

**05491 Abstracts Collection**  
**Spatial Cognition: Specialization and Integration**  
— Dagstuhl Seminar —

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**Abstract.** From 04.12.05 to 09.12.05, the Dagstuhl Seminar 05491 “Spatial Cognition: Specialization and Integration” was held in the International Conference and Research Center (IBFI), Schloss Dagstuhl. During the seminar, several participants presented their current research, and ongoing work and open problems were discussed. Abstracts of the presentations given during the seminar as well as abstracts of seminar results and ideas are put together in this paper. The first section describes the seminar topics and goals in general. Links to extended abstracts or full papers are provided, if available.

**Keywords.** Spatial cognition, knowledge representation, spatial reasoning, spatial and linguistic ontologies, integration, cognitive robotics

**05491 Executive Summary – Spatial Cognition:  
Specialization and Integration**

Spatial Cognition: Specialization and Integration

*Keywords:* Ex. Summary

*Joint work of:* Freksa, Christian

*Extended Abstract:* <http://drops.dagstuhl.de/opus/volltexte/2007/982>

**Spatial Ontology**

*Brandon Bennett (University of Leeds, GB)*

The link between language and ontology is via a complex "word-concept" interface. Natural language vocabulary is often vague and ambiguous, so that they correspond to a cluster of precise concepts in an ontology.

The debate about whether there is a single or multiple ontologies hinges on whether it is possible to map the terminologies of different cultural groups onto a single conceptual structure.

A crucial aspect of word meaning is that a given term very often conflates a number of different "modes of characterisation". For instance a house may be described in terms of:

- its physical properties, its function as a dwelling place,
- its origin as a built artifact, or its legal status as a domestic property.

Typically these modes coincide, but may become separated, resulting in "identity schism".

Several kinds of vagueness complicate the definition of spatial concepts:

1. Mode ambiguity,
2. ill-defined thresholds on relevant observables that characterise spatial objects.
3. individuation of objects from continuously varying spatial distribution of matter.

A promising approach to modelling vagueness is to parameterise the meanings of geographic feature terms relative to choices of thresholds on relevant observables.

A further problem is the ontological status of "place".

Human geographers have described "place" as being "space with meaning". This idea can be modelled formally by treating a place as a spatial region, associated with a spatial predicate expressing a "principle of integration". The predicate is not only true of the region but provides a means of individuating the region from the surrounding space.

*Keywords:* Spatial Concepts, Ontology, Vagueness, Place

## **Reasoning with Mental Models, Images, and Diagrams Û Spatial focus and problem solving**

*Sven Bertel (Universität Bremen, D)*

The representational properties of diagrams have been shown to lead to specific characteristics of diagram-based problem solving. For example, the coupling between processes and structures used in imagery and visual perception allow for perceptual inferences to be drawn at low cognitive costs ('reading off of information'), leading to coupled mental/external processes to develop, in which information in turns gets externalized and internalized, and is subject to diagrammatic and mental processing.

Collaborative and assistive scenarios in which human and computational reasoners jointly operate on a common diagrammatic medium require models of the human reasoner's current mental foci of attention in problem solving to be

used by the computational part (i.e. to better predict next reasoning steps). This contribution suggests that, because of the special coupling of imagery and perception subsystems, common internal and external mechanisms of orienting spatial focus may exist, and that tracking external attention (e.g. through eye movement tracking) may be used to get a handle on mental attentional foci in problem solving. Some ideas from a recent eye movement study on matchstick configuration problems are presented. The talk ends with a list of open issues proposed for a subsequent break-out discussion.

*Keywords:* Diagram, problem solving, eye movement, assistance, spatial focus

### **Commonsense notions of proximity and direction in environmental space**

*Matt Duckham (University of Melbourne, AU)*

It is desirable that formal theories of qualitative reasoning should be informed by the ways in which humans conceptualize the spaces in which they live. The work described in this talk uses data provided in experiments with human subjects to derive some regularities in such conceptualizations.

The data concerns human conceptualization of proximity and direction within a university campus. The results are analyzed using several approaches. In particular, the relationship between geometric and human conceptual models of the space is explored; the structure and regularities of combinations of proximity and direction relations are examined; and the issue of granularity in vague spatial relations is considered. Overall, the results show that while individual differences between humans are important, there are striking regularities in the population's notions of distance and direction in the space.

*Keywords:* Qualitative spatial reasoning, vagueness, granularity, near, left

*Joint work of:* Worboys, Mike; Duckham, Matt; Kulik, Lars

*Full Paper:*

<http://www.geosensor.net/papers/scc2.pdf>

*See also:* Worboys, M., Duckham, M. and Kulik, L. (2004) Commonsense notions of proximity and direction. *Spatial Cognition and Computation* v4 n4, 285-312.

### **From a linguistic point of view: Spatial language and ontology**

*Carola Eschenbach (Universität Hamburg, D)*

The triadic interrelation between natural language, ontologies and space mainly depends on processes of generating and interpreting natural language. These processes serve to make experiences the speaker gained by perception and action in the external world accessible to the hearer.

In an extreme case there are up to four different situations related to the gain and use of information formulated in the text. For example, the author of a written route description verbalizes information acquired by earlier experiences and stored in memory, and the reader uses the information he gained from this text later for navigation. While perceiving and acting demand the use of quantitative concepts, memory and language typically employ qualitative concepts.

The relation between natural language and the external world is mediated by the internal representations of language users. Correspondingly, ontologies are not purely related to language and space but form an integral part of the language user's internal representations of the world that support communication. The ontologies of humans are both developed via perception and action, and coordinated among humans by communication using natural language.

*Joint work of:* Habel, Christopher; Eschenbach, Carola

## **Interactivity and Reinterpretation in Diagrammatic Inference**

*Ron Ferguson (Georgia Institute of Technology, USA)*

One of the current challenges in diagrammatic reasoning is to create diagram editors that support problem-solving. As noted by Goldschmidt, this requires a drawing substrate that is interactive (allowing changes to be made or reversed at any point) and which can handle incomplete or vague information. Here we examine these issues in the context of our diagrammatic reasoner, GeoRep.

*Keywords:* Diagram spatial ai

## **What robotics can learn from Cognitive Science**

*Christoph Flores (Universität Bremen, D)*

The talk was about the question of transferability of results from one area of research to another. Taking a sceptical standpoint about possible successes, it put a (rather uncommon) focus on methodological questions. (The more common concern about notions and concepts was not in the focus of the talk.) Providing an example of succesful processing in a software package "SCIP2", a proposal was made to make our habitual focus on good representations (and the processes that lead to them) a bit weaker and to make our focus on representation-process-pairs a bit stronger (and therefore our focus on processes for both the production and the further processing of representations).

The semiotic idea of "continuous processing" was presented as a general idea, a game of thought.

*Keywords:* Representation-process pairs, causal analysis of empirical findings, semiotic information processing

## Probabilistic Spatial Calculi

*Andrew Frank (TU Wien, A)*

Reasoning with spatial relations produces often the universal relation (top) as a result; this is not informative and not satisfactory for the user. The problem is even more pronounced when information from different calculi is combined.

Human performance in such situation is better; it seems to rely on a probabilistic approach: For human problem solving, a most likely answer is often sufficient. I hoped that a clever selection of how the discretization of distance and direction values would result in a combined qualitative spatial reasoning calculus with optimal power, even if results were only the most probable ones. Unfortunately, the research by Jung Hong was not completely convincing and the question, how humans perform, remains open.

*Keywords:* Spatial reasoning, probability reasoning, heuristic for spatial reasoning, Distance reasoning, reasoning with cardinal directions

## Spatial Cognition - the past fifty years

*Christian Freksa (Universität Bremen, D)*

The talk gives an introduction to the interdisciplinary research area Spatial Cognition and presents a few landmark publications in the field from cognitive psychology and biology, architecture and urban planning, cognitive geography and geographic information science, artificial intelligence and cognitive neuroscience, touching upon philosophy of mind and linguistics, cognitive robotics and physics, mathematics and informatics. A focus of the presentation is on wayfinding and navigation and on qualitative spatial reasoning.

*Keywords:* Interdisciplinary research, psychology, geography, urban planning, architecture, artificial intelligence, wayfinding, qualitative spatial reasoning

## Invisible Geography—A Cognitive Perspective on Spatial Context

*Christian Freksa (Universität Bremen, D)*

This paper develops a representation-theoretic notion of spatial context for cognitive agents interacting with spatial environments. We discuss the current state of the art in defining context as used in context-aware and/or location-aware systems.

In contrast to existing approaches, we define context through cognitive processes. The term 'invisible geography' alludes to the fact that knowledge about geographic space develops through complex cognitive interaction and is not simply 'out there' to be looked at. Placing (cognitive) processes in the focus of our context definition allows for a truly user-centered perspective: conceptualizations imbue spatial structures with meaning. This allows for fixing terminological problems and relating context definitions to work in spatial information theory and cognitive science. Although we focus on spatial context, the approach is generic and can be adapted to other domains in which cognitive aspects concerning users of information systems are central.

*Keywords:* Representation theory, spatial context, location aware systems

*Joint work of:* Freksa, Christian; Klippel, Alexander; Winter, Stephan

*Full Paper:* <http://drops.dagstuhl.de/opus/volltexte/2007/980>

## **Towards an Integrated Multi-layer Spatial Information Structure**

*Antony Galton (University of Exeter, GB)*

It is typical for a geographical information system to be organised in terms of layers, e.g., for topography, hydrology, demography, etc. These layers are aligned with each other through being anchored to a common coordinate frame, which may be thought of as a 'bare space' layer. This kind of structure presents a number of problems, for example with the handling of scattered entities, spatially indeterminate entities, and entities of different types. To handle these problems, we need to determine the types of layers required and to diversify the types of inter-layer linkage. Proposed layer types include a space/geometry layer, a topographical layer, with a layer for the built environment possibly separated off from this, and an institutional layer. Cutting across this system of layers is a set of distinctions between different ways of organising the information within a layer, for example fields, objects, and networks. Finally, we might require a separate cartographic layer concerned with how features are represented on a map, including textual labels. Types of inter-layer linkage include ways of handling vague location (e.g., by means of 'anchoring' relations which fall short of exact location), relations between objects and fields, and relations of use or function. An element in the institutional layer, e.g., a hospital or a university, will be linked by use/function relations to buildings and other physical features in the built environment layer, and these will in turn be linked by location relations to elements in the space/geometry layer; this decoupling of use/function from location facilitates updating the knowledge base to reflect, for example, changes in the use of a building, or the expansion of an institution by acquisition of new premises. The crucial point here is that elements from different layers can be linked directly in a variety of ways, without always having to go through the space/geometry layer as an intermediary.

## Sketches as mental facilitators in complex visually-mediated tasks

*Gabriela Goldschmidt (Technion - Haifa, IL)*

Compositional tasks belong to the category of ill-structured problems, and as such a search is conducted in the process of solving them. Complex tasks that are meant to lead to outcomes that embody shapes and forms, such as visual arts and design assignments, entail visual representations in the course of such a search. We therefore refer to them as visually-mediated tasks. Visual representations can be internal, in imagery, or external, e.g., various notations, drawings and 3D objects. External representations partake in the reasoning process, and they are also memory aids and can serve as communication and specification devices as well. As thinking aids the most effective representations are rapid sketches, which can be produced by hand or digitally. Ferguson (1992) distinguished among three types of sketches: a) thinking sketch, b) talking sketch, and c) prescriptive sketch. Prescriptive sketches, like measured drawings, best serve the purpose of specification. Communication uses primarily talking sketches; both communication and specification make use of measured drawings, though usually in later stages and not during the search phase of problem-solving.

As a reasoning aid the thinking sketch, usually produced by an individual for private usage, is of great interest in terms of the cognitive scaffolding it affords, provided its maker is an experienced sketcher. A sketch, however rough, serves as a display and therefore can potentially serve as a cue-bearing stimulus. It can be manipulated in imagery and then re-represented externally in revised form, thus creating a feedback loop. We may therefore regard the self-generated sketch as participating in interactive imagery. As a representation - again in experienced hands - the sketch has the following properties that are cognitively valuable to the effectiveness of the search process:

- Rapid production (minimal cognitive resources)
- Flexible stop rules
- Only minimally rule-bound
- Reversible and transformable at any stage (overlays)
- Tolerant of incompleteness
- Tolerant of inaccuracy and lack of scale
- Supports feedback loops

It is therefore not surprising that artists and designers have relied on sketching for centuries in their problem-solving processes, and it is important to further unveil the cognitive processes involved in the activity of sketching.

## **From a linguistic point of view: Spatial language and ontology**

*Christopher Habel (Universität Hamburg, D)*

The triadic interrelation between natural language, ontologies and space mainly depends on processes of generating and interpreting natural language. These processes serve to make experiences the speaker gained by perception and action in the external world accessible to the hearer.

In an extreme case there are up to four different situations related to the gain and use of information formulated in the text. For example, the author of a written route description verbalizes information acquired by earlier experiences and stored in memory, and the reader uses the information he gained from this text later for navigation. While perceiving and acting demand the use of quantitative concepts, memory and language typically employ qualitative concepts.

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*Joint work of:* Habel, Christopher; Eschenbach, Carola

## **Cognition & Architecture: Design & Usability of Indoor Spaces**

*Christoph Hölscher (Universität Freiburg, D)*

One can regularly observe that orientation and navigation around a large building are difficult tasks for human users (Passini, 1984) and often lead to severe wayfinding problems.

This is most prominently the case for complex public buildings such as airport terminals, hospitals or office spaces. The design and architecture literature acknowledges these handicaps, yet without supplying much scientific basis for planning remedies. A number of researchers have identified factors contributing to wayfinding difficulties, ranging from visual access to issues of building configuration and layout complexity (esp. Weisman, 1981), but the concrete triggers of wayfinding difficulties are still not well understood. How can we bridge the gap between architectural design practice and spatial cognitive research on human navigation behavior? How can building design be better suited to human wayfinding needs, i.e. how can the cognitive and behavioural dispositions (preferences/ strategies) of building users be supported by architectural design? In my position statement I would like to raise questions about what information cognitive studies must provide to be useful for designers.

Also, I wonder what technical support could be provided - both to designers and users of buildings - to help overcome wayfinding challenges in indoor spaces.

*Joint work of:* Hölscher, Christoph; Strube, Gerhard

## **Orientation Calculi and Route Graphs: Towards Semantic Representations for Route Descriptions**

*Bernd Krieg-Brückner (Universität Bremen, D)*

Our work is part of the DFG-funded Research Center “Spatial Cognition” (SFB/TR 8) in the project “Shared Control via Dialogs”. One particular goal in this context is the resolution of shared-control problems by clarification dialogs between the driver and the Bremen semi-autonomous wheelchair Rolland. In this context we are aiming for semantic representations of route descriptions. In order to support the checking for consistency of route descriptions and to be able to make formal deductions, we try to link linguistic ontologies to conceptual ontologies, integrated with formal spatial calculi. These are then related with corresponding formalisations at the robot level for execution at run-time. All theories are formalised in the Common Algebraic Specification Language, *CASL*, and supported by tools in the Heterogeneous Specification framework, *Hets*. In this presentation of work in progress, we are trying to integrate qualitative orientation calculi with Route Graphs. Star orientations, and the algebraic properties of the inverse and full complement operations, are the basis for specifying properties of orientations between directed edges, i.e. qualitative vectors, between locations. 8-star orientations at the entry and the exit of a vector are then used to define the relations of variants of the Double Cross Calculus with 8 and 12 orientations, resp. With an additional predicate “at” a location, we then define all 15 relations. Vectors are related to route segments with orientation predicates at entries and exits. The inherent origin orientation at a place is then used to solve the place integration problem when joining individual routes into Route Graphs. Finally, some abstract predicates for route descriptions such as “via”, “pass by”, etc., are defined in terms of these calculi which provide a foundational semantics.

*Keywords:* Orientation, double cross calculus, route graph, route descriptions

## **The Role of Spatial Cognition for Robotics**

*Benjamin Kuipers (Univ. of Texas at Austin, USA)*

There are many well-documented peculiarities of human spatial cognition. Are these simply limitations of the human mind and brain, and the design for an intelligent robot should ignore or avoid them? Or are they unavoidable trade-offs in optimal strategies for solving the spatial problems faced by an autonomous

agent? In our work on the Spatial Semantic Hierarchy (SSH), we take the latter position, focusing on the ability to express incomplete knowledge of space.

At the Control level, the agent selects and follows control laws to define a discrete set of distinctive states within the continuous environment. These states, along with actions abstracting the control laws linking them, form the Causal level of the SSH. From this, we derive the Topological level, which describes the environment qualitatively in terms of places, paths, and regions, related by connectivity, order, and containment. The Hybrid SSH generalizes previous work by building local metrical maps directly from perceptual information, and by building global metrical maps on the skeleton provided by the global topological map. By having multiple representations for these kinds of incomplete spatial knowledge, we hope that the Spatial Semantic Hierarchy will contribute to understanding robustness and scalability of human spatial cognition.

Papers and other information can be obtained at <http://www.cs.utexas.edu/~qr/robotics/>.

*Keywords:* Spatial Semantic Hierarchy, cognitive map, robot exploration, map learning

*Extended Abstract:* <http://drops.dagstuhl.de/opus/volltexte/2007/981>

*See also:* <http://www.cs.utexas.edu/~qr/robotics/papers.html>

## Qualitative Spatial Representations in Robotic Soccer

*Gerhard Lakemeyer (RWTH Aachen, D)*

Traditionally spatial representations in robotic soccer have been mainly quantitative in nature, consisting, roughly, of position estimates for team members, opponents, and the ball. In the context of high-level plan languages for robot control like Golog, the use of more abstract qualitative representations has at least three advantages: it facilitates the classification of game situations, plans become re-usable, and plan specifications by humans become more user-friendly. This talk is about our efforts to develop qualitative representations and reasoning methods suitable for the high-level control of robotic soccer agents.

*Keywords:* Qualitative spatial representations, robot control

## Geometrical Logics

*Ian Pratt-Hartmann (Manchester University, GB)*

The talk takes a broad historical view of the development of geometry, with special emphasis on recent interest in geometrical formalisms.

By ‘geometrical logic’, we understand a formal language interpreted over a (class of) geometrical structures, broadly construed.

Informally, we can identify three ‘dimensions’ of variation in geometrical logics: (i) the (classes of) structures considered; (ii) the primitive geometrical terms interpreted thereover; (iii) the logical (and set-theoretical) resources by means of which these terms may be combined. We present several examples of geometrical logics from the recent literature, and survey some of the key questions that arise in the study of geometrical logics.

*Keywords:* Geometry, logic, topology

## Mappings For Cognitive Semantic Interoperability

*Martin Raubal (Universität Münster, D)*

Semantic interoperability for geographic information and services has been a main research area within Geographic Information Science. Success in solving semantic interoperability problems has been limited though, because many efforts are based on so-called realist semantics approaches. Considering the fact that geographic information is eventually used by people, it is necessary to account for people’s (geographic) concepts and their semantic relation to different system views of the same concepts. We propose to tackle the problem of Cognitive Semantic Interoperability for geographic information by defining mappings between conceptual spaces. Such spaces can be utilized to formally represent the meanings of concepts within geometrical structures, both from a system’s and a user’s perspective. We present a formal definition of possible mappings-projections and transformations-and the occurring losses of information. A wayfinding service scenario is used to demonstrate the applicability and usefulness of the approach.

*Keywords:* Semantic Interoperability, conceptual spaces, mappings

## A Systematics of Elements in Route Directions

*Kai-Florian Richter (Universität Bremen, D)*

A (representation-theoretic) analysis of routes and route directions providing instructions on how to follow them, as well as an analysis of the kind of knowledge required to determine and conceptualize references in route directions reveals classes of elements addressable in route directions. These elements may be summarized in a systematics based on their level of granularity, i.e. on the level of abstraction from a detailed description of the exact turning action at a decision point. Furthermore, depending on different properties of these elements, they may take different roles in wayfinding: this results in differing conceptualizations of elements depending on their function, which needs to be captured

for modelling by proper categorization, for example with respect to geometric (dimensional) or functional aspects.

In this talk, I will motivate and present the resulting categorization.

*Keywords:* Route directions, landmarks, environmental characteristics, conceptual structure

## **Language, culture and cognition: Frames of spatial reference and why we need ontologies of space**

*Gunter Senft (MPI - Nijmegen, NL)*

One of the many results of the "Space" research project conducted at the MPI for Psycholinguistics is that there are three "Frames of spatial Reference" (FoRs), the relative, the intrinsic and the absolute FoR. Cross-linguistic research showed that speakers who prefer one FoR in verbal spatial references rely on a comparable coding system for memorizing spatial configurations and for making inferences with respect to these spatial configurations in non-verbal problem solving. Moreover, research results also revealed that in some languages these verbal FoRs also influence gestural behavior. These results document the close inter-relationship between language, culture and cognition in the domain "Space". The proper description of these interrelationships in the spatial domain requires language and culture specific ontologies.

*Keywords:* Frames of spatial Reference; language, culture and cognition; ontologies

*See also:* Haviland, John. 1993. Anchoring, iconicity and orientation in Gugu Yimithirr pointing gestures. *Journal of Linguistic Anthropology* 3: 3-45. Levinson, Stephen C. 2003. *Space in Language and Cognition*. Cambridge: Cambridge University Press. Pederson, Eric, Danziger, Eve, Wilkins, David, Levinson, Stephen, Kita, Sotaro, and Senft, Gunter. 1998. Semantic typology and spatial conceptualization. *Language* 74: 557-589. Senft, Gunter. 1997. Referring to Space - Studies in Austronesian and Papuan Languages. Oxford: Clarendon Press. Senft, Gunter. 2001. Frames of Spatial Reference in Kilivila. *Studies in Language* 25: 521-555.

## **Probabilistic Approaches in Mobile Robotics**

*Cyrill Stachniss (Universität Freiburg, D)*

This work provides an introduction to probabilistic techniques used by mobile robots. We focus on state estimation, utility maximization, and representation aspects and compare the pros and cons of frequently used approaches. We then introduce three classical robotic problems related to space, which are mapping,

localization, and path planning. Besides these three problems, we discuss solutions to the combined problems like simultaneous localization and mapping (SLAM), exploration, as well as integrated approaches. In this context, we discuss several state-of-the-art solutions. Furthermore, we present an integrated approach that efficiently solves all the individual problems at the same time. It reasons about potential actions and seeks to minimize the uncertainty in the model of the robot. The result is a robust technique to autonomously learn environmental models.

Finally, we relate the way humans deal with probabilities to the way robots do. As identified by several researchers in the field of cognitive science, we show that people have certain problems to deal with probability distributions in the appropriate way. People, for example, are insensitive to priors and typically select the most representative hypothesis and not the most likely one. However, humans are quite successful in the real world. This is due to the fact, that humans have good heuristics to solve problems and have a huge amount of background knowledge. Making these two aspects available to robots is identified as important issues for the next future.

*Keywords:* Probabilistic robotics, Bayes filter, uncertainty, humans

### **Methods for analyzing natural discourse: Investigating spatial language in HRI vs. in a no-feedback web study**

*Thora Tenbrink (Universität Bremen, D)*

The focus of interest in my research lies in the investigation of spontaneously produced natural language used to refer to the spatial position of a goal object. In this short paper I compare two central elicitation scenarios which have been useful for the investigation of speakers' strategies to achieve given discourse purposes by using spatial reference: a no-feedback web study and a human-robot interaction scenario. In both cases the task was to identify one out of several similar objects in a configuration by using spatial reference. The results of the two kinds of studies show a number of important systematic differences as well as striking parallels with respect to speakers' conceptual and linguistic strategies.

*Keywords:* Human robot interaction, discourse analysis, spatial reference

*Full Paper:* <http://drops.dagstuhl.de/opus/volltexte/2007/983>

### **Path planning and optimization in the traveling salesman problem: Nearest neighbor vs. region-based strategies**

*Jan Wiener (MPI für biologische Kybernetik - Tübingen, D)*

According to the number of targets, route planning can be a very complex task. Human navigators, however, usually solve route planning tasks fastly and efficiently.

Here two experiments are presented that studied human route planning performance, route planning strategies employed, and cognitive processes involved. For this, 25 places were arranged on a regular grid in a large room. Each place was marked by a unique symbol. Subjects were repeatedly asked to solve traveling salesman problems (TSP), i.e. to find the shortest closed loop connecting a given start place with a number of target places. For this, subjects were given a so-called 'shopping list' depicting the symbols of the start place and the target places. While the TSP is computationally hard, sufficient solutions can be found by simple strategies such as the nearest neighbor strategy. In Experiment 1, it was tested whether humans deployed the nearest neighbor strategy (NNS) when solving the TSP. Results showed that subjects outperformed the NNS in cases in which the NNS did not predict the optimal solution, suggesting that the NNS is not sufficient to explain human route planning behavior. As a second possible strategy a region-based approach was tested in Experiment 2. When optimal routes required more region transitions than other, sub-optimal routes, subjects preferred these sub-optimal routes. This result suggests that subjects first planned a coarse route on the region level and then refined the route during navigation. Such a hierarchical planning strategy would allow to reduce computational effort during route planning.

In a control condition, the target places were directly marked in the environment rather than being depicted on the shopping list. As subjects did not have to identify and remember the positions of the target places based on the shopping list during route planning, this control condition tested for the influence of spatial working memory for route planning performance. Results showed a strong performance increase in the control condition, emphasizing the prominent role of spatial working memory for route planning.

*Keywords:* Spatial cognition, navigation, route planning, path complexity, traveling salesman problem, regions, hierarchical planning, nearest neighbor strategy

*Joint work of:* Wiener, Jan Malte; Ehbauer, Nicole N.; Mallot, H. A.

*Full Paper:* <http://drops.dagstuhl.de/opus/volltexte/2007/984>

## **Granular Route Directions in Urban Environments**

*Stephan Winter (University of Melbourne, AU)*

I will report on an ongoing PhD research by Martin Tomko. He investigates forms of route directions given to recipients in principle familiar with the environment. His goal is finding the rules to construct such route directions.

*Keywords:* Route directions

*Joint work of:* Winter, Stephan; Tomko, Martin

## Mapping and Map Handling in Cognitively Motivated Robotics

*Diedrich Wolter (Universität Bremen, D)*

This talk argues for research to improve spatial representations employed by mobile robots. To mediate between the demands of robot mapping/navigation and map applications (e.g. mapping or localization with a a-priori coarse, schematic map) , it is necessary to move away from uninterpreted sensor maps towards an object-centered representation which can serve as a basis for (qualitative) spatial reasoning.

*Keywords:* Shape, spatial representation, spatial reasoning, mobile robot

## Qualitative Constraint Calculi: Heterogeneous Verification of Composition Tables

*Stefan Wölfl (Universität Freiburg, D)*

In the domain of qualitative constraint reasoning, a subfield of AI which has evolved in the past 25 years, a large number of calculi for efficient reasoning about spatial and temporal entities has been developed. Reasoning techniques developed for these constraint calculi typically rely on so-called composition tables of the calculus at hand, which allow for replacing semantic reasoning by symbolic operations. Often these composition tables are developed in a quite informal, pictorial manner and hence composition tables are prone to errors. In view of possible safety critical applications of qualitative calculi, however, it is desirable to formally verify these composition tables. In general, the verification of composition tables is a tedious task, in particular in cases where the semantics of the calculus depends on higher-order constructs such as sets. In this paper we address this problem by presenting a heterogeneous proof method that allows for combining a higher-order proof assistance system (such as Isabelle) with an automatic (first order) reasoner (such as SPASS or VAMPIRE). The benefit of this method is that the number of proof obligations that is to be proven interactively with a semi-automatic reasoner can be minimized to an acceptable level.

*Keywords:* Knowledge representation and reasoning, geometric and spatial reasoning, qualitative reasoning, automated versus interaction proving, heterogeneous specification

*Joint work of:* Wölfl, Stefan; Mossakowski, Till; Schröder, Lutz

*Full Paper:* <http://drops.dagstuhl.de/opus/volltexte/2007/979>