Enrichment of Cartographic Maps with the Elements of Spatial Cognition

Farid Karimipour, Ali Khazravi
Department of Surveying and Geomatics Engineering, College of Engineering, University of Tehran
Tehran, Iran
e-mail: {fkarimipr, khazravi}@ut.ac.ir

***Abstract*—Human activities are embedded in the space. People need to know where they are and how they can arrive to their destination. They may use their spatial cognition in familiar space, or navigation aids (e.g., cartographic maps and satellite navigation systems) in unfamiliar areas for positioning and wayfinding purposes. Today, satellite navigation systems are widely used by even non-expert users. Dealing with cartographic maps, however, need prior knowledge and experience on map reading as well as enough spatial cognition. Enriching cartographic maps with the elements of spatial cognition could help to navigate more easily in unfamiliar environments. This paper represents the result of a research to enrich cartographic maps with features used by pedestrians for navigation in urban areas.**

Keywords-Spatial cognition; Cartographic maps; Cognitive map; Urban navigation; Pedestrian navigation

I. INTRODUCTION

Human activities are embedded in the space. People need to know where they are and how they can arrive to their destination. This so-called *wayfinding* is a directed process to move from a source to a given destination through intermediate path(s) [1]. People may use their spatial cognition in familiar space, or navigation aids (e.g., cartographic maps and satellite navigation systems) in unfamiliar areas for positioning and wayfinding purposes. Today, satellite navigation systems are widely used by even non-expert users. Dealing with cartographic maps, however, need prior knowledge and experience on map reading as well as enough spatial cognition.

Suppose you are navigating in a familiar environment (for example, you are walking from your home to the university). In this case, you will navigate through the path without paying attentions to the name of the streets, roundabouts, etc.; instead your spatial cognition is used to get oriented in the environment based on existing familiar features in the way (e.g., landmarks). On the other hand, suppose you are in an unfamiliar city for a conference and you are walking from hotel to the conference venue. In this case, you use a cartographic map and the only connection between the environment and the map is the name of the streets, roundabouts, etc. as well as their relations. However, there are different distinguished features in the way that could have helped you for an easier navigation. More clearly, your map shows that you have to walk straight until you reach the street “A”. Then, you walk and look at the name of the streets until finding the street “A”. However, a big blue building located at the corner of the street “A” could have been a better indicator for you to find the street even before you reach the street and see the street name plate.

A shortcoming of cartographic maps is that they are limited to a top view representation of the space [2]. Therefore, they only provide metric information and topological relations, but do not contain any spatial categorical knowledge (e.g., landmarks), which is the basis of human spatial cognition.

Spatial cognition has been extensively studied in psychological and geographical research. Kevin lynch investigate the spatial cognition and its relation with urban design [3]. He studied behavior of people in wayfinding and environment recognition in three cities with different textures. The elements of cognitive maps introduced in his book are the main elements for cartographic map enrichment proposed in this paper.

A recent research in the field of pedestrian navigation was done by Giasbauer and Frank [2], who modeled a pedestrian navigation system for urban areas. There are many studies on spatial cognition in psychology including [1, 4, 5, 6, 7].

This paper suggests enrichment of cartographic maps with the elements of spatial cognition to improve their value for navigation in unfamiliar environments. Especially, we concentrate on enrichment of cartographic maps with features used by pedestrians for navigation in urban areas. Section 2 reviews spatial cognition and spatial knowledge in more details. In Section 3, the elements of spatial cognition are introduced from geographic point of view. Section 4 contains the results of enriching a cartographic map with the elements of spatial cognition introduced in Sections 2 and 3. Finally, Section 5 concludes the paper and represents ideas for future work.

II. SPATIAL COGNITION AND SPATIAL KNOWLEDGE

Cognition encompasses acquiring, storing, retrieving and manipulation of information used by human, animals or intelligence machines. Especially, *spatial cognition* is acquiring, organizing, updating and usage of spatial knowledge about the environment [8]. A cognitive system may consist of sensing and imagery, learning, reasoning, decision making, and problem solving sub-systems [9].

A. *Cognitive map*

A *cognitive map* is a mental model of the environment. It may contain spatial elements (e.g., path, landmarks, direction and distance) and sensual attributes (e.g., odor, sounds, images, and sensations). Cognitive maps do not have an integrated structure, but they consist of five distinct spatial elements: *paths*, *edges*, *districts*, *nodes* and *landmarks* [3].

B. Types of spatial knowledge

Spatial knowledge is divided into *metric* and *categorical knowledge*. Metric parameters are quantitative and comparable. While, categorical parameters are qualitative terms (e.g., left, right, near, far, etc.). Categorical parameters are better understood by people. In some cases, however, they could be ambiguous.

In terms of types of the elements and comprehensiveness, spatial knowledge is divided into *landmark knowledge*, *route knowledge*, and *survey knowledge*.

1) Landmark knowledge

In the first step of understanding the environment, people pay attention to specific objects or features, called landmarks (Fig. 1). Landmark knowledge is an egocentric knowledge and is the first element of spatial knowledge [1].

Ferdowsi square Tehran University Azadi square

Figure 1. Landmark knowldege: distinct landmarks

2) Route knowledge

Route knowledge is a sequence of familiar or known paths, junctions, and landmarks. This kind of spatial knowledge is gained gradually, and makes a sequential structure by its elements (Fig. 2). This knowledge is used to move in routes and paths based on a sequence of landmarks, features, junctions, and nodes. Route knowledge is based on egocentric view, too [1].

Figure 2. Route knowledge: sequence of features

3) Survey knowledge

Survey (also called configurational) knowledge is more comprehensive comparing to the landmark and route knowledge. It is built up by integrating all the landmarks, routes, and paths as well as the relations among these elements into a unified complex network. Survey knowledge could be thought of as the view of a bird that flies over a city and see everything and their relations at once (Fig. 3).

Figure 3. Survey knowledge

III. ELEMENTS OF COGNITIVE MAP

As mentioned, Lynch defines five spatial elements for a cognitive map: *paths*, *edges*, *districts*, *nodes* and *landmarks* [3].

A. Path

A path is a linear channel through which the navigators move. Streets, sidewalks, railways, and channels are examples of paths (Fig. 4). For many people, paths are the main elements of their cognitive map, along which other spatial elements are organized [3]. Slope is an attribute of a path that can be easily reminded and recognized by people, but is neglected in current cartographic maps.

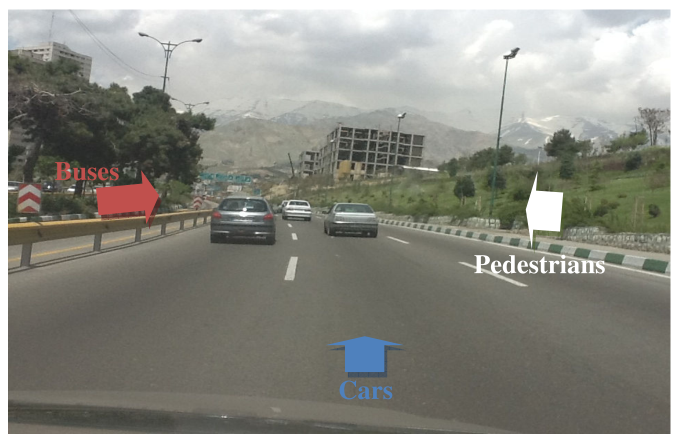

Figure 4. Different paths for different navigators: Buses (left); cars,(middle) and pedestarians (right)

B. Edge

Edges are linear features that are not considered as a path, but are located between two areas. A wall is an example of an edge [3]. Hard edges are continuous visible features that are passable or impassable. Note that the difference between paths and edges depends on the navigator, i.e., an object considered a path for a navigator could be an edge for others. For instance, a road is a path for a car, railway is a path for a train, and both are hard edges for a pedestrian. The same applies to passable or impassable edges. For example, in Fig. 5, the left edge is an impassable hard edge for a car, while it is passable for a pedestrian.

(a) (b)

Figure 5. Examples of edges: (a) An impassable hard edge for a car, but passable for a pedestrian; (b) An impassable hard edge for both cars and pedesrians

C. *District*

Districts are medium to large scale 2D areas of a city. A navigator enters mentally into a district. Each district is recognized and identified by some features [3], including the building structure, air quality, traffic, inhabitants' appearance, topography, vegetation cover, etc. Some districts have a hard core (visible object), and features around which are homogeneous.

D. *Node*

Nodes are strategic and reference points in the city into which a navigator mentally enters. A node can be a junction, the start or end of a path, the intersection of two paths, or the centric points or the core of a district.

Lynch considers nodes as decision points [3]. The number of relations to a node is a key factor to assign an importance value to a node: The more relations to a node, the more importance value is assigned to it. Furthermore, prominence of a node depends on selected paths and destination of the navigator.

E. *Landmark*

Landmarks are special type of reference points that navigators do not enter into it, but see it in their path (e.g., buildings, mountains, etc.). Different disciplines represent different definitions for landmarks, but they all agree on visibility, contrast and usability for navigation. Landmarks may be used for:

- Selecting a path based on familiar landmarks
- Selecting a path by excluding unfamiliar landmarks
- Approving or denying a selected path
- Orientation

1) *Global vs. local landmarks*

Regarding the scale and distance to the viewer, landmarks are divided into local and global [10]:

- *Local landmarks* are only visible from near distances and are used for selecting a proper path. These landmarks are relatively small and conspicuous. Examples are signs and buildings.
- *Global Landmark* are visible from far distances and are used to create an allocentric reference system. A global landmark can determine a cardinal direction for the reference system. The sun, mountains, and sky scraper are instances of global landmarks. Global landmarks can be useful on nodes where the navigator has to choose a path considering the direction to a global landmark.

2) *Objective vs. subjective features*

Landmarks may have two types of features; *objective* and *subjective* features.

a) *Objective features*

Objective features are unequivocal features which do not need any interpretation. They are physical attributes of a landmark and people with different individual perception have the same understanding of them. Objective features are so critical for a landmark that an object with no objective features cannot be considered as a landmark [1].

One of the most important objective feature is contrast (Fig. 6). It is the key to recognize and to identify a landmark. Objects with high contrast in the environment are naturally considered as a landmark [1]. Such contrast could be visual (e.g., a red house in a block where other buildings are white), or defined based on other senses (e.g., odor, sounds, etc.).

Figure 6. Examples of contrast in the environment

b) *Subjective features*

Subjective features rely on individual knowledge or memory [1]. Subjective feature are less equivocal, namely they mostly depend on the individual perception, which is different from a person to another.

Table 1 illustrates the characteristics of objective and subjective features of landmarks.

TABLE 1. CHARACTERISTICS OF OBJECTIVE AND SUBJECTIVE FEATURES OF LANDMARKS [1]

Objective features	Subjective features
Contrast	Point of reference
Creation	Usage
Visibility	Remembrance
Location	Legend
Stationary	Distinguishability

IV. IMPLEMENTATION

This section represents the result of enriching a cartographic map with the elements of spatial cognition to improve its value for pedestrian navigation purpose. For

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landmarks, we only concentrate on objective features discussed in Section 4.

The study area is a cartographic map of the Sohrevardi area located in the North of Tehran. The transportation network of the area was extracted from a digital map (Fig. 7). Then, the following elements of spatial cognition were selected to be added to the map:

- The study area will be highlighted on the map as a district.
- The nodes of the area will be added to the map.
- The local and global landmarks that could be used for navigation in the area will be added to the map.
- All the streets and highways will be considered as edges for pedestrians.
- The sidewalks will be added to the map as paths for pedestrians.
- The crosswalks, where pedestrians can cross the streets, will be added to the map.

The data needed for the above enrichment were collected on the field. As mentioned, we concentrated on objective features and unequivocal features of the landmarks, which need a little description. The collected data are as follow:

- The objective features of local landmarks, along some unequivocal description about their appearance
- Slope of the paths
- The crosswalks and other paths where a pedestrian can cross an edge
- Identifying junctions, which have heavy usage, as nodes
- Identifying features that are repeated along the district

In the enrichment process, landmarks were identified and highlighted on the map by a symbol. This information is used for a categorical addressing or address matching systems. In order to assign descriptive (textual) information about the objective features of the landmarks, a distinct number were added to the symbols used for each landmark, and the related descriptions were provided on the side of the map.

To help the user to find the cardinal direction, a global landmark was used. In case of Tehran, the mountain chain located in the top north of the city (called Damavand) was used.

Finally, the street slopes were classified into low, medium, and high, which were illustrated by different symbols and colors (Fig. 8). Furthermore, a symbol was used to represent abrupt changes in slope of a path. Then, each path on the map was equipped with such slope symbols.

The final cartographic map enriched with these unequivocal elements of spatial cognition is illustrated in Fig. 9.

V. Conclusion and Future Work

Cartographic maps are one of the most important navigation aids. They are mostly a top view representation of the space, which provide metric information and topological relations. However, maps do not contain any spatial categorical knowledge (e.g., landmarks), which is the basis of human spatial cognition. In this paper we suggested that cartographic maps are enriched with the elements of spatial cognition to improve their value for navigation in unfamiliar environments.

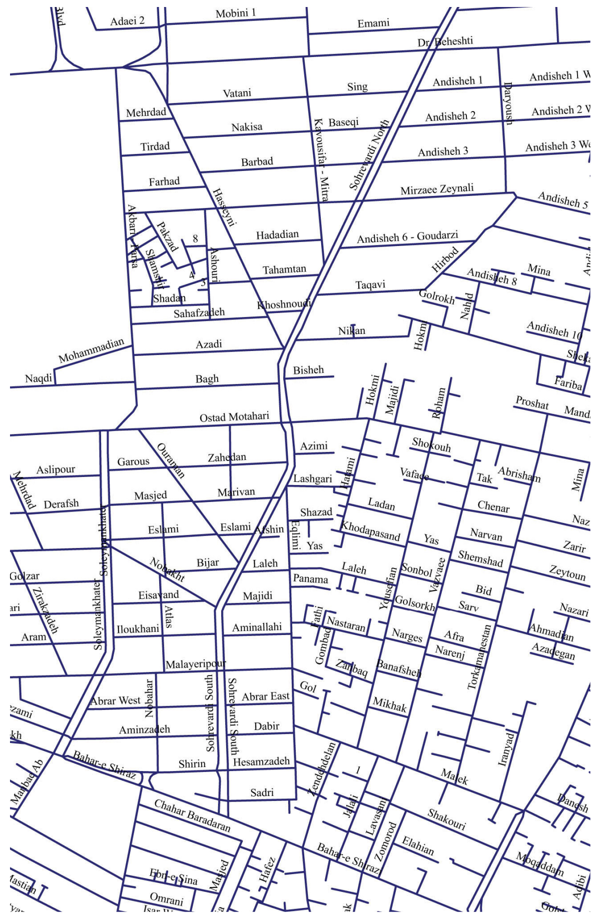

Figure 7. GIS-Ready Road-Network of studied area

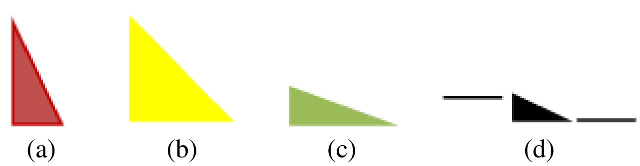

Figure 8. slopes (a): high, (b): medium, (c): low, (d): change in slope

The result of this study is a cartographic map that is enriched with the unequivocal elements of spatial cognition. Deploying this map will increase the performance of navigation in unfamiliar places. However, the output was presented on a paper map, which results in limitations and complexities for adding attribute information. The same process could be applied on digital maps, which are dynamic. It will enable us to provide the user with more attributes through filtering the presented information, changing the map scale and usage of other media (e.g.,

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voice). Such map will support a spatial information system for navigation purposes.

In order to evaluate the validity and usability of the produced map, we are developing an agent-based model that deploys the enriched map for navigation. The results will be compared with another agent that performs the task using a plain cartographic map.

Adding visibility constraints to landmarks is considered as a future work. It helps the user to know where to expect a landmark to be seen. Furthermore, by investigating other districts, it is possible to compare the results and find more specific features to be added to the map. Finally, we are working on an automatic cognitive map enrichment system, which uses cadastral and land-use data.

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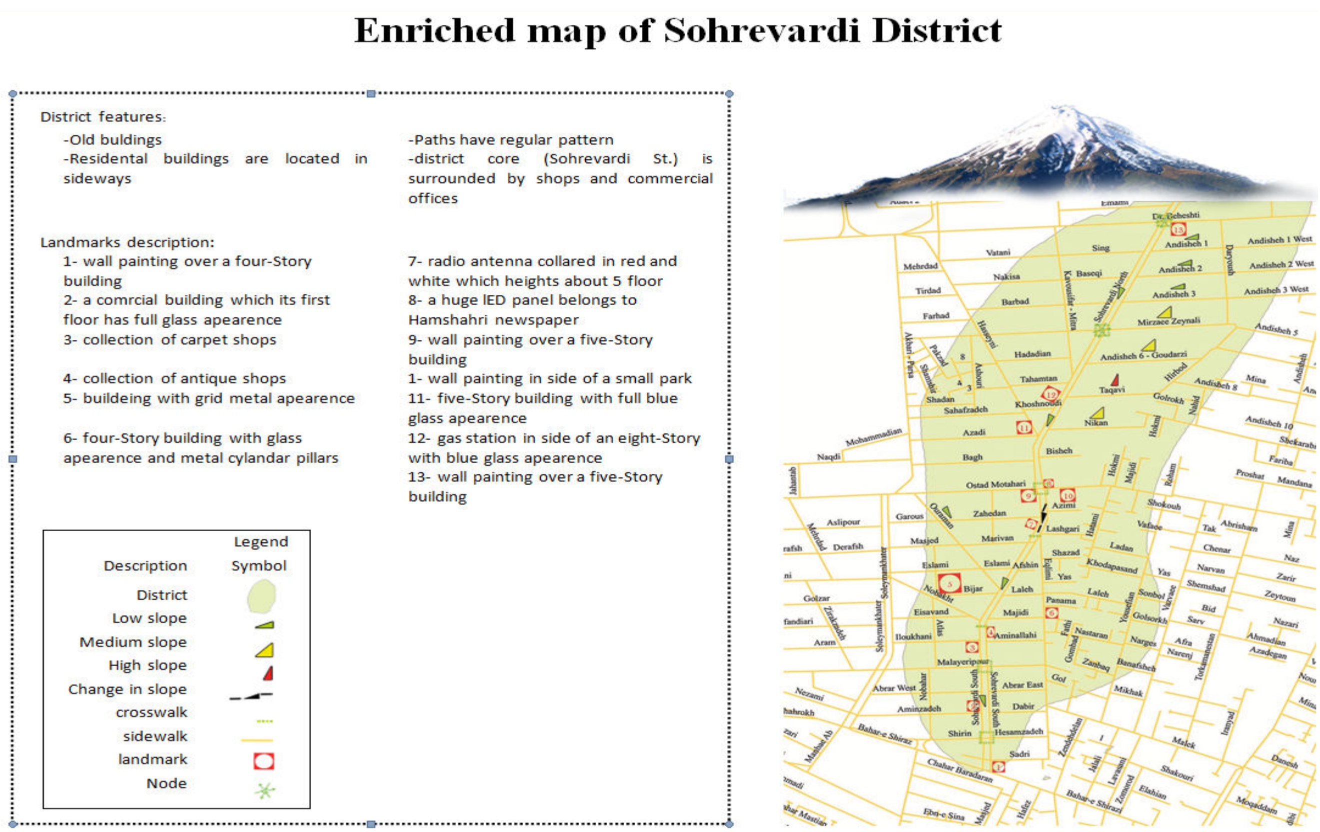

Figure 9. The final enriched cartographic map with the elements of spatial cognition