Cognition and spatial behavior

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Introduction

A core goal for geographers is to describe, predict, and explain human activity on the earth. The concept of spatial behavior highlights the geographer's focus on the spatial and temporal aspects of this activity – where people go to carry out particular activities at particular times, and how they travel there. Because the smallest cohesive unit of human spatial activity may be one trip carried out by one person at one time, some geographers study human activity at the level of single trips by individual people rather than groups of trips or the activity of groups of people. In contrast, most studies by human geographers traditionally take a group approach, analyzing activity at the level of neighborhoods, cities, institutions, cultures, and so on. In the 1960s and 1970s, what was then the new individualistic approach to understanding human geography came to be known as *behavioral geography*.

Historically, this turn toward understanding human activity at the disaggregate level that was at the heart of behavioral geography led relatively directly to the further idea that human activity should be understood in terms of human beliefs and reasoning. From the inception of behavioral geography, scholars realized that individual people are not passive agents in the world but active decision-makers who reason about behavioral choices. This reasoning, it was assumed, would not be based upon actual properties of the world and the individuals, but upon people's *beliefs* about properties of the world and themselves. That is, behavior is based on the subjective or perceived world. The subjective world consists of beliefs about spatial properties, such as location, distance, direction, connectivity, and containment. It also consists of beliefs about nonspatial properties, including temporal properties and thematic properties, such as what objects and events are in the world, what their positive or negative hedonic qualities are (i.e., their potential as resource or hazard), what preferences and abilities a person has, and so on.

Human beliefs and reasoning are part of the study of cognition, and behavioral geographers focusing on cognition are sometimes said to be doing *cognitive geography*. (Other behavioral work is not specifically cognitive but does focus on the behavior of individuals.) Cognitive geographers participate in a multi- and interdisciplinary scholarly endeavor, in terms of theories, concepts, and methods. Besides connecting with the work of other geographers, such as those in economic geography, human–environment relations, and cartography and geographic information science, they connect directly with the work of psychologists, including those in cognitive, environmental, perceptual, social, and developmental subfields. They also connect with the work of other cognitive scientists, including those in computer science, philosophy, linguistics, and neuroscience, and other social-behavioral scientists and scholars, including those in sociology, economics, anthropology, animal behavior, and planning and architecture.

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Basic concepts of cognition

Several concepts are basic to understanding cognition and spatial behavior. *Sensation* is the first response of the nervous system to stimulation from the world. Sensory receptors transduce patterned world energy, such as light or chemical, into patterned nervous system energy, which is electrochemical. A widespread misconception is that humans have but five sensory modalities; depending on how one slices it, the correct number is at least eight or nine, and includes vision, hearing, smelling, tasting, pressure and texture sensing, temperature sensing, kinesthesis (limb position and movement), and vestibular sensing (linear and angular acceleration). Pain is sometimes considered a sense. To (sighted) humans, vision is probably most important for sensing the spatiality of the world, but hearing, kinesthetic sensing, and vestibular sensing all play important roles. Senses like smell and texture and temperature sensing are important for place or feature identification, but play a limited role in humans for sensing spatiality. One can detect the direction of the wind or the sun on one's face, which sometimes provides a useful cue to heading or travel direction.

The organization of sensory input into meaningful impressions of oneself and of the world, as influenced by prior beliefs, is *perception*. In commonsense experiential terms, the environment as perceived is three-dimensional with oneself in the center, and detachable objects and events against a stable background. The perceived world has varied sensory qualities, such as colors, tones, and so on; presents information redundantly (e.g., different depth cues typically coincide); is incompletely apprehended from a point of view and point in time; demonstrates constancies; and tends to be perceived in terms of meaningful and familiar objects, events, and settings. *Constancies* are the phenomena wherein entities appear to stay the same even as the sensory information they offer changes radically. A longstanding puzzle for perception theorists has been to explain constancies in the face of our locational perspective from a single place and time. How does a swinging door appear to remain rectangular even as its outline on the retina changes shape?

Perception is considered to be part of the larger topic of *cognition*, which is about knowing and knowledge (believing and beliefs), and also includes *thinking*, *learning*, *memory*, *concepts*, *imagery*, *language*, and *reasoning*. The focusing or directing of cognition is *attention*. Attention is controlled internally, as when you intentionally retrieve a certain belief from memory or try to listen to a particular speaker, or externally, as when a loud sound or colorful building captures your attention (the degree to which stimuli attract attention is called *salience*). Some types of cognitive processing require explicit attentional resources – they are said to have *capacity limitation* and are readily subject to *interference* by distracting tasks. Attempting to find your way in an unfamiliar environment is an example. But at the same time, other cognitive tasks require little or no attentional resources. Following your typical route to work each day is an example. Walking around without running into walls is another.

Cognition clearly influences and is influenced by *emotion* (affect), as when certain mental images lead to emotional states or certain emotional states motivate one to focus attention on certain aspects of the world. Although human emotions can be complex and nuanced, at their core is the central component of *evaluation* or hedonic tone – a positive or negative response to beliefs about the world. The results of coupling beliefs with affective states, possibly leading to behavioral intentions, are known as *attitudes*.

As we described earlier, geographers are interested in cognition primarily because of its links to behavior. *Behavior* is potentially observable, goal-directed body movement; it is sometimes called action or activity. Behavior is goal-directed in that its purpose is to achieve some end, such as getting to a place, obtaining a resource, or avoiding a hazard. It is not an internal mental state, such as thoughts or moods, although it is profoundly interrelated to them, as we have noted. In fact, the relationship of behavior to cognition (and emotion) provides a large and complex set of issues for ongoing research and theoretical debate in several fields. That said, behavior is clearly influenced by cognition, if not entirely determined by it. Sometimes overlooked is that cognition is also influenced by behavior, as when people travel about in order to gather information about their surroundings.

Just as behavior is not equivalent to internal mental states, it is not equivalent to neurological states of the brain or the rest of the nervous system. The relationship of the *mind* and *brain* is the profound and very old *mind–body question* in philosophy. Briefly, this asks, what is the nature of mind (experience, awareness, soul, spirit), the nature of body (brain, body, physical world), and their relationship? There are many highly developed philosophical views on this question over the centuries. Many behavioral and cognitive scientists believe the mind emerges from the action of a brain in a body, living in a physical and sociocultural world. Thus, mind requires a brain but is not reducible just to the brain. Still, without committing to the strong reductionism that equates mind and brain, it is evident that we learn more about the mind (and behavior) by better understanding the brain. In the last two or three decades, there has been a great increase in research on the neuroscience of cognition, much of it fueled by advances in brain imaging technologies, especially *fMRI* (functional magnetic resonance imaging). Such research attempts to relate patterns of activity in various regions of the brain to particular cognitive states, such as particular reasoning styles or content. *Cognitive neuroscience* has made substantial contributions to our understanding of the cognition of space and place over the last couple decades, and such studies are just now beginning to appear in geographic literature. We can expect to see the influence of neuroscience grow in the discipline of geography, as it is doing in nearly every other field that studies human mind and behavior.

Empirical methods for studying cognition and spatial behavior

As in other problem domains within geography, researchers who study cognition and spatial behavior need methods to observe and measure their phenomena of interest. The major approach to such methods in the study of cognition and behavior has been observing and recording the behaviors of research participants, individually or in groups. Other useful methods include examining secondary *archives*, including data mining of the Internet and social media. *Physical traces* can support inferences about where behaviors occurred and what people believed about something; these physical traces may have been intentionally or unintentionally created. *Computational modeling*, including robotics and other forms of artificial intelligence, continue to shed light on cognition and spatial behavior. During the late twentieth century, neuroscience methods became available for studying brain activity during ongoing thought in conscious, nonclinical respondents. Finally, a truly geographic approach to studying cognition and behavior should involve thorough analysis of the environment, whether natural or built, and any informational material involved in cognition and behavior (such as cartographic maps, photos, texts, etc.).

Recognizing this methodological diversity, it can still be noted that behavioral methods are the dominant way geographers study cognition and spatial behavior. These can be based on verbal or nonverbal behaviors, and include where people travel and along which routes, where and at what they look or point, what they draw, and what they say or write. Some behavioral geographers focus on the observed behaviors themselves as their phenomena of interest. For instance, some geographers record daily commuting trips without considering what people believe about their trips or why they think they make them. Other geographers with more cognitive interests typically make inferences about thoughts and beliefs from the observed behaviors. Either way, one can broadly distinguish behavioral methods involving the nonmanipulated observation of ongoing behavior from those that ask people to explicitly express their beliefs. The latter are called *explicit reports*; whether written, drawn, or spoken, these expressions are behaviors. Explicit reports are used to study people's beliefs about themselves or others, about places or events, about objects or activities; any of these beliefs can include beliefs about spatial properties or attributes. When providing data via explicit reports, research participants know they are supplying information about their beliefs to a researcher, and these beliefs must be consciously accessible to the participants. Explicit reports can be further distinguished as *tests*, which generate responses that are evaluated for accuracy, or *surveys* (polls, interviews), responses to which cannot readily be judged in terms of accuracy or whose degree of accuracy is not of central interest to researchers (although truthfulness is). That is, surveys generally assess opinions, preferences, or personal experiences rather than knowledge. Of course, the explicit reports used to study spatial cognition are more often tests than surveys, but other cognitive geographers use surveys frequently.

Sketch mapping

A widely used method to obtain data for the study of cognition and spatial behavior is having research participants sketch maps (or construct physical models, etc.) of places or regions. Sketch mapping is among the most straightforward ways to find out what people believe about spatial layouts at any scale, and perhaps hundreds of studies and thousands of informal demonstrations have collected sketch maps. But as with other open-ended methods, the ease and simplicity of collecting sketch maps is not matched by easy and simple coding and analysis. In the end, the questions you want answered by the sketch maps should determine how you code and analyze them – there is no omnirelevant approach. Types or specific instances of features such as paths or landmarks can be counted. Spatial properties such as distance or direction can be measured. The orientation of the sketches can be coded, as can their drawing style, or the presence or absence of particular verbal labels. The challenge of unambiguously identifying map features and making comparisons across individuals or groups can be made easier if the sketching task starts with more prior structure than just a blank sheet of paper or blank computer screen. Cardinal directions, distance scales, road networks, or mountains and water bodies can be present at the start. A list of features to be located on the map can be provided, allowing the researcher to focus on the location of placed features rather than whether they are included at all.

Scaling

A diverse set of explicit-report techniques used to study spatial cognition is known as *scaling*.

When scaling, research participants directly express their beliefs about quantitative properties, meaning properties that are not just classified but rated or estimated at a metric level of measurement – interval or ratio. Scaling derives from two methodological traditions within the history of research psychology: *psychophysics* and *psychometrics*. Psychophysical scaling originated during the nineteenth century. It requires participants to estimate quantities of a property that researchers relate to values of objectively measured quantities. For instance, participants can estimate distances, directions, or sizes. A specific example would be asking someone to estimate the distance between two cities in miles. Psychometric scaling, in contrast, originated during the early twentieth century. It requires participants to estimate quantities of a property that cannot be compared directly to objectively measurable quantities. For instance, participants can quantitatively express attitudes, abilities, preferences, or moods. A specific example would be asking someone to rate how much they like different cities on a scale from 1 to 10. Both psychophysics and psychometrics demonstrate persuasively that subjective mental states in humans can be scientifically studied.

Values generated with scaling techniques can be statistically interpreted as individual variables describing individual entities, such as the area of a city, or relational variables describing pairs of entities, such as the distance between two cities. A sophisticated way to analyze scaling data called *multidimensional scaling (MDS)*, however, provides a way to analyze and interpret values concurrently across an entire set of entities of interest. To understand this technique intuitively, imagine using a ruler to measure distances on a map between pairs of points representing cities in order to create a traditional mileage chart, a matrix of distances between pairs of the cities. MDS effectively reverses this procedure (computationally) to create a configuration of points given only the matrix of pairwise distances between cities in a given set. In fact, MDS algorithms can generate metric configurations from nonmetric input, such as ranks of distances, instead of metric distances, and other spatial properties such as directions can provide a basis for MDS. Importantly, when the separations between points represent dissimilarities between the entities rather than literal distances, so-called *semantic spaces* can be created that use space metaphorically to represent meaning with any types of entities as a spatial configuration.

Cognitive maps and mapping

The concept most central to the study of cognition and spatial behavior is the *cognitive map*. Downs and Stea (1973, 9), in the introductory chapter to their influential edited collection, defined cognitive mapping as "a process composed of a series of psychological transformations by which an individual acquires, codes, stores, recalls, and decodes information about the relative locations and attributes of phenomena in his [or her] everyday spatial environment"; the stored information is the cognitive map. Cognitive maps are fundamentally idiosyncratic to individuals but are partially shared among groups of people. The notion that mental representations of the environment guide behavior may be found in the academic literature at least as long ago as the early twentieth century, but the specific term "cognitive map" is attributed to the animal behaviorist Tolman (1948) to explain the behavior of his rats in a tabletop maze.

The concept of the cognitive map is a metaphor, suggesting that mental representations of the environment are like cartographic maps in the mind. Many other metaphors for this concept are possible and have been suggested by various scholars, such as imaginary map, mental model, or cognitive collage. But like any metaphor, the source domain of cartographic maps may not capture the target domain of environmental knowledge perfectly; research literature has discussed this issue at length. Both cartographic and cognitive maps are representations that contain spatial and nonspatial information, both are selective, both distort properties of the world, both encode from different spatial perspectives, both represent features on a continuum of abstractness (from relatively iconic to relatively arbitrary), and both serve various functions beyond just guiding navigation. The metaphor can be quite misleading, however. The cognitive map is not a unitary and uniform representation, contrary to the idea of a "mental picture" in the mind. It is a collection of pieces (separate representations) that are not continuously integrated with a constant or continuously varying scale. The cognitive map derives from multiple sources and is mentally represented in various formats and perspectives. The pieces that make up the cognitive map are not mutually coordinated, at least not completely, and they may express spatial beliefs that do not follow a Euclidean metric or any metric geometry at all. While cartographic maps can certainly stimulate emotional responses in map users, cognitive maps themselves incorporate emotionality, such as attitudes of fondness or fear toward places.

In the end, aspects of evolution and learning shape beliefs and decision-making to generally support adaptive behavior, leading people to be spatially oriented, travel efficiently, make rewarding choices and avoid harmful ones, and communicate effectively. In this regard, the idea that internal mental states and processes mediate observed spatial behavior leads us to see geographic beliefs and reasoning as functioning to organize, direct, and enrich experience. But early in the scholarly history of this domain, behavioral researchers also recognized that the subjective world may deviate greatly from the objective world and that beliefs can be maladaptive. Spatial knowledge includes beliefs that are in error relative to objective reality. These errors have both systematic (consistent) and random components. Researchers study errors as a way to understand several aspects of spatial knowledge, including its content, its resolution, how it is structured and processed in the mind, and how it relates to emotion and behavior.

Landmarks

An important component of people's knowledge of the environment is the *landmark*, which in general terms is a feature or object in the environment that is relatively distinct and can be noticed and remembered. People use landmarks to recognize places and orient themselves, and to communicate that with other people. In more sophisticated terms, landmarks can express a symbolic meaning for a place, serve as cues for actions, or function as reference points around which place knowledge more broadly is mentally organized. Although we usually think of landmarks as providing a key to location, in many cases, it is our knowledge of a landmark's location that provides the context to disambiguate its identity as a landmark in the first place. And even though landmarks are often caricaturized as prominent point-like features (the Eiffel Tower!), they are often extended features that are line-like or areal, especially at particular spatial scales. Even acknowledging how common it is that people orient themselves by visually (or via other senses) recognizing the environment, it is important to realize they often do it by recognizing entire scenes within the visual field, perhaps without being consciously aware they are doing it. Such "landmarks" are not useful as part of verbal route directions the way landmarks as distinct and discretely labeled features are.

Regions

Another important structural component of spatial knowledge of the environment at any scale is the areal (two-dimensional) concept of *regions*. Long studied by geographers and used by them to organize their understanding of the earth's surface, regions are central to the spatial thinking of lay people as well. Regions break a continuous earth surface into discrete pieces, essentially spatial categories. They are bounded, and the boundaries vary in their precision or vagueness, and in their permeability to matter, energy, and information. Furthermore, regions are often organized hierarchically, with regions at different levels of status (such as size or power) connected to each other in relations of containment. This allows hierarchical reasoning, wherein spatial relations between places are inferred from relations between the regions to which they belong rather than stored directly (Stevens and Coupe 1978). More subtle models of hierarchical reasoning suggest that locations are inferred by weighting combinations of coarse regional membership and precise metric location.

There are various types of regions in geography. *Cognitive regions* (also called perceptual regions) are informal regions in the mind, socially/culturally shared to varying degrees. A diverse set of behavioral phenomena have been offered as evidence for regional organization and hierarchical reasoning, including systematic errors in direction or distance judgments, particular patterns of response latencies to answer questions about spatial relationships, systematic ordering of sequences of recalled places or features, and more. Friedman and Brown (2000) collected estimates of cities' latitudes to show that people organize their knowledge of spatial relations at the continental scale in terms of regions (they termed them *cognitive plates*) that compress spatial relations within the regions but exaggerate them between regions. Furthermore, the separate regions can be mentally shifted independently of each other, producing distinct patterns of distorted knowledge (see Figure 1).

Environmental spatial learning and development

Any process of systematic change over time may be called *development* or *evolution*. Processes of change are of interest across the discipline of geography. They occur at any temporal and spatial scale and for entities at many levels of analysis, including individuals, cultures, institutions, ecosystems, species, and landforms. Cognitive researchers in geography are most interested in *ontogenesis* (ontogeny), the development of cognition from an individual's conception to his/her death (also called child or lifespan development), and *microgenesis* (microgeny), the development of cognition over shorter time periods from initial exposure to new information or new situations to later states of familiarity.

An important distinction for those studying ontogenesis and microgenesis is that between *learning* and *maturation*. Learning refers to relatively permanent change in the content, structure, or processing of knowledge due to specific cognitive experiences such as those involving new information or semiotic representations, not physical experiences such as those involving illness, injury, or exercise. Maturation is the unfolding of innate change processes over time, not requiring specific environmental experiences (but usually requiring general experiences, such as adequate nutrition). Of course,

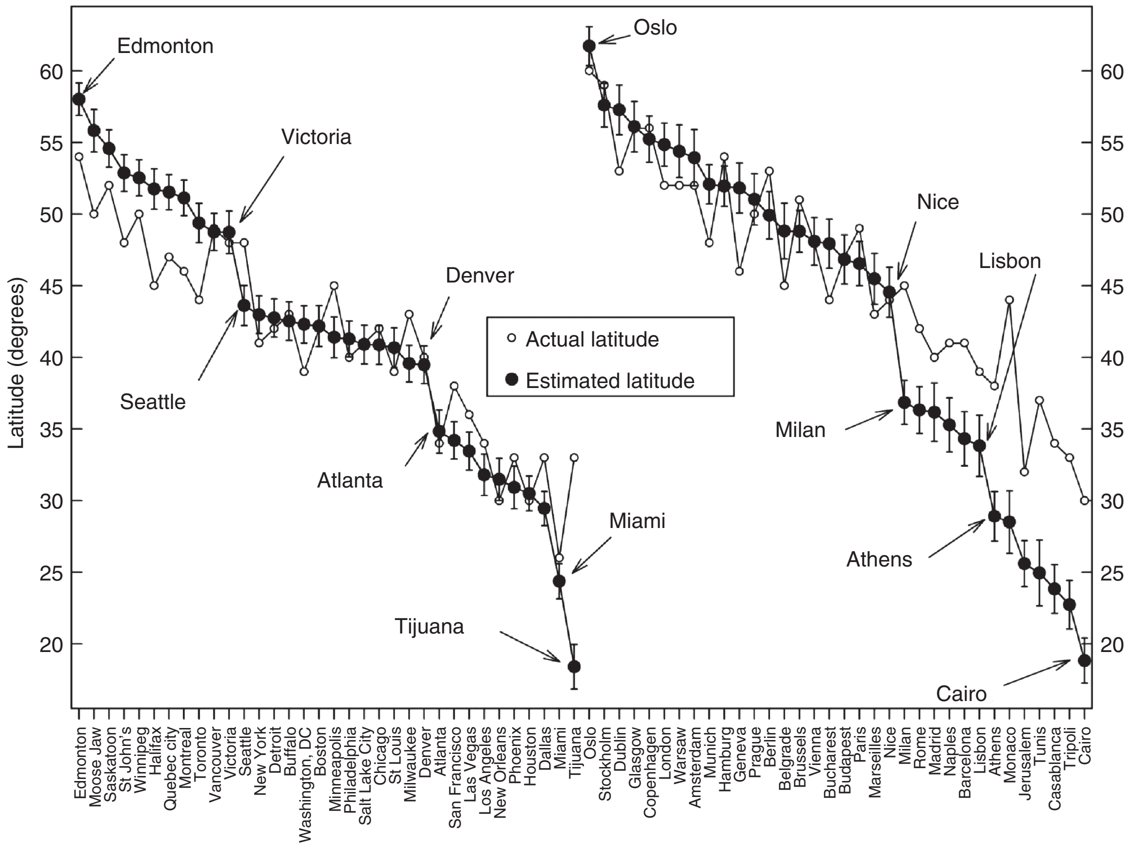

Figure 1 Estimated latitudes of cities in North America, Europe, and North Africa, ordered left to right from cities judged most northerly to cities judged most southerly, and plotted against actual latitudes. The pattern reveals subjective latitude compression within regions, exaggeration between regions, and north- or southward shifting of cities in certain regions.

Friedman and Brown (2000), Fig. 2. Copyright American Psychological Association. Reprinted with permission.

while learning occurs as part of both developmental processes, maturation typically does not take place within the limited time periods of microgenesis, which often occur within as little as seconds or minutes. Nonetheless, the nature of an individual's learning is strongly linked to his or her maturational development, as when older children can learn more complex spatial layouts than younger children can in the same exploration period.

Commonly, theorists studying change of any type in any system contrast *stage* and *continuous* models of development. Stage models propose that change occurs in qualitatively distinct episodes or periods, each stage having a coherent theme of interrelated events or abilities, with relatively abrupt transitions between stages, and an invariant sequencing of stages (although the timing of transition may vary). Continuous models oppose these ideas, suggesting that change occurs relatively continuously rather than in discrete stages, and is more accurately described as quantitative rather than qualitative in nature. Although the contrast between stage and continuous models is intellectually fruitful, it is typically ambiguous to choose between them definitively, in part because processes that appear discontinuous at one scale of analysis appear continuous at another.

Scholars study a host of specific aspects of cognitive change, but central to those studying geographic spatial cognition is the issue of how children and adults organize their understanding of location on the earth's surface, both in thought and in communication. This is the topic of *reference systems* (sometimes called frames of reference). As geographers know well, all locational information is relative; reference systems are the ways that locational statements are defined or anchored. These include the precise and quantitative systems familiar to surveyors and geographic information scientists, known as coordinate systems. Cognitive geographers are usually more interested in the approximate and qualitative systems mostly employed by lay people. A variety of typologies of cognitive and linguistic reference systems have been proposed over the years. Such typologies usually distinguish *egocentric* systems based on one's body ("front-back," "left-right") from *allocentric* systems based on something external to the body. The latter is sometimes further distinguished as being based on nearby features or landmarks that define location only very locally ("near the tree," "at the gas station") versus distant or global features that define location over large areas ("head toward the ocean," "go north"); those based on global features are also known as *absolute* reference systems. The topic of reference systems is a rich one. Individuals of different ages clearly tend to use different references systems, as do people differing in their level of familiarity with places. Different cultural or linguistic groups use reference systems somewhat differently; even people of the same cultural group apparently use them differently as a function of their residential environment (for instance, whether they live in flat or mountainous terrain). And a single person can use multiple reference systems in thought and language, either as a result of subtle changes in context or even with the same chain of reasoning or expression.

Ontogenesis of environmental cognition

A great deal of research for over half a century has looked at the spatial cognitive development of infants and children. Early in their life, infants develop in various aspects of spatial perception, including the perception of shape, depth, size constancy, and perspective changes. Important to perceptual and cognitive changes are changes in motor behaviors, whether lifting one's head, crawling, or walking. As infants become toddlers and young children (variously up to age 6 or so), they are typically able to travel much further in their environment and acquire richer, more extensive cognitive maps. Other research has looked at the acquisition of spatial concepts at different levels of geometric sophistication, including metric and topological properties. As young children become middle children (up to adolescence) and teenagers, they further develop in their abilities to plan and choose routes, and conduct organized spatial searches. Their abilities to give and interpret verbal directions improve, and their understanding and use of cartographic maps increases in accuracy and complexity.

During the decades of the mid-twentieth century, the theories of the Swiss psychologist Jean Piaget and his colleagues were widely explored to explain cognitive development in children, including spatial and environmental cognition.

His stage theory of cognitive ontogenesis saw development as a biologically evolved process of adaptation to the complex, uncertain environments that children encounter. For Piaget, knowing involves actively selecting, interpreting, and constructing. Action upon the world and its effects on the surroundings is critical to knowledge development. The nature and modification of knowledge structures (*schemas*) can be characterized in terms of four major stages, typically taking place during certain characteristic age spans: sensorimotor (ages 0–2 years), preoperational (2–7), concrete operational (7–11), and formal operational (11+). The theory is rich and rather complicated, but in brief, changes through these stages can be summarized as cognition going from simple to complex, prelogical to logical, concrete to abstract, and perceptual/action-based to conceptual/reasoning-based. Besides his elaborate theoretical framework, Piaget's work also provided a series of influential empirical tasks and concepts for later scholars, including object permanence, spatial egocentrism and perspective taking, conservation, and nonmetric spatial thought.

Substantial problems have been identified with Piaget's large body of work, including doubts about the timing of his stages, his tendency to underestimate the abilities of infants and young children, and his tendency to overestimate the abilities of teenagers and adults. Various theoretical alternatives have cast doubt upon the existence of coherent general stages of cognitive development and criticized Piaget's relative ignoring of the roles of language, culture, and social interaction, including formal and informal schooling. Some of these alternative theories include information-processing theory, situated cognition, linguistic relativity, and conceptual nativism (see Newcombe and Huttenlocher 2000).

Microgenesis of environmental cognition

By analogy to stage theories of ontogenesis, an influential framework for understanding the microgenesis of environmental spatial knowledge arose during the 1960s and 1970s. This "dominant framework" was most eloquently expressed by Siegel and White, as described by Ishikawa and Montello (2006). It proposed that spatial knowledge in a new environment, such as when a person moves to a new city, develops over time in an invariant sequence of three stages. The first is *landmark knowledge*, which is not explicitly spatial at all, but merely implies recognition of distinctive features or objects. The second stage is *route knowledge*, which refers to locomotor routines connecting sequences of landmarks. Knowledge at this stage, at least initially, is nonmetric and organized only egocentrically or with reference to local landmarks. The third and most mature level of knowledge is *survey knowledge* (or configurational knowledge). This is two-dimensional layout knowledge, simultaneously representing spatial interrelations of landmarks and routes. It contains metrically scaled distances and directions, and integrates stored landmarks and routes into a unified, coordinated representation organized according to a global allocentric reference system. Taking inspiration from Tolman's (1948) rats, the behavioral sign of survey knowledge is the ability to create novel shortcuts and detours – in short, to navigate creatively. Although presentations of this framework have never specified how much time passed between stages, they implied that the time periods would be substantial, perhaps on the order of months or years.

Some researchers have questioned this dominant stage theory of spatial microgenesis. Ishikawa and Montello (2006) describe an alternative framework, published earlier by Montello, that proposes that development is relatively continuous and quantitative, not stage-like. That is, spatial knowledge acquisition starts immediately upon arrival at a new place, and the extent, accuracy, and completeness of knowledge continue to grow indefinitely (the exact time-course and ultimate limit of knowledge development were recognized as important research questions). This spatial knowledge includes some approximate metric knowledge right away; there is no period of pure nonmetric landmark or route knowledge. This framework does include the relatively abrupt step that separately learned knowledge of routes and regions acquired during unitary travel episodes can relatively suddenly be integrated into more complex, hierarchically organized structures in what might be considered a form of spatial insight.

Ishikawa and Montello (2006) presented a longitudinal study designed to compare these two frameworks for microgenesis. Participants rode individually with the researcher on automobile trips through a local neighborhood they were not previously familiar with, taking one ride per week for 10 weeks. Their distance and directional knowledge about the relationships between landmarks on two test routes was tested each week, and participants drew sketch maps of the routes every other week. Unexpectedly, the results, shown in Figure 2, indicated that different participants showed very different patterns of knowledge acquisition over time, which neither framework implies. Contrary to the dominant framework, some participants acquired accurate and surprisingly precise metric knowledge after their first trip, and continued to demonstrate very good spatial knowledge throughout the 10 weeks. Contrary to both frameworks, other participants acquired little or no metric knowledge after their first trip, and even 10 weeks of visiting the site resulted in little or no metric spatial knowledge. Only a subset of participants showed marked improvement over 10 weeks, and this improvement appeared more continuous than stage-like.

Navigation and orientation

All human geographers are interested in people's activities in space and place, and perhaps the most central example of such activity is travel between places, whether temporary, as in shopping trips, or more permanent, as in migration (residential relocation). Perhaps the most salient aspect of travel for cognitive geographers is that people so often do it in a coordinated and efficient manner. Such coordinated and goal-directed movement of oneself through the environment is *navigation*. Navigation includes not just the specialized activity of professionals on ships and airplanes, but something almost everyone does many times every day, when they walk to class, drive to work, and so on. Because the literal navigation referred to here – actual body movement over the earth's surface – provides such a concrete and universal case of problem-solving within a complex situation, lay people and scholars alike often speak of other problem-solving contexts metaphorically as navigation. For example, we may navigate through a math problem, a difficult text, an Internet website, or an emotionally vexing relationship crisis.

One can distinguish two components of navigation: *locomotion* and *wayfinding*. Locomotion is the coordination of the body to the local surrounds during movement, serving to avoid obstacles and barriers, move toward perceptible landmarks, and so on. It involves processing information about the surrounding environment that is directly accessible to sensory and motor systems, and thus does not typically require internal (memory) or external (cartographic maps, etc.) representations of the environment. Locomotion takes place via various modes, whether

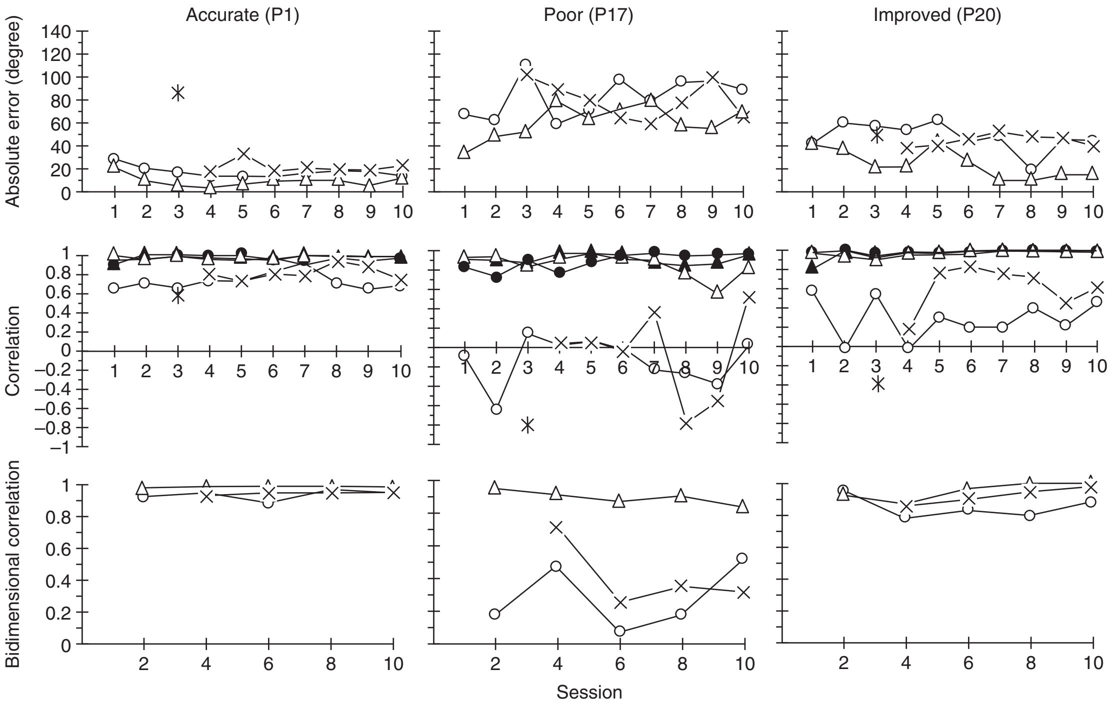

Figure 2 The accuracy of distance estimates, direction estimates, and sketch maps by three representative participants who learned novel routes in an unfamiliar neighborhood over 10 weeks. Participant 1 on the left is extremely accurate from the first week to the last; Participant 17 in the middle is extremely inaccurate from the first week to the last; Participant 20 on the right shows improvement in accuracy over time.
Ishikawa and Montello (2006). Copyright Elsevier Publishing. Reprinted with permission.

strictly body-based or involving technologies, like automobiles or airplanes. People locomote at various speeds, facing various headings, and following various courses. Active locomotion is often distinguished from passive, usually referring to whether the movement is self-directed or not. Navigation also involves wayfinding, the goal-directed planning and decision-making part of travel. The goal of navigation is getting to a destination efficiently. Wayfinding is the set of processes by which a person strives to achieve this in the common situation where the goal is not perceptible from the person's current location. That is, wayfinding is coordinated to the distal environment not directly accessible to sensory and motor systems. Thus, wayfinding does require either an internal or an external representation of the environment, although it may be very schematic or incomplete. Typical wayfinding tasks include choosing routes, scheduling trips, and maintaining orientation to the environment beyond the immediate surrounds.

Maintaining *geographic orientation* – a sense or knowledge of where you or where your destinations are on the earth's surface – involves some combination of knowledge about location, distance, and direction. Of course, a significant wayfinding problem, unfortunately common for some individuals, is that people are not always oriented. You are oriented when you think you know where you are or where to go, and you are correct. If you are not oriented, you may be either *disoriented* or *misoriented*. Disorientation is subjective, occurring when you think you don't know where you are or which way to go, or aren't sure; it is what people usually mean by saying they are *lost*. Misorientation is objective, occurring when you are actually not where you think you are or are actually going the wrong way. Each state often happens without the other, especially being misoriented without being disoriented. This is unfortunate, as people do not attempt to reorient if they are misoriented without being disoriented.

There are two types of processes people use to update their orientation as they move about: *landmark-based updating* and *dead reckoning*. Landmark-based updating, also known as pilotage, position fixing, or taking a fix, is based on recognizing external features or objects. Sometimes a visible (or audible, etc.) landmark is available at a person's destination location, and the person can simply locomote toward it, a process called *beacon-following*. This is actually fairly rare as a case of landmark-based updating. Much more commonly, people pilot by recognizing visible landmarks in the surrounds, which in turn allows them to identify their location and heading within their cognitive or cartographic map, which then allows them to relate their current position to the locations of distal features and places. In contrast to landmark-based updating, dead reckoning, also known as path integration or inertial navigation, does not involve recognizing external features. Instead, given knowledge of one's initial location, information about the direction and speed of one's travel can be used to infer one's final destination, after travel. Without specialized technology, people can sense movement direction and speed with the help of *idiothetic* (internal) or *allothetic* (external) signals. An important example of idiothetic information is the information one gets about linear and angular acceleration from vestibular sensing. An important example of allothetic information is the information one gets from *optic flow*, the movement of textural elements through the visual field, without recognizing specific features. Of course, dead reckoning is useful in completely unfamiliar areas, but it has some important limitations. It requires that you know the location where you started for full orientation on the earth's surface. And it suffers from the accumulation of error over time, which must be corrected by position fixing.

When cartographic maps are used to maintain orientation during ongoing travel, the navigator must coordinate his or her current location and heading on the map with his or her location and heading in the surrounding environment. Examples are "you-are-here" (YAH) maps or road maps used while riding as a passenger in a car. Such navigation maps exhibit *orientation specificity*: They are perceived and interpreted best in a single orientation. That orientation is generally "forward-up," with the navigator's forward heading in the surrounds represented as up on the map (assuming a vertically held map, facing the navigator). Any other relationship between the map's orientation and the navigator's heading tends strongly to produce *misalignment effects* (usually called "alignment effects" in the literature). This is the extra time, error, effort, and/or displeasure that results when using misaligned navigation maps. Travelers typically rotate detached navigation maps to keep them forward-up aligned as they change headings; digital navigation systems usually have the option of automatically reorienting in this way. Fixed YAH maps cannot be rotated in this way, and it is surprisingly common to find such misaligned maps mounted in public places. Various cognitive strategies have been identified for reasoning effectively with misaligned navigation maps, but the map user must recognize these strategies are called for, they must know how to use them correctly, and they must have the cognitive abilities to do so. Interestingly, while the automatic forward-up realignment of maps in digital navigation systems helps most people stay oriented, it may not support the acquisition of cognitive maps of an area as well as a fixed orientation, such as north-up, does.

Distance and direction knowledge

Being oriented often requires knowing something about distances and/or directions in the environment, and effective spatial planning and decision-making more broadly typically require some knowledge of distances and directions. From a cognitive perspective, the concept of an environment implies a space that is so large and otherwise obscured by features that one can directly apprehend its spatial layout only by locomoting around and mentally integrating separate sensorimotor experiences over time. It cannot be viewed entirely from a single point, as a cartographic map allows. Thus, beliefs about distances in directly experienced environments are beliefs about distances along traveled routes. Research has suggested a variety of types of information that can provide a basis for beliefs about environmental distances, or at least that can influence judgments of distances if they do not entirely determine them. Evidence indicates that the presence of environmental features such as path intersections and segments, turns, barriers, and landmarks will typically increase subjective distances. The cognitive mechanism for this is not entirely clear. People might just mentally equate distance traveled with the number of features noticed and remembered. It appears more likely that they use prominent features to subjectively segment routes into pieces, which in turn lead to longer subjective distances on more segmented routes because of category or psychophysical scaling effects in estimation.

The presence of environmental features can also affect one's sense of travel time, which in turn can influence one's sense of traveled distance. Geographers often treat travel time as distance itself, insofar as they consider distance abstractly to mean any measure of the cost of overcoming the separation between places. In many cases, people undoubtedly use travel time as the relevant cost to consider when they spatially plan. This does not mean that people cognitively equate time and distance, however, only that in some situations they use time instead of physical distance to make decisions. Limiting cases show that people do cognitively distinguish time and distance, as when they realize they have not gone far when sitting in a traffic jam, or they know they *have* gone far while sitting for a couple hours on a jet plane. But it is still quite likely, especially when people have poor access to information about their movement speed, that travel time influences judgments of traveled distance. Evidence does not suggest this relationship is very robust, however, whatever intuition suggests. And basic psychological research indicates that the relationship of events (such as the presence of features) to subjective time is not simple. Events can expand estimates of past time intervals when the events are recalled retrospectively as part of judging the interval. But events can shrink estimates of time intervals if they are the focus of attention prospectively, during travel – they can distract one from focusing on time or distance. Finally, physical effort has also been proposed to influence judgments of traveled distances, at least over relatively short extents, but demonstrations of the influence of effort are also not robust and invite severe criticisms about the possible role of participant expectations on observed judgments (known as *demand characteristics*).

Knowledge of directions in the environment is also important to spatial planning and especially central to being oriented. Given that localizing entities on the earth's surface is mostly a two-dimensional problem, the focus of cognitive research has almost entirely been on azimuths rather than elevations or slopes. Many studies ask research participants to point to features (with their hand or a tool) from their current location and heading, or from an imagined location and heading ("point to the grocery store as if you were at the courthouse steps, facing west"); these are often called *judgments of relative direction*. When exploring theoretical questions about the resolution or vagueness of spatial knowledge, researchers are most interested in random or unsystematic errors in direction estimates. It is generally correct to calculate *variable errors* in this case. At other times, researchers want to explore theoretical questions about bias or distortion in spatial knowledge; they are most interested in systematic tendencies to estimate directions either clockwise or counterclockwise of the correct direction. It is generally correct to calculate *constant errors* in this case. At still other times, researchers want to explore theoretical questions about how people differ from each other in their abilities to estimate directions; they are interested here in analyses that combine the two types of error, calculating *absolute errors* to do so. Properly calculating absolute errors is just a matter of taking the absolute value of the difference between estimates and correct directions. Properly calculating variable and constant errors is more involved and requires using *circular (directional) statistics*.

Cognition of cartographic maps and other geographic information displays

People experience the earth and acquire geographic information, including spatial, temporal, and thematic information, from directly interacting with the world via sensorimotor systems or from interacting with some type of symbolic medium. The nature of people's experience and the information they acquire varies as a function of the nature of this interaction. If one directly interacts with the world, they can be stationary or locomoting. If locomoting, they can be crawling, walking, or running. Their locomotion may be mechanically aided, with a bicycle, car, boat, or plane. If one interacts indirectly with the world via symbolic media, they may do so with static pictorial representations, such as graphs, maps, drawings, or photos. Or they may do so with dynamic pictorial representations, such as animations or movies. They may experience the world through natural language like English or Mandarin Chinese, whether spoken, written, sung, or signed, or formal language like mathematics, symbolic logic, or a computer programming language. *Virtual reality* systems may be more like dynamic pictorial representations or more like direct experience, depending on the nature of the system. Of course, people commonly experience the world through more than one of these, either simultaneously or sequentially over time. Ongoing research addresses how information from multiple sources is combined, or even whether it is.

These different ways of interacting with the world present the world and its properties differently, and likely influence the beliefs one acquires about the world. They involve different sensory and motor systems; for instance, some involve body locomotion and some do not.

Some present static information about the world and some present dynamic; furthermore, some present their information statically and some present it dynamically (for example, a map with arrows statically presents dynamic information). Some ways provide nearly simultaneous access to the world and others provide it sequentially, perhaps over long time periods. Indirect interaction requires the interpretation of symbol systems. The semiotic abstractness of symbols varies, ranging from very iconic (resembling what they represent) to very arbitrary (not at all resembling what they represent). Some symbols require scale translation for interpreting spatial or temporal scale, and some are more flexible in showing different scales. Different ways give different viewing perspectives on the world, ranging from horizontal to oblique to vertical. They vary in the precision with which they depict spatial properties, as well as the detail they provide.

Map symbols represent spatial, temporal, and thematic entities and properties of the earth's surface. That is, they express meaning (semantics) by referring (corresponding) to a portion of the earth's surface and the events and features found there. Cognitive map research asks questions such as how information is perceived from maps, how it is interpreted and stored in memory, how it is used to reason and solve problems, how it is used to guide behavior, and so on. An ongoing academic debate explores the degree to which map skills (interpreting, using, making maps) have an innate basis and how maps should be incorporated into early education. But there is no question that the sophistication of different map skills develops over childhood, and in fact, that many adults struggle with various map skills. The meaning of largely arbitrary symbols, such as contour lines, can be obtuse to children and adults; iconic symbols, such as green for vegetation or blue for water, can readily mislead children and adults to over-interpretation. Understanding spatial scale and translations between scales confuses many people, as does the proper interpretation of symbol generalizations and perspective transformations (e.g., overhead to terrain-level perspectives). The appropriate interpretation of size, distance, and direction as depicted on various projections may even vex quite a few professional geographers.

Cognitive aspects of geographic information science

Almost from its beginning in the 1980s, basic research on geographic information science (GIScience) included concerns with human beliefs, communication, reasoning, and decision-making about and with geographic and environmental information. A distinct area of study within this focus on *cognitive GIScience* looks at cognitive and computational *geo-ontologies*. The traditional philosophical study of ontology concerns the ultimate nature of what exists in reality. During the 1980s and 1990s, it became widely recognized that geographic databases and information systems are essentially computational models of reality, and at the same time, mental and linguistic representations are conceptual models of reality. Cognitive GIScientists address the possibility and desirability of increasing the congruence of these computational and cognitive ontologies.

Another central cognitive research program within GIScience continues the tradition of research on map perception and cognition, but no longer dealt only with traditional flat and static pictorial maps. Digital technologies allowed a host of new forms of *geographic information displays*, often referred to as geovisualizations (notwithstanding the unintended limitation this implies to the visual modality). Images need not be flat but could incorporate *stereopsis* (three-dimensional vision); they could include nested images and textual annotations revealed only with interaction; they could include dynamic animations; and they need not be only visual, but could incorporate sound, touch, even smell and taste! Critically, the traditional passive consumption of maps designed by others and inflexible in appearance could be replaced by interactive user control, including variable or theme selection, slider bars, brushes, zooming, panning, and more. Spatial displays of nonspatial information that resemble familiar spaces like landscapes were dubbed *spatializations*. This fit in with the explicit recognition that the appearance of computer interfaces functioned metaphorically, by suggesting particular familiar domains for users. Ongoing cognitive research looks at various digital interface-design issues, whether maps on the Internet, on cell phones, on eyeglass screens, or as part of location-based services.

Natural language and space

Another symbolic medium for mentally and externally representing spatial properties is natural language. The relationship of language to thought is an old question for philosophers and social scientists. It is relevant to geographers insofar as it suggests something about cultural (linguistic) variation in spatial thought, which in turn has important implications, for instance, for the design of geographic information systems (GIS) outside a monolinguistic context.

Linguistic expressions often include spatial content. The spatial properties of the characters, objects, places, and events that make up narratives are often described, whether size, shape, or location; changes to spatial properties, especially location, often figure centrally in the story. Other common examples of linguistic expressions containing spatiality include instruction manuals, road signs, and giving verbal route directions. GIScientists are quite interested in entering, storing, processing, and outputting verbal geographic information in systems like general-purpose GIS, navigation systems, digital libraries, tourist systems, and more.

A variety of intriguing issues concern how language expresses spatiality. Spatial terms sometimes involve a spatial scale for their interpretation, and this scale is often provided implicitly by context. We can be “near the mailbox” or “near Mumbai.” “Near” likely refers to very different extents in these two cases. Language expresses mostly nonmetric or very imprecise metric information, such as in terms like “near” and “right” (although it can express precise information). Does this reflect something fundamental about the imprecision and nonmetric nature of spatial thought, or does it simply mean that language avoids encoding our more quantitative thoughts because communication typically doesn’t need it, perhaps because metric precision is so often perceptually available in the surrounding environment? Spatiality is expressed in nearly all grammatical classes, including nouns (top), verbs (approach), adjectives (far), and adverbs (nearby). Prepositions are an especially important and interesting case, as most deal with spatial relations, and yet they are difficult to translate – even native speakers often struggle with them. We get “on a bus” but “in a car”; we refer to “the house on the lake” as well as “the boat on the lake.” Linguistic scholars study the expression of spatial relations in prepositions in different languages and the nature of constraints on preposition use. For example, it has been shown that larger, more stable objects usually serve as reference objects for figural objects; we say the “book is on the table” not the “table is under the book.”

Probably the greatest amount of cognitive research on spatiality in language of interest to geographers has been on *verbal route directions* (navigational instructions). In a prototypical route direction exchange between two people, the direction giver (person G) has a series of cognitive and social tasks to accomplish as part of providing directions to the asker (person A). G must identify the identities and locations of A's start and destination. In many cases, the start is the location where the direction-giving exchange is occurring, but even then, G must become cognizant of where the two of them are, and how it relates to other locations in a cognitive map that includes the start, destination, and intervening route. (In rare situations, such as at an information help desk, a person may have "canned" directions in their mind that can be expressed without accessing a cognitive map.) After G has determined the spatial relationship of the start and destination from the cognitive map, he or she must plan a route for A; this may be presented in whole or piece by piece. G must select the information advisable to communicate to A, including which turns, street names, landmarks, and so on. G must monitor A for ongoing comprehension, repeating and/or revising instructions as necessary. To complete the interaction, G and A must achieve consensus that the directions have been understood and make sense. In live situations, gestures are critical, although they are absent from navigation systems (arrows have been described as "graphical gestures").

Cognitive geographers have carried out descriptive analyses of how people actually give and interpret route directions. Does G choose the shortest, simplest, safest, or most aesthetic route? G must judge A's ability to handle routes with particular characteristics. How many landmarks does G include, and which landmarks are those? How much metric information about distances and directions is included, if any? How do people use gestures when giving directions? Does G show sensitivity to aspects of routes that are potentially more ambiguous? What does G mean by the common expression "you can't miss it" and what makes G say this?

Researchers have also carried out prescriptive analyses aimed at determining how directions can optimally be generated and interpreted. Researchers have suggested many ideas as to what constitutes "good" or "best" directions, but more empirical evaluation is needed. Every question that can be asked about what people say or write when giving directions can be turned into a question about whether they *should* say or write those things – whether they help or hinder the traveler's thoughts, emotions, and behaviors. Substantial research suggests that directions work better when they contain explicit reference to landmarks, especially salient landmarks at critical decision points along routes, but also along routes for course maintenance, and off or beyond routes for error correction. How much metric information should be given? How valuable are corrective or overshoot statements, considering that they require extra time and effort? How much redundancy is good? Efforts to automate direction-giving, as in digital navigation systems, struggle with two considerable complexities. First is the substantial difference among individuals and groups of individuals as to what is optimum. A prominent example of such differences that has received considerable empirical support is the distinction between route thinkers and survey thinkers. As in the theories of spatial microgenesis discussed earlier in this entry, route thinkers reason about the environment in terms of linear sequences of places and simple turns, such as right or left; their thought is one-dimensional and largely nonmetric. Survey thinkers reason about the environment in terms of a two-dimensional layout of places that supports spatial inferences directly between places, even if the thinker has not previously traveled directly between those places; their thought requires more metric distance and direction knowledge. Besides this and many other potentially relevant individual and group differences, a second complexity in determining optimal route directions is the large difference between particular places and routes as to what directions will work best there. This depends on a large variety of factors, such as spatial scale, street geometry, street signage, architectural style, and topography.

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SEE ALSO: Behavioral geography; Cognitive geoengineering; Geographic information science; Ontology: theoretical perspectives; Qualitative spatial and temporal representation and reasoning; Routing and navigation; Spatial concepts; Spatial thinking, cognition, and learning; Time geography and space–time prism; Visualization

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Abstract: Geographers describe, predict, and explain human activity on the earth. The concept of spatial behavior highlights the geographer's focus on the spatial and temporal aspects of this activity. An important way to understand spatial behavior is to understand the human thought and reasoning partially underlying it, including the subjective mental representations that people have about the world and themselves. This is known as cognitive geography. After reviewing basic concepts of cognition and empirical methods for studying cognition and spatial behavior, this entry discusses concepts, theories, and empirical research on cognitive maps and mapping, environmental spatial learning and development, navigation and orientation, distance and direction knowledge, cognition of cartographic maps and other geographic information displays, and natural language and space.

Keywords: GIScience; language; learning; perception; space and spatiality; spatial behavior; spatial cognition; spatial thinking