# 2004 年度　修　士　論　文

# A Geocoding Method for Natural Route Descriptions using Sidewalk Network Databases
# 歩道ネットワークを基本とした経路記述を対象としたジオコーディング手法

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# *CHAPTER 1*

# *INTRODUCTION*

# 1. INTRODUCTION

## 1.1. BACKGROUND OF THE THESIS

We have been able to use the information space connected by networks since the birth of the Internet. The Internet became an elementary part of everyday life for over half a billion people worldwide [1]. In Japan, over 50 million people, representing over 40% of the population, had access to the Internet in 2002. That is part of the reason that it has become easy for people to generate multimedia content including documents, pictures and movies with a mobile phone, and then distribute them over the Internet. Ordinary people have increasing opportunities to transmit the information across the Internet since user-friendly weblog tools have emerged.

While the mount of information is increasing on the Internet, retrieving the information on the Internet has become indispensable in our daily life. When we want to have a tasty meal with our friends, we get information of restaurants from the Internet using search engines for some keywords. However, it is not easy to get exact information because there are billions of documents and the number of them is increasing. It may cause us inconvenience when we find information using computers, especially local information like restaurants. We assume that the inconvenience stems from the difference in the framework of managing information between our brains and the current computer systems. One of people's methods of memorizing information is associated with locations. Examples of this are "Mr. Suzuki who lives in Tokyo", "a good Chinese noodle shop under the elevated rail" and "an important file in the second drawer of my desk". In other words, locations remind people of their memories. However, it is difficult for us to deal with information corresponding to locations in the real world. On the other hand, we can acquire stable and inexpensive location data by a GPS sensor as if we can know time by a watch. Location based services in which we can obtain information based on locations are expected to be developed in the years ahead. We especially focus on text content with location information as part of challenges for advanced use of multimedia content.

## 1.2. GEOCODING FOR GEO-REFERENCED DESCRIPTIONS

Most text data such as word processing documents, HTML documents and email messages in our computers and on the Internet includes geo-referenced descriptions which are addresses, phone numbers, postal codes, place names and route descriptions (Figure 1.1). We define these descriptions which correspond to the region in the real world as *geo-referenced descriptions*. These geo-referenced descriptions are spatial data with no (x, y) coordinates data. When geo-referenced descriptions are converted into machine readable data, we will access a lot of our documents by the key of positions in the real world [2]. The purpose of this research is to consider the framework to deal with information using geo-referenced descriptions as one of the important keys referring to the information.

We have studied a method of converting geo-referenced descriptions like addresses and place names into their corresponding geographic coordinates [3]. The process of converting descriptions into coordinates is called geocoding. In this thesis, we focus on natural route descriptions as a new type of target to geocode. Our key idea is that a route description can be represented as a sub-graph of sidewalk network databases. On the basis of this idea, we consider a geocoding method for natural route descriptions using sidewalk network databases.

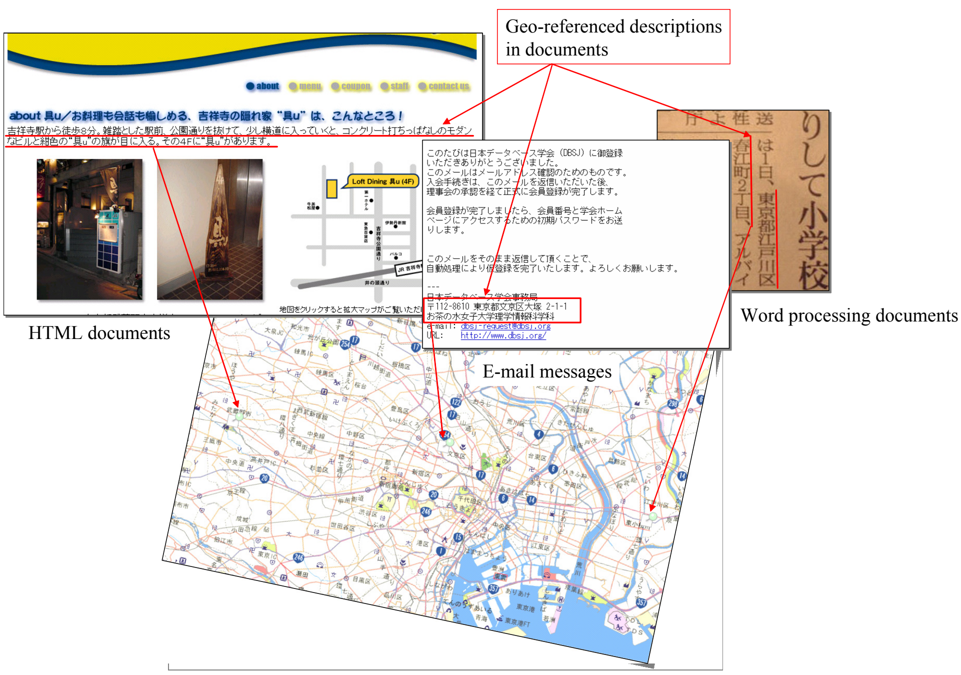


**Figure 1.1.** Geo-referenced descriptions in documents

## 1.3. RELEVANT WORKS

Search engine industries also focus on geo-referenced descriptions as the key for searching information. Google Local Search engine emerged from the 2002 Google Programming Contest winning project, the geocoding project of Dan Egnor [4]. As mentioned in [5], his system provides an interface that allows the user to augment a keyword search with the ability to restrict matches to within a certain radius of a specified address. It is useful for queries that are difficult to answer using just keyword searching, such as "all bookstores near my house". *Google Local* [6] was launched officially on March, 2004. The engine searches for address patterns on the Web sites and geocodes them using US Census TIGER databases. Yahoo launched its local search service, *Yahoo Local* [7], officially on October, 2004. *Yahoo Local* can search by keywords and by place names. It is usually entered as suburb name and street name combination. These proved to be very useful and provided high success rate of search. However, search engines such as Google or Yahoo cannot search the information contained on the Internet unless it has a well defined pattern or contains clearly advertised location based keywords. Those engines cannot search location information hidden in databases and stored as dynamic content.

In Japan, the geocoding for addresses is more complex because of no custom to leave a space between words, variations for representing for the same place in Japanese and old and complex structures of cities in Japan. *Distributed Address Matching System (DAMS)* and *BASHO* solved these problems [8]. *DAMS* is the system for converting addresses in Japanese into geographic coordinates. The system can deal with Japanese descriptions which have variations for representing the same Japanese addresses and mixed descriptions of previous address and new address. *BASHO* is the system for extracting addresses from various documents. *CSV Geocoding Service* [9] and *Search Restaurants in Tokyo* [10] are available as applications of *DAMS* and *BASHO*. *CSV Geocoding service* adds the column of geographic coordinates to table data including addresses in CSV form. *Search Restaurants in Tokyo* can retrieve rumors, which are information in Web pages by ordinary people, about 100,000 restaurants in Tokyo Metropolis.

These works have commonly observed features dealing with geo-referenced descriptions as points in the real world. For example, local search engines get information around your position for your query which is “coffee shops near my place”. These web pages are posted as point data on the map using a geocoding method for addresses. There are, however, descriptions which can not be converted into point data such as route descriptions.

Since Sidewalk network databases, which are large-scale spatial network databases, merged in 2003, useful services have become available. *Ekitan-Odekake-Map* [11] is one of online services using sidewalk network databases. Using the site of Ekitan-Odekake-Map, people can search for buildings or restaurants and get maps showing the shortest route between a selected place and the nearest train station. The Ekitan-Odekake-Map also allows you to send maps to other personal computers or mobile phones. In addition to this, human navigation service with a mobile phone which is described in Chapter 3 is also realized using sidewalk network databases.

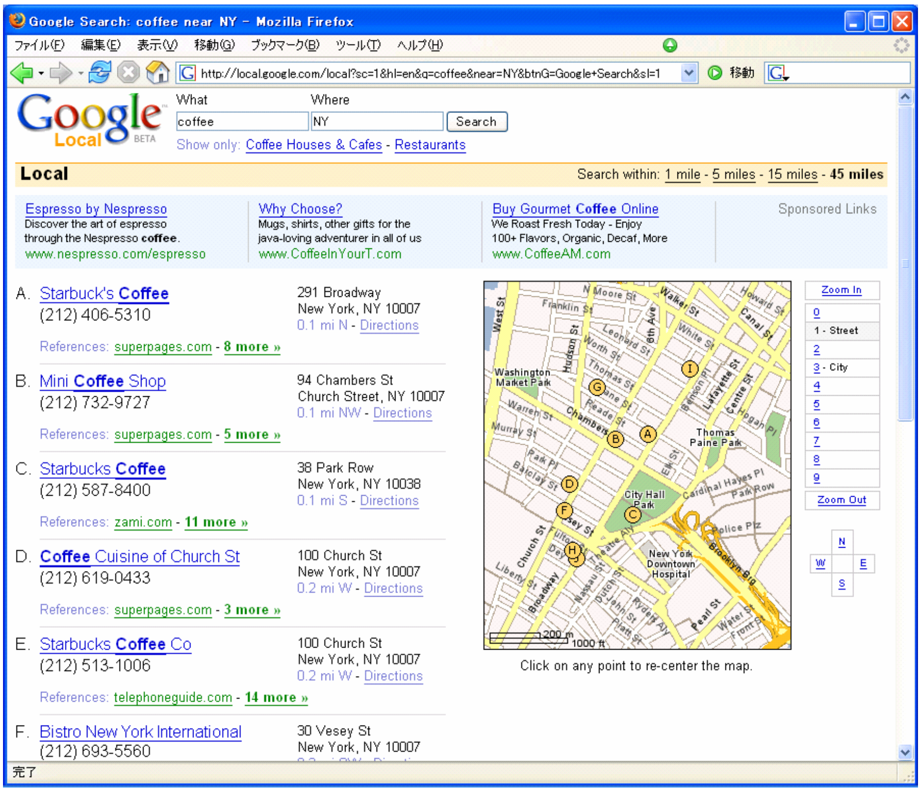


**Figure 1.2.** Graphical user interface of *Google Local*

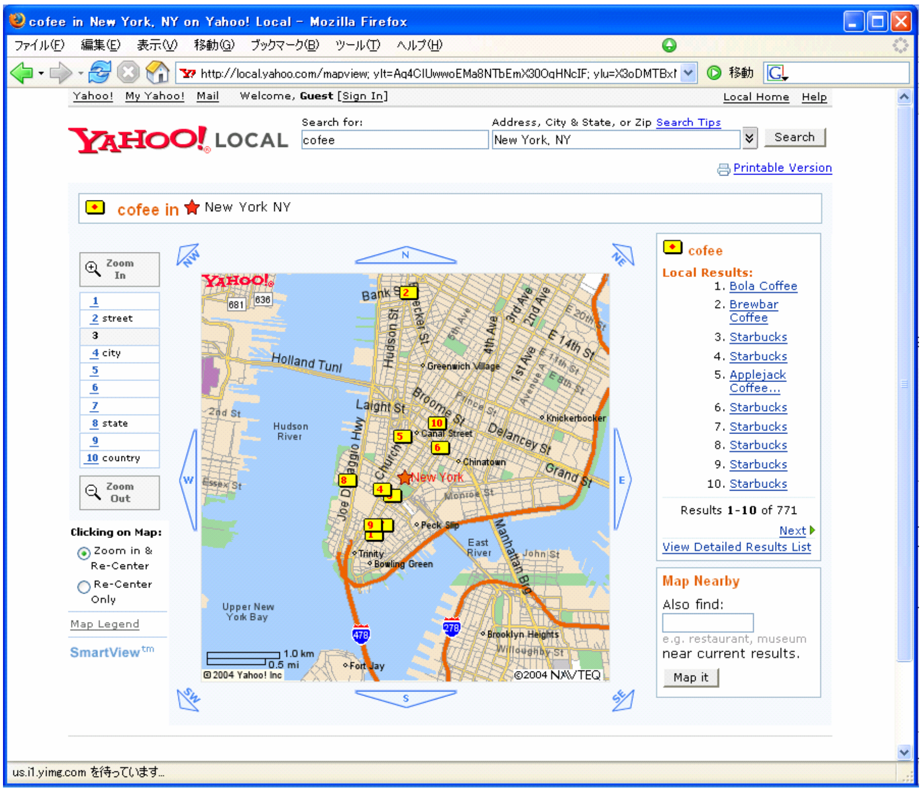


**Figure 1.3.** Graphical user interface of *Yahoo Local*

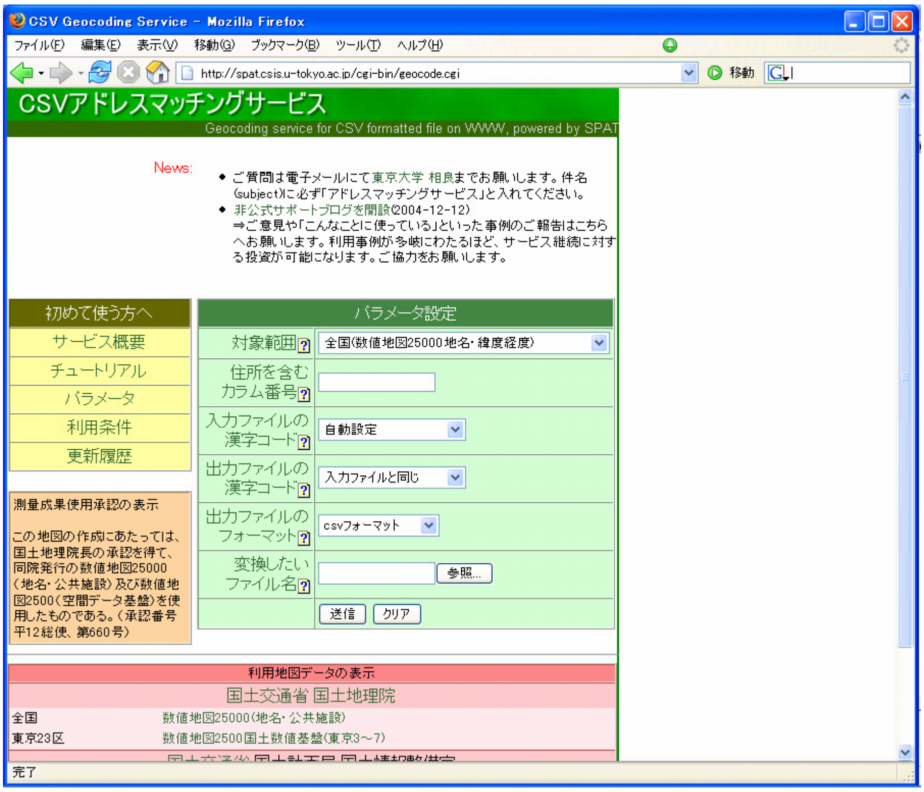


**Figure 1.4.** Graphical user interface of *CSV Geocoding Service*


**Figure .1.5.** Graphical user interface of *Search Restaurants in Tokyo*


**Figure .1.6.** Graphical user interface of *Ekitan-Odekake-Map*

## 1.4. ORGANIZATION OF THE THESIS

Chapter 2 of this thesis describes interpretation and structure of natural route descriptions and presents Formal Route Statement (FRS) to represent natural route descriptions by computers. Computers are able to interpret natural route descriptions through the intermediary of FRS. Chapter 3 introduces sidewalk network databases and explains the schema of sidewalk network databases on the basis of a characteristic of natural route descriptions. A prototype system for managing sidewalk network databases is presented at the close of the chapter. Chapter 4 mentions a method to geocode natural route descriptions using Formal Route Statement as queries and sidewalk network databases. In addition, a prototype system which has been developed based on our proposed framework and experimental demonstration is explained. Finally, Chapter 5 states conclusion and future work.

# *CHAPTER 2*

# *ROUTE DESCRIPTIONS*

# 2. ROUTE DESCRIPTIONS

People often refer places through their daily life (Figure 2.1). A route description is the description that represents a route from place to place by natural language. People would easily arrive at their destinations when a given route description is appropriate. People are able not only to understand a route description but to decode natural route descriptions into geometric figures (e.g., point, line and plane) like Figure 2.2. Why people can do that? The answer to the question will be solutions to the big questions that how people understand natural language and how people take cognizance of the real space. Researchers in Artificial Intelligence (AI) have been tackling these issues of *spatial cognition* and *natural language understanding* for a long time [12, 13]. Section 2.1 explains the interpretation and structure of route descriptions on the basis of those studies in AI. Section 2.2 presents Formal Route Statement as a framework to solve geocoding problems for route descriptions.


**Figure 2.1.** Image of referring to places in the daily scene


**Figure 2.2.** Decoding the route descriptions into figures on the map

## 2.1. Interpretation and Structure of Natural Route Descriptions

### 2.1.1. Interpretation of Natural Route Descriptions in Japanese

In this section, the basic premise of the interpretation of natural route descriptions is explained as follows using three keywords: (1) *common-sense knowledge of geographic space*, (2) *geometric conceptualization* and (3) *virtual walker* on the basis of studies in AI.

**(1) *Common-sense knowledge of geographic space***

We assume that there is *common-sense knowledge of geographic space* for the real world to understand natural route descriptions. Such common-sense knowledge is learned through people's daily experience in the space they live. Focusing on the experience of walking in a city, we take (a) *exit*, (b) *intersection*, (c) *street* and (d) *slope street* for instance and state structure of each feature[1] from the perspective that what action walkers can take for each feature. The reason why we focus on walker's action for features is that expressions of walker's actions in route descriptions are clues to topology between places. We also describe usage and example of them in a natural route description.

[1] In Geographic Information Science, *feature* is the term referring to abstract concept of phenomenon in the real world (e.g., house, building, road, river and typhoon.)

**(a)** ***Exit***

Structure: Exits have unique direction to come in or go out for walkers. Exits have a boundary separating inside and outside of a building. A walker's direction is approximated from a cross-line for the boundary (Figure 2.3).

Usage: Exits are set as a start place in route descriptions in many cases.

Example: "A1 出口を出て左に進む (exit from A1 exit and go to the left)"

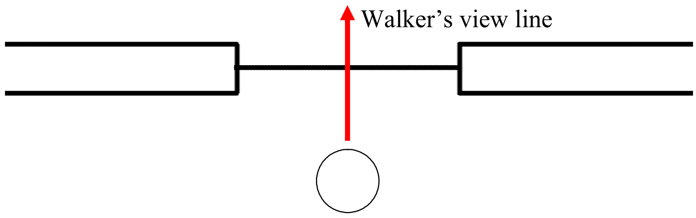


**Figure 2.3.** Example of an exit

**(b)** ***Intersection***

Structure: Intersections have some streets to come in or go out for walkers (Figure 2.4). A walker's direction cannot be decided by the structure.

Usage: Intersections are set as a passage place to change walker's direction.

Example: "交差点を右に曲がる (turn right at the intersection)"

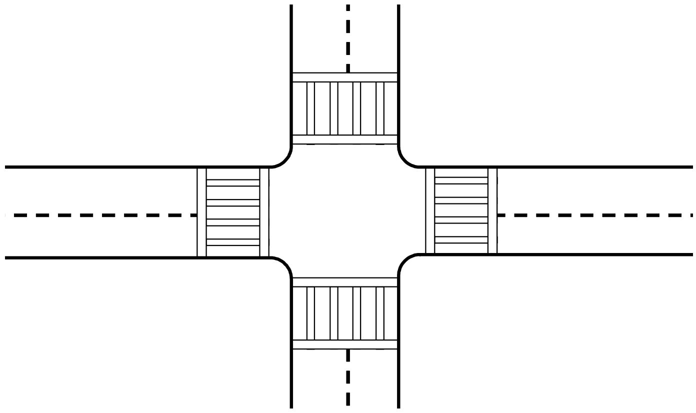

**Figure 2.4.** Example of an intersection

**(c) *Street***

Structure: Streets are long paths having both ends as gates to come in or go out for walkers. Large streets having broad width and long length include some intersections connecting other paths (Figure 2.5). Walkers can access the street by internal intersections.

Usage: Streets are set as a passage place to walk long distance.

Example: "その通りを真っ直ぐ進む (go straight through the street)"

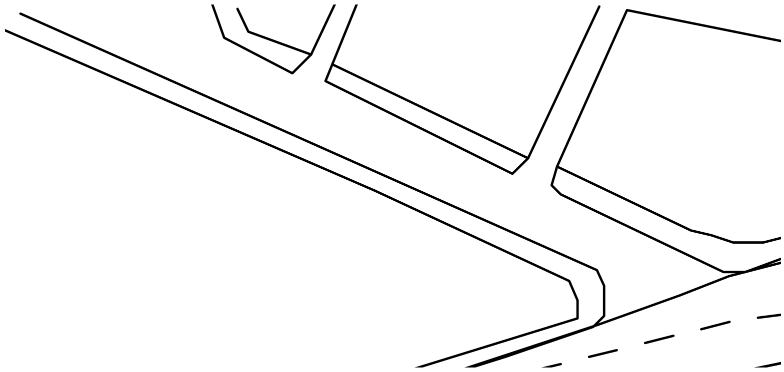

**Figure 2.5.** Example of a street

**(d) *Slope Street***

Structure: Slope streets are streets which have vertical interval between both ends. Slope streets become upslope for walkers (Walker A in Figure 2.6) when walkers enter the slope streets from the lower end. Slope streets become down slope for walkers (Walker B in Figure 2.6) when walkers enter the slope streets from the higher end.

Usage: Slope streets are set as a passage place to walk long distance.

Example: "その坂を上り(go up the slope street)"

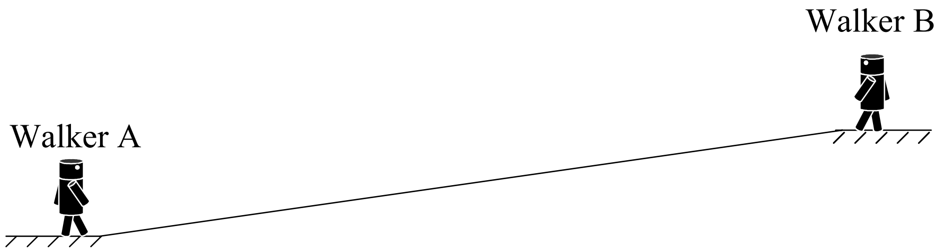


**Figure 2.6.** Example of a slope street

**(2) *Geometric conceptualization***

When people say something, they do not always express the fact and need not to express all of the fact.

*The Starbucks is on the way to the building.* (Figure 2.7)

The above example is thought that the point referring to the Starbucks is on the line to the point referring to the building in our brains. Thus, features referred in route descriptions can be taken as points, lines and planes. This process for taking an object in the real world as point, line or plane is called *geometric conceptualization* [12]. In route descriptions, places of start, passage and destination are taken as points and route to them is thought as a line. A route description is considered to be geometric descriptions which include the process of geometric conceptualization. In addition, descriptions referring to features in a route description show a part of the features such as one corner of an intersection, an area in front of a building or a side of a large street.

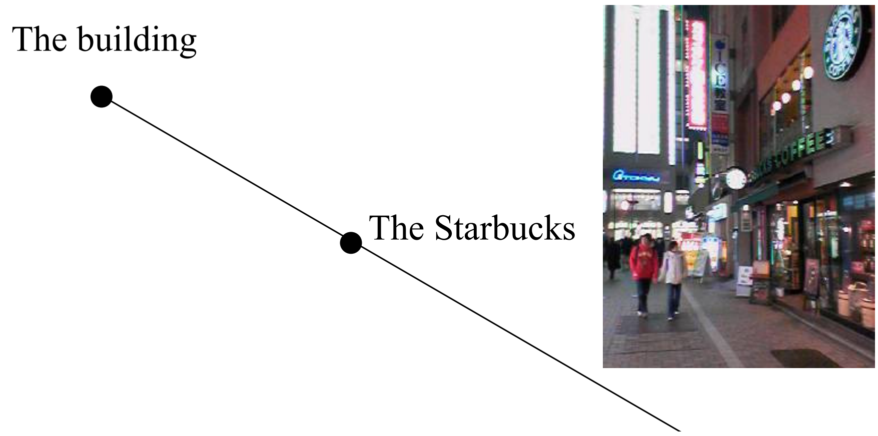


**Figure 2.7.** Example of geometric conceptualization

**(3) *Virtual walker***

People can understand expressions of relative direction such as “go straight”, “turn right” and “go up” in route descriptions in spite of the case that an agent noun is omitted in a route description. The reason is that there is common view for an implicit walker as an actor in a natural route description. The visual line of a walker is the basic axis for finding direction. Figure 2.8 shows that there are six directional axes for front, rear, right, left, up and down for people. People project a *virtual walker* in actual maps and cognitive maps in their brains as shown in Figure 2.9 in order to imagine a route. People interpret expressions about direction by the visual line of a virtual walker.

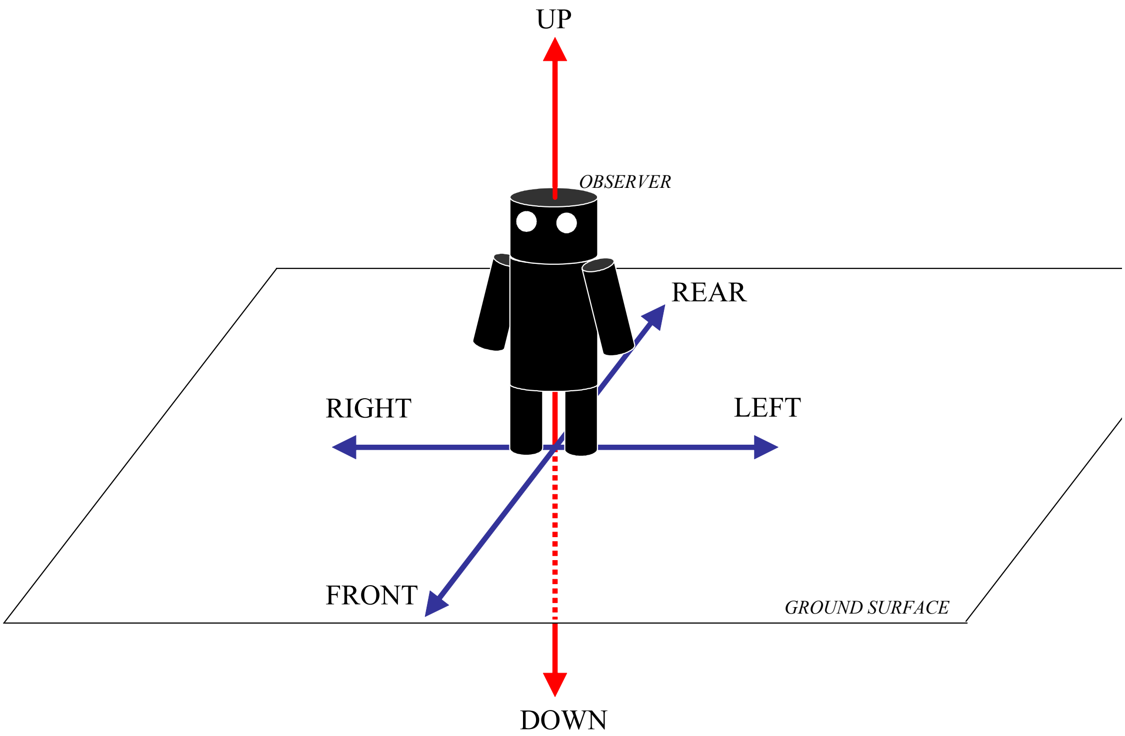


**Figure 2.8.** Six axes for finding direction

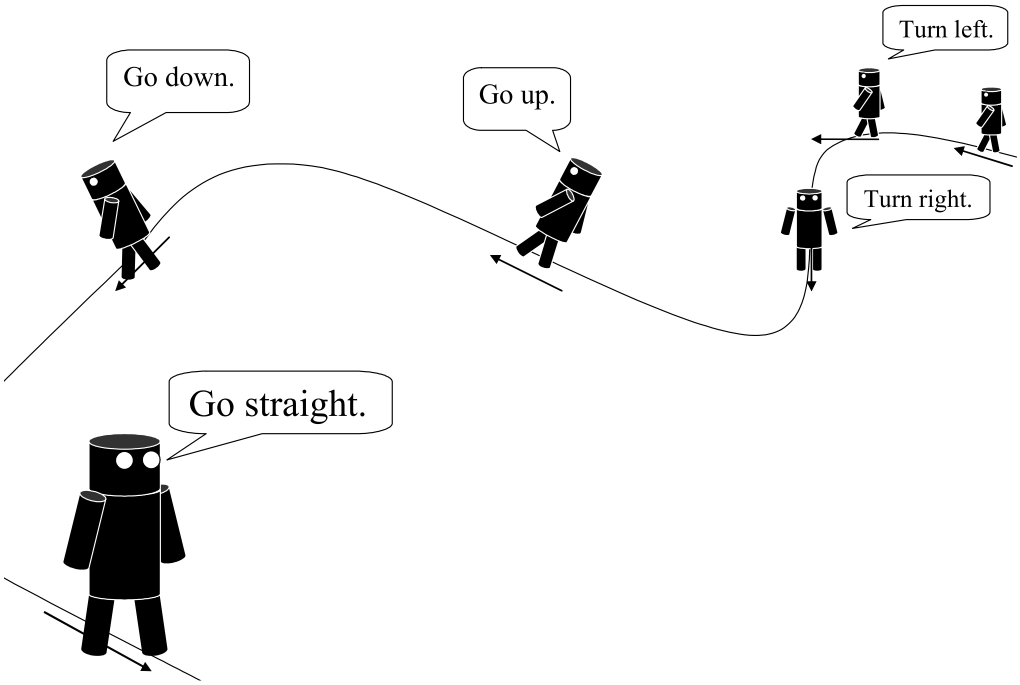


**Figure 2.9.** Finding direction

### 2.1.2. Structure of Natural Route Descriptions in Japanese

A natural route description[2] can be divided into noun phrase and verbal phrase. For example, the description "渋谷駅ハチ公口を出て道玄坂を上り交差点を右へ曲がる (You exit from the Shibuya Hachiko Exit and go up Dogen-zaka, and then turn right at the intersection)" is divided as follows:

渋谷駅ハチ公口を出て道玄坂を上り交差点を右へ曲がる
↓
[渋谷駅ハチ公口][を出て][道玄坂][を上り][交差点][を右へ曲がる]
↓
noun phrase: [渋谷駅ハチ公口], [道玄坂], [交差点]
verbal phrase: [を出て], [を上り], [を右へ曲がる]

[2] We call route descriptions by natural language *natural route descriptions*. *Natural route descriptions* mean descriptions generated by not only people but computers (e.g., car/human navigation system). "*Natural*" in *natural route description* does not mean very well or very easy.

All of the above noun phrases have a place name. A place name refers to the unique place in the real world and works as a reference point for the next verbal phrase. The above verbal phrase has a preposition such as “を(at, from or through)”, a verb such as “曲がる(turn)” or “出る(exit)” and an adjunct such as “右へ(right)”, “100 メートル(100m)” or “5 分(5minutes)”. It is usual for Japanese people that an agent noun for the verbal phrase is often omitted in a description. A person who is referred by an omitted agent noun is a walker who is a writer of a description or third person.

Figure 2.10 shows pictures of places in the real world referred by noun phrases in a natural route description. We call a noun phrase in a natural route description *spatial anchor description*. Spatial anchor description includes unique noun and general noun. A general noun such as “the intersection” is deduced from context of a description and situation. In Table 2.1, we collect typical places which are referred by spatial anchor descriptions in Shibuya, one of the big cites in Tokyo, Japan. Spatial anchor descriptions referring those places can be used as start points, passage points and end points of routes in natural route descriptions. Table 2.2 gives instances of verbal phrase. These verbal phrases are the expressions of a walker’s action on the route. Walker’s actions on the route denote topology between places. On the other hand, we call a verbal phrase in a natural route description *spatial relationship description*. We divide a route description into spatial anchor descriptions and spatial relationship descriptions as follows:

[渋谷駅ハチ公口][を出て][道玄坂][を上り][交差点][を右へ曲がる]

↓

| | |
|---|---|
| spatial anchors descriptions: | [渋谷駅ハチ公口], [道玄坂] , [交差点] |
| spatial relationships descriptions: | [を出て] , [を上り] , [を右へ曲がる] |


**Figure 2.10.** Pictures of places referred by spatial anchors in Shibuya

The top left is Shibuya Station. The top right is Dogenzaka-ue police box. The middle left is Meiji Street. The middle right is Park Street. The bottom left is Miyamasuzaka. The bottom right is Dogenzaka.

**Table 2.1.** Examples of spatial anchor descriptions in Shibuya

| Category | Examples |
|---|---|
| *Spatial Anchor* | |
| Building | タワーレコード(Tower Records),エイチエムブイ(HMV), QFRONT(QFRONT), 道玄坂上交番 (Dogenzaka-ue Police Box), 渋谷駅前交番 (Shibuya Station Police Box) … |
| Station Exit | JR渋谷駅東口/ハチ公口/宮益口(JR Shibuya Station East Exit / Hachiko Exit/ Miyamasu Exit),京王井の頭線渋谷駅(Keio Inokashira Line Shibuya Station) … |
| Street | 明治通り (Meiji Street), 公園通り(Park Street), 井の頭通り(Inokashira Street), 文化村通り(Bunkamura Street), センター街(Center Street) … |
| Slope Street | 宮益坂 (Miyamasuzaka), スペイン坂 (Spain-zaka), 道玄坂 (Dogenzaka) … |
| Intersection | 渋谷スクランブル交差点 (Shibuya Scramble Intersection), 道玄坂上交番前交差点(Dogenzaka-ue Koban-mae Intersection)… |

**Table 2.2.** Examples of spatial relationship descriptions

| *Spatial Relationship* | Examples |
|---|---|
| Direction | まっすぐ進み，直進し(go forward, go ahead, advance)<br>右へ曲がり, 右手に進み(turn to the right, on the right, on one's right)<br>左へ曲がり，左手に進み(turn to the left, on the left, on one's left) |
| Distance | 200 メートル(in 200 meter), 5 分(in 5 minutes) |

## 2.2. Formal Route Statement (FRS)

### 2.2.1. Simple Model of Natural Route Descriptions

We simplify route descriptions, such as a list structure in Figure 2.11. A description of spatial anchor corresponds to an ellipse and spatial relationship description corresponds to a rectangle in Figure 2.11. Figure 2.12 illustrates the image of geocoding a natural route description into spatial database. Constructing a natural route description can be compared to sticking of pins and stretching of a thread between pins on a map. Using this simple model, we define the formal statement of natural route descriptions.

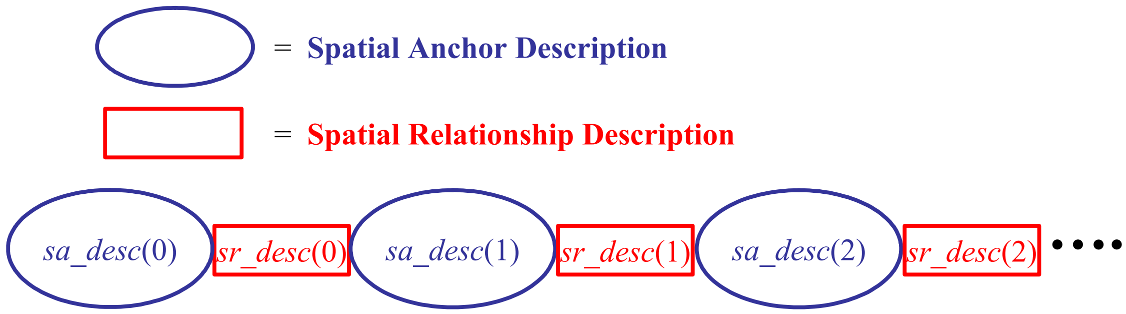


**Figure 2.11.** Image of model for natural route descriptions

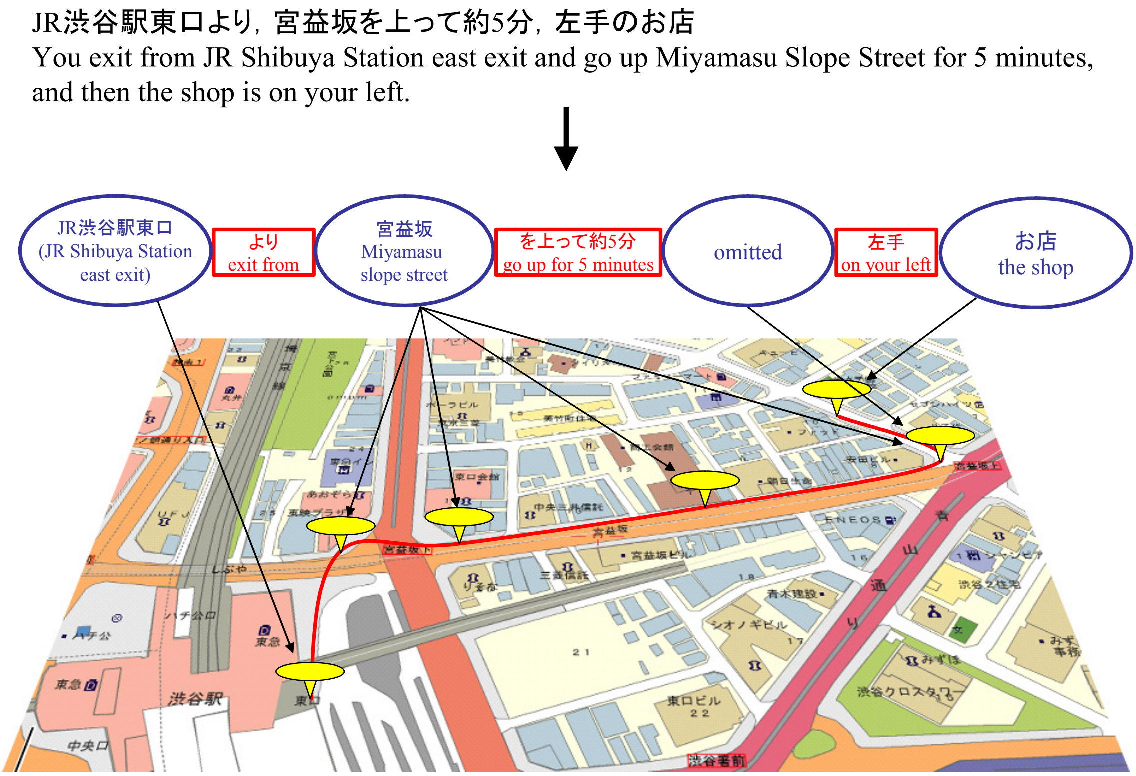


**Figure 2.12.** Image of geocoding a natural route description into spatial database through the intermediary of simple model

### 2.2.2. Grammar of Formal Route Statement

Formal statements are necessary for computers to indirectly deal with natural route descriptions. On the assumption that all of natural route descriptions can be expressed with nodes and links, we propose *Formal Route Statement* (*FRS*) to represent and process natural route descriptions. *FRS* also works as a query language for sidewalk network databases. Using *FRS*, a natural route description is represented as a sub-graph of a directed graph of sidewalk networks (Figure 2.13).

Figure 2.14 shows the grammar of *FRS*. Generalization tables are indispensable for converting various casual descriptions into regular ones, one of which is *FRS* (Table 2.3). A use case of the generalization tables is to make an instance of the spatial relationship as a value of the attribute "*link.connect*" in Figure 2.14. The attribute "*link.connect*" plays an important role to find spatial object when a name referring to the next place is omitted.

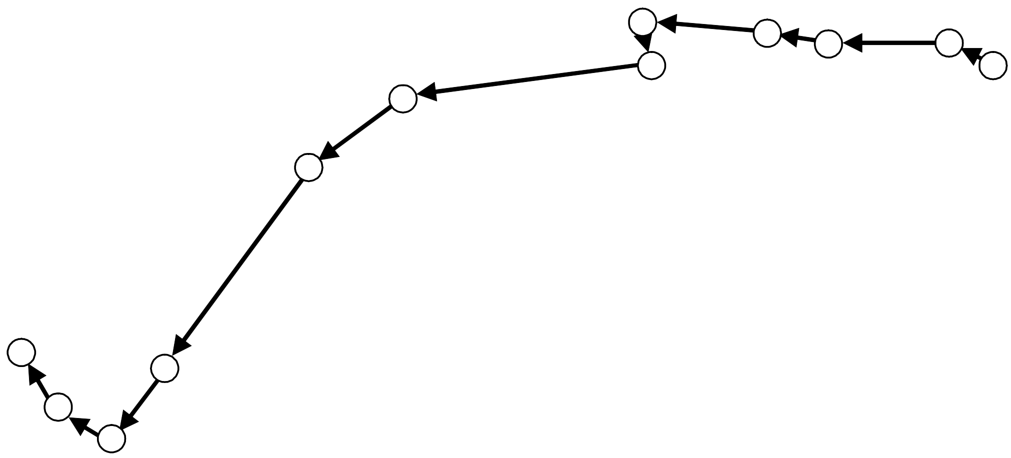

**Figure 2.13.** Sub-graph *G* which is the result of *FRS*(*route_desc*), where *route_desc* is a text string of a natural route description

| | |
|---|---|
| *FRS* ::= | *sa_desc*(0)(:*sr_desc*(*i*):*sa_desc*(*i*+1))* [*i*={0,...,*n*}]; |
| *sa_desc*(*i*) ::= | *node*(*i*).*node_attribute_list* |
| *node_attribute_list* ::= | *none* \| *node_attribute_value* (&*node_attribute_value*)* |
| *node_attibute_value* ::= | *node_attribute* = *value* |
| *node_attribute* ::= | *id* \| *name* \| *coordinate* \| *class* \| *status* |
| *value* ::= | *numerical_value* \| *stirng_value* \| *url* \| *status_values* \| *connect_values* |
| *status_values* ::= | *start* \| *end* \| *via* |
| *connect_values*::= | *straight* \| *right* \| *left* |
| *sr_desc*(*i*) ::= | *link*(*i*).*link_attribute_list* |
| *link_attribute_list* ::= | *none* \| *link_attribute_value* (&*link_attribute_value*)* |
| *link_attibute_value* ::= | *link_attribute* = *value* |
| *link_attribute* ::= | *id* \| *start_node*(*id*) \| *end_node*(*id*) \| *direction* \| *connect* \| *distance* |

**Figure 2.14.** Grammar of *Formal Route Statement*

**Table 2.3.** Example of a generalization table for descriptions of spatial relationship and values of the attribute "*link.connect*"

| Specialized descriptions for spatial relationships | Generalized descriptions for spatial relationship (values of *link.connect*) |
|---|---|
| go forward, go ahead, advance | Straight |
| turn to the right, on the right, on one's right | Right |
| turn to the left, on the left, on one's left | Left |

# *CHAPTER 3*

# *SIDEWALK NETWORK DATABASE*

# 3. SIDEWALK NETWORK DATABASE

Human fundamental activities are done in large-scale spaces. A circle of 30 centimeters in diameter is enough for standing up. A length of stride is less than 1 meter. Our physical activity scale ranges from centimeters to meters. However, there were no databases corresponding to human activity space such as walking environment (Figure 3.1) before 2003. Sidewalk network databases changed the situation.

Walking is a fundamental behavior for human being and sidewalk is a space which we walk through on a daily basis. Sidewalk network databases are a kind of large-scale databases, and are regarded as digital copies of our walking environment. We redesign the schema of sidewalk network databases in order to increase flexibility in advanced applications. In this chapter, we explain the schema of sidewalk network databases and prototype system for managing it. Section 3.1 mentions features of sidewalk network databases with introducing products and services. Section 3.2 explains the schema of sidewalk network databases to geocode and to visualize natural route descriptions by computers. We define the attributes of a node and a link. We also define rules for representing features in the real world as spatial objects in databases. Finally, Section 3.3 presents our prototype system for managing sidewalk network databases.


**Figure 3.1.** Walking environment in the city of Shibuya Tokyo

## 3.1. WHAT IS SIDEWALK NETWORK DATABASE?

*Sidewalk network databases* store underground walks, footbridges and cross walks for pedestrians. Sidewalk network databases are simply structured as *nodes* and *links*. A node has geometric coordinates. A link is defined as a vector between two nodes. Sidewalk network databases are provided as commercial products by Shobunsha Publications Inc. [14]. The commercial sidewalk network databases presently cover major cities in Japan.

Before the emergence of sidewalk network databases, there have been popular geographic network databases such as road networks for car navigations (Figure 3.2), railroads, facilities networks and so on. However, the previous geographic network databases were all designed for small scale uses, not for large scale uses such as human navigations. On the other hand, sidewalk network databases for walkers (Figure 3.3) are getting popular for human navigation systems since 2003 in Japan. Some services and products using sidewalk network database have already been on the market. "*EZnaviwalk*" provided by KDDI au is one of the most popular human navigation services using a mobile phone, GPS, and electric compass [15]. Figure 3.4 shows a graphical user interface of "*EZnaviwalk*". Using sidewalk network databases, train timetables and airline timetables, *EZnaviwalk* finds the most direct, time-saving or money-saving route. This service has begun since October 2003. At present, October 2004, there are more than 100,000 users of *EZnaviwalk*. In addition, Shobunsha Publications Inc. has researched on marketing digital barrier-free maps for all pedestrians including the elderly and the disabled since 2004 [16].

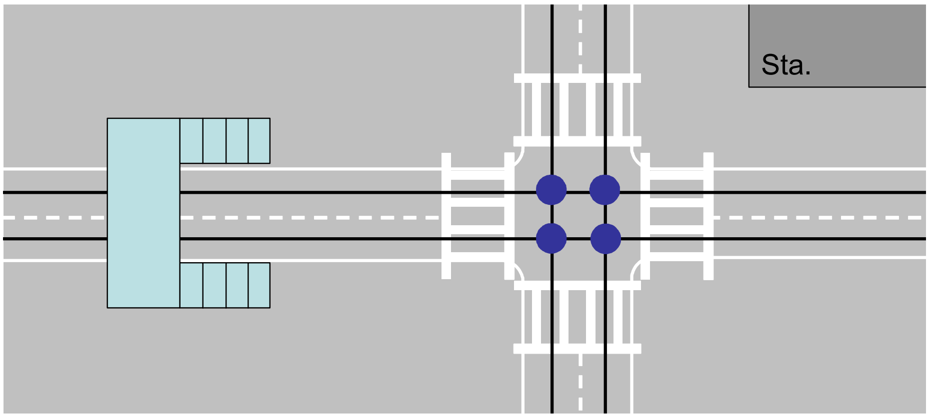


**Figure 3.2.** Schematic diagram of a road network database

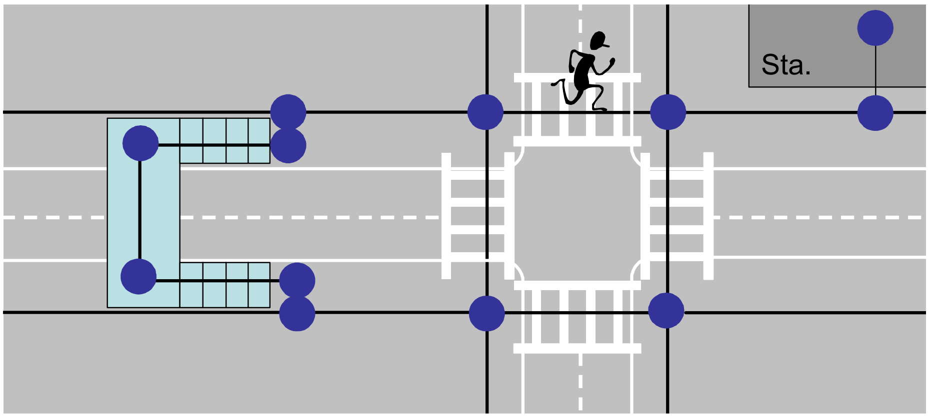


**Figure 3.3.** Schematic diagram of a sidewalk network database


**Figure 3.4.** Graphical user interface of *EZnaviwalk* which is Human Navigation Service

## 3.2. SCHEMA OF SIDEWALK NETWORK DATABASE

A sidewalk network database is a directed graph representing sidewalks in urban environment. It consists of the following two components:

1. A set $N$ of nodes
2. A set $L$ of links

   A link is a binary relation on $N$. Also, a link is a pair of two nodes. A tuple ($N$, $L$) comprises directed graphs.

We define spatial objects as data units corresponding to entities in the world (e.g., footbridges, crosswalks and intersections). An example of a sidewalk network database is shown in Figure 3.5. Each node is represented by a circle. In Figure 3.5, a set $N$ is the set of node data $n_i$.

$$N = \{n_1, n_2, n_3, n_4, n_5, n_6, \ldots\}$$

A node data $n_i$ has the following structure.

$$n_i = (id_i, name_i, class_i, coordinates_i, urli_i, in\_link_i, out\_link_i)$$

The elements of $n_i$ are the followings:

| | |
|---|---|
| $id_i$ | the identifier of the node |
| $name_i$ | a name of an instance of spatial objects |
| $class_i$ | a class of spatial objects |
| $coordinates_i = (x_i, y_i)$ | geographic coordinates |
| $urli_i$ | information for the point of interest like a picture image |
| $in\_link_i$ | the identifiers of the incoming links to $n_i$ |
| $out\_link_i$ | the identifiers of the outgoing links from $n_i$ |

A $name_i$ is a text data referring to the instance of spatial objects. Nodes composing the specific instance of spatial objects have $name_i$ value only if the place has a name. Spatial objects in the database can be classified into four main classes according to their role in the city or geographic characters (Chapter 2). Each class has its own characteristics and restrictions. Spatial objects of the same type are categorized as classes such as “exit”, “intersection”, “street” and “slope street”. For example, the node $n_2$ has “$\alpha$ Station Exit” as $name_2$ and “station exit” as $class_2$. Composing the $\beta$ Intersection on the map, the nodes $n_3$, $n_4$, $n_5$ and $n_6$ have “$\beta$ Intersection” as $name$ and “intersection” as $class$.

Next, in Figure 3.5, a set $L$ is the set of link data $l_i$.

$$L = \{l_1, l_2, l_3, \ldots\}$$

A link data $l_i$ has the following structure:

$$l_i = (start\_node_i, end\_node_i)$$

The elements of $l_i$ are the following:

$start\_node_i$ the identifier of the node which $l_i$ starts from
$end\_node_i$ the identifier of the node which $l_i$ arrives at

Each link in $L$ is represented by an arrow from $start\_node_i$ to $end\_node_i$. For example, $n_3 \rightarrow n_6$ is the link $l_7$ of Figure 3.5 and $n_6 \rightarrow n_3$ is the link $l_{110}$ of Figure 3.5. It is a notable fact that there is not the link $n_2 \rightarrow n_1$ because sidewalk network databases do not include sidewalks leading to the inside of buildings. We chart the schema of the sidewalk network database into Figure 3.6.

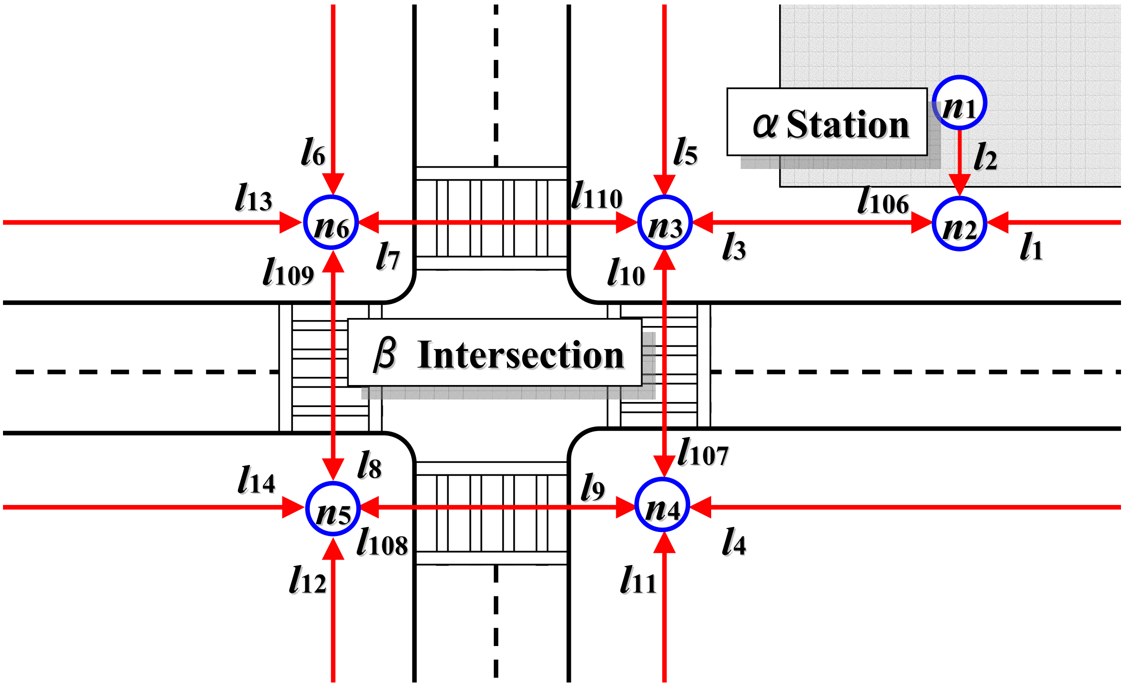


**Figure 3.5.** Example of a sidewalk network database

| | |
|---|---|
| *Sidewalk network DB* : | (*Nodes*, *Links*) |
| *Nodes* : | a set of *node* |
| *Links* : | a set of *link* |
| *node* : | (*id*, *name*, *coordinates*, *class*, *in_link*, *out_link*, *urli*) |
| *link* : | (*id*, *start_node*, *end_node*) |
| *node.id* : | *id* of the node |
| *node.name* : | *name* of an instance of spatial objects |
| *node.coordinate* : | *coordinates* (*longitude*, *latitude*) |
| *node.class* : | *class* of spatial objects |
| *node.in_link* : | *id* of the incoming link |
| *node.out_link* : | *id* of the outgoing link |
| *node.urli* : | information for the point of interest |
| *link.id* : | *id* of the link |
| *link.start_node* : | *id* of the start node |
| *link.end_node* : | *id* of the end node |

**Figure 3.6.** Schema of the sidewalk network database used in our research

***Classes of spatial objects***

Spatial objects in the sidewalk network database can be classified into four main classes. Spatial objects of same type are categorized as the four classes: (a) *exit*, (b) *intersection*, (c) *street* and (d) *slope street* as I have already stated in the preceding chapter. An attribute value of class is available as one of parameters for deducing valid spatial relationship descriptions. As simple examples, intersection class is clue to deduce “turn right at”, “turn left at” and “cross at”. Slope street class is also clue to deduce “go up” and “go down”. We explain how to represent spatial objects on a map by class as follows:

**(a)** ***Exit***

The exit class is the class of exits of buildings such as department stores, railway stations and underground railway stations. In particular, station exits are often used as a start place in a route description. Exits are the boundary which separates inside and outside of buildings. For example, we are moving from the inside to the outside of station by crossing the boundary such as an automatic ticket gate or stairway which connects the underground to the ground. In the sidewalk network database, exits are the objects having an orientation. Figure 3.7 illustrates a typical exit composed of two nodes and a link that crosses a boundary. The link is a vector from the inside node to the outside node. The outside node has attributes of a name and class. Figure 3.8 shows a stairway exit of an underground railway station.

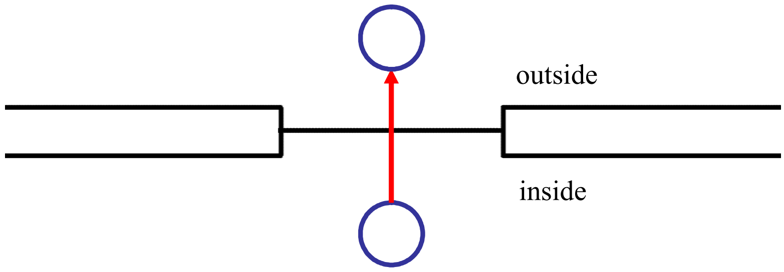


**Figure 3.7.** Example of an exit stored in sidewalk network databases

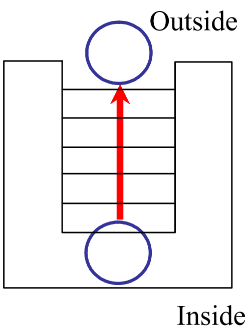


**Figure 3.8.** Example of a stairway of subway station exit stored in sidewalk network databases

**(b)** ***Intersection***

The intersection class is the class of places where roads meet or cross. Intersections are often used as a turning and passage point in route descriptions because we pass over or by an intersection. Intersections do not have an explicit boundary. In Figure 3.9, four nodes and eight links are needed to shape an intersection. Four links correspond to crosswalks. Each node has the attributes of a name and class. Intersections do not have a specific orientation.

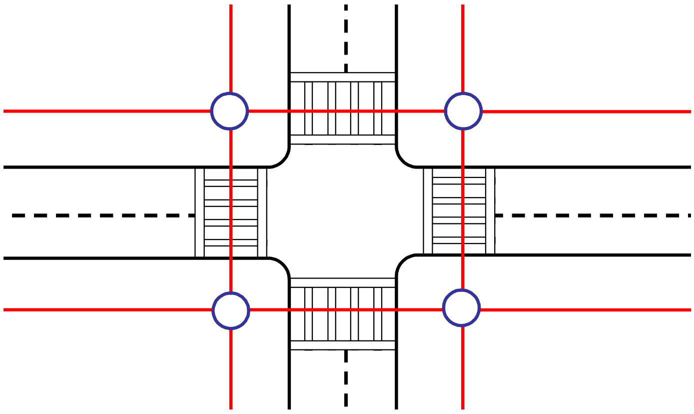

**Figure 3.9.** Example of an intersection in sidewalk network databases

**(c)** ***Street***

The street class is the class of places where pedestrians can go through and usually with shops, buildings and houses along it. Streets' names appear frequently and play a role of referring a passage area in route descriptions. Streets are also bi-directional paths for walkers. In addition, there are narrow streets where only walkers can go through and wide streets where both of cars and walkers can go through. Wide streets include a road for cars in the middle of the street and two walkways along the road. Wide streets often include some intersections. In the example of Figure 3.10, streets are shown as a data unit by nodes more than two. End nodes of the street are connected to other streets. Nodes in the street are posted at link's direction changing point. A center line of the street corresponds to each links between two nodes. Figure 3.11 shows a wide street stored in sidewalk network databases.

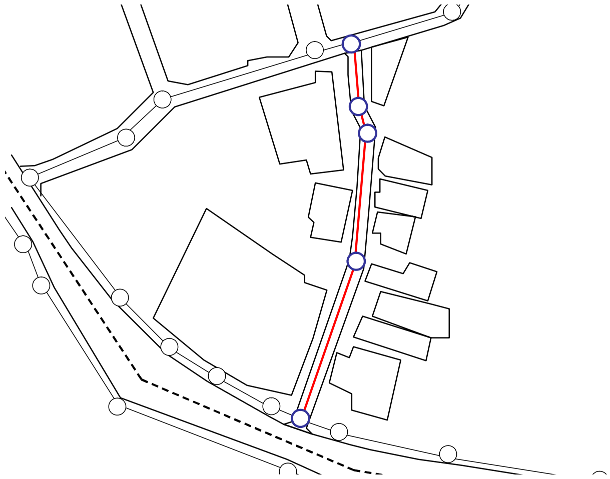

**Figure 3.10.** Example of a street stored in sidewalk network databases

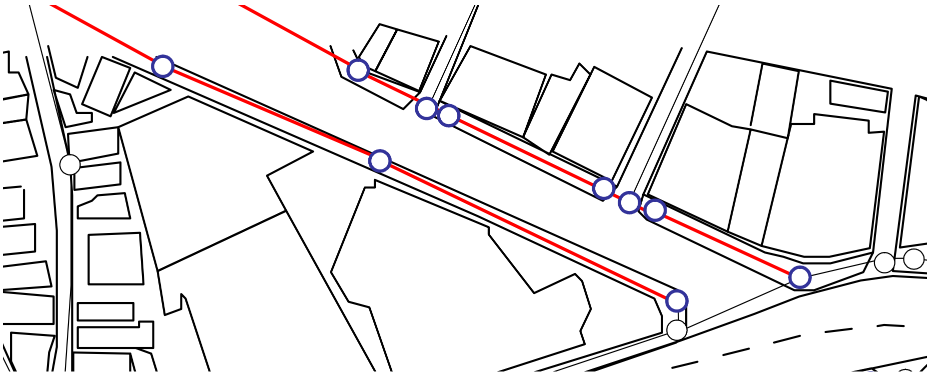

**Figure 3.11.** Example of a wide street stored in sidewalk network databases

**(d)** ***Slope Street***

The slope street class is the class of slopes. Slope streets are particular streets such as one end of a street is higher than the other. The expression "Slope Street" is Japanese-specific. Japanese distinguish streets from slope streets because there are many slope streets in Japan. Westerners do not distinguish between streets and slope streets. Slope streets are shown as well as streets in the database. Figure 3.12 shows a slope street stored in sidewalk network databases.

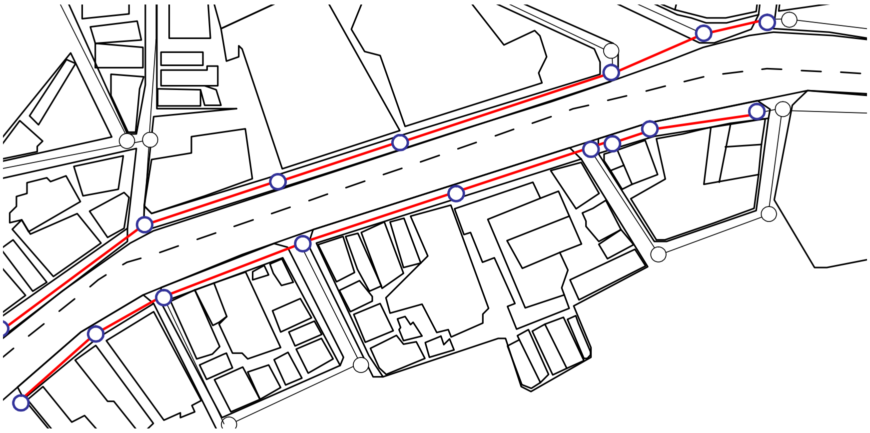

**Figure 3.12.** Example of a slope street stored in sidewalk network databases

## 3.3. PROTOTYPE OF DATABASE MANAGEMENT SYSTEM

We have developed a naive management system for sidewalk network databases. We explain each component in the user interface (Figure 3.13 and Figure 3.14) as follows. In addition to this, Figure 3.15 and Figure 3.16 show the both of Document Type Definition and an instance document of XML at the close of the chapter.

(A) Menu button

Users can change the operation mode by the menu buttons. Main functions are (1) loading and saving network data which are XML formatted and (2) adding, erasing and moving both nodes and links. Furthermore, we select functions of referring to node information (e.g., a name of a place) and filling it using the entry form.

(B) Map area

Sidewalk network databases and a map image in the selected area are overlapped and visualized. Figure 3.14 shows a dialog box for an entry form of node information, which allows users to add values in name and class for spatial objects to nodes. This window appears when users push the entry button in menu buttons and click a node on the map area.

(C) Display of node information

This area allows users to see values of attributes name, class and picture image for an instance of a spatial object in the map area.

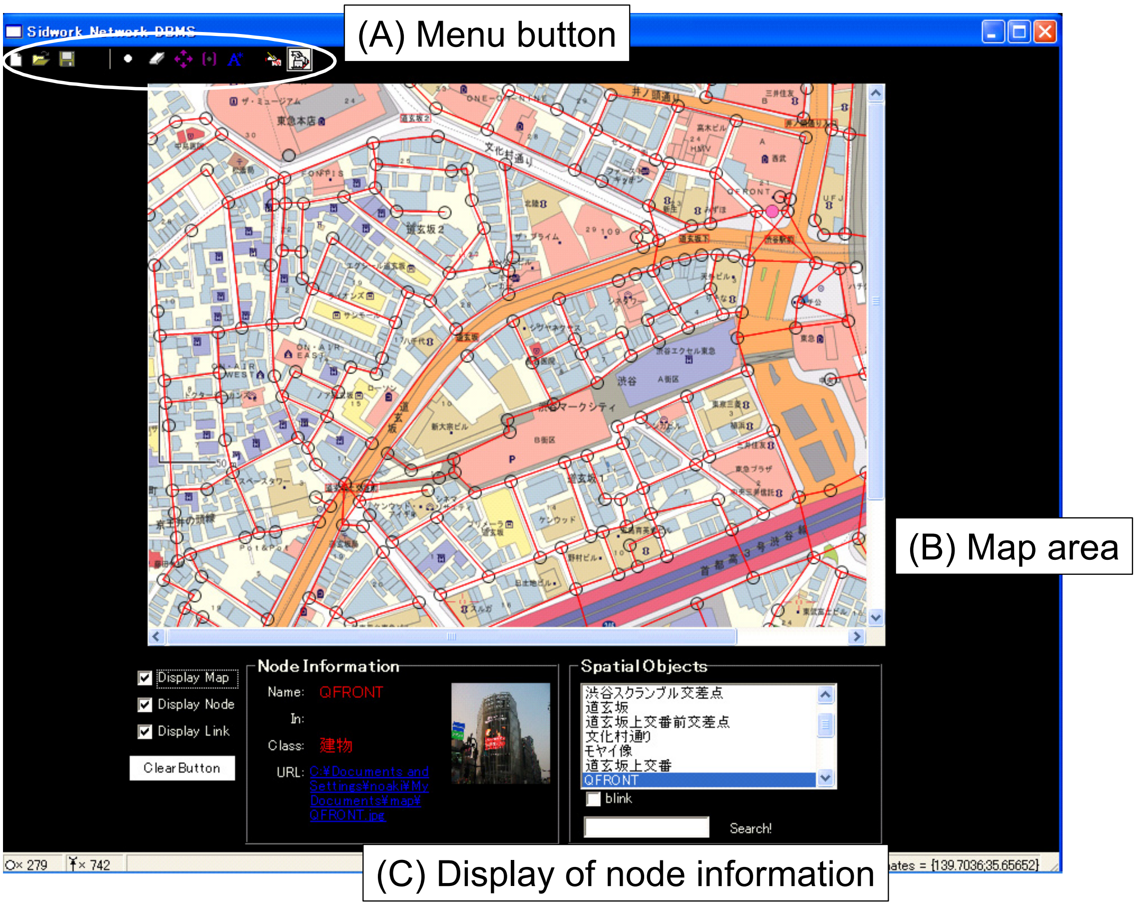


**Figure 3.13.** Graphical user interface of the prototype system for managing sidewalk network databases

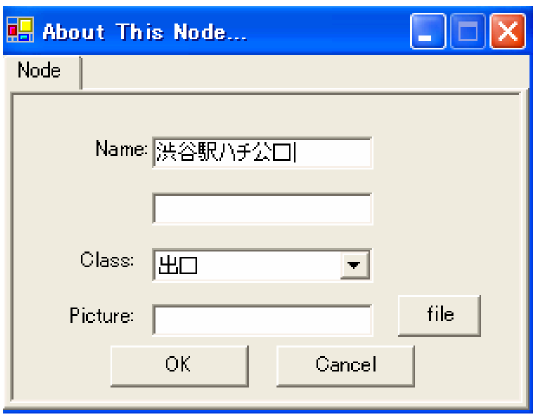


**Figure 3.14.** Dialog box of entry form for node information

```
<!--  Root  -->
<!ELEMENT sidewalk_network (nodes, links)>
<!ELEMENT nodes(node+)>
<!ELEMENT links(link*)>

<!-- node -->
<!ELEMENT node(node_id, coordinates, name, class, in_link,
out_link, urli)>
<!ELEMENT node_id(#PCDATA)>
<!ELEMENT coordinates(x, y)>
<!ELEMENT name(#PCDATA)>
<!ELEMENT
class(exit|intersection|street|slope_street|null)>
<!ELEMENT in_link(link_id)>
<!ELEMENT out_link(link_id)>
<!ELEMENT urli(#PCDATA)>

<!-- link -->
<!ELEMENT link(link_id, start_node, end_node)>
<!ELEMENT link_id(#PCDATA)>
<!ELEMENT start_node(node_id)>
<!ELEMENT end_node(node_id)>
```

**Figure 3.15.** Document Type Definition of XML for the sidewalk network database

```
<sidewalk_network>

<node>
<node_id>3</node_id>
<coordinates>139.6993, 35.6543</coordinates>
<name>β intersection </name>
<class>intersection</class>
<in_link>3,5,10,110</in_link>
<out_link>7,106,107,200</out_link>
<urli>040523.jpg</urli>
</node>
<node>
<node_id>4</node_id>
<coordinates>139.6993, 35.6540</coordinates>
<name>β intersection </name>
<class>intersection</class>
<in_link>4,9,11,107</in_link>
<out_link>10,108,205,210</out_link>
<urli>null</urli>
</node>
.......

<link>
<link_id>10</link_id>
<start_node>4</start_node>
<end_node>3</end_node>
</link>
.......

</sidewalk_network>
```

**Figure 3.16.** Example of a XML instance document for the sidewalk network database

# *CHAPTER 4*

# *GEOCODING METHOD FOR NATURAL ROUTE DESCRIPTIONS*

# 4. GEOCODING METHOD FOR NATURAL ROUTE DESCRIPTIONS

Geocoding problem is a problem in inquiring a region in the real world which is referred by the geo-referenced description. We define the geocoding problem as follows:

*Input data*: a text string $g$ of geo-referenced description
*Output data*: a region $r$ corresponding to $g$ in the real world

A geocoding process $G$ is defined as a mapping function which meets the following equation.

$$r = G(g)$$

This chapter provides a solving method of the geocoding problem using sidewalk network databases. Section 4.1 explains the outline of geocoding process for natural route descriptions. Section 4.2 and Section 4.3 go into detail about geocoding process. Section 4.4 describes the prototype system and experimental demonstration.

## 4.1. OUTLINE OF GEOCODING PROCESS

An *address description*, that is a kind of geo-referenced description, includes both some *numbers* for representing the locations of buildings, and some *names* for representing administrative areas where someone lives or works. An address description corresponds to a closed region on a large-scale map or a point on a small-scale map. On the other hand, a natural route description includes both some *nouns phrase* referring to place and *verbal phrase* for representing spatial relationships indirectly between places. A natural route description usually corresponds to a polyline on a map. The geocoding process for natural route descriptions is not only converting place names into geographic coordinates, but also verifying spatial validity between places.

The geocoding for natural route descriptions consists of the following two processes. We go into details of them in the following Sections 4.2 and 4.3.

- Converting natural route description into formal route statement (Section 4.2)
- Validating formal route statement (Section 4.3)

Formal route statement (FRS) is a geometric model for representing natural route descriptions. Computers can deal with natural route descriptions indirectly through FRS as an intermediate description.

## 4.2. Converting Natural Route Description into Formal Route Statement

The procedure to convert natural route descriptions into FRS can be classified into two main processes. In this stage, FRS need not have geographic coordinates.

(a) Separating spatial anchors and spatial relationship descriptions in a natural route description

In the case that the input text is "ハチ公口を出て道玄坂を上り交差点を右へ", the text is separated as follows:

*sa_desc*(0) = "ハチ公口" : "Hachiko Exit"
*sr_desc*(0) = "を出て" : "exit from"
*sa_desc*(1) = "道玄坂" : "Dogenzaka (slope street)"
*sr_desc*(1) = "を上り" : "go up"
*sa_desc*(2) = "交差点" : "Intersection"
*sr_desc*(2) = "を右へ" : "to right"

(b) Generalizing spatial anchors and spatial relationship descriptions

In the above example, *sa_desc*(0), *sa_desc*(2) and *sr_desc*(0) are inappropriate descriptions for matching with sidewalk network databases. They are generalized as follow:

*sa_desc*(0) = "JR 渋谷駅ハチ公口" : "JR Shibuya Station Hachiko Exit"
*sa_desc*(2) = "道玄坂上交番前交差点" : "Dogenzaka-ue Koban-mae Intersection"
*sr_desc*(2) = "を右へ曲がる" : "turn right"

For the above process of parsing natural route description in (a), there are already significant achievements in the fields of natural language processing [17]. We use

Japanese morphological analysis system *ChaSen* [18] for the process. For the process of dealing with incomplete or ambiguous information in (b), we plan to realize the functions to complement the incomplete place names and to correct inappropriate natural route descriptions using sophisticated geographic thesaurus and generalization rules for place names. Thus, the process of (b) is the future work and we do not focus on it in the current stage of our research.

## 4.3. VALIDATING FORMAL ROUTE STATEMENT

This stage verifies the spatial validity between places which are referred by a set of *sa_desc* of FRS. The procedure to validate FRS can be classified into two subprocesses for *sa_desc* and *sr_desc*.

A *sa_desc*(*k*) is needed to match with the set of valid spatial anchors. The set of valid spatial anchors is the result from the following function.

$$valid\_sa(passedlink, sr\_desc(k\text{-}1)) \qquad k=1\ldots n$$

In the function *valid_sa*, *passedlink* is $node(p-1) \rightarrow node(p)$. node(*p*) is the last node which is matched at the time. node(*p*) is derived by the following geocoding function *G*.

$$node(p) = G(sa\_desc(k))$$

For example, in Figure 4.1, the plane is divided in quarters using the angle of *passedlink*. Depending on the meaning of *sr_desc*(*k*-1), the target of matching with *sa_desc*(*k*) is changed. Figure 4.1 shows that three target areas for matching a set of nodes with *sa_desc*(*k*) as follows:

(1) within the plane of II when *sr_desc*(*k*-1) means “right”.
(2) within the plane of III when *sr_desc*(*k*-1) means “left”.
(3) within the plane of II+III when *sr_desc*(*k*-1) means “straight”.

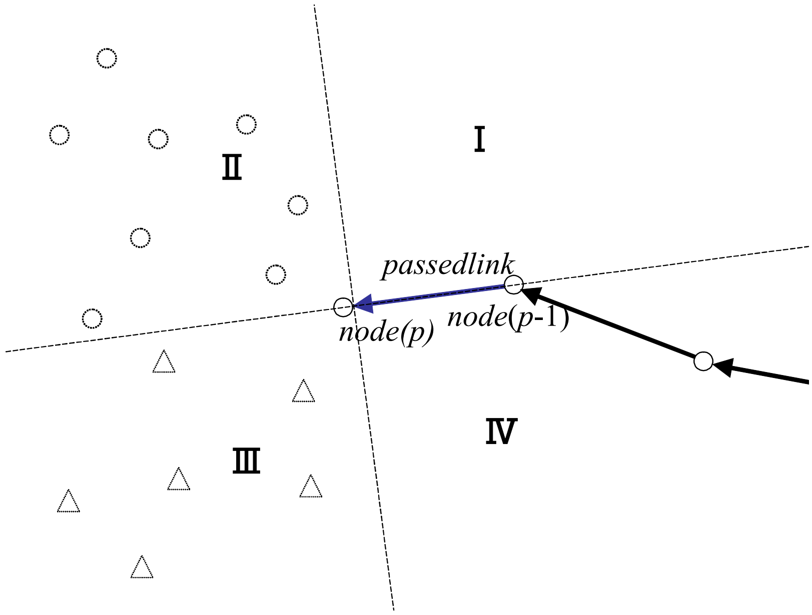


**Figure 4.1.** Quarters division of the plane for matching with valid spatial anchors

The *sa_desc*(0), that is the head in a set of *sa_desc*, is matched with the set of all spatial anchors because there is no *passedlink*.

Furthermore, there are the following two types of matchings with *sa_desc*. Both matchings are executed simultaneously.

A) **Spatial anchor point matching**: The results of the queries are a set of nodes corresponding to the spatial anchors.

B) **Path matching**: This step decides the sequence order of places in the route using the rule which minimizes each of the moving costs between neighbor places.

A *sr_desc*(*k*) is needed to match with the set of valid spatial relationship descriptions. The set of valid spatial relationship descriptions is the result from the following function *valid_sr*.

*valid_sr*(*passedlink*, *node*(*p*).*out_link*) $p=1 \ldots n$

Depending on an angle formed by *passedlink* and *node*(*p*).*out_link*, the target of matching with *link*(*p*).*connect* of *sr_desc*(*k*) is changed. Figure 4.2 shows that three target areas for matching a set of links with *sr_desc*(*k*) as follows:

- "right" is the target when one or more link data of *node*(*p*).*out_link* are within the region I.
- "straight" is the target when one or more link data of *node*(*p*).*out_link* are within the region II.
- "left" is the target when one or more link data of *node*(*p*).*out_link* are within the region III.

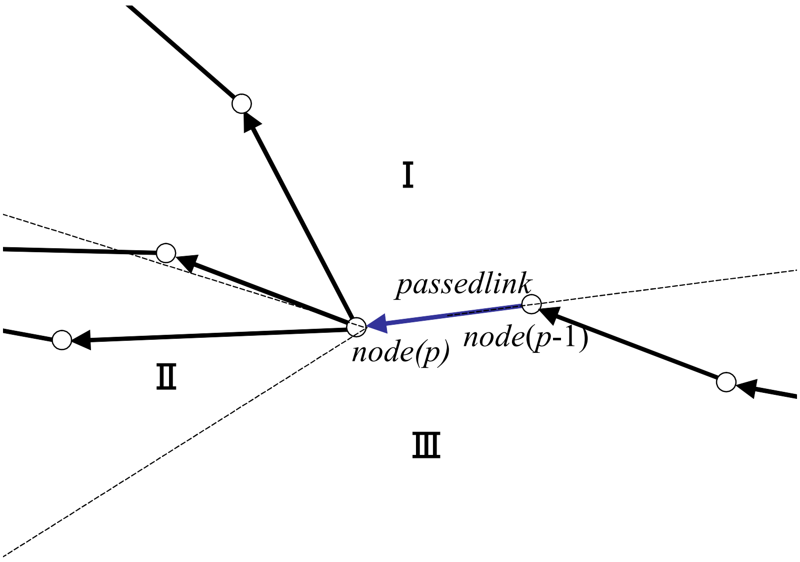


**Figure 4.2.** Division of the plane for matching with *link.connect*

## 4.4. PROTOTYPE SYSTEM

Our proposed framework has been verified through developing a prototype system. Figure 4.3 shows the user interface of the prototype system.

### 4.4.1. OVERVIEW OF PROTOTYPE SYSTEM

We have developed a prototype system which processes a natural route description in Japanese and then visualize it as a polyline on the map using sidewalk network databases. Each component in the user interface (Figure 4.3) is as follows:

(A) Input text form

Users can input a natural route description using this text form.

(B) Output text form

A result of separating input text and validating separated elements is displayed in this form.

(C) Output map area

A route is visualized on the sidewalk network database as a result of geocoding a natural route description.

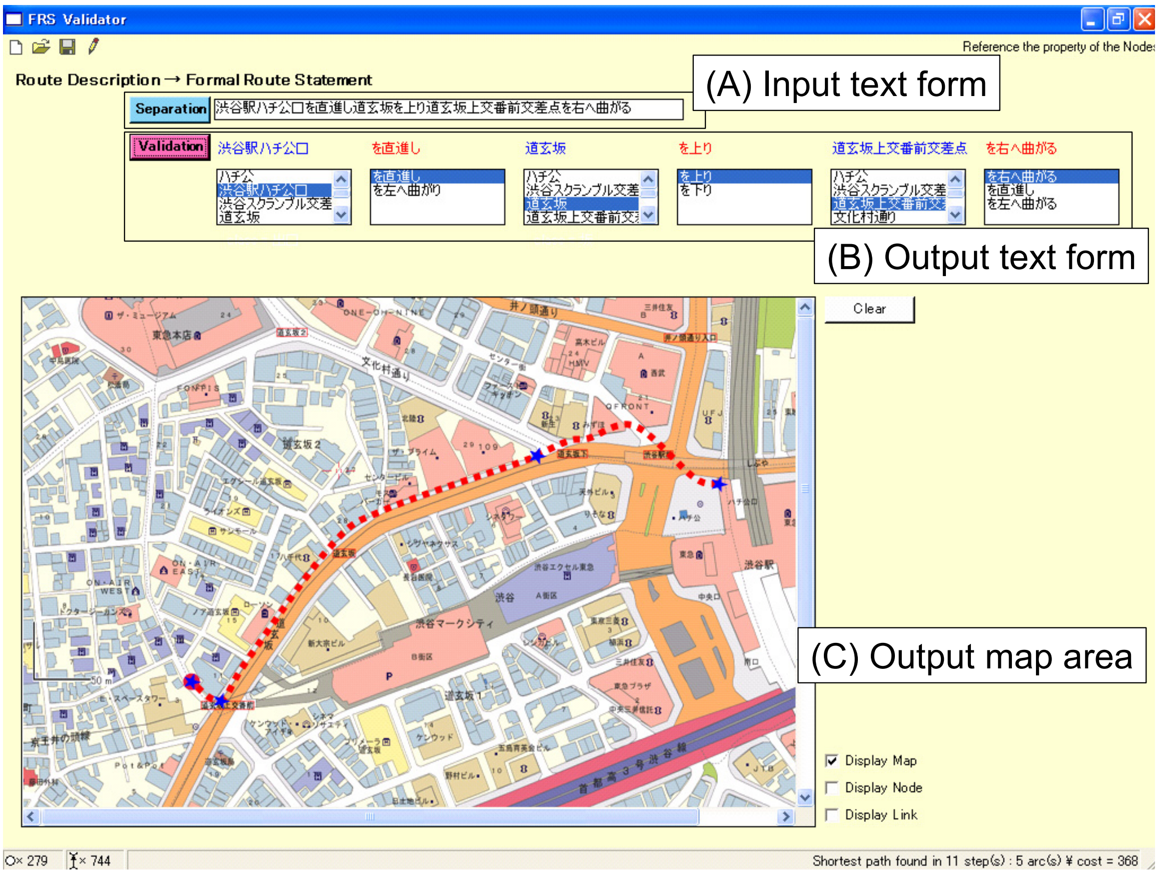


**Figure 4.3.** Graphical user interface of the prototype system

### 4.4.2. Experimental Demonstration

Using the natural route description used in Section 4.2 as an example of an input text, Figure 4.4 shows behavior of processing. The captions of the figures explain the details of the behavior.

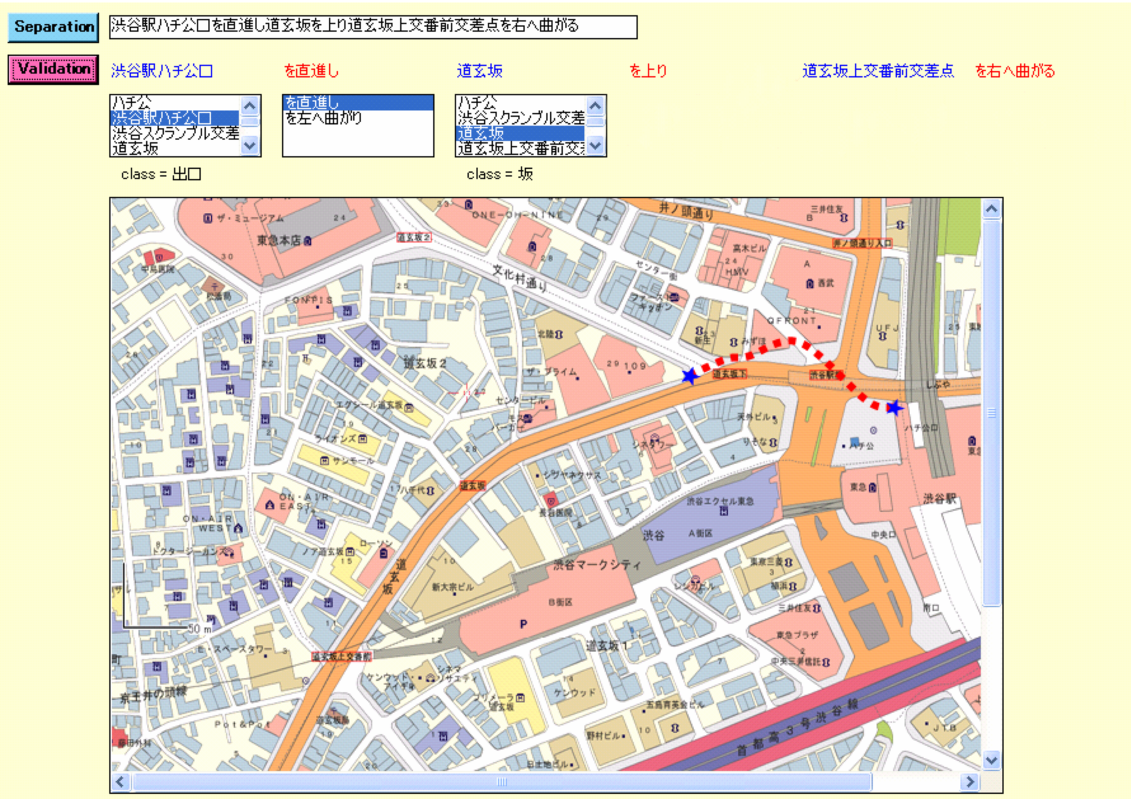


**Figure 4.4(a).** Our prototype system searches the shortest path (the dashed line) from the node matched *sa_desc*(0) to the nearest one of the nodes making up *sa_desc*(1). *sr_desc*(0) is also matched with the sidewalk network database. This figure shows the result of processing *sa_desc*(0) + *sr_desc*(0) + *sa_desc*(1).

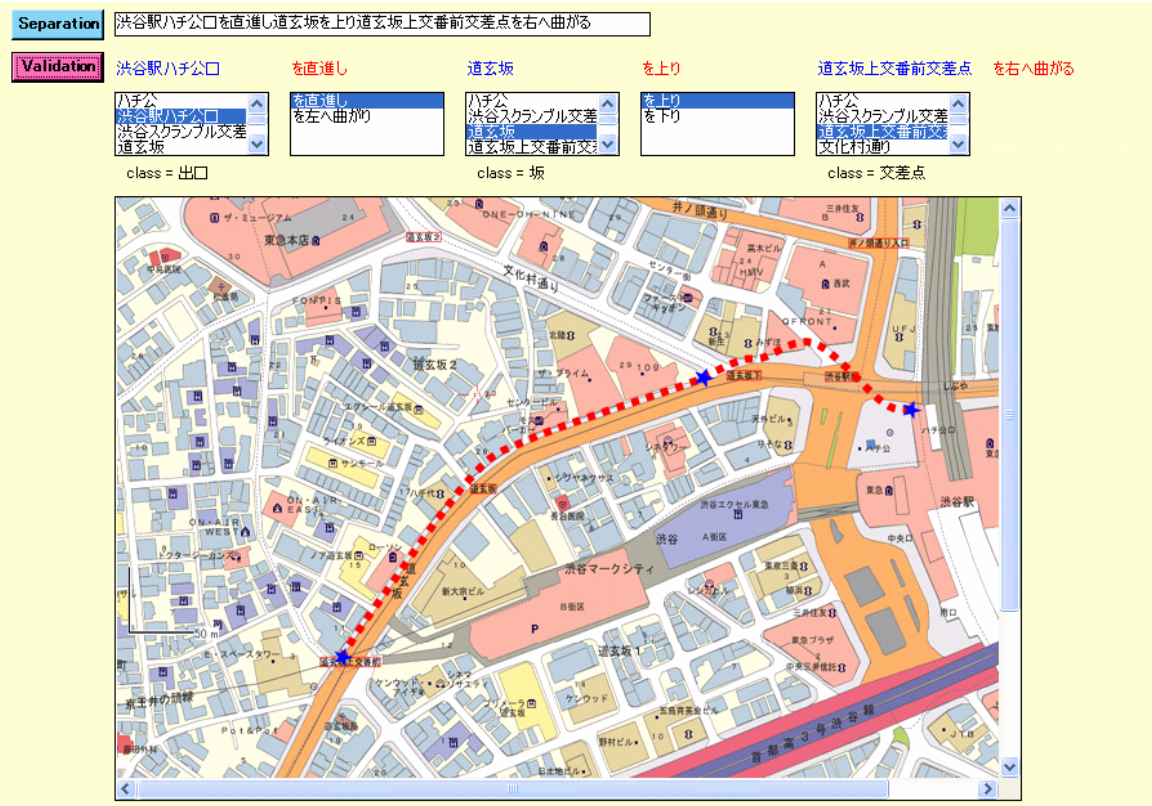


**Figure 4.4(b).** The system searches the shortest path to the nearest one of nodes matched with *sa_desc*(2). This figure shows the result of processing *sa_desc*(0) + *sr_desc*(0) + *sa_desc*(1) + *sr_desc*(1) + *sa_desc*(2).

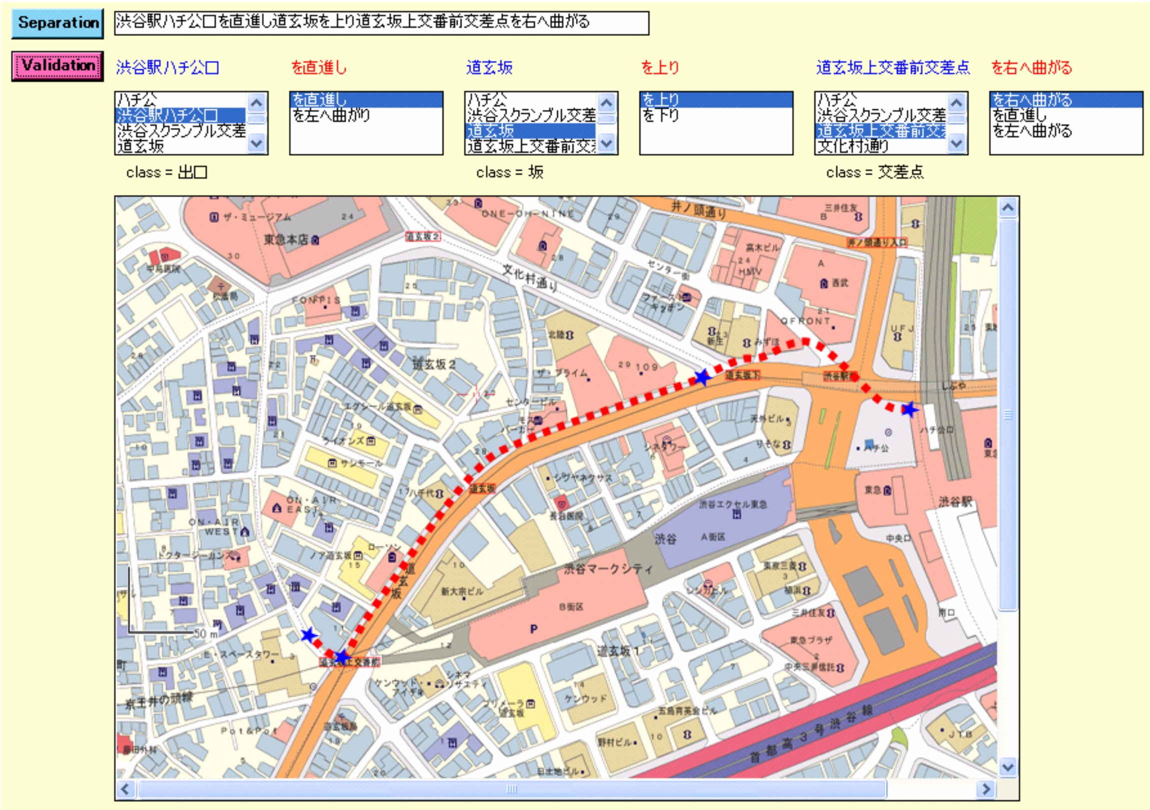


**Figure 4.4(c).** The end node is deduced from the description of *sr_desc*(2) and the direction of the last matched link. This figure shows the result of processing *sa_desc*(0)+ *sr_desc*(0) + *sa_desc*(1) + *sr_desc*(1) + *sa_desc*(2) + *sr_desc*(2).

# *CHAPTER 5*

# *CONCLUSION AND FUTURE WORK*

# 5. Conclusion and Future Work

In this research, we proposed a basic framework to geocode natural route descriptions for pedestrians walking through an urban city by means of sidewalk network databases. On the basis of the structure of natural route descriptions, we proposed three frameworks as follows:

- Formal Route Statement
- Schema of sidewalk network databases
- A method to validate Formal Route Statement

Formal route statement (FRS) is a formal statement of a natural route description in order to match with sidewalk network databases. FRS is able to represent a route for walkers as a directed graph in sidewalk network databases. Sidewalk network databases are one kind of large scale spatial databases. We redesign the schema of sidewalk network databases in order to process FRS using computers. Sidewalk network databases are indispensable for validating FRS. Validating methods for FRS verify the spatial validity between places. The prototype systems have been developed to prove the validity of our proposed framework. The primary function of the prototype systems is a naive database management system for sidewalk network databases. Also, the secondary functions include both FRS Validator and FRS Visualizer using our validating method. Our research is converting a route description in natural language into FRS which is a geometric description using sidewalk network databases. It is distinguished from the previous research of generating route descriptions using network databases in both car and human navigation services.

The system is able to process natural route descriptions composed of spatial anchors and spatial relationship descriptions which are stored in the database. In other words, the current system cannot recognize variations for representing the same place. Furthermore, the expressions of distance (e.g., “go about 100 meters”) and direction using absolute indicator (e.g. “go up north”, “go to the direction of Harajuku”) are also tasks that exceed the system’s ability.

We plan to extend the sidewalk network database and the processible expressions in the system, and implement other functions. In the sidewalk network database, the database needs to store z-coordinates. For example, spatial relationship descriptions can be anticipated by using the knowledge of not only the class of spatial objects but also geographic features stored in the sidewalk network databases. In walking starting from a lowest place, it is clear that we cannot go down there. Furthermore, with street grade, width and paving as attributes of link, the system presents the route in consideration of user's preference or physical ability. The system can present women who do not want to walk through poorly-lighted street at night and elderly people who also want to avoid hard slope and long stairway with information of the best route for them.

We aim for the realization of the robust system. For example, the system corrects route descriptions when invalid route descriptions are detected. In addition, there is a problem about ambiguity of natural language. In that case, multiple solutions, which are possible routes to a destination, should be ranked by some criteria of quality of the geocoding results.

This study proposed one of the advanced methods of geocoding geo-referenced descriptions. As a result of establishment of these methods, we will be able to get local information using the spatial representation among ever-increasing digital data.

# BIBLIOGRAPHY


[1] NUA: How Many Online? , <http://www.nua.com/surveys/how_many_online/index.html>, 2002.

[2] Kaoru Hiramatsu: "Studies for Web information retrieval using geo-reference" (in Japanese), Doctorial dissertation, 2002.

[3] Masatoshi Arikawa, Takeshi Sagara, Koji Okamura: "Spatial Media Fusion Project", Proceedings of 2000 Kyoto International Conference, on Digital Libraries: Research and Practice, pp.75-82, 2000.

[4] Dan Egnor, <http://dan.egnor.name/google.html>.

[5] Google Programming Contest 2002, <http://www.google.com/programming-contest/winner.html>.

[6] Google Local, <http://local.google.com/>.

[7] Yahoo Local, <http://local.yahoo.com/>.

[8] Takeshi Sagara: "Studies for advanced practical use of non-structured and semi-structured data" (in Japanese), Doctorial dissertation, 2003.

[9] CSV Geocoding Service, <http://spat.csis.u-tokyo.ac.jp/cgi-bin/geocode.cgi>.

[10] Search Restaurants in Tokyo, <http://157.82.157.42:8080/%7Esagara/cgi-bin/search/restaurant8.cgi>.

[11] Ekitan-Odekake-Map, <http://www8.ekitan.com/rmap/Find.jsp?ar=4>.

[12] Annette Herskovits: Language and Spatial Cognition, Cambridge University Press, Melbourne, 1986.

[13] Atsushi Yamada, Katsutoshi Amitani, Taiichi Hoshino, Toyoaki Nishida, Shuji Doshita: "The Analysis of the Spatial Descriptions in Natural Language and the Reconstruction of the Scene", IPSJ Magazine [Joho Shori] Vol.31 No.5, 660-672, 1990.

[14] Shobunsha Publications Inc., <http://www.mapple.co.jp/>.

[15] *EZnaviwalk*, KDDI au, <http://www.au.kddi.com/>.

[16] Ikuko Eguchi Yairi, Kazuhiko Nagao, Niima Iiduka, Seiji Igi: "Plan for Practical Use and Standardization of Mobility Support Geographic Information System for All Pedestrians Including the Elderly and the Disabled", The 18th Annual Conference of the Japanese Society for Artificial Intelligence, 2004.

[17] Makoto Nagao, Satoshi Sato, Sadao Kurahashi, Tatsuhiko Tsunoda: "Natural Language Processing" (in Japanese), Makoto Nagao (edit), Iwanami Shoten, Tokyo, 1996.

[18] Japanese Morphological Analysis System *ChaSen*, <http://chasen.aist-nara.ac.jp/hiki/ChaSen/>.

# RESEARCH ACHIEVEMENT

**Papers:**

Kouzou Noaki, Masatoshi Arikawa: "Geocoding Natural Route Descriptions using Sidewalk Network Databases", International Workshop on Challenges in Web Information Retrieval and Integration (WIRI), IEEE, Tokyo, Japan, April 8-9, 2005 (To appear).

Kouzou Noaki, Masatoshi Arikawa: "A Geocoding Method for Natural Route Descriptions using Sidewalk Network Databases", The 4th International Workshop on Web & Wireless Geographic Information (W2GIS 2004), Lecture Note in Computer Science, Springer-Verlag, Seoul, Korea, November 25-27, 2004 (To appear).

Kouzou Noaki, Masatoshi Arikawa: "A geocoding method for route descriptions using sidewalk network databases"
the Geographic Information Systems Association vol.13/2004, Kogakuin University, October 5-7, 2004.

Kouzou Noaki, Takeshi Sagara, Masatoshi Arikawa: "Geocoding method for daily local expressions using sidewalk databases and geographic name dictionaries"
Data Engineering Workshop (DEWS2004), The Institute of Electronics, Information and Communication Engineering, Iseshima, March 4-6, 2004.

Kouzou Noaki, Takeshi Sagara, Masatoshi Arikawa: "Workshop for Evaluation Methods of Geographic Information Retrieval Systems for WEB Documents"
the Geographic Information Systems Association vol.12/2003, Kogakuin University, October, 2003.

**Verbal Presentation:**

Kouzou Noaki, Masatoshi Arikawa: "A Natural Route Description Geocoder using Sidewalk Network Databases"
the 11th World Congress on ITS, Nagoya, Japan, October 18-24, 2004.

Kouzou Noaki, Masatoshi Arikawa: "A Geocoding Method for Walking Directions"
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