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Cognitive Maps and Urban Travel

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COGNITIVE MAPS AND URBAN TRAVEL

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1. INTRODUCTION

The focus of this chapter is an examination of the relationship between cognitive maps and travel behavior in urban environments. We do this examination incrementally, beginning with clarifications of terms relating to cognitive maps, cognitive mapping and wayfinding. We then emphasize transportation-related issues such as cognizing of transportation networks, path selection, wayfinding and navigation. We further examine problems of selecting paths to destinations by using existing transport networks. We also introduce concerns relating to the role of trip purpose in path selection and discuss how different purposes spawn different path or route selection strategies. In a final section we briefly examine the interaction between cognitive maps, cognitive mapping, and current practice of travel choice modeling.

2. BASIC CONCEPTS

2.1 Cognitive Maps

The bulk of human travel is repetitive and relatively invariant in time and space. It would be unusual for humans to consult a cartographic map of an environment prior to every trip. Rather, humans travel by virtue of the knowledge stored in their long-term memory or cognitive map. The term "cognitive map" is generally used as a metaphor or as a hypothetical construct (Kitchin, 1994). It is convenient for us to think metaphorically of consulting a "map" as we engage in developing a travel plan (Gärling et al., 1984; Gärling and Golledge, 1989). The map concept, however, is a convenient one for summarizing the processes involved in making a geographically structured travel plan. This includes establishing locations, understanding distances between locations, comprehending the direction of one location from another, linking locations in sequence, and transferring knowledge from the mental arena to the surrounding physical environment (i.e., matching knowledge structures with street and highway networks and associated land uses).

Cognitive maps thus are the conceptual manifestations of place-based experience and reasoning that allows one to determine where one is at any moment and what place-related objects occur in that vicinity or in surrounding space. As such, the cognitive map provides knowledge that allows one to solve problems of how to get from one place to another, or how to communicate knowledge about places to others without the need for supplementary guidance such as might be provided by sketches or cartographic maps. Traditionally, cognitive map information has been collected by asking people to produce "spatial products" or external representations of what they know about a specific place. The representations may be in the form of sketch maps, written or verbal descriptions of routes or layouts, images of places such as slides, photos, or videos, and judgments about spatial relations that might reveal a latent structural knowledge of a setting (Golledge, 2002).

2.2 Cognitive Mapping

Cognitive mapping is the process of encoding, storing, and manipulating experienced and sensed information that can be spatially referenced. What guides this mental processing is being actively researched in cognitive psychology, neuropsychology, and related fields (Golledge, 1999). But, essentially, cognitive mapping involves sensing, encoding, and storing experienced information in the mind. This is referred to as "declarative" knowledge. This information is subjected to internal manipulations such as spatial thinking and reasoning. These activities manipulate and interpret the declarative knowledge base stored in long-term memory as parts of it are needed to solve problems. These problems include decision-making and choice related to travel behavior.

3. TRANSPORTATION ISSUES

3.1 Cognizing Transportation Networks

Most household or personal trips take place on existing transportation systems. These systems include public and private, mass and individual, modes that either share networks (e.g., cars, buses), have dedicated networks (e.g., tracked vehicles like trains, trolleys and funiculars), or are usually confined to specific corridors or lanes (e.g., air and surface ocean traffic). We deal here only with private and individual movements (e.g., car, bicycle, pedestrian), with most emphasis on private vehicle movement.

In many countries the household car (or cars) represents an important form of movement. To satisfy economy of movement, minimize air and noise pollution, achieve door-to-door delivery of drivers and passengers, and guarantee independence in route choice, networks of surface roads have been developed. Usually these are differentiated into freeways, highways, arterials (major and minor), local streets, and lanes or alleys.

When making a trip, each individual must consider how to use the local road hierarchy. These decisions can be made *a priori* (as in a travel plan) or en-route (as in real-time wayfinding). The mere existence of the hierarchy, combined with individual memories of travel experience, leaves the way open for different route-selection strategies to be developed and for different paths to be followed. Thus one next-door neighbor might try to maximize use of a freeway for, say, a trip to work and maximize use of local streets to facilitate a trip chain on the way home, while another neighbor might use the reverse strategy. Thus two spatially adjacent householders, going to the same destination, can choose completely different paths. By doing this, their environmental experiences may differ, and their cognitive maps thus may likewise be quite different.

In many urban environments, traffic control measures such as one-way streets and limited on-street parking can also influence path selection and, consequently, the nature of the detail that is georeferenced in the cognitive map. Apparently, to facilitate communication and development of a general understanding of complex environments, people tend to define “common anchors”—significant places in the environment that are commonly recognized and used as key components of cognitive maps—and idiosyncratic or “personalized anchors” that are related to a person’s activities (e.g., specific work place or home-base) (Couclelis, Golledge, Gale, & Tobler, 1987). These anchor the layout or structural understanding of an environment (regardless of its scale). Objects and features in an environment “compete” for a traveler’s attention, with the most successful reaching the status of common anchor, recognized by most people and consequently incorporated into most cognitive maps. Other features and objects are less successful in general, but might achieve salience for a specific trip purpose (e.g., “the odd-shaped building where I park in order to go to my favorite restaurant”). Minor pieces of information are attached to anchors and act as “primers and fillers”—the second, third, or lower orders of information experienced but used only in selected ways and with varying frequencies.

Little research has been completed on the creation of network knowledge and the relationship between network knowledge systems and real world transportation systems. We all realize from personal experience that our knowledge of existing networks is but partial and quite minimal. But, if we have an overall anchoring structure or general layout understanding of en-route and off-route landmarks and can determine a route or course through multiple networks of links and nodes, we can—either by using a travel aid such as a map or by independently accessing cognitively stored information—find our way between specific origins and destinations in urban environments. Sometimes this task seems simple, with minimal feasible alternative path structures to be considered (e.g., a trip from home to a nearby elementary school). At other times the task seems complex and substantial and requires serious planning and implementation (e.g., a trip from home to a distant work environment). We shall explore these concepts further below.

3.2 Travel Behavior

Travel behavior consists of a movement through space using a particular mode of travel. It can be recorded as a trace throughout the environment. This trace is sometimes called a path or a route. Paths or routes are defined by selecting sections from a network of connecting nodes and links. Nodes consist of places where links join or intersect. The route then consists of a sequence of links and nodes between a specified origin and destination. Different human activities require designation of different routes in order to link places where wants or needs can be satisfied. Routes must be experienced and learned if they are to be used repeatedly over time. Learning a route involves identifying the origin and destinations, knowing the number of link segments and their appropriate sequencing; recognizing intersection nodes and identifying choice points where turning decisions may have to be made; remembering the number and direction of turns embedded in a given route; being able to recognize on or off route landmarks that help interpret where one is along the route at any particular point in space or time; and being able to retrace and/or reverse the route on an as-needed basis. If the route is circuitous, the learning process will involve understanding its configural complexity, thus facilitating the process of taking a shortcut if needed (e.g. if the route is blocked by congestion, construction, accident, or some other barrier).

Sholl (1996) suggests that travel requires humans to activate two processes that facilitate spatial knowledge acquisition—person-to-object relations that dynamically alter as movement takes place, and object-to-object relations that remain stable even when a person undertakes movement. The first of these is called egocentric referencing; the second is called the anchoring structure of a cognitive map (or layout referencing). Given this conceptual structure, it is obvious that poor person-to-object comprehension can explain why a traveler can become locally disoriented even while still comprehending in general the basic structure of the larger environment through which movement is taking place. Error in encoding local and more general object-to-object relations can result in misspecification of the anchor point geometry on which cognitive maps are based. The latter seems to be responsible for many of the distortions and fragmentations found in attempts to externalize cognitive maps (frequently referred to as "spatial products," see Liben, 1981).

In both cognitive mapping and wayfinding, environmental anchors play an important role. Anchors can be landmarks (on- or off-route), important choice points (e.g., transfer between freeway and arterial or local streets), path segments (e.g., the final freeway segment before exiting to work or home), or even a distinct area (such as a park, shopping center, or ethnic or cultural neighborhood). Their actual cognized locations and the awareness of the spatial relations among them (i.e., their layout) provide a framework on which is grafted piecemeal knowledge acquired during urban experience (e.g., personal travel, TV or video or film coverage, or verbally described places in the city).

Although there are many electronic, hardcopy, and other technical aids that can be used as wayfinding tools, nevertheless, humans most frequently tend to use cognitive maps and recalled information as travel guides. There are three different types of knowledge usually specified with relation to travel behavior. Perhaps the most common is called route learning (or systematic encoding of the route geometry by itself). A second concept is route-based procedural knowledge acquisition that involves understanding the place of the route in a larger frame of reference, thus going beyond the mere identification of sequenced path segments and turn angles. A third version is called survey or configural knowledge, and this implies comprehension of a more general network that exists within an environment and from which a procedure for following a route can be constructed.

Human-based methods for wayfinding carry all the imprecision and error baggage that instruments were designed to eliminate. This error baggage includes a variety of spatially based concepts. For example, many studies show that human pointing errors (even between familiar places) average about 25°-30°. In addition, shorter distances are usually overestimated, while longer distances are underestimated. Perceived distances to and from a particular origin and destination are often perceived to be asymmetric. Triangle inequality does not always hold for judged distances between places. People do not always perceive the same object to be at the same place. And changing perspective often changes evaluation of spatial relations (e.g., with regard to left/right, front/back, up/down, along/across). It can be expected, therefore, that spatial representations in humans are incomplete and error prone, producing the distortions or fragmentations of spatial products that have been found by numerous researchers. But what is significant of course is that an individual need not have a correctly encoded and cartographically correct "map" stored in memory to be able to successfully follow a route. Route knowledge by itself requires that a very small section of general environmental information is encoded. In its pure form, the route is completely self-contained, anchored by choice points and en-route landmarks and consisting of consecutive links with memorized choice points and turn angles between the links. The integration of specific routes is a difficult task, but apparently not an impossible one, for many people develop either skeletal or more complete representations of parts of urban networks through which their episodic travel takes place (Ishikawa, 2002).

3.3 Path Selection Criteria

Human wayfinding can be regarded as a purposive, directed, and motivated activity that may be observed and recorded as a trace through an environment. The trace is usually called the route or course. A route results from implementing a travel plan (Gärling et al., 1984**;** Gärling and Golledge, 1989) which is an *a priori* decision-making process that defines the sequence of segments and turn angles that comprise the course to be followed or the general sector or corridor within which movement should be concentrated. The route represents the trace over the ground (spatial manifestation) from following a specified course. The travel plan is the outcome of using a particular strategy for path selection.

A large number of different criteria are used in path selection. The major types that can be found referred to in travel-related literature in fields such as travel behavior, operations research, transport geography, and behavioral travel modeling are summarized in Table 1.

Table 1: Types of Route Selection Criteria

Longest leg first	Ensuring locomotion remains within a given width (corridor) surrounding a straight line connection between origin and destination
Shortest leg first	Maximizing aesthetics
Fewest turns	Minimizing effort
Fewest lights or stop signs	Minimizing actual or perceived cost
Fewest obstacles or obstructions	Minimizing the number of inter- modal transfers
Variety seeking behavior	Minimizing the number of layers of a road, street, or highway system that have to be utilized
Minimizing negative externalities (e.g. pollution)	Fastest route
Avoiding congestion	Least hazardous in terms of known accidents
Avoiding detours	Least likely to be patrolled by authorities
Responding to actual or perceived congestion	Minimizing exposure to truck or other heavy freight traffic
Minimizing the number of segments in a chosen route	
Minimizing the number of left turns	
Minimizing the number of non- orthogonal intersections	
Minimizing the number of curved segments	

3.4 Navigation and Wayfinding

It is becoming more common to differentiate between navigation and wayfinding. Navigation implies that a route to be followed is predetermined, is deliberately calculated (e.g., humans often use mechanical equipment and mathematical equations to do this), and defines a course to be strictly followed between a specified origin and destination. Progress along the course is sometimes monitored (e.g., by air traffic controllers or, in the case of private delivery systems like UPS or FedEx, by centralized tracking of GPS in delivery vehicles). Wayfinding is taken more generally to involve the process of finding a path (not necessarily previously traveled) in an actual environment between an origin and a destination that has previously not necessarily been visited. Wayfinding can thus be identified with concepts such as search, exploration, and with incremental path segment selection during travel. Wayfinders can also use technical assistance (e.g., compass, global positioning system, network map) but, more often, use cognitive maps.

Navigation is usually dominated by criteria such as shortest time, shortest path, minimum cost, least effort, or with reference to specific goals that should be achieved during travel. Thus, it lends itself to optimalization modeling. Wayfinding is not as rigidly constrained, is purpose dependent, and can introduce emotional, value and belief considerations, and satisficing constraints into the travel process. This procedure lends itself to stochastic probability models or any of a variety of logistic models. Whereas navigation usually requires the traveler to preplan a specific route to be followed, wayfinding can be more adventuresome and exploratory, without the necessity of a pre-planned course that must be followed. While for some purposes travel behavior will be habitualized (thus lending itself to the optimalization modeling activities of the navigation process), for other purposes variety in path selection may be more common (indicating more of a wayfinding concern and requiring a different type of model base).

3.5 Route Learning

Repeated path following facilitates remembering path components and recalling them for further use. This is called route learning. Paths or routes are represented as one-dimensional linked segments or, after integration with other paths, as networked configurations. The latter, along with on- and off-route landmarks, spatial relations among them, and other spatial and non-spatial attributes of places—such as prominence of visible form—make up the anchoring layout of a remembered environment. Route learning and route following strategies help build up cognitive maps via an integration process (Gärling et al., 1981; Ishikawa, 2002). Difficulties experienced in mentally integrating different routes and their associated features into network structures help to explain why cognitive maps may be fragmented, distorted, and irregular (Gale, Golledge, Pelegrino, & Doherty, 1990).

3.6 The Role of Trip Purpose

Human wayfinding is very trip purpose dependent, and it is thus difficult to attribute any specific cognitive process to wayfinding generally. The question remains as to whether specific purposes are better served by certain types of wayfinding strategies. For example, journey to work, journey to school, and journey for convenience shopping are often best served by quickly forming travel habits over well-specified routes. Such an activity would minimize en-route decision-making, and often it conforms to shortest path principles. However, journeys for recreation or leisure may be undertaken as search and exploration processes and require constant locational updating and destination fixing. Thus, as the purpose behind activity changes, the path selection criteria can change, and, as a result, the path that is followed (i.e., the travel behavior) may also change. Recent work on Intelligent Highway Systems (IHS) and Advanced Traveler Information Systems (ATIS) has shown that humans sometimes respond to advanced information on congestion or the presence of obstacles by substituting destinations, changing travel times particularly in the early morning, by delaying or postponing activities, or by selecting alternate routes particularly in the evenings; (see Chen and Mahmassani, 1993). All these produce different travel behavior in response to trip purpose changes. Cognitive maps must be very versatile to allow such behavioral dynamics.

3.7 Travel Guidance

To help minimize inefficiencies in travel behavior that contribute to excess air pollution, noise, and danger, Intelligent Highway Systems (IHS) are being developed to provide advanced and en-route information for the upper levels of road hierarchies (e.g. freeways, highways, major arterials). These include:

- Pre-trip information on traffic conditions (speed, congestion, accidents)
- Variable Message Signs (VMS) and other Automated Traffic Management Systems (ATMS)
- En-route radio broadcasts
- Automated Vehicle Guidance Systems (AVGS) (e.g. GPS or LPS locators and in-car route maps).
- Automated Transit Advisory Systems (ATAS)
- Directional Lane Control
- Specialized traffic lanes (e.g. bus lanes, carpool lanes).

4.0 INCORPORATING COGNITIVE MAPS INTO TRAVEL CHOICE MODELS

Models that link spatial behavior to travel choice have over the past 30 years become more dominant (McFadden, 2001). Ways to incoporate spatial cognition in such models have not yet, however, achieved widespread adoption by transportation professionals interested in predicting flows over a transportation network, presumably because of their difficulties in operationalizing and measuring constructs such as cognitive maps, cognitive mapping, navigation, and wayfinding. Yet, no one denies that travelers´ choices depend on what spatial information they perceive and store in long term memory.

Current sentiment appears to indicate that, because factors such as cognitive mapping ability, cognitive map knowledge of feasible alternatives, navigation and wayfinding strategies, and preferences for path selection criteria all are presumed to have a substantial impact on travel choices, there is a growing need to include spatial cognition explicitly in models. Specifically, cognitive maps must become a part of the modeling process in that they are summaries of what is known about the network over which travel must take place; they provide information on what is known about the location, possible destinations, and feasible alternatives for any choice; and they provide a means for spatializing attribute information by attaching values and belief or preference ratings or measures to specific geocoded places.

In an attempt at addressing these issues, Gärling and Golledge (2000) posit that information stored in the cognitive map impacts travel choices in that (i) potential travelers can only choose from known destinations brought to their attention, and (ii) knowledge of spatial relations between these destinations impact choices of them as well as choices of travel between them. Furthermore, the degree and accuracy of knowledge dependent on familiarity with the environment are important moderators of these relationships. In particular, it is argued that multistop multipurpose trip making requires an extensive and accurate cognitive map.

Promising attempts to incorporate cognitive maps and cognitive mapping in travel choice models are perhaps most evident in computational process models (Gärling et al, 1994; Smith et al, 1982). In particular, Gärling, et al. (1989, 1998) make explicit assumptions about the role of these factors. However, empirical verification is still needed. A step in the direction of producing comprehensive models that incorporate issues of cognitive concepts is that recently taken by Arentze and Timmermans (2002) who are developing a rule-based model capable of learning the environment. We believe that important progress can be expected in these respects.

Two early computation process models stand out for their attempts to incorporate cognitive map concepts. These are Scheduler (Gärling, et al., 1989) and GISICAS (Kwan, 1994). Scheduler required a potential traveler to indicate places and time slots that would be filled with obligatory activities. Discretionary events (e.g., working out, shopping, socializing) were then integrated into a person's activity schedule, depending on the time required to perform an activity, the travel time to and from the activity place, and a subjective priority attached to the activity. GISICAS built on Scheduler by using GIS procedures to define a "feasible set" of alternate locations where activities could be performed, producing a map representation of the alternatives with most probable routes plotted. The feasible alternative procedure was an operationalization of the cognitive map idea. It defined a small set of alternative locations that were probably "best known" to a given traveler. This concept was based on proximity to home, work locations, and to places within a pre-set distance corridor along the most likely route that linked home and work.

An even more difficult task is to provide a cognitive map measure for incorporation into logistic choice models—the most favored format for analyzing and predicting travel associated with daily activity patterns.

Ben-Akiva, Ramming, and Golledge (2001) are experimenting with a set of scale values representing a person's self-assessed spatial ability. Factors such as self-assessed ability to estimate direction and distance, self-assessed knowledge of landmark layout in an area, and self-assessed ability to perform spatial tasks such as wayfinding, recalling distant places, and so on are being evaluated to see how well they evaluate local spatial knowledge structures. Eventually, they may be incorporated as latent structure variables in travel behavior models.

5.0 CONCLUSION

Because of individual differences in the content of cognitive maps, different motivations or purposes for travel, and different preferences for optimizing or satisficing decision strategies, human travel behavior is difficult to understand or predict. If we add to that the unexpected barriers and obstacles to traffic flow that occur spontaneously and intermittently (e.g., from congestion, accidents, construction, or other obstacles that impede movement over a selected path or over a network), then problems of intelligently modeling travel behavior in the real world become substantial. Yet, some success has been achieved in doing this, using simplified assumptions about human behavior (e.g., assuming that, knowingly or unknowingly, travelers adopt shortest path optimizing practices). But models like this and the predictions they make can be very inadequate. The question facing future research is that of combining travel demand (considering people's activities) with network supply (considering the tracks, corridors, or transport systems available) with an understanding of how humans decide on where they prefer (or have) to go and how they prefer (or have) to get there. Emphasizing cognitive mapping principles may give a level of insight that has not so far been provided.

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