Spatial Cognition 2020/1

2-4 AUGUST , 2021

University of Latvia, 19 Raina blvd, Riga, Latvia

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Spatial Cognition 2020/1
Book of abstracts
August 2–4, 2021, University of Latvia

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GENERAL INFORMATION

August 2–4, 2021
University of Latvia, Latvia

Spatial Cognition is concerned with the acquisition, development, representation, organization, and use of knowledge about spatial objects in real, virtual or hybrid environments and processed by human or artificial agents.

Spatial Cognition includes research from different fields insofar as they are concerned with cognitive agents and space, such as cognitive and developmental psychology, linguistics, computer science, geography, cartography, philosophy, neuroscience, and education. Research issues in the field range from the investigation of human spatial cognition to mobile robot navigation, including topics such as wayfinding, spatial planning, spatial learning, internal and external representations of space, and communication of spatial information.

SC 2020/1 brings together researchers working on spatial cognition from all of these perspectives.

Initial conference was scheduled August 2020; this is the postponed version of it.

More information: *https://sc2020.lu.lv/*

PROGRAM SC2020/1

Conference and affiliated events:

Sunday, August 1 & Thursday, August 5, 2021: satellite events, workshops, and symposia

Monday, August 2 – Wednesday, August 4, 2021: main conference

Sunday, August 1
Symposium, Tutorial

15:00–19:00	Afternoon Session: Parallel Sessions, Break 17:00–17:15
	Heather Burte, Jung Eun Hong and Michael N. DeMers (Texas A&M University, University of West Georgia, New Mexico State University, USA) **Developing Geospatial Expertise** (Symposium)
	Mehul Bhatt, Jakob Suchan, Vasiliki Kondyli and Vipul Nair (Örebro University, Universität Bremen, University of Skövde, Sweden / Germany) **Spatial Cognition and Artificial Intelligence: Methods for In-The-Wild Behavioural Research in Visual Perception** (Tutorial)
19:00	Social Program

Monday, August 2
Workshop, Main conference

12:00–15:00	**Tobii Workshop on Eye Tracking research in screen-based solutions** (Workshop)
	Main conference
15:00–15:15	**Opening ceremony**
15:15–16:30	**Keynote** **Prof. Sara Irina Fabrikant** **University of Zurich, Switzerland** **Smart cartography for wise navigation assistance** Chair: Ruth Dalton (Lancaster University, UK)
16:30–16:40	Break

16:40–18:00 Session 1

Chair: Michael Peer (University of Pennsylvania, USA)

Iva Brunec, Melissa Nantais, Jennifer Sutton, Russell Epstein and Nora Newcombe
(Temple University, University of Western Ontario, Brescia University College, University of Pennsylvania, USA / Canada)
Exploration patterns and environmental structure shape cognitive maps

Kate Lawson, Robert Woodry and Elizabeth Chrastil
(University of California, Irvine, USA)
Does exploration behavior explain navigation performance?

18:00–18:10 Break

18:10–19:40 Poster session 1

19:40 Social Program

Tuesday, August 3
Main conference

15:00–16:15 Keynote

Dr. Laure Rondi-Reig
CNRS Research Director, Sorbonne University, France
Cerebellar networks of spatial cognition in rodents and humans
Chair: Nora Newcombe (Temple University, USA)

16:15–16:30 Break

16:30–18:30 Session 2

Chair: Iva Brunec
(Temple University & University of Pennsylvania, USA)

Gozdem Arikan, Peter Boddy and Kenny Coventry
(University of East Anglia, UK)
Action speaks louder than words and gaze: the relative importance of modalities in deictic reference

Snejana Shegheva and Ashok Goel
(Georgia Institute of Technology, USA)
The role of symmetry in core geometry

Max Kinateder and Emily A Cooper.
(National Research Council Canada, University of California, Berkeley, Canada / USA)
Assessing effects of reduced vision on spatial orientation ability using virtual reality

18:30–18:40 Break

18:40–20:10 Poster session 2

20:10 Social Program

Wednesday, August 4
Main conference

15:00–17:00 Session 3

Chair: Aina Puce (Indiana University, Bloomington, USA)

Jeremias Stüber, Lina Junctorius and Annette Hohenberger
(University of Osnabrück, Germany)
Tracking non-visual eye movements non-invasively: comparing manual and automatic annotation styles

Andrius Pašukonis
(Stanford University, USA)
Cognitive maps in rainforest frogs

Alina Tu and Elizabeth R. Chrastil
(University of California, Irvine, USA)
The relationship between hippocampal subfield volumes and navigation ability

17:00–17:15 Break

17:15–18:45 Poster session 3

18:45–20:00 Keynote
Prof. Steve Franconeri
Northwestern University, USA
Thinking with visualizations, fast and slow
Chair: David Uttal (Northwestern University, USA)

20:10 Conference closing

Poster session 1	Poster session 2	Poster session 3
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Poster 1.2. Błażej Skrzypulec. **Tactile field and the dual nature of touch**	Poster 2.2. Nikki Hatamian, Robert Woodry, Bailey Tranquada-Torres, Andre Yee and Elizabeth Chrastil. **The relationship between navigation abilities and mental disorders**	Poster 3.2. You Lily Cheng and Elizabeth Chrastil. **Head Direction Signals during Navigation: Comparing movement and stationary periods**
Poster 1.3. Thora Tenbrink, Anwen Williams and Constance Croguennec. **Close to my heart: Meanings associated with places near and far**	Poster 2.3. Phillip Fernberg, Brent Chamberlain, Morgan Saxon, Sarah Creem-Regehr and Jeanine Stefanucci. **'Imageable' numbers: Theory-based urban design for immersive psychometrics research**	Poster 3.3. Sungjoon Park, Brandon Watanabe and Heather Burte. **Reference frames for spatial and social thinking: Individual differences in strategy use**
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Poster 1.7. Maria Photiou, Alexia Galati and Marios Avraamides. **Spatial updating and domain expertise: the case of dancers**	Poster 2.7. Pierre Gander, Anna Jia Gander. **Based on a true story: how fictionality affects spatial cognition of events**	Poster 3.7. Margarita Zaleshina and Alexander Zaleshin. **Changes in the flight paths of pigeons based on extended spatial landmarks**
		Poster 3.8. Bingjie Cheng, Ian T. Ruginski, and Sara I. Fabrikant. **Enhancing spatial learning during navigation by optimizing landmark density on digital maps**
		Poster 3.9. Vladislava Segen, Giorgio Colombo, Marios Avraamides, Timothy Slattery and Jan Wiener. **Difficulties in extracting spatial information induce a bias towards the use of non-spatial heuristics in a spatial memory task**

KEYNOTES


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SMART CARTOGRAPHY FOR WISE NAVIGATION ASSISTANCE

Prof. Sara Irina Fabrikant

University of Zurich, Switzerland

We daily make time critical and societally relevant decisions on the go, using smart, mobile assistive geographic information displays (GIDs). How should the GIDs of the future look like, to avoid what others have coined "the technological infantilizing of society", that is, the reduction of our capacity to still make wise decisions without smart technological assistance?

I will highlight ongoing empirical research on human and context responsive GIDs used in the lab and in the wild, capitalizing on ambulatory human behaviour sensing methods (i. e., eye tracking, galvanic skin response, and EEG measurements). Based on collected empirical evidence and supported by cognition and vision theories we are guiding the process of designing smart human, task, and context responsive geographic information interfaces supporting wise navigation decisions of smart urban wayfinders.

THINKING WITH VISUALIZATIONS, FAST AND SLOW

Prof. Steve Franconeri

Northwestern University, USA

In the natural world, the visual system can identify objects, faces, and scenes rapidly and in parallel. But in the artificial worlds of data visualizations, maps, and diagrams, the more critical task is to extract spatial and magnitude relations among objects. This process is far slower and can be daunting for both students and adults. I'll use interactive visual tasks to show how relational processing can challenge our visual system, and will suggest that visual relations are limited by a serial representation similar to a sentence. Understanding these constraints leads to design guidelines and instruction techniques for information visualizations, from public data communication to STEM Education.

CEREBELLAR NETWORKS OF SPATIAL COGNITION IN RODENTS AND HUMANS

Dr. Laure Rondi-Reig

Sorbonne University, France

The ability to maintain a sense of direction and location while moving in one's environment is fundamental for our daily travels. Self-motion perception is a demanding problem in sensory integration, requiring the neural combination of visual signals (e. g., optic flow), vestibular signals regarding head motion, as well as somatosensory and proprioceptive cues. The cerebellum is adequately wired to combine the diversity of sensory signals to be monitored during self-motion and to fuel the navigation circuits. I will first describe the different pathways by which the cerebellum anatomically projects to the navigation networks. I will then illustrate how distinct cerebellar mechanisms are involved in the stability of place and direction coding depending on the availability of external sensory conditions. These results put forward a role for the cerebellum in mediating a stable hippocampal representation of place and a stable and unitary thalamo-cortical representation of direction. I will finally detail key systems-level mechanisms that support such large-scale brain connectivity during navigation or during 'offline' states such as sleep.

CONTRIBUTED TALKS

ACTION SPEAKS LOUDER THAN WORDS AND GAZE: THE RELATIVE IMPORTANCE OF MODALITIES IN DEICTIC REFERENCE

Gozdem Arikan, Peter Boddy, and Kenny Coventry

University of East Anglia, UK

Deictic communication is fundamentally multimodal. Spatial demonstratives frequently co-occur with eye gaze and physical pointing to establish joint attention of speaker and addressee (e. g. this cup; that chair). However, the relative importance of language, gesture and eye gaze in deictic reference has not this far been elucidated. We designed three online experiments, manipulating the (in)congruency in pointing, gazing and linguistic cues to establish their relative importance for demonstrative choice (Experiment 1) and choice of referent (Experiments 2 and 3). While pointing and linguistic cues significantly affected demonstrative choice (Experiment 1) and all three factors affected referent choice (Experiments 2 and 3), results show that pointing is the dominant deictic cue to demonstrative/referent choice.

Keywords: deictic communication, gesture, spatial perception, multimodal communication, language, spatial demonstratives

EXPLORATION PATTERNS AND ENVIRONMENTAL STRUCTURE SHAPE COGNITIVE MAPS

Iva K. Brunec[1], Jennifer E. Sutton[2,3], Russell A. Epstein[4], and Nora S. Newcombe[1]

[1] Temple University, USA;
[2] Brescia University College, Canada;
[3] University of Western Ontario, Canada;
[4] University of Pennsylvania, USA

When we navigate a new city, we construct a map of our surroundings by linking sensory experience to landmarks. Decades of research have focused on how we build structured knowledge of spaces we navigate (cognitive maps; [1]). In most studies published to date, the fidelity of cognitive maps was measured after a discrete training period. In everyday life, however, we often have to find our way in new places through exploration without guidance. However, as a field we have no mechanistic explanation for how exploration patterns structure cognitive maps in real time.

In the present study, we investigated how cognitive maps are formed through novel experience. Prior work suggests that not everyone successfully forms a spatial map [2]. Further, studies of real-world wayfinding suggest that environmental and architectural features shape how people navigate in the world [3]. To bridge these findings in a naturalistic behavior, we investigated whether differences in free exploration patterns predicted cognitive map quality, and how these patterns were determined by environmental features.

We analyzed participants' ($N = 84$) moment-to- moment exploration dynamics while they freely navigated around a virtual reality environment (Virtual Silcton) for 16 minutes. They were also asked to point between different buildings in the environment, and to draw an overhead map. To capture environmental structure, we used space syntax measures which describe the environment as a network graph. Specifically, we used the measure of axial integration, which provides a measure of topological proximity of each street segment to every other street segment. For each timepoint of each participant's exploration timecourse, we extracted the axial integration value corresponding to the participant's current location. We then averaged across the entire exploration period to derive a measure of average experienced integration for each participant.

The results suggested that participants who tended to explore more in high-integration areas had better spatial memory. This relationship was reflected in both lower pointing error and higher Gardony map scores. These results highlight that exploration dynamics are an important window into mechanisms underlying successful memory formation.

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Keywords: navigation, exploration, cognitive map, space syntax

ASSESSING EFFECTS OF REDUCED VISION ON SPATIAL ORIENTATION ABILITY USING VIRTUAL REALITY

Max Kinateder[1] and Emily A. Cooper[2]

[1] *National Research Council, Canada*
[2] *University of California, Berkeley, USA*

Spatial orientation refers to knowing one's location and heading direction in the environment. Little is known about how this complex perceptual and cognitive task is affected when people lose vision. We investigated the influence of simulated reduced central vision and reduced visual field on the performance of a controlled spatial orientation task in virtual reality. Reductions in vision were simulated using either blurring or field-restricting goggles. Participants with normal vision were assigned to one of three groups: control, reduced central vision (low acuity and contrast sensitivity), and reduced field (restricted peripheral vision). In two experiments, participants were disoriented within a virtual room, and then re-oriented themselves towards a remembered target. In Experiment 1, we manipulated the shape of the room (square or rectangular) and the presence/location of a salient visual feature. In Experiment 2, the room was rendered under different, sometimes dynamic, lighting conditions. We measured response times and developed a probabilistic model to quantify re-orientation precision. We analyzed the effects of experimental group and room-type on these variables. In Experiment 1, participants in the reduced field group were slower and less precise to reorient themselves; all groups were slower when presented with conflicting cues. In Experiment 2, participants in the reduced field group were again slower than the other groups, but we did not observe a difference in precision. When environment lighting was dynamic, all groups were slower to reorient. Quantitative characterizations of how reduced vision affects spatial cognition can help with the development of assistive tools that support independence.

Keywords: spatial orientation, low vision, virtual reality

DOES EXPLORATION BEHAVIOR EXPLAIN NAVIGATION PERFORMANCE?

Kate Lawson, Robert Woodry, and Elizabeth Chrastil

University of California, Irvine, USA

Spatial navigation is an important skill, but there is a large range of abilities in the human population. In particular, some people seem to completely learn an environment after a few minutes, while others struggle even after experiencing the environment many times. One possibility for this difference could be that good navigators explore differently from poor navigators. For example, they might look around more or travel further when they are learning. Here, we investigated multiple behaviors that could elucidate a relationship between exploration behavior and performance during the test. 104 participants completed a virtual maze task, consisting of two 8-minute exploration sessions where participants were encouraged to find the nine objects in the maze, followed by 48 test trials. During the test sessions, participants were told to navigate from one object to another while all objects were concealed and within a 45 second time limit. Examining the relationship between exploration behavior and test performance revealed several key findings: i) There was no relationship between distance traveled in the exploration sessions and accuracy in the test. ii) We used the standard deviation of the number of visits per object as an indicator of how evenly a participant explored the environment and found that this evenness was correlated with accuracy for only part of the exploration phase. iii) We then examined the strategy used by participants in the test session and found a decreased likelihood that participants would follow the exact route they took in the explore sessions as the test trials went on. This result suggests that participants may be learning new paths in the maze during the test session. However, the change in strategy over the course of the test trials was not related to accuracy or improvement. iv) Finally, we measured the betweenness centrality (a measure of how connected a location is to other locations in a network) of every location in the maze and found that the number of location visits for all participants was highly correlated with betweenness centrality regardless of navigation performance in the test session. Our findings indicate that behavior during the exploration period is not sufficient to explain navigation performance during the subsequent test. Future work will investigate the temporal dynamics of behavior during learning and will integrate fMRI functional connectivity data to reveal potential brain activity differences that could distinguish good navigators' exploration from poor navigators.

Keywords: navigation, virtual reality, individual differences, learning

COGNITIVE MAPS IN RAINFOREST FROGS

Andrius Pašukonis[1, 2, *]

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Remembering places and moving effectively between them is almost a universal cognitive challenge in the animal kingdom. Modern spatial cognition research successfully spans the taxonomic and disciplinary boundaries, but our understanding of the evolution of vertebrate spatio-cognitive abilities remains limited. Studying amphibian spatial cognition is crucial for understanding the homologous and convergent traits in vertebrate cognition as well as for understanding the selective pressures that shaped ancestral tetrapod spatio-cognitive abilities. Finding water for hydration and breeding is one of the oldest wayfinding tasks for terrestrial vertebrates, and it remains the key navigational challenge for most amphibians today.

South American poison frogs are terrestrial and lay their eggs on land, but parents must shuttle their tadpoles from land to small pools of water on their backs. Like many other amphibians, poison frogs navigate through complex habitat to find small pools tens to hundreds of meters away, but how frogs find their way around was until recently unknown. Over the last years, I have studied poison frog spatial cognition in the wild using miniature trackers and experimental manipulations. Over a series of field experiments, I revealed that poison frogs have well-developed spatial memory and navigational abilities. They can flexibly and reliably choose direct routes to small invisible and distant goals inside their familiar area, even when translocated experimentally. Their outstanding ability to orient is only disrupted when frogs are released in an unfamiliar place. Together, my findings suggest that poison frogs form and use large-scale cognitive maps to find optimal routes over several hundred meters in the rainforest understory. I speculate that map-like spatial memory might be more ancient and widely spread among vertebrates than previously thought.

Keywords: cognitive map, amphibians, animal cognition

THE ROLE OF SYMMETRY IN CORE GEOMETRY

Snejana Shegheva and Ashok Goel

Georgia Institute of Technology, USA

The exploration of geometrical patterns stimulates the imagination and encourages abstract reasoning, which is a distinctive feature of human-level intelligence. In cognitive science, Gestalt principles such as symmetry have often explained significant aspects of human perception. We present a computational technique for building artificial intelligence (AI) agents that use symmetry as the organizing principle for addressing Dehaene's test of geometric intelligence. Our work offers symmetry as a core principle for building AI agents capable of geometric intelligence and understanding Gestalt principles in human perception.

Keywords: artificial intelligence, cognitive science, computational perception, geometrical intelligence, symmetry, Gestalt principles

TRACKING NON-VISUAL EYE MOVEMENTS NON-INVASIVELY: COMPARING MANUAL AND AUTOMATIC ANNOTATION STYLES

Jeremias Stüber, Lina Junctorius, and Annette Hohenberger

University of Osnabrück, Germany

Non-visual eye-movements (NVEMs) do not serve the provision of visual information but are related to memory retrieval processes (Ehrlichman, & Micic, 2012; Micic, et al., 2010). Literature on "memory foraging" holds that the way our internal memory search unrolls might be similar to actual foraging movements in physical space (Hills, & Butterfill, 2015; Patten, et al., 2020). Here, we lay the method(olog)ical foundations for studying NVEMs as evidence for mental foraging in episodic and semantic cognition. Participants had to remember and report episodes of the past or imagine future episodes related to or provide a semantic description of an object, e. g., a door or key. As NVEMs are not bound to a specific location as they are during visual eye-tracking tasks and, moreover, eye-tracking might disrupt NVEMs, here, we used and compared two approaches that operate on the basis of face-centered video footage of participants, obtained from an external camera. The first approach involves manual annotation in the open-source application ELAN (Elan, 2020) according to a coding grid which divides the visual field into nine sections (plus one "other"), in the form of "pie slices" around a central region where, on the computer screen, pictures of the to be mentalized objects were presented. The second approach makes use of the open-source neural-network driven face recognition software OpenFace (Baltrusaitis, et al., 2018), allowing for the representation of the participant's NVEMs in terms of Cartesian vectors. Both annotation styles achieved good reliability quantitatively, and converged qualitatively, as shown by k-means clustering. Overall, our chief finding is best described as providing two distinct, but potentially converging approaches to the study of NVEMs. They may be used alternatively, according to the specific research question and available resources. Having laid the methodological foundation, we are now in a position to tackle the question how NVEMs are related to memory processes, in terms of "spatial cognition".

Keywords: non-visual eye movements (NVEMs), memory search, mental foraging, episodic and semantic cognition, spatial cognition, OpenFace, manual and automatic annotation styles, neurolinguistic programming (NLP)

THE RELATIONSHIP BETWEEN HIPPOCAMPAL SUBFIELD VOLUMES AND NAVIGATION ABILITY

Alina Tu and Elizabeth R. Chrastil

University of California, Irvine, USA

Navigation is a critical skill, important for finding resources and returning to safe locations. Despite its importance, there are large individual differences in navigation ability. Although studies in navigational experts and older populations have shown a relationship between overall hippocampal volume and navigation ability, this relationship in the young healthy population has recently been called into question. However, there has not yet been a consensus on whether volumes of certain hippocampal subfields can explain the variability in navigational performance amongst the young adult population. This study tested the abilities of 27 young adults to successfully navigate a new virtual desktop maze environment. After freely exploring the maze for 16 minutes, participants were asked to go from one object in the maze to another object, using the shortest route. Feedback was minimized by removing the objects during the test phase, so participants did not know if they reached the correct target. High-resolution T1 and T2 MRI brain images were obtained from the participants and automatically segmented into seven hippocampal subfields and adjacent medial temporal lobe regions via the Automatic Segmentation of Hippocampal Subfields (ASHS) pipeline. The volumes of the segmented hippocampal regions were then used to measure whether regions within the hippocampus correlate with navigation ability. We theorize that successful navigation of this maze involves pattern separation ability, since many of the hallways look similar and participants needed to discriminate between partially overlapping routes to reach the target. Thus, we hypothesized that the Cornu Ammonis 3 (CA3) and Dentate Gyrus (DG) regions may explain the differences in navigation of this population. If pattern separation is not important, we still predicted that the CA1, CA2/3, and DG volumes are correlated with the immediate recall of target objects in the maze. Preliminary results suggest that certain subfield regions may relate to navigation performance, and that subfield volumes - not just overall hippocampal volume - could be more informative to understanding the link between brain and behavior in the healthy, young adult population.

Keywords: hippocampal subfields, memory, spatial navigation, structural MRI

POSTERS


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DEVELOPMENT AND TESTING OF A TOOL FOR LEARNING STEREOMETRY AT HIGH SCHOOL

Santa Bartušēvica

University of Latvia, Latvia

The focus of the current study is to develop and support spatial thinking skills for high school students. According to a variety of research results (e. g., Uttal et al., 2013) the acquisition of spatial skills relates to successful learning in STEM fields.

In Latvian the high school program, spatial thinking and spatial skills are applied in the acquisition of stereometry (a direction of mathematics that studies geometric bodies and shapes whose points are not in the same plane). In order to learn the concepts of stereometry more productively, National Centre for Education (NCE) recommends students using various digital tools while learning the subject. NCE is a public administration institution directly subordinated to the Minister of Education and Science. One of NCE's primary functions is to develop curricula for high school education.

Remote learning in current pandemic circumstances has raised issues about the provision of self-directed learning for students, including the use of digital tools in high school curricula. For the acquisition of stereometry concepts in the mathematics program for high school students, there are several tools that can be used to visualize and comprehend spatial objects. NCE recommends MathIsFun, GeoGebra and Uzdevumi.lv as the self-learning support platforms for students.

The aim of the current research is, first, to study and compare the functionalities of the tools included in the high school mathematics program; second,, to provide an overview of today's major research results; third, develop empirically supported guidelines for creating a new tool that includes the missing functionalities. The design of the study involved a comprehensive theoretical summary of the required functions for stereometry learning tools as well as an overview of the requirements for the high school mathematics program. The empirical part of the study included (a) the testing of the program on high school students; (b). survey concerning students' opinion and usage habits for the support tools for learning stereometry included in the current mathematics program. The methods used in the study were developed based on research on usability testing with adolescents in human-centered design and adaptation of selected UX analysis methods. The study applied a 5E usability development approach to assess the tools. A total of 78 students aged 16 to 19 in the 10th, 11th and 12th grades of Cesis State Gymnasium were selected for the research sample.

In the study, students were given a specific task to be performed using one of the proposed stereometry learning tools. In total, the students completed 3 tasks. In each of the tasks, it was recommended to use one of the support tools offered by NCE. The tasks were compiled based on the course of stereometry acquisition in secondary schools. In order to ensure as equal conditions as

possible, the students performed the tasks simultaneously, divided into groups. After completing the tasks, the students were given an electronic questionnaire, in which the Likert scale was used to evaluate the tool used in each of the five dimensions of the 5E model. Before evaluating the tool, each of the dimensions of the 5E model was explained to the students so that they were able to evaluate the functionality of the tool more objectively. The electronic survey has been supplemented with questions to find out what are the daily habits of students in their usage of stereometry learning tools. The obtained results were evaluated based on the amount and accuracy of the work done. After performing all three tasks each task was rated on a percentage scale. The task evaluation was based on the same criteria that are used in the high school curricula.

In general, the stereometry learning tools recommended by the NCE contain important functionalities; however, these tools do not provide a complete visualization of the concepts included in the high school mathematics program. Additionally, these tools lack intuitive UI implementation techniques for students. In all 5E categories, the participants of the study rated Uzdevumi.lv the highest (average 3.89). The MathIsFun tool was also rated positively by students, giving an average score of 3.80 in 5E categories. The Geogebra tool performed its functions less efficiently, receiving the lowest rating of 2.18. Although Geogebra offers a wide range of functionality and includes interactive spatial visualizations, the complex implementation of the UI prevents students from taking full advantage of all the functionality offered by the tool. The problem of insufficient learning tools could be eliminated by focusing on the requirement of the student's education curriculum. When considering the development of learning tools, the student's abilities, knowledge, previous experience and requirements should be evaluated before moving on to the development.

Keywords: STEM, stereometry, spatial skills, visualization

ENHANCING SPATIAL LEARNING DURING NAVIGATION BY OPTIMIZING LANDMARK DENSITY ON DIGITAL MAPS

Bingjie Cheng, Ian T. Ruginski, and Sara I. Fabrikant

University of Zurich, Switzerland

Introduction: Navigation aids that employ GPS have been increasingly used to facilitate wayfind- ing. However, a large body of literature has found that use of GPS negatively affects spatial learning of traversed environments. Considering that millions of citizens navigate everyday using digital devices, more research is needed to re- duce and identify reasons for the negative effects of GPS device use on spatial learning.

Landmarks are identifiable features of the environment that support navigation and spatial learning. Even with the help of landmarks, navigation and spatial learning are both mentally demanding tasks that tax cognitive resources and increase cognitive load. Cognitive capacity theories suggest that learning performance drops when the number of learning items exceed an individual's limited cognitive capacity.

We thus hypothesize that 1) EEG cognitive load will increase when the number of landmarks on a digital map increases, and that 2) spatial learning performance will increase when the number of landmarks increases until the number of landmarks exceeds cognitive capacity, at which point spatial learning performance will decrease.

Methods: To test these hypotheses, we will recruit 24 male and 24 female adults. We will assess participants' navigation abilities by the using the Santa Barbara Sense of Direction Questionnaire. Participants' individual spatial memory span will then be measured using the Corsi block-tapping task. Next, participants will be asked to navigate to a specific destination in three virtual areas with the assistance of a digital map. The three maps will feature three within-subjects levels of landmark density (two, four and six landmarks on each map respectively).

Participants' cognitive load during the Corsi task and navigation will be measured by a 64-channel EEG device. EEG theta power will be extracted as an indicator of cognitive load [1]. After each navigation trial, participants' spatial knowledge of the environment will be tested with the Judgements of Relative Direction task.

Preliminary Results: One participant was tested with EEG during the Corsi task. Preliminary EEG results show that the power of the theta band (4-7 Hz) from the parietal lobe increased during encoding and recall phases of the Corsi task. Specifically, the power of the theta band during the recall phase was higher than during the encoding phase. Moreover, the amplitude of the theta power of the parietal lobe was positively correlated to the level of cognitive load (i. e., the number of highlighted squares) during the recall phase. These preliminary results indicate that theta power could be a reliable marker to measure the level of cognitive load.

Conclusion: This study aims to improve the understanding of landmark density and cognitive load during digital map assisted navigation and spatial learning. The results will contribute to the development of a neuroadaptive navigation system that enhances pedestrians' spatial learning.

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THE EFFECTS OF MOVEMENT AND SPATIAL ACTIVITIES ON REAL AND IMAGINED SPATIAL UPDATING

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Abstract. Imagined movement, especially rotations, results in less accurate spatial updating than real movement, but we know little about individual differences. Dancers and non-dancers completed a real and imagined triangle completion task with and without body-based information. Errors on imagined trials were higher than real trials, but contrary to our predictions there were no effects of expertise. Spatial activities related to better performance on the imagined task.

Keywords: spatial updating, imagined movement, movement experts

HEAD DIRECTION SIGNALS DURING NAVIGATION: COMPARING MOVEMENT AND STATIONARY PERIODS

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Head direction is crucial in human wayfinding, but whether head direction signals can be classified in the brain when navigating in a complex environment, and how this signal relates to navigation performance remain open questions. In an fMRI study, we tested participants in a cardinal-direction-aligned virtual maze. The navigation task consisted of exploration and a test phase. During the 16-minute exploration, participants freely explored to find 9 objects located in the environment and were instructed to remember their locations. For each of the 48 test trials, participants started at one object and were directed to go to another object, without feedback and with a limited time. Movement in both exploration and test alternated between stationary decision points, where the participant decided whether to proceed straight or to turn and move to the next position or orientation. We conducted an intra-subject multivariate pattern classification for the four head directions (north, south, east, west) in five a priori regions of interest (ROIs) in translational movements and stationary decision-making periods during the exploration phase.

Our preliminary results suggest that during translational movement, we were able to discriminate between head directions in the retrosplenial cortex, extrastriate cortex, precuneus, early visual cortex, but not in the thalamus. Furthermore, we observed a relationship between an individual's brain signals' classification strength and their subsequent navigation performance. Preliminary correlations (N=21) found that some were positive, while others were negative, but they did not reach significance with the current sample size.

During the stationary decision-making period, however, we could not discriminate between head directions in the retrosplenial cortex, extrastriate cortex, precuneus, early visual cortex, or thalamus. Additionally, we observed positive correlations between an individual's brain signals' classification strength and their subsequent navigation performance in all areas of interest, but they did not reach significance.

This study indicates that there are differences between the basic head direction signal during stationery decision-making and translational movement. Specifics of the task need to be considered when assessing head direction signals for successful navigation in a complex environment.

Keywords: individual differences, multivariate pattern classification, navigation, decision-making, fMRI

MINI-MAPS AID SPATIAL COGNITION WITHIN VIRTUAL WORLDS

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Virtual environments are archiving high levels of realism, thanks to advances is graphics cards and processing power. Users can now move though these virtual worlds freely and fluidly. For a cognitive science point of view, questions arise of how can the orientation and wayfinding in these virtual space be most efficiently supported. Wayfinding has indeed become a cornerstone for the enjoyment of many virtual experiences, such as virtual tours (e. g. of a museum) or gaming (adventure games, role-playing games, blobbers, ego-shooters, stealth games, vehicle simulations, etc.).

When such a explorable virtual environment is presented, often the exploration takes place using the so-called first-person view. In this study, spatial cognition in first-person view with and without an extra aerial representation of the surroundings is compared. The accuracy of the mental representation of the space in each experimental condition is accessed through oral retellings of the traversed space. We operationalized the informative content and linguistic coherence of the texts produced. A database of 204 route directions was collected empirically. Adult German native speakers (N=200) saw a video three times. The video showed a route through corridors of a building filmed in the first-person perspective. In the one condition the participants only saw the video, in the other condition a miniature map of the area was added next to the video. A moving red dot showed the current position of the viewer on the map. Afterwards, they were asked to write a text explaining how to get from the beginning of the route to the end.

The use of "mini-maps" is widespread in real-time strategy, ego-shooters and MMORPG video games, often being placed at a small portion of a screen corner. The purpose of the experiment was to empirically test if the mini-map actually aid users in orienting themselves within the virtual world, which is their intended use in games. It was hypothesized that the added information provided by the mini—map would lead to more informative and accurate route directions in that experimental condition. It was further hypothesized that the differences in the informational content would be more pronounced on so-called decision points along the route, i. e. points along the route where the moving person has many possibilities to keep moving, so it would be advisable to re-orientate the person to avoid them taking a wrong turn. Results of the experiment support the hypotheses: The placement of landmarks at the different segments of the route as contained in the texts was operationalized to account for the conceptualization of the surroundings. Results show that the video only condition is less likely to successfully lead to the final goal. The informative content and linguistic coherence of texts produced in the video and map condition were higher as in

the other condition. While differentiating on the parts of text referring to the different route segments, significant differences on the placement of landmarks were found on four segments, corresponding to the decision points along the route. The proposed explanation for the results is that the first person view of the video is akin to a horse wearing blinkers, because it restricts the possibilities of looking to the side (or the rear). In this way participants often fail to identify decision points as such, and accordingly not specially mark this points along the route verbally. The results shows that persons can successfully integrate a second channel of spatial information and use it e. g. to compose a coherent text; even then both channels use different perspectives. In this way, the benefits of the added spatial information provided by the mini-map surpass the added cognitive effort of integrating both information channels. This work contributes to an emergent literature on the way humans represent and use spatial knowledge in virtual environments.

Keywords: mini-map, first-person view, route directions, decision points, spatial cognition

‘IMAGEABLE’ NUMBERS: THEORY-BASED URBAN DESIGN FOR IMMERSIVE PSYCHOMETRICS RESEARCH

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Wayfinding and navigation are complex processes that combine spatial memory and decision-making amidst a wide range of environmental contexts. A common psychometric approach used to measure navigational abilities in large spaces is to assess the precision with which an individual can recall specific objects, landmarks or even retrace routes. However, these are limited in explaining how individuals create meaning from the relationships and hierarchy of elements in a dynamic 3D geographic space. Our work seeks to fill that gap by demonstrating the role landmarks play in improving navigation of urban spaces and arguing that place attachment, the emotional bond between person and place, is associated with how individuals encode spatial memory of the configuration of different elements in an environment (Bruns and Chamberlain 2019; McCunn and Gifford 2018). It has inspired us to construct a new approach to assess how encoding happens at the scale of districts, neighborhoods, or communities. We believe there is untapped potential for exploring spatial memory at these scales by hybridizing foundational urban design theories with emerging technological approaches to psychological experimentation.

Numerous theories attempt to link the role that urban design plays in one’s construction of a cognitive map; for designers and planners, none eclipses the significance of Kevin Lynch’s “Image of the City” (1960). In it Lynch offered a framework of five spatial elements which are foundational to the construction of a cognitive map: *paths, nodes, districts, edges, and landmarks*. It posits that the cities where association of these elements is strong evoke meaningful images in the mind of their inhabitants; images that facilitate navigation and foster attachment to place. This seminal work influenced a generation of speculative urban design and inspired further research in spatial cognition across many disciplines. In reflecting on its impact, Lynch was unimpressed with what he saw in his own field as the inappropriate interpretation of his methods as a predictive planning technique rather than a strategy for making cities more responsive to their citizens and affecting actual public policy (Lynch 1984). He inferred from his observations that the concept of imageability would be relegated to mostly qualitative exercises, leading to a lack of systematic measures that are critical for policy adoption. We argue that recent advances in design, computation, and psychological research methods offer opportunities for a quantitative evaluation of the efficacy of his framework – and that this framework has much to offer spatial cognition scientists working within urban environments.

Our work builds on Lynch's framework in the context of wayfinding, whereby we employ sketch mapping and spatial quantitative measures to evaluate the role different elements play in constructing spatial memory. Our empirical approach aims to provide a mechanism to systematically measure urban space and design to directly influence public planning policy (Lynch 1984). For the past several years, our project team has developed approaches to measure how individuals recall elements in of urban environments following Lynch's theories. One of those approaches is to recall navigating through a 3D virtual environment (VE) using sketch maps encompassing a wide range of *path*, *landmark* and *district* measures.

We introduce a design process that rests at the intersection of theory-based environmental design, 3D gaming environments, and spatial cognition measurement. This VE-based approach utilizes gaming engines for designers to build a virtual world that adheres to prescriptions of urban design 'best practices', and then embed empirical structures to test the influence of Lynch's framework elements using spatial cognitive measures in a precisely controlled context. The design process follows several iterative steps: 1) identify key research questions and hypotheses, 2) identify critical measures, 3) determine environmental and scale controls, 4) build virtual world schematic (*districts, edges, nodes*), 5) develop road network (*paths*), 6) implement *landmark* locations and assets, 7) implement buildings and vegetation, 8) integrate user experience. Thus far, initial experiments tested the significance of strategically placing landmarks into a gridded small town center environment, a typical archetype of the American Great Plains (Bruns and Chamberlain 2019). Our latest project is a dense urban environment simulating 'organic city' configurations like those theorized and analyzed by Lynch (1981) and Kostof (1991) in their works on urban form. It also explores how the same spatial concepts can be coupled with principles of landscape legibility (Bell 1999; Ode et al. 2008) and replicated in wildland environments, giving us a controlled, interchangeable world structure that contributes to the discourse on the 'separate from nature' concept. To control experience across these VEs, we have made the road network transferrable across scales and experiences, merged *edges* and *nodes* to be thresholds between *districts*, and designed *districts* to maintain spatial balance, ratios, overall shape, and circulation (*paths*) between different scales and environment types.

These controls allow for the use of quantitative measures to compare real (our schematic) and perceived (by participants) locations and experience of Lynch's five elements. We design the environments in parallel with metrics such as bidimensional regression for *landmarks* (analysis of similarity between two configurations of points), minimum bounding geometry for *district* locations (smallest measure of where all points lie) and various shape indices to determine *district* shape.

Adopting Lynch's design framework with a focus on step 4 (VE schematics), has offered a way to advance spatial cognition measures. The ability to assess how a participant recalls and infers district boundaries lays the foundation for a new spatial memory construct. Most current metrics focus on precision of recall of elements seen. However, boundaries of districts can be inferred based on a limited

experience of place offering an ability to measure a general accuracy of memory and inference. The combination of the design process with Lynch's framework, creates a way to control for district experiences across virtual environments and scales. This structure provides a basis for forthcoming cognition studies with the hope that results will provide both meaningful empirical commentary on the significance of Lynchian design theory as well as further understanding of the nature of human cognition in complex, novel environments.

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BASED ON A TRUE STORY: HOW FICTIONALITY AFFECTS SPATIAL COGNITION OF EVENTS

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The visual perspective, or vantage point, from which one sees events imagined or remembered has been studied in recollection from memory and when thinking about future scenarios. A number of factors have been found to influence whether events are experienced from a field persepctive (through one's own eyes) or from an observer visual perspective (St. Jacques, 2019). However, the factual/fictional dimension of events and its possible effects on visual perspective has not been addressed in previous research. Earlier research on fiction reading has found that the factual/fictional distinction does not affect reading behavior or the experiential aspects of reading (Hartung et al., 2017). On the other hand, other studies suggest that constructive processes may be involved to a greater degree when the events read are fictional (Altmann et al., 2014), which could influence visual perspective. Differences between factual and fictional events may surface in remembering (in contrast to in the reading situation). In the present study, we bring together research on visual perspective and fiction. We studied visual perspective in both imagination and remembering of factual and fictional events. In an experiment, 153 participants were instructed to read and imagine the events of four short stories in English labelled as either fact or fiction. Stories varied regarding first/third-person narrative perspective and emotional valence. Results show that the factual and fictional situations are highly similar in terms of visual perspective of mental imagery, consistent with earlier research on fiction reading. Further, visual perspective does not seem to be determined by the narrative perspective used in the story. Differences between fact and fiction in observer perspective locations (from which vantage point the participant experiences the event) indicate that readers of fact are more visually aligned to the person in the story.

Keywords: visual perspective, memory, imagination, fiction

THE RELATIONSHIP BETWEEN NAVIGATION ABILITIES AND MENTAL DISORDERS

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This study examined the relationship between aspects of navigational ability and behavioral traits associated with various mental disorders. We propose that navigational ability may utilize the same brain circuitry that has dysfunction in certain mental disorders and may be a beneficial early marker for these disorders. This study was inspired by the Research Domain Criteria (RDoC), a framework outlined by NIMH to study the basic dimensions of functioning that span the range of behavior from normal to abnormal. For example, we hypothesized that spatial perspective taking, which is important for navigation, could be associated with social perspective taking in disorders such as autism spectrum disorder or eating disorders. To test this question, participants recruited online through Amazon Mechanical Turk (n>200) completed two web-based spatial cognition tasks and a self-report measure of navigational ability. They also completed a battery of standardized questionnaires to capture non-pathological ranges of mental disorders. The Open Field Task (OFT) is similar to a virtual Morris water maze. It tests an individual's ability to recall, locate, and navigate to four hidden objects scattered in an open field environment from a first-person perspective. The Spatial Orientation Task (SOT) tests spatial perspective taking by imagining different viewpoints in a layout of objects. The Santa Barbara Sense of Direction Scale (SBSOD) is a self-report measure of navigational ability. The behavioral questionnaires assessed pathological and non-pathological levels of mental disorders such as depression, anxiety, autism, and schizotypy to examine individual variability within the healthy population. Preliminary correlations indicate relationships between navigational ability and several mental disorders. In particular, obsessive-compulsive disorder and impulsivity showed relationships with performance errors in the SOT. These preliminary results also identify relationships between apathy as well as eating disorders and errors in the OFT. Together, these findings suggest that the circuitry for navigation and certain mental disorders could overlap, leading to new avenues for understanding these disorders.

Keywords: hippocampal subfields, memory, spatial navigation, structural MRI

WHY KNOW MYSELF? FLEXIBLE BEHAVIOUR AND THE NEED FOR SELF-MODELLING

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In this paper I argue that some forms of the capacity for behavioural flexibility entail a specific kind of representation, a self-model. This means that systems with that capacity, among them human beings, must have self-models. In its basic form, the capacity for behavioural flexibility allows a system to respond to the same sensory stimulus differentially, depending on the values of parameters with which it represents the world. On seeing a street, I might cycle straight ahead or take a sharp turn left – depending on whether I represent it to blocked off just around the corner. More advanced forms expand on this. Self-models are a form of self-representation in which states are represented by placing a token in a model of the world. The relations this token bears to the modelled features represent the system's states (Ismael 2007). A useful analogy are smartphone navigation apps, where a central blue dot indicates the location of the user. With my contribution I hope to, first, clarify the cognitive advantage of subject/object differentiation. Second, I want to improve on Ismael's very promising proposal by extending it to non-map-like formats of representation and system states other than spatial and temporal properties. This, I hope, should convince authors in the burgeoning literature on self-models that paying close attention to broadly 'Ismaelian' accounts of self-modelling – rather than the much more widely discussed proposals by Metzinger (2007) and Hohwy and Michael (2017) – could significantly advance our understanding of the mechanisms and uses of self-representation.

Keywords: self-models, maps, self-representation, representation, flexible behaviour

DIRECTIONAL SENSE IN FAMILIAR ENVIRONMENTS MISALIGNED WITH THE CARDINAL DIRECTIONS

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The ease or difficulty with which people navigate through an environment depends on a variety of factors: their environmental familiarity, their physical relationship to that environment, their perception of their own sense-of-direction, etc. In order to better understand how these factors combine to impact to navigational success, recent research has investigated how those factors influence directional sense. Directional sense refers to the skill with which individuals can identify, maintain, and compare allocentric headings or facing directions that are fixed within an environment, e. g., cardinal directions, and is foundational to navigational success (Burte, et al., 2018). Directional sense is impacted by global orientation cues and environmental familiarity (Burte & Hegarty, 2012), use of allocentric or egocentric reference frames (Burte & Hegarty, 2013), an individual's physical relationship within the environment, e. g., oriented versus disoriented, seated versus lying down (Burte & Hegarty, 2014), and is impacted by an individual's gender, self-reported sense-of-direction, and knowledge of environmental distances (Burte, et al., 2018). One potential factor impacting directional sense that has not previously been investigated is misalignment with the cardinal directions. All previous research has been conducted in environments that are aligned with the cardinal directions and, by extension, have used experimental stimuli that are aligned. In the current research, we investigated directional sense in an environment that is misaligned with the cardinal directions. Texas A&M University students participated in a two-part experiment. The first part included demographics, self-reported sense-of-direction measures, and environmental familiarity measures. The second part was an experiment in which participants were trained on and then completed the Relative Heading task, a measure of directional sense. The experimental stimuli used the Texas A&M campus which is aligned with the intercardinal directions (i. e., northeast, southeast, southwest, northwest). This experiment will elucidate whether or not the factors that impact directional sense within environments aligned with the cardinal directions have the same impact on directional sense within environments misaligned with the cardinal directions.

Keywords: navigational abilities, directional sense, individual differences, sense-of-direction, environmental familiarity

DOES THE MOVEMENT PATTERN OF NON-VISUAL EYE MOVEMENTS DURING EPISODIC VS SEMANTIC MEMORY TASKS CORRESPOND TO LÉVY FLIGHTS?

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Non-visual eye movements (NVEMs) during recall give insight into mental processes (Hiscock and Bergstrom, 1981; Ehrlichman et al., 2007). Fixations have been mapped to active recall and saccades to mental search (El Haj & Lenoble, 2018; Ferreira, Apel & Henderson, 2008). An optimal form of random search are Lévy Flights with a step length corresponding to a Lévy distribution (Viswanathan et al., 2000). If foraging through memory is represented by saccades, the saccade length depicts the foraging path, which can take on a Lévy Flight pattern.

This paper investigates the spatio-temporal distribution of the NVEMs during episodic and semantic memory tasks and examines if they correspond to Lévy Flights. Fixations were classified in raw NVEMs data gathered in a previous episodic vs semantic recall study and the distance between successive fixations was calculated for the three memory conditions – episodic past vs episodic future vs semantic memory. Lévy, lognormal, gamma and normal distributions were fitted to the distance data for each memory condition showing the best fit for the lognormal distribution. Since Lévy distributions have a power law-like tail with an exponent between 1 and 3 a power law distribution and lognormal distribution was fitted to the tail data. For larger amounts of tail data a power law in Lévy range fits the data better than a lognormal distribution. These results replicate previous findings by Patten et al. (2020) for inter-retrieval intervals during category recall.

It can be assumed that heavy tailed distributions represent foraging processes in a mental space during memory recall. Similar results across the three memory conditions lead to the conclusion that the memory retrieval process embodied by NVEMs seems to be the same for all forms of declarative memory on some fundamental level.

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Keywords: non-visual eye movements (NVEMs), Lévy flights, declarative memory, semantic vs episodic memory, mental foraging, fixation classification

EMBODIED SPATIAL KNOWLEDGE ACQUISITION IN IMMERSIVE VIRTUAL REALITY: COMPARISON OF DIRECT EXPERIENCE AND MAP EXPLORATION

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Investigating spatial navigation in virtual environments allows including embodied interaction under highly controlled research conditions, thus closing the gap to real-world navigation. Furthermore, it enables to study spatial learning with different sources of information. Therefore, we designed a large virtual city and investigated spatial knowledge acquisition by three spatial tasks after 90 minutes of direct experience in the virtual environment. We compared these results with those of participants who explored the city with an interactive map (König et al., 2019). Our results suggest that survey knowledge measured in a straight line pointing between houses resulted in better accuracy after direct experience in VR than tasks directly based on cardinal directions and relative orientations. In contrast, after map exploration, the opposite pattern evolved. Further, we found an alignment to north effect after exploration by an interactive map, but not after VR exploration. Independent of the exploration source, time for cognitive reasoning, while responding in the spatial tasks, and better familiarity of houses increased task accuracy. Unexpectedly, our results revealed the same pattern for distances after VR and map exploration with a distance effect only in judging relative orientations of houses with a spontaneous response. Performance after 90' direct exploration in VR was still far below performance after living in a city for at least 1 year (König et al., 2017), making a direct comparison difficult. Nevertheless, learning in VR and in the real world both lead to highest performance in the pointing task and thereby differ from the observations after map learning.

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THE INFLUENCE OF OTHERS' ACTIONS ON PERSPECTIVE TAKING

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During social interaction and coordination with other people we share the same environment, are surrounded by the same objects, and often see the same things as others see. However, how we are situated within our surroundings and the perspective from which we see objects always differs from that of others. To judge where objects are located relative to others, people engage in mental body rotation, imagining themselves in others' location (Hegarty, 2004; Kessler & Thomson, 2010). However, little is known about how observing others engaging in goal- directed action influences the ability to take their perspective.

The experimental work presented here investigated how taking the perspective of a person differs from taking the perspective of an inanimate object and, further, whether people are faster when taking the perspective of a person who is acting on an object compared to a person who is sitting still. We hypothesised that the possibility for bodily mapping provided by the presence of another person, and action simulation processes triggered by observing someone acting, both will facilitate perspective taking.

We conducted six online experiments. The first two experiments (N=157) investigated differences in reaction time patterns between taking the perspective of a person sitting at different angles at a round table and taking the perspective of an empty chair positioned at the same angles. Participants were shown photograph stimuli and asked if a specific object was on the right or on the left side of the person/chair. The experiments had a mixed design with the between-participant factor condition ('Person' and 'Chair Only') and the within-participant factor angle (seven different angles: 45, 90, 135, 180, 225, 270, 315). The findings showed that taking the perspective of the person was much faster than taking the perspective of the chair. These differences were highest at the highest angular disparities.

Further, in Experiments 3 to 6 (N=154, within participant design) we investigated whether observing an object-directed action would facilitate perspective taking. In the 'No action' condition stimuli pictures showed a person sitting still at a round table with either both hands on the lap or with one hand resting on the table. In the 'Action' condition, stimuli pictures showed a person acting towards one of the two objects. The results showed that participants were faster in the 'Action' condition compared to the 'No Action' condition and that it was harder to take the perspective for higher angles in both conditions.

Taken together, the results show the importance of bodily mapping in computing visuospatial perspective as well as the facilitatory effect of seeing another person acting when we take their perspective.

Keywords: perspective, perspective taking, visuospatial perspective, action perception, action simulation, mental rotation

LEARNING PATHS FROM REAL NAVIGATION: THE ADVANTAGE OF INITIAL VIEW, CARDINAL NORTH AND VISUOSPATIAL ABILITY

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Background: Spatial cognition research strives to maximize conditions favoring environment representation. Navigation is a complex process where space is experienced from an egocentric viewpoint (self-to-object relations). A spatial representation's orientation depends mainly on the learner's initial view. The representation can be integrated with allocentric information (object-to-object relations; Meilinger et al., 2015; McNamara et al., 2003). In navigation, allocentric information can be expanded, in the absolute sense, using world-based information, such as when cardinal points are taken for reference in environment representations. Cardinal points seem to influence a representation's proprieties of familiar environments (Tlauka et al., 2011; Frankenstein et al., 2011). There is less evidence of the role of Cardinal points for environments newly acquired by navigation. This study examined how initial (egocentric) navigation headings interact with allocentric references, in terms of world-based information (such as cardinal points), in forming new environment representations. The role of individual visuospatial factors was also examined, given their relevance to environment representations (Hegarty et al., 2006; Meneghetti et al., 2016).

Method: Ninety-one undergraduates took an unfamiliar path (330 m long) in a nature park in two learning conditions: 46 walking from cardinal south to north (SN learning); 45 from cardinal north to south (NS learning). Path recall was tested with SN and NS pointing tasks. At the entrance to the park, the experimenter asked participants to point in the direction of cardinal north. Participants were then told they were at the north or south gate, in the NS- or SN-learning conditions, respectively. After that, they walked through the park (with the experimenter just behind them), identifying 8 landmarks visible from the path. In the SN-learning condition, the initial view (personally north-up) and the compass north-oriented information were aligned, whereas the NS-learning condition prompted a potential misalignment between the initial view (personally north-up) and the compass south-oriented information. Perspective-taking ability and self-reported sense of direction were also assessed.

Results: Most participants could indicate cardinal north in the environment considered. Linear models showed a better performance (fewer degrees of error) for SN learning than for NS learning, and for SN pointing than for NS pointing. The learning condition x pointing interaction proved SN pointing more accurate than NS pointing after SN learning, while SN and NS pointing accuracy was similar after NS learning. When participants walked northwards (SN-learning), their performance was better for SN pointing than for NS pointing, but when participants walked southwards (NS-learning), their performance in SN and NS

pointing was similar. Concerning the role of spatial factors, only perspective-taking ability (not sense of direction) predicted pointing accuracy.

Conclusions: These results indicate that initial headings aligned with cardinal north prompt north-oriented representations. No clear orientation of the representation emerges when the initial heading is aligned with cardinal south. Environment representations are supported by individual perspective-taking ability. These findings offer new insight on environmental and individual factors facilitating environment representations acquired from navigation.

ENVIRONMENTAL LEARNING AND INDIVIDUAL SPATIAL FACTORS: THE ROLE OF SELF-EFFICACY

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Background. In spatial cognition domain, of particular interest are individual spatial factors (self-reported and cognitive abilities) that may contribute to greater success in environmental tasks. Among these factors self-efficacy is defined as personal judgements of one's abilities to accomplish a task and execute actions, and these beliefs predicts performances in cognitive tasks. There are few evidences on the relationship between environmental learning and motivational factors, such as spatial self-efficacy, meant as personal beliefs of one's ability to accomplish environmental tasks. Recent studies, using a wayfinding self-efficacy questionnaire (Mitolo et al., 2015), showed that spatial self-efficacy is positively related with the ability to find a shortcut in a virtual environment, especially in more complex environments (Pazzaglia et al., 2018, 2017). One method for measuring spatial self-efficacy has been the use of questionnaires assessing self-efficacy in achieving performances in everyday environmental tasks. However, it is worth noting that self-efficacy and performance predictions depend on a set of representations of tasks and tasks context (Hertzog & Dixon, 1994). Thus, it would be interesting to examine whether self-efficacy, assessed immediately before the performance of a certain environmental task (task-specific self-efficacy), can affect its performance.

Aim. The main aim of this study is to investigate the relationship between spatial self-efficacy assessed before performing different environmental tasks and their performance. We examine also the relationship between environmental performance with other self-reported spatial measures (i. e., sense of direction, spatial anxiety and general spatial self-efficacy) and spatial abilities.

Method. 114 young adults (Mage = 23.93 SD = 4.48) learned a route in a virtual environment. Afterwards each participant was required to i) retrace the route (route retracing) ii) indicate the direction of landmarks (pointing) and iii) locate landmark's positions on a sketch map (locating landmarks). Perceived self-efficacy referred to the task was measured immediately before each spatial task, after the instructions. Spatial self-reports were assessed using questionnaires on spatial anxiety, sense of direction and general spatial self-efficacy, while spatial abilities were assessed with two cognitive tasks.

Results. The influence of the variables on the performance in spatial recall tasks (route retracing, pointing and locating landmarks) was examined using generalized linear regression models. A stepwise approach was adopted to enter the predictors in the model. Results showed that self-efficacy assessed before the tasks (task-specific self-efficacy) together with spatial abilities were the statistically

significant predictors in route retracing and locating landmarks. Moreover, sense of direction and spatial abilities predict performance on pointing task.

Conclusion. Our findings showed that, along with spatial abilities, self-efficacy assessed before environmental tasks became prevalent in predicting the performance in retracing routes and locating landmarks indicating that task-specific self-efficacy may have a role in explaining spatial learning performance.

Keywords: environmental learning, spatial self-efficacy, individual spatial factors

IS ADDRESSABLE MEMORY REQUIRED FOR SPATIAL COGNITION?

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This paper investigates the computational basis of the temporal and spatial cognition that underlies certain animal behaviours. For example, ants, when they find food, are able to encode the compass direction which takes them back to their nest. In their (2009) book, Memory and the Computational Brain (MCB), Gallistel and King articulate a classicist view: animals must do this using a symbolic, addressable, read-write memory. Here we challenge this view, arguing that complex behaviour can be explained by computational mechanisms which do not need to look like addressable random-access memory.

Keywords: memory, representation, spatial cognition

REFERENCE FRAMES FOR SPATIAL AND SOCIAL THINKING: INDIVIDUAL DIFFERENCES IN STRATEGY USE

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People use both egocentric and allocentric reference frames when thinking about space and social situations. In the spatial cognition literature, reference frames pertain to the different ways people use perspectives when thinking about the self and other objects in the environment. With egocentric reference frames, we use our own perception and bodily orientation. With allocentric reference frames, we use internal representations (e. g., mental maps) of the environment (Burgess, 2008). Similar concepts exist in the theory of mind literature where egocentrism refers to people's proclivity to assume that their own knowledge is commonly shared (Nickerson, 1999). In contrast, allocentric perspective is thought to be the opposite, where people make judgements or behave without considering other's differing knowledge states (Akimoto et al., 2012). The two literatures clearly share a similar conceptualization of reference frames. The similarity seems to lie in people's ability to remove themselves from the center of focus and evaluate the situation from an external perspective. However, the nature of the relationship between the two conceptualization of reference frames is currently unknown. One is involved in a variety of spatial activities (e. g., navigation, STEM learning) while the other is often relegated to a more social or interpersonal purview. With findings that suggest neural structures involved in spatial cognition can accommodate for nonspatial processes such as interpersonal relationships (Peer et al., 2020), this study is motivated to explore commonalities between the two conceptualization of reference frames. Specifically, we explore how individual differences in personality and anxiety effects people's tendency to use egocentric and allocentric reference frames during a spatial perspective taking task and in a false belief task. We will discuss our findings and how they provide a starting point to establishing a more unifying conception of reference frames.

Keywords: reference frames, spatial thinking, theory of mind, egocentrism, individual differences, personality, anxiety

SPATIAL UPDATING AND DOMAIN EXPERTISE: THE CASE OF DANCERS.

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Dancers are a unique group of individuals who routinely engage in coordinated highly skilled performances with others in the immediate environment. Previous research suggests that, compared to non-dancers, dancers have superior cognitive and motor skills, such as memory, posture control and balance. Although differences between dancers and non-dancers are reported for spatial skills as well, it is still unknown whether they are the result or the cause of dancing experience, with individuals having superior skills being more likely to take up dancing. To answer this question, we asked novices with no formal dance experience to attend dance lessons for a year. To investigate the effects of dance experience on spatial awareness, we used a spatial updating task in Virtual Reality at two different times: prior to the onset of dance lessons and 12 months later. We compared the dance novices' performance to that of expert dancers and of a control group of non-dancers. Results indicated that experienced dancers performed more accurately in the spatial updating task, in both phases of data collection. There was also a non-significant improvement in spatial updating performance for the beginner dancers after a year of dance training, suggesting that dance lessons may be a potential means for enhancing spatial updating skills.

Keywords: spatial updating, dance expertise, dance intervention

BIAS IN OBJECT LOCATION ESTIMATION FOLLOWING A PERSPECTIVE SHIFT

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Individual differences in spatial orientation and navigation may in part be driven by differences in the resolution of spatial representations. We attempted to characterise the precision of spatial encoding using the psychophysics approach. To do so, forty-four participants memorised the position of an object in a virtual room and at test judged whether the object had moved left or right following a perspective shift. The results revealed that participants exhibited substantial bias in their responses. Specifically, participants' performance was below chance level in a large proportion of the congruent trials in which the camera and the object moved in the same direction. Whilst, performance in incongruent trials, in which the camera and the object moved in the opposite directions, reached almost 100% regardless of the distance by which the object was displaced. The bias reduced when additional spatial information was added into the environment. On the other hand, it was more pronounced in older adults. Further investigations suggest that the bias does not result from distortions introduced by spatial memory and instead that it is driven by the perspective shift, with participants expecting the object to "move" in the same direction as the perspective shift. We propose that the systematic bias in the same direction as the perspective shift is driven by difficulties in understanding the perspective shifts that may lead participants to use an egocentric representation of object positions as an anchor when estimating object locations. Results from a follow-up experiment that disentangle the perspective shifts into camera rotations and translations will be discussed.

Keywords: spatial encoding, spatial precision, spatial perspective taking

TACTILE FIELD AND THE DUAL NATURE OF TOUCH

Błażej Skrzypulec
Jagiellonian University, Poland

I investigate whether it is justified to postulate tactile field analogous in its properties to visual field. I argue that the answer is both 'yes' and 'no' due to the dual nature of touch: touch is both an interoceptive modality which presents states of one's body and an exteroceptive modality which presents external entities. More specifically, the interoceptive tactile space, in which tactile bodily sensations are experienced to be localized, has a character of a spatial field. On the other hand, the exteroceptive tactile space, in which external, tactile objects are experienced to be localized does not have field-status.

Keywords: tactile perception, interoception, exteroception, spatial perception

CLOSE TO MY HEART: MEANINGS ASSOCIATED WITH PLACES NEAR AND FAR

Thora Tenbrink, Anwen Jago Williams, and Constance Croguennec

Abstract. Places are understood as spaces with associated meaning. Spaces may be relevant and meaningful simply because they are closeby, or for other, possibly related reasons. Here we explore ways in which the linguistic expression of place, i. e., people's appreciation of spatial surroundings, relate to notions of proximity. To elicit platial language, we asked 72 participants in Wales (UK) various questions about their local environment. Responses were collated as a corpus of place-related discourse, and examined concerning the contribution of spatial proximity terms to the expression of appreciation.

Introduction. The notion of 'place', generally understood as space with associated meaning (Massey, 2000), has been addressed across disciplines over the last few decades, most prominently in areas of human geography, environmental psychology, and GIScience (Hamzei, Winter, and Tomko, 2020). However, despite the clear role of language for platial concepts (Cresswell, 2014), there is surprisingly little insight from a linguistic perspective (Tenbrink, 2020). The lack of understanding of how precisely speakers express the meaning they associate with spaces has dire consequences. If we design a questionnaire aimed to elicit platial concepts, how should questions be formulated – and answers interpreted? What search terms do we use for a corpus study to extract platial meanings? And what is the conceptual basis of platial discourse, paralleling spatial concepts (e. g., Landau & Jackendoff, 1993)?

Here we contribute to the understanding of platial concepts by focussing on one prominent aspect: the relation between appreciation and spatial proximinity. That the location of a place relative to a person affects its conceptualisation is widely acknowledged in the literature (e. g., Acedo & Johnson, 2020) – complementing the well-established insight that emotions affect perceived distance (Ekman & Bratfisch, 1965). Places matter to us for a reason, and spatial distance provides a very strong rationale for emotional connectedness; intuitively, we are more likely to feel closely attached to nearby places, as reflected in metaphors such as 'close to my heart'. Hence, spatial proximity and accessibility should feature in linguistic descriptions of place. Our exploratory study addresses whether and how this may be the case.

Empirical study. Our questionnaire contained 14 questions covering participants' background information (age, gender, where they lived and for how long, native language etc.) and data on their perceptions of three local coastal areas (Menai Strait, Caernarfon Bay, Conwy Bay). The participants were randomly recruited passers-by at various public places in North Wales, chosen for their location relative to the coastal areas that featured in the questions. 72 people consented to participate (39 females; 33 males); 21 of them chose to respond in

Welsh, the others in English, and 1 person used both languages. Altogether, we collected 3,648 words in Welsh and 9,491 in English.

Participants were first asked to describe each area individually, and then to specify what made them different to each other. The next question asked how the location of things in the area (where places and attractions are) affected what these areas meant to them. Then they were asked about area boundaries, and how their perception would change if changes were made to the environment. A brief report of responses is available at *http://knirb.net/Tenbrink_etalMCA2020.pdf*. Here we treat the elicited language data as a corpus, focusing on the expression of platial appreciation relative to spatial proximity.

We identified the following recurring proximity terms in the data: *near, close, doorstep, local, access, proxim-, here, not far*, and their Welsh equivalents. A semi-automatic count of these key proximity terms (supported by advanced search functions in Excel) yielded 85 (0.9% of all) English words, and 41 (1.12% of all) Welsh words. However, as such this tells us very little. For instance, compare the use of 'here' in 'a lot to see *here*' (which appears like a fairly factual, spatially anchored statement) to its use in 'whenever I'm on holiday, I always think I couldn't live anywhere but *here*'. The first one does not speak to the idea that proximity matters for appreciation, since the term '*here*' is simply used to refer to the place the person is talking about – it could be used in this way for any place in the world. In contrast, the second example creates a contrast between being away ('on holiday') and the feeling of home ('I couldn't live anywhere but') associated with '*here*'.

Many examples in the data combine both aspects; they are statements of facts that also convey appreciation of the local environment, expressing the relation between proximity and appreciation explicitly as in 'we have it all in one place *here* – mountains, greenery, beaches, innovative entrepreneurs, tourism, and so much diversity in culture and language'; 'I live *near* the Menai Strait, so it means more to me than the other areas', 'appreciate how lucky we are to have all this *on our doorstep*' and 'having beaches, walks and other attractions *nearby* is important'.

Clearly the linguistic expression of place is creative and diverse; the elicited appreciation of local places finds expression in a wide range of ways, allowing for very few quantifiable insights. Nevertheless, the difference to appreciative statements that do *not* include proximity terms is striking. Although responses such as 'it's incredibly scenic, and the tranquillity of the area sets it apart' or 'Peaceful. Ideal for walks. Healthy atmosphere. Interesting sights. Stunning views' refer to a location specified in the question asked, they are not *spatially* related to the speaker. As a result, they appear less connected, less personal; statements such as these could easily appear in a tourist magazine, praising an environment for its virtues, rather than expressing meaning of the kind that the literature tends to identify with the notion of place (e. g., Cresswell, 2014).

Beyond direct expression of spatial proximity, emotional closeness was also conveyed by references to personal experience. Unexpectedly, *temporal* terminology can be relevant here; statements like 'looks different every day – so

many quiet, beautiful spots' and 'I appreciate it every single day' convey a clear sense of living close enough to enjoy regularly. Distance terms (such as *away*, *far* and Welsh equivalents) are not frequent in the data, but where they are used they contribute to place attachment by expressing a welcome distance to the less appreciated aspects of modern cultural life, as in 'the fact that it still seems so untouched by mass tourism and that you can still get *far away* from other people and off the beaten track', and 'quiet tranquillity *away* from business and technology'.

Conclusion. The presented observations based on our small corpus of appreciative discourse are qualitative, explorative, and preliminary. Nevertheless, we hope to have demonstrated an important point, to be explored more systematically in future research: that there is a qualitative difference between linguistic appreciation of location in a general sense, and a sense of place that is far more personal and associated with a *spatial* connection and entrenched experience. This corroborates previous findings that platial attachment relates to degree of spatial distance, though getting *away* from everyday life can also enhance positive connections.

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THE ROLE OF SPATIAL COGNITION IN SURGICAL NAVIGATION IN ARTHROSCOPIC SURGERY.

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Spatial cognition is an important ability for minimally invasive surgery (MIS) (Vajsbaher, Schultheis & Francis, 2018), especially in enabling surgical navigation inside the body (Stüdeli, 2008). Arthroscopic surgery is a type of MIS, where small incisions are made, and an arthroscope (camera) is placed in one port to display the joint on a simple 2- dimensional monitor viewed by the surgeon. The entire procedure relies on the surgeon's ability to accurately and precisely navigate the camera in the spatially restricted cavity of the shoulder. Awareness of spatial orientation during joint navigation and wayfinding based on the anatomical structures displayed on the monitor are thus the core challenges faced by an orthopaedic surgeon during the procedure (Monahan & Shimada, 2005). Thus, although spatial skills are central to performing such a procedure, no research to date has yet attempted to explore arthroscopic performance in the context of the surgeons' own spatial ability and its impact on surgical navigation in orthopaedic surgery. The aim of this study was twofold; First, to explore the spatial cognitive profile of orthopaedic surgeons and explore whether specialist surgeons possess better spatial cognitive skills compared to the resident surgeons. And second, to explore the relationship between the spatial cognitive test performance and arthroscopic surgery navigation tasks. To the best of our knowledge, this is the first study to clinically explore the impact of spatial cognition on arthroscopic surgical navigation performance using a human cadaver.

Keywords: spatial cognition, minimally invasive surgery, arthroscopy, surgical navigation

CHANGES IN THE FLIGHT PATHS OF PIGEONS BASED ON EXTENDED SPATIAL LANDMARKS

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The navigational behavior of birds is based on the spatial perception of the terrain over which they fly. Not only single reference points, but also continuous linear and areal objects can be visually perceived in flight and affect the flight path. In this work, we studied the features of the trajectories of pigeons during flights in order to identify the effect of discrete or continuous extended landmarks on spatial orientation. For this purpose we compared the GPS tracks of pigeons flying over weakly familiar terrain, and the visual features of this terrain, calculated on the basis of remote sensing data. Various cases of linear landmarks (alleys, rivers, roads) and boundaries between different surfaces (vegetation covers, water surfaces, rural or urban areas) were considered. Values of changes in flight parameters of pigeons were calculated for 150 flights over various mixed landscapes: natural forests, agricultural fields, urban and suburban areas, and the sea coast. Linear and area landmarks were recognized by satellite images of the territories, using spatial analysis methods to highlight the boundaries of particular homogeneous and heterogeneous patterns. As a result, typical reactions to extended objects during movement were revealed: either a long flight along the border with small fluctuations in the trajectory, or a sharp perpendicular crossing of the object's border. In this study, all spatial data were processed using the geographical information system QGIS.

Keywords: spatial cognition, navigation, pigeon flight, QGIS

SYMPOSIUM
'DEVELOPING GEOSPATIAL EXPERTISE'

Heather Burte[1], Jung Eun Hong[2], and Michael N. DeMers[3]

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Geospatial thinking and expertise are at the heart of arguably one of the most integrative professional disciplines; that of geographer. Geospatial thinking is commonly associated with geographic problem solving in general and geographic information systems (GIS) specifically. The problems geographers solve involve a complex integration of disparate and often obscure data and information over both space and time. The very nature of spatial thinking, reasoning, and expertise is considered one of the big questions in geography (Cutter et al., 2002). Geospatial expertise draws on and recognizes a vast array of seemingly unrelated interconnections allowing the geographer to find solutions to otherwise incomprehensible problems. The complexity of geospatial thinking necessitates an equally complex set of learning experiences that collectively, and through multiple interactions, are characterized by the professional geographer. Little is known about how individuals progress from being novices in high school and college through to attaining expertise in geospatial thinking. The goal of this symposium is to bring together experts across multiple disciplines to present, discuss, and build collaborations that will support research investigating how individuals develop their geospatial expertise. Individuals who are interested in presenting at the symposium will submit short papers by June 1st, and the symposium committee will review and notify authors of acceptance by June 15th. Accepted authors will present their work along with engaging in round-table discussions with symposium attendees. This symposium will provide Spatial Cognition 20/21 attendees with an opportunity to network and bridge disciplinary divides to fuel new research agendas on geospatial expertise.

Keywords: geospatial expertise, geospatial thinking, expertise development geography

TUTORIAL
'SPATIAL COGNITION AND ARTIFICIAL INTELLIGENCE: METHODS FOR IN-THE-WILD BEHAVIOURAL RESEARCH IN VISUAL PERCEPTION'

TUTORIAL PRESENTERS: Mehul Bhatt *(Örebro University, Sweden)*, **Jakob Suchan** *(University of Bremen, Germany)*

ASSISTED BY: Vasiliki Kondyli *(Örebro University, Sweden)*, **Vipul Nair** *(University of Skövde, Sweden)*

The tutorial on "Spatial Cognition and Artificial Intelligence" addresses the confluence of empirically-based behavioural research in the cognitive and psychological sciences with computationally-driven analytical methods rooted in artificial intelligence and machine learning. This confluence is addressed in the backdrop of human behavioural research concerned with "in-the-wild" naturalistic embodied multimodal interaction. The tutorial presents:

1. an interdisciplinary perspective on conducting evidence-based (possibly large-scale) human behaviour research from the viewpoints of visual perception, environmental psychology, and spatial cognition.

2. artificial intelligence methods for the semantic interpretation of embodied multimodal interaction (e. g., rooted in behavioural data), and the (empirically-driven) synthesis of interactive embodied cognitive experiences in real-world settings relevant to both everyday life as well to professional creative-technical spatial thinking

3. the relevance and impact of research in cognitive human-factors (e. g., in spatial cognition) for the design and implementation of next-generation human-centred AI technologies

Keeping in mind an interdisciplinary audience, the main focus of the tutorial is to provide a high-level demonstration of the potential of general AI-based computational methods and tools that can be used for multimodal human behavioural studies concerned with visuospatial, visuo-locomotive, and visuo-auditory cognition in everyday and specialised visuospatial problem solving. Presented methods are rooted in foundational research in artificial intelligence, spatial cognition and computation, spatial informatics, human computer interaction, and design science. We highlight practical examples involving the analysis and synthesis of human cognitive experiences in the context of application areas such as (evidence-based) architecture and built environment design, narrative media design, product design, and visual sensemaking in autonomous cognitive systems (e. g., social robotics, autonomous vehicles).

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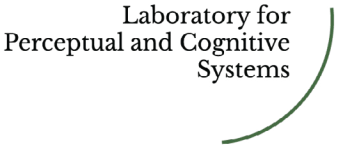
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