of the utility of continuing the trip from that destination. Dellaert et al. (1998) generalized Kitamura's approach to account for multipurpose aspects of the trip chain.

Trip chaining is only one aspect of multiday activity/travel patterns. Several models have recently been suggested to predict more comprehensive activity patterns. These models can be differentiated into the older constraints-based models (e.g., Lenntorp 1976), utility-maximizing models (e.g., Recker et al. 1986), rule-based or computational process models (e.g., Golledge et al. 1994, ALBATROSS – Arentze and Timmermans 2000).

6. *Conclusions*

This article has given a very brief overview of spatial choice modeling. Due to the limited available space, we have focused on some of the key modeling approaches, disregarding alternatives (e.g., dynamic models) altogether.

If we examine the accomplishments, one cannot escape the conclusion that the models developed over the years have been increasing in complexity. The theoretical underpinnings of the recent activity-based models are much richer than the Markov or gravity models of the 1960s. Moreover, the brief overview indicates that geographers have been using alternative data, such as experimental design data and activity diaries, in addition to the more conventional survey data.

See also: Spatial Analysis in Geography; Spatial Decision Support Systems; Spatial Interaction; Spatial Interaction Models; Spatial Optimization Models; Spatial Pattern, Analysis of; Spatial Statistical Methods; Spatial Thinking in the Social Sciences, History of

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H. Timmermans

Spatial Cognition

Spatial cognition concerns the study of knowledge and beliefs about spatial properties of objects and events in the world. Cognition is about knowledge: its acquisition, storage and retrieval, manipulation, and use by humans, nonhuman animals, and intelligent machines. Broadly construed, cognitive systems include sensation and perception, thinking, imagery, memory, learning, language, reasoning, and problem-solving. In humans, cognitive structures and processes are part of the mind, which emerges from a brain and nervous system inside of a body that exists in a social and physical world. Spatial properties include location, size, distance, direction, separation and connection, shape, pattern, and movement.

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1. The Geographic Study of Spatial Cognition

Geographers study spatial cognition for three reasons. First and foremost, spatial cognition provides questions of geographic interest in their own right, given that cognition about space and place is an expression of human-environment or human-earth relations. Second, geographers have hoped that spatial cognition would improve their understanding of traditional phenomena of interest; for example, where people choose to shop should depend in part on their beliefs about distances and road connections. Finally, there has been an interest in improving the use and design of maps and other geographic information products which depend in part on human understanding of depicted spatial relations.

In addition to geographers and cartographers, researchers from many different disciplines study spatial cognition, including psychologists, architects and planners, anthropologists, linguists, biologists, philosophers, and computer scientists. While overlapping and interacting with these disciplines, the geographer's interest in spatial cognition is distinct in some ways. Geographers are interested in the earth as the home of humanity. Their concern is with the cognition of humans, not the cognition of barn swallows or underseas robots. Geographers focus on spatial scales relevant to human activities on the earth's surface, such as temporary travel, migration, settlement, and economic activities; a geographer wants to understand human conceptualizations of the layout of a city or a region, not of an atom or the solar system. Finally, the geographer ultimately desires to describe, predict, and explain external human-environment relationships, and focuses on internal mental and neuropsychological structures and processes only insofar as it helps in the understanding of external relationships.

1.1 History of Spatial Cognition in Geography

The notion that a subjective understanding of space partially mediates human relationships with an objective physical world is undoubtedly quite old. Within the modern discipline of geography, the study of spatial cognition first appeared with work on geographic education early in the twentieth century. However, interest in spatial cognition flowered during the 1950s and 1960s. The subdiscipline of experimental cartography emerged with the insight that maps could be improved by understanding how humans perceive and think about information depicted in map symbols. In an attempt to explain human responses to floods and other natural hazards, the subdiscipline of environmental perception began to study people's subjective beliefs about the occurrence and consequences of hazard events. Most importantly for the study of spatial cognition, behavioral geographers began developing theories and models of the human reasoning and decision-making involved in spatial behavior e.g., migration, vacationing, and trip scheduling. This approach gained insight from the work of Kevin Lynch (1960), a planner who argued that 'images' of cities guide people's behavior and experiences of those cities. All of these historical developments constituted a new focus on disaggregate or microscale approaches within human geography, approaches that focused on the geographic behavior of individuals as an accompaniment to traditional approaches that focused on human settlements and larger aggregations of people.

2. Topics in the Geographic Study of Spatial Cognition

The study of spatial cognition in geography sheds light on questions such as how spatial knowledge and beliefs are acquired and develop over time; the nature of spatial knowledge structures and processes; how people navigate and stay oriented in space; how people use language to communicate with each other about space; and how aspects of spatial knowledge and reasoning are similar or different among individuals or groups.

2.1 Acquisition and Development

Humans acquire spatial knowledge and beliefs directly via sensorimotor systems that operate as they move about the world. People also acquire spatial knowledge indirectly via static and dynamic symbolic media such as maps and images, 3-D models, and language. Geographers are interested in how different media have consequences 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 geographers. Both physical maturation and experience influence development. A person's activity space; the set of paths, places, and regions traveled on a regular basis, is an important example of spatial experience that influences people's knowledge of space and place, no matter what their age. Most people know the areas around their homes or work places most thoroughly, for example (as in the anchor-point theory of Couclelis et al. 1987).

A widely accepted model of spatial learning suggests that spatial knowledge of places develops in a sequence of three stages or elements. First is landmark knowledge, unique features or views that identify a place. Second is route knowledge, based on travel routines that connect ordered sequences of landmarks. The final element is survey knowledge, knowledge of two-dimensional layouts that includes the simultaneous interrelations of locations; survey knowledge would support detouring and shortcutting. Not everyone has detailed or comprehensive survey knowledge of their surrounds, and exposure to maps of places clearly advances the development of such knowledge.

2.2 *Spatial Knowledge Structures and Processes*

The metaphor of a cognitive map was coined by Tolman in a 1948 paper to refer to internally represented spatial models of the environment. The cognitive (or mental) map includes knowledge of landmarks, route connections, and distance and direction relations; nonspatial attributes and emotional associations are stored as well. 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 landmarks, route segments, and regions. The separate pieces are partially linked or associated frequently so as to represent hierarchies such as the location of a place inside of a larger region. Furthermore, spatial knowledge is not well modeled by metric geometries such as the Euclidean geometry of high school math. The ways in which spatial knowledge is internally represented in human minds lead 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, South America is thought to be due south of North America when it is actually rather far to the east as well.

2.3 *Navigation and Orientation*

Humans travel over the earth's surface to reach destinations. This typically requires planning and the ability to stay oriented while moving. Navigation is this coordinated and goal-directed travel through space. It consists of two components, locomotion and wayfinding. Locomotion refers to the guidance of oneself through space in response to local sensorimotor information in the immediate surrounds, and includes such tasks as identifying surfaces of support, avoiding obstacles, and moving toward visible landmarks. Locomotion generally occurs without the need for an internal model or cognitive map of the environment. Wayfinding refers to the planning and decision-making that allows one to reach a destination that is not in the immediate sensory field, and includes such tasks as choosing efficient routes, scheduling destination sequences, orientating to nonlocal features, and interpreting verbal route directions. Wayfinding tasks generally do involve a cognitive map of the environment. Various locomotion and wayfinding tasks vary greatly in their demand on attentional capacity. Following a familiar route is not very demanding on attention; finding one's way in a new city may be quite demanding.

Orientation is knowing 'where you are,' although the precision and comprehensiveness of this knowing varies greatly in different situations and for different people. Two fundamental processes are involved in orientation during navigation. The first process is the recognition of external features or landmarks—pilotage. In some cases, the recognized landmark is the goal, but more commonly the landmark aids orientation by serving as a key to knowledge of spatial relations stored in an internal cognitive or external cartographic map. The second process is dead reckoning, updating a sense of orientation by integrating information about movement speed, direction, and/or acceleration without reference to recognized features.

People also use symbolic media such as maps to navigate and stay oriented. Maps used for navigation show robust alignment effects, a common confusion in using maps when the top of the map is not the direction in the surrounds that one is facing when looking at the map. It results from the fact that spatial perception is 'orientation-dependent'; objects and pictures have a top and a bottom in the perceptual field. In the case of road or trail maps, many people turn the map to bring about alignment. Unfortunately, this option is not available with ubiquitous 'You-Are-Here' maps, which are surprisingly often placed in a misaligned way with respect to the viewer's perspective. The resulting alignment effect is reflected by the fact that misaligned maps are interpreted more slowly and with greater error by most people (Levine et al. 1984). While an annoyance in many situations, misaligned emergency maps placed in public buildings are potentially disastrous.

2.4 *Spatial Communication via Language*

Spatial information is often communicated verbally, in natural language such as English. People give and receive verbal route directions, read spatial descriptions contained in stories, and increasingly interact with computer systems via verbal queries. There are two notable characteristics of the way language expresses spatial information. One is that language expresses mostly nonquantitative or imprecise ('fuzzy') quantitative information about space. Statements about connections and approximate location are more important than precise statements. For example, people say 'turn left at the gas station' rather than 'turn 80° after you go 0.6 miles.' Great precision is typically unnecessary or even confusing. A second characteristic is that various aspects of the context of communication are critical in interpreting spatial language. Context is provided by knowledge of who is speaking, where they are, physical features in the situation, the previous topic of conversation, and so on. 'The bicycle is near the church' is generally understood differently than 'Wisconsin is near Michigan.'

2.5 Individual and Group Similarities and Differences

No two individuals 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 such problems, all of which may be effective. In such cases, one might speak of 'stylistic differences' in spatial cognition rather than 'ability differences.' Geographers are interested in measuring and explaining such individual differences. Traditional psychometric paper-and-pencil tests of spatial abilities tend not to measure these differences very well (Allen et al. 1996).

There are many factors that may contribute to variations in spatial cognition: body size, age, education, expertise, sex, social status, language, culture, and more. A first goal for geographic research is to measure and document ways these factors might covary with spatial cognition. Females and males appear to differ in some ways in their spatial abilities and styles, for example, but not in others (Montello et al. 1999). In addition to describing such covariations, geographers have the research goal of distinguishing their underlying causes. For example, the two sexes likely differ in their spatial cognition in part because of different travel experiences afforded them by their socialized roles. 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.

3. Technologies and the Future of Spatial Cognition Research

A variety of technologies are poised to have a large impact on the questions and methods of spatial cognition research in geography. Global positioning system (GPS) receivers have recently become small and inexpensive, and are increasingly used by sailors, hikers, and other outdoor enthusiasts. 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 also part of the technology of automated navigation systems built into automobiles to provide drivers up-to-date and locally relevant information about routes and destinations. Several research issues concern how locational information is best displayed or communicated, and how the availability of such information might change people's experiences and behaviors in space and place.

Other computer technologies will lead to new research and thinking in spatial cognition. There are a host of spatial cognition questions inspired by efforts to improve the effectiveness and efficiency of geographic information systems (GISs). 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. However, undoubtedly the most dramatic technological development in spatial cognition will be the advent of computer-simulated worlds known as virtual environments or virtual reality.

See also: Cartography; Cognitive Maps; Geographic Education; Geographic Learning in Children; Knowledge (Explicit and Implicit): Philosophical Aspects; Space: Linguistic Expression; Spatial Memory Loss of Normal Aging: Animal Models and Neural Mechanisms; Spatial Thinking in the Social Sciences, History of

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Spatial Data

Spatial data are the sum of our interpretations of geographic phenomena. Taken literally, spatial data could refer to any piece of information that associates an object with a location—from stars in the heavens to tumors in the human body. Typically, however, when used in a geographical context, spatial data is restricted to describing phenomena on or near the earth's surface. In digital form, the data are the primary information needed by geographic information systems (GIS), the software tools used for spatial-data analysis.

1. What Are Spatial Data?

'Spatial data' is used as an all-encompassing term that includes general-purpose maps, remotely sensed images, and census-tract descriptions, as well as more specialized data sets such as seismic profiles, distribution of relics in an archeological site, or migration statistics. Information about buildings, bridges, roads, streams, grassland, and counties are other examples of types of spatial data. Broadly, spatial data refers to any piece of information that has an absolute or relative location (see *Location: Absolute/Relative*). More commonly, spatial data are associated with information shown on maps and images of natural and man-made features that range in size from 1 m to 10 km. Such data are often referred to as geospatial data (see *Geographic Information Systems*; *Spatial Data Infrastructure*; *Remote Sensing*; *Landsat Imagery in Geography*; *Remote Sensing and Geographic Information Systems Analysis*; *Global Positioning System* for examples of the varying types and usages of spatial data). Spatial data sets are collections of locational and nonlocational information about selected geographic phenomena. This collection of information forms the heart of a spatial database. Once the information is in the database, computers provide the capabilities to handle geographic data in ways that were previously impossible.

2. Data Models

A digital spatial data set represents a certain model of geographic reality. These models describe both the locational and nonlocational aspects of the phenomena of interest. For users to make sense of the data they are receiving, they must understand the conceptual model underlying the data.

Table 1
Terminology for describing geographic features

Feature type	Example	Digital database term (and synonyms)
Point feature	Benchmark	Node (vertex, 0-cell)
Linear feature	Road centerline	Arc (edge, 1-cell)
Areal feature	Lake/pond	Polygon (face, 2-cell)

The locational aspect of a spatial data set is usually described by one of two types of models, either grid-cell (sometimes called raster) data models, or vector data models. Grid-cell data models use collections of fixed units of space, for example, cells of land 50 m on a side, to describe the location and extent of a geographic phenomenon. Digital remotely sensed images are collected in this form. Vector data models use graphic elements (points, lines, and polygons) to describe the location and extent of the phenomenon under study. Most digital map data are in this form.

The spatial data also must include all of the nonlocational information used to describe the features in the database. In the case of digital-image data, the amount of nonlocational data is relatively small, usually a set of values measuring characteristics such as the greenness of vegetation. With vector data the amount of nonlocational, or attribute, data can be quite large, even exceeding the amount of spatial data. This includes information about the various features included in the database (for example, the number of lanes of a highway) and their relationships to each other (for example, that the railroad tracks lie between the stream and the highway). In the context of GIS, features are the sum of our interpretations of geographic objects or phenomena. Buildings, bridges, roads, streams, grassland, and counties are examples of features.

2.1 Feature Data Structures

The real world of geographical variation is infinitely complex and often uncertain, but must be represented digitally in a discrete, deterministic manner. In one method of describing geographic reality, characterized by the information shown on maps, we think of the world as a space populated by features of various kinds—points, lines, and areas. This is commonly referred to as the vector or feature data model. Features have attributes that serve to distinguish them from each other. Any point in the space may be empty, or occupied by one or more feature. These features may exist in one combined database, or may be separated according to a theme or variable into a number of layers or classes. The terminology used to describe these features is given in Table 1.

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