Emily Grossnickle Peterson[2], David H. Uttal[3], and Adam Green[4]

[1] James Madison University, Harrisonburg, VA, USA
[2] American University, Washington, DC USA
[3] Northwestern University, Washington, DC USA
[4] Georgetown University, Washington, DC USA
kolvoora@jmu.edu

Abstract. Spatial thinking is important for a wide range of outcomes in science, technology, engineering, and mathematics (STEM) fields. Despite calls to spatialize K-12 curricula (NRC, 2006), spatial thinking has not been systematically taught in schools. As a result, researchers and practitioners have had limited opportunities to study the effects of spatial education at the K-12 level. The present study investigates the outcomes of a year-long course (i.e., the Geospatial Semester) that teaches high school students Geographic Information Systems (GIS) technology and project management skills to solve real-world spatial problems. Students were tested before and after the course on measures of core spatial skills (e.g., mental rotation, embedded figures), STEM-specific spatial reasoning, beliefs about spatial ability, spatial anxiety, and spatial habits of mind. Compared to students taking other elective classes (n=125), students enrolled in the Geospatial Semester (n=84) demonstrated an increase in some core spatial skills, but not others, and showed benefits in STEM-specific spatial reasoning. Students enrolled in the Geospatial Semester had some positive motivational changes, and for some measures, females benefitted more than males. Together, these findings suggest that using real-world problem solving with GIS in the high school classroom promotes cognitive and motivational aspects of spatial thinking. Additional research is necessary to examine the specific aspects of the course that provide the greatest advantage, and to understand the effects of spatializing courses throughout the K-12 curricula.

Keywords: Geographic Information Systems, School-Based Learning, Spatial Ability, Spatial Habits of Mind, Motivation.

Age-related preference for geometric cues during real-world navigation: behavioral and neuroimaging correlates*

Marcia Bécu, Guillaume Tatur, Denis Sheynikhovich, Stephen Ramanoel, Catherine Agathos, and Angelo Arleo

Sorbonne Université, INSERM, CNRS, Institut de la Vision, 17 rue Moreau, F-75012 Paris, France

Abstract. Healthy aging is associated with changes in the way people navigate in space. These changes have been previously characterized in terms of age-related deficits in the use of allocentric strategies. However, given that navigation strategies are conditioned by the sensory cues present in the environment, an alternative hypothesis is that navigation difficulties in aged people are associated with spatial cue processing rather than with strategic choices. By having young and old participants navigate in a real, ecological environment, we show that old adults reorient preferentially according to geometric cues, thus neglecting landmark information, whereas young adults preferentially use landmarks. Recording of both body and gaze dynamics as subjects reoriented and navigated in space allowed us to identify specific behavioral patterns associated with either landmark or geometric preference. In particular, eye movement analysis revealed that the geometry-based coding adopted by older adults manifested itself in the spatiotemporal signatures of oculomotor fixations, but not in other navigational variables, and, moreover, gaze dynamics were predictive of spatial cue preference. Also, the longer reorientation time observed in old subjects was due to the need for a repetitive sampling of visual information. In addition, preliminary data from offline anatomical MRI scans show a negative correlation between navigation performance and gray matter integrity of scene-selective structures involved in landmark processing (parahippocampal place area and retrosplenial cortex), whereas no correlation was found with hippocampal regions. These results extend previous findings on geometric cue preference in children and therefore suggest an inverted U-profile of landmark processing across lifespan. Given the extensive use of landmarks during spatial navigation paradigms, these results challenge the traditional view of a specific deficit for allocentric strategies in aging.

Keywords: real-world navigation · aging · eye movements · landmarks · geometry.

* This research is supported by ANR-Essilor SilverSight Chair ANR-14-CHIN-0001.

Aging and spatial performance: Searching for Culture-free Diagnostic Markers of Mild Cognitive Impairment in the Tactile Domain

Leandra Bucher[1], Kateryna Nural[1], Henrike Nagel[1], Roja Palma de Figuireido[1], Frank Zobel[2], and Markus J. Hofmann[1]

[1] University of Wuppertal, Max-Horckheimer-Strasse 20, 42119 Wuppertal, Germany
bucher@uni-wuppertal.de
katerynawuppertal@gmx.de
henrike.nagel@web.de
roja92@hotmail.de
mhofmann@uni-wuppertal.de

[2] Forschungsgemeinschaft Werkzeuge und Werkstoffe e.V, Remscheid, Papenberger Str. 49, 42859 Remscheid, Germany
zobel@fgw.de

Mild Cognitive Impairment (MCI) describes a subtle decline in cognitive abilities that goes beyond the decline in cognitive abilities in normal aging. MCI is considered to be a predictor of Alzheimer's disease, rendering the detection of MCI, among those affected, an important factor in early dementia treatment. The present research is devoted to the search for diagnostic markers of MCI in the tactile domain. Tactile tasks have been recently shown to be sensitive to early perceptual and functional deficits in MCI patients. With the current study, we address the question whether MCI (as a frequent precursor of AD) is associated with lateralized tactile deficits similar to the well-documented lateralized deficits of extinction and hemi-spatial neglect associated with AD. To that end, we collected a set of parameters of tactile signal detection, separately for the left and right hand, and under various cueing conditions. The detection performance for tactile stimuli (at the left and right hand) was specified using detection times, false responses, hits, misses, false alarms, and correct rejections. Currently, we are comparing tactile performance (according to the assessed parameters) of a sample of MCI patients (N = 7) with the performance of healthy age-matched controls (N = 20) and a sample of young participants (N = 16). Preliminary results show a general age-related increase in detection times and error rates. In addition, specific error measures such as false alarms under specific cueing conditions were found to discriminate between healthy elderly subjects and MCI patients. In a next step, we will compare sensitivity and specificity indices of left and right hand signal detection. The goal is to determine whether there are tactile parameters that are sensitive to MCI deficits and could serve in diagnosing MCI. Tactile measures in diagnostics have the enormous advantage of being culture-free. A current problem with the examination of potential MCI patients is the language-based nature of the common tests. Many patients with a migrant background therefore remain without diagnosis and thus without treatment of their deficits. Assessments based on tactile perception, could solve this problem.

Word Count: 345

Keywords: Mild Cognitive Impairment, Signal Detection, Tactile Perception.

Do age differences affect performance in 2D sketching based on a first-person perspective (3D) route learning task in *differently-designed* virtual environments?

Ismini E. Lokka[1], Arzu Çöltekin[1]

[1] University of Zurich, Zurich 8057, Switzerland
{ismini-eleni.lokka, arzu.coltekin}@geo.uzh.ch

Virtual environments (VEs) are widely used in navigational behavior studies. We examine VEs as assistive technologies that help people learn a route. We take a visualization perspective, as we believe the 'visualization design' of a VE affects how well people learn with them, and VEs can be optimized to specific tasks and audience. In this study, we primarily take a *visual realism* perspective, given that the mainstream VEs aspire to create realistic experiences [1]. Therefore, we examine the impact of three differently designed VEs on route learning, as expressed by the ability to produce correct sketches of the route from the memory. Specifically, we compare a RealisticVE (photorealistic) and an AbstractVE (non-photorealistic) to a "MixedVE", which we optimize for route learning. MixedVE is a result of 'mixing' the other two in terms of realism: We leave the photo-textures only on scene elements that are *relevant* for navigation (thus, highlight them), while we remove the photo-textures elsewhere in the scene [2]. Thus, the design of the MixedVE is optimized both regarding levels of realism, and regarding navigational memory (i.e., placement of the highlighted elements are informed by the knowledge on navigational attention/memory). Importantly, because there are individual differences in navigational performance [3] and memory abilities based on age [4]; we examine how age differences affect route learning performance. Specifically, 42 younger (25-35yo) and 39 older (65-75yo) participants learned a route in a fictional city in the three different VEs, and produced sketches of the route immediately after the experiment ("immediate"), and one week later ("delayed").

Here we report on participants' accuracy in sketching the route on 2D screenshots based on each VE. A 2 (age) x 2 (recall) x 3 (visualization) mixed-design ANOVA revealed statistically significant differences as follows: a) *age* $F(1, 79)= 17.04$, $p<.001$, $\eta_p^2=.15$ (young: 66.3%±31.7%, older: 40.5%±30.0%), b) *visualization* $F(2, 158)=11.69$, $p<.001$, $\eta_p^2=.01$ (Abstract: 53.6%±32.9%, Mixed: 57.6%±33.9%, Realistic: 50.5%±33.4%) and c) *age x visualization* $F(2, 158)=3.80$, $p<.05$, $\eta_p^2=.01$ (Fig. 1). The *age x visualization* interaction is explained by the significantly large difference in the sketching performance using the MixedVE and the RealisticVE for the younger and older participants (young: 11.0%±21.3%, older: 3.0%15.0%, $t(149.35)=2.77$, $p<.01$, $r=.22$; Fig 1d). Interestingly, the recall stage did not reveal statistically significant differences (immediate: 55.4%± 32.1%, delayed: 52.4%± 34.7%), neither did any other of the interactions.

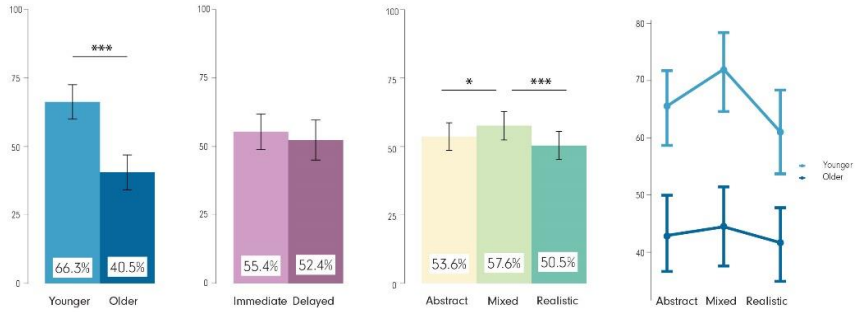

Fig. 1. Main effects of a) *age*, b) *recall stage*, c) *visualization type* on sketch task, and d) interactions between *age x visualization type* (irrespective of recall stage). *** p<.001, * p<.05. Error bars: SEM.

Besides the overall findings described above, we investigate the impact of different VEs on sketching performance with varying spatial and memory abilities (as measured by standardized tests). Overall, our results demonstrate that irrespective of age, participants learn routes better with the MixedVE.

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Mechanisms of Visuospatial Thinking in STEM

Mike Stieff[0000-0002-1639-891X], [1], Mary Hegarty[0000-0002-7777-8844], [2], Steven Franconeri[0000-0001-5244-97644], [3], Stephanie Werner[0000-0001-6442-0037], [1], Dane DeSutter[0000-0002-4340-9514], [1], Peri Gunlap[2], Zoe Rathbun[2], Nicole Jardine[3], Hauke Meyerhoff[0000-0003-1836-4737], [4]

[1] University of Illinois Chicago, Chicago IL 60607, USA
[2] University of California-Santa Barbara, Santa Barbara, CA 93106 USA
[3] Northwestern University, Evanston IL 60208, USA
[4] Leibniz-Institut für Wissensmedien, 72076 Tübingen, Germany
mstieff@uic.edu

Abstract. Visuospatial thinking in STEM requires students to encode and transform complex spatial information depicted in disciplinary representations that seemingly exceed known capacity limits of visuospatial working memory. Understanding these limits and how visuospatial information is encoded and transformed differently by STEM novices and experts presents new avenues to addressing the challenges students face navigating STEM classrooms and degree programs. Here, we describe our ongoing work to characterize the differences in visuospatial thinking processes between individuals with more and less expertise in a STEM discipline. We examine three competing hypotheses: (1) experience in STEM disciplines increases one's raw visuospatial capacity for storing and processing spatial representations in a general way (or that only people with large capacity can excel in STEM); (2) expertise in a STEM discipline restricts improvement in spatial ability to represent and transform domain-specific representations via domain-specific chunking strategies; (3) expertise in STEM is supported by domain-general compression strategies that allow experts to compress repeating patterns of spatial information, allowing them to exceed their otherwise limited visual memory capacity, by reducing the amount of information encoded. In this poster we present the results of our recent studies comparing these competing hypotheses, by analyzing the performance of high and low spatial STEM students in a series of experiments where students were asked to detect color changes across abstract shapes and chemistry stimuli.

Among naïve and novice chemistry students, change detection performance decreased as stimulus complexity (number of unique colors) increased, but raw visual capacity was similar across abstract shapes and chemistry stimuli. For both abstract shapes and chemistry stimuli, students were better able to detect color changes within "representational chunks" (e.g., groups of colors that co-occur) than changes that occur outside of these chunks for stimuli. Interestingly, the dimensionality of the representation (1d v 2d v 3d) had no effect on performance. For both types of stimuli, we observed no relationship between performance on the task and measures of spatial ability (e.g., Cube Comparison, Paper Folding). These initial studies yield support for the hypothesis that visuospatial thinking in STEM is characterized by the refinement of domain-specific compression strategies applicable to abstract shapes and that raw visuospatial ability does not

Practising Spatial Reasoning using Qualitative Descriptors and Computer Games*

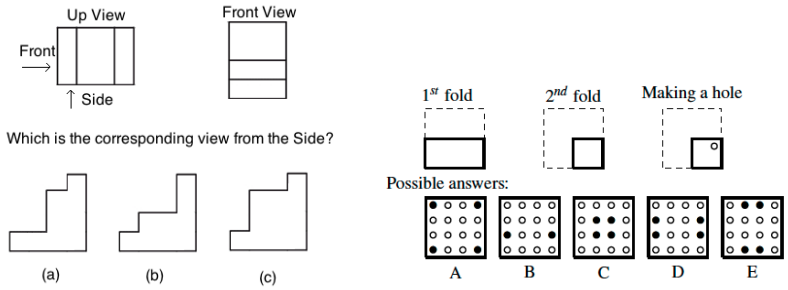
Zoe Falomir

Bremen Spatial Cognition Centre, Universität Bremen, Germany
zfalomir@uni-bremen.de

1 Extended Abstract

Spatial cognition studies showed that there is a strong link between success in Science, Technology, Engineering and Math (STEM) disciplines and spatial abilities [5]. These abilities are basic for job skills like visualizing the result of a surgery, designing bridges, aircrafts; interpreting charts, maps, engineering drawings, etc. Moreover, it appears that 3D spatial skills can be developed through practice since research showed [6] that students who attended a course at university to improve their ability to visualize in 3D, improved their success and retention significantly, particularly female students.

Spatial reasoning skills are measured in people using e.g. perceptual ability tests which include some parts on 3D object perspective reasoning, and paper folding and hole punching (see Fig. 1). These tests are used by the German Academic Foundation



(a) reasoning about 3D perspectives (b) reasoning about paper folding

Fig. 1. Spatial tests: (a) 3D perspective test, the front and up views of an object are provided and the view from the side is asked; and (b) a sequence of paper foldings are drawn and then the location of a hole punched in the final paper is shown; the locations of the hole(s) when the paper is unfold are asked.

* The project *Cognitive Qualitative Descriptions and Applications* (CogQDA) funded by the Universität Bremen is acknowledged.

measure intelligence in students[1]; and also by Dental Admission Testing Program[2] by the American Dental Association.

Qualitative models that try to solve spatial cognition problems have appeared in the literature [2, 4, 3]. A logic-based formalization of the Fishermans Folly puzzle was proposed using qualitative spatial reasoning about strings and holes and reasoning about actions and change on these objects [2]. A qualitative model for describing 3D objects (Q3D) using depth and different perspectives [4] was defined based on designs of pieces described using 3 canonical views (top, lateral and front), which allows reasoning through logics defined to test the consistency of descriptions and it can infer features of the unknown perspectives (i.e. back, down and the other lateral). A qualitative descriptor for solving paper folding tests was defined [3] by establishing a correspondence between the possible folding actions and the areas in the paper where a hole can be punched.

Research has shown that video game training enhances cognitive control [7], specially when aging [1]. Thus, the qualitative descriptors for reasoning about 3D perspectives [4] and about paper folding and punching [3] were implemented in video games (see Fig. 2). These games are intended to test (i) if the qualitative logical algorithms can be applied to provide spatial intelligence to artificial agents (e.g. those in video games) and (ii) if the feedback provided by the qualitative descriptors can help users to improve their spatial thinking skills when solving spatial reasoning tests.

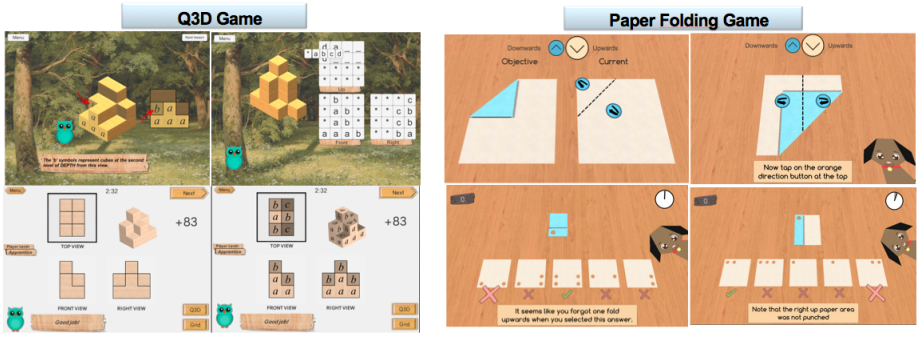


Fig. 2. Games for practising spatial reasoning skills: 3D perspective reasoning and paper folding and punching.

Both games were developed using Unity 5 game engine because it provides multiplatform exportation to mobiles and tablets. And the user experience in both games is similar, they both start with a training part and end with a test part. In the training part, players practise: (i) in Q3D, how to build an object out of cubes, and how to describe an object from its perspectives using the Q3D model; and (ii) in QPF, how to fold a paper

[1] *Test der Studienstiftung*: http://www.spiegel.de/quiztool/quiztool-49771.html
[2] *Dental Admission Testing Program example*: http://www.ada.org/

by indicating a line, and area to fold and a direction. Both games have help options during the evaluation test: (i) in Q3D, depth information is provided for the perspectives of the object; and (ii) in QPF, the sequence of folding actions can be repeated automatically as many times as needed. Both games provide feedback: (i) in Q3D, the real object is visualised after each question is answered; and (ii) in QPF, the paper is unfold and the assistant provide an explanation using the qualitative concepts defined by the model. Finally, participants provide ratings to the game regarding: interactivity, usability, educative feedback, fun, etc.

Experiments on participants are carried out at the moment to see if playing these video games make them improve their spatial reasoning skills. Results will be published in the near future.

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constrain performance on the encoding and retrieval of spatial information in disciplinary representations.

Keywords: Visual memory, spatial ability, expertise.

The Induced Roelofs Effect Presented in a Virtual Environment

Svenja Neuneier

University of Koblenz-Landau, Campus Koblenz
S.Neuneier@gmx.de

Stefan Müller

University of Koblenz-Landau, Campus Koblenz
stefanm@uni-koblenz.de

Eva Neidhardt

University of Koblenz-Landau, Campus Koblenz
neidhardt@uni-koblenz.de

Keywords. Induced Roelofs Effect, visual-conceptual perception, immersive virtual environment

"When a visible frame is offset left or right of an observer's objective midline, subjective midline is pulled toward the frame's center, resulting in an illusion of perceived space known as the Roelofs effect." [1]. This optical illusion effect was first described by Roelofs in 1935 [2]. The changing position of an observer relative to a frame induces an adverse shift of perceived objects within the frame which is called the Induced Roelofs Effect [3]. In experiments situated in real environments or on common computer screens (CS) the shifting frame is surrounded by other geometrical structures which may serve as additional cues for the observer's perception adjustment relative to the experimentally manipulated frame. In immersive virtual environments (VR) this adjustment can be omitted as the surrounding of the experimental frame can be created without additional geometric cues. It is hence expected that the Induced Roelofs Effect (IRE) i.e. the perceived shift of the objects' position should be larger in a VR than in a CS condition.

N=42 subjects were tested (n=21 per condition, age range: 12 yrs. to 65 yrs., 28 female and 14 male, VR: m=25.9 yrs., sd=2.5 yrs.; CS: m=31.6 yrs., sd=2.5 yrs.).

Each subject started with a **training** of the objects' positions: Objects (balls) were shown at five fixed positions without a frame, one after the other for one second each. The five ball positions were symmetric to the center of the view field or in the center of the computer screen, respectively. Subjects had to name the shown position of each ball appearing. This sequence was presented three times. Afterwards in the motor condition all objects in all five positions were shown and were called in random order by the experimenter. Subjects had to point with a laser pointer (VR) or with a mouse (CS) to the object at the called position and to "fire" when the position was decided. The object disappeared when hit.

In the tests, all nine combinations were presented in random order first in the visual-conceptual condition (subjects had to name the object position).

The subjects were tested either with a presentation on a laptop screen or on a HTC Vive.

As expected, the Induced Roelofs Effect was significantly more frequent in the VR than in the CS condition ($F(1,40)=12.7$, $p<.01$, $\eta^2=.24$).

The visual IRE effect was larger compared to the CS presentation. This experiment shows convincingly that virtual environments may be used to create experiments in a very strict way by eliminating elements that can never be excluded in real environments. The study presented here is not only a proper replication: it enlarges the effect by putting it into a new borderless environment.

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Where Am I, in Terms of My Physical and of My Perceived Body, When Using Different Virtual Reality Setups

Albert H. van der Veer[12*][0000-0002-2754-5989], Matthew R. Longo[3][0000-0002-2450-4903], Adrian J. T. Alsmith[4][0000-0002-1557-4133], Hong Yu Wong[56][0000-0002-5662-7553], Heinrich H. Bülthoff[1][0000-0003-2568-0607], Betty J. Mohler[178][0000-0003-3403-3110]

[1] Max Planck Institute for Biological Cybernetics, Tübingen, Germany
[2] Graduate Training Centre of Neuroscience, University of Tübingen, Germany
[3] Department of Psychological Sciences, Birkbeck, University of London, United Kingdom
[4] Center for Subjectivity Research, University of Copenhagen, Denmark
[5] Philosophisches Seminar, University of Tübingen, Germany
[6] Werner Reichardt Centre for Integrative Neuroscience, University of Tübingen, Germany
[7] Max Planck Institute for Intelligent Systems, Tübingen, Germany
[8] Institute for Sport Science, Technical University Darmstadt, Germany
* albert.vanderveer@tuebingen.mpg.de

Abstract

We investigated the following four questions. 1) Where do people locate themselves in their bodies when using different types of virtual reality (VR) setups, i.e. a VR headset and a large immersive panoramic screen (panoscreen) 2) How accurately can people locate their body parts in these setups? 3) Do people locate themselves differently in terms of their perceived compared to their physical body dimensions? 4) How do the VR results relate to previous self-location findings from a physical setup [1]?

In both VR setups, participants rotated a pointer in their sagittal plane while instructed to "Point directly to you", but also to nine of their body parts (feet, knees, hips, waist, shoulders, chin, nose, eyes and top of the head) previously measured for their physical heights. From the indicated body part locations a perceived body was constructed, to which the self-locations were alternatively scaled.

Pointing to self relative to the physical body was frequently found for all body regions above mid-torso, as well as above the head, in both VR setups. Participants pointed accurately to many body parts, but not to their feet and knees, nor to the top of their heads, particularly not in the VR headset. Relative to the perceived body, pointing to self was mainly to the (upper and to a lesser extent the lower) face and to a lesser extent to the (upper and to a still lesser extent the lower) torso.

In the previously employed physical setup, self-location was found mainly for two distinct locations, the upper face and the upper torso [1]. For the current VR setups, the self-locations in terms of perceived bodies resemble more these results from the physical setup than the self-locations in terms of physical bodies do.

These findings suggest that when using VR as compared to when not, might not so much change where people experience themselves to be, but rather their perceived body part locations, which then modulate where the self is experienced or indicated on the body. Therefore, in situations in VR where self-location is important (cf. perception, action), it seems relevant to consider how people perceive their bodies there.

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Finding regularities in vitual reality human motions regarding object fetch and place

Lisset Salinas Pinacho, and Michael Beetz

Institute for Artificial Intelligence,
University Bremen, Germany
{salinas,beetz}@cs.uni-bremen.de

Abstract. Due to the increase of robotic technologies in household environments, robots require to adquire the right amount of commonsense knowledge to be able to perform tasks autonomously. For this I make use of the semantic knowledge base KnowRob introduced by Tenorth and Beetz [4], which also includes reasoning methods to perform inference about semantic concepts. In this work, humans performing a table setting for breakfast in virtual reality (VR) were recorded following the method presented by Haidu and Beetz [2]. Then, event segmentation is presented regarding the understanding of relations between actions, objects and motion regularities.
The data includes two hands with fingers and the head location, which hold semantic relations regarding to their function, which are also related to actions. This kind of relations can help robots for planning.
This kind of information is useful when a robotic platform makes a decision about object manipulation ordering [3], e.g. take the bowl and cereal, the juice and glass as pairs in each hand. It also gives an intuition on which object to arrange first, e.g. the cereal, glass, and milk go behind the bowl, while the spoon goes to the right. For this reason we consider that human demonstrations are useful to improve the decision process of a robotic platform.
The majority of programming by demonstration (PbD), learning from human demonstrations (LfD) or imitation learning literature focus on systems which learn directly from a human demonstrator [1]. However, in this work reasoning is the main focus instead of imitation.

Acknowledgements

This work is partially funded by Deutsche Forschungsgemeinschaft (DFG) through the Collaborative Research Center 1320, *EASE*.

Lisset Salinas Pinacho acknowledge support from the German Academic Exchange Service (DAAD) PhD scholarship.

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Do We Need Actual Walking in VR? Leaning with Actual Rotation Might Suffice for Efficient Locomotion

Thinh Nguyen-Vo[1], Bernhard E. Riecke[1], Wolfgang Stuerzlinger[1], Duc-Minh Pham[1], and Ernst Kruijff[2]

[1] School of Interactive Arts + Technology, Simon Fraser University, BC, Canada
{tnguyenv,ber1,w.s,ducminhp}@sfu.ca
[2] Institute of Visual Computing, Bonn-Rhein-Sieg University of Applied Sciences, Germany
ernst.kruijff@h-brs.de

Abstract. Walking has always been the most common locomotion mode for humans in the real world. For this reason, walking has also been considered as the ideal condition in a large body of VR research involving navigation. Physical walking provides body-based sensory information about both the translational and rotational components of locomotion. Though the rotational body-based information has been shown to be important for several spatial tasks, the benefit of the translational component is still unclear with mixed results from previous studies. In this study, we aim to investigate how much translational body-based sensory information is required for people to efficiently navigate the virtual world, given full rotational information. Depending on the locomotion interface used, more or less translational body-based information might be provided at different levels of accuracy. The current mixed method study investigated how different levels of translational body-based information might influence the performance of participants in a navigational search task in a HMD-based virtual environment. Participants were asked to find eight balls hidden in 16 target boxes randomly positioned in a two-meter radius circular area. To check whether there is a ball inside a target box, participants must stand right in front of the box within 0.80 meter and look at it. If there is a ball, they can collect it by touching the ball with a wand controller. The environment has been designed not to provide any additional orientation cue other than the optic flow from the fireflies. Participants could not see targets farther than two meter from them. In other words, they were not able to see all targets at a time, hence, they had to build up their spatial awareness gradually along with their locomotion. In this within-subject experiment, there were four levels of translational body-based information: none (participants used the trackpad of an HTC Vive wand controller to visually translate), upper-body leaning (participants sitting on a Swopper chair, used their upper-body leaning to control their visual translation), whole-body leaning (participants standing on a platform called NaviBoard, used their whole body leaning or stepping to navigate the virtual environment), and actual walking (participants physically walk with a wireless

HMD on). Every participant performed a navigational search task once in every condition in a counter-balance order. All 24 participants finished all four trials (even with more or less fatigue). Results showed that locomotion mode had significant effects on various measures including task performance, task load, and simulator sickness. While participants performed significantly worse when they used joystick-based interface with no body-based information, compared to the other conditions, there was no significant difference between leaning-based interfaces and actual walking. More data in other measures are still in need for a more concrete conclusion. However, current results also suggested that body-based information from a leaning-based interface might suffice for a cost-effective alternative to actual walking in spatial cognition research and applications in VR.

Keywords: Spatial Orientation · Virtual Reality · Virtual Locomotion · Experimentation · Human Factors · Performance.

A survey of surgeon's perception and awareness of the role of spatial cognitive abilities in surgical learning

Tina Vajsbaher and Holger Schultheis

Bremen Spatial Cognition Centre, University of Bremen
Bremen Germany

tina.vajsbaher@uni-bremen.de
schulth@uni-bremen.de

Abstract. Laparoscopy is considered the gold-standard surgical procedure for diagnosis and treatment of most abdominal and pelvic-related conditions. However, although such minimally invasive technique offers countless advantages to the patient, they come at a cost: surgeons must learn to overcome a unique set of visuo-spatial cognitive and dexterity challenges, which are associated with the application of the technique. Although the existing literature provides valuable insights about the overall role of spatial cognition in laparoscopic learning, one fundamental question remains unanswered: How are these fundamental spatial cognitive challenges perceived and understood by surgeons themselves. **Method.** In aim to gather further insight regarding the influence of spatial cognition in surgical learning among medical professionals, an online questionnaire was circulated to members of the Professional Association of German Surgeons (BDC) and German Society of Surgeons (DGCH). The responders were asked to rank-order a list of technical, cognitive or psychological factors they found to be most challenging when learning to operate laparoscopically. **Results.** A clear generational difference in awareness of spatial cognition was observed; 1) Younger surgeons showed greater awareness of the taxing conditions related to spatial abilities in laparoscopy, compared to their senior colleagues, 2) lack of tactile feedback was identified as the most challenging factor for both younger and senior surgeons and finally, 3) novice surgeons identified the ability to visually process the 3D internal structures through a 2D monitor in direct relation to specific spatial loci to be most challenging. **Discussion.** Spatial cognition plays a notable role in influencing the learning of minimally invasive surgical skills. Nonetheless, its nature and challenges appear to be largely underestimated by the senior surgeons in charge of training, leading to the hypothesis that this is most likely one of the reasons for observed learning difficulties, as no support and/or training for developing spatial skills is offered to residents with weaker spatial abilities. **Conclusion.** The new generation of surgeons appears to be more aware of the influential nature of spatial cognitive abilities, with lack of tactile feedback and impaired spatial orientation causing the most difficulties for novices learning minimally invasive surgery.

Keywords: Spatial Cognition; Skill Acquisition; Medical Cognition; Surgical Education; Minimally Invasive Surgery

Geographical Nearness and Graphical Nearness
More or less complicated than thought?

Francis Harvey
Leibniz-Institute for Regional Geography
Leipzig, Germany
f_harvey@ifl-leipzig.de

Poster Abstract

"Near things are more similar than more distant things" states Tobler's first law of geography. Evident regarding spatial behavior, which cognitive research into the perception of the environment has researched. The question of how readily near things in a graphic, especially a map, are understood to geographically near, has, however, yet to be studied. This poster considers this issue through theories originating in Gestalt concepts. Behavioral, ecological psychology and information psychology expand these concepts to take account of psychology research into the preattentive comprehension of graphical representations. The initial findings the poster presents suggest that the impact of previous experience or even geography or cartography training are ambiguous. They point to participants' rapid acquisition of affordances from the survey instruments as an essential factor. People's visual capacities can quickly develop the mental recognition of graphical nearness and apply it to tasks requiring the use of a map or map-like images. The acquisition of this capacity is a matter for future research.

The perception of space in South African townships post 1994

Baleseng T Mokoena[1], Walter Musakwa[1] and Thembani Moyo [2]

[1] Department of Town and Regional Planning, University of Johannesburg, South Africa
[2] Department of Quality and Operations Management, University of Johannesburg, South Africa

Abstract. The perception of space and place in South Africa by planners is ever informed by various attributes that stem from the injustices of the past. As a result of this the spatial form in South Africa is highly dictated by policy that focuses on redressing some of these. With the poor having to travel long distances to economic opportunities, planning becomes more social than it is about organizing space according to ideal planning principles and form. In this paper we look at Ekurhuleni and Johannesburg as a case study to understand how planners understand space given the location and history. Using questionnaires, the results indicate that legislation and spatial redress influences the spatial cognition of South African cities. The results further indicate that GIS, ICT in planning, the smart city concept and planning theory play a minor role in influencing spatial planning in South Africa. As a solution this paper therefore advocates for smarter methods of planning to be used in order to advance planning in South African cities.

Comparative Analysis of Case Studies Based on the Physical Effort Model (PEM)

This work presents a new cognitive model for the analysis and prediction of pedestrian movement in hilly urban settings. A comparative analysis of four case studies was conducted for the assessment of the model.

Topography affects pedestrian movement in two main ways: it can block lines of sight restricting spatial awareness and the extra physical effort exerted from walking on sloped surfaces can effect travel distance and route selection. Although physical effort affects all pedestrian movement, this effect would be most pronounced on sloped surfaces.

A method called the Axial Map, which uses mutual visibility as a cognitive basis was chosen for modification to create the new model as it excels in the analysis of pedestrian movement in large urban systems [1]. An Axial Map is created by dividing the space of the entire system into a minimal number of discreet convex shapes in plan and then connecting all those spaces with a minimal number of axes covering the entire system, representing lines of sight. This map can be represented as a graph describing the connections between the various axes and different centrality measures can be calculated. This method was demonstrated as effective in describing and predicting various social phenomena [2]. The axial map will be referred to as the topological model. A refinement to this method uses the incident angles between axes along a path to assign weights in the graph, with the weight increasing with the angle [3]. This version will be referred to as the angular model.

The proposed model differs from the abovementioned models in that it has a dual cognitive basis - taking physical effort into account in addition to mutual visibility. The model solves the problem of topography that blocks visibility by a further division of axes along peak points in topography [4]. The role of physical effort as an incentive in route selection is represented by two weights that are attached to each axis in the graph – one for going uphill and one for going down [5, 6]. This model is referred to as the Physical Effort Model or PEM.

Four hilly urban areas in Israel were chosen for assessment of the model: the Hadar and Neve Sha'anan neighborhoods in Haifa and the City Center and Southern Nahlaot neighborhoods in Jerusalem. In addition to the PEM analysis, all case studies were analyzed by topological and angular models for a measure called Integration which correlates well with pedestrian activity [1]. Then, differences in the results within each case are highlighted and compared to the realistic condition. The outcomes of the models were compared regarding the accuracy of their predictions and appraised for their weak and strong points.

A reliable and accurate model can improve our understanding of the relationship between topography and life in the urban fabric built upon it and allow for a more informed approach when planning such environments. All this can help us build livelier, healthier and overall better cities.

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Space-time segmentation of sensor data along a route

Annina Brügger[1] [0000-0003-3517-664X] and Kai-Florian Richter[2] [0000-0001-5629-0981]
and Sara Irina Fabrikant[1] [0000-0003-1263-8792]

[1] University of Zurich, Winterthurerstr. 190, 8057 Zürich, Switzerland
annina.bruegger;sara.fabrikant@geo.uzh.ch
[2] Umeå University, 90187 Umeå, Sweden
kai-florian.richter@umu.se

Today, smart devices and sensors offer ample opportunity to collect huge amounts of data in wayfinding studies in virtual and real-world environments. These sensors may record interactions, physical and physiological activities, and assist researchers in understanding spatio-temporal behavioral effects [1] and learning impacts [2]. Reporting empirical results often involves categorization of qualitative information [3] or statistical and visual analysis of quantitative measurements [4]. The strength but also a challenge of analyzing sensor data in wayfinding studies is the spatio-temporal context in which data is collected. To study temporal patterns of simultaneously collected sensor data during a wayfinding task, researchers typically resort to statistical measures or graphs, such as timelines [3,4], for instance. One drawback of such data depiction can be the missing link to the traversed space where wayfinding happened. Various navigation studies have handled spatial segmentation in empirical analysis differently, such as discretizing the route according to decision points [5], landmarks [6] or route properties, for example, pedestrian crossings and bike lanes [7]. To date, there is no agreed-upon method how to segment space to infer behavioral characteristics from large complete temporal datasets, let alone one, grounded on principles derived from empirical data or analytical results. It seems obvious that the segmentation of sensory data collected in a dynamic and continuous environment is critical.

We will demonstrate a case study using eye tracking data collected during a wayfinding experiment outdoors. The eye tracking method in real-world studies yields massive amounts of fine-grained and multi-media data (e.g., video, sound, gaze points, scan paths, human-system interaction data, etc.) highly dynamic and not synchronized across participants and within the spatio-temporal context. This typically means a great deal of tedious manual data processing labor, to isolate desired and meaningful units of analysis [2,8]. As a consequence, the sheer volume of this fine-grained, continuous space-time data stream might only been partially analysed, due to time constraints, and other limitations. We apply statistical measures on collected wayfinding data, based on different segmentations (e.g., on the basis of turns or intersections) of a tracked route, and present how various space-time segmentation strategies impact the resulting statistical measures. Further research should focus on determining (empirically grounded) conventions of space–time segmentations for collected continuous sensor data along a route, to enable (I) efficient and thorough wayfinding data analyses and, (II) comparison of results across empirical wayfinding studies for cross-validation.

Keywords: Assisted Wayfinding, Discrete and Continuous Data, Human Behavior, Spatial Cognition.

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Influence of cognitive data classification on VGI quality

Ahmed Loai Ali[1][0000−0001−8939−3426] and Christian Freksa[1][0000−0002−0330−0004]

Bremen Spatial Cognition Center, University of Bremen, Bremen, Germany
loai@uni-bremen.de , freksa@uni-bremen.de
https://bscc.spatial-cognition.de/

In VGI, humans are the fundamental source of knowledge. They utilize various models to provide information, regardless of their experience and backgrounds. In particular, they categorize geographic objects based on their geographic conceptualization. This fact results in heterogenous data classification quality. In this work, data classification quality implies accuracy and precision; when individual geographic perception determines classification accuracy, while whether contributors provide an abstract or a fine categorization depends on the utilized classification model.

In abstract levels of details, contributors utilize definition-based model, where categories are pre-defined, and have at least arbitrary but fixed boundaries. In fine levels of details, contributors use cognitive-based model. They utilize commonsense categories used in natural language. The more fine details they provide, the more soft boundaries between categories they face, and hence, overlapping categories. Actually, data categorization in VGI follows a combination of these models. In both models, a single object may be assigned to multiple categories with various degrees of correctness and precision, particularly in fine granularity levels. Although multiple categories represent challenges for data representation and interpretation, they can be exploited as a source of data validity and outlier detection.

We conducted an empirical study that demonstrates human-centered data classification models in VGI projects. The study adopts land-use classification emulating definition-based and cognitive-based models. The study shows how volunteers utilize their cognitive abilities to provide valid and precise information, however, with various degrees of both accuracy and precision. It demonstrates how contentions among overlapping concepts can be used for meaningful data interpretation.

Fig. 1 shows part of the findings. The figure demonstrates participants classifications for a set of grass-related objects; when the size of internal (orange) circles indicates validity degree of a particular label for a given object. The figure illustrates clearly subjective classification and overlapping boundaries between categories. Due to the semantic overlap of neighboring concepts, observers sometimes choose a label which does not correspond to the most appropriate category. However, knowing the conceptual neighborhood structure of the concepts helps to interpret the label assignment and thus is useful for outlier detection as well as for data validation. Taking into consideration conceptual neighboring categories reduces the search space for less valid meaningful choices.

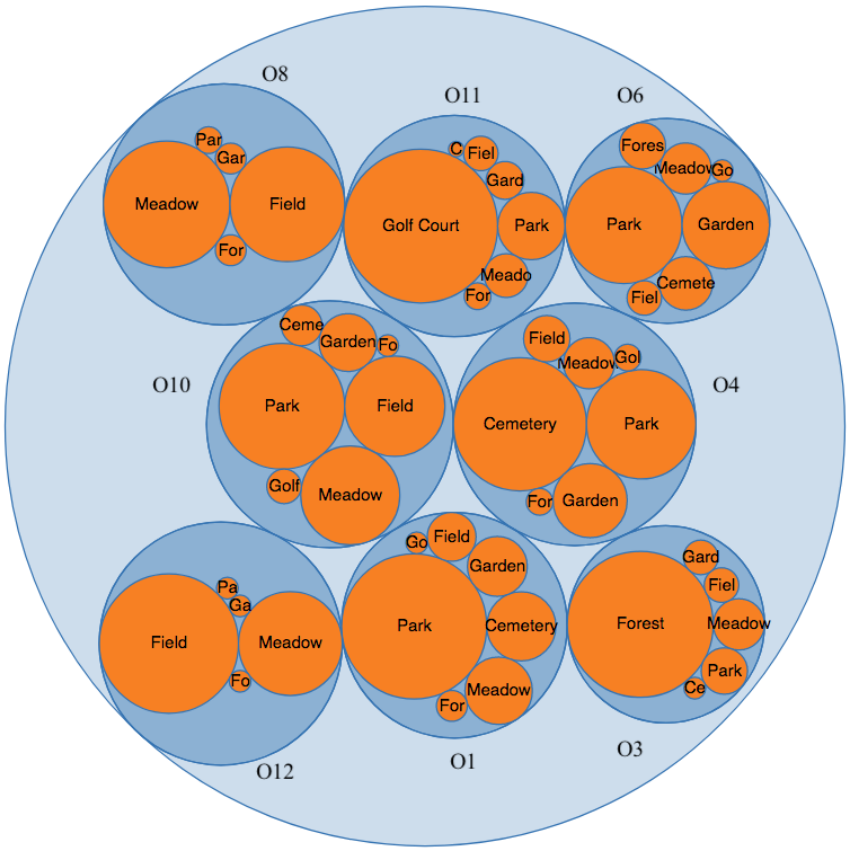

Fig. 1. Part of participants' classification for 8 grass-related objects

In VGI projects, contributors conduct mental comparison utilizing qualitative measures to avoid extreme values. As non-experts of the field they typically end up with a small set of plausible categories. In such situations, forcing an observer to make a more precise classification can lead to loss of information. The categorization task is conducted in a natural way of human-sense that legitimizes the accuracy of data classification. Although as humans we interact with the same real world, our geographic conceptualizations are developed differently. Thus, the use of different labels to describe an identical observation is natural. However, we should be able to utilize these contention labels to generate useful meanings by accounting for the different contexts in which they were created. Integration and dual interpretation methods should be developed to tackle cultural aspects, different perceptions, and language differences.

A Machine Learning Framework in Spatial Analysis

Cecilia Ferrando[1]

[1] Carnegie Mellon University, Pittsburgh PA 15213, USA
cferrand@alumni.cmu.edu

Abstract. How can we build a Machine Learning model of learnable spatial rules? How would a Machine Learning framework prove a useful tool in the analysis of architectural qualities? Inspired by the long-open question whether it is possible to build an AI design assistant, this thesis researches a Machine Learning framework for spatial analysis of floor plans. It shows that Machine Learning algorithms trained on large datasets of plan configurations have the potential to characterize abstract architectural qualities in terms of quantifiable spatial features.
Two commonly adopted techniques used in spatial analysis are isovists, introduced by Michael Benedikt (1979), and graph theory, explored in architecture by Christopher Alexander, but dating back to XVIIIth century France. These are contextualized within Space Syntax, the set of theories and methods studying spatial configurations and their cultural implications. Such techniques convey different types of information on architectural space - visual connectivity on one side, hierarchies and accessibility on the other. In this thesis, I aim at relating spatial features to architectural qualities through a Machine Learning algorithm. Specifically, I look at the quality of architectural privacy in homes.
One obstacle in building a Machine Learning framework for the analysis of architectural space is that a large amount of labeled data is needed. In order to prove the feasibility of building a large dataset of floor plans labeled according to a set of spatial features, a software extracting spatial features out of image data is outlined in its structure. Finally, the technical aspects of this newly proposed Neural Network framework for spatial analysis are presented and discussed. From a proof-of-concepts experiment, it emerges that when statistical analysis is run on a relatively small dataset of spaces in house floor plans, patterns relating Space Syntax features and the level of intimacy of different rooms in a house floor plan are found. At the same time, the limits in these results reinforce the need for a more complex function approximator (such as a Neural Network) to detect spatial patterns.
By presenting a novel AI approach to spatial analysis on the floor plan, this thesis opens the floor to both analytic and generative applications of Machine Learning in architecture.

Keywords: Spatial Analysis · Architectural Information · Machine Learning · Neural Networks · Artificial Intelligence

Egocentric Anisotropy in the Representation of Horizontal and Vertical Traveled Distance

Thomas Hinterecker[1,2][0000-0002-3214-651X], Paolo Pretto[1], Ksander N. de Winkel[1], Hans-Otto Karnath[3], Heinrich H. Bülthoff[1], and Tobias Meilinger[1]

[1] Max-Planck-Institute for Biological Cybernetics, Tübingen, Germany
[2] Graduate Training Centre of Neuroscience, Tübingen, Germany
[3] Center of Neurology, Division of Neuropsychology, University Tübingen, Germany

Abstract. Previous animal research suggested that distance estimation is subject to anisotropy, with lower accuracy in estimating vertical movements as compared to horizontal ones. In humans, studies on spatial anisotropies mostly focused on location memory in multi-level environments, leaving an open question as to whether an anisotropic model in internal representations of traveled distances holds true in humans as well. We addressed this question by using a traveled distance estimation paradigm using horizontal and vertical movements in the sagittal plane. In each trial, blindfolded participants had to first memorize the distance traveled during a passive translation and then reproduce it in a similar setting. Participants performed this task in an upright and a 30° backward-pitch body orientation. The accuracy of traveled distance estimates in the upright body condition was best explained by a horizontal-vertical anisotropy model, with higher accuracy along the horizontal than the vertical translation axis. The backward-pitch orientation was used to examine whether this anisotropy was body or earth-centered. Correlations between the accuracy patterns of the upright and the backward-pitch condition encoded in a body-relative coordinate system are suggestive of an egocentric anisotropy. Overall, the findings are consistent with previous research on motion perception. They suggest that traveled distance estimation, as a sub-process of path integration, is subject to egocentric horizontal-vertical anisotropy, with lower accuracy in the vertical dimension.

Keywords: traveled distances, horizontal, vertical, anisotropy, egocentric, motion simulator

Crowding effects in real depth for binocular and monocular observation

Lisa Valentina Eberhardt & Anke Huckauf

General Psychology, Faculty of Engineering and Computer Science, Ulm University
Albert-Einstein-Allee 47
89081 Ulm, Germany
✉ lisa.eberhardt@uni-ulm.de
anke.huckauf@uni-ulm.de

One of the main limiting factors in peripheral vision is crowding. Crowding describes the interference of surrounding flanker stimuli in the recognition of a peripheral target stimulus. Thus, the effect is relevant for a variety of tasks and should be considered in the design of new technologies, e.g. head-up displays. The crowding effect depends mainly on the spatial arrangement of target and flanker stimuli: The effect decreases with increasing target-to-flanker spacing and increases with increasing target eccentricity. The present study investigates whether and how the third spatial dimension, i.e. depth, affects crowding. It was assumed, that crowding is pronounced the stronger the farther crowded stimuli deviate in depth from the fixation depth. In Experiment 1 binocular observation provided defocus blur and binocular depth information. In Experiment 2 the impact of defocus blur on its own was tested by applying monocular observation.

Real depth was presented, similarly to head-up display technology, by superimposing the displays of two orthogonally arranged screens via a half-transparent mirror. Depth differences were achieved by adjusting the distances of the screens along the orthogonal axis. Participants (n = 16) had to fixate on a central cross (white; size: 0.6°) in a constant distance (190cm), while their task was to identify the gap position (up, right, down, left) of the middle of three horizontally arranged, peripherally presented Landolt rings (stimulus size: 0.6°; target eccentricity 2°; target-to-flanker spacing 1°). The stimuli appeared either on the fixation depth, or in front of or behind the fixation depth, i.e. defocused, in near (± 0.06 diopters) and distant distances (± 0.1 diopters) each.

In Experiment 1 results indicated increased crowding effects in distant compared to near defocused depths as expected. This result was present in the recognition performance as well as by trend in the reaction time data. To disentangle whether this was due to binocular depth information or due to defocus blur, Experiment 2 was conducted binocularly. The results of Experiment 2 revealed no differences in crowding effects between defocused depths. Thus, the impact of defocus blur on crowding seems to be neglectable. However, data show that reaction time depends on direction

of depth: Correct reaction toward stimuli in front was faster than toward stimuli behind. This is in line with evidence showing faster simple reaction times for approaching compared to departing stimuli.

Taken together, the data indicate that crowding actually increases when flanked stimuli are presented in depth. Mainly binocular depth information drives the effect. Most likely diplopia due to large disparities for distant defocus depths explains this result. The impact of defocus blur seems to be neglectable for the range of depth which was tested in the present study. These results should be considered in the design of applications like head-up displays.

A Tool for Large-Scale Spatial Behavior Analysis in Indoor Environments

Angela Schwering, Sergey Mukhametov, Jakub Krukar

Institute for Geoinformatics, University of Muenster, Germany
[schwering | sergey.mukhametov | krukar]@uni-muenster.de

Poster Abstract

Spatial behavior analysis in indoor environments is challenging: GPS is not available to track the location. Furthermore, analyzing the interaction of people with their environment goes beyond pure movement trajectories. Dalton et al. [1] developed "People Watcher", an iPad application for recording the path and spatial behavior of the observed participants. Since the recording is manual, applying it to simultaneous observation of groups or large-scale environment is challenging.

We present a sensor-based system (Figure 1) to automatically monitor the behavior of people in indoor environments such as museums, airports and other public spaces. Multiple sensors are distributed across the monitored space so that the sensors' range cover all areas of interest. A central system integrates separate measurements into a single spatial reference frame. The system supports different sensors: depth cameras (e.g., Kinect) can be used for a smaller range, recording also other aspects of spatial interaction such as the skeleton of the body and the position of the hip, feet, and the head. This can be used to detect and interpret the person's pose and their viewing direction. Based on the unique features of the skeletal and the facial coordinates, the system can re-identify visitors after they temporarily walk outside the area covered by the system. LIDAR sensors having larger range are also supported, but only for recording spatial movement. The system also allows for recording several people simultaneously over time making it possible to analyse group interactions (Figure 2).

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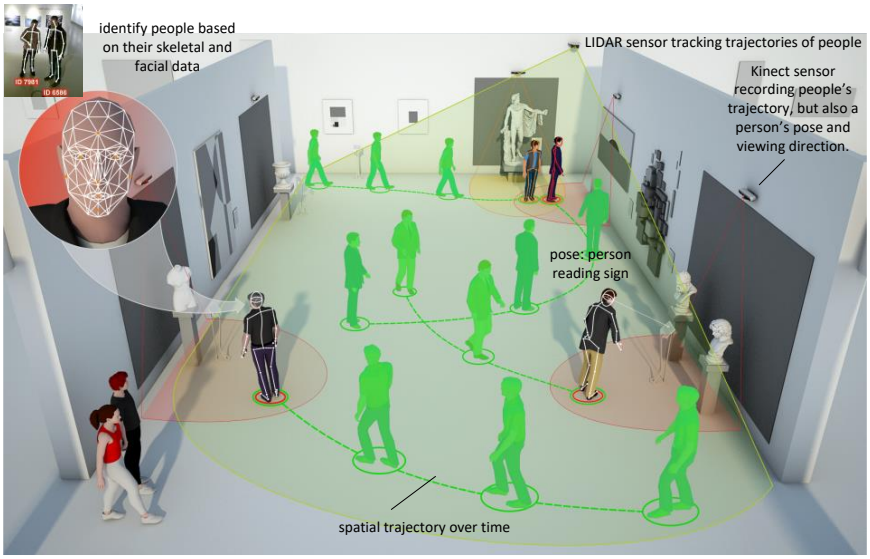

Fig.1 Recordings of sensors in an indoor environment.

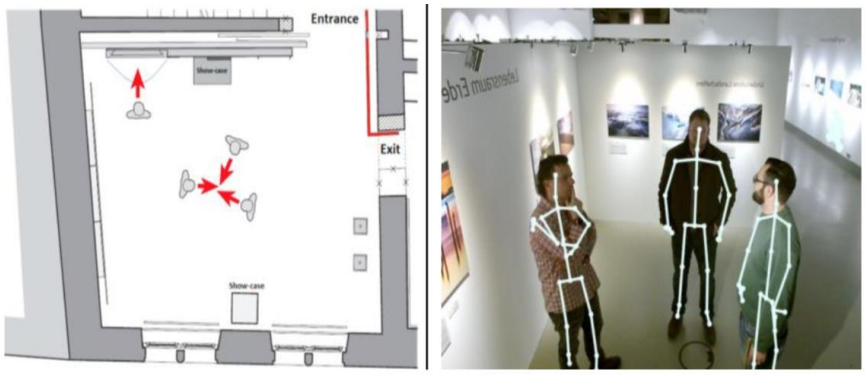

Fig.2 Group interaction.

The system (Figure 3) has been tested for in the Horse Museum in Münster, Germany. After the set-up, it recorded data of visitors for 60 days without interruption. We also conducted controlled tests to investigate the reliability of the data:

- People are localized with the accuracy of 3-10 cm.
- The viewing direction is determined with the accuracy of 20-100 cm, depending on the distance and the angle of the observer.
- Recognition of people in the frontal position equaled 80%. This can be improved by recording additional data about the visitors. Currently, due to privacy concerns, we limited the recording to core skeletal and key facial points.

Within Bitgod's attention model [2] of museum visitors, we can automatically identify the following events:

- Approach: trajectory entering a certain region in front of the exhibit, slowing down;
- Stop: Speed slowing down up to complete stop for a certain time;
- Look At: Location within the zone in front of the exhibit and viewing direction toward the exhibit;
- Focus on: Looking toward the exhibit for a certain time.

Future work involves identifying a broader range of actions, such as reading labels, and interactions between visitors.

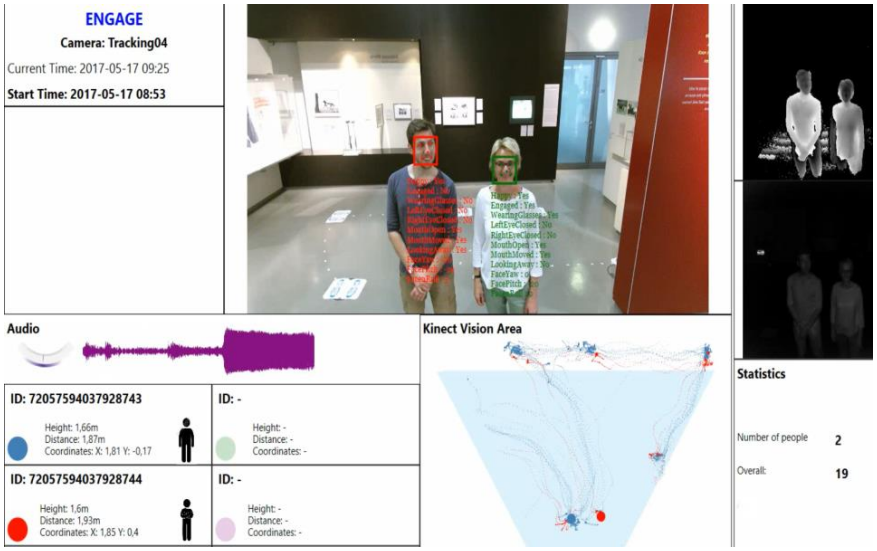

Fig.3 Screenshot of the tool's interface.

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Identification of the flood susceptible bank lines using multi-temporal change detection

Srutiparna Neogi[1], Sanjit Maitra[2], and Kuntal Ghosh[1]

[1] Indian Statistical Institute, 203, B.T. Road, Kolkata 700108, India

[2] Indian Statistical Institute North-east Center, Tejpur, India
kuntal@isical.ac.in

Abstract. Change detection is a very useful method to find the interaction between human activities and the natural environment. Multiple factors such as economic, cultural, political, and human habitat influence land use changes. In change detection process, multi-temporal datasets are quantitatively analyzed to assess the multi-temporal effects of these phenomena. LANDSAT multispectral and muti-temporal imagery is a very important source of data in this case for observing changing features. Remote sensing thus provides a unique opportunity to characterize the spatio-temporal distribution of these changes and to collect important baseline of information that is too difficult to obtain using field-based methods. Satellite images can easily detect and map both local and large area land use/land cover changes. Riverside sand deposition, changing nature of course lines can also be well detected by the image interpretation methods.

In north eastern India people are forced to leave their houses due to devastating flood each year and a number of endangered animals are drowned during monsoon. This work is aimed to assess the bank line shifting nature of Brahmaputra river around Kaziranga National Park from 2008 to 2016, to compare the bank line shifting within these years, assess the causes of bank line shifting of Brahmaputra in that predefined area, detect the changes of riverside land covers, detect the land type beside the most frequently changing bank line and find the correlation among all these land cover changes.

Well known image processing tool ENVI is used to collect the reflectance values from LANDSAT images. Choice of effective end members provided the best spectral unmixing of heterogeneous pixels, to determine the exact land type. Simultaneously maximum likelihood estimation in conjunction with proper spectral signature observation is applied to segregate the individual classes based on the different land cover types. Change detection involves band differencing, band ratioing, post-classification comparison, NDVI, change vector analysis using tasseled cap transformation. The river bank line is detected by band ratioing and thresholding. Observation of the land type adjacent to the gradually delineating bank line area provides added information to the factor analysis of erosion.

In this work collection of reflectance spectra from satellite images help to determine the classes correctly. Geometric and radiometric corrections were needed to set a normalized resolution and destriping before classification. Besides Normalized Difference Vegetation Index, Soil Adjusted Vegetation Index and Wetness Index are required for thorough investigation and to detect the position of majorly changed areas. Thus there is a chance of erosion through the bank lines. We are planning to detect the erosion prone areas through the bank line in these specific years. Our future research work includes the identification of

physical parameters like rainfall, slope, elevation, soil types, position of the tributaries etc. that may be responsible for river bank erosion.

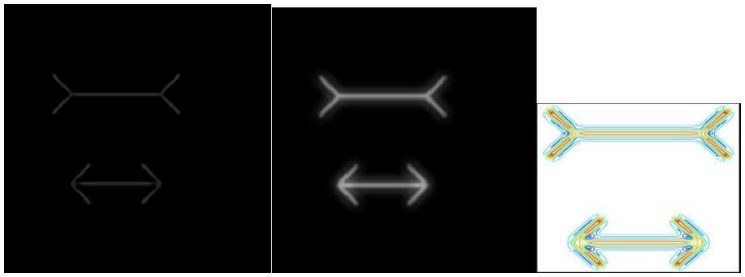
Understanding the Geometry of Visual Space through Muller-Lyer Illusion

Rahul Kumar Ojha[1], Mainak Mandal[2], Debasis Mazumdar[3], Kuntal Ghosh[1]

[1] Indian Statistical Institute, 203, B.T. Road, Kolkata 700108, India
[2]University of Hamburg, Department of Mathematics, Hamburg, Germany
[3] C-DAC Kolkata, Plot - E-2/1, Block-GP, Sector-V, Kolkata 700091, India

kuntal@isical.ac.in

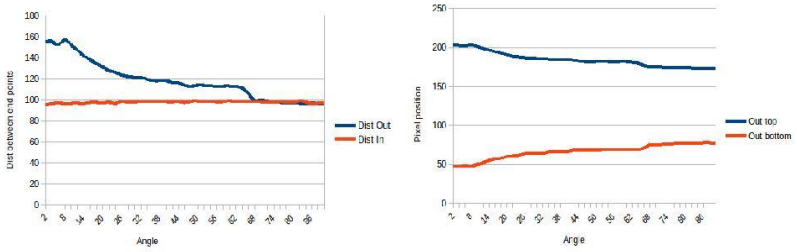
Abstract. *Introduction* Geometric illusions like Muller-Lyer have been studied thoroughly for several years. Kawabata [1] used a mathematical model based on perceptual image field to find the distance which basically is a threshold based function to find perceived length of a line in the Muller-Lyer illusion. We propose to take this study further by using the same model of perceptual field with other bio-inspired filters to explain the illusion and understand the possible mechanism of cognizing the geometry of visual space. Further explored is the relevance of attributes making up the illusion like angle of arrow and the length of line. *Methodology* The perceptual image field of the illusory stimulus is found by convoluting a non-Classical Receptive Field (nCRF) based Gaussian filter [2, 3] on the image. Finding a contour plot of this image, we get artefacts indicating the endpoint of the perceived line. These artefacts are figured out via a threshold based method. The stimulus, filtered image and its perceptual field is shown in Fig. 1. The circular artefacts have been used to find the perceived length of a line. This method is repeated on a number of variants of the illusion with arrow angle in range of 0^0 to 180^0. The perceived length is then measured between the two artefacts to find the relevance of angle with perceived length. *Results* The application of nCRF based filter clearly enhances the distance between the artefacts.



(a) (b) (c)

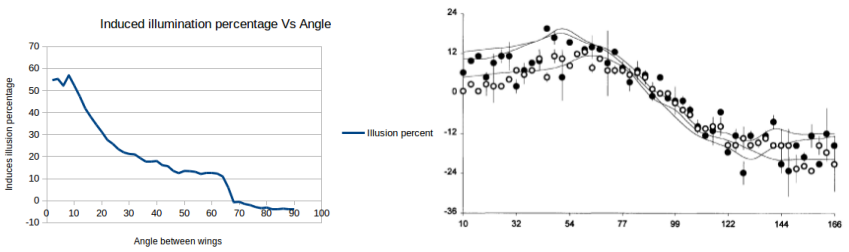
Fig 1. (a) Muller Lyer Illusion (b) nCRF filtered image (c) contour plot or perceptual plane representation

Kawabata [1] in his study did not provide any perceptual length difference figure. In our case the perceptual length difference between both the lines is found to be approximately 30% of the line



(a) (b)

Fig. 2 (a) Plot for perceived length between artefacts vs arrow angle (b) plot for position of artefact and arrow angle



(a) (b)

Fig. 3 (a) Plot for induced illusion vs arrow angle using proposed method (b) plot for induced illusion vs arrow angle found experimentally [4]

length whereas the use of DoG based Gaussian filter [1] shows a difference approximately 20%. The application of the proposed method on a variance of arrow angles yields a plot as given in Fig. 2. *Conclusion* The results shows that the nCRF based filters which are modelling the extended classical receptive fields of retinal ganglion cell [3], can explain the illusion through perceptual plane method better than the DoG based filters [1]. Comparison [4] with induced illusion for psychophysical experimental data is shown in Figure 3.

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Axial information as determining in geometric and functional stimuli

Jurģis Šķilters[1][0000-0002-3235-970X] and Līga Zariņa[1][0000-0003-1799-3339]

[1] Laboratory for Perceptual and Cognitive Systems at the Faculty of Computing, University of Latvia, 19 Raina Blvd., Riga, LV 1586, Latvia
lpcs@lu.lv

Abstract. According to previous research, symmetry perception is sensitive to axial orientation: first, vertical axis is the most prominent followed by horizontal and oblique and, second, the closer to the axial part of the object the easier to detect it (Barlow & Reeves, 1979, Wagemans, 1995, 1997, Wenderoth, 1994). In our experiment, we tested (a) whether axial information is equally important in perceiving to geometric (square, circle) and functional (mushroom, apple) objects, and (b) what are the differences between different spatial relations in respect to axial information and object type (i.e., functional and geometric and the underlying symmetry features).

We conducted an in-group online experiment (n=113) where we asked to indicate locations of 12 spatial relations (e.g., on, over, above) corresponding to both types of objects (20 geometric and functional objects) (Logan & Sadler, 1996). The objects used in our experimental stimuli included different symmetry features (e.g., reflection, rotational symmetry). The stimuli were randomized within each set of objects (i.e., geometrical or functional) for each subject. We used two independent tests where the sequence of object type was varied - first geometric objects were presented and then functional ones, and vice versa.

According to the results of our experiment axial information determine the interpretation of spatial objects. There is an association between the areas (corresponding to the object and the relations) that were indicated by the subjects and symmetry axes and/or rotation centers. However, the variance of association is determined by (a) the order of presentation (i.e, a different results arise when the set of geometric stimuli is followed by functional ones or vice versa) and (b) the symmetry features contained in objects.

Further, functional objects have a more focused scope of interpretation whereas geometric objects have more diverse scopes of interpretation. However, narrower and more focused areas of interpretation tend to be the case in respect to geometric objects if the functional objects are presented first. And the tendency of wider areas of interpretation seems to be the case in respect to functional objects if the geometric objects are presented first.

Finally, based on our results we are discussing some interesting implications for perceptual learning.

Keywords: spatial relations, object form, geometry, symmetry types, order effects.

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Evaluating Sketch Maps Qualitatively: A new Software-Supported Method

Angela Schwering, Sahib Jan, Jakub Krukar, Malumbo Chipofya

Institute for Geoinformatics, University of Muenster, Germany
[schwering | s_jan001 | krukar | Malumbo.chipofya]@uni-muenster.de

Poster Abstract

Many experimental studies use sketch maps to investigate spatial knowledge of their participants. While drawing sketch maps has proven to be a suitable method to investigate mental representations of the environment, their systematic analysis is still problematic: Although we know that human spatial knowledge is (mostly) qualitative, there exist no suitable tools that support a qualitative analysis of sketch maps.

The best known quantitative approach is bi-dimensional regression [1]: It analyzes the degree of shape and scale distortions between reference points in the map. However, it is well known that these distortions are typical for sketch maps [2-3]. Another popular type of analysis involves counting objects without analyzing the spatial configuration at all. Qualitative approaches such as [4-8] give some guidelines how to analyze qualitative aspects of sketch maps, but these approaches are neither formalized nor tested with respect to their reliability as an evaluation method.

We present a new software-supported method to analyze sketch maps qualitatively. In our previous research [3,9], we identified a set of sketch aspects which are typically not affected by cognitive distortions. These sketch aspects are used for the evaluation. The evaluation procedure has the following steps (corresponding software screenshots below):

Step 1: The experimenter annotates the reference map and marks *all* relevant features (streets, landmarks, regions) on the map that should be investigated. That means it is possible to limit the evaluation to only those features mentioned in your experiment materials (Fig. 1). It can be specified if participants had to follow a particular route.

Step 2: Analogously to step 1, the experimenter marks the sketched features in the sketch map (Fig. 2). The sketch map will only be evaluated with respect to those features selected in the reference map, e.g. the participant marked in the sketch map the location of her home, which was not mentioned in the experiment material and thus is not of relevance for the evaluation.

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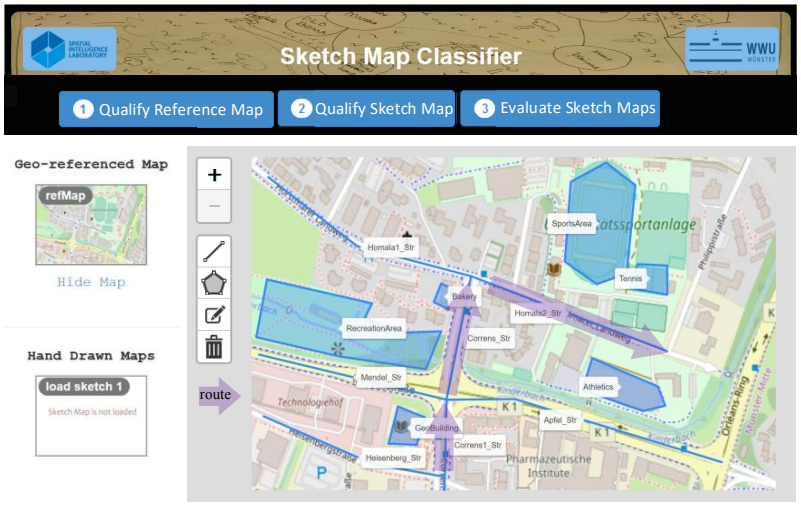


Fig.1 Step 1: Annotation of the Reference Map using drawing tools of the software.

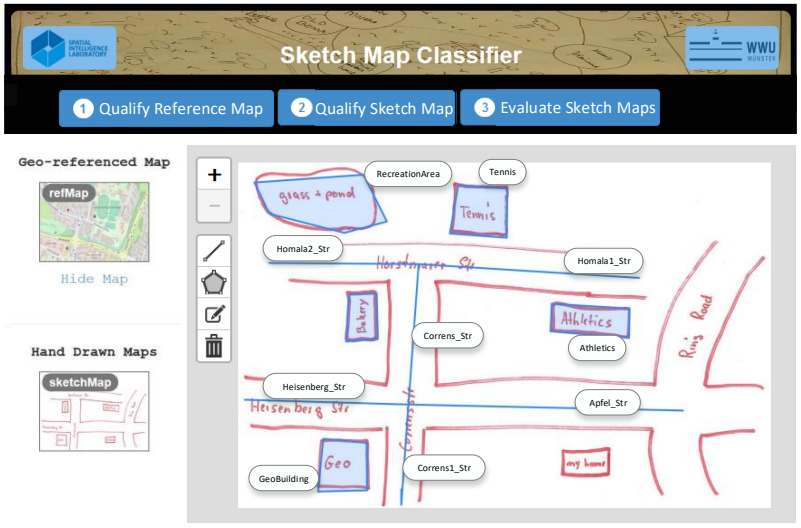
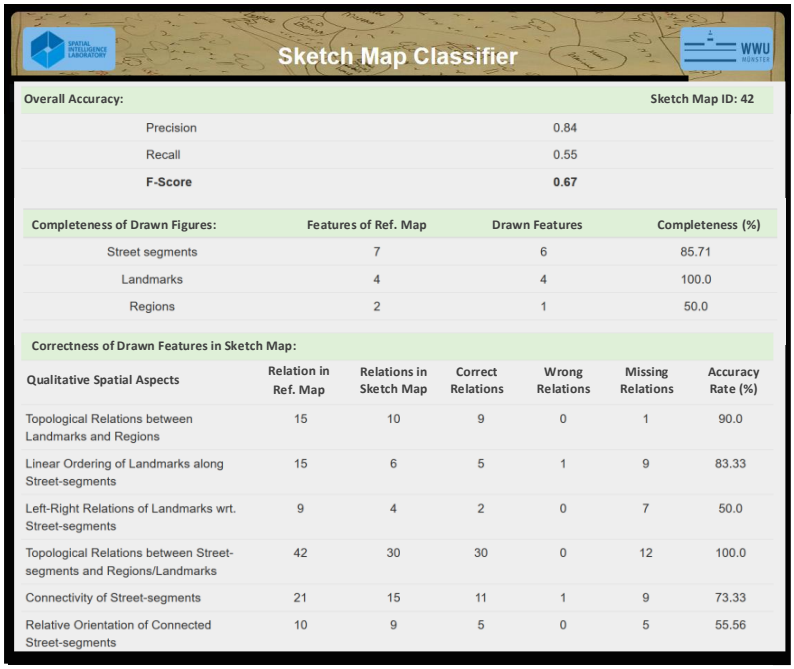


Fig.2 Step 2: Annotation of the Sketch Map (original sketch map in red, annotations in blue).

Step 3: The qualifier of the software automatically calculates the qualitative relations among all features marked in the maps. It compares all features and spatial relations found in the sketch maps to the features and qualitative relations in the reference map and calculates their completeness and correctness for each sketch map. (Fig. 3). The evaluation shows the precision and recall of all features and spatial relations found in the sketch map. Further, detailed information on the completeness of the drawn features is given: In our example, the participant's sketch map does not include the region

"SportsArea" and she mixed Mendel_Str. with Heisenberg_Str. Afterwards, the correctness of the features is evaluated by the number of correct/wrong/missing qualitative spatial relations found in the sketch map. The fact that the sketcher drew the recreationArea next to the wrong street leads to one wrong relation in "linear ordering of landmarks along street segments". The fact that Heisenberg_Str. and Medel_Str. are confused leads to 1 wrong relation in "Connectivity of Streets".

We are currently conducting a reliability study of the method and evaluate, to which extend each qualitative relation predicts the quality of a sketch map.



Overall Accuracy: — **Sketch Map ID: 42**

Precision	0.84
Recall	0.55
F-Score	**0.67**

Completeness of Drawn Figures:	Features of Ref. Map	Drawn Features	Completeness (%)
Street segments	7	6	85.71
Landmarks	4	4	100.0
Regions	2	1	50.0

Correctness of Drawn Features in Sketch Map:

Qualitative Spatial Aspects	Relation in Ref. Map	Relations in Sketch Map	Correct Relations	Wrong Relations	Missing Relations	Accuracy Rate (%)
Topological Relations between Landmarks and Regions	15	10	9	0	1	90.0
Linear Ordering of Landmarks along Street-segments	15	6	5	1	9	83.33
Left-Right Relations of Landmarks wrt. Street-segments	9	4	2	0	7	50.0
Topological Relations between Street-segments and Regions/Landmarks	42	30	30	0	12	100.0
Connectivity of Street-segments	21	15	11	1	9	73.33
Relative Orientation of Connected Street-segments	10	9	5	0	5	55.56

Fig.3 Step 3: Evaluation Results after Qualification.

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MapRecorder: Analyzing Real World Usage of Mobile Map Applications

Gian-Luca Savino[1], Miriam Sturdee[2], Simon Runde[1], Christine Lohmeier[1], Brent Hecht[3], and Johannes Schning[1]

[1] University of Bremen, Bremen, Germany
{gsavino,srunde,christine.lohmeier,schoening}@uni-bremen.de
[2] Lancaster University, Lancaster, United Kingdom
{m.sturdee}@lancaster.ac.uk
[3] Northwestern University, Evanston, IL 60208, United States
{bhecht}@northwestern.edu

Keywords: Human-Computer Interaction · Mobile Maps · Mobile Devices.

1 Abstract

Mobile map applications like *Google Maps* and *Apple Maps* are extremely popular. For instance, the annual *ComScore* report on US application usage suggests that *Google Maps* is the fifth-most-used mobile application [5], whereas large-scale user studies suggest that *Google Maps* is the fourth-most-used application in terms of total usage time [2]. However, despite their popularity, we know very little about how these applications are used within the general population, as usage data from commercial providers is not publicly available.

Studies examining application or program usage and behaviour have been receiving increasing attention in HCI thanks to the foundational background knowledge they can provide and the research direction guidance they afford (e.g. [2–4, 7–9]. However, there are a number of obstacles to the publication of these studies that limit their number. In particular, many companies do not share usage data from their applications. While the reasons for this reticence are often understandable (e.g. privacy concerns), the end result is often enormous black boxes in important areas of the literature.

This paper seeks to begin the process of shining a light on the high-profile black box that is mobile map application usage behaviour. To do so, we take inspiration from Carrascal and Church [3] and create an application that wraps the *Google Maps* mobile website. This allows us to capture rich behavioural logs whilst affording a very similar experience to the standard application. We made such a "wrapper" application for *Google Maps* called "MapRecorder", and recruited 28 participants from our local university to use *MapRecorder* for 4 weeks. We capture 483 minutes of interaction with *MapRecorder*, spanning 443 sessions. From these sessions, we are able to paint a broad picture of current mobile map application usage for our participant pool.

This work contributes the first openly available findings for mobile map application usage, collected via wrapping and logging user behaviour in *Google Maps*

with the *MapRecorder* application, and analysed across the four main interaction states of *Google Maps*: *Search*, *Place*, *Direction* and *Map-View Manipulation*.

Users demonstrated exploratory behaviour for almost 50% of their sessions with *MapRecorder*, indicating a preference for non-prescriptive methods of interaction with mobile map applications, and supporting the user-as-explorer ideal [1, 6]. This has implications for the development of mobile maps, which currently focus on text search to enable way-finding. Users also expressed search behaviours which demonstrate a preference for specific named places rather than entity classes such as "restaurants" or other near me options.

Our findings also suggest that users exhibit similar patterns of use in order to get directions to a specific location, with a high percentage of sessions displaying specific sequences of interaction between states within the map application. Additionally, there was an interaction between the user location and the place or destination of interest. The latter suggests that local users are more likely to search for places which are not within close distance (median: 8.0 km).

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