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Preface

This is the fifth volume in a series of book publications featuring basic interdisciplinary research in spatial cognition. The study of spatial cognition is the study of knowledge about spatial properties of objects and events in the world. Spatial properties include location, size, distance, direction, separation and connection, shape, pattern, and so on. Cognition is about the structures and processes of knowledge: its acquisition, storage, retrieval, manipulation, and use by humans, nonhuman animals, and machines. Broadly construed, cognitive activities include sensation and perception, thinking, attention, imagery, attitudes, memory, learning, language, and reasoning and problem-solving; the interaction of these activities with motoric (body movement) and affective (emotional) processing is recognized as critically important, as well. Cognition is typically considered to make up much of the activity of the mind. But though the mind is an expression of the structures and processes of the brain and nervous system, it is also an expression of an organism or agent with a physical body that typically exists in a physical and socio-cultural world.

Researchers study spatial cognition for several reasons. Spatial cognition plays important roles in most of the domains of knowledge and behavior of sentient beings, including activities associated with biological survival, social interaction, cultural practice, and economic exchange. Attempts to describe, predict, and explain the basic components of spatial cognition and their interrelationships stimulate a host of interesting basic questions about how important parts of reality work. Cognition about space and place is an important expression of human-environment or human-earth relationships. What's more, the study of spatial cognition holds the promise of helping to solve many practical problems and improve the lot of humanity, whether by improving information systems, the layout and appearance of built environments, the equitable selection of personnel, or the design of effective and efficient educational programs.

As we stated above, spatial cognition is an interdisciplinary field. That means two things. First is that researchers from a variety of disciplines engage in the study of spatial cognition. Authors and participants at this meeting included representatives from many disciplines, including computer and information science, psychology, geography and cartography, engineering, linguistics, anthropology, architecture, and biology. But this fact only makes the field *multi*disciplinary. The second requirement for *inter*disciplinarity is that the representatives from the different disciplines communicate with each other, with all that this implies, about shared vocabularies, methodologies, and basic philosophical frameworks. Such a truly interdisciplinary spatial cognition community began flowering within the last couple of decades (with a few earlier roots). The meeting at which the papers in this volume were presented provided an example of the emergence of such a community and a contribution to furthering its reality.

Space exists at many scales, and spatial cognition can concern itself with cognition at any or all of these scales. However, a tradition has arisen according to which most research on spatial cognition focuses on spatial scales relevant to human activities over the earth's surface, such as finding one's way, planning trips, and using cartographic maps. Space at this scale is variously known as large-scale, environmental, or geographic space. Spatial cognition researchers want to understand human cognition about the layout of buildings, cities, and regions, not about the layout of atoms or the solar system. However, this scale preference is not universally held, and we expect that insights about cognition at one scale may inform, and be informed by, insights about cognition at other scales. What's more, cognition about space often incorporates multiple scales, as when a person uses a small picture of space—a map—to wayfind in a city.

Historical Roots of Spatial Cognition

The study of spatial cognition has a variety of historical roots. In psychology, the behaviorist Edward Tolman (1948) introduced the term "cognitive map" to explain the behavior of rats that took shortcuts to find goal locations directly, without traversing the routes of the maze. But the developer of one of the earliest successful intelligence tests, Alfred Binet, had written about the psychology of orientation and disorientation several decades before (Binet, 1894). Furthermore, the psychologist C. C. Trowbridge (1913) introduced the idea that people form internal mental representations of the layout of environments, calling them "imaginary maps." The child psychologist Jean Piaget and his colleagues devised the most influential theoretical framework for cognitive development in children, and spatial cognitive development was an essential part of this (Piaget & Inhelder, 1948/1967). The perceptual psychologist J. J. Gibson (1950) developed a theory of perception and activity that prompted cognitive researchers to carefully consider the structure of the world and the structure of information in the patterned energy available to sensory receptors, not just the structure of the mind.

Others besides psychologists contributed to the development of spatial cognition as a field. Trowbridge had actually been influenced by very early work by the geographer, F. P. Gulliver (1908), who wrote about the influence of cartographic map orientation on spatial and geographic learning in school children. This concern with the implications of spatial cognition for spatial learning and education continued throughout the twentieth century. Geographers, planners, and architects in the 1950s and 1960s began to ask questions about the subjectivity of spatial knowledge and its implications for models of spatial behavior that depended on subjective beliefs about spatial layout, including beliefs about distances and directions (e.g., Golledge, Briggs, & Demko, 1969). Much of this got impetus from the writings of Kevin Lynch (1960), an urban planner, who convinced many to look at the pattern of the built environment in terms of its effects on mental representations. Connections among geographers, planners, psychologists, and others became explicit in the 1960s and 1970s with the advent of new journals and conferences (e.g., Downs & Stea, 1973).

Finally, researchers in the middle of the twentieth century began to apply digital computers to understanding a host of phenomena, including the behavior and cognition of humans and other animals. Spatial behavior and cognition was no exception. As early as the 1960s, mathematicians and computer scientists attempted to produce formal and computational models of spatial cognition that were realized on computers (Zadeh, 1965). Researchers in these disciplines also became interested in creating “simulated animals,” computational agents that could act or reason intelligently. Researchers in artificial intelligence naturally included action and reasoning in space and place, and about space and place, within the scope of their work (Kuipers, 1978). Some of these researchers focused on creating computational entities—robots—that could act in a coordinated fashion, for example, by moving from place to place without collisions. Other researchers focused on creating computational entities that could reason effectively about space and place, solving problems such as sequencing multiple destinations into one efficient trip or understanding the geometric layout of the world.

Topics in the Study of Spatial Cognition

There are a variety of research topics within the domain of spatial cognition. A first topic concerns the structures and processes of spatial knowledge and reasoning. The cognitive or mental map refers to an internally represented model of the environment; it is a metaphorical term meant to appeal to the idea that something like a cartographic map is stored in the head. However, in many ways the cognitive map is not like a cartographic ‘map in the head.’ It is not a unitary integrated representation but consists of stored discrete pieces, including representations of landmarks, routes, and regions. The separate pieces are partially linked or associated, often in a hierarchical manner (e.g., when the location of a place is stored in terms of a larger region). Furthermore, spatial knowledge is not well modeled by Euclidean or any other metric geometry, although it clearly expresses spatial information beyond the mere level of topology. The nature of internally represented knowledge in human minds leads to certain patterns of distortions in the way people answer spatial questions. For example, people often believe the distance from place A to B is different than from B to A. Turns are frequently adjusted in memory to be more like straight lines or right angles. At larger scales, most people have somewhat distorted ideas about the sizes and locations of continental land masses on the earth; for example, Southern Europe is thought to be near the equator, when it is actually located at 35-45° north latitude.

A second research topic concerns how cognitive agents acquire spatial knowledge and how the knowledge develops over time. Cognitive agents like humans acquire spatial knowledge directly via sensorimotor systems that operate as they move about the world. They also acquire spatial knowledge indirectly via static and dynamic symbolic media such as maps and images, 3-D models, movies, and language. Researchers are interested in the consequences of different learning media for the nature of acquired knowledge. Spatial knowledge changes over time, through processes of learning and development. Both changes in the child's spatial knowledge and reasoning, and that of an adult visiting a new place for the first time, are of interest to researchers. A widely discussed model of spatial learning in the environment suggests that it develops in a sequence of three stages or elements: landmark knowledge, route knowledge, and survey knowledge. However, a variety of evidence throws into question both the progressive nature of this sequence and the degree to which most people reach the level of survey knowledge.

A third research topic involves questions about how cognitive agents navigate and stay oriented in space. Navigation is coordinated and goal-directed travel through space, and it consists of the two components of locomotion and wayfinding.

Locomotion refers to moving through the local surroundings in coordination with immediately available sensorimotor information, such as when avoiding obstacles and moving toward sensed landmarks. Wayfinding refers to the planning and decision-making that allows one to reach a destination that is not immediately available to sensorimotor systems, such as when choosing efficient routes or orienting to nonlocal features. Wayfinding tasks generally require an internal or external representation of the environment. In order to reach destinations while navigating, agents must establish and maintain orientation—they must know ‘where they are,’ although the precision and comprehensiveness of this knowledge may not be high. Two broad types of processes are involved in orientation during navigation. One involves recognizing external features such as landmarks, sometimes called piloting. The second involves updating orientation by integrating information about movement speed, direction, and/or acceleration, without reference to recognized features. This is called dead reckoning or path integration.

A fourth research topic concerns how agents use natural language to communicate with each other about space and place. Spatial information is often communicated verbally. People give and receive verbal route directions, read spatial descriptions contained in stories, and increasingly interact with computer systems via verbal queries. There are at least two notable characteristics of the way language expresses spatial information. One is that language expresses mostly nonquantitative or imprecise (“vague”) quantitative information about space. Statements about connections and approximate location are more important than precise statements. For example, people say “turn left at the sausage shop” rather than “turn 97° after you have gone 1.3 kilometers.” A second characteristic is that interpreting spatial language critically depends on various aspects of the context of the communication. Context is provided by knowledge of who is speaking (or writing), where they are, physical features in the situation, the previous topic of conversation, and so on. The scale of “the umbrella is near the table” is generally understood differently than that of “Belgium is near Germany.”

A fifth research topic involves how aspects of spatial knowledge and reasoning are similar or different among individuals or groups. No two individual people know exactly the same things or reason in exactly the same way about space and place. Some people are better at tasks such as wayfinding, learning spatial layouts, or reading maps. In some cases, there may be different ways to think about spatial problems, all of which may be effective. In these cases, we might speak of ‘stylistic differences’ in spatial cognition rather than skill or ability differences. Researchers are interested in measuring and explaining individual differences. Many factors may be related to variations in spatial cognition: body size, age, education, expertise, sex, social status, language, residential environment, and more. A first goal for research is to measure and document ways these factors might covary with spatial cognition. In addition to describing such covariations, researchers have the goal of distinguishing their underlying causes. Explanations for such covariations are generally quite difficult to determine, however, as one cannot readily do randomized experiments on person characteristics such as age, sex, culture, and activity preferences. Nonetheless, even describing patterns of differences is quite valuable for practical goals such as designing spatial information systems.

A sixth and final topic concerns the neurological structures and processes involved in spatial cognition, an area of research that has advanced considerably with the technical developments of the last couple of decades. Research in this area attempts to answer questions such as how spatial information is encoded in nervous systems, which brain areas process spatial information of different types, how spatial information from different sensory modalities is integrated in the nervous system, and how particular injuries or organic syndromes produce particular deficits in spatial cognition. For example, the role of the hippocampus and other brain structures in spatial cognition (and other domains of cognition) continues to be researched. Recordings of the activity of single brain cells in the hippocampi of rats has revealed the existence of neurons that preferentially fire when the rat is in a particular location, known as place cells. Recordings of cells in other structures that have connections to the hippocampus have uncovered head-direction cells that fire preferentially when the rat is facing in a particular absolute direction in the environment. Clinical studies of organic brain syndromes and injuries in humans have shed light on the neuroscience of spatial cognition in humans, such as specific impairments in aspect of navigational skill following localized brain injuries, a syndrome known as topographical disorientation. Probably the most rapidly advancing research area for studying the neuroscience of spatial cognition is the use of brain-imaging techniques applied to awake and alert human subjects while they reason about or remember spatial information. The most promising of these is functional Magnetic Resonance Imaging (fMRI).

Technologies and the Future of Spatial Cognition Research

A variety of technologies influence spatial cognition, both as a domain of study and a domain of reality. Global Positioning System (GPS) receivers have recently become small and inexpensive, and are increasingly used on an everyday basis by lay persons and specialists alike. A GPS receiver provides information about one's location by geometrically combining distance signals it picks up from several geosynchronous satellites constantly orbiting the earth. This system is part of the technology of automated navigation systems included with many automobiles and increasingly found on cell phones and other portable devices. Several research issues concern how locational information is best displayed or communicated by electronic information systems, and how the availability of such information might change people's experiences and behaviors in space and place. There are a host of spatial cognition questions inspired by efforts to improve the effectiveness and efficiency of Geographic Information Systems (GIS). How can complex geographical information be depicted to promote comprehension and effective decision-making, whether through maps, graphs, verbal descriptions, or animations? How does exposure to new geographic information technologies alter human ways of perceiving and thinking about the world? There are also research issues concerning the way that people do or do not spatialize their understanding of other types of information networks such as the World Wide Web; one often speaks metaphorically of ‘navigating’ the Web. Undoubtedly one of the most dramatic technological developments with great implications for spatial cognition is the advent of computer-simulated worlds known as virtual environments (virtual reality).

About This Book

This volume contains the 28 contributions that were presented at the international conference *Spatial Cognition 2006*, which was held at the University of Bremen, Germany in September 2006. *Spatial Cognition 2006* was the second international conference organized by the Transregional Collaborative Research Center SFB/TR 8 Spatial Cognition funded by the German Research Foundation (DFG). For this conference, 59 full paper contributions were received, from across the spectrum of research topics within spatial cognition. These submissions were evaluated by an international review committee in a thorough peer review process.

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