The Transregional Collaborative Research Center SFB/TR 8 Spatial Cognition

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Abstract. The SFB/TR 8 pursues interdisciplinary research in Spatial Cognition. In twenty projects, computer scientists, psychologists, and linguists collaborate in basic research as well as in application-oriented development. We present a selection of projects to illustrate the variety of research issues addressed within this research center.

Keywords: Spatial Cognition, Interdisciplinary Research, Autonomous Spatial Agents, Spatial Language, Social Robotics, Design Assistance

1 Overview

The Transregional Collaborative Research Center SFB/TR 8 *Spatial Cognition: Reasoning, Action, Interaction* is concerned with basic research related to intelligent spatial information processing based on cognitive principles as well as with spatial task assistance for variable environments. The overall goal of the SFB/TR 8 is the integration of competence for reasoning about space, for acting in space intelligently, and for interacting in spatial environments. The SFB/TR 8 is located at the Universities of Bremen and Freiburg. It involves approximately 70 scientists from various disciplines like informatics, cognitive science, psychology, and linguistics. The SFB/TR 8 started in 2003. It is funded by the German Research Foundation (DFG) for an overall duration of twelve years.

The conceptual basis of the SFB/TR 8 is the hypothesis that cognitive agents – i.e., humans, animals, robots, or computer programs – apprehend their spatial environments through (1) mental or computational operations (e.g., association and reasoning); (2) perception and action in space; and (3) communication in or about space and other forms of interaction.

In all cases, spatial structures are interpreted and computationally transformed into new structures; the new structures reflect insights about spatial situations. They form the basis for further reasoning processes, for actions in the spatial environment or on external representations (for instance diagrams or maps), and for the interaction with other agents.

The projects of the SFB/TR 8 investigate cognitive agents in spatial environments. Several projects address the question how cognitive agents can assist one another in solving spatial tasks such as reasoning about space, map comprehension, navigation,

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and understanding and evaluating actions in space. The SFB/TR 8 also studies how to communicate about space using language and map-like representations to enable this assistance. The research is concerned with mental processes and structures underlying behavior in large-scale space, environmental space, vista space, and tabletop space environments. Solving spatial tasks in these environments requires adequate representation structures and processing capabilities as well as locomotion, navigation, or the movement of physical or mental objects.

The projects in the SFB/TR 8 are structured into three research areas: The research area *Reasoning* is concerned with investigations in mental and computational spatial processing, the research area *Action* is concerned with spatial tasks for autonomous robots and bio-inspired agents, and the research area *Interaction* deals with ontologies and representations of spatial descriptions. The three research areas are strongly interconnected.

Currently, 16 DFG-reviewed research projects including a Junior Research Group, an integrated Research Training Group, and three strategic projects established by the SFB/TR 8 board are pursued in the SFB/TR 8.

The SFB/TR 8 also forms the nucleus of the International Quality Network (IQN) on Spatial Cognition that connects researchers from more than 30 universities. The IQN researchers are frequent visitors at University of Bremen and enhance the scientific exchange in the area of spatial cognition.

We will exemplarily present four research projects carried out in the SFB/TR 8 to illustrate the variety of research issues addressed within the research center.

2 Project ActionSpace: Bio-Inspired Self-Localization

Determining one's position within a spatial environment is a basic competence of biological as well as artificial agents. The project ActionSpace in the SFB/TR 8 develops a bio-inspired architecture for self-localization, which is based on basic neurobiological research and on specific behavioral experiments, which are designed and conducted within the project. By using physically impossible virtual worlds implemented in VR environments, researchers in this project found that human subjects have no problem in dealing with global spatial inconsistencies regarding geometry and even the general topological layout of a spatial environment. This supports their hypothesis that the primary representation underlying human self-localization is not an integrated image-like one, but rather of a more local, sensorimotor nature.

Thus, in the architecture developed in the project, bottom-up sensory features and motor data are combined in a sensorimotor representation of the spatial environment. This sensorimotor representation is integrated with a knowledge-based top-down mechanism, which controls the active exploratory perception of a scene according to the principle of maximum information gain. The architecture can operate on different sensorimotor levels, for instance movements of the agent in space and the control of eye movements. Currently, the architecture is implemented in two systems, a mobile robot and a virtual agent capable of navigating in ordinary as well as physically impossible virtual environments.

3 Project NavTalk: Spatial Inference in Navigation and Language

The project NavTalk addresses the ways in which humans make inferences about spatial relationships during complex navigation tasks. For this purpose, wayfinding behavior and linguistic data are investigated both in indoor and in outdoor environments. We know that adult humans navigating in buildings and street networks do not perceive their surroundings with a blank mind; rather, previous experience leads to systematic expectations both about the structure of certain types of environment, and the options for navigating in them. Such mental presuppositions supplement the information that wayfinders actually receive via perceiving the real world, and via maps, signs, and linguistic descriptions.

As a consequence, inference processes (which may be partly subconscious as well as probabilistic) support the wayfinders' task of navigating in partially unknown environments; the incomplete spatial information is extended by standard expectations together with spatial reasoning. Together, these processes add up to the development of a (partial) cognitive map, guiding the wayfinder's subsequent navigation decisions. This procedure may be encouraged or discouraged by particular environmental features or types of information provided to the wayfinder.

The aim in this project is to gain a better understanding of these spatial inference processes by investigating human behavior and linguistic representations given different types of tasks, environments, and verbal and visual route information. Naturalistic navigation experiments address inferences made between floors in multi-level buildings with respect to local route choices and detour planning, pragmatic solutions found across different tasks, inference and reasoning processes in inconsistent (virtual) environments or those distorted by disaster, and the impact of varying types of input in the form of language-based route descriptions and maps.

The behavioral results of these navigation experiments are analyzed in tandem with language data collected via think-aloud protocols and retrospective reports. In addition to a basic content analysis, also the structural features of the language data are investigated, which are expected to be systematically related to the underlying conceptual phenomena. The systematic combination of linguistic and behavioral analysis will lead to a better understanding of the cognitive processes involved in wayfinding tasks with incomplete knowledge.

4 Project SocialSpace: Making Robots Socially Compatible

Next-generation robots will work closely with humans as companions at home, as caretakers for the elderly, in the form of intelligent cars, or as helpers in the service industry. Their tasks require advanced social and cognitive skills to effectively interact and cooperate with humans. It seems plausible that the key to long-term acceptance and to utility of robots is their ability to perceive, understand, learn, and reproduce human social behavior. Thus, the project SocialSpace investigates how robots can learn to become socially more compatible, for instance by learning human social behavior by observation and imitation.

Another aspect investigated in the project addresses the question how robots may be able to recognize intentions and goals of humans to naturally blend into the human's activities they are expected to support. So a core question may be what are the cognitive processes and how can they be implemented to enable robots developing socially sensible behavior. As an overall goal, SocialSpace aims to enable the creation of sustainable and efficient human-robot relationships.

5 Project DesignSpace: Assistive Intelligence for Spatial Design

The project DesignSpace aims to develop computational techniques and tools to be used as a basis of providing assistive design intelligence within a conventional spatial and architectural design workflow. Such a workflow typically involves an iterative refinement cycle consisting of modeling, evaluation, and re-modeling phases. Intelligent capabilities in spatial design are essential to reduce design errors and failures by iterative design validation and verification, and also to ensure that functional requirements of a design are met when the design is deployed in reality. The DesignSpace project is especially interested in the relationship between the structural form and function and its formal interpretation within the assistance system.

As an example, user-centered design analyses during the master-planning stage should be one of the most crucial considerations in the spatial design of large-scale public environments such as airports, museums, train stations, exhibition halls, or hospitals (i.e., all places with clearly definable functional purposes). In the research on computational design analysis in the Project DesignSpace, a range of analytical aids is developed that aim to relieve the designer from the cognitive stress involved during the early master-planning stage. In the context of wayfinding analyses for circulation planning, the assistance system developed in DesignSpace (1) derives the logical structure of topological connectedness, (2) generates all possible topological and geometric routes, (3) derives affordance-based routes aimed at predicting the motion pattern of special interest groups, (4) performs hypothetical 'what-if ' scenarios by providing comparative analyses, and (5) visualizes not only the explicitly existing physical space, but also the implicitly existing affordance spaces, physical and non-physical artifacts, and so on.

The long-term goal in this project is to develop a methodology that is able to detect requirement inconsistencies in the preliminary CAD design and communicate them back to the designer. This also includes the ability to perform diagnosis, and the derivation of alternate recommendations that do not violate the explicit and implied requirement constraints of the designer or architect. Initial studies have investigated this for the specific case where the new generation of smart environments and building-automation systems are being designed.