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# Spatial cognition driven context-adaptive route directions

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**Abstract:** A route representation framework and its main implementation procedures are proposed for generating context-adaptive route directions, which could meet human cognitive habits, reflect user's spatial knowledge, and is apt to be expressed in natural language. In the framework, a route is represented as a sequence of uniform temporal and various granular instruction units, which can be processed into route instruction phrases or sentences. For the implementation of context-adaptive route directions, landmark extraction, various granular instruction unit generation and most appropriate instruction unit sequence selection are introduced, while some contextual factors such as environmental structures, route characteristics and prior knowledge are also considered in these procedures. After compared with traditional route directions predominantly using distance-to-turn information, it can be found that the context-adaptive route directions based on spatial cognition is more conformable to the way people describe routes, and thus could decrease user's cognitive workload and promote the efficiency of navigation systems.

**Keywords:** route directions, spatial cognition, landmark, spatial knowledge

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## 1 INTRODUCTION

Cognitively motivated route directions fascinate researchers in several fields in recent years, such as computer science, cognitive science, geography and psychology. Route directions are task-oriented specifications of the actions to get from origin to destination, for the assistance of human wayfinding or following a route (Denis, 1997). Without the introduction of landmarks which are the core elements of spatial cognition, current navigation systems which predominantly use distance-to-turn information enable users to locate forthcoming maneuvers are effective but not natural, causing their high mental workload but low navigation efficiency (Burnett, 2000; May & Ross, 2006).

Currently, most scholars studying on cognitive route directions focus their attentions on turn-by-turn directions (Tversky & Lee, 1999; Werner, *et al.*, 2000; Dale, *et al.*, 2005; Klippel, *et al.*, 2005; Richter, 2007; Klippel, *et al.*, 2009). These researches adopt a common implementation process. Firstly, the actions and features related to every decision points in a route are extracted from the data model or cognitive map of the surrounding environments. Then, interactive tools (Tversky & Lee, 1999), conceptual models (Werner, *et al.*, 2000), natural language (Dale, *et al.*, 2005), wayfinding choremes (Klippel, *et al.*, 2005), abstract turn instructions (Richter, 2007) or data structures (Klippel, *et al.*, 2009), are used to uniformly represent that information, which sometimes is hierarchically organized. At last, information is output as graphics or language. However, when a user possesses some prior knowledge of surrounding environments, the turn-by-turn directions referring to every decision point may appear excessively detailed. In this case, the introduction of destination description would make route directions more close to the experience of the locals (Tomko & Winter, 2009). The basic principle of destination description is that some locations which are familiar to a user are first provided as coarse references to the destination, and then increasingly more detailed ones as the description proceeds. In the process of approaching to the references, which could be called intermediate destinations, his or her own cognitive map of surrounding environments rather than the detailed turn-based instructions is used to direct the user.

Because most people are familiar with some locations of surrounding environments while unfamiliar with the others, next generation navigation systems should support both turn-by-turn route directions and meanwhile destination description. Richter, *et al.* (2008) presented an approach to discover the user's prior knowledge through real-time human-computer dialogue, and adapted route directions to the way better meet user needs based on smoothly switching between turn-by-turn directions and destination

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descriptions. However, as the two direction ways refer to different spatial objects, decision points and environmental features respectively, this dialog-driven approach hardly achieves the seamless integration of turn-by-turn directions and destination descriptions. Srinivas and Hirtle (2007) introduced an approach of schematizing route directions based on the user's prior knowledge of a route, through dividing a route into several familiar and unfamiliar parts, and generalizing the familiar parts by means of knowledge chunking. Although the concept of known locations like decision points is introduced, the method of determining familiar routes and known locations by surveying the frequencies of every location being travelled is inefficient and unreliable. In addition, researches indicated that route descriptions closer to natural language are easier to be understood and accepted by users (Dale, *et al.*, 2005).

For the purpose of generating a kind of route directions, which meet human cognitive habits, reflect user's spatial knowledge, and are apt to be expressed in natural language, a spatial cognition oriented route representation framework is proposed and some methods are introduced to generate context-adaptive route directions in this study. In this framework, a route is abstracted as a sequence of uniform temporal and various granular instruction units, which can be processed into route instruction phrases or sentences. After building up instruction units varying in granularity, selecting the most appropriate ones by virtue of contextual factors such as environmental structure, route characteristic and prior knowledge, and then processing these units into natural language via natural language generation systems (NLG), natural language based context-adaptive route directions could be implemented. The remainder of this work is organized as follows. Section 2 defines the structure of the route representation framework. Section 3 discusses the main methods for realizing context-adaptive route direction. In section 4 experiments were carried out to show an instance of context-adaptive route directions. Finally, section 5 concludes our proposition and outlines future works.

## 2 A SPATIAL COGNITION ORIENTED ROUTE REPRESENTATION FRAMEWORK

Route directions are essentially the description of a sequence of actions for the user to carry out in constrained space, such as streets (Denis, 1997). In order to accurately express the meaning of every action, its description needs to contain information in three aspects: the ojective of the action, the spatial features being referred and the spatial relationships being involved. Therefore, in this representation framework, a route is abstracted as a sequence of instruction units, and each instruction unit is composed of its direction objective, one reference object or more and one spatial relationship or more, as illustrated in Fig. 1.

### 2.1 Direction objective

The direction objective of every instruction unit could be orientation, reorientation or route confirmation. According to the classification of the main route direction phases, which could be called starting phase, midway phase and terminal phase (Denis, *et al.*, 1999), orientation takes place in the starting and terminal phases, being used to determine direction or position from the middle of an open environment, while reorientation and route confirmation take place in the midway phase, being used to select the correct direction among several options and to confirm that the user is moving in the correct direction respectively. This classification of direction objective is consistent with the aspectual attribute categories of the semantics of route directions (Marciniak & Strube, 2005): orientation is stative, reorientation is culminated, and route confirmation is durative.

The decision points of reorientation refer to visual spatial features, or only exist in a user's cognitive map. For the latter, prior knowledge could be used for the user to achieve automated wayfinding. Similarly, if instruction units implying prior knowledge are used in the starting phase of route directions, the orientation processes could be not explicitly instructed but be done by the user automatically.

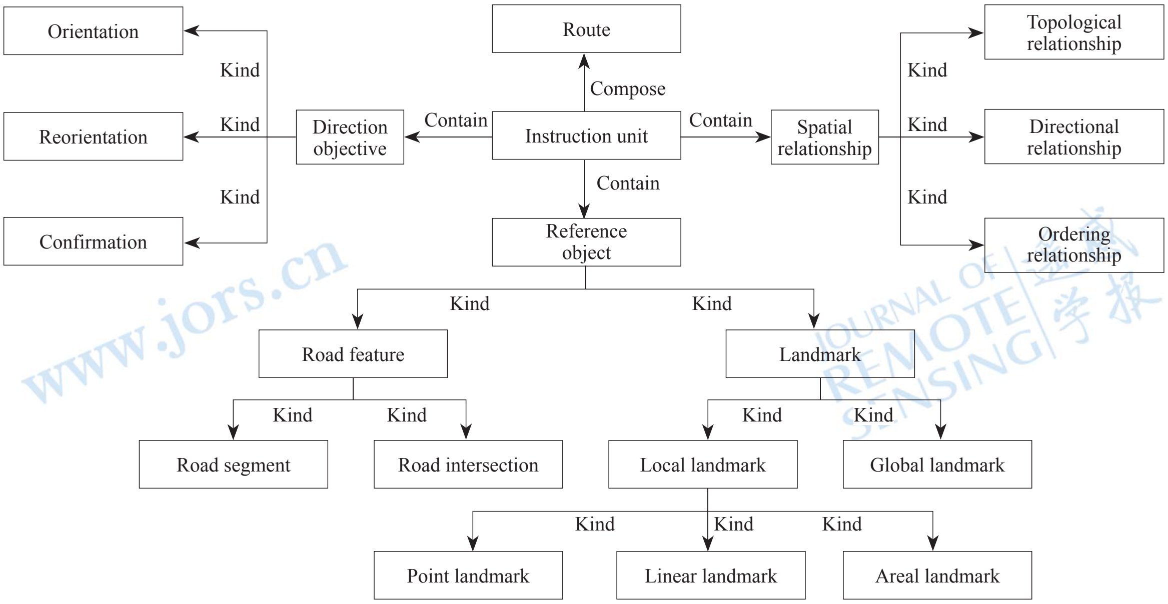

Fig. 1 A route representation framework for spatial cognition

## 2.2 Reference object

Any spatial feature can be referred by an instruction unit. In order to be compatible with current distance-to-turn route directions, two types of reference objects of instruction units are defined in our route representation framework: road features and landmarks. Road features include road segments and road intersections. Road segments are always described by their names, while road intersections are always characterized by their structures, such as crossing and roundabout. Current distance-to-turn route directions usually only refer to road features.

Today it is a common view that everything that stands out of the background may serve as a landmark (Raubal & Winter, 2002). According to the contexts they are being used, landmarks are categorized into local and global landmarks. Local landmarks are the spatial features which are in sight of the user's location or may be seen instantly. They are typically used for conveying visual cues or positional information for wayfinding, are close to the route, and are further categorized into point landmarks, linear landmarks and areal landmarks. Point landmarks are always used to identify the precise locations of instantaneous actions, such as turning, while linear and areal landmarks are always referred by continuous actions, such as following (Lovelace, *et al*., 1999). Global landmarks are the spatial features which are far from the user's current location and cannot be reached right away, but exist in his or her cognitive map. Because they can represent a user's prior spatial knowledge, global landmarks can be used as intermediate destinations for automated wayfinding, being at a distance or off the route; and their structures could be ignored. Although global and local landmarks are usually used in two distinct context (turn-by-turn directions and destination description) (Winter, *et al*., 2008), their uniform representation in instruction units can generate route directions meeting human cognitive habits and reflecting user's spatial knowledge.

## 2.3 Spatial relationship

In order to describe the environments with natural language, three types of qualitative spatial relationship, which are directional relationship, topological relationship and ordering relationship, and their corresponding relationship predications are defined in this route representation framework, as listed in Table 1.

**Table 1 Qualitative spatial relations & corresponding predications**

| Reference object | Relationship type | Relationship predications |
|---|---|---|
| Road segment | Ordering relationship | follow, along, … |
| Road intersection | Directional relationship | (veer) left, (veer) right, straight, … |
| | Ordering relationship | first (exit), second (exit), … |
| Point landmark | Directional relationship | (veer) left, (veer) right, straight, … |
| | Ordering relationship | before, after, at, pass, … |
| Linear landmark | Ordering relationship | follow, along, … |
| | Topological relationship | cross, … |
| Areal landmark | Topological relationship | cross, in, … |
| Global landmark | Directional relationship | north, east, south, west, toward, … |

Directional relationships can be defined in absolute or relative reference systems. Absolute directional relationships, referring to the center of the earth, are always defined as "north", "east", "south", "west" and so on. Relative directional relationships, referring to the observer or other objects, are always defined as "front", "back", "left", "right". Route directions referring to global landmarks usually adopt absolute directional relationships, or general directions such as "toward", in order to avoid ambiguity. Otherwise, relative directional relationships are usually adopted in route directions to decrease the user's cognitive workload.

Ordering relationships are usually used for reorientation and route confirmation. In reorientation, the locations of decision points relative to point landmarks are usually described with ordering relationships, such as "before", "after", "at" and so on (Richter & Klippel, 2007); and in other case, such as describing the exit of a complicated intersection, ordering relationships are also needed, *i.e.* "the third exit of the forthcoming roundabout". In route confirmation, ordering relationship can be used to describe the continuous process of "following" a linear landmark, or the instantaneous action of "passing" a point landmark.

Topological relationships are mainly adopted in route directions under non-urban environment, such as foot orienteering, to describe the process of the user "crossing" linear or areal landmarks, or the state of the user "in" an areal landmark.

Ordinarily, only one spatial relationship needs to be defined in an instruction unit, such as "turn right at the crossing". However, when point landmarks are referred for reorientation, directional relationships and ordering relationships should be described meanwhile, such as "turn right after passing the post office".

## 2.4 Characteristics of instruction units

There are temporal relationships among instruction units. Absolute temporal relationships defined in the theory of temporal intervals (Ivry & Hazeltine, 1995) could be used to describe the temporal relationships among instruction units, but are difficult to reflect their conceptual relationships. Therefore, three relative temporal relationships defined in the aspectual category of route directions, initial, subsequent and ongoing (Marciniak & Strube, 2005), are introduced to represent the temporal relationships in conceptual level. An initial relationship is used to relate the orientation instruction in a starting route direction phase to the next instruction. A subsequent relationship is used to relate two successive reorientation instructions, or a continuous route confirmation instruction and its succeeding reorientation instruction. An ongoing relationship is used to describe an instantaneous route confirmation, or the orientation instruction in a terminal route direction phase.

Multi-granularity is another characteristic of instruction units. As the most detailed turning information provided by current turn-based navigation systems may confuse and overload the users, the route direction process should be generalized in various levels, according the structures of the environments and routes, and reasoning abilities and prior knowledge of the users (Tenbrink & Winter, 2009). In this paper, semantic characteristics and spatial structures are used to chunk instruction units for bottom to top, and prior knowledge of the user is found to segment the route from top to bottom, for the purpose of generating various granular instruction units with different abstract degrees.

## 3 IMPLEMENTATION OF CONTEXT-ADAPTIVE ROUTE DIRECTIONS

A bunch of procedures need to be executed successively to automatically generate spatial cognition oriented context-adaptive route directions based on the route representation framework presented in the last section, just as shown in Fig. 2. At first, local and global landmarks independent of specific routes should be extracted from the environments or navigation electronic map in accordance with some rules. Then, the landmarks and some other environmental features related to the route predetermined by any route calculation algorithm should be taken to constitute various granular instruction units with a specific method, resulting with a set of interrelated hierarchical instruction units. Next, the user's real-time location and prior spatial knowledge should be acquired by virtue of position tracking and human-computer interaction techniques, to select a sequence of instruction units most appropriate to the user's need from the hierarchical instruction unit set. At last, natural language generation systems could be used to process the sequence of instruction units into phrases or sentences for instructing users to follow the route, achieving natural language based cognitively context-adaptive route directions. As route calculation algorithm, human-computer intersection and natural language systems are not the emphases of this paper, we only introduce the methods of extracting landmarks, generating various granular instruction units and selecting the most appropriate instruction units in this section.

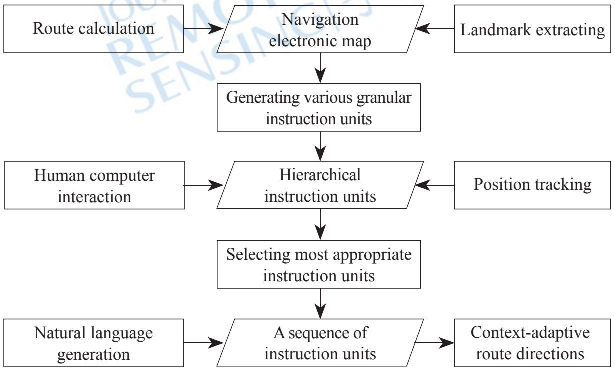

Fig. 2 The implementation process of context-adaptive route directions

### 3.1 Landmark extraction

The most popular approach for extracting landmarks is firstly collecting the characteristic information for every spatial feature in visual aspect, structural aspect and semantic aspect, then developing a significance measure model to calculate the significant degree of every feature. Lastly select the most significant features as landmarks (Raubal & Winter 2002; Nothegger, *et al.*, 2004; Klippel & Winter, 2005; Caduff & Timpf, 2008). However, as this approach requires troublesome data collection, maintenance and computation, it is hard to be implemented and widely used. Duckham, *et al.* (2010) proposed a more practical method of extracting landmarks from commonly available categorized point of interest (POI) data in three procedures: firstly, a heuristic weighting process is followed to assign general weights to categories of POIs; and then POI category weights are adjusted by generating refined landmark weighting functions while POI instance weights are adjusted based on the spatial or route structure; lastly, the POIs with weights higher than a determined level are selected as landmarks.

The landmarks extracted by above approaches could be used to assist users in wayfinding, but could not reflect their prior spatial knowledge, and hence are unsuitable to be global landmarks. Therefore, in our earlier study, a method of extracting hierarchical landmarks from POI data was proposed to reflect public spatial knowledge (Zhao, *et al.,* in press). In this method, a POI significance measure model could be firstly defined according to the three factors influencing the significance of a POI, which are public cognition, spatial distribution and individual characteristic; then three methods which are questionnaire survey, multi-density spatial clustering and data normalization could be applied to compute the significant degree for every POI object; and lastly the POIs with different significances are treated as global landmarks in different levels. Furthermore, through constructing weighted Voronoi diagrams with the seeds of different levels of landmarks, the influence area of every global landmark could be determined.

After several levels of global landmarks extracted from POI data with our method, other POIs could be treated as local landmarks, and their significances could be further adjusted according to the method proposed by Duckham, *et al.* (2010). Moreover, there are also some other prominent spatial features which are not represented as POIs, such as rivers, lakes and railways, could be treated as global or local landmarks according to their significant degrees. It also should be pointed out that the differences between global landmarks and local landmarks are relative, and are only meaningful for specific instruction units. Generally, a global landmark may also play a role of a local landmark but it is hard for a local landmark to be used as a global landmark. For example, the famous Yellow Crane Tower in Wuhan could be either set as an intermediate destination for destination description, or used as visual cues for navigating in its neighborhood.

### 3.2 Generation of various granular instruction units

As local landmarks are mainly used to reflect the spatial structures of routes while global landmarks are mainly used to represent where the destinations locate in the cognitive maps of people, we generate two kinds of hierarchical instruction units from two different levels and then construct the relationships between them. One kind of instruction units are called characteristic instruction units (CIUs) which reflect the spatial characteristics of routes, and other type of units are called locational instruction units (LIUs) which represent the cognitive locations of destinations.

#### *3.2.1 Generating hierarchical CIUs*

Hierarchical CIUs are constructed from bottom to top through referring to the landmarks distributed around the routes and related road features. This process can be implemented through five steps as follows.

(1) Finding the most relevant local or global landmark at every decision point on the route, where decision points include the starting point, terminal point and all of the intersections along the route. The relevant degree of every landmark with a decision point is proportional to the significance of the landmark, and is inversely proportional to their distance. Therefore, if a landmark is irrelevant to a decision point when their distance is larger than a threshold, such as 200 meters, the most relevant landmark to every decision

point could be determined.

(2) Constructing primary CIUs for each decision point in this step, the instruction units for the starting point and terminal route of the route are both used for orientation, while those for intersections of the route are used for reorientation; the reference object of every instruction unit is the most relevant landmark, or the road features connecting the corresponding decision point when there is no relevant landmark; the spatial relationships included in the instruction units are dependent on their direction objectives and reference objects, as defined in section 2.3.

(3) When there are some significant local or global landmarks along a road segment between two decision points, the most significant landmark will be selected as reference object for constructing an instruction unit for route confirmation.

(4) Establishing temporal relationships between all the constructed CIUs according to the regulations defined in section 2.4.

(5) Chunking the primary CIUs meeting the environmental contextual conditions into various granular composite CIUs. All the commonly used chunking methods could be adopted in this step, such as numerical chunking, chunking based on structural features and chunking based on all kinds of landmarks, which have been the subject of intensive research (*e.g.*, Dale, *et al.*, 2005; Klippel, *et al.*, 2005; Richter, 2007; Klippel, *et al.*, 2009).

### *3.2.2 Generating hierarchical LIUs*

Hierarchical LIUs are constructed from top to bottom through checking the spatial relationships between hierarchical global landmarks and the route. This process can be implemented through the following four steps.

(1) Partitioning the research area into several weighted Voronoi diagrams, where the global landmarks of different levels are used as the seeds and their significance values are used as the corresponding weights, to reflect the influence areas of every global landmark in different levels.

(2) Searching for the global landmarks whose Voronoi polygons intersect with the route level by level, and then building up the memberships between those landmarks of different levels based on the overlap relationships between their Voronoi polygons. In this step, the membership degree of each lower landmark relative to each upper one could be determined by the coverage ratio of their Voronoi polygons.

(3) Constructing LIUs referring to the global landmarks of different levels, with the essential direction objectives of reorientation by virtue of the prior spatial knowledge of users and the directional relationships for representing where those landmarks locate.

(4) Sequentially designating the subordinate lower LIUs to every upper LIU beginning from the top level. In this step, every lower LIU is only subordinate to one lower LIU whose reference landmark is superordinate to the landmark referred by the lower LIU with the largest membership degree, and all the lower LIUs referring to the same global landmark with a lower LIU should be excluded from the final determined hierarchical LIUs.

### *3.2.3 Associating two kinds of instruction units*

As being abstracted from environmental structures and spatial knowledge respectively and adopted different hierarchicalization strategies, hierarchical CIUs and LIUs are hard to be organized with a uniform hierarchical data structure. However, they still could be associated with the landmarks referred by them.

For every LIU, there must be an interchange point between it and a CIU, which could be used to realize the seamless transition between turn-by-turn route directions and destination descriptions. As prominent references, landmarks are the links between these two kinds of instruction units: when a LIU and a CIU both refer to the same landmark, the decision point related to this landmark is exactly the interchange point between the LIU and the CIU; otherwise, the decision point, which is closest to the global landmark referred by a LIU and whose corresponding CIU refers to some easily distinguishable local landmarks, could be set as an interchange point.

After all the interchange points having been determined, all the primary and composite CIUs between the starting point and the first interchange point or two successive interchange points can be generalized by the interchangeable LIU, if the global landmark referred by the LIU is familiar to a user.

## 3.3 Selection of the most appropriate instruction units

The process of selecting the most appropriate instruction units from the set of hierarchical instruction units mainly depends on two factors: the prior spatial knowledge of a user and his or her real-time locations. Spatial knowledge, which should be found before beginning the route directions, is used for selecting the most appropriate LIUs. Real-time locations of users are only necessary when real-time route directions is implementing, where the route directions are usually carried out progressively in mobile navigation device, but not considered when all of the route directions are provided in advance, such as online navigation services.

Two commonly used methods could be applied to acquire the prior spatial knowledge of a user. In the first method, user's tracking histories during their trips are stored for extracting the frequently visited locations which are treated as known ones. In the second one, human-computer interactive dialogues are carried out to adapt the level of spatial information provided to users' own spatial knowledge. As the accuracy of the first method is hardly assured, the second one is applied in this paper to launch dialogues about whether users know how to reach the locations represented by global landmarks. In order to reduce the times of human-computer dialogues as possible as we can, relevance theory (Sperber&Wilson, 2004) is introduced to select the most relevant global landmarks to the destination to be intermediate destinations of destination description, with the basic principle of human cognitive processes that maximizing the cognitive effect of a stimulus while minimizing the cognitive effort necessary to process it.

The candidate global landmarks are those landmarks referred by the lowest LIU, the Voronoi polygon of whose reference global landmark contains the destination, and its superordinate LIUs. If there is only one candidate landmark, then it is the one both holding the maximal cognitive effect and costing the minimal cognitive effort. In other cases, the lower the hierarchy of a landmark, the better is the cognitive effect, but higher the cognitive effort of processing the reference; the higher the hierarchy of a landmark, the lower is the cognitive effort, but worse the cognitive effect of processing the reference. Therefore, through sequentially inquiring a user whether he or she knows how to reach the candidate landmarks according to their hierarchies, the last one he or she knows is the most relevant global landmark to the destination, and it could be used as an intermediate destination. After being informed the LIU referring to this landmark, the user could approach the intermediate destination by automated wayfinding.

By means of the interchange points between LIUs and CIUs, appropriate CIUs could be selected to direct users to follow parts of the route, which cannot be described by LIUs. When in advance route direction mode is applied for navigation, the CIUs with the coarsest granularity would always be selected prioritily, to provide users with the most concise information easy to remember. Otherwise, if real-time route direction mode is applied, more flexible services would be provided according to the real-time location of a user and other user requirements, such as selecting different granular CIUs for specific needs or even reconstructing new CIUs dynamically.

## 4 EXPERIMENTS

Traditional route directions always describe the turnings along a route with the information of quantitative distances and road names. Nevertheless, this kind of route direction may lead confusion to users, increasing mental workload, and reducing driving safety, because quantitative distances are difficult to intuitively and accurately measure in mind and it is common for people to spend some time merely finding a street name within road signs.

An instance of traditional route directions is provided by a website of online map services, to instruct users to follow a route from Information Science Department of Wuhan University to Medicine Department of Wuhan University, as illustrated in Fig. 3. Those directions are described as follows: "Departure from the starting point to go west along the G316 Avenue, travel 3 kilometers and then turn slight right onto Zhongnan Street; Travel 1 kilometers and then turn right after passing Chung Nam Building on the right side about 250 meters; Travel 110 meters and then turn slight left; Turn left front after travelling 60 meters; Travel 70 meters and then turn slight right onto Hongshan Street past the Hubei Science and Education Building; Follow Hongshan Street 1.2 kilometers, and then left front onto Swan Road after passing Huguang Building on the right side about 180 meters; Travel 510 meters along Swan Road and then turn right front onto East Lake Road after passing Double Lake Bridge about 180 meters; Travel 50 meters along East Lake Road and then turn left; Now the destination is reached after 20 meters." It's obvious that a large number of quantitative distances and road names are utilized in this instance. Even though several landmarks are also employed, they are only used for route confirmation, but not for identifying the exact locations of turnings in the route.

In our route direction approach proposed in this paper, landmarks are frequently employed to assist users to make turning decisions or used as reference objects for automated wayfinding. Furthermore, some contextual factors such as environmental characteristics and users' prior spatial knowledge are considered to realize context-adaptive route directions, which reflect human cognitive habits and meet the way of human route communication, to effectively decrease user mental workload and promoting navigation efficiency. On the basis of the route representation framework and those implementation procedures presented in section 2 and section 3, an experiment of automatically achieving context-adaptive route directions based on spatial cognition was carried out. The main procedures and possible results will be indicated to direct the route shown in Fig. 3, for comparing the differences between traditional approach and our one for route directions.

The landmarks utilized in this experiment are extracted from POI data in accordance with the method proposed in our previous work (Zhao, *et al.*, 2011). After all the POI objects being hierarchized according to their significance degrees, those POI objects

Fig. 3 An example of traditional route directions

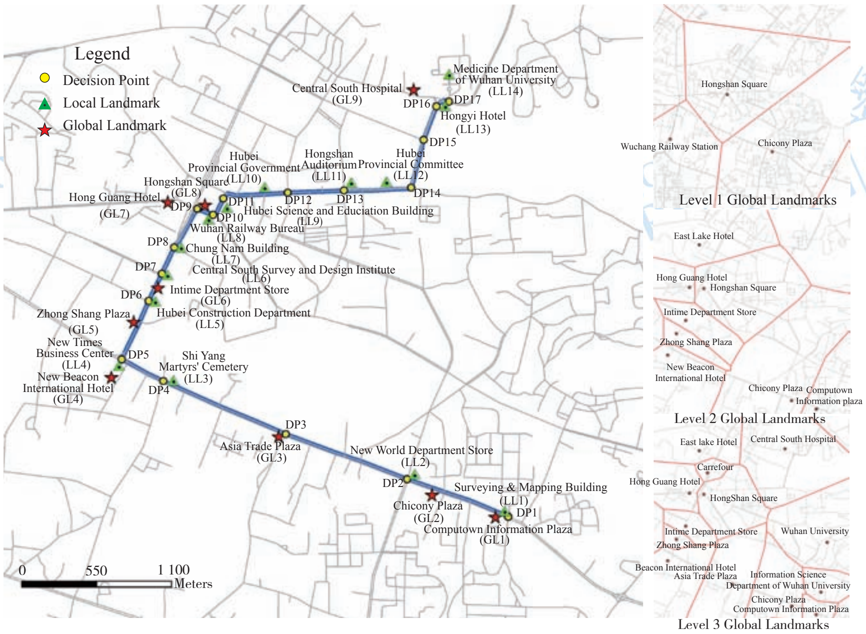

Fig. 4 Decision points in the route and landmarks related to the route

of the highest three levels are treated as global landmarks, and the others as local landmarks. All of the decision points in the route, the landmarks relevant to every decision point, and the global landmarks related to the route are labeled in Fig. 4. Meanwhile, the Voronoi diagrams of global landmark in each level are illustrated in Fig. 4. It should be noted that the intersections of main roads and internal roads are not treated as decision points, since internal roads are usually close to public transportation.

**Table 2 The character instruction units and location instruction units of the route**

| Characteristic instruction unit (CIU) | | | | | | Locational instruction unit (LIU) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Primary CIU | | | Composite CIU | | | No. | Components | Interchange point with CIUs | Level |
| No. | Components | Temporal relationship | No. | Components | Temporal relationship | | | | |
| 1 | (Ori, LL1, Facing) | Init(1, 2) | | | | 1 | (Reo, GL1, Toward) | DP1 | 2 |
| 2 | (Con, Road, Follow) | Seq(2, 4) | 22 | (Con, Road, Follow) | Seq(22, 24) | 2 | (Reo, GL2, Toward) | DP2 | 1 |
| 3 | (Con, GL2, Pass) | Ong(2, 3) | 23 | (Con, GL2/LL2,/GL3/LL3, Pass) | Ong(22, 23) | 3 | (Reo, GL3, Toward) | DP3 | 3 |
| 4 | (Reo, LL2, At/Str) | Seq(4, 5) | | | | | | | |
| 5 | (Reo, GL3, Before/Str) | S2q(5, 6) | | | | | | | |
| 6 | (Reo, LL3, After/Str) | Seq(6, 7) | | | | 4 | (Reo, GL4, Toward) | DP5 | 2 |
| 7 | (Reo, LL4, At/Right) | Seq(7, 8) | 24 | (Reo, LL4, At/Right) | Seq(24, 25) | | | | |
| 8 | (Reo, LL5, At/Str) | Seq(8, 9) | 25 | (Con, Road, Follow) | Seq(25, 27) | 5 | (Reo, GL5, Toward) | DP6 | 2 |
| 9 | (Reo, LL6, At/Str) | Seq(9, 10) | | | | 6 | (Reo, GL6, Toward) | DP7 | 2 |
| 10 | (Reo, LL7, At/Str) | Seq(10, 12) | | | | 7 | (Reo, GL7, Toward) | DP9 | 2 |
| 11 | (Con, Subway, Avoid) | Ong(10, 11) | 26 | (Con, Subway, Avoid) | Ong(25, 26) | 8 | (Reo, GL8, Toward) | DP9 | 1 |
| 12 | (Reo, GL8, At/Right) | Seq(12, 13) | 27 | (Reo, Roundabout, 2nd exit) | Seq(27, 28) | 9 | (Reo, GL9, Toward) | DP16 | 3 |
| 13 | (Reo, LL8, At/Left) | Seq(13, 14) | | | | | | | |
| 14 | (Reo, LL9, After/Right) | Seq(14, 15) | | | | | | | |
| 15 | (Reo, LL10, After/Str) | Seq(15, 16) | 28 | (Con, Road, Follow) | Seq(28, 29) | | | | |
| 16 | (Reo, LL11, Before/Str) | Seq(16, 17) | | | | | | | |
| 17 | (Reo, LL12, After/Left) | Seq(17, 18) | 29 | (Reo, LL12, After/Left) | Seq(29, 20) | | | | |
| 18 | (Reo, T-Int, Str) | Seq(18, 20) | 30 | (Con, Bridge, Pass) | Ong(29, 30) | | | | |
| 19 | (Con, Bridge, Pass) | Ong(18, 19) | | | | | | | |
| 20 | (Reo, Fork-Int, Right) | Seq(20, 21) | | | | | | | |
| 21 | (Ori, LL13, Opposite) | Ong(20, 21) | | | | | | | |

Note: "Ori" stands for orientation, "Reo" stands for reorientation, "Con" stands for confirmation, "Init" stands for initial, "Seq" stands for subsequent, "Ong" stands for ongoing, "Int" stands for intersection, "Str" stands for straight.

On the basis of these decision points, landmarks and other environmental features, a set of hierarchical CIUs and LIUs are constructed for route directions, as listed in Table 2. Firstly, explain the composition of primary CIUs: for their direction objectives, unit 1 and 21 are used for orientation, unit 2, 3, 11 and 19 are used for route confirmation, and other units are used for reorientation; for their reference objects, unit 2, 11 and 19 refer to road segments, unit 18 and 20 refer to road intersections, unit 3 refers to a significant landmark between two decision points, and the others refer to the most relevant landmarks to every corresponding decision points. Next, consider the chunking of primary CIUs into composite CIUs. In this experiment, two kinds of chunking strategies were applied: one is that successive reorientation CIUs for going straight are chunked into a route confirmation CIUs, such as unit 3 to 6, 8 to 10, 15 to 16, and 18-19 being respectively chunked into unit 23, 25, 28 and 30; the other is that successive reorientation CIUs referring to complicated intersections are chunked into another reorientation CIUs referring to the overall characteristics of the intersections, such as unit 12 to 14 being chunked into unit 27 which could be described as "passing through the roundabout from the second exit". Besides, chunked composite CIUs may also cause the change of temporal relationships among other CIUs, for example, unit 2, 7, 11 and 17 should be updated into unit 22, 24, 26 and 29 respectively. Lastly, for the hierarchical LIUs referring to global landmarks of different levels, only the interchange points between them and the CIUs need to be defined before determining whether they are consistent with users' prior spatial knowledge, and the temporal relationships among them are ignored.

After the available LIUs being determined through human-computer interactive dialogues, the most appropriate instruction units could be selected from the hierarchical instruction unit set. As shown in Fig. 4, there are two global landmarks relevant to the destination: Hongshan Square in level 1 and Central South Hospital in level 3. The former costs lower cognitive effort, while the latter is better in cognitive effect. If neither of the two global landmarks is familiar to a user, the coarsest successive CIUs would be selected as the most appropriate instruction unit sequence, which includes unit 1, 22, 23, 24, 25, 26, 27, 28, 29, 30, 20 and 21 in Table 2. Processed by a natural language generation system, that sequence of instruction units could be expressed as follows: "Facing Surveying & Mapping Building and follow the G316 Avenue; Turn right at New Times Business Center after passing Chicony Plaza, New World Department Store, Asia Trade Plaza and Shi Yang Martyrs' Cemetery; Follow Zhongnan Street, avoid the subway, and then pass through the roundabout from the second exit after reaching Hongshan Square; Follow Hongshan Street and then turn left after passing Hubei Provincial Committee; Turn right at the fork-intersection after passing Double Lake Bridge; Medicine Department of Wuhan University is opposite to Hongyi Hotel." If a user knows how to reach Hongshan Square, locational instruction unit 8 could be employed to replace characteristic instruction unit 1, 22, 23, 24, 25 and 26 in above instruction unit sequence. In this case, the corresponding route directions could be adjusted into following expressions: "Get to Hongshan Square from Zhongnan Street at first, and then pass through the roundabout from the second exit; Follow Hongshan Street and then turn left after passing Hubei Provincial Committee; ..." Furthermore, if a user knows how to reach Central South Hospital, locational instruction unit 9 and characteristic instruction unit 21 could compose the most appropriate instruction unit sequence, and the resultant route directions could be expressed as follows: "Arrive at Central South Hospital firstly; Medicine Department of Wuhan University is opposite to Hongyi Hotel which is located in southeast of the hospital."

It is indicated in this experiment that context-adaptive route directions are realizable on the basis of instruction units proposed in this paper, because (1) their composition is consistent with the theories of route description and spatial cognition, (2) their various granular characteristic could reflect environmental and route structures, and (3) their selection process could embody users' prior spatial knowledge. Therefore, route directions generated in this approach is consistent with human cognitive habits, apt to be expressed in natural language, and adaptable to different situations.

## 5 CONCLUSIONS

The fundamental theories and implementation processes for spatial cognition based context-adaptive route directions are introduced in this paper. The representation of a route into a sequence of instruction units mainly referring to landmarks according with the human habits of spatial cognition and route description, and supports the seamless integration of turn-by-turn route directions and destination description. As the major implementation procedures of context-adaptive route directions, landmark extraction, various granular instruction unit generation and most appropriate instruction unit selection are easy to automatically implement. More importantly, some contextual factors, such as environmental structures, route characteristics, the cognitive abilities and spatial knowledge of users, are also considered in these procedures, showing excellent adaptability. Furthermore, the finally selected sequential instruction units are easy to understand and accepted for users after being translated into natural language based route description through natural language generation systems. Consequentially, our experiments show that the spatial cognition based context-adaptive route directions proposed in this paper perform better than the traditional distance-to-turn route directions in decreasing user cognitive workload and promoting navigation efficiency.

Nevertheless, there are still some limitations in acquiring prior spatial knowledge of users. Although the most relevant global landmarks to the destination could be found by virtue of relevance theory, some significant global landmarks locating in the middle part of a route would hardly be effectively utilized when the route is complicated or quite long in distance, even though those landmarks may exist in a user's cognitive map. In our future study, new methods will be explored for comprehensively discovering users' prior spatial knowledge, in order to make route directions more convenient and efficient.

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# 空间认知驱动的自适应路径引导

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**摘　要：**为了生成符合人们认知习惯、反映用户空间知识并易于利用自然语言表达的路径引导, 提出了一个将路径抽象为一系列结构统一、具有时序性和多粒度性且可以被加工为指导用户沿路径前进的短语或句子的指示单元的表达框架, 并说明了利用环境结构、路径特征、先验知识等上下文因素生成多粒度的指示单元, 从中选择最合适的指示单元, 进而实现自适应路径引导的方法。通过与传统的采用“Distance-to-Turn”模式的路径引导进行对比可以发现, 基于空间认知的自适应路径引导更加符合人们描述路径的方式, 能够降低用户的认知压力并提高导航的效率。

**关键词：**路径引导, 空间认知, 地标, 空间知识

**中图分类号：** P208　　**文献标志码：** A

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## 1　引 言

符合人们认知习惯的路径引导(Route Direc-tions)是近年计算机科学、地理科学、认知科学、心理学等领域的研究热点。从认知角度看，路径引导是对沿预定路径抵达目的地需要采取的一系列行动的描述，以辅助人们寻路(Wayfinding) (Denis，1997)。由于未引入核心空间认知要素—地标(Landmark)，当今采用“到转向距离(Distance-to-Turn)”引导方式的导航系统有效却不够自然，造成用户认知压力大，导航效率低(Burnett，2000；May和Ross，2006)。

目前，此领域大多研究转向引导(Turn-by-Turn Directions)方式(Tversky和Lee，1999；Werner 等，2000；Dale 等，2005；Klippel 等，2005；Richter，2007；Klippel 等，2009)。其共同特点是：首先从环境的数据模型或认知地图中提取与路径中各决策点(Decision Points，需要进行方向选择的点)相关的行动及要素，然后用交互工具(Tversky和Lee，1999)、概念模型(Werner 等，2000)、自然语言(Dale 等，2005)、示意符号(Klippel 等，2005)、抽象基元(Richter，2007)或数据结构(Klippel 等，2009)等统一组织这些信息，并时而对组织结果优化处理(Dale 等，2005；Klippel 等，2005；Richter，2007；Klippel 等，2009)，最后输出为图形或语言。当用户对环境具有先验知识(Priori Knowledge)时，涉及每个决策点的转向引导可能显得拖沓。此时，引入目的地描述(Destination Description)机制才更加接近人们的路径表达(Tomko和Winter，2009)。目的地描述的基本原理是：当用户知道如何抵达路径经过的某个地点时，将该地点作为中继目的地并省略具体引导过程，进而由用户利用认知地图自主抵达中继目的地。

由于大多数用户对所处环境既有熟悉又有陌生的部分，新一代导航系统应该融合转向引导和目的

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地描述两种路径引导方式。Richter 等人(2008)利用实时人机对话发现用户的空间知识，并在实现这两种引导方式平滑切换的基础上选择更符合用户需求的引导方式。但是，由于两种引导方式分别参考不同的空间对象(分别是决策点和环境要素)，该方法难以实现转向引导和目的地描述的无缝融合。Srinivas和Hirtle(2007)在转向引导基础上提出了基于用户先验知识的路径示意化(Schematization)方法，将路径划分成若干熟悉和不熟悉的部分，并对熟悉部分进行了高度的归纳(Knowledge Chunking)。尽管引入了类似决策点的已知位置(Known Locations)概念，他们采用的通过经验统计(对用户经过各地点次数的统计)确定熟悉路径和已知位置的方法效率较低且可靠性不足。此外，相关研究表明，采用自然语言表达的路径引导更加易于用户理解和接受(Dale 等，2005)。

为了使路径引导符合人们的认知习惯，反映用户的空间知识，并易于使用自然语言表达，本文提出了一个面向空间认知的路径表达框架，并说明了在此基础上实现自适应路径引导的方法。在该框架中，路径被抽象为一系列结构统一、具有时序性和多粒度性、且可以被加工为指导用户前进的短语或句子的指示单元。将路径划分为一系列多粒度的指示单元，然后根据环境结构、路径特征及先验知识等上下文因素选择最合适的指示单元，进而交由自然语言生成系统(Natural Language Generation，简称NLG)加工，就可以实现基于自然语言的自适应路径引导。本文的第2节定义框架的基本结构；第3节说明实现自适应路径引导的主要方法；第4节介绍实验的过程；第5节对全文进行总结。

## 2 面向空间认知的路径表达框架

路径引导本质上是指示用户在受限空间内完成一系列行动(Denis，1997)。为了准确表达其含义，对各行动的描述需要包含3方面信息：(1)行动目的；(2)被参考空间要素；(3)涉及的空间关系。在该框架中，路径被抽象为一系列由目的、参考对象和空间关系构成的指示单元(Instruction Units)。其基本结构如图1所示。

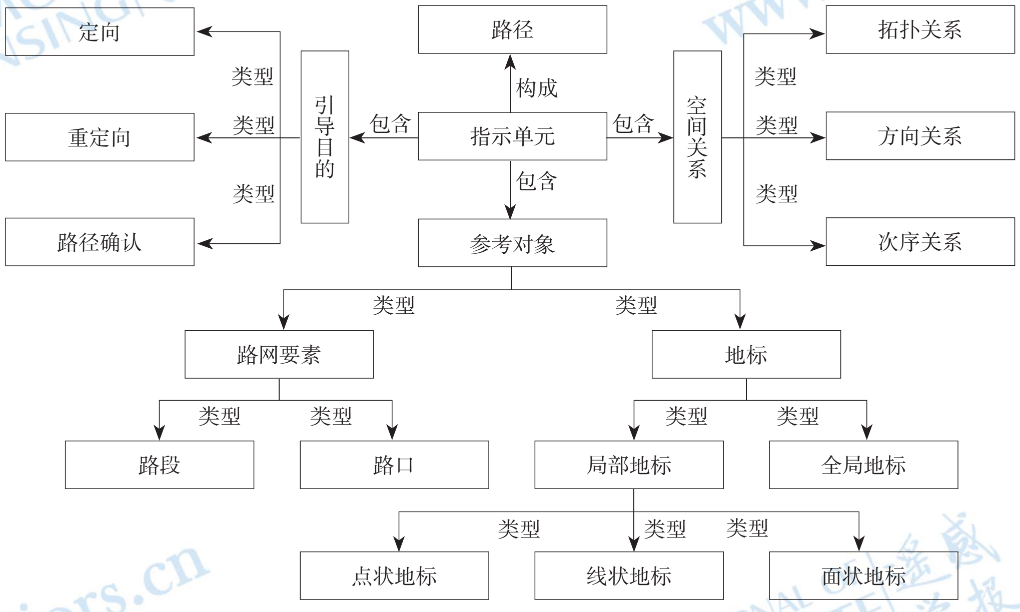

图1 面向空间认知的路径表达框架

### 2.1 引导目的

路径引导有3种目的：定向、重定向和路径确认。结合路径引导的主要阶段，即起始、中间和结束阶段(Denis 等，1999)，定向发生在起始和结束阶段，用于在开放环境中确定方向或位置；重定向和路径确认发生在中间阶段，分别用于在决策点选择正确的前进方向，以及在决策点之间增强用户的信心。此分类符合对路径描述的语体划分(Marciniak和Strube，2005)：定向主要进行状态描述；重定向和路径确认都用来说明行动，且前者侧重表达结果，后者侧重表达过程。

重定向的决策点是可视的空间要素，或者仅存在于认知地图中。对于后者，用户可以利用先验空间知识进行寻路。如果包含先验知识的指示单元用于起始引导，通常由用户自主定向。

### 2.2 参考对象

指示单元可以参考任何空间要素。尽管任何显著的空间要素都可以当作地标(Raubal和Winter，2002)，本文定义了路网要素和地标两类参考对象，以兼容传统的路径引导方式。路网要素包括道路和路口。道路通常用道路名指代；路口通常由其结构特征描述，如十字路口、环岛等。传统的路径引导方式通常仅以道路和路口为参考对象，并辅以距离和方向信息。

地标分为局部地标和全局地标两种。前者可以从当前位置观察到或很快观察到，用作人们寻路的视觉线索，被分为点状、线状和面状3种类型，其中点状地标用于标识行动的位置，线状及面状地标则常用来反映持续性的行动(Lovelace 等，1999)；后者距离当前位置较远且不能马上抵达，反映用户的空间知识，通常被忽略结构特征并用作人们寻路的中继目的地，可以在路径上或路径附近。尽管通常被用于不同场合(如转向引导和目的地描述) (Winter 等，2008)，用统一概念表达的两种地标可以使路径引导既体现用户的认知习惯又反映其空间知识。

### 2.3 空间关系

为了便于利用自然语言描述场景，本文引入了一系列定性的空间关系及关系谓词，如表1所示。

**表1 定性空间关系和关系谓词**

| 参考对象 | 关系类型 | 关系谓词 |
|---|---|---|
| 道路 | 次序关系 | Follow, Along, …… |
| 路口 | 方向关系 | (Veer) Left, (Veer) Right, Straight, …… |
|  | 次序关系 | First (Exit), Second (Exit), …… |
| 点状地标 | 方向关系 | (Veer) Left, (Veer) Right, Straight, …… |
|  | 次序关系 | Before, After, At, Pass, …… |
| 线状地标 | 次序关系 | Follow, Along, …… |
|  | 拓扑关系 | Cross, …… |
| 面状地标 | 拓扑关系 | Cross, In, …… |
| 全局地标 | 方向关系 | North, East, South, West, Toward, …… |

方向关系可以在绝对或相对参考系统下定义。前者以地球为参考中心，通常定义为东、西、南、北等；后者以观察者或其他对象为参考中心，通常定义为前、后、左、右等。参考全局地标的路径引导通常采取绝对方向，或仅描述大致方位，如“朝着(Toward)”，以避免产生歧义；否则通常采用相对参考系统，以降低用户的认知压力。

次序关系常用于对路径的重定向和路径确认。重定向时常需要描述决策点相对点状地标的位置，如“之前(Before)”、“之后(After)”及“附近(At)”等(Richter和Klippel，2007)，或描述复杂转向的出口，如“从第3个出口通过环岛”。路径确认时可以说明持续地“沿着(Follow)”某条线状地标，或者瞬时地“经过(Pass)”某个点状地标。

拓扑关系主要应用在非城市环境下的路径引导，如定向越野，用于描述用户“穿过(Cross)”线状或面状地标的过程，或者在面状地标内部的状态。

通常，每个指示单元仅涉及一个空间关系，如“在十字路口右转”。但是，在参考点状地标的重定向时需要同时描述方向关系和次序关系，如“经过邮局后右转”。

### 2.4 指示单元的特性

指示单元具有时态特征。利用时态间隔理论(Ivry和Hazeltine，1995)可以定义指示单元间的绝对时态关系，却难以反映其概念间的联系。本文借鉴了路径描述语体理论(Marciniak和Strube，2005)，定义了起始(Initial)、顺序(Subsequent)和伴随(Ongoing)3种概念层面的指示单元时态关系。起始关系用于联系开始阶段的定向和下一个行动。顺序关系用于联系两个连续的重定向，或者一个持续性的路径确认及其后继的重定向。伴随关系用于说明一个动作完成后或进行中瞬时性的路径确认，或者结束阶段的定向。

指示单元还具有多粒度性。传统的转向引导通常描述在每个决策点的重定向，却可能由于为了大量细节信息而给用户带来的混淆。根据环境结构、路径特征以及用户的推理能力和先验知识等，可以对路径引导过程进行不同抽象程度的组合或概括(Tenbrink和Winter，2009)。本文利用语义特征、空间结构等对指示单元进行从下至上的归纳，利用用户的先验空间知识对路径进行从上至下的分割，可以生成具有不同抽象等级的多粒度指示单元。

## 3　自适应路径引导的实现方法

在上节介绍的路径表达框架基础上自动生成基于空间认知的自适应路径引导需要完成如图2所示的一系列操作：首先，按照一定的规则从环境或导航电子地图中提取不依赖具体路径的局部和全局地标数据；然后，根据预先确定的路径选取与路径相关的地标和其他环境要素，并采用特定的算法生成多粒度的指示单元，进而形成分层且相互联系的指示单元集合；接下来，利用通过位置追踪和人机交互获取的用户实时位置和空间知识从分层指示单元集合中选择最符合用户需求的指示单元序列；最后，利用自然语言生成系统将指示单元序列加工为指导用户沿路径前进的短语和句子，生成基于自然语言的、符合用户认知规律的自适应路径引导。由于路径选择算法、人机交互界面和自然语言生成系统等不是本文的研究重点，本节主要介绍地标提取、生成多粒度指示单元和选择最合适指示单元的方法。

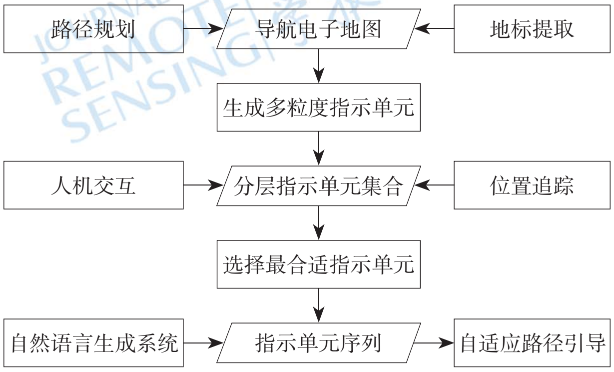

图2　自适应路径引导实现流程

### 3.1　地标提取

地标提取的常见方法是采集各空间要素的外观、语义和结构特征等指标数据，定义显著性度量模型并计算其显著度，最后选择显著度较高的空间要素作为地标(Raubal和Winter 2002；Nothegger 等，2004；Klippel和Winter，2005；Caduff和Timpf，2008)。不过由于数据采集、维护和计算比较繁琐，这种方法难以推广。Duckham等人(2010)提出了一种更实用的地标提取方法：针对易于获取的、分类的兴趣点 (Point of Interest，简称POI) 数据，利用启发式方法为各类对象赋以统一的权重，并根据具体应用对各类权重进行调整，最后选择与路径相关的权重较高的对象作为所需的地标。

上述方法提取的地标主要用于辅助导航，而未能反映用户的空间知识，故不能作为全局地标。因此，在较早的研究中，提出了一种从城市POI数据中提取反映用户空间知识的分层地标的方法(赵卫锋等)。该方法从公众认知、空间分布和个体特征3个方面定义影响POI显著性的因素并提出一个POI显著性度量模型；然后通过认知度问卷调查、多密度空间聚类和特征属性规格化的方法计算各POI对象的显著性度量指标及其整体显著度；最后根据显著度的差异将POI数据划分为若干个层次并进行Voronoi图空间剖分，得到的具有不同空间影响范围的全局地标。

按照我们的方法从POI数据中提取出显著度较高的若干层的全局地标后，其他POI可以被当作局部地标，并且其显著度可以利用Duckham等的方法进行调整。而对于不能被抽象为POI对象但特征突出的空间要素，如河流、湖泊、铁路等，可以根据其显著程度被当作全局地标或局部地标。需要指出，导航中全局地标和局部地标的区别是相对的，且仅对特定的指示单元有意义。通常，全局地标也可以起到局部地标的作用，比如武汉地标黄鹤楼即可以被设定为中继目的地又可以作为其邻域内导航的视觉线索，而局部地标则难以被当作全局地标使用。

### 3.2　生成多粒度指示单元

由于局部地标主要反映路径的空间特征，而全局地标主要表达目标在人们认知地图中的位置，本文分别从两个层面生成反映路径特征的特征指示单元和表达目标位置的位置指示单元，然后建立它们的联系。

#### 3.2.1　多层特征指示单元

多层特征指示单元是以路径周围的地标分布和路网结构为参考对象自下而上地建立起来的，主要包括以下5个步骤：

(1)找出与路径上每个决策点(包括起终点和路口)关联度最高的全局或局部地标。其中，关联度与地标的显著度成正比，与其距离决策点的长度成反比；且假定距离大于一定阈值时(如200 m)路标与决策点不关联。

(2)针对每个决策点生成基础的特征指示单元。其中，起终点和路口处指示单元的引导目的分别为定向和重定向；指示单元的参考对象为与决策点关联度

最高的地标或决策点连接的路网要素(当不存在与决策点关联的地标时)；指示单元包含的空间关系取决于其引导目的和参考对象(参见2.3节)。

(3)当决策点之间的道路附近存在较显著的全局或局部地标时，以最显著的地标为参考对象生成用于路径确认的特征指示单元。

(4)根据2.4节的定义建立各特征指示单元之间的时态关系。

(5)利用环境上下文将满足条件的基础特征指示单元归纳为多粒度的复合特征指示单元。常见的归纳方法有计数式归纳、基于路口或环境结构的归纳、基于地标的归纳等，具体方法参考(Dale 等，2005；Klippel 等，2005；Richter，2007；Klippel 等，2009)。

### 3.2.2 多层位置指示单元

多层位置指示单元是根据路径和各层全局地标的空间关系自上而下地建立起来的，主要包括以下4个步骤：

(1)以各层全局地标为种子、其显著度为影响因子对研究区域进行加权的Voronoi剖分，以反映各全局地标的空间影响范围。

(2)逐层查找其Voronoi多边形与路径相交的全局地标，并根据Voronoi多边形的覆盖关系建立上下层地标之间的隶属关系。其中，下层地标相对上层地标的隶属度由其Voronoi多边形被上层地标的Voronoi多边形的覆盖比例确定。

(3)依次以各层全局地标为参考对象生成位置指示单元。其中，位置指示单元的引导目的实质是借助用户空间知识的重定向，且仅采用表示目标方位的方向关系。

(4)从最上层开始，依次设定每个位置指示单元蕴含的下层位置指示单元。其中，每个下层位置指示单元仅从属于其参考地标记录的隶属度最大的上层地标对应的位置指示单元，并且剔除与任意上层位置指示单元参考到相同地标的下层位置指示单元。

### 3.2.3 关联两类指示单元

由于分别对环境特征和空间知识进行抽象，且采用了不同的分层策略，各层特征指示单元和位置指示单元难以用统一的分层数据结构管理。但是，通过它们参考的地标可以建立特征指示单元和位置指示单元之间的联系。

每个位置指示单元都和某个特征指示单元存在交汇点，以支持转向引导和目的地描述之间的无缝切换。作为显著的参考对象，地标是两种指示单元产生联系的纽带：当一个位置指示单元和某个特征指示单元具有相同的参考地标时，该特征指示单元对应的决策点就是两种指示单元的交汇点；否则，交汇点被设定为距离位置指示单元参考的地标最近、且参考到地标的特征指示单元对应的决策点。只要符合用户的空间知识，起点到第一个交汇点或连续两个交汇点之间的基础或复合特征指示单元就可以被对应的位置指示单元概括。

## 3.3 选择最合适指示单元

从分层指示单元集合中选择最合适的指示单元序列主要取决于两个因素：用户的空间知识及其实时位置。空间知识用于选择最合适的位置指示单元，通常在路径引导开始前确定。实时位置仅在采用实时路径引导(即在引导过程中逐步进行指示，常用于移动导航设备)时是必要的，而在预先路径引导(即在引导开始前一次提供所有指示，常用于在线导航服务)时通常不予考虑。

常见的用户空间知识获取方法有两种：一种在用户经过每个地点的统计次数基础上进行推测，另一种是按照一定的规则通过人机交互的方式进行确认。由于前一种方法的准确性难以保证，本文采用了后一种方式，即询问用户是否知道如何抵达某个全局地标。为了尽量减少人机对话的次数，我们采用关联理论(Relevance Theory)从各全局地标中选取与目的地关联度最高的地标作为中继目的地。其基本原则是：使人们处理信息时能够以最小的认知心力(Cognitive Effort)获取最好的认知效果(Cognitive Effect) (Sperber和Wilson，2004)。候选地标包括其Voronoi多边形包含目的地位置的最低层位置指示单元参考的地标以及其对应上层位置指示单元参考的地标。如果候选地标仅有一个，则其既具有最好的认知效果又花费最小的认知心力。否则，层次越低，其认知效果越好而认知心力越大；层次越高，其认知心力越小而认知效果越差。因此，按照其所属层次由高到低依次询问，用户最后知晓的那个地标具有最高关联度。根据参考到该地标的位置指示单元，用户就可以采用自主寻路的方式向其参考的全局地标前进。

利用位置指示单元和特征指示单元的交汇点，路径中位置指示单元无法覆盖的部分需要选取合适的特征指示单元。在采用预先路径引导模式时，我们总优先选择最粗粒度的特征指示单元，以提供方便用户记忆的最简捷信息。而在采用实时路径引导模式时，由于可以根据用户的实时位置及其请求提供更加灵活的服务，可以根据不同的需要选择不同粒度的特征指示单元，甚至实时生成新的特征指示单元。

## 4 实 验

传统的路径引导应用主要以“定量距离+道路名称”的方式描述路径中的转向信息。但是，由于人们对定量的距离难以有直观、准确的认识，且有时难以及时发现道路的名称信息，这种路径引导方式经常给用户造成较大的认知压力，并容易引起错误的转向决策。

图3 传统的路径引导实例

图3展示了某地图服务网站规划的从“武汉大学信息学部”到“武汉大学医学部”的一条路径，其对应的路径引导内容为：“从起点向正西方向出发，沿G316行驶3 km，稍向右转进入中南路；沿中南路行驶1 km，过右侧的中南大厦约250 m，右转；行驶110 m，稍向左转；行驶60 m，左前方转弯；行驶70 m，过右侧的湖北科教大厦，稍向右转进入洪山路；沿洪山路行驶1.2 km，过右侧的湖光大厦约180 m后，左前方转弯进入天鹅路；沿天鹅路行驶510 m，过左侧的双湖桥约180 m后，右前方转弯进入东湖路；沿东湖路行驶50 m，左转；行驶20 m到达终点。”可以发现，该实例中包含了大量的定量距离和路名信息。尽管其中包含了若干个地标，它们也仅用于路径确认，而非标识转向的具体位置。

本文提出的方法则主要以地标为辅助用户进行转向决策或自主寻路的参考对象，并根据环境特征和用户空间知识等上下文因素实现反映人们空间认知习惯、符合人们路径描述方式的自适应路径引导，能够有效降低用户的认知负荷并提高导航的效率。在前文提出的路径表达框架和路径引导实现方法基础上，进行了自动实现基于空间认知的自适应路径引导的实验。本节以图3所示的路径为例简要说明该实验的主要流程和可能的结果。

本实验采用的地标数据是根据(赵卫锋 等，2011)提出的方法从实验区域的POI数据中提取的，其中显著度最高的3层POI被当作全局地标。图4标出了路径中所有决策点、各决策点关联的地标以及与路径相关的全局地标，并展示了以各层全局地标的

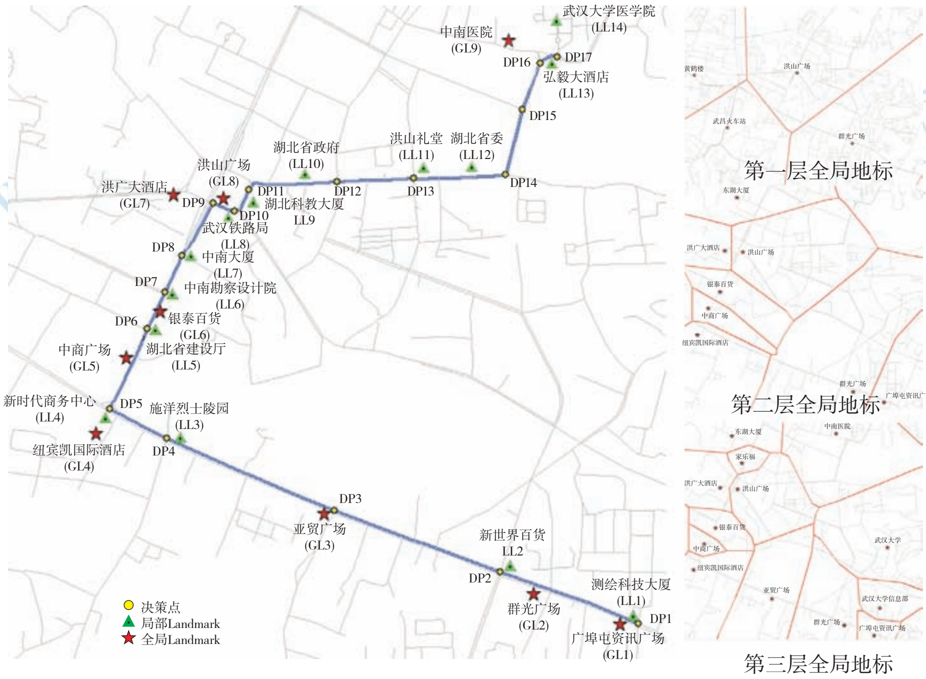

图4 路径上的决策点和路径相关的地标

**表2 路径中的特征指示单元和位置指示单元**

| 特征指示单元(CIU) | | | | | | 位置指示单元(LIU) | | | |
|---|---|---|---|---|---|---|---|---|---|
| 基础单元 | | | 复合单元 | | | | | | |
| 编号 | 成员 | 时态关系 | 编号 | 成员 | 时态关系 | 编号 | 成员 | 与CIU的交汇点 | 层次 |
| 1 | (Ori, LL1, Facing) | Init(1, 2) | | | | 1 | (Reo, GL1, Toward) | DP1 | 2 |
| 2 | (Con, Road, Follow) | Seq(2, 4) | 22 | (Con, Road, Follow) | Seq(22, 24) | 2 | (Reo, GL2, Toward) | DP2 | 1 |
| 3 | (Con, GL2, Pass) | Ong(2, 3) | 23 | (Con, GL2/LL2,/GL3/ LL3, Pass) | Ong(22, 23) | 3 | (Reo, GL3, Toward) | DP3 | 3 |
| 4 | (Reo, LL2, At/Str) | Seq(4, 5) | | | | | | | |
| 5 | (Reo, GL3, Before/Str) | S2q(5, 6) | | | | | | | |
| 6 | (Reo, LL3, After/Str) | Seq(6, 7) | | | | 4 | (Reo, GL4, Toward) | DP5 | 2 |
| 7 | (Reo, LL4, At/Right) | Seq(7, 8) | 24 | (Reo, LL4, At/Right) | Seq(24, 25) | | | | |
| 8 | (Reo, LL5, At/Str) | Seq(8, 9) | 25 | (Con, Road, Follow) | Seq(25, 27) | 5 | (Reo, GL5, Toward) | DP6 | 2 |
| 9 | (Reo, LL6, At/Str) | Seq(9, 10) | | | | 6 | (Reo, GL6, Toward) | DP7 | 2 |
| 10 | (Reo, LL7, At/Str) | Seq(10, 12) | | | | 7 | (Reo, GL7, Toward) | DP9 | 2 |
| 11 | (Con, Subway, Avoid) | Ong(10, 11) | 26 | (Con, Subway, Avoid) | Ong(25, 26) | 8 | (Reo, GL8, Toward) | DP9 | 1 |
| 12 | (Reo, GL8, At/Right) | Seq(12, 13) | 27 | (Reo, Roundabout, 2nd exit) | Seq(27, 28) | 9 | (Reo, GL9, Toward) | DP16 | 3 |
| 13 | (Reo, LL8, At/Left) | Seq(13, 14) | | | | | | | |
| 14 | (Reo, LL9, After/Right) | Seq(14, 15) | | | | | | | |
| 15 | (Reo, LL10, After/Str) | Seq(15, 16) | 28 | (Con, Road, Follow) | Seq(28, 29) | | | | |
| 16 | (Reo, LL11, Before/Str) | Seq(16, 17) | | | | | | | |
| 17 | (Reo, LL12, After/Left) | Seq(17, 18) | 29 | (Reo, LL12, After/Left) | Seq(29, 20) | | | | |
| 18 | (Reo, T-Int, Str) | Seq(18, 20) | 30 | (Con, Bridge, Pass) | Ong(29, 30) | | | | |
| 19 | (Con, Bridge, Pass) | Ong(18, 19) | | | | | | | |
| 20 | (Reo, Fork-Int, Right) | Seq(20, 21) | | | | | | | |
| 21 | (Ori, LL13, Opposite) | Ong(20, 21) | | | | | | | |

注：Ori代表定向，Reo代表重定向，Con代表确认，Init代表起始关系，Seq代表顺序关系，Ong代表伴随关系，Int代表路口，Str代表直行

Voronoi多边形。需要说明，由于不符合人们的通行习惯，内部道路与主干路交叉形成的节点不被当作决策点。表2中列出了为该路径生成的分层特征指示单元和位置指示单元集合。对于基础特征指示单元：一方面，1和21用于定向，2、3、11和19用于路径确认，其他用于重定向；另一方面，2、11和19参考到路段，18和20参考到路口，3参考到决策点间最显著的地标，其他参考到与决策点关联度最高的地标。对这些基础特征指示单元的归纳涉及两种策略：将表示连续直行的重定向归纳为路径确认，如3-6、8-10、15-16和18-19分别被归纳为23、25、28和30；将针对复杂路口的连续重定向归纳为描述路口整体特征的重定向，如12-14被归纳为27，表示为“通过环岛的第2个出口”。另外，归纳后的特征指示单元还会引起其他一些特征指示单元的时态关系发生变化，如2、7、11和17需要分别被更新为22、24、26和29。对于与各全局地标对应的各层位置指示单元，在判断其是否符合用户的空间知识之前，仅需定义其与特征指示单元的交汇点，而不需定义它们之间的时态关系。

通过人机对话确定可用的位置指示单元后，就能够确定最终的指示单元序列。由图4可知，与目的地关联的候选全局地标有洪山广场和中南医院，其中前者花费较低的认知心力，后者具有较高的认知效果。假设这两个全局地标对于用户都是未知的，则最合适的指示单元序列仅包括最大粒度的特征指示单元，分别为表2中的1、22、23、24、25、26、27、28、29、30、20和21。经过NLG系统加工，这些指示单元可以表达为：“朝向测绘科技大厦，沿G316直行，经过群光广场、新世界百货、亚贸广场和施洋烈士陵园，在新时代商务中心右转；沿中南路直行，不走地下通道，到洪山广场后从环岛的第2个出口离开；沿洪山路直行，经过湖北省委后左转；经过双湖桥，在叉形路口右转，武汉大学医学部就在弘毅大酒店对面。”如果用户仅知道如何抵达洪山广场，最合适的指示单元序列就是位置指示单元8，以及特征指示单元27、28、29、30、20和21。相应的路径引导内容可以被调整为“先沿中南路抵达洪山广场，并从环岛的第2个出口离开；沿洪山路直行…”。如果用户知道如何抵达中南医院，则最合适的指示单元序列就是位置指示单元9，以及特征指示单元21。相应的路径引导内容可以被调整为“先抵达中南医院，武汉大学医学部就在位于中南医院东南的弘毅大酒店对面。”

通过该实验可以发现，作为路径引导基础的指示单元具有如下特点：其构成符合路径描述和空间认知理论，其多粒度性体现环境和路径的结构特征，其选择过程反映用户的空间知识。因此，基于该方法的路径引导符合人们空间认知习惯，易于利用自然语言描述，而且具有良好的自适应性。

## 5 结 论

本文介绍了基于空间认知的自适应路径引导的理论基础和实现方法。将路径表达为由以地标为核心的指示单元序列符合人们空间认知和路径描述的习惯，并支持转向引导和目的地描述的无缝融合。作为实现自适应路径引导的主要步骤，地标提取、生成多粒度指示单元以及选择最合适指示单元的过程易于实现，又考虑了环境结构、路径特征以及用户的认知能力和空间知识等上下文因素，体现了良好的自适应性。此外，利用NLG系统将指示单元序列转换为基于自然语言的路径描述便于用户的理解和接受。实验表明，本文提出的基于空间认知的自适应路径引导较传统的“Distance-to-Turn”式的路径引导能够降低用户的认知压力并提高导航的效率。

本文在用户空间知识的获取上具有一定的局限性。尽管利用关联理论能够发现与目的地具有较高关联度的全局地标，但是，当路径比较复杂或跨度较长时，路径中间部分一些存在于用户认知地图中的地标却难以得到有效应用。在下一步的研究中，我们将探索全面发现用户先验空间知识的新方法，以使路径引导更加简捷而高效。

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