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Enrichment of Routing Map and Its Visualization for Multimodal Navigation

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Abstract

A personalized routing map is a preferred choice by many travelers. Its design challenges cartographers involved in the development of real-time routing systems because not only the turn-by-turn instructions should be provided, but also the efficiency and robustness of the usage in the volatile mobile environment should be ensured. Based on the existing route planning algorithms, this thesis presents a novel approach for the design of customized routing maps which demonstrate the route along with the fast rendering of a right amount of routing-relevant background information that matches the cognitive capacity of the user on route.

Traveling through an unfamiliar environment needs certain cognitive elements to increase the certainty of approaching the destination. Landmarks are among the most relevant cognitive elements due to their high salience in the environment. They can be derived from geographic objects in the spatial database and symbolized as map features. Two types of salience the landmarks bear to support the navigation tasks are addressed: active salience and passive salience. The active salience is task-oriented and depends on variables such as travel modality and the characteristics of the traveler. It is usually ignored in existing routing systems. The passive salience represents the outstanding nature of the objects in the surrounding environment of a predefined route. Both types are combined and calculated for the individual mapping objects in the proposed approach with the aim to provide the user a better guide and a salience hierarchy necessary for the real-time visualization at multiple scales. The relative weights of various variables for the computation of salience are empirically determined in the experiments.

Among the variables that influence the active salience, the traveling modality is comprehensively discussed with the emphasis on two related issues - the perceptual capacity of the traveler constrained by his modality, and an evaluation metric of the landmarks. More specifically, the author attempts to extract the information that is perceptually essential for the traveler and his on-going routing task. The salience of geospatial objects for two traveling modalities - driving and walking - is simulated by using the valid perceptual range for each modality. Three characteristics of an individual object - the intrinsic property, the property dependent on its spatial context and the route-dependent property are considered in the estimation of passive salience. Taking into account cartographer’s conceptual space for the map design, we applied the outlier detection approach to compute the passive salience from the features. The active and passive salience of the objects for the given routing task and traveling modality is united into one single quantitative indicator.

In order to help users focus on the important map features, the author has developed an appropriate method of cartographical symbolization with the dynamic label placement and on-the-fly visualization. Two constraints are considered in the labeling algorithm: 1) visualizing as many objects as possible for different display formats; 2) minimizing the workload of the user's decision-making with the right amount of salient information.

The customized routing map is realized as a web-based service, demonstrating the overall performance of the proposed approach that ranges from salience computation for driving and walking, fast rendering of salient landmarks as well as conflict-free label placement. The experiments with selected test datasets from navigation databases representing three different cities - Munich in Germany, Nanjing in China and Auckland in New Zealand are prototypically conducted with a limited number of variables. The platform can be further elaborated and extended to cope with more complex cases. The results have proved that the automatically extracted salient information is reasonable and the automatic enrichment of route with routing-relevant information is feasible. The currently available route planning system can benefit from the proposed approach and be extended to embrace the personalized routing map for the real-time routing applications.

Zusammenfassung

Die erste Wahl vieler Reisender sind personalisierte Streckenkarten. Die Herausforderungen solcher Karten sind in ihrem Design zu suchen und durch die Echtzeit Darstellung von Informationen bedingt, in deren Entwicklung Kartographen eingebunden werden. In personalisierten Karten sollten nicht nur Abbiegeinformationen bereitgestellt werden sondern auch die effiziente Benutzung in einer mobilen Umgebung muss sichergestellt werden. Basierend auf bekannten Navigationsalgorithmen zeigt diese Arbeit einen neuartigen Ansatz für das Design angepasster Navigationskarten, in denen die Route schnell gerendert und mit einem am Nutzer orientierten Maß an Hintergrundinformationen dargestellt werden soll.

Wenn man sich in unbekannten Gegenden befindet braucht es verschiedene kognitiv relevante Hinweise, die die Sicherheit, an das richtige Ziel zu gelangen, erhöhen. Landmarken gehören aufgrund ihrer hohen Salienz (Auffälligkeit) innerhalb ihres Umfeldes zu den wichtigen kognitiv relevanten Hinweisen. Landmarken werden in der Regel aus geographischen Datenbanken extrahiert und als Kartenelemente dargestellt. Zwei verschiedene Arten der Salienz zur Unterstützung einer Navigationsaufgabe lassen sich mit Landmarken in Verbindung bringen: aktive und passive Salienz. Die aktive Salienz ist anwendungsorientiert und basiert auf Variablen wie der Fortbewegungsart und den Charakteristika des Reisenden. Diese wird im Allgemeinen von Navigationssystemen nicht berücksichtigt. Die passive Salienz repräsentiert die besondere Beschaffenheit von Objekten in der Umgebung einer vorgegebenen Route. Beide Arten der Salienz werden in dem vorgeschlagenen Ansatz kombiniert und für jedes einzelne Kartenobjekt berechnet, mit dem Ziel den Nutzer besser zu leiten und eine Salienz Hierarchie zu erzeugen, die notwendig für die Echtzeitdarstellung in verschiedenen Maßstäben ist. Die relative Gewichtung der verschiedenen Variablen für die Berechnung der Salienz wird empirisch durch mehrere Experimente belegt.

Unter den Variablen, die die aktive Salienz beeinflussen, sind zwei sich gegenseitig beeinflussende Aspekte der Fortbewegungsart ausführlich diskutiert worden – die Wahrnehmungskapazitäten des Reisenden, eingeschränkt durch das Fortbewegungsmittel und eine Beurteilungsmetrik für Landmarken. Die Autorin versucht hierbei die Informationen zu erfassen, die für den Reisenden essentiell sind. Die Salienz georäumlicher Objekte für zwei Fortbewegungsarten – fahren und gehen – wird simuliert, in dem die Wahrnehmungshinweise für jede der beiden Fortbewegungsarten verwendet werden. Drei Charakteristika eines individuellen Objektes – die dem Objekt innewohnenden Eigenschaften, die Eigenschaften, die auf dem räumlichen Zusammenhang basieren und die von der Route abhängigen Eigenschaften – werden in der Berechnung der passiven Salienz berücksichtigt. Unter Berücksichtigung des kartographischen Theoriegebäudes, wurde der Ausreißer Detektions-Ansatz angewendet um die passive Salienz der Objekte zu berechnen. Die aktive und passive Salienz der zu visualisierenden Objekte, für eine gegebene Navigationsaufgabe und Fortbewegungsart, werden in einem einzigen quantitativen Indikator vereint.

Um den Nutzer bei der Fokussierung auf die wichtigen Kartenelemente zu unterstützen hat die Autorin eine Methode zur kartographischen Symbolisierung mit dynamischer Beschriftung und einer „on-the-fly“ Visualisierung entwickelt. Zwei Randbedingungen sind bei der Beschriftung berücksichtigt: 1) die Visualisierung von möglichst vielen Objekten für unterschiedliche Displaygrößen; 2) die Minimierung der kognitiven Belastung des Nutzers in der Entscheidungsfindung durch ein optimales Maß an salienter Information.

Die personalisierte Navigationskarte ist als Web-Service realisiert, um die Performanz des vorgestellten Algorithmus aufzuzeigen, die von der Berechnung der Salienzinformationen für Auto- und Fußgängernavigation über ein schnelles Rendering bis hin zu konfliktfreien Platzierung der Beschriftung reicht. Die Experimente sind prototypisch mit einer begrenzten Anzahl an Variablen durchgeführt worden. Der Web-Service ist so angelegt, das er zukünftig auch mit komplexeren Testfällen erprobt werden kann. Die Ergebnisse zeigen, dass die automatische Extraktion salienter Informationen sinnvoll und die Anreicherung von Navigationsinformationen brauchbar ist. Die derzeitigen Systeme zur Routen Visualisierung können von dem vorgestellten Ansatz profitieren und erweitert werden, um personalisierte Navigationskarten in Echtzeit Routing Anwendungen zu implementieren.

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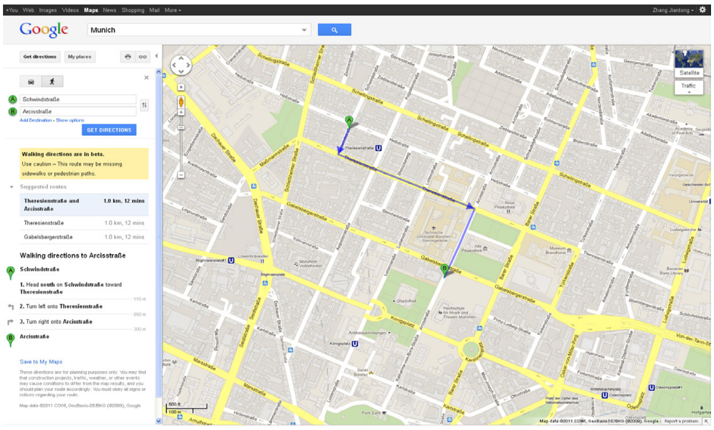
Chapter 1

Introduction

1.1 Motivation

Travelling in a novel environment is always a great challenge of human being, and the uncertainty from the origin to destination is the most important factor which influences the travelers. It restricts the scope of human activities and hinders the development of the civilization. The routing maps emerged particularly for the long-distance traveling. As the communication media between the traveler and the novel environment they have led to a dramatic increase of the degree of freedom for travelling. Today, progresses of navigation technologies allow a very accurate routing plan along with a voice guidance, which can reduce the uncertainty and make the travel an easy endeavor. Moreover, we can plan a new travel via the Internet, e.g. a long journey across several cities or a short trip for shopping in the same city. Since this kind of Internet service is free of charge, the route planning has become an everyday exercise.

At present, the online web map services such as Google map, Bing map, Mapquest and Nokia (Map 24) are prevailing in the GIS (Geographic Information System) community, and it is possible to design web routing maps without the previous limitations such as the display size of mobile maps. The existing services usually provide two kinds of information: 1) the complete routing plan; 2) the text information related with the route. The routing plan entails the geometric and topologic information about the route along with the direction, whereas the text information contains both derived attributes and semantic information such as the length and the road name. The route-related spatial information, e.g. the POIs (Points of Interest) or other salient buildings, is usually neglected, although some systems allow the user to choose one or more layers as the background information for the route. A typical example is shown in Figure 1.1.



Munich

Ⓐ Schwindstraße
Ⓑ Arcisstraße

Walking directions are in beta.
Use caution – This route may be missing sidewalks or pedestrian paths.

Suggested routes

Theresienstraße and Arcisstraße	1.0 km, 12 mins
Theresienstraße	1.0 km, 12 mins
Gabelsbergerstraße	1.0 km, 12 mins

Walking directions to Arcisstraße

Ⓐ Schwindstraße

1. Head south on Schwindstraße toward Theresienstraße
110 m
2. Turn left onto Theresienstraße
550 m
3. Turn right onto Arcisstraße
300 m

Ⓑ Arcisstraße

These directions are for planning purposes only. You may find that construction projects, traffic, weather, or other events may cause conditions to differ from the map results, and you should plan your route accordingly. You must obey all signs or notices regarding your route.

Map data ©2011 COWI, GeoBasis-DE/BKG (©2009), Google

Figure 1.1 An example of a routing plan with a background layer in Google map

The ignorance of the route-related information does increase the efficiency of the route planning system, but it leads to new uncertainty for the traveler. Assume that you are travelling along a very long street, it is normal for you to check some salient buildings to make sure you are in the right way. Moreover, current route planning and navigation systems usually disregard any feedback from the traveler who may be the protagonist in the trip and can capture the updated information that is still missing in the routing plan. One obvious reason is the large amount of the route-related spatial data, and it is time consuming to identify the salient landmarks for a specific route. Lynch (1960) defined the landmark as any element that can "potentially serve as a point-of-reference". In the context of database construction, we may make a distinction between a landmark and a POI. The POI is one or more feature layers in a navigation database, whereas landmarks refer to salient features which could be a subset of POIs or from other data layers such as building objects. Due to its various outstanding characteristics, the landmark can help the travelers to easily locate themselves. There are global landmarks valid for a whole city or a whole country, and the local landmarks which are salient only for specific routing applications within a certain extent.

Introducing the landmark to a routing task may allow the combination of the travelers' subjective consciousness with the route, thus the creation of a routing map. Unlike a routing plan, the routing map considers more the cognitive elements that can guide the travelling task in a more intuitive way. The landmark detection has become more and more significant with the increasing requirements of the travelers who conduct multimodal trips. Particularly, a pedestrian may need more interactive searching than a car driver when he or she approaches the destination.

The landmark-based navigation is not a new concept and the landmark is always the most important navigational support on a routing map. On a strip map (a continuum of map forms that exhibit increasing degrees of abstraction in relation to a central element) for long distance travel (Schwartz and Ehrenberg, 1980), the landmarks e.g. bridges, viaducts, railroad crossings, the locations of service centers serve as important orientation for the travelers. However, these landmarks are largely ignored in web-based orientation services. The currently available electronic systems for routing or navigation purposes usually contain some global landmarks, but local landmarks for the turn-by-turn way finding are missing.

In spite of the difficulties of the landmark detection from large spatial datasets, some research works have been reported in recent years. They can be roughly grouped into two different types: the conceptual model and the computational model.

The conceptual model emphasizes the formation and the usability of the landmark. Warren (1999), for instance, discussed the perceptual space for the landmark, while the advantages of using landmark were verified by several previous works (Allen 1997; Werner et al. 1997; Fontaine and Denis 1999; Lovelace et al. 1999; Lee et al. 2002; Steck et al. 2003). It has been proved that the landmarks bear the most fundamental characters of the environment. They can be estimated both visually and semantically and they help the travelers to easily approach the destination, especially when they move around in an unfamiliar environment.

In the computational model, semi-automatic and automatic landmark generation approaches have been proposed to guide travelers through the environments (Hampe and Elias 2004; Lee et al., 2002). These approaches typically combine the extraction of spatially prominent features by utilizing traveler's psychological skills such as perceptual, cognitive, and intuitive behavior.

The new approach in this thesis is inspired by a computational model. It addresses two issues in the context of multimodal routing: the detection of the landmarks and their visualization with respect to specific routes. This new model incorporates many cognitive elements into the landmark detection algorithm. To be more specific, the passive and active salience of the landmarks is calculated for the given spatial dataset and the traveler respectively. The passive salience is related to the cognitive model of the map designer and derived from the given spatial dataset as well as the route itself, depending on the distributional nature of the spatial environment; whereas the active salience is deduced from the simulation of the travelers' cognitive behavior. Such a dichotomy is based on the two keys of human perception - the integrity and selectivity. The integrity of human perception tends to organize an overall sense-making image without considering the fine details. It requires that the routing map reflect the large and major spatial information. The selectivity of human perception makes sense from the individual objects that appear to be meaningful to the underlying task. It is a concentrated reflection and related to parameters such as profile, motion, situation and etc. It requires that the map display the easily recognizable or task-related, novel or outlier information, thus complement a map with the major information. Instead of considering the perception parameters for general purposes, the thesis is devoted to landmark detection and visualization for the traveling modalities of driving and walking. It contains both the landmark extraction algorithm and the landmark rendering algorithm with the aim to create high quality routing map which is in essence a compromise between the fidelity and usability.

To provide the traveler with the accurate information is a fundamental objective of this work since the fidelity is the basic user requirement of all navigation systems. In addition, we combine multiple factors to assess salience of landmarks from large spatial datasets. The salience resulted from the detection algorithm is then used as a parameter to control the visual look of the landmark. The proposed model is implemented as a web-based map service which answers the following research questions:

1) What kinds of spatial features can be regarded as landmarks?
2) How can a salient landmark be determined with respect to a specific route?
3) How can the multiple travel modalities be modeled in order to access the landmark?
4) How can the cognitive elements be integrated in an algorithm of landmark detection?
5) How can the salient landmarks be visualized in a routing map with a balance between fidelity and usability?

1.2 Thesis structure

Following the introductory chapter, the methodological fundamentals of the routing map are reviewed in Chapter 2. By analyzing the differences between a routing plan and a routing map, we emphasize the cognitive elements embedded in a routing map. The state of the art for the landmark detection and its design are discussed and summarized respectively.

Chapter 3 is dedicated to a cognition-based model of a routing map. In the model, we focus on users' perception of landmarks from both the allocentric and the egocentric perspective, and formalize the dynamic perceptual space for the access of the salient landmarks by means of an additional metric. The modality constraints have been comprehensively discussed, and they are integrated into the model as visual factors. Based on the different perspective, we summarized the attributes into four categories: intrinsic attributes, context-dependent attributes, route-dependent attributes, situation-dependent attributes.

The computation procedure of the salience is implemented in Chapter 4. The passive and active salience is separately computed by exploring their individual characters. The Inherent Spatial Salience (ISS), Semantic-Dependent Salience (SDS), and Route-Dependent Salience (RDS) are fall into the passive salience. The Perception Dependent Salience (PDS) is taken as the active salience. We combine these salience factors into a unique model by simply assigning different weights for different factors. The relative weights are the empirical values determined by the experiments.

The number of route-specific landmarks may be too large to visualize. In order to visualize as many salient objects as possible and minimize the workload of the user’s decoding the right amount of supporting information, we propose a dynamic labeling algorithm in Chapter 5, which defines the upper limit of the landmark information to be visualized with the consideration of legibility. The relationship between the optimal label size and the number of the labels is discussed in detail on given specific display screen.

We build up a prototype system to verity the approach of cognition-based routing map and the dynamic visualization algorithm for a given large spatial dataset in Chapter 6. With experiments on selected test datasets from navigation databases representing three different cities, Munich in Germany, Nanjing in China and Auckland in New Zealand, we want to prove: 1) the salience estimation model; and 2) the selective rendering of landmarks on routing maps. In the first part of this chapter, a web-based prototype system with cartographic web map services is described. The emphasis is laid on pre-computation of the passive salience. As a result of the passive salience computation, web map services are enriched with POIs and tested with data from the urban area of Munich. In the second part of this chapter, we address the active salience computation, landmark extraction and visualization. A series of landmarks for different travel modalities and different study areas are extracted and evaluated.

As the final part of the dissertation, Chapter 7 summarizes the main achievements from this work and presents a brief outlook for the crucial issues in future works.

Chapter 2

Routing map and related works for its design

2.1 Routing map

2.1.1 Routing plan vs. routing map

As discussed in the introduction, *routing* is the movement process of people from one location to another. Two important types of guiding information are involved: the routing plan and the routing map. A routing plan aims to provide the best-route services according to user's preferences in terms of traveling time, distance etc., whereas a routing map helps users conduct traveling through a special environment. It provides routing-relevant information which usually consists of detailed turn-by-turn route descriptions in addition to a graphical representation of the route. To be more exact, a routing plan enables the routing process by providing the route as the most essential information, whereas the routing map makes the navigation more comfortable with additional information. Routing plans have been intensively studied with frequently updated algorithms and application scenarios for mono- and multimodal routing. However, a routing map is traditionally regarded as an accessory of a routing plan and its design constraints are less studied or largely ignored so far. In recent years, the situation is changing with the increasing demand on individualized navigation services and therefore, the research community is paying more attention to design issues of routing maps.

Suppose that the individual locations in the set $P \in \{p_1, p_2, ..., p_m\}$ in a road network are reachable, routing for the simple case from p_i to p_j, where *i, j = 1, 2 …m,* is to find one or many paths bearing the ground-true information of geographic space by employing a relation-preserving projection from the geographic sphere to a two-dimensional and bounded display surface. The routes are usually depicted with directions in a 2D sketch and / or a 3D perspective presentation. This kind of graphic structure is widely used for navigational purposes and often referred to as a routing plan.

Since the old times, navigating in the open world has been a dream for an individual who should afford expensive outdoor travels. With the development of easily available navigation services embedded in maps, the Internet or the mobile phones with GPRS connection, this dream has become a daily exercise for everybody. Today, online map providers, such as *Google map services*, *Bing map, Map Quest* and *NAVTEQ (MAP24)* all include numerous routing services, which have further stimulated the desire for navigation.

Routing information with directions is required for many favored traveling modalities such as car driving, biking, walking or their combinations. Users generally regard routing direction as assisting information for navigation, but ideally they would expect from a routing map more routing-related information that can provide them with a reasonable overview and some details of the surrounding.

Before we discuss what attributes or what information is useful for the mono- or multimodal routing, several terms should be clarified. The first term is navigation which implies that a route is predetermined and deliberately calculated (e.g., humans often use mechanical equipment and mathematical equations to do this). It defines a course to be strictly followed between a pair of specified origin and destination. The progress along the course is sometimes monitored (e.g., by air traffic controllers or, in the case of private delivery systems like UPS or FedEx, by centralized tracking of GPS in delivery vehicles). Wayfinding is another term which is more generally taken as the process of finding a path (not necessarily previously traveled) in an actual environment between an origin and a destination. Wayfinding can thus be identified with concepts such as search, exploration, and incremental selection of path segment in a ring travel. Wayfinding can depend on technical assistance (e.g., compass, global positioning system, network map) or the use of cognitive maps.

Comparing these two terms, it is obvious that navigation is usually governed by constraints in terms of time, distance, cost, effort, or with reference to specific goals that should be achieved during travel. Thus, it is a process of optimization. Wayfinding which is not as rigidly constrained as navigation is dependent on the traveling purpose. It can introduce emotional value, belief considerations, and constraint satisfaction into the travel process, thus leading to stochastic probability models or any of a variety of logistic models.

Whereas navigation usually requires the traveler to plan a specific route to be followed, wayfinding can be more adventuresome and exploratory without the necessity of following a pre-calculated course. While the traveler behavior will be habitualized, leading to the optimization modeling of the navigation, the variety in path selection may be more common for other purposes, indicating more the wayfinding concern.

In addition to navigation and wayfinding, the term web direction is also widespread in the Internet. However, no literature could reveal since when and why the term web direction is used to indicate the web-based routing plan services. What has become a common sense is the fact that with the abundant overview information and elaborated text description, web direction can facilitate the convenience of our travel. Different from the navigation systems which can guide the traveler by voice, taking the navigation map as the supporting affixation, the web direction is based on the highlighted route and the wealthy surrounding information. It aims to provide the reliable spatial knowledge and help the traveler move towards the wanted direction. With the accessible wireless Internet and a large enough mobile screen, web direction is today easily affordable for individuals.

Keeping the current development and the user expectation in mind, we term in this thesis the routing map as a map which contains not only the route and the routing directions, but also the elaborated cartographic objects. The information selection is conducted following the criteria defined in the routing services.

As mentioned in Chapter 1, the purpose of this thesis is to improve the usability of the routing map with a high geometric fidelity and the right amount of semantic information. More specifically, the usability of a routing map depends mainly on the route enrichment that considers the users' preference on the one hand and the geometric precision on the other hand. In this chapter, we begin with an overview about the evolution of routing maps. Existing routing maps are then categorized with the aim to identify the main problems involved in their usage and the challenges of how to overcome these problems.

2.1.2 The evolution of routing maps

Early routing maps took the strip format. That is, the living space with its linear routes was organized and visualized in strips. MacEachren (1986) first termed strip map as a continuum of map forms that exhibit increasing degrees of abstraction in relation to a central element. He also summarized that the strip map was more popular than other formats based on four aspects: 1) construction materials, 2) the available information, 3) the map purpose and 4) strategies for cognitive organization of geographic information. The linear view of strip maps according to him could be considered as an excellent reference for the evolution of routing map. However, in the recent decades, with the popularization of the Internet, navigation services have become accessible for any individual Internet user instead of only for car drivers. Consequently, the routing maps have gained more design constraints from the perspectives of individual users and are being developed at an unprecedented speed and scope. The development and applications of various map construction equipments such as automotive navigation device, Personal Navigation Assistant (PNA), GPS facilities with Internet connection have played an important role over the long history of routing map. Figure 2.1 shows some milestones of the evolution of routing maps.

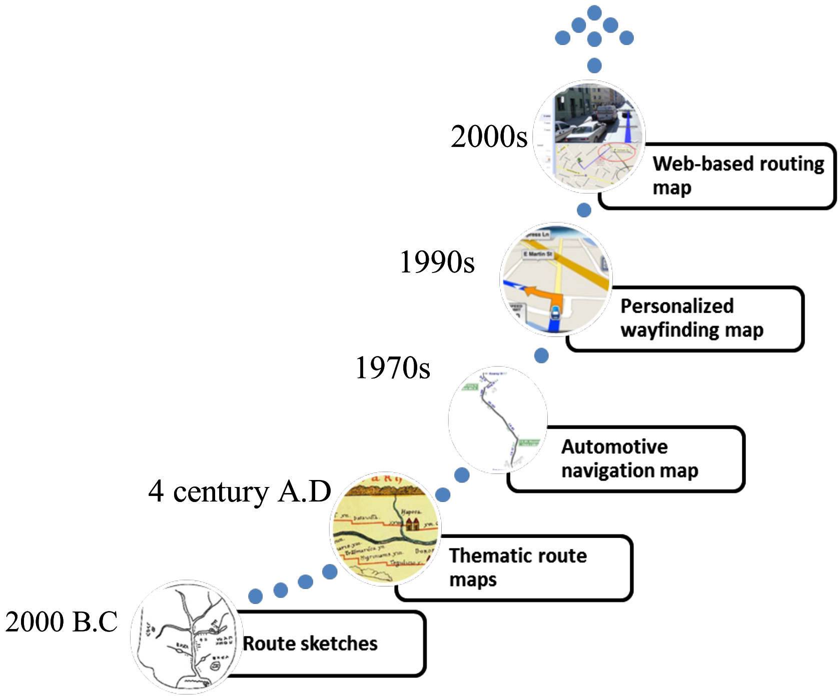


Figure 2.1 Milestones of the development of routing maps

(1) Route sketches

Route sketches could be dated back to 2000 B.C. or early. They were engraved on clay tablets or stones and scattered in caves or tombs. They depicted traces of roads, river courses or even the routes that should guide the dead towards the afterlife. Figure 2.2 (left) shows a map restored from an ancient river sketch. It reflects the Mississippi river valley carved into the surface of a pocket sized stone (Figure 2.2right) about 2000 years ago.

(2) Thematic routing map

The various types of thematic route maps emerged around the 4th century. They were typically designed to represent the imperial roads. A well-known example is the Roman Peutinger Table made in the fourth century. It depicted the road network of Roman Empire in a very abstract linear format measuring approximately 1-by-21 feet (MacEachren , 1986; Gohm 1972). During the medieval times, travel maps, specifically the route maps of church visits, were prevailing and used as guide for the pilgrimage to Jerusalem. They showed both the length of the journey through unfamiliar lands with a defined destination and descriptions of the travel purpose. One of the best known maps of this kind was produced by Matthew Paris in ca. 1250 (Dilke and Dilke 1975). In post-middle ages, verbal and pictorial itinerary maps appeared for land travel and coastal navigation of trading vessels. John Ogilby's Road Atlas Britannia published in 1675 contained a hundred strip road maps of England and Wales (Booth 1979). The coastal itineraries usually indicated the bearing of the travel. The Coasting Pilot of the Great Britain produced by Captain Greenville Collins in 1693 was such an example (MacEachren, 1986). In the same period between 1680 and 1700, China issued its scroll maps to visualize the Great Wall (Kish 1973).

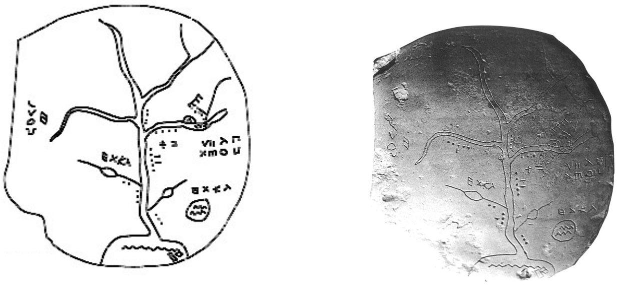


Figure 2.2. A stone map of the early Mississippi River Valley on a Burrows Cave Artifact

(3) Automotive navigation map

One of the first meaningful routing maps designed for automobile travel in strip format was produced by G. S. Chapin in 1907 (Schwartz and Ehrenberg 1980; MacEachren 1986). It was oriented in a convenient direction of the page with east at the top, and included information along the route such as distances, bridges, viaducts, railroad crossings, the location of service centers, and major landmarks. The commercial automotive navigation maps emerged in 1970s. During those days, automobile companies focused on the solution of storage and display for the digital map. For example, Electro Gyro-Cator represents the first generation of such maps that include the graphic display of the route on a CRT (Cathode Ray Tube) screen showing the present location and the travel direction at an appropriate scale. In 1980's, Toyota developed a system to display the digital map with a CD-ROM (Compact Disc Read-Only Memory) connected to a color CRT.

Later, Bosch in 1985 developed and presented the first prototype of a full functional navigation system "Electronic Pilot for Drivers" (EVA) to generate optimal route and presented turn-by-turn route guidance by the LCD (Liquid Crystal Display) with a synthesized voice (Akerman, 2006). Its routing maps are generated from the road database and displayed with some POIs supported by the standard navigation data structure such as GDF (Geographic Data Files) or CDF (Common Data Format). The visualization of routes combines: 1) top view, 2) bird's-eye view, 3) distance indicators, and 4) schematic pictograms along with the voice prompts. There was less additional information about the context and the user profile until the introduction of PDAs (Personal Digital Assistants) in 1990's.

(4) Personalized wayfinding map

The wayfinding in a personalized map is referred to as a consistent use and organization of sensory cues from the external environment according to the definition by Lynch (1960). The primary work involved in the wayfinding task is to decide which aspects of the environment are crucial and must be emphasized, which aspects require precision and must be truthfully preserved, and which aspects should be ignored (Tversky, 1993), and then present the selected information by intentional simplification beyond technical needs to achieve cognitive adequacy. It is a specific form of schematization process composed of three stages.

In the first stage, in order to preserve legibility constrained by the limited display surface and the routing task, the mapmaker selects the necessary objects or features from the existing datasets and ranks them as aspects in display precedence. The resulted routing map is also called schematic map or aspects map (Barkowsky, 1997; Berendt, 1998). A concern of such maps is that the user behavior of map use is ignored, and the ranking order of the mapmaker may not match the actual user’s preferences. This may lead to mis- or overinterpretation (Berendt, 1998).

In the second stage, in order to speed up the information processing, focus maps are generated to guide the reader's attention to the relevant information. The concept “focus map” was first proposed by Zipf and Richter (2002). Depending on different focuses, various focus maps have been generated. DeepMap, CRUMPET, GiMoDig, and WebPark are some examples which emphasize the structural information, i.e., objects or areas, the user should attend to. Klippel (2005) generated way-finding chorematic focus maps that combine the structural and functional information which emphasizes the actions during the routing to guide user’s attention to the relevant information in the relevant areas. Later, Richter et al., (2008) enriched the focus map by covering a range of different kinds of maps that all have in common that they guide map user to the relevant information for a given task. In this way, maps are designed not only for the intended task, but also for the target user.

Since personal wayfinding routing maps are task-specific, the map design can be additionally context dependent (Freksa, 1999). The context study with its multiple components ranging from computing facilities, user characteristics, physical environment, time-related constraints to history-related attributes (Chen and Kotz, 2000; Nivala and Sarjakoski, 2003; Nivala and Sarjakoski, 2005) has substantially stimulated the development of personal wayfinding routing maps (Freksa and Nebel, 2007; Richter, et al., 2008). The travel modality is treated as a context component in this thesis.

The third stage is about the visualization with the aim to improve the usability and utility of routing maps. Existing scientific works include the approaches of adaptive visualization for mobile devices (Reichenbacher, 2004) and attention-guiding visualization (Swienty, 2008), which can benefit the routing map design of this thesis with regard to the cognitive aspects.

(5) Web-based routing map

With the development of web technology, more and more routing services have emerged. At first, the web-based visualization of a route from one location to another was used for the travel planning. In order to provide more knowledge to allow the user to locate him easily, the primary route which is usually generated from a road network simply was highlighted and overlaid on a larger scale web map, where except for the route; any cognitive elements such as landmark were neglected. The routing information such as the turn-by-turn details was commonly generated based on the text description. The development of routing map mainly focus on the application of various routing planning algorithms to the web, such as routing planning via driving, walking, biking, public transit, or even the multimodal movement (Liu, 2011). Besides that, the dynamic traffic information delayed on routing plans has also play an important role in the web-based routing map.

With the popularization of open map services such as the Open Street Map in the recent years, the web-based routing during the travel has been made possible. With the new elements of routing map enrichment such as the street view and current locations by simulating or by connecting GPS, the routing map has moved towards a new stage. In this stage, the primary restrictions such as the limitation of representation space of mobile routing map for routing have become fainted. While we overview a route, the details of the routing information become accessible as well. However, few considerations have been taken in reviewing web-based routing map experience in this stage. Questions such as how to improve the cognitive ability of the web-based routing map and how to represent the relevant information for different travel modalities remain unanswered. Since Internet and GPS services provide a large design potential, we need to make use of the current technologies and methods to improve the usability of routing maps, for example, by including cognitive elements and personalizing the way-finding task on a web map. This dissertation is intended to apply cognitive theories and methods for the generation of cognitively adequate web-based routing maps and web-based mobile routing maps for different travel modalities.

2.1.3 Categories of routing maps

Routing maps can elegantly represent the spatial knowledge in different granularity levels, thus foster the creation of mental representations (Klippel et al., 2006). In spite of their various types, routing maps share the same fundamental purpose to guide the user to move along a route with the most important information. Various criteria, such as media, functions and visualization methods can be used to design routing maps. In the following sections, we try to analyze the available routing maps from the perspective of visualization methods.

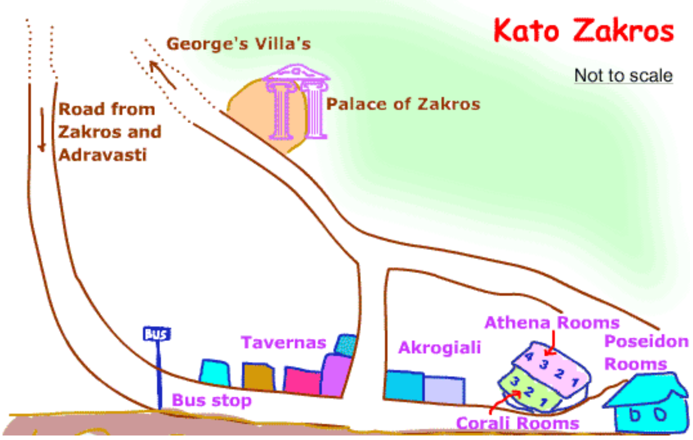


Figure 2.3 An example of sketch routing maps (CreteTravel.com, 2001)

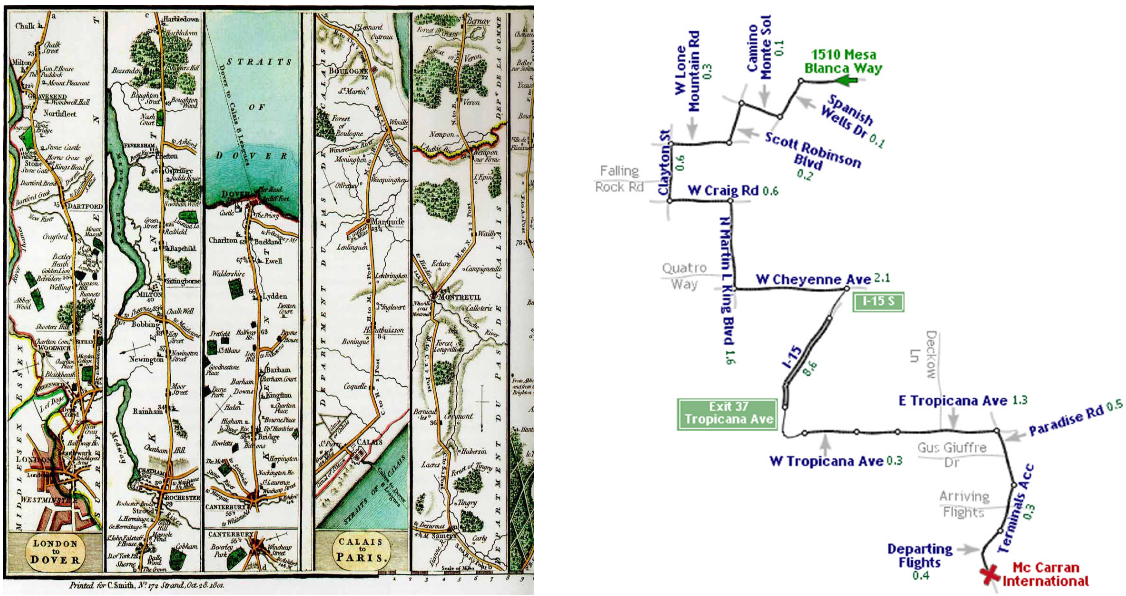
(1) **Sketch routing maps**

The sketching routing map is a common routing map style in our daily life. When we describe a route to follow, we usually sketch this information on any available material such as the clay tablet, stone, paper or display screen. On such a map, the decision points such as start, destination and some large turning points are marked with text or symbols. The orientation symbol is included as well for the user to follow (see the example in Figure 2.3). Since such a map is created by the mapmaker from his memory without the aid of any reference maps, it is a suitable style for individual way-finding. However, the contextual information is largely ignored and geometric values such as lengths, angles and shapes are distorted, a sketch routing map reveals a low precision and therefore has a limited usage.

(2) **Strip routing maps**

Strip maps were firstly used as printed documents of roads and streets for private and public transport, but later they were also designed to guide the travel. Figure 2.4 (left) illustrates two routes: one from London to Dover, and the other from Calais to Paris. The route's direction orients each strip as the normally fixed compass pointer diligently rotates from slice to slice. Various inns and rest stops are indicated along the journey which was taken by horses and coach in 1801. The routes are highlighted and placed in the center with the landmarks or other important information along the route. They do allow viewers to focus directly on the relevant part (Tufte, 1990; Bell, 1995).

Analog to sketch routing maps or hand-drawn routing maps, strip routing maps with legible routes match pretty well the human capability of recognizing the environment such that way-finding task can be easily conducted. However, it is difficult to accommodate more detailed and related information within the limited display space of either printed medium or computer monitor (see Figure 2.4 right).



Left: A New Plan of the route from London to Dover, and from Calais to Paris, Charles Smith, mapseller, No. 172 (London, 1801); Right: A computer-generated strip map (Agrawala, 2001).

Figure 2.4 Examples of strip map

(3) **Overview routing maps**

The purpose of overview routing maps is to provide an understanding of the entire route in a region. It is the prevailing style of web-based routing maps. The route is usually derived from a separate road database. Cognitive elements are seldom considered. The overview routing maps often cover a rather extensive region and therefore can hardly allow the turn-by-turn instructions while traveling. Figure 2.5 shows an example of the overview routing maps on which the route is created by a multimodal routing plan algorithm and overlaid on a Google map.

Although in recent years more and more web-based routing maps allow users to interactively select and present POIs along the route, most of the POIs are distance-based rather than for the routing purpose, therefore, their usability is not very much improved.

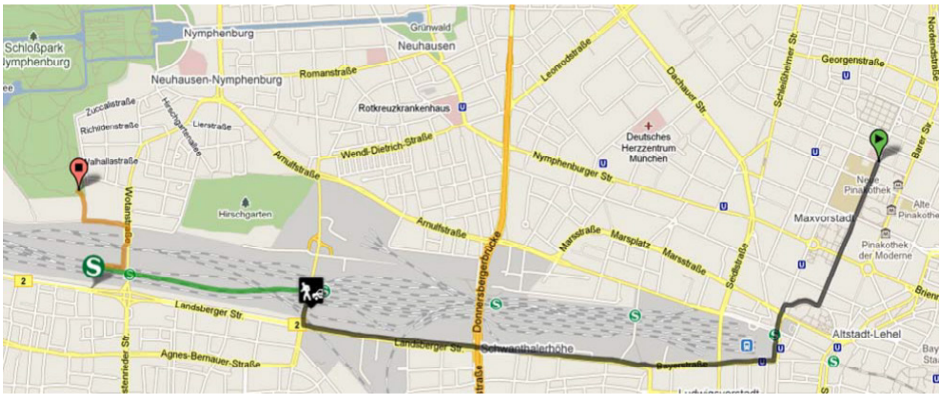
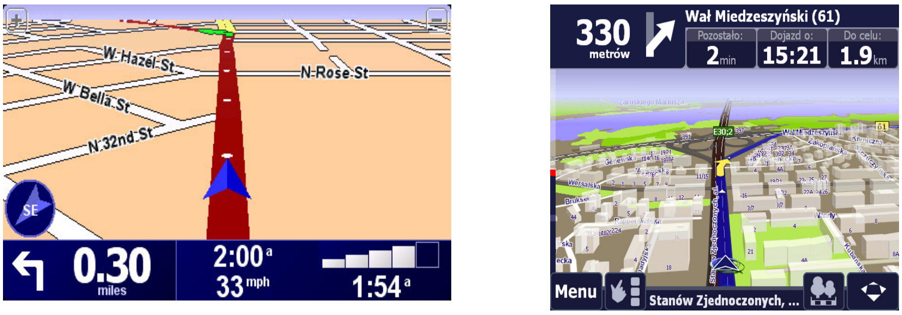


Figure 2.5 An example of overview routing maps (Liu, 2011)

(4) **Turn-by–turn routing maps**

The turn-by turn routing map is also termed as navigation map that shows a route to follow during a travel. It is usually embedded in a mobile navigator with the GPS function. The route is typically displayed in 2D, 2.5D or 3D (see Figure 2.6). Due to the limited display size and the limited storage capacity for an embedded or a mobile device, a navigation map usually provides only a simple path and guides the user mainly with verbal instructions, making the map an auxiliary product. If the commercial navigators provide related information with pull or push styles, some symbols may overlap and cause a cluttering problem (as Figure 2.7 shows). Therefore, research is necessary to visualize the different granularity levels of a navigation map.



(a) Simple egocentric navigation map[1] (b) 2.5D navigation map[2]

(c) Integration of 2D and 3D Navigation map[3].

Figure 2.6 Examples of automotive navigation maps.

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[1] http://www.roadmapgps.com/models/tomtom-go-510/

[2] http://imageshack.us/photo/my-images/69/screen1rl.png/

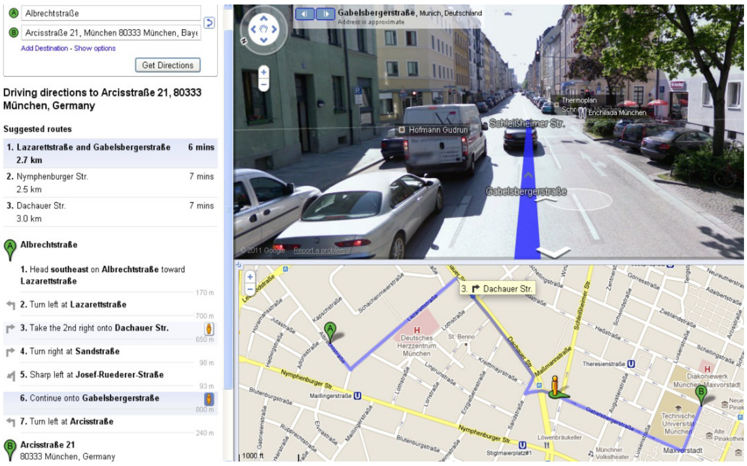
[3] http://www.tuvie.com/inavi-k2-3d-gps-navigation-from-thinkware/

Figure 2.7 POIs on the routing map[4]

(5) **Combined overview and turn-by-turn routing maps**

With the development of the web2.0, map web services become more fashionable and the rapid progresses of web-based routing have led to multiple representations. Figure 2.8 is an example of the combination of an overview map with the turn-by-turn views. Figure 2.9 illustrates the union of an overview map, a street view.

Figure 2.8 A turn-by-turn map with magnified views (Karnick, et. al., 2009)


Ⓐ Albrechtstraße
Ⓑ Arcisstraße 21, München 80333 München, Baye

Driving directions to Arcisstraße 21, 80333 München, Germany

Suggested routes

1. Lazarettstraße and Gabelsbergerstraße 6 mins 2.7 km
2. Nymphenburger Str. 7 mins 2.5 km
3. Dachauer Str. 7 mins 3.0 km

Albrechtstraße

1. Head southeast on Albrechtstraße toward Lazarettstraße 170 m
2. Turn left at Lazarettstraße 700 m
3. Take the 2nd right onto Dachauer Str. 650 m
4. Turn right at Sandstraße 98 m
5. Sharp left at Josef-Ruederer-Straße 93 m
6. Continue onto Gabelsbergerstraße 800 m
7. Turn left at Arcisstraße 240 m

Arcisstraße 21
80333 München, Germany

Figure 2.9 A 2D overview map with a Google street view[5]

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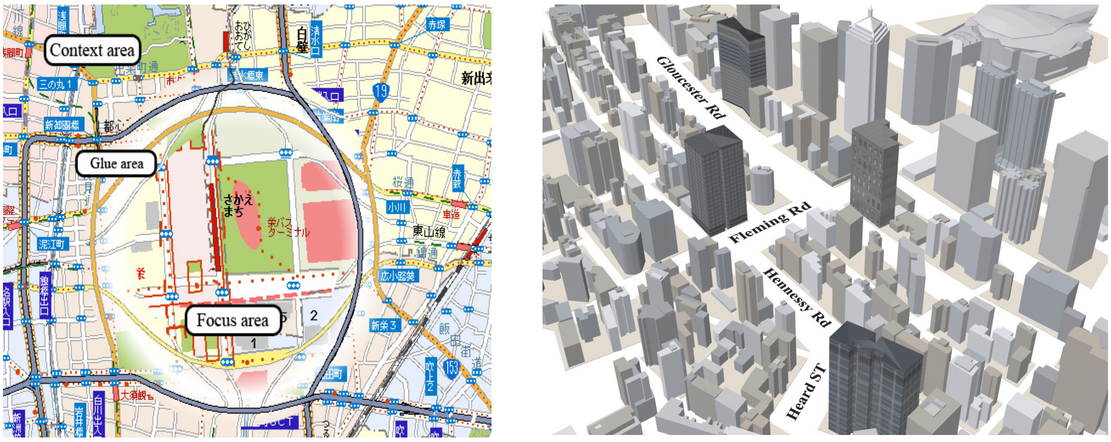
[4] http://www.amazon.co.uk/Panasonic-Strada-Satellite-Navigation-Widescreen/dp/B000WHBLQS
[5] http://google.com/maps

(6) Nonlinearly distorted routing map

There are also other design styles of routing maps, e.g. a 2D map based on a nonlinear distortion (Figure 2.10 Left), 3D urban environment with the focus on annotated route (Figure 2.10 Right).

On these currently available routing maps, the routing overviews and detailed views at decisive points are simultaneously displayed. But the routing model and the personal preference are not considered. Similar to the turn-by-turn map, no clues on how to simplify the routing tasks are provided.



Left: a 2D map based on a nonlinear distortion (Pablo et al., 2010). Right: 3D urban equipped with a focused route (Qu, et. al., 2009)

Figure 2.10 Nonlinearly distorted routing map

2.2 Cognition-based routing map

2.2.1 Cognitive aspects of routing information

It is common that people use mental map to travel from *A* to *B* in a novel environment (Lynch 1960, Tversky 1993; Timpf et al.1992, 2002). The term ‘mental map’ was first used to describe a conceptual representation of spatial information for navigation (Tolman, 1948). This mental image of environment can be constructed from any kind of routing instructions, printed or digital, e.g. sketch map, and verbal depictions incremented with map, pictures or videos.

In case of navigation, it requires a conversion from the egocentric perceptive to geocentric perceptive, or vice versa, and needs much more mental activity which consists of acquisition, encoding, storage, recall and recognition (Darken & Peterson 2001). If the current observation can remind users of the previously stored attributes of spatial objects, the process will become easier. There are convincing evidences that a routing map can be derived from the ‘cognitive map’ or memory work (Thomas and Donikian, 2003, 2007, Frank, 2000, 2003, Raubal and Worboys, 1999, Mark, 1999). On the other hand, empirical studies from Radoczky and Gartner (2005) have verified that the graphic presentation form (routing map) could favorably influence the generation of the user’s mental map of the environment, particularly when navigating along a familiar or unfamiliar route.

When employing maps to build a mental map for way finding, two major tasks are involved:

1) Selecting the aspects of attention; and
2) Selecting a suitable structure to visualize it.

In other words, optimal contents should be combined with a suitable representation form so as to generate an attention map that matches the cognitive process of the way finding. Various attention-based models and computing methods from neurology have found their applications in routing map (Section 2.3). Some popular examples are demonstrated in the Focus+Context map (Richter et al., 2008), elastic maps (Takahashi, 2008; Yamamoto et al., 2009; Pablo et al., 2010) and its extension to Focus+Glue+Context (Daisuke, et. al., 2009). The task-specific map and context-driven map are deemed selective in terms of mapping contents. They both need to reflect the extraction process of enriching objects such as landmarks for routing.

Freksa (1999) described the correspondence between a wayfinding task and the routing map as two extremes of representation: a conceptual structure developed in the cognitive process and a physical structure perceived in the environment. He suggested that the narrower the gap between these two extremes, the better the cognitive support for way finding. He also proposed that schematic map could bridge the gap between the conceptual and the physical structure by emphasizing some aspects and neglecting others.

Frank et al. (2000) proposed the homomorphism (as in Eq.2.1) between the routing plan and its implementation within the two environments, i.e. the real environment and the user’s mental representation.

$$f(sp(l)) = sp'(f(l)) \tag{2.1}$$

Where f is a mapping between the user’s mental representation and the environment, sp and sp' are two corresponding operations i.e. planning a shortest path in user’s mind and the other is walking the shortest path in the environment. They used user’s belief while walking in the environment to match the belief of the mental map derived from the routing map to denote the usability of routing maps.

Thomas and Donikian (2003) reported a hierarchical model for landmark extraction based on a simulated route, in which a mental map is regarded as a filter with two memory parameters - recall and recognition. The hierarchical model included three factors:

- Exogenous: the attention is spread on a high number of objects, where exceptional and peripheral events are noticed, which leads to a high recall and a normal recognition;
- Endogenous: the attention is drawn to its environment, which leads to a normal recall and recognition;
- Passive: the perception is attracted by highly contrasted and salient zones, but the attention is quite low, which leads to a high recognition and a normal recall.

Klippel (2005a) explored the possibility of organizing the map by Conceptual Spatial Representations (CSRs). CSR refers to a mental representation that is instantiated in the interaction with a spatial environment for solving spatial problem such as a wayfinding problem. In contrast to the Data-Driven Approach (DDA) which starts with the presentation of rich data, it is not only more schematic by means of systematic abstraction, but also a more precise image of the environment. The CSRs focus on a set of relevant spatial aspects and provide design freedom, allowing the representation of highly focused, context-adapted information. The approach has been reported in several research works which aim to improve the communication and provide proper means for the automatic generation of graphic representations, for example, in ubiquitous computing environments.

In a similar way, Caduff and Timpf (2008) proposed an approach of attention-based landmark extraction. They divided the process of attention into three memory stages: 1) sensory memory, 2) working memory, and 3) long-term memory. When the relative salience of landmarks is assessed, these stages are linked together in the computational processes ranging from pre-attentive, attentive, encoding, updating, recognizing, to familiarizing process. The sensory memory perceives and stores the visual similarity without any processing. The working memory involves pre-attentive processing and sequential processing. The pre-attentive processing produces a perceptual representation of the spatial scene that contains the spatial objects and quantifies their low-level variables, e.g., size, length, color, intensity. The sequential processing simulates the process of attention and includes top-down factors, such as the degree of recognition and idiosyncratic relevance with an object, and contextual factors such as task and traveling modality. These factors modulate the perceptual salience of the object. In the last stage a new mental object is created in the long-term memory or, if the object is already present, updated with the new information. Updating object in long-term memory ensures that the object saliency evolves over time and varies with the level of observer’s experience.

2.2.2 Landmarks as primary cognitive elements of routing

Lynch (1960) defined landmark as any element that can ‘potentially serve as a point-of-reference’. Currently, the term “landmark” has been widely used in interdisciplinary literatures, and elaborated into global landmark, local landmark and distant landmark. Landmarks are the primary cognitive elements. Usually, they are manually derived from salient or relevant information, play an important role during the way finding, and thus help increase the usability of routing maps. The extraction of landmarks has been discussed in many research works concerned with the location of the landmark (global or local), the travel modality, the presentation medium (geo-tag photo or video) etc. In this section, we review related works on the landmark classification and extraction.

For different applications, the landmark has different functional characteristics, which requires us to know the specific context. Two categories of landmark are useful for routing maps. The first category is related to the scope of the reference region and can be regarded as a global landmark in a large space or a local one in a small space, we term the location-based category as the first category. The second category is based on attributes of landmark, for instance, visual and structural ones, we also call this category as semantic-based category.

The discussions around the first category started from 1960. Lynch distinguished distant landmark, which was physically inaccessible and invisible from a large region, and local landmark, which was physically and visually accessible in a restricted space. Presson and Montello (1988) described a symbolic landmark and a distant landmark for two purposes: 1) for the representation of the spatial knowledge; 2) for the navigation context. The symbolic landmark provides a strong identity for its surroundings but may or may not aid the orientation of other spatial relations. The distant landmark describes a visible, distant point of reference with respect to user’s orientation. Steck and Mallot (2000) indicated that different users relied on different strategies to make decisions: Some chose only the local landmarks, whereas others prefer global landmarks or both to get orientation. They also pointed out that the landmark salience could influence the decision. For example, the user may tend to choose the local landmark during the travel and neglect the global landmark. Raubal and Winter (2002) regarded the decision points or route marks as local landmarks with respect to a specific route. Lazem and Sheta (2005) verified that a global landmark such as a high tower is visible from a large area, so they defined a global reference framework that does not change when moving a small distance; in contrast, a local landmark is visible only from a short distance. However their method was based on empirical approaches without computational details. The approaches about local and global landmarks from (Klippel and Winter, 2005, Winter et al., 2008) were based on the relative size of the reference region. Takahashi et al. (2006) introduced the terrain landmarks which are characteristic points on the silhouettes of mountains and valleys, as well as road landmarks which are the extreme points of road curvature and inflection points along the road. In a similar way, Alexander and Stefan (2009) distinguished between global and local landmarks based on whether it required the user to reach these elements on a specific route. Figure 2.12 summarizes the geometric classes of landmarks. A number of attributes describing the routing task and routing space can be used to enrich the taxonomy of landmark.

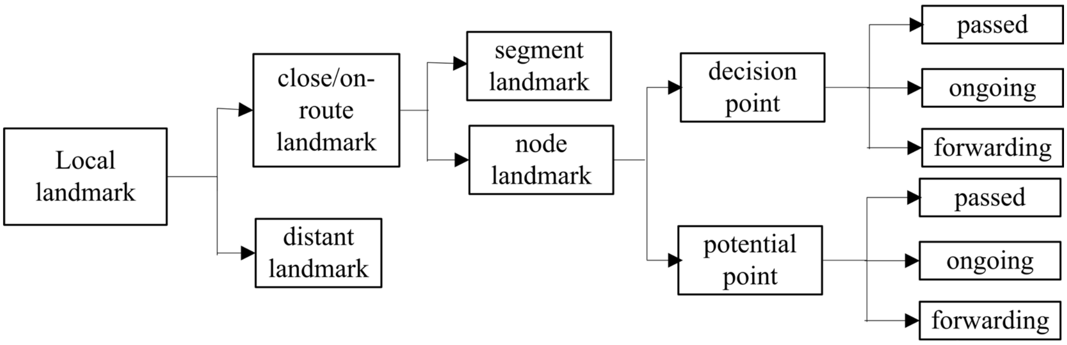


Figure 2.11 Location-based landmarks

The studies on the second category started in the 90ties. Sorrows and Hirtle (1999) categorized landmarks into three types based on the attributes of landmarks: 1) visual landmarks: visually salient elements; 2) cognitive landmarks: meaningful elements; 3) structural landmarks: elements that are salient because of their location and placement within a large spatial configuration. In a similar way, Raubal and Winter (2002) listed three items for the landmark salience: 1) visual salience perceivable from shape and color etc.; 2) semantic salience such as cultural and historical value; 3) structural salience embedded in location. Furthermore, Santos-Delgado (2005) reported more types of landmarks according to their semantic properties: 1) social landmarks: places where people interact and socialize (e.g. mosque, park, and school); 2) historical landmarks: places with historical value or where an historic event occurred (e.g. monument and cemetery): 3) symbolic landmarks (e.g. church and mosque); 4) economic landmarks (e.g. plant and harbour); 5) aesthetic landmarks: places with aesthetic value. Caduff and Timpf (2008) classified the landmark into 5 types based on attention theory, i.e., the modality-based landmark, recognition-based landmark, task-based landmark, scene-based landmark and object-based landmark. We summarize the classes based on the second category in the Figure 2.12.

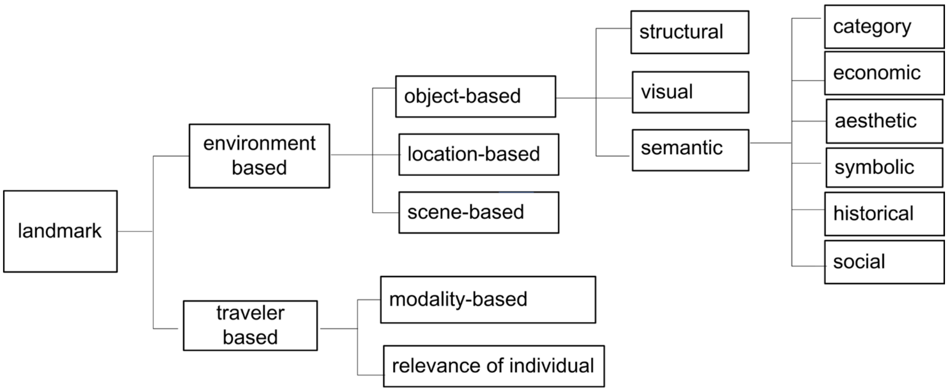


Figure 2.12 Semantic-based landmarks

2.3 Attention assessment for routing

2.3.1 Strategies for attention assessment

An attention map is referred as a map with salient information. It considers more about user behavior and the mobile environment than the classical way-finding approach does. However, the computation of attention is a complex process which contains both object-inferred model and traveler-inferred model, or their combinational model (James, 1981).

(1) Object-inferred attention

The most important object-inferred model which is also termed as bottom-up model for attention computation was proposed by Itti (1998, 2001). It follows Treisman's Feature Integration theory (Treisman and Gelade, 1980) by calculating the salience for different low-level variables of the object, e.g. color, texture or movement, and it is stimulus-driven (Khadhorui and Demiris, 2005). This model describes the visually conspicuous objects in the eyes of travelers and measures their corresponding visual salience. So far many different variables, e.g. color, orientation, curvature, texture, scale, offset, size, spatial frequency, scale, motion, shape, depth cues etc., that make an object more salient than others (Wolfe, 1992, 1998) have been integrated into this model. And many applications have been reported (Itti, 2001; Treisman, 1988; Wolfe, 1998; Findlay et al., 1999; Theeuwes, 2004, 2005, Treisman, 1980, 1986).

The computation of salience has two basic applications. On the one hand, the symbolic saliences for a city is applicable for tourist map or 'where are you' map (Klippel, 2006). On the other hand, salience focused on the distant landmark can support the orientation and is suitable for routing, or way-finding tasks (Presson and Montello 1988). The assessment of landmark salience is reflected in three aspects: environment, observer and computing method.

With regard to the characteristics of environment, visual, semantic and structural are the three common dimensions which have been applied in measuring of the landmark salience (Sorrows and Hirtle's, 1999; Nothegger, 2004; Klippel et al., 2005). Winter (2003) added the approaching direction as another dimension to assess the visibility of the object.

Since most of these above methods depend on the detailed visualization of geometric characteristics of environment, such as the 3D city models, cadastral data sets, and/or building façades, the proposed landmark salience measurement method are not readily available except at some restricted spatial locations (Winter, 2009).

Duckham et.al (2010) proposed a weighting system that assigns weights based on the expected (e.g., average) properties of the POI categories. In this model, the geometry and semantic information of POIs can be derived from the geocoded directory, which is more commonly available and easily accessible. However, it is a challenge to build a complete weighting system for larger areas, for example, for two cities with distinctive characteristics.

(2) Traveler-inferred attention

The salience derived from the objects could only reflect one part of the story. Ho (2003) proposed an active attention method related to the traveler. The mobility modalities in this thesis belong to this kind of consideration. There are a few studies on the 'relevance' for landmark detection.

Rees (1966) defined the relevance as the criterion to quantify the involved phenomenon (Greisdorf 2000). Sperber and Wilson (1995) identified that factors like situation, topic, motivation, and cognition have large impacts on the selection of related geographic information. Schmidt and Gellersen (2001) proposed a formal approach to determine the validity of context based on space and time. It can be easily applied to model the relevance using the fuzzy set theory. Zipf (2003) proposed a method to model the relevance of geographic object for focus map and mobile map respectively, which was based on the calculation of a dominant value. Reichenbacher (2004, 2005 and 2009) followed the method of Schmidt and Gellersen (2001) and presented a spatial relevance model. In his model, the spatial distance function is derived from three variables: the location or spatial relevance, the temporal relevance, and the thematic relevance. Swienty (2008) elaborated the theory of cognitive relevance based on the previous research of Saracevi (1996) and Sperber & Wilson (1995) and put forward the design framework of attention-guiding geo-visualization as shown in Figure 2.13.

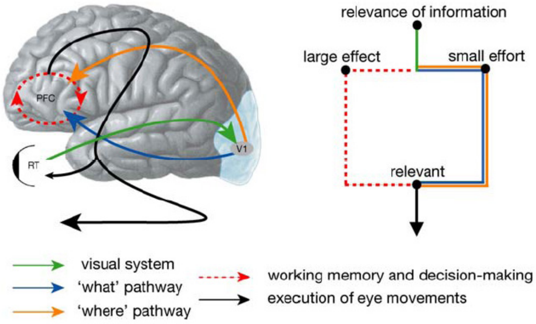


Figure 2.13 Visual information processing and cognitive relevance (Swienty 2008, Saracevi 1996, Sperber & Wilson 1995)

(3) Attention by a hybrid model

Both salience and relevance are selection criteria for the attention. They are sometimes treated as synonyms in the neurophysiologic literature (Bichot et al., 1999; Bisley et al., 2003; Fecteau et al., 2003; Goldberg et al., 2002; Gottlieb, 2002; Thompson et al., 2005; Robinson et al., 1992). (Dale, 2005) already approached to combine salience and relevance in the automatic generation of route descriptions, but no published work is yet known for the generation of a routing map with both. In a hybrid model, salience is based on the location or the surrounding, whereas relevance is decided by a given task (Belardinelli, 2010).

Pattabhiraman and Cercone (1990) pointed out the importance of salience and relevance for content selection, and they also identified that the salience was a function of external factors, but the relevance was decided by the internal factors. However, they did not present how to derive the orientation, distance and location information based on these factors.

Fecteau (2006) recommended the priority map to reflect the combinational roles of salience and relevance in the selection process. The idea is also used by Belardinelli (2010) in her work. Caduff (2008) treated the salience measurement as the combination of the recognition degree and the idiosyncratic relevance. According to his theory, the degree of recognition describes how well an object can be identified, while the idiosyncratic relevance indicates the object's individual importance. For example, he assumed that an object with a high degree of recognition was more likely to be used as reference than other objects with lower recognition values. However, the feasibility of this conceptual framework needs to be verified through practical experiments (Li, 2010).

Previous researches suggested that four facets of the physical environment are important for a successful way finding: 1) degree of (architectural) differentiation, 2) degree of visual access,

3) complexity of the spatial layout (Gaerling et al., 1986, Caduff, 2008), and 4) the given task, which includes time, weather, travel modality, speed and so on.

2.3.2 Frameworks of attention assessment

There are two popular frameworks which have been applied to compute the attention information based on the above three attention models.

(1) Exocentric framework

In this framework, the salience is defined on the basis of the relationship between geographic feature and environment with three main components: 1) visual salience with the singularity or sharp contrast with the surrounding; 2) structural salience with the prominence of the spatial location; 3) semantic salience with the content, implication, or cultural significance. Table 2.1 exemplifies a number of instances of the salience components. But in this approach, as shown in Figure 2.15, the perception or cognition capabilities of the user are neglected.

Table 2.1 The components of salience and their instances

Factors	Instance
Visual salience	Facade area
	Shape
	Shape deviation from rectangle
	Color
	Height of object
	Visibility
Structural salience	Nodes
	Boundaries
Semantic salience	Cultural and historical importance
	Explicit mark

Few studies were reported on the visibility analysis which is an expensive process. Brenner and Elias (2003) implemented the visibility analysis by the laser scanning along a trajectory, by which the virtual view of a trajectory is processed and plotted in a frame, and then based on the frame it can be decided if the landmark is visible or not. Stephan (2003) used two parameters to calculate the visibility for a specific route (Eq.2.2):

a) Route coverage of the object's visible area;
b) Orientation of the objects with respect to the current route segment from the visibility analysis : $v = c \cdot o$

$$c = \frac{|p_i p_e|}{|p_s p_e|} \quad \text{and} \quad o = \frac{|d_f - d_r|}{180} \tag{2.2}$$

Where p_s, p_e is the start and end point of the entering route segment, and p_i its intersection with the boundary of the visibility area; d_f is the cardinal direction of the normal vector on the facade's ground line, and d_r is the cardinal direction of the entering route segment. *c* is the proportion of the visible covered part and *o* is the normalized orientation of the object with respect to the entering route segment.

(2) Egocentric framework

In this framework the salience is defined on the basis of a trilateral relationship among the observer, the environment, and the spatial object. The observer locates himself in the environment and perceives or prefers some geographic object, which has a higher contrast in the environment. The significance of this framework is that it suggests that only a limited part of the whole environment and only the perceived physical property of the topographical objects rather than all objects need to be compared and computed in the model.

Following this principle, Caduff and Timpf (2008) proposed an attention-based landmark extraction model which is composed of three salience metrics: perceptual salience, cognitive salience and contextual salience. Perceptual salience can be classified into three sub-variables: object salience, scene salience, and location salience. The object salience accounts for the property derived from the geometric attributes such as shape, size, and orientation. It provides the basis for the assessment of the geometric similarity or difference among objects and is regarded as equivalent to the visual salience of the preceding framework. The location salience assesses the potential attention crossing spatial scenes, that is to say, all visual information within the visual field is processed in a parallel way, and the most salient region is the candidate. But this model considers the location-based and object-based attention in an integrated way. Scene salience is assessed by means of the bilateral relation, which is the topology (e.g., adjoin, disjoint), or direction among the objects in the spatial scene. The cognitive salience contains the degree of recognition and the idiosyncratic relevance of individual objects. The degree of recognition for each individual geographic object is based on the vision field from observation points along the route. The contextual salience deals with two contexts. The first one is a task-based context and indicates that the navigation task is different from the sightseeing, thus all salience information should be related to navigation. The second one is a modality-based context.

Table 2.2 Salience categories (Caduff and Timpf, 2008)

Salience category	Conceptual variables	Computational variables
perceptual	object salience	object salience
	location salience	structural salience
	scene salience	distance and direction
cognitive	degree of recognition	observation numbers along the route
	idiosyncratic relevance of individual objects	not clear
contextual	task relevance	structural salience
	modality relevance	useful field of view

The term idiosyncrasy is typically defined as a behavioral attribute, which has a distinctive and peculiar meaning for an individual object. It is assumed that the idiosyncratic relevance increases with the higher recurrence number for a specific object. Table 2.2 summaries the conceptual and computational variables in the model of Caduff and Timpf (2008). The familiarity or unfamiliarity of the environment as well as the difference of a landmark for man, woman, children and old people was investigated as an extension of this model. However, idiosyncrasy is task dependent. For example, the gas station has a higher relevance to the driver, while the shopping center or public transport station has a higher relevance to the pedestrian. This fact was not yet considered in Caduff and Timpf (2008).

2.3.3 Methods of attention assessment

In line with the above mentioned frameworks, various numerical approaches have been developed to compute the attention information for the routing task. In this section, we introduce some of the approaches dedicated to the extraction of salient landmarks for routing.

(1) Z-score method

To evaluate the visual, semantic and structural salience of building facades, a z-score method was proposed by Raubal and Winter (2002), Nothegger et al., (2004) and Winter et al., (2005). This method measures the differences of individual properties under the assumption that the properties obey a continuous and normal distribution. The corresponding algorithm can be implemented by hypothesis testing of the deviation significance from the mean or median of characteristics of the local neighborhood (Eq.2.3):

$$s(x) = \left| f(x) - E(f(x)) \right| / \sigma \quad \text{or} \quad s(x) = \left| f(x) - med(f(x)) \right| / Mad(f(x)) \tag{2.3}$$

$$\text{with} \quad Mad(f(x)) = med(f(x) - med(f(x))) / 0.6745$$

where $f(x)$ represents the attribute value of individual buildings such as the height, area and color and so on, and $s(x)$ is the significance score of the attribute; $E(f(x))$ is the mean value of these attributes; $med(f(x))$ denotes the median, and $Mad(f(x))$ is the median absolute deviation from the median. Herein, the salience of a facade $s(x)_f$ (Eq.2.4) is computed from weighted salient components of visual $s(x)_v$, semantic $s(x)_s$, structural $s(x)_t$, and advance visibility $s(x)_a$ respectively.

$$s(x)_f = (s(x)_v \cdot w_v + s(x)_s \cdot w_s + s(x)_t \cdot w_t) \cdot s(x)_a \tag{2.4}$$

There is no consideration about the different weight for the different attribute in Eq 2.3. A modified method was applied to the weighted evaluation system for POIs (Duckham et al., 2010), which used category-level of landmarks instead of instance-level of individual landmarks. For example, they assign a higher weight to the visibility of a takeaway-food building as a potential landmark, and a lower weight to the visibility of a consulate / embassy building. This modified approach not only allows extra flexibility and the integration of domain knowledge from different sources (e.g., POI) into the landmark extraction, but also adopts the category as an important attribute of the landmark detection (Raubal and Winter, 2002; Nothegger et al., 2004; Winter et al., 2005). However, because the measure function remains the same as the normal z-score approach, the assumed Gaussian distribution of the attributes may not be always true for geo-related objects although it is difficult to test (Sun and Chawla, 2004). For example, color or the semantic information is difficult to quantify in numerical sense. Therefore, this approach is not applicable for an arbitrary distribution which includes various or multiple attributes. Additionally, according to Tobler's first law of geography, 'Everything is related to everything else, but near things are more related than distant things' (Tobler, 1970), (Winter et al., 2005) stated that the neighborhood is constructed by the visibility analysis, which means that all buildings that can be seen from each decision point should be regarded as candidate landmarks even if the visual space may be very large. This sort of spatial autocorrelation is ignored in the z-score method. Moreover, in the z-score with its modified measuring methods, all potential landmarks from a static point, all salience degrees of potential landmarks will depend on the neighborhood, therefore it won't provide a measure reflecting the relative or absolute ranking of different neighborhoods along an entire route.

(2) Logistic model

Logistic analysis model is suitable for ordinal scaling (Osaragi and Onozuka, 2005), and quite a few applications have been reported in the field of data mining and knowledge discovery (Delen et. al., 2004; Abu-Hanna and de Keizer, 2003; Landwehr et al., 2003). The basic idea is to compute the probability P(x) of a potential local landmark (Eq.2.5).

$$s(x) = P(x) = 1/\left(1 + \exp(-\sum w \cdot f(x))\right) \tag{2.5}$$

where f(x) is an attribute value of individual buildings, and w is the corresponding weight of the attribute. Intuitively, this method overcomes the limitation of normal distribution assumption in z-score approach. However, there are still some problems with this approach, such as the ignored autocorrelation, the neighborhood dependence and the difficulty to rank all potential landmarks for the entire route.

(3) Information entropy

The local landmark extraction can be regarded as a classification or clustering problem. Two decision tree algorithms have been investigated, which employ the *ID3* classification algorithm (Elias 2003; Elias et al., 2004; Winter, 2006) and *COWEB* clustering algorithm (Elias, 2003). The identified landmarks by *ID3* are characterized by their salience in the environment, and the procedure reveals singularities of objects in a certain environment. The salience or significance test uses entropy as a measure of the uncertainty associated with a random variable (Eq.2.6):

$$E(s(x)) = -\sum_{j=1}^{n} f(x) / \sum f(x) \cdot \log_2(f(x) / \sum f(x)) \tag{2. 6}$$

where the f(x) is the attribute value of an individual building, s(x) is the distance between an individual building and others, and E(s(x)) is the information entropy of the distance. The lower the E value is, the more significant the building object is. The building object with the lowest E value is the landmark.

The COWEB regards the landmark detection as a hierarchical clustering problem. The dissimilarity between two clusters is defined as the longest distance between two individual building (Eq.2.7).

$$s(x,\bar{x}) = \max(\left\|\overrightarrow{f(x)} - \overrightarrow{f(\bar{x})}\right\|) \quad (\vec{x} \in c_i, \vec{\bar{x}} \in c_i) \tag{2.7}$$

Where f(x) is the attribute value of each individual building, and $f(\bar{x})$ is the average attribute value of the buildings of the same cluster. $\left\|\overrightarrow{f(x)} - \overrightarrow{f(\bar{x})}\right\|$ denotes the dissimilarity, and the object that has the largest deviation from the mean is most salient.

Both methods provide a proper mechanism to automatically extract salient objects with relative uniqueness in the given environment. But they do not accommodate various conditions of the objects, e.g. varying illumination condition during the day, nor a different type of objects. They do not consider neighborhood structure which varies with different contributions of the objects. It is also difficult to consider different weights associated with different traveling modalities. Moreover, the output of these two algorithms is the most salience landmark. It does no measures reflecting the relative or absolute ranking in a neighborhood, and the differences of neighborhoods.

(4) Outlier detection method

The outlier detection methods have been employed recently by Haghighat et al. (2009) and Lazem and Sheta (2005), which regard the salience estimation as a spatial outlier detection problem as formulated in Eq. 2.8:

$$s(x) = f(x) - \frac{1}{|N(x)|} \Sigma_{\, y \in N(x)} f(y) \tag{2.8}$$

where f(x) is the attribute value of a spatial object, and N(x) is the number of local neighbors to this object. f(y) is the attribute value of a local neighbor. The object with the largest s(x) is considered as salient in neighborhood. The advantage of the approach is its easiness to deal with a large available database with multiple attributes. Another advantage is that the both spatial and non-spatial attributes have been considered which have solved the autocorrelation problems. However, as proved by many investigations in spatial outlier research (Sun and Chawla, 2004, Chen et al. 2010), and landmark hierarchies (Winter, 2008), it is difficult to rank landmarks for an entire route, which is important for the generation of a routing map with multiple levels of details. Furthermore, it is hard to calculate the relevance degree and handle semantic meanings.

(5) Relevance information

Reichenbacher (2004, 2005, and 2009) adopted the method of Schmidt and Gellersen (2001) and presented a spatial relevance model to improve the usability of mobile map. In the model, the spatial distance function is derived from three variables:

- Location or spatial relevance: $r_{sp} = f(d(p_1, p_2))$
- Temporal relevance: $r_{te} = f(d(t_1, t_2))$
- Thematic relevance: $r_{th} = f(d(c_1, c_2))$

The general relevance *R* between two objects can be modeled as a function: $R = r_{sp} \cdot w_{sp} + r_{te} \cdot w_{te} + r_{th} \cdot w_{th}$ where w_{sp}, w_{te}, w_{th} are the corresponding relevance weights.

2.4 Rendering based on salience

Several researchers have investigated different approaches for landmark visualization on routing maps. Deakin (1996) examined the integration of landmark into maps by employing two different landmark portrayal styles: 1) the geometric, pictorial, symbolized visualization; 2) the stereotype sketches. Landmark symbolization represented by geometric symbols or stereotype sketches was found to be equally effective (Elias and Brenner 2004). Figure 2.14 demonstrates the landmark visualization in three different ways.

Lee et al (2001) proposed a prototype for visualization using photographic images to represent landmark, and then matched them directly on a perspective view of map. Radoczky (2003) also recommended photorealistic image for the visualization of landmark. Sester (2002) visualized salient objects by means of cartographic generalization. Birgit Elias et al. (2008) presented a concept for the visualization of building landmarks and explained how they can be effectively visualized. Qu et al. (2009) employed a context-zooming technique, which allows users to zoom into a route and perceive the associated landmarks in a 3D urban environment from a bird's eye view of 45°. The zooming-in function can minimize the distortions of buildings in the

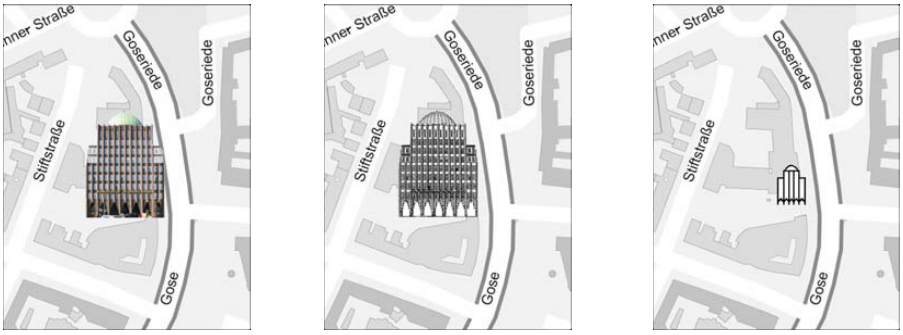


Image (left), sketch (centre) and symbol (right) (Elias and Paelke, 2008)

Figure 2.14 The Anzeiger-Hochhaus building of Hannover

Chapter 3

Cognition-based routing map model

3.1 Communication via routing maps

Using a road navigation service means the communication with a pre-calculated optimal route and a sequence of instructions guiding the user from one decision point (the present location) to another (the next location). Traditionally, the instructions use geometric data from the street network because there is no other data available (Martin and Stephan, 2002). This kind of orientation-based instructions is helpful for car navigation. However, it may not be sufficient for multi-modal navigation tasks which also rely on spatial information and the perceptual ability of the traveler other than road geometries. Human beings develop their own feelings for a route when they approach a specific and unfamiliar location. They tend to compare the surroundings with their mental map derived from their prior knowledge or other descriptions to make sure if their orientation is correct or not. Two different strategies of routing map generation are possible: 1) Classical Routing Map (CRM) that only present the geographical data; 2) Perceptual Routing Map (PRM) that includes the human factor during the navigation.

CRM has a long history as shown in Chapter 2, and it is also one of cartographic tenets which aim to provide a precise map for users (Dorling & Fairbairn, 1997). Designers of CRM usually rely on cartographic symbols which have been agreed in advance to transform geophysical data to a specific routing map. This kind of method has been also defined as Data-Driven Approach (DDA) by Klippel (2005). This conceptual communication of the mapmaking process directly relates data and map, in which map can be seen as the function of the geophysical data and other parameters such as color, shape, projection and so on.

However, as stated by Klippel (2005), the conceptualization process is essential for map design. In case of CRM, the given data sets have always been rendered in traditional mapmaking process according to cartographers' conceptualization of the spatial data or real world until interactive computerized visualization systems emerged. In other words, the conceptualization and generalization in the traditional mapmaking process only reflect the experts' experience without considering users' preference.

On the other hand, a routing map takes in most cases a diagrammatic or schematic outlook instead of showing the entire spatial dataset. The schematic representation focuses on a relevant set of spatial aspects (e.g., Barkowsky & Freksa, 1997). There is much freedom to represent highly focused, location-adapted and context-adapted information (Klippel, 2005). In a simple way, besides the route, lots of landmarks have been used to support the orientation (Habel, 1998, Michon & Denis, 2001). In addition, users are active when they try to match their mental map with the real environment.

Allen (1999) summarized user's behavioral abilities as being composed of perceptual capability, information-processing capability, previously acquired knowledge, and motor capability. Since the user plays an important role during routing, he or she should be regarded as a primary factor for the design of a routing map.

With the increasing awareness of user's behavioral abilities, the generation of personalized map which aims not only to satisfy cartographer's requirements but also to maximize the benefit of the user becomes more popular. The relationship of the cartographer and map user to the routing map and the real world is summarized and demonstrated in Figure 3.1 and 3.2.

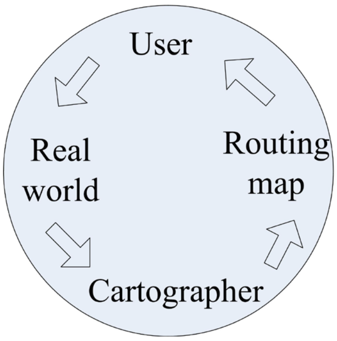


Figure 3.1 Communications of cartographer with the real world and the routing map

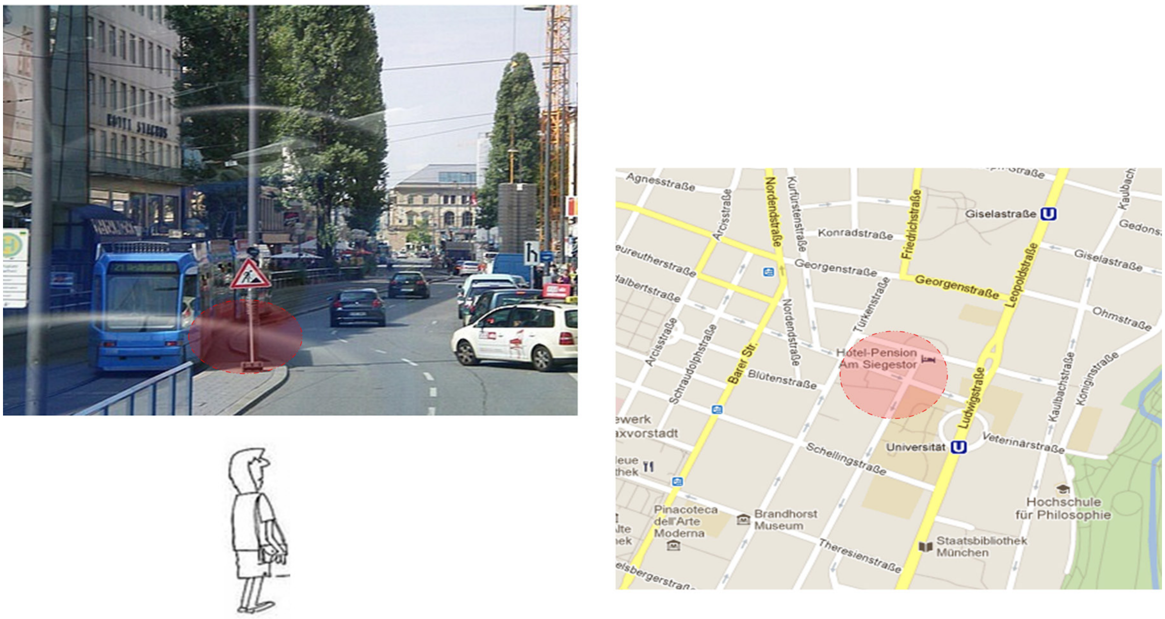


Figure 3.2 Communications of a user with the map and the real world

The term 'conceptual space' was proposed by Gärdenfors (2000) to indicate humans' understanding of the real world and routing map. Figure 3.3 illustrates a communication model of conceptual space-routing map.

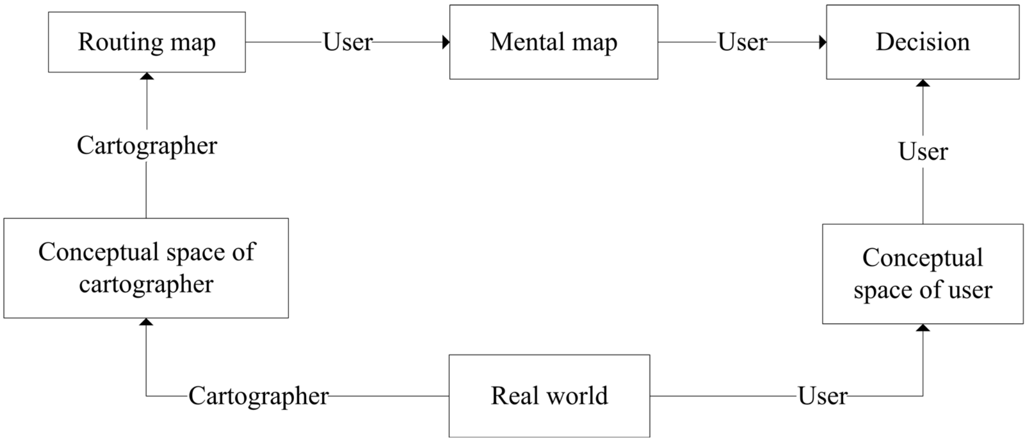


Figure 3.3 A traditional communication model of conceptual space-routing map

It is obvious in this model that the cartographer's perception of the real world (conceptual space) is the key factor for representing the route information. The perception of user (conceptual space of user) is totally neglected or considered only a little by the cartographer. In this thesis, we employ a hybrid conceptual space model to generate the routing map as shown in Figure 3.4, the routing map is derived from two conceptual spaces: 1) the conceptual space of cartographers with understandings of the route and their prior knowledge; and 2) the conceptual space from the user who generates the mental map from the prior knowledge and perception during the movement. However, according to the current development of cartographer, it is impossible or difficult for user to add symbols to a routing map in a professional way; therefore, the 'user' we discussed in this thesis is a simulated one. And we employed the dashed lines in the Figure 3.4 rather than solid line to describe the connection between the user and the routing map.

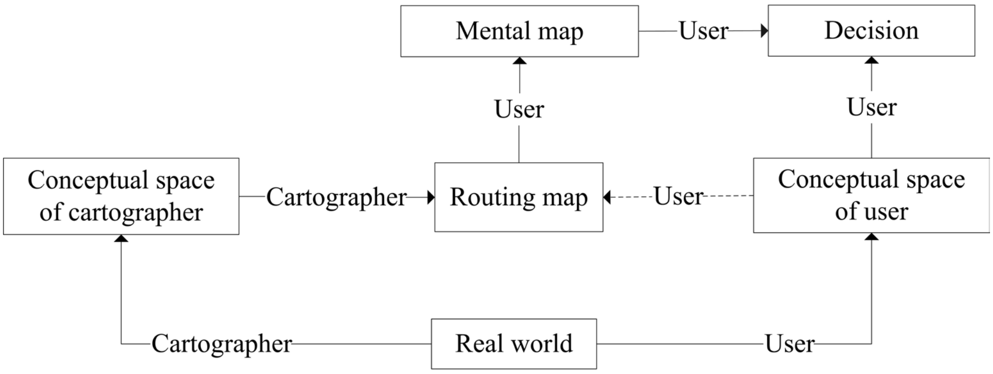


Figure 3.4 Cognitive communication of a routing map

As shown in Figure 3.5, we summarized the communication model as being composed of 4 steps. In the first step, a routing map is created on the basis of the cartographer's conceptual space as well as the routes from a network, and it is an exocentric map generation process (framed in black). In the second step, traveler forms the conceptual space or mental map by reading the routing map in advance or in real time (framed in blue). This phase aims to map the conceptual space from the cartographer to the user based on the exocentric reference frame so the user belief can have the same belief as the cartographer. In the third step, a conceptual space is constructed from the reality during the user's traveling through the environment based on an egocentric reference (framed in green). The last step is the decision-making process (framed in brown). As stated by Frank et al. (2000), when the two conceptual spaces matched well, the decision-making process became easier.

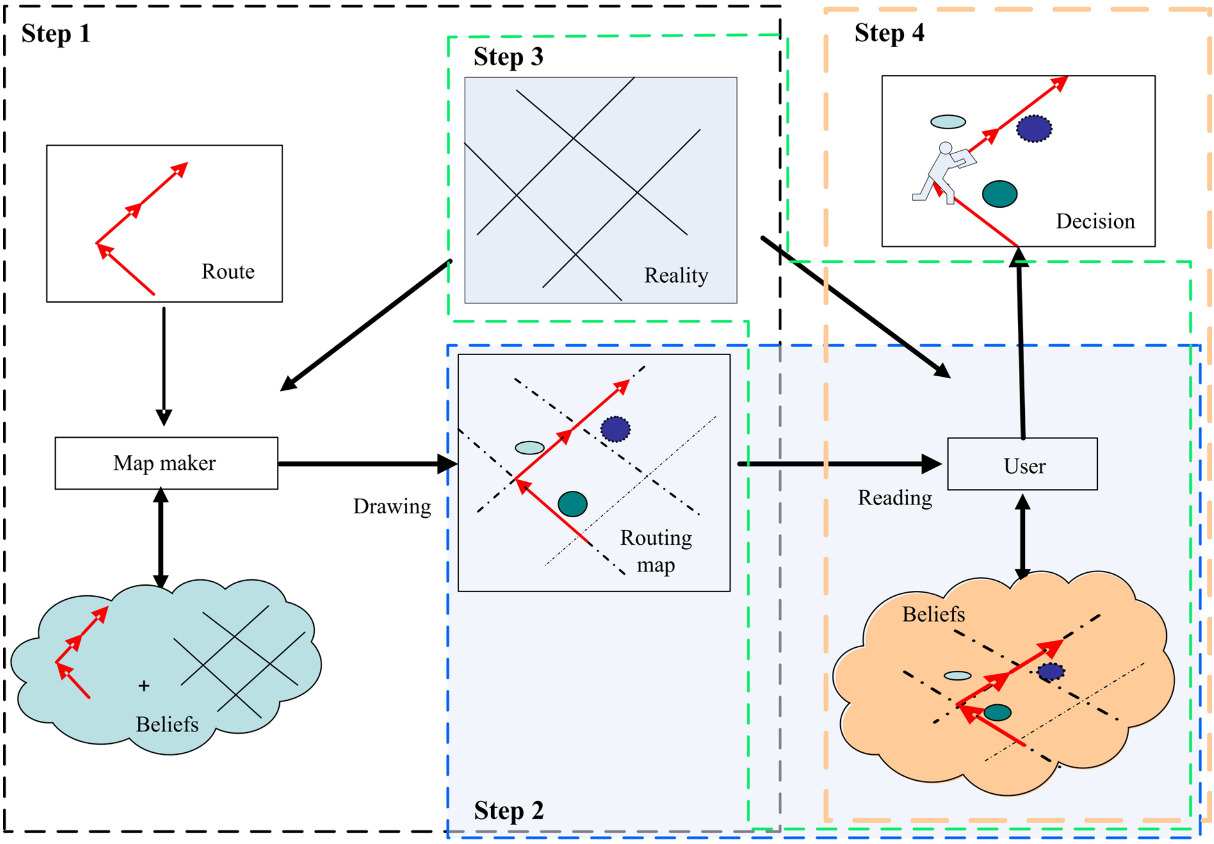


Figure 3.5 The communication model with a routing map

Based on the aforementioned analysis, we may define an attention-guided routing map model in which the interesting information is captured by both cartographer and user, or the information is evaluated both exocentrically and egocentrically as Figure.3.6 shows. Here, the interesting information originates from a spatial cognitive reasoning process and serves to reduce the mental work during the routing. It contains landmarks, information with high belief, reference points and information with high recall. Such information can be extracted both exocentrically by the cartographer and egocentrically by the users. In the following section, we will focus on the human perception during the routing as well as the related factors, our aim is to clarify the difference from the two perspectives and measure the salience separately.

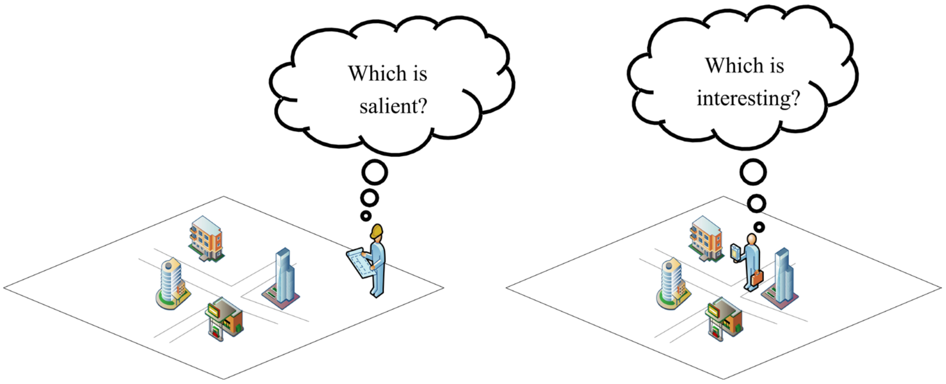


Figure.3.6 The framework of cognition-based routing map

3.2 Modality constraint

3.2.1 Visual perception in space

The perceptual space is defined as the view of spatial object at a particular time and from a fixed position. Mike Warren (1999) treated the perceptual space as a ‘mind-space’ with the visual factor as its key. The perceptual space is different from the physical space in the environment. We employ the perceptual space to describe the various perceptions associated with the motion such as driving, walking etc.

The cognitive process during routing can be divided into three phases as shown in Figure 3.7. It includes: 1) perception acquisition; 2) perception division; and 3) perception preservation. By simulating this process we can compute the salience which is the result of the final decision made by the traveler.

When the user travels through a physical space, he quickly attends to certain things in either passive or active way, and gets the general visual perception of the surrounding along the entire route. The most interesting information is stored in a short-term memory.

In the second stage, the general perception is divided into smaller pieces depending on the temporal or spatial scale. Each piece is terminated at a decision point or ‘viewing point’ by the user (to a specific routing task). The rule for the division is related to the applications, for example, by using a time interval of *n* minutes, or at a turning point.

In the final stage, the spatial entity is perceived along a sequence of viewing points. The final winners (or the highest belief from these perception pieces) are stored into the long-term memory and will be chosen and visualized on the routing map.

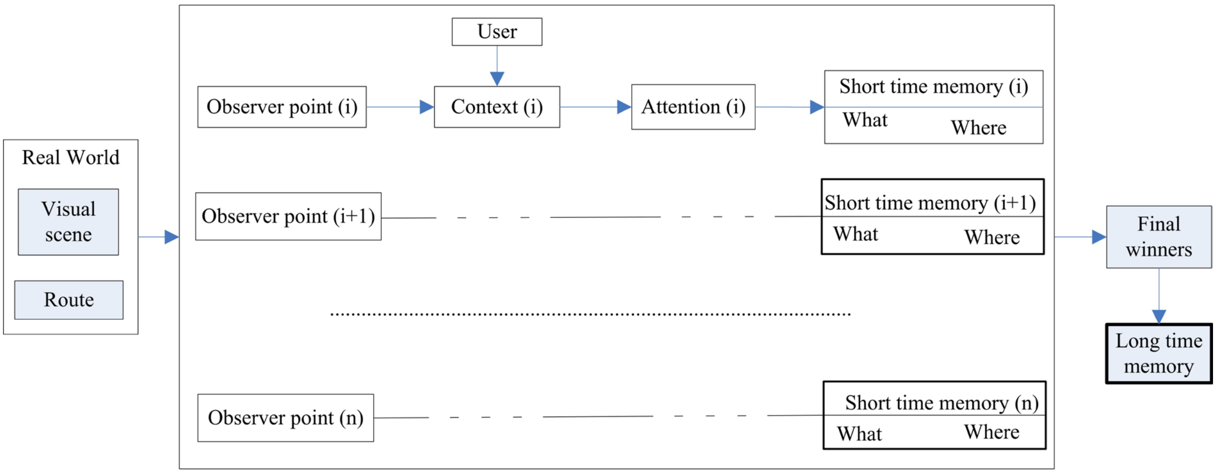


Figure 3.7 Process of spatial perceptual information

3.2.2 Influence factors of visual perception

Depending on the perceptual ability during the routing, the human attention captures the related information due to the ‘perceivable’ or ‘believable’ characteristic in the vicinity of an individual. It has been reported that perception is related to the human visual character, whereas the believable characteristic depends on the prior knowledge or task, so visual perception is the key factor for the traveler’s visual searching. It has become a well-known fact that the perception is influenced by the perceiver, the situation and the task. However, little has been reported about the influence of the travel modality. Therefore, before addressing the extraction of information of high belief from the different travel modalities, we discuss the traveler's visual ability in different situations during routing with the focus on the constrained visual space.

The most important factor of human perception is the visual field, and it is commonly defined as the visible area at a single glimpse, or the area within which a point source can be perceived without movement of the eye or the head (Grossman 1967). Mason and Kandel (1991) defined the visual filed as everything that (at a given time) causes light to fall onto the retina, 'visual field... is the view seen by the two eyes without movement of the head'. In related literatures, it is also referred to as the macular region (Henderson, 2003), which has a binocular overlap region of about 180 degrees in horizontal.

There are many influences of the visual field, like age, gender, speed and so on. Due to the complexity of human visual system, it is difficult or impossible to get the precise quantitative relationship between the visual field and the traveler's speed. Table 3.1 provides a set of empirical values.

Table 3.1 Visual field vs speed

Speed (km/h)	0	40	70	100
Angle of visual filed (degree)	160	95	65	40

Yang, et al (2005) deduced a function between the range of visual field and driving speed using a linear least square method:

$$\theta = -1.19V + 152.81 \tag{3.1}$$

Where θ is the useful visual field (degree), V is the speed (km/h) of driver, and $V \in [0,100]$.

The 'field of view' is the extension of the observable world, which is visible at any given moment. It represents the largest region of horizontal visual perception and it can be extend to approximately 280 degree (Arditi and Zihl, 2000). In contrast to visual field, the 'field of view' refers to the visual angle with the movement of eye and head. For example driving in a low speed allows the driver to move the head more frequently to check the outside of the car. Some attention map has been suggested based on the field of view (Swienty, 2008).

The field of view and visual field are both based on the assumption that the visual fixation is at the center of the view when the driver is looking at something. However, it is not always true for all tasks because participants do not necessarily focus on the visual stimulus to get interesting information (Larry, 2007). The physical structure of the eye, especially the distribution of rods and cones of the retina allows the perception of the stimulus without actually focusing on the center of the retina. As Figure 3.8 shows, an enormous density of cones in the fovea centralis allows both color vision and the highest visual acuity in the fovea. On the other hand, the rods are absent in the fovea. At a few degrees away from it their density rises to a high value and spreads over a large area of the retina. These rods are responsible for night vision, our most sensitive motion detection, and our peripheral vision.

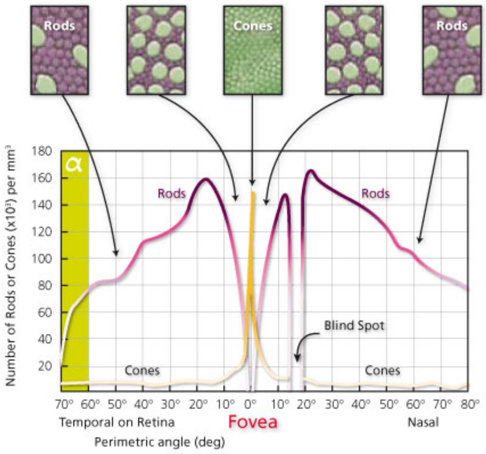


Figure 3.8 Rods and cones densities along the horizontal meridian[1]

In recent research works, the term ‘peripheral vision’ or ‘side vision’ which is about the view that surrounds the central part of the visual filed becomes increasingly popular. Experiment results in Table 3.21 show that the degradation mainly depends on the speed of the peripheral target (Rog, et al. 2002).

Table 3.2 Peripheral vision as related to speed (Dixon and Layton, 2010)

Speed (m/h)	Cone of vision from line of sight (degree)
64.5	37
80.5	29
96.5	20

These experiments show that with the increasing speed, the driver focuses more on the center of gaze, resulting in the decrease of the peripheral vision. The loss of peripheral vision while retaining central vision is known as tunnel vision and Figure 3.9 shows the relationship between the tunnel vision and the driving speed.

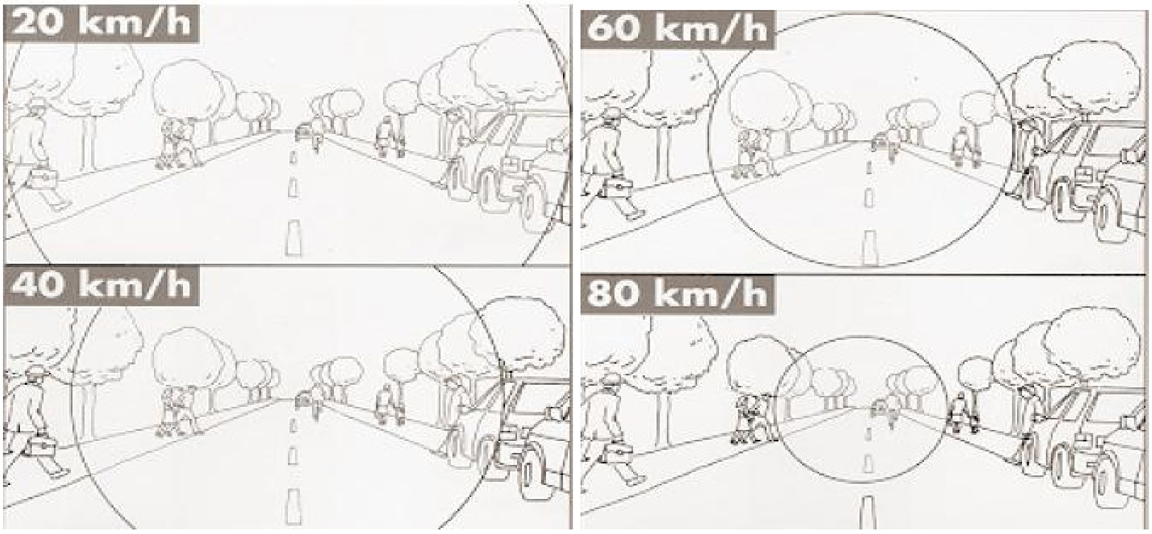


Figure 3.9 Tunnel vision depending on speed (Dixon and Layton, 2010)

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[1] http://thebrain.mcgill.ca/flash/i/i_02/i_02_cl/i_02_cl_vis/i_02_cl_vis.html

Besides the center and peripheral vision, the dynamic visual information, i.e. ‘Useful Field of View’ (UFOV), is also a research topic especially for fast movement. UFOV is defined as the region of the visual field, from which information can be acquired without any movement of the eyes or the head (Ball et al., 1988). The concept of the UFOV was originally introduced by Sanders (1970) who used the term “functional visual field” to indicate the visual field area over which information can be obtained in a brief glance without eye or head movements. Subsequently, Verriest et al., (1985) described UFOV as an “Occupational Visual Field”. The term “useful field of view” was first used by Ball et al., and has subsequently been most widely associated with a specific computer-based test. UFOV was used to assess visual processing speed, divided attention, and selective attention. UFOV was also defined by Rantanen & Goldberg (1999) as the area where more information of the stimulus must be extracted (e.g. the stimulus must be recognized, categorized, or identified), so UFOV is considerably smaller than the visual filed, and the relative size of UFOV is defined as the range of the visual field in which a subject can consistently localize 75% of peripheral target (Ball, et al. 1993). It becomes smaller at higher driving speed which demands a larger workload (Miura et al., 1998, 1999). Experiments have shown that the UFOV varies not only with different variables such as moving speed (Meza et al., 2009; Hidetoshi et al, 2007; Rog et al. 2002; Gilland, 2002), but also with the changing character of the subject. For example, the UFOV decreases with the age (Dixon and Layton, 2010; Ball et al., 1988).

Sanders (1970) summarized three categories of UFOV, i.e. stationary field, eye field, and the head field. Each field is defined as the range of the maximum angle at which the visual task can still be performed efficiently. In stationary field, the subject uses only near peripheral vision (20^{o} ~ 40^{o} of visual angle) to sense the stimulus of the target. In the eye field, only near peripheral vision works or eye movements need to be incorporated for its subsequent detection, when the stimulus is beyond the useful field in horizontal (40^{o} ~ 90^{o}). The vertical field (90^{o}) videtects the stimulus when the stimulus is beyond the useful range, so the eye movement and the head also need to be requisitioned. UFOV has also been deemed as the essential area in the field of view, from which one can extract a useful amount of information during a single fixation (Sekuler and Ball, 1986; Sanders, 1970).

Besides the visual range measurement, ‘visual acuity’ is another important factor for the visual attention, which includes the Static Visual Acuity (SVA) and Kinetic Visual Acuity (KVA). SVA is the ability to see stationary details, and it is influenced by the users’ characteristics. The ability to see the details of sign, mark, and geometric features is governed by the SVA of the driver. Furthermore, SVA is a function of the background, brightness, contrast, and time. KVA refers to the visual range, in which a moving target can be vividly seen (Wu et al., 2009). Suzumura (1971) defined the KVA as the ability to distinctly see a target which linearly moves forward and its characteristics can be summarized as follows:

(1) Decreases with the increasing velocity of target or self-motion;
(2) Improves with increased exposure time;
(3) Varies from driver to driver with the same static acuity.

Experiments have verified that the KVA decreases with the increasing mental workload. For example, the driver can see the traffic signs from 240 meter far away at the speed of 60 km/h, however, he can only see the signs from 160 meter when the speed has been increased to 80 km/h (Wang, et al, 2008). For this reason, KVA is also termed as the identifiable distance during moving, i.e. the maximal distance for humans to identify an object. They use Eq. 3.2

to describe the relationship between the identifiable distance and speed based on their experiment:

$$d_{iden} = -4.0V + 480 \tag{3.2}$$

With d_{iden} is the identifiable distance (meter); *V* is the speed (km/h), $V \in [60, 80]$.

The experiment by Pan et al. (2004) showed a relationship between the fixation distance and speed as Eq.3.3, the fixation distance is the distance between the traveler and the fixed point:

$$d_{fix} = 6.45V - 82 \tag{3.3}$$

With d_{fix} is the fixation distance (m); *V* is the speed (km/h), $V \in [40, 120]$.

According to the principle of the dynamic vision, the average reaction time is around 0.15 ~2.0 seconds for the driver to analyze a scene and then turns it to a meaningful perception. The target faster than the reactin time will be blurred and cannot be perceived. Therefore if we employed the meaningful perception time t=1.5s, the visible distance from the front of the vehicle can be calculated using Eq. 3.4 (Pan et al., 2004), and some spatial objects within the visible distance with their perception time smaller than 1.5s are not perceivable, therefore meaningless in our visual system.

$$d_{vis} = 0.417V \tag{3. 4}$$

Where d_{vis} is the visible distance from the front of the car (m); *V* is the speed (km/h). For example, when *V* = 60 km/h, the driver can only see something beyond 25m, while *V* = 120 km/h, the driver can approximately see 50m from the car.

Pan et al. (2004) represented the dynamic visual space as shown in Figure 3.10. It is determined by the useful visual field and the identifiable distance, but without considering the visible distance in front of the vehicle. With the increasing driving speed, the useful visual field gets narrower and the identifiable distance longer.

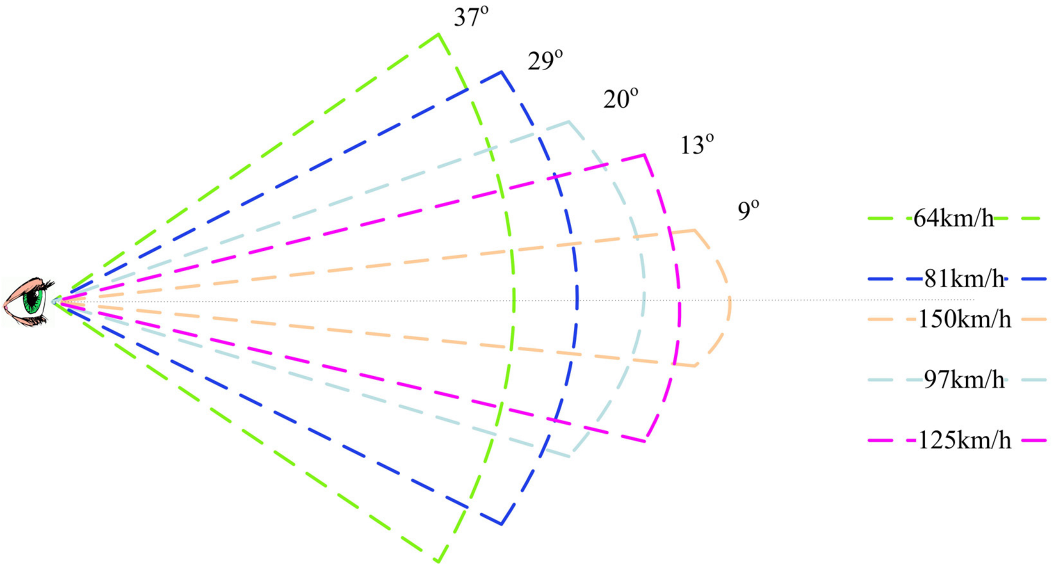


Figure 3.10 Dynamic visual spaces with the visual field and identifiable distance

From the above analysis, we may summarize the factors of visual perception in Table 3.3.

Table 3.3 Visual factors of perceptual space

ID	**Visual function**	**Definition**	**Influence factor**
1	Static Visual Acuity (SVA)	Ability to see static target	age
2	Kinetic Visual Acuity (KVA)	Ability to see moving target	age, velocity
3	Visual field	Visual range without head movement	age
4	Field of view	Visual range with head movement but without body movement	age
5	Field of peripheral vision	It is a part of visual field that surrounds the central portion of the vision field	age, velocity
6	Useful field of view	The visual field area over which information can be extracted (e.g. the stimulus must be recognized, categorized, or identified) in a brief glance without eye or head movements	age, velocity
7	Identifiable distance	Distance within which a target can be clearly seen	age, velocity
8	Visible distance	Distance beyond which a target can be clearly seen	age, velocity
9	Dynamic visual space	It is a space within which a target is visible, and the influence parameters are the identifiable distance, and the visual field	age, velocity

As can be seen in Figure 3.11, point O is the origin of the coordinates. X-axis is the intersection of horizontal visual plane and vertical visual plane, with right movements resulting in higher horizontal values and downwards movements resulting in greater vertical values. The line between eye and fixation point is defined as visual line, and the length of visual line is the fixation distance. Values θ and β are the visual angles on horizontal and vertical axes separately.

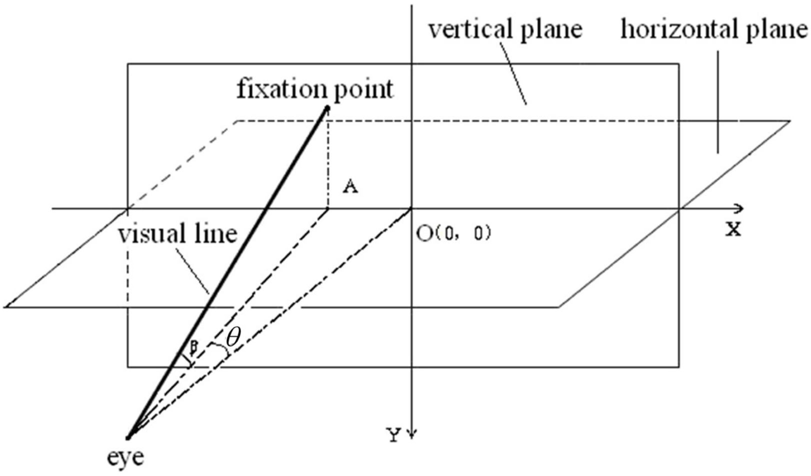


Figure 3.11 Diagram of eye position and the influence factors

3.2.3 Modality-constrained perceptual space

According to the discussion in the preceding section, the size and shape of the dynamic visual perceptual space rely on the speed and the personal characteristics of the traveler. In order to extract the higher belief information on the current location for traveler who is routing by a specific modality, we introduce the perceptual space model with modality constraint. This model is based on the above discussion and a simple idea that the shape of the monocular (as well as binocular) visual field is roughly elliptical.

Actually, the elliptical distances can effectively use spatial indexes (Seidl & Kriegel, 1997; Ankerst et al., 1998). For example Yoshiharu et.al, (2002) adopted an ellipse as region to retrieve and provide neighborhood information to moving objects. The elliptical region shown in Figure 3.12 is computed based on the past and future trajectories of the object and slightly biased toward the “future”. The black point is the current position of the traveler. Two different regions – a narrow ellipse and a nearly round ellipse have been developed to express the different situations.

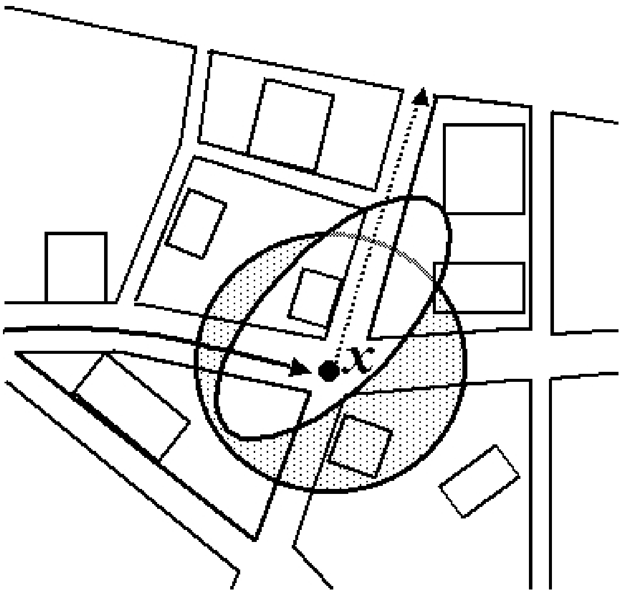


Figure 3.12 Adaptive ellipse for neighborhood information retrieves (Yoshiharu et al., 2002)

As stated by Yoshiharu et.al. (2002), elliptical region is appropriate and useful to get the neighborhood for the different routing behaviors. For example, for the straight roads driven with high speed, the ellipse may take an elongated shape (the white ellipse), and for the walking at a low speed, the ellipse is more round (the dotted ellipse). However, this model just pointed out that the user’s preference is the key parameter influencing the shape of ellipse; no explanation was given on why and how the travelers bias toward the “future” not others. Moreover, as discussed in section 3.2.1, the size and the shape of the dynamic visual field mainly depend on the modality or speed. The short-time memory is updated in comparison with the new perceptional information. The influence factors of the perceptual space should contain the previous passed through environment, the maximum extension visual filed of the current location and the future preference. We defined our perceptual space as follows:

The modality-constrained perceptual space is a perceptual space or mental image of traveler under a specific modality at each viewing point. It is derived from the visual field within which perception may be deployed and the short-term memory of the traveler at the last time. This area may be as large as the visual field, or is smaller, its size and shape depend on the traveler, the viewing point and the modality.

In the following section, we will model this modality-constrained perceptual space as ellipse (as Figure 3.13 shows). And the signs used in our ellipse model are explained in Table 3.4.

Table 3.4 Signs and their meanings

Name	Definition
M	The modality of travel may consist of walking, driving, cycling and motorcycling and the public transport
R	The planned route which involves the start and destination point and the characteristics of the route (e.g. the time, modality and speed etc.)
d_{fix}	The identifiable distance at a viewing point
θ	The visual field at a viewing point
o_1	The current viewing point (x_1, y_1)
o_2	The next viewing point (x_2, y_2)
o_c	The center of the ellipse (x_c, y_c)
a	The length of the semi-major axis of the ellipse
b	The length of the semi-minor axis of the ellipse

As Figure 3.13 shows, the two focus points of the ellipse (the gray point and the black point) are defined as the two viewing points, the center of the ellipse o_c (red circle) can be computed by Eq.3.5. The maximum angle from the viewing point (o_1) to the boundary of ellipse is defined as the visual field θ, and the semi-major (a) and semi-minor (b) of the ellipse are calculated by Eq. 3.6 and Eq.3.7 respectively.

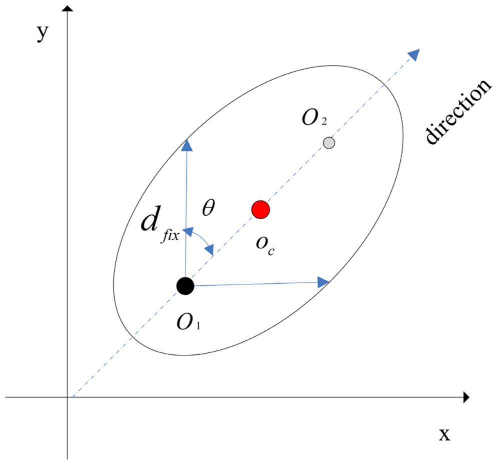


Figure 3.13 Modality-constrained perceptual spaces

$$\begin{cases} x_c = x_1 + d_{fix}.\cos\theta \cdot \cos\beta \\ y_c = y_1 + d_{fix}.\cos\theta \cdot \sin\beta \end{cases} \text{ with } \beta = arc\tan(\frac{y_2 - y_1}{x_2 - x_1}) \tag{3.5}$$

$$a = d_{fix} \tag{3.6}$$

$$b = d_{fix} \cdot \sin(\theta\ ) \tag{3.7}$$

Although these constraints of visual perceptual space are designed only on the basis of the self-movement variables such as modality, speed, and direction, they can be extended to include other variables such as age, sex, and weather conditions. For example, in foggy weather condition, smaller d_{fix} should be assigned. Similarly, different d_{fix} can be tuned for different ages.In addition, there are three main reasons for us to employ the constrained ellipse for our dynamic perceptual space. The first reason deals with the determination of the exact shape of the perceptual space. Lots of research works have been reported that the shapes of the visual lobe which were significantly different from the circles were also significantly different from the ellipses. The term visual lobe which aims to measure a slice (an area) of the volume is referred to the limit of peripheral sensitivity for a particular task and background characteristics (Chan and So, 2006). However it was agreed upon that the length–width ratio is larger for an easier task than for a more difficult task (Rantanen & Goldberg ,1999). For example, the length-width ratio of the static viewer is larger than that of a driver. The second reason is related to the distribution of attention. Some researches such as Jing (2011) considered the distribution of attention in the visual field as a bivariate probability distribution over the visual field, and it is continuous in space and time. The continuity in space implies that the attentional intensity at any given location within the attended area is larger than zero. Furthermore, the focus of the attention is associated with a higher attentional intensity than surrounding locations. In general, it decreases with an increase in the distance from the fixation point. Continuity in time suggests that the distribution of attention may change to reflect not only the current attentional process, but also the history of previous processes (LaBerge & Brown, 1989; LaBerge, Carlson, Williams & Bunny, 1997). Finally, the third reason is about the height of viewing point which affects our perceptual space in the vertical dimension. The average height of viewing point varies with the travel modality as Table 3.5 shows.

Table 3.5 Height of viewing point

Travel modality	Eye height (m)
Driver	1.15
Cyclist	1.4
Motorcycles	1.3-1.6
Pedestrian	1.5

These different heights of viewing point are derived from the physical characteristics of traveler (as shown in Figure 3.14).

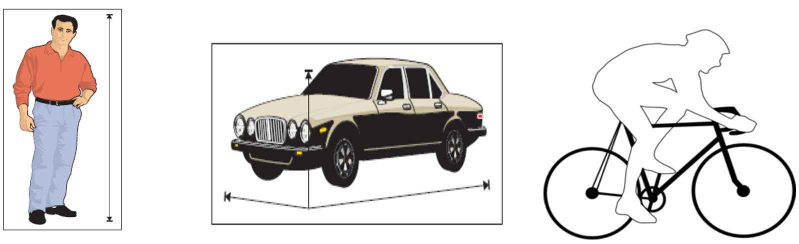


Figure 3.14 The physical characteristics of a traveler (a: Pedestrian; b: Car driving; c: Cyclists)

3.2.4 Metric representation of visual perceptual space

Visual perception and cognition is a complex spatio-temporal process that involves many variables such as weather conditions, movement modalities, tasks, personal characteristics etc. Therefore, it is necessary to formalize the metrics for the spatial-temporal assessment. In the symbolic approaches (phlyshyn, 1984; Pinker, 1997) and associationism models (Quinlan, 1991), investigations were made to answer the questions such as how to compare, share and compute the information between the system and the user, between different users, or in different situations. Gärdenfors (2000) proposed a conceptual space to quantity the dimensions within a metric structure which has been extended to users' action (Gärdenfors, 2007). The conceptual space can be formalized as a vector space consisting of *n* dimensions orthogonal to each other. Each dimension represents a specific character of the whole space. An individual concept is represented as a point in the *n*-dimensional conceptual space. The concepts are dynamic (Barsalou, 2003). Comparing to other methods, the conceptual space takes more essential aspects of human's conception into account than the symbolic approach, and reveals three advantages: 1) it allows us to consider the fact that different people have different conceptualizations of the world; 2) it allows to express the similarity between objects as the spatial distance (Schwering & Raubal, 2005); 3) it allows to assign an adaptive weight to each dimension depending on different contexts.

Raubal (2004) formalized the conceptual space, particularly by means of projection and transformation, in order to implement the reasoning capability. In this section, we extend Raubal's formalization to accommodate the requirements for multi-modal navigation. We divide the conceptual space into a number of subspaces, each representing a special domain with its own dimensions. For instance, the visual scene and the modality can be regarded as two subspaces. A visual scene can be described by three dimensions – structure, semantics and visibility. The relative importance of each dimension is expressed by a weight factor. The modality is related with the traveller who may care about a number of changing aspects during the travel. Each aspect again should be assigned a reasonable weight.

Before using the described conceptual space, it's important to normalize the measurements of the individual dimensions. The Z-transformation algorithm (Bahrenberg, 1999) (Eq. 3.8) is adopted in our model:

$$Z_i = \frac{x_i - \overline{x}}{s_x} \tag{3.8}$$

with Z_i is the new value of the measurement *i*; x_i and $\overline{x}$ are the value of the original measurement *i* and the mean value of all original measurements of the dimension *x*, and s_x is the standard deviation of *x*.

Following the definition of conceptual space, the salience of a concept can be expressed using the semantic distance in the conceptual space, where the concept is represented as individual point. Analog to the Euclidean distance, the semantic distance between concept *u* and *v* could be computed in the following steps (Gärdenfors, 2000):

a. Variables normalization

$$\begin{cases} (u_1, u_2, \cdots, u_n) \to (z_1^u, z_2^u, \cdots, z_n^u) \\ (v_1, v_2, \cdots v_n) \to (z_1^v, z_2^v, \cdots, z_n^v) \end{cases} \tag{3.9}$$

b. The semantic distance between *u* and *v*:

$$\left|T_{uv}\right|^2 = (z_1^v - z_1^u)^2 + (z_2^v - z_2^u)^2 + \cdots + (z_n^v - z_n^u)^2 \tag{3.10}$$

The following sections will address the question in the conceptual space about how to get the optimum solution for a given problem in multi-modal navigation.

3.3 Quantitative evaluation of cognitive element

After constructing the perceptual space and its metric representation, the characteristics of cognitive elements are transferred to various space vectors. In the neural system, the individual concepts within the conceptual space change dynamically along the route or in a scene. The visual salience of an object in conceptual space is stored before the next salient object pops up. The focus is shifted from one object to another. This process involves a pre-attentive stage and a post-attentive stage (Wolfe 1994). In the first stage, several object dimensions, e.g., shape, size, color and visual factors are computed in a parallel and bottom-up manner. The second and top-down stage is dependent on the low-level objects. It requires each object to be weighted by additional information such as task, prior knowledge etc. and guides visual attention in a sequential manner. Therefore, the assessment of the believable degree of an object is essentially reflected in its visual salience and relevance degree for each conceptual space or for each specific context; its cognitive optimization is based on the Eq. 3.11.

$$f = \arg\max \left\{ \sum_{i}^{n} \left(S_{x-i} \cdot R_{x-i} \middle| CS \right) \right\} \tag{3. 11}$$

where S_{x-i} represents the salience, i.e. attention degree of perception at viewing point *i*; R_{x-i} is the relevance, i.e. task-related attention at the same viewing point; *n* is the number of viewing points for a specific route or the number of the scenes; *CS* is the specific conceptual space for a traveler during routing, and it is the perceptual visual space at each viewing point. For cartographer, it is the perspective of the surrounding and the route.

S_{x-i} and R_{x-i} are intrinsically related instead of independent of each other, although they can be separately computed for each subspace. An in-depth study on relevance is reported by Reichenbacher (2006). Therefore, we will focus in our study more on the evaluation of salience information. As argued in Section 3.1, humans perceive spatial information from two reference frames, i.e. exocentric and egocentric perspective, which correspond to the conceptual space from cartographer and user.

3.3.1 Exocentric perspective

In order to understand the natural space from a synthetic perspective, we perceive the landscape exocentrically, which is an exterior view of things. When we perceive an overall space, we regard ourselves as subjects traveling on the surface of the map.

In the Image of the City, Lynch (1960) identified five cognitive elements that people use to form their mental representation of cities: landmark, path, district, node and edge. Indeed, these elements have a number of properties that make them essential in navigational task and in the general understanding of a new environment. Among those properties, visual salience, semantic salience, and structural salience are three well-accepted properties. From the exocentric perspective, the salience is only based on the mutual relationship between the geographic object and its environment and it can be measured by using intrinsic attribute and spatial context-dependent attribute.

The intrinsic attribute does not depend on the object's relations with others. For example, the shape and size of objects can be intrinsically salient (Susanna, 2007; Noë, 2004, 2005).

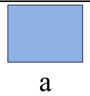
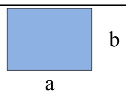
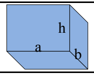
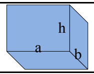
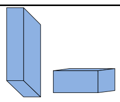
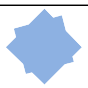
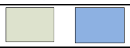
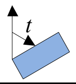
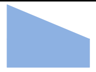
Table 3.6 gives an overview of the intrinsic attributes of a building. According to their relative accessibility and influence, these intrinsic attributes are used with different frequencies. We may group them into four classes: always, often, sometimes and seldom. For example, the height of a building can be easily accessed and differentiated, and it is always used in tourist maps to indicate the important landmark. The perpendicular angles of a building can be hardly accessed, although it is also an important attribute. These categories are fundamental for our landmark salience assessment.

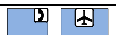
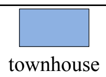
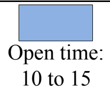
Table 3.6 Intrinsic attributes

Always	**Often**	**Sometimes**	**Seldom**
Size	Depth	Explicit mark	Perpendicular angles
Area	Building corners	Orientation	Existence duration
Height			
Color Form			
Shape factor			
Usage function			
Culture / history Visibility			

The details of these intrinsic attributes are demonstrated in Table 3.7.

Table 3.7 Details definition of intrinsic parameter and measurement

No.	***Graphic***	***Attribute***	***Description***
1		Building length	The maximum length of a building a
2		Building width	The maximum width of a building, b
3		Building area	A=a*b
4		Building height	The maximum height of a building h
5		Building size	S=a*b*h
6		Building form	Deviation from a typical building: length/width
7		Building shape factor	$F = \frac{h \times 2}{a + b}$
8		Number of corners:	Countable quoins
9		Building color	Dominating color of building facade
10		Orientation	Main alignment of a building in comparison to the North
11		Perpendicular angle	Generic characteristic of building outline

12		Cultural and / or historical meaning	The cultural or historical events related to the building
13		Explicit mark	Special function of a building
14		Existence duration	temporary or durable building
15		Building function	Functional type of a building
16		Opening time	Accessibility of a building

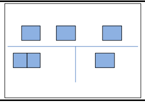
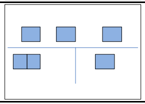
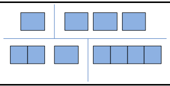
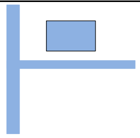
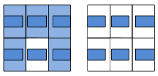
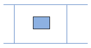
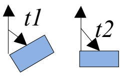
Context-dependent spatial attributes are functions of the intrinsic attributes and the context in which the object is located. Usually, people recognize an object because of its outstanding appearance in its local context. In Table 3.8 we summarize some context-dependent attributes in four categories.

Table 3.8 Context-dependent attributes

Always	**Often**	**Sometimes**	**Seldom**
Neighborhood density	Neighborhood land use	Orientation to neighbor	Difference form surroundings
District density Adjoined or detached building	Ratio of Building size to parcel area	Form of parcel	
Building at intersections			

The details of these context-dependent attributes can be presented as Table 3.9 shown.

Table 3.9 Details definition of context-dependent attributes measurement

No.	***Graphic***	***Attribute***	***Description***
1		Neighborhood density	Number of buildings within a certain area
2		District density	Number of buildings within an administrative unit
3		Relation of a building to its neighbors	Detached, adjoined
4		A building at an intersection	The crossing roads can be scored based on their relative importance
5		The land use of neighborhood	Difference of the building to its surrounding in terms of land use
6		Ratio of footprint size and its parcel area	Relative dominance of a building in terms of its footprint area
7		Orientation of a building relative to its neighbor	Angle difference to the neighbor

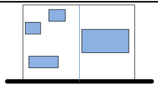
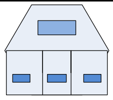
8		Number of buildings within the parcel	Countable buildings
9		Shape of the parcel in which the building is located	The number of corners, the number of neighbors

Figure 3.15 shows two different contexts of the same objects, leading to their different degrees of salience in each local context (Knopfli, 1983; Li, 2002). Figure 3.16 shows the different salience degree of the house *A* and *B*, although they share the same intrinsic attributes (David, 2008). It is obvious that the salience degree of building B is larger than the building A.

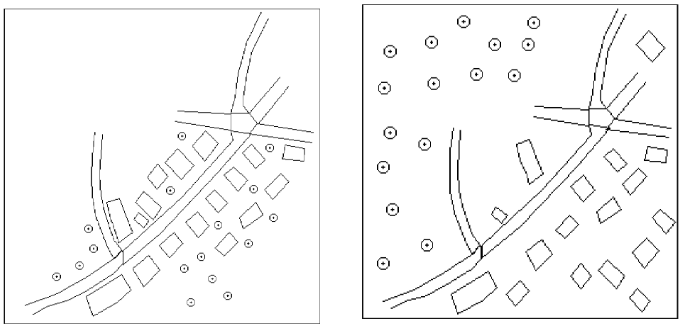


Figure 3.15 Different layouts with the same objects (Knopfli, 1983; Li, 2002)

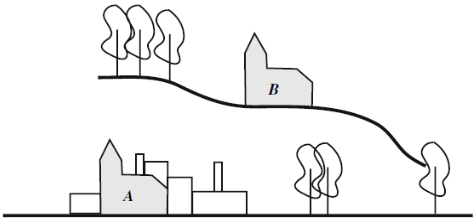


Figure 3.16 Object A and B situated in two different scenes (David, 2008)

The intrinsic attributes describe the salience of a spatial object using similarity or dissimilarity of the distance, which could be either Euclid distance or logical fuzzy entropy. The salient object has the largest dissimilarity or smallest similarity distance to its neighbors.

The spatial context-dependent attributes usually serve as an auxiliary parameter to the intrinsic ones. The strategy of salience measurement includes two steps. The first step is to partition the spatial space into small cells, for example, by applying the Voronoi Diagram. Each spatial object is assigned one cell which has one or many immediate neighbors. The second step is to calculate the similarity of each cell to other cells in the neighborhood.

Spatial auto-correlation is used to represent the similarity between the objects according to their intrinsic property and the distances among each other. Different approaches have been developed to measure the spatial auto-correlation. In this thesis, we regard the similarity as a spatial local outlier problem, and the spatial local outlier factor S_{ex} is expressed as in Eq. 3.12:

$$S_{ex} = \arg\max\left\{P(X_i|E)\right\} \tag{3. 12}$$

where X_i is an object i with attributes like color, size and so on, $P(X_i|E)$ is the probability of the spatial object i as a spatial local outlier within the environment *E*, $E = (X_1, X_2, ...X_n)$. The environment is usually termed as the local neighborhood. It could be a small area, for example, the immediate neighborhood in the Voronoi Diagram, or a larger area in a road network, a city or even a country.

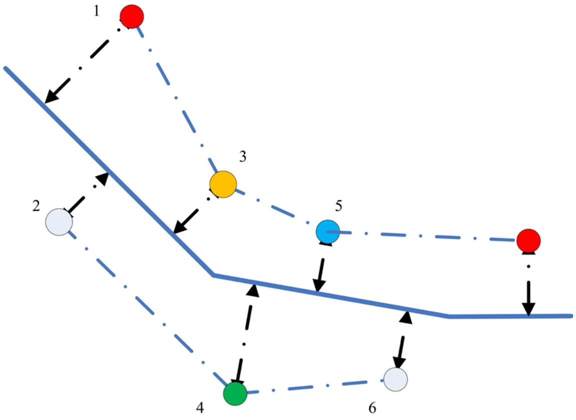


Figure 3.17 Relationship between a route and a number of spatial objects

In case of routing, we can analyze the spatial relationship among objects from the exocentric perspective, although the route is only a temporary spatial feature on the map with a physically tangible and visible form. The assessment of exocentric salience information also benefits from Eq. 3.12. As shown in Figure 3.17, the spatial object in question here is a line rather than points. A number of additional attributes should be considered as Table 3.10 shows.

Table 3.10 Route-dependent attributes

Always	Often	Sometimes	Seldom
Proximity to road	Distance to destination	Distance to starting point	Alignment to street

3.3.2 Egocentric perspective

It is common that we always perceive objects from a particular location, under particular illumination conditions. Only part of the environment or an object can be perceived under specific location and specific time. Susanna (2007) and Matthen (2006) defined the situation-dependent properties as properties of the object given the perceiver's location and the specific time. As discussed in Chapter 2, the salience in the egocentric perspective is based on the trilateral relationship among the observer, the environment and the geographic features. The observer perceives or prefers some geographic objects which have higher contrast to the environment. So we regard the perceptual salience as the salient information or high contrast from the user perspective in the various situations. It is a function of the object's intrinsic properties and the perceiver's situation. In this sense, the route is no more the physical body in the environment, and it is transferred into trajectory of points or a sequence of perceptual points called viewing points. In this case, the attributes of the spatial objects and their relationships are transformed to situation-dependent properties i.e., perceptual attributes such as the perceptual distances, perceptual shapes and so on. Figure 3.18 is an example of the situation-dependent properties for a building.

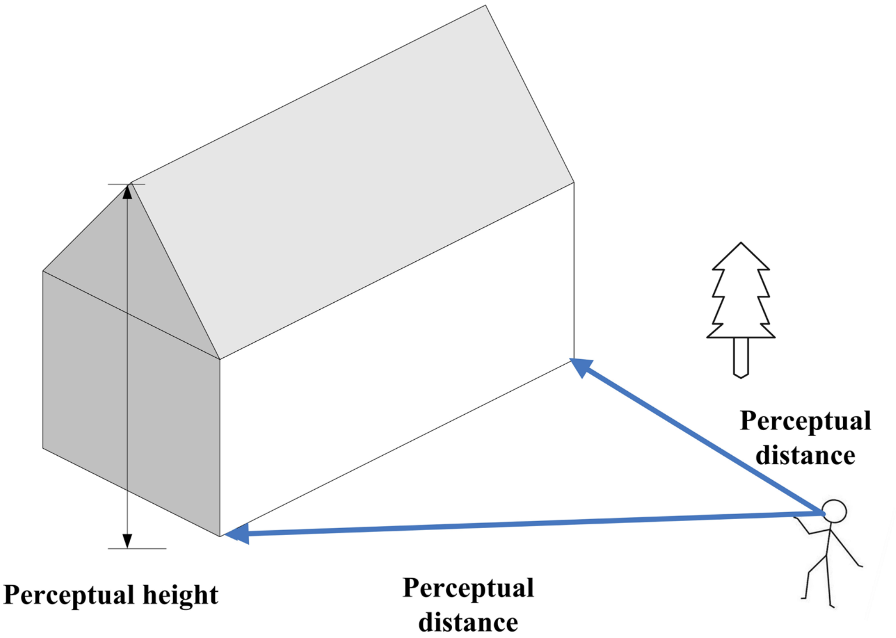


Figure 3.18 Situation-dependent properties of a building

Similar to other properties, we summarized these situation-dependent attributes in four categories as Table 3.11 shows.

Table 3.11 Situation dependent attributes

Always	Often	Sometimes	Seldom
Perceptual shape Perceptual distance Perceptual area Perceptual height	Perceptual orientation Perceptual size	Perceptual width Perceptual length	Perceptual difference from surroundings

As we know, the perceiver in the world is not just a passive receiver of information, and his perception is dependent on action, for example, walking, driving, and reading etc. These actions restrict the perception of the surrounding into a specific viewing angle or in our dynamic perceptual space as proposed in the section 3.2.3, not all the extension of our visual field. For example, as discussed above, for a driver who driving a car at 80km/h, his maximum of viewing angle is about 60° in horizontal direction. So the salience measurement by these situation-dependent attributes does not obey the traditional triangle relationship. Besides the traveler, the parameters are extended to four components: the location (viewing point), environment, spatial object and the action. In our thesis, we narrow the term action to the modality. The perception process is illustrated in Figure 3.19.

In addition, when the traveler is moving forward during the routing, the highly salient information is stored and updated in the mind. The frequency of updates depends on the traveler’s experience. Any highly salient information shall strive for the chance to become the final winner and be stored in the long-term memory. According to the principle of spatial cognition, the longer an object remains in the short-term memory, the larger the chance it has to be shifted to the long-term memory. The time remaining in the short-term memory depends on the degree of salience and the frequency of an object as a salient one along the entire routing.

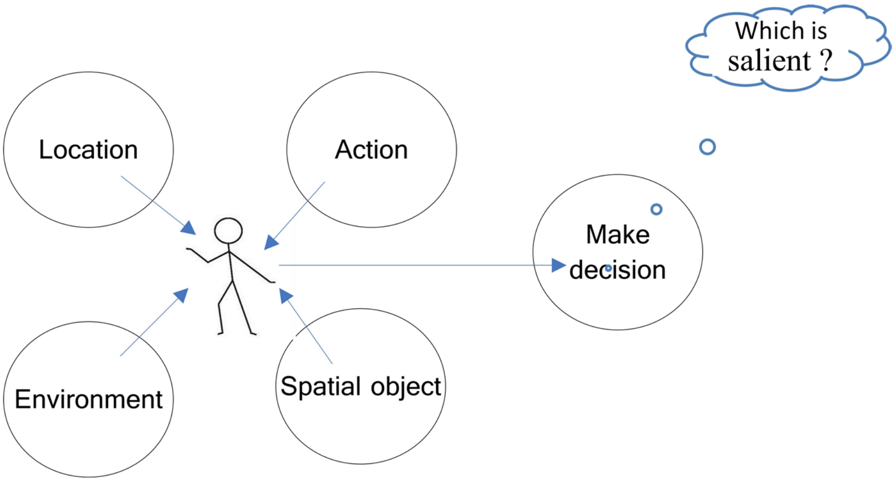


Figure 3.19 Perception process with situation-dependent attributes

Figure 3.20 demonstrates the process. To the left, it is a scenario which simulates a driver passing through a turning point consists of the route, the surrounding and the car. To the right, the routing and the mental map generation processes are simulated. Before a driver passes through the turning point (abstracted as the black point along the route in Figure 3.20 right,), four spatial objects - the *turning point*, the *house*, *parking sign*, *stop indication* and *traffic light* are visible in driver's perceptual visual space. After the driver has passed through the turning point, again four spatial objects *parking sign*, *zebra crossing*, *traffic light* and *tree* are in his perceptual visual space. The *zebra crossing* is remembered for the second time and therefore has the highest salience in this case.

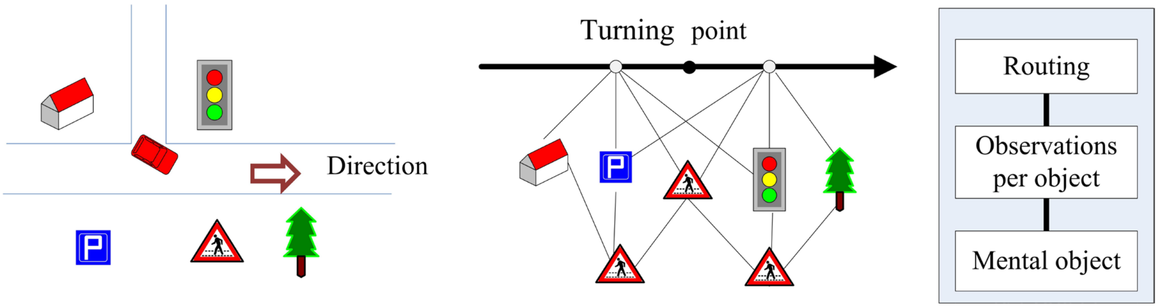


Figure 3.20 Cognition salience (modified from Caduff and Timpf, 2008)

It is reasonable to choose the time interval or specific location as the decision point which could be converted to each other in a specific scenario. The sequence of decision points is used for the salience evaluation. Suppose that there are *n* spatial objects along the route and *m* observer points, z_{ij} is the salience of a spatial object *i* at viewing point *j* , the overall salience s_i of this object is the weighted sum of its salience at all viewing points (see Eq.3.13).

$$s_i = \sum_{j=1}^{m} z_{ij} \cdot w_j \tag{3.13}$$

where the w_j is the weight of each viewing point *j*. Due to the linear characteristic of the route, it is reasonable to assume that objects nearer the destination point of the route have proportionally larger contributions than objects far away. In this way, the weight for the decisive point can be expressed as Eq.3.14.

$$w_j = (D - d_j) / D \tag{3.14}$$

where d_j is the distance from the decisive viewing point to destination, and D is the distance from the start point to destination.

3.4 Representation based on an adaptive context

In order to improve the usability of map, specific visualization variables were employed to represent spatial information in a hierarchical style (Swienty, 2008). Traditional maps like printed maps have a read-only nature and can therefore only present permanently salient information such as city center and capital name from an exocentric perspective. The usage context cannot be changed once the map is completed. On a mobile map which has a limited display size, on the other hand only a small facet of a digital landscape data can be visible. The context information for navigation is often minimized or omitted (Meng, 2005, 2009). With the further development of Internet map and the popularization of mobile map services, neither the presentation of unchangeable information nor the naked egocentric perspective on a mobile display can satisfy the user requirements. How to accommodate different levels of details, especially how to hierarchically display the context of a route or a location as shown in Figure 3.21 has become a challenging cartographic problem. In other words, it is demanding to rank the relevant mapping objects at a specific time and represent them in an order, e.g. using the white number with the drogues in Figure 3.21 and the overlapping number in red at the same location.

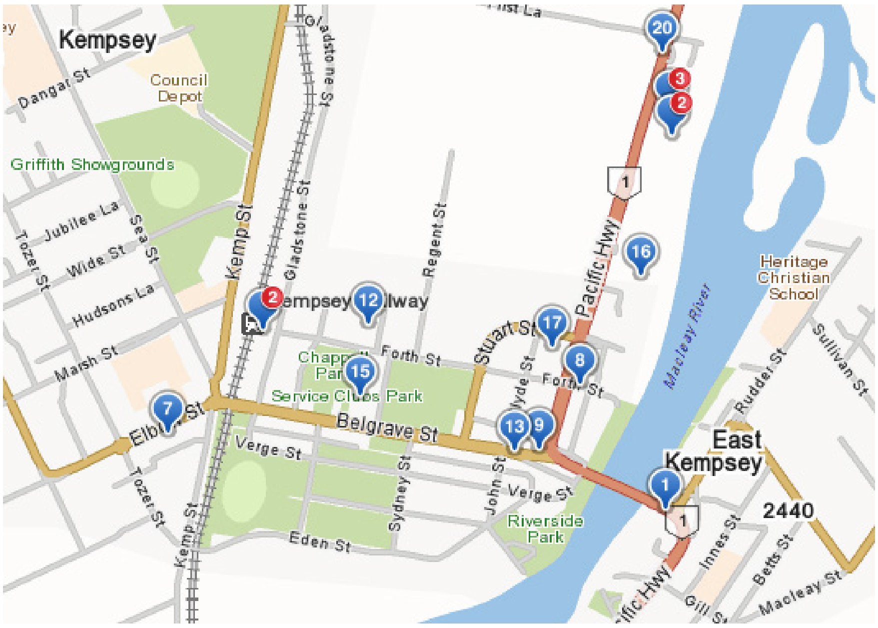


Figure 3.21 Hierarchical representation of POI

It is an example from whereis.com (the white number on these drogues express the relevance or salience degree to the screen center and the red number represent the number of overlap POI at the same location)

Based on the analysis from both the exocentric and egocentric perspective, we intend to create route maps with hierarchical salience information derived from the context. Two steps are involved: the first step is dedicated to the selection of salient objects which are then sorted into a hierarchical order. This hierarchical order will guide the cartographic generalization in the second step. For example, landmarks in a city can be treated at different levels, according to the size of the reference region. A local landmark is defined by the so-called “vista space”, whereas a global landmark is the landmark that refers to a larger region.

According to Winter (2008), the ‘vista space’ is related to the traveler as well as his location in the travel modality. In the vista space, spatial objects can be compared and graded from the egocentric perspective. However, for the global landmark, a larger space is involved and embedded in a dynamic context which includes the location and identities of nearby people or objects (Schilit and Theimer 1994) or can be extended to embrace related objects in the applications (Brown et al., 1997; 2000; Chen and Kotz, 2000; Dey, 2001). Numerous previous studies have been conducted for mobile usage. Nivala and Sarjakoski (2003) defined the surrounding context according to the location of user, user tasks, the location and orientation, time, social physical, cultural surroundings and so on, as shown in Figure 3.22.

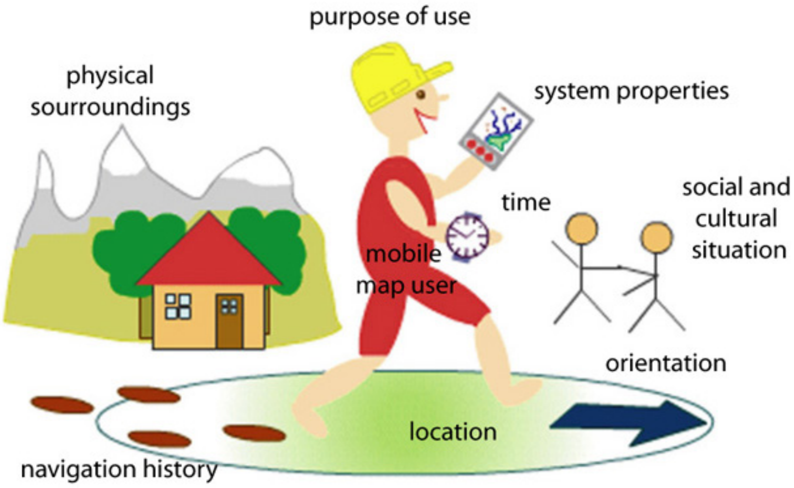


Figure 3.22 The context of a mobile user (Nivala and Sarjakoski, 2003)

Koile et al, (2003) proposed an activity-centric view focused on the information relevant to user’s activity. The key components of this view are users and activities. Taking into account the individual user with his knowledge, abilities, focuses of attention, or emotions, Freksa et.al (2007) defined context as being composed of situation context, mental context and map context. They extended the internal influence factors of the context from users’ profile, task, and activity to user’s perception and cognitive abilities. They treated the map context as the related information of representation constraints, and the representation context is related to spatial objects for a certain display style that may affect relevant information generation and interpretation process. For map generation, the representation context contains entities that influence the map generalization process; for map interpretation, the representation context contains entities that capture the map user’s attention. This context is dynamic and adaptive. As shown in Figure 3.23, the study area (1) can be changed into different displace areas (2)-(4) according to different operations, leading to different results of salience assessment.

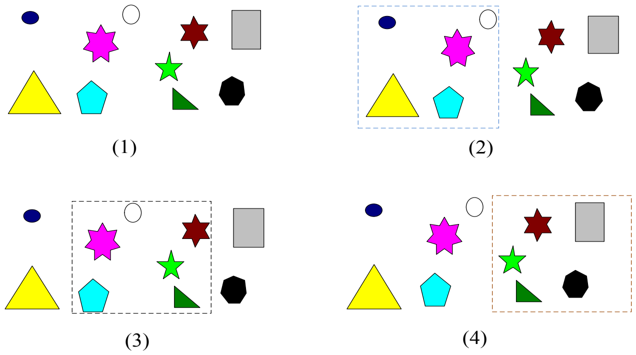


Figure 3.23 adaptive contexts for representation (2)-(4) three different display areas of (1)

Within the representation context, not all the objects from a study area will be involved in the hierarchical evaluation for a specific scenario. In the implementation process, we use the display size as the representation context. In case of routing map creation, the display size serves as a boundary and the related information within the region is filtered and evaluated. Two strategies are employed: for long routes exceeding a given threshold, the spatial related data is derived from a specific representation scale of cartographic generalization; otherwise, the context should be derived from the original data source.

Chapter 4

Generation of cognitive routing maps

4.1 Cognitive elements of routing maps

4.1.1 Travel in a multimodal context

Routing through a familiar or unfamiliar environment to reach the destination is the basic task of navigation. It requires extra information about the environment, for instance, street name, landmarks, proximal and directional instructions etc. to increase the accuracy, efficiency, comfort, and safety during the navigation. The selection of suitable extra information is often task-driven and must consider specific user groups. For drivers on the highway, for example, the selection of the road name is better than selecting a restaurant name which is more suitable for a pedestrian. Therefore, the extraction of suitable information or cognitive elements for route description is a context or scene-dependent problem that needs a careful consideration of multiple parameters. As described in Section 2.3, landmarks have been extensively used as a remarkable cognitive element to enrich the route description because they indicate conceivably the most fundamental spatial information in the environment, both visually and semantically.

Landmark-based navigation was introduced by acquiring the knowledge about prominent or salient objects to guide travelers through the environments in (Hampe & Elias 2004; Lee, Tappe, & Klippel, 2002). The salient objects usually exist in a way that travelers can easily access them with a unique value such as outstanding appearance, important semantic attributes at a prominent location. In contrast to the network-based navigation with the street name indication, landmark-based route description has more cognitive ability, which has been verified by lots of previous work. However, automatic generation and incorporation of landmarks along a route for users in a multimodal context (Liu, 2010) is a highly complex task because this process involves not only the extraction of salient features, but also the traveler's psychological skills of perception, cognition and intuition. As shown in Figure 4.1, travelling through the environment is a spatial-temporal task. Caduff and Timpf (2008) reported that the complexity was related to the 'good' landmark in a specific context, and they argued that the original definition of the landmark was a distinct geographic feature used by hunters, explorers or others to search the way back through an area on a return trip. The modern usage of the term is nearly the same. A landmark can be any features or even idiosyncratic objects in the environment that can be easily recognized. In this thesis, we term landmark as any salient feature along a route.

Since Lynch (1960) introduced the concept of landmark, encouraging progresses on evaluating such cognitive elements have been made in two interconnected computational aspects: passive salient landmark and active salient landmark, which are based on different viewpoints of the navigation system. The salience in our context denotes relatively distinct, prominent or obvious objects comparing to other objects in the environment. The property of being a landmark relies on the large contrast within the environment, either in terms of its attributes (color, texture, size, shape, etc.) or due to its spatial distributional characters. The concept ‘contrast’ is the most critical aspect of salience which allows differentiating the landmarks from spatial environments (Montello and Freundschuh 2005). After comparing the commonalities between real and electronic space, Sorrows and Hirtle (1999) proposed one of the most influential descriptions of the characteristics of landmarks in GIS, which includes: (1) Visual salience, which describes the visual importance of a spatial feature, to be more specific, the feature with larger visual contrast than others, (2) Semantic salience, which describes the cultural or historical importance of the feature, i.e. use, meaning of the feature, and (3) Structural salience, which indicates the prominent location of the feature in the environment. Salient landmarks have been used as the local guide to enrich the instruction of the route. The hypothesis of the research works seems to be reasonable: a feature, such as a facade, a church, or an outstanding building, is a landmark because of its intrinsic properties (Raubal and Winter 2002; Sorrows and Hirtle 1999; Winter 2003).

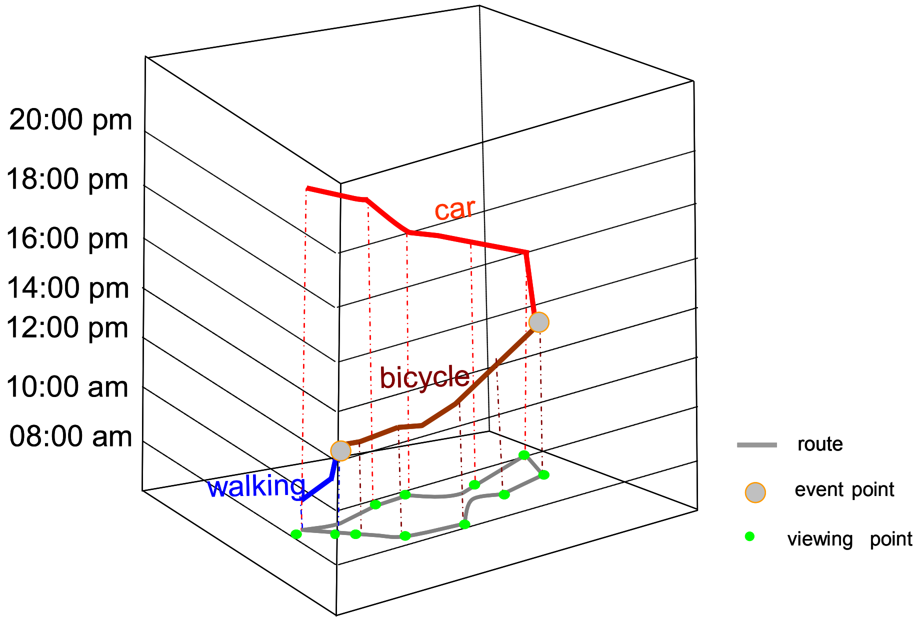


Figure 4.1 Multimodal routing as a spatial-temporal task

Researchers also take into account the subjective factors of the travelers, which focus on the psychological skills such as perception and cognition ability. Golledge and Gärling (2004) investigated the relationship between cognitive maps and behavior during the traveling in urban environments, and they summarized the travel behavior into three interrelated steps. The first step was the learning procedure, which systematically encoded the route geometry in mind. The second step was the procedure of route-based knowledge acquisition, which involved understanding the place of the route in a larger frame of reference, thus going beyond the mere identification of sequential path segments and turning angles. The final step was the surveying procedure, which implied comprehension of a more general network that existed within an environment and from which a procedure for following a route could be constructed. Montello1 and Sas (2006) conducted a study of the human factors during the way finding, and they stated that the navigation included two components: way finding and locomotion. They stated that way finding is an explicit decision-making problem, which includes the steps e.g. choosing the routes, orienting toward landmarks, creating shortcuts, and scheduling trips. In contrast, locomotion refers to the localization of a traveler in real-time when he moves successfully in the correct direction without injuring himself or moving into obstructions, so it requires the accessibility of location information about the immediate surrounding by means of sensors or maneuvering himself in time. Caduff and Timpf (2008) proposed the integration of a conceptual model for the trilateral relationships between observer, referenced spatial feature, and physical environment, and they summarized three types of salience: perceptual salience, cognitive salience, contextual salience.

We argue that the routing map for navigation is the communication media between the traveler and the surrounding environment, where the salience depends on not only the inherent properties of some specific spatial objects in the environment, but also the cognitive elements from the traveler's point of view. The inherent salience of an object is termed as the passive salience in this thesis, for example, the famous Frauenkirche in Munich, is always a landmark for the navigation task because it has huge passive salience in every context, whereas the salience perceived by the user is termed as active salience. An object becomes a landmark because it has a large contrast to its environment due to its inherent properties and user's perception. The cognitive salience of an object for the user during routing is a synergy effect of both passive and active salience.

The generation of a cognitively adequate routing map enriched with landmarks is an optimization procedure, which should determine the relative weights of various salience components as well as compute the synergetic salience based on all accessible and calculable parameters. In practice, it's reasonable to choose a limited number of parameters for a specific task; however, it's necessary to analyze and understand the components of cognitive salience.

4.1.2 Components of cognitive salience

As mentioned above, the salience is related to spatial objects, the environment, and the traveler incl. his action (in our thesis, we narrow the action to the traveling by different modality). However, its quantification in a specific context remains a challenging task. The computational framework of landmark salience is an interesting topic for many related scientific fields such as GIS science, Robotics and Artificial Vision, Remote Sensing, etc., and a series of different approaches already exit. We will focus on an approach for the multimodal routing purpose. It involves two steps: analyze the key components and then formulize them in a computational model to get the numerical values of salience.

Besides the route information, many other types of spatial-based information, for example, the Geo-tagged pictures (Beeharee and Steed, 2006; Hile et al., 2008; Hile and Grzeszczuk, 2009), Videos and Panoramas (Kolbe, 2004), and POIs (Grabler, et al., 2008; Duckham et al., 2010) could be the candidates for landmark. Moreover, some area objects near to the road, e.g. land parcels, are also important for the routing task because they can also attract the traveler's attention along the route. The cognitive salience is composed of three components: Inherent Spatial Salience (ISS) at a low level, Semantic-Dependent Salience (SDS), Route-Dependent Salience (RDS) and Perception Dependent Salience (PDS).

The Inherent Spatial Salience (ISS) is reflected in the spatial distribution of the objects, and each object has a unique value in that environment, which is determined in contrast to its neighborhood, i.e. the intrinsic properties and the context-dependent properties. This is a combination of the object and location salience. To be more specific, one feature has higher SIS if it has a larger difference from the neighboring features in terms of shape, height, distance etc. The definition of the neighborhood is a controversial issue for spatial datasets, which considers the adjacency of all related regions, and we choose the modified Voronoi graph to compute the salience for the feature. The SIS is independent of the route information or the users' perception. It is usually applied for general cartographic visualization instead of being specially designed for navigation. Therefore, it can be separately calculated in advance in order to reduce the computational complexity. This kind of salience is useful for travelers who enter into an unfamiliar environment. Even the traveler cannot understand the signs that describe the individual spatial objects; he can still conduct the spatial reasoning on some basic geometric information. The pre-computation of salience for each spatial object not only reduces the computational complexity, but also provides relevant information for specific routing as a prior parameter.

The Semantic-Dependent Salience (SDS) is based on the work of Sorrows and Hirtle (1999). They proposed that an object may have a larger semantic salience than other objects if it has a significant meaning. For the users in a familiar environment, objects become landmarks based on semantic salience and contribute significantly for routing. The same objects may be meaningless to users who are unfamiliar with the environment. The numerical evaluation of the semantic salience has usually an empirical nature. A ranking system, such as those dedicated to searching in the Face book (Grabler, et al., 2008), has the aim to capture and grade the relevant semantic items. SDS is usually separately treated because that semantic information is difficult to acquire. It does not influence the whole assessment if the semantic data is missing.

The Route-Dependent Salience (RDS) focuses on the route information in the environment. The characteristics of the route, especially the route direction, play an important role for the determination of landmarks. A route includes a series of decision points from the origin to the destination. From each decision point, visible features which are influenced by various factors are potential landmarks. Existing approaches mainly rely on the visibility to evaluate the relative salience of the features. That is, the assessment of RDS is based more on intrinsic properties of spatial object in relation to the route which is usually abstracted as a directed graph. We consider the attributes shown in Table 3.10 (Chapter 3) for the evaluation of RDS.

The Perception-Dependent Salience (PDS) focuses on the participant of the routing task. Unlike the above three passive salience components, PDS is the most difficult part of the salience model due to human interferences. In previous works, the human-specific salience is usually mixed up with the passive salience. Visual parameters of human-specific salience are related with both decision points and the characteristics of the participant. Our work takes user's stimuli ignorance and perception ability into account. The ignorance is influenced by the task. For example, if we search for places to have dinner, restaurants are the first choice for landmark, other objects will be ignored, but if we will park the car, we may pay more attention to the parking lots. Previous studies indicated that many properties may influence the subject's perception ability. Brewer (1992) and Susanna (2007), for example, categorized these influences into intrinsic spatial property, situation-dependent property, and action-dependent property. However, they did not consider the human factors. In our work, we will integrate human factors to the salience assessment. There are two groups of human factors. The first group reflects the demographic characteristics, such as the age, gender, educational background or prior knowledge. The second group is about the subject's self-movement modality such as walking, driving etc. In this thesis, we focus on the second group with the attributes shown in Table 3.5. The proposed dynamic perception space will contribute to this salience measurement. The changing illumination and weather condition during routing may also be considered as an extra parameter that influences the perception space.

4.1.3 Formalization of salience

Previous works of the computational approach are usually based on a set of measures for each aspect, i.e., visual, semantic, and structural salience, to specify the landmark salience (Caduff and Timpf, 2008). Moreover, it also assumed that these aspects have an equal weight in the computation. However, it's difficult to model the human factor in such a framework, even if it only considers the attributes of visual perception from traveler's standpoint. The human factor is as important as the passive salience of objects; we therefore include it in our integrated salience computing model expressed in Eq. 4.1:

$$S = F(ISS \cdot w_{iss}, SDS \cdot w_{sds}, RDS \cdot w_{rds}, PDS \cdot w_{pds} \left| (r, p_j)) \right. \qquad (4.1)$$

where

1) S is the integrated salience of the object *i* ; $i \in [1, N], N \in R$; N is the total number of the visible spatial objects from the viewing point p_j , $j \in [1, m], m \in R$ along the route *r;*
2) w_{iss}, w_{sds} , w_{rds} and w_{pds} are weights of ISS, SDS, RDS and PDS.

For a given route in the navigation, the salience for each related features along this route can be computed based on the assumption that the relationship, e.g. linear combination, is already known. This procedure can be used for each observer point, and objects are ranked according to their salience scores. An advantage of this approach is that each object corresponds to a unique salience vector, which makes it easier for the system to decide the salient candidates for this route as well as to visualize them in multiple scales. In this thesis we will compare the linear combination approach with the probabilistic approach in order to determine a more suitable computational model for the salience assessment. We will first discuss various computing methods for the passive and active salience.

Theoretically, the accessible input parameters of our computing model can be grouped as traveler information, route information, external environment, and information about the landmarks. Traveler information is reflected in the personal profile and the traveling modality. Route information is about the location and geometry of the route. External environment includes parameters on weather, traveling time and associated illumination conditions etc. The information about landmarks can be size, color, spatial location and so on. The traveler information contributes mainly to the computing of active PDS. All other components - ISS, SDS and RDS are more related to the passive salience.

4.2 Estimation of the passive salience

4.2.1 Salient objects as local spatial outliers

In a spatial environment, the relationship of the adjacent objects plays a significant role during the perception process. As mentioned by Knopfli (1983), Li and Huang (2002), different spatial environments with the same objects could produce different visual impressions for visual attention and cognition. Since they reveal various distribution patterns, the differences may be measured according to the relative density and other distributional characteristics. Caduff and Timpf (2008) explained that the same spatial object could appear different when its relation to neighbors is changed. This is the inherent character of the spatial environment, and the salience is mainly dependent on both of the inherent property and the surrounding i.e., the ISS and the context dependent properties. We regard this type of character as the basis of other saliences. In a specific environment, the prominent or salient feature has a large contrast to other features. Two strategies can be used to calculate the contrast. The first one is realized by defining a buffer area around a given point and grading the relative contrast of each object in comparison with other objects within the buffer. The size of the buffer and the comparison function play an important role. The second strategy relies on the spatial partition to get the immediate neighborhood for each spatial object. Each salient object is a local spatial outlier within its immediate neighborhood.

Many approaches about landmark salience were introduced in the literature. The statistical methods (Raubal and winter, 2002; Nothegger et al., 2004; Winter et al., 2005), probability methods (Toshihiro and Satoko, 2005), information entropy (Elias 2003, 2004; winter, 2006) are some examples. These approaches are mainly based on the above-mentioned first strategy. In our thesis, we apply the second strategy with the algorithm of local spatial outlier detection in order to get a more stable salience factor. Hawkins (1980) defined the outlier as "an observation which deviates so much from other observations as to arouse suspicions that it was generated by a different mechanism". Similar terms were reported in other literatures, such as anomaly in (Agarwal, 2006; Shyu and Chen, 2003; and Eskin, 2000), novelty in (Markou and Singh, 2003; Diehl and John, 2002). In our thesis, we term the local spatial outlier as the local landmark or the local salient object.

The development of the outlier detection algorithm has undergone four phases - global outlier detection, local outlier detection, spatial outlier detection, spatial-temporal outlier detection phases. In the early stage of outlier detection, researches usually assumed that there was a normal distribution, or other well-known distributions of the original data, e.g. Poisson distribution. Outlier detection approaches usually use variations of the Chebyshev's inequality as Eq. 4.2.

$$P(|X-\mu|\geq k\sigma)\leq\frac{1}{k^2} \tag{4.2}$$

Where μ and σ are the mean and variance of a random variable X. *K* is a real number larger than 0.

A method of distance-based outlier detection was introduced by Knorr and Ng (1998), which does not consider any distributional assumption so it is a general method for multidimensional datasets. The principle of this method is to test whether the distance is larger than the average distance. More related methods and algorithms have been used to detect the distance-based outliers (Aggarwal and Yu 2001; Bay and Schwabacher 2003; Angiulli and Pizzuti 2002; Knorr and Ng 1998; Ramaswamy et al. 2000).

The method of distance-based outlier detection works well as for global outlier detection. However, Breunig et al. (2000) argued that local outliers were more important than global outliers, and later Papadimitriou et al. (2003) proposed the Local Outlier Correlation Integral (LOCI), which considers the relationship of the neighborhood as being correlated. Later, semantic information, e.g. attributes of the object, has also been considered for the outlier detection, for instance, Shekhar et al. (2001) addressed the graph-based detection of spatial outlier using a single attribute, whereas multiple attributes were proposed by Lu, et al. (2003) and the algorithm of weighted spatial outlier detection was proposed by Kou et al., (2006), which took the impact of spatial attributes such as location, area, contour etc. into account.

Due to the characteristics of spatial data, Shekhar et al. (2001) defined the spatial outlier by considering the qualitative difference between spatial and non-spatial information: "a *spatial* *outlier is a spatially referenced object whose non-spatial attribute values are significantly different from those of other spatially referenced objects in its spatial neighborhood"*. The spatial space needs to be divided in order to identify spatial outliers. The spatial clustering technique based Delaunay Triangulation (DT) was proposed by Kang et al., (1997), which identified outliers as a by-product from spatial clustering. Huang et al. (2006, 2004) proposed an approach to identify collocation patterns in the proximity-based spatial neighborhood, which considered spatial relationships defined in Euclidean space, such as adjacency and metric relationships.

The spatial local outlier during movement is dependent on not only the spatial characteristics but also the time. In our case, the salience relies on the decision points of a route; therefore, it is a matter of space and time as Figure 4.1 shows. Birant and Kut (2006) and Cheng and Li (2006) defined the spatial-temporal outlier as a "spatial-temporal object whose thematic attribute values are significantly different from those of other spatially and temporally referenced objects in its spatial or/and temporal neighborhoods". In general, spatial-temporal outlier detection combines both space and time in the computational model. In fact, the multi-dimensional salience is possible under the known constraints. To capture the spatial-temporal outliers, the unsupervised approaches by using a shifting window of time (Mandis et al., 2008) or the supervised approaches, e.g. Hidden Markov Model (HMM) (Rybski and Veloso, 2004), Coupled Hidden Markov Model (CHMM) (Oliver et al., 2000), can be applied.

4.2.2 The measurement of ISS

The ISS of an object is related to its neighborhood and inherent properties. We may employ the spatial local outlier detection technique to evaluate the relative salience for each object. According to the geographical first rule, the spatial objects are related to each other, but the near objects have important influence (Knopfli, 1983). The mutual influence among the neighboring objects is inversely proportional to their distances. We use on the one hand an outlook distance that indicates the contrast between the neighboring objects in terms of their visual outlook, and on the other hand the inverse of spatial distance as the weight. Neighboring objects are located in the same sub-region or cell of the Constrained Voronoi diagram. Similar to the computation of *LOF* a (Local Outlier Factor) (Breunig et al., 2000), the salience of a given object is defined as the ratio between its difference to its neighbors and the mean difference of its neighbors, as shown in Eq. 4.3.

$$ISS(i) = \frac{dist(x_i, N(x_i))}{\left[\dfrac{\sum\limits_{y \in N(x)} dist(y, N(y))}{|N(x_i)|}\right]} \cdot w_x = dist(x_i, N(x_i)) \cdot \frac{|N(x_i)|}{\sum\limits_{y \in N(x_i)} dist(y, N(y))} \cdot w_{x_i} \qquad (4.3)$$

with: *1)* $dist(x_i, y) = \dfrac{\sum\limits_{y \in N(xi)} |f(x_i - f(y)|}{|N(x_i)|}$

2) $w_{x_i} = \dfrac{S(x_i, N(x_i))}{\sum\limits_{y \in N(x_i)} S(y, N(y))}$

Herein *ISS* (*x*) is the Inherent Spatial Salience of the object *x* compared to the neighbors; $dist(x, N(x))$ is the dissimilarity of spatial object x to its neighbor set $N(x)$; $f(x)$ stands for the values of outlook attributes of the object *x*, w_y is the weight for object *y* to *x*; $S(x, y)$ is the distance between spatial objects *x* and *y.*

Algorithm 4-1: Computation of ISS

Input:

1) *The environment E with n spatial objects* $\{x_1, x_2, \ldots, x_n\}$
2) *The characteristics of each object are reflected in its geometric attributes and its location in its surrounding.*

Main steps of the algorithm:

1) *Normalize the attribute values of each object to* $\{f\ (x_1), f\ (x_i), \ldots f\ (x_n)\}$*,*
2) *Spatial partition for the objects based on Planar Voronoi Diagram*
3) *For each object* x_i*, get the m neighbors* $N(x_i) = \{x_{i1}, \ldots x_{ii}, \ldots x_{im}\}$*,*
    a) *compute the outlook distances* $dist(x_i, y)$ $y \in N(x_i)$ *according to Eq. 4.6*
    b) *compute the weight using Eq. 4.7*
    c) *calculate the ISS using Eq. 4.5*
4) *Repeat step 3 for each object*
5) *Return the ISS values for the N objects*

The algorithm is demonstrated on a test dataset simulating a neighborhood region as shown in Figure 4.2. Here the area of each polygon object is taken as the value of its outlook attribute. The weight is inversely proportional to the spatial distance.

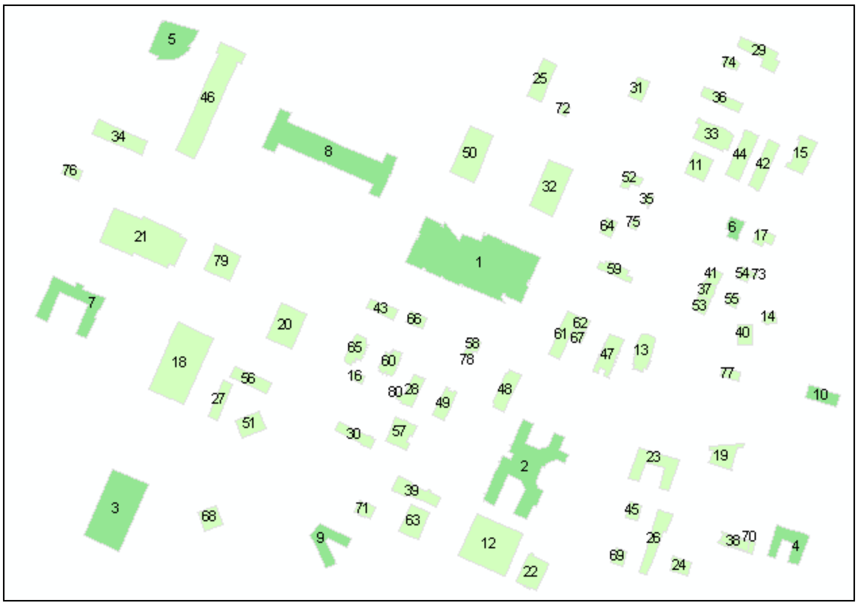


Figure 4.2 A test dataset with building footprints and the salience order

The result reveals that both spatial distance and outlook attributes are important for the ISS value. For example, the object with the largest area is labeled as No.1, i.e. the most salient one; the object ranked as No.6 and No.10 do not have very prominent sizes, but their spatial distances to their local neighbors are rather prominent.

4.2.3 The measurement of SDS

As mentioned above, we separately consider the semantic information that is independent of the outlook of the object not just because it is difficult to quantify semantic information, but we can take into account other types of information such as POIs. POIs do not necessarily have the prominent outlook characterized by attributes such as the area or height of a building, but they have thematic or semantic prominence. It is difficult to detect the thematic outlier using the computing method for ISS. A new approach is necessary.

Previous studies on the semantic of the landmarks are related to the function of the spatial object, for example, the industrial and residential building. The historical meaning also plays an important role. Different object types are expressed using different map symbols. Different semantic attributes of the same object type are usually expressed through different graphic variables of the map symbol. Different values of the same semantic attribute may be categorized (qualitative values) or classified (numerical values) are then differentiated through variations of the corresponding graphic variable. If an object shares the same type, category or class with all its neighbors in a region, then it has a low semantic salience. If it reveals a high contrast in terms of its type, category or numerical class to all its neighbors, it is regarded as a semantic outlier.

'Entropy' is a quantitative measure for the information content contained in a message. Sukhov (1967, 1970) was among the first researchers who employed the entropy to compute the different types of symbols represented on a map. In order to take into account the spaces occupied by map symbols and the spatial distribution of these symbols, Li and Huang (2002) applied Voronoi diagram and calculated the entropy of symbols in the individual sub-regions. We adopt this idea of ‘Voronoi entropy’ in our work to compute the semantic contrast of a spatial object within it’s immediately neighborhood, i.e., we employed the entropy of each map symbol to denote the Semantic-Dependent Salience (SDS). Assumed that for the i_{th} spatial object represented by the symbol x_i on the map, there are N_i neighbors composed of m_i types, categories or classes. The SDS of map symbol of the i_{th} spatial object can be computed with Eq.4.4:

$$SDS(i) = -\frac{m_{x_i}}{N_{x_i}} \ln\left(\frac{m_{x_i}}{N_{x_i}}\right) \tag{4.4}$$

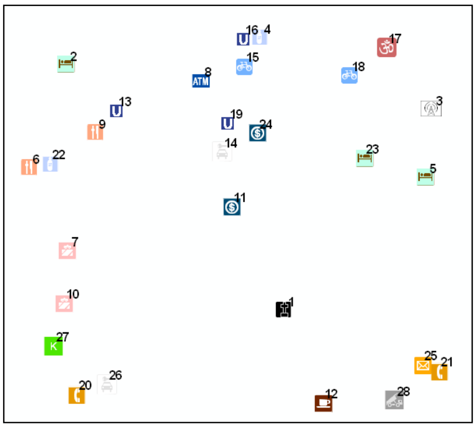


Figure 4.3 Various types of POIs and their semantic outliers

For example, there are 28 symbols of POIs on the map with a distribution shown in Figure 4.4 (left). 5 of them as shown in Figure 4.3 (right) are detected as semantic outliers and ranked according to their measures.

The result reveals that each outlier either occupies a larger free space or has a relatively uniqueness. We can apply the same principle to different attributes of the same object type. If the test dataset of building objects from Figure 4.3 is enriched with a semantic attribute “function” as shown in Figure 4.4 (left), where the number within each polygon indicates its functional category, the resulted semantic outliers will have a distribution as illustrated in Figure 4.4 (Right).

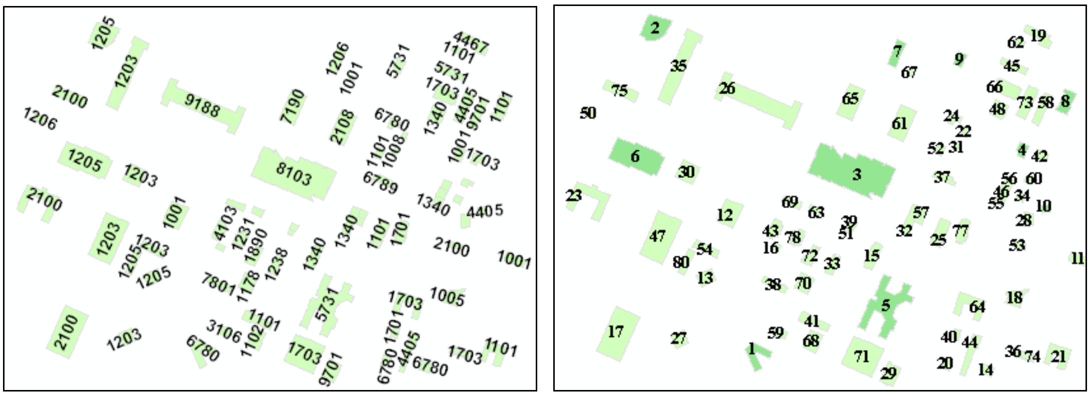


Figure 4.4 Distribution of buildings with different functions (left) and semantic outliers (right)

Besides the visual perception salience of semantic information embedded in map symbols, the personal preference during spatial reasoning may also be mixed in the semantic information. For example we tend to identify a hospital or a university more easily than a restaurant. Further, the different routing modalities may influence our selection of POI. For example, drivers may pay more attention to gas stations and parking lots than shopping centers and restaurants which are more relevant for pedestrian. Therefore, the different weights assigned to different object types should be refined for different modalities. Eq.4.4 should be modified as Eq.4.5.

$$SDS(i) = -\frac{m_{x_i}}{N_{x_i}} \ln\left(\frac{m_{x_i}}{N_{x_i}}\right) \cdot w(x_i) \tag{4.5}$$

Where $w(x_i)$ is the modality-dependent weight for the map symbol of the i_{th} spatial object. The idea is in line with the relevance computation to a given task. Details about the weight assignments are reported in Chapter 6.

4.2.4 Computation of RDS

A route has several implications in the navigation context. Werner et al. (1997) distinguished three different kinds of routes: a) the original route which was not elaborated and in a field’s perspective; b) a route which was elaborated and also in a field’s perspective, c) a route which was translated into an observer’s perspective.

Regardless of the kind, a new generated route is recognized as a new task-related spatial object from the original environment. Since it has only a temporal validation during the routing activity, it is viewed as a sequence of points along the way during the navigation or a series of travel events, which incorporate the external activity from the human or natural phenomenon, e.g. weather or time. We separately handle these two distinctive meanings for our salience evaluation.

Using landmarks as the route instructions has two purposes (Daniel and Denis, 1998): 1) anchoring a navigation action to a location which is the decision or potential decision point; 2) providing reference information that the observer is going the right way. This statement differs considerably from just mentioning that a landmark can be seen from some point of view, as it not only refers to the landmark as a main attraction, but in that it uses the spatial relation between landmark and path in order to identify what path to take next (Duckham et al., 2010). The relative position between the decision point on the route and spatial objects is the fundamental factor to identify the potential landmark, moreover, the granularity of landmark should satisfy user's positioning task as shown in Figure 4.5. For example, the route specific salience objects (as these green buildings) should be derived from the Inherent Spatial salient objects (the red buildings) and the routed-dependent salient objects (the yellow buildings). These considerations indicate that the circumstances of the circumstances and the purpose of routing) influence the selection of salient objects and need to be considered separately.

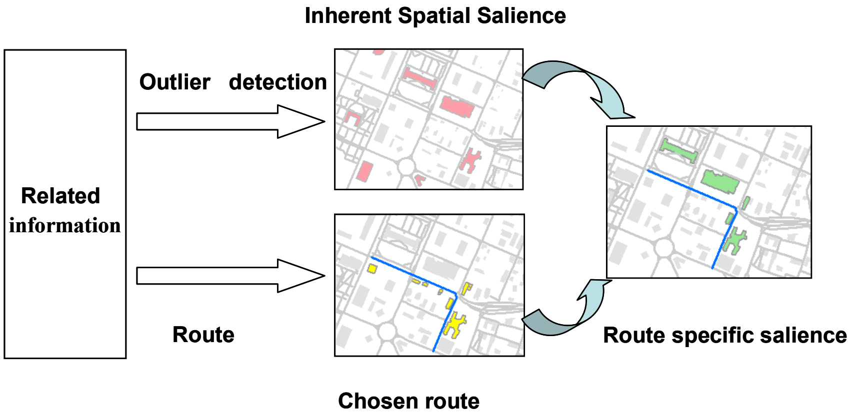


Figure 4.5 Detection of route-specific salient objects in green

The RDS of an object is determined by its relationship to the route represented by a series of decision points, which in turn are related with the travel speed of the observer. We choose a rectangular display area as the reference area to extract the route specific salience.

The travel direction is an important factor for salience detection. The smaller the angle between the line of the spatial object and observer and the moving direction, i.e. orientation, the larger the salience. Similar to the distance, the salience also increases with the decreasing distance (Steck & Mallot, 1997; Wang & Spelke, 2000). In the landmark-based route generation model (Caduff and Timpf 2002), the direction in potential visual filed is divided into the sections. It is a combination of the visual filed which view from the driver (the white circle) and other potential visual way, e.g., the former and rear mirror (the red dots) of the car as shown in Figure 4.6.

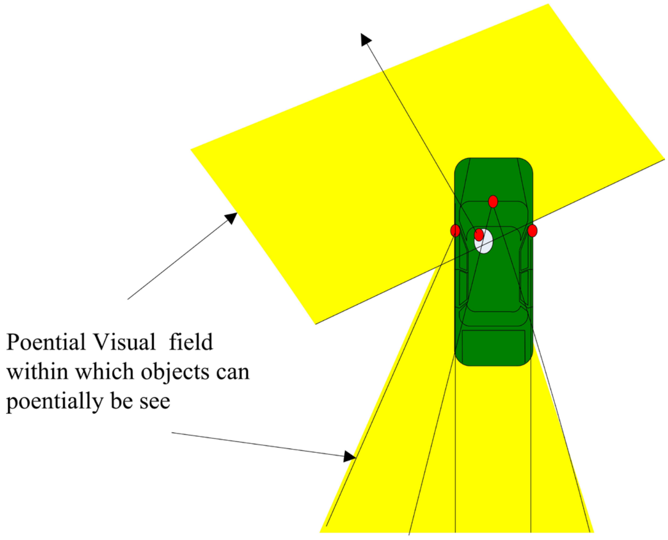


Figure 4.6 Potential extension of visual field of driver

A landmark located in the front of the traveler and close to the route is more likely to be used as reference than those located behind the traveler. The RDS is measured using Eq. 4.6.

$$RDS(i,j) = w_d / d(i,j) + w_o / \theta(i,j) \tag{4.6}$$

where $RDS(i,j)$ is the RDS value of the ith spatial object from the jth observer point ; w_d, w_o are weights for distance d and orientation θ, and $w_d + w_o = 1$; $d(i,j)$ is the distance from the ith spatial object to the jth viewing point; $\theta(i,j)$ is the angle $(0 \sim \pi)$ from the spatial object to the route direction, as illustrated in Figure 4.7.

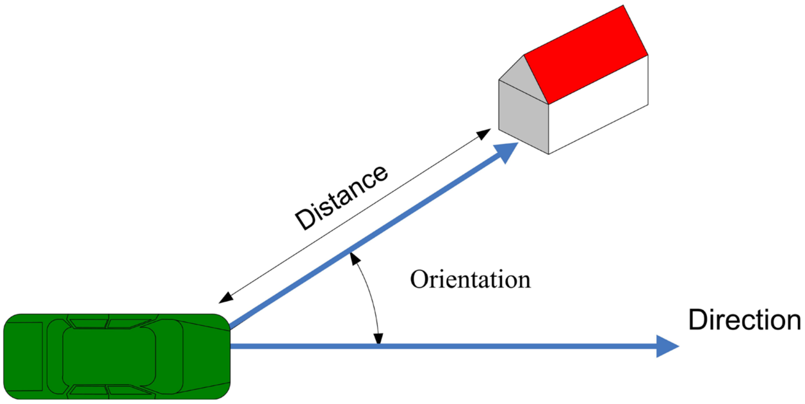


Figure 4.7 Orientation at a decision point of a route and its relation to the salient object

Assume that m is the total number of viewing points, the overall salience of object i is computed in Eq. 4.7.

$$RDS(i) = \frac{\sum_{j=1}^{m} RDS(i,j)}{m} \tag{4.7}$$

Algorithm 4-2: Route-Dependent Salience:
Input:

```
    1) A dataset of the land parcel P with n objects;
    2) The route L;
    3) The weight for distance $w_d$, and orientation $w_o$
Output:
    1) The salient value $RDS(i)$ for i_th spatial object.
Steps:
    1) Initialize the data with the calculation of the area covered by each object in P;
    2) Initialize the route with a sequence of m viewing points $p_j \in \{p_1, p_2, ...p_m\}$;
    3) At each viewing point $p_j$:
        a) Compute the representation area for each viewing point
        b) If the object falls within the area, calculate the distance and its deviation from
           the routing direction;
        c) Compute the salience at the current viewing point using Eq.4.7;
    4) Repeat step 3 for each viewing point;
    5) Return the salient values.
```

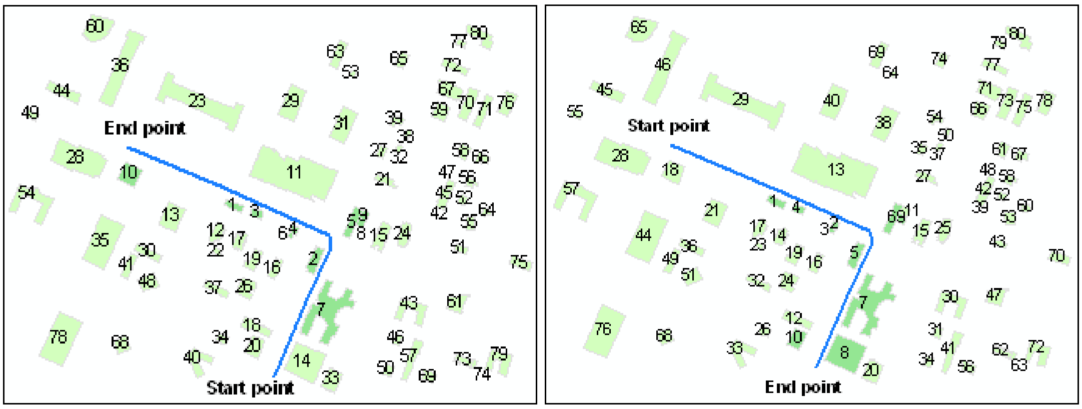


Figure 4.8 RDS for a route in two opposing directions

Figure 4.8 demonstrates the results of Algorithm 4-2 by using the same test data as in previous figures, with $w_d = 0.2$, $w_o = 0.8$. The blue line indicates the designed route, and the labels indicate the salience rating. If we change the route direction, the ranking result becomes different. Similarly, if we change the weights of distance and angle, for example, setting w_d and w_o both equal to 0.5, we get different results as shown in Figure 4.9 left. If we combine ISS with RDS using an equal weight, we may get an integrated salience value at each viewing point as shown in Figure 4.9 (right).

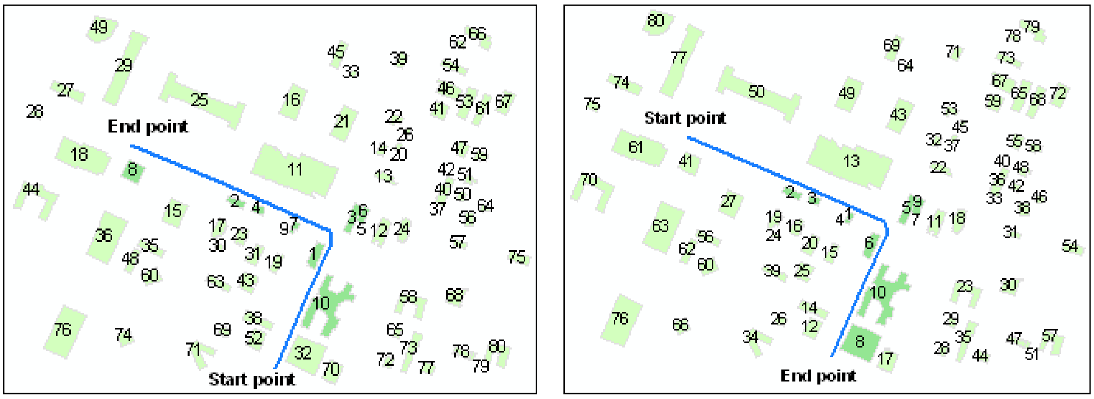


Figure 4.9 RDS with *a* = 0.5, *b*=0.5 (left); integrated result of ISS and RDS (right)

4.3 Estimation of active salience

4.3.1 Modality-based visual attention

According to the definition of Perception Dependent Salience (PDS) in Section 4.1, the traveler is the protagonist of any navigation task, and his perception decides the salience of objects in the environment. In this way, some passive objects are transferred to the active prominent objects or useful landmarks for the routing. However, human being is a complex intelligent creature, so we can only simulate a part of his behavior during the way finding. This section is dedicated to the PDS with two aspects: the perception ability and the perception ignorance of the traveler. The former relies on the characteristics of traveler and his visual conditions such as the weather, time and the travelling speed. The latter is influenced by traveler's task or movement modality. The assessment of PDS is therefore composed of a perception ability assessment and a perception ignorance assessment.

The most significant difference caused by various travel modalities is reflected in the visual ability which is derived from the velocity and the limited vista space as discussed in Chapter 3. We may simulate the visual perception for a given travel modality by comparing the dynamic visibility polygon with the environment at each viewing point. Visible objects are those that lie inside the visibility polygon. The perception salience factor is defined as the degree of overlap between the visibility polygon and the environment. The spatial objects with larger overlaps have higher perception salience values. The visibility analysis based on line of sight is an efficient way to compute such perceptional salience. Many investigations on 2D or 3D visibility analysis have been reported. One of the most widespread studies on 3D visibility was introduced by Isovist (Benedikt, 1979; Gardiner and Yin, 2009). A single Isovist is the volume of space visible from a given point in space, together with a specification of the location of that point. Many efforts have been made to provide better solutions in the form of 3D analysis for urban settings, such as the Viewsphere visibility analysis (Putra, 2005; Yang, Putra & Li, 2005a, 2005b), the sky view factor (Bosselman, 1998; Ratti, 2002; Souza et al, 2003), the Teller's sky opening indicator (Teller, 2003) and the spatial openness index (SOI) (Fisher-Gewirtzman and Wagner, 2003; Fisher-Gewirtzman et al, 2003; 2005) etc.

Many previous landmark assessment methods are either qualitative or quantitative methods. One good example of the qualitative methods was proposed by Burneet et al. (2001) who considered whether the landmark can be clearly seen in all conditions as the key extraction parameters. With regard to quantitative methods, Raubal and Winter (2002) proposed a visibility value derived from the area of the space covered by the visibility cone of the front side of a building. Winter (2003) advanced the method by computing a building's visible area with the consideration of the direction of the routing and characteristics of the building. The frequency-based method proposed by Brenner and Elias (2003) assumes that the salience of a building as landmark is correlated to the size or the visibility area (distance) of the building.

In order to fully consider the perception space, Bartie et al., (2008) put forward a number of visibility metrics at entity level based on a 3D visibility modeling engine. According to them, the road sections making up the designated route are set as the target objects. The observer and target locations are restricted to the locations on the road, therefore the results are not an indication of the total area visible from each point, but limited to how much of the route ahead is visible. Brenner and Elias (2003)'s frequency-based method is more useful and easily to understand, however, their computation depends on the expensive laser scanning and their salience is merely expressed as the visible area or length. Other aspects such as the perception shape, size and color were not considered. To overcome these limitations and reduce the computational complexity of the 3D visibility analysis, we apply the VisiLibity Library by (Obermeyer, 2008) to express the adaptive dynamic perception space in 2D. The reason of using the 2D visibility analysis is that the routing is a task-guided process; the visual attention is paid more on the ground than toward the vertical dimension.

In the real environment, for example, when a traveller turns his body and eyes, he can perceive spatial objects from a specific viewpoint within a perception area and distance. The visible polygon is based on the viewpoint as well the obstacles, without or with little influence by other parameters. In this case the perception is only around his location. However, in the case of dynamic situation, for instance, while driving, the freedom of moving the body to perceive the information around the road is limited. The dynamic useful view field is also constrained by the cognition capacity of the traveler. On the other hand, the visibility analysis is a kind of simulation of human visual system, which indicates that the salience result is influenced only by the constrained recognition space. In this work, we implement the method of visibility analysis with the constrained cognitive space to simulate the dynamic perception and the travel modality as the constraint for the size of cognitive space.

For observer at location *p*, the salience of the spatial objects of environment *E* is dependent on the constrained cognitive space, which is a function of the position and the self-movement. The perception salience is expressed in Eq. 3.14 and Eq. 3.15. Here we discuss its measurement in detail.

4.3.2 Computation of PDS

The perception space or visual area is the visible scope subtracted by the spatial objects which block the vision. As shown in Figure 4.10, the red polygons are visible from the centre of the ellipses. Figure 4.10 (left) and (right) assume a visual field of 180° and 360° respectively. The boundary of the visible scope is defined as the maximum visual distance of the traveler in this thesis.

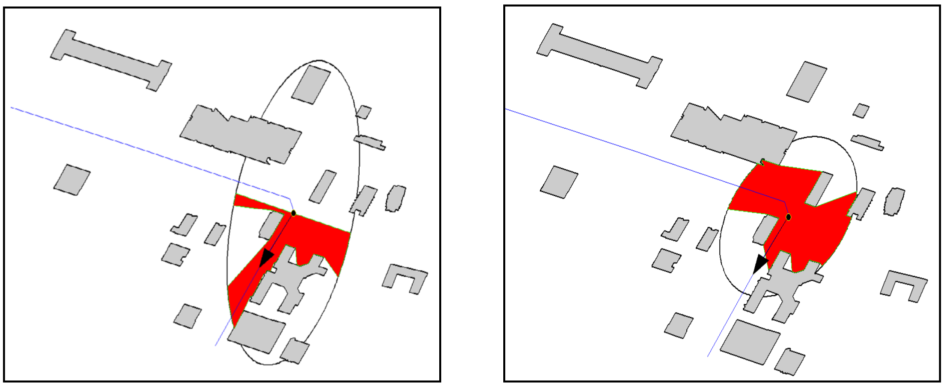


Figure 4.10 Visible areas under different conditions

Upon seeing a spatial object, we can identify its height, area, perimeter, color, distance, shape etc. The situation-dependent attributes in Table 3.7 as discussed in chapter 3 can be involved the assessment. However, some parameters, e.g. color, are not easily accessible. We therefore do not include them in the implementation. Instead, we select shape, distance, area and perimeter as the most important perceptional parameters in our model. They are defined as follows:

1) Perceivable shape (PDS_{shape}): the ratio between the number of intersection points with the visual surface and the perimeter;
2) Perceivable distance (PDS_d): the average distance from the observation point to intersection points;
3) Perceivable area (PDS_{area}): the product of the perimeter and the height of the building.
4) Perimeter (PDS_p): the overlapping perimeter of the visible area (red polygon in Figure 4.11) and the spatial object (the white polygon in Figure 4.11).

The PDS of the i_{th} spatial object at the j_{th} viewing point can be expressed by a logistic model as in Eq.4.8

$$PDS(i,j) = \frac{1}{1+\exp(-Temp(i,j))} \tag{4.8}$$

with: $Temp(i,j) = f_{shape}(PDS_{shape}(i,j)) \cdot w_{shape} + f_{area}(PDS_{area}(i,j)) \cdot w_{area} + f_d(PDS_d(i,j)) \cdot w_d$

Where w_{shape}, w_{area} and w_d are the weights of the individual perceptual parameters shape, area distance respectively; f_{shape}, f_{area} and f_d are functions that normalize the individual salience part to a value between [0-1]. The cognitive salience of the i_{th} along the route is expressed in Eq.4.09

$$PDS(i) = \sum_{j=1}^{m} PDS(i,j) \cdot w_j \tag{4.9}$$

Where w_j is the weight of the j_{th} spatial object of the entire route, m is the total number of the viewing points.

The computing process is described in Algorithm 4-3.

Algorithm 4-3: Perception Dependent Salience

Input:

1) *A dataset of the parcel E with n spatial objects around a given viewing point (e.g., the j_{th} viewing point p_j, and the subsequent $(j+1)_{th}$ viewing point, p_{j+1}, $h(i)$ is the height of the i_{th} spatial object;*
2) *The speed and the modality of traveler.*

Output:

1) *$PDS(i,j)$ of the i_{th} spatial object at the j_{th} viewing point*

Step I: Data initialization and preparation

Transfer the input 2) to parameters (θ_v, d_{fix}), calculate the visible ellipse and run the visibility analysis library to get the visible region $V(j)$.

Step II: Computation of the overlapping segments between the i_{th} spatial object and $V(j)$

Get the intersection points between the i_{th} spatial object and $V(j)$;

Get the overlapping segments and summary them as the perception perimeter $PDS_p(i,j)$;

Compute the distance between the view point and each intersection point and compute the average distance value as the perception distance $PDS_d(i,j)$.

Step III: Computation and normalization of perceivable parameters shape, area and distance

Step VI: Computation of the PDS of the i_{th} spatial object at j_{th} viewing point accor*ding to Eq.4.08*

The algorithm is tested on a series of static viewpoints. The traveler's parameters for driving and walking from a static point are assumed as shown in Table 4.1.

Table 4.1 Parameters of the routing

Parameters	Driving	Walking
Speed v	60km/h	4 km/h
d_{fix}	300m	250m
θ_v	30°	90°

As shown in Figure 4.12 there are 18 buildings visible from the route (the yellow polygons), and their attribute values are shown in Table 4.2.

Table 4.2 Attributes of buildings

Building ID	Area	Height	Building ID	Area	Height
1	1797.1	19.13	**10**	4781.37	28.37
2	8572.01	19.76	**11**	1459.15	6.68
3	812.47	23.88	**12**	1332.28	18.60
4	4222.89	29.91	**13**	781.29	17.42
5	3253.45	22.48	**14**	898.04	14.41
6	525.54	24.47	**15**	275.15	22.29
7	604.06	27.67	**16**	469.60	15.13
8	860.02	21.44	**17**	843.39	26.77
9	797.34	26.50	**18**	952.63	21.53

In the Figure 4.11, the route is shown as a blue line, and the viewing point *p1* is a turning point, *p2* is the subsequent turning point, and the route direction is $\overrightarrow{p1p2}$. The dotted gray circle and the black ellipse are the boundaries of visual scopes for walking and driving.

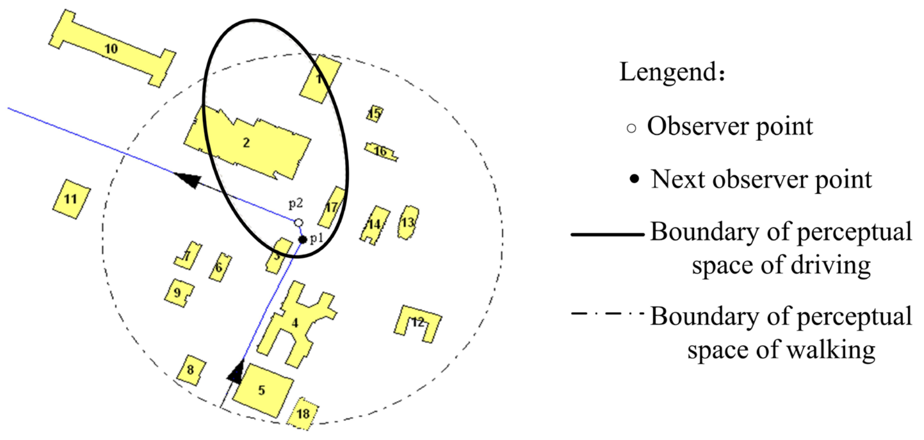


Figure 4.11 Buildings visible from a route and the visual scopes for walking and driving

The visible region during driving is illustrated in Figure 4.12, where the dashed rays from p1 represent the lines of sight of the driver. Their intersection points (black crosses) along the outlines of the green buildings indicate the foci of driver without any movement (useful view of field); whereas their intersection points (red crosses) on the outlines of yellow buildings indicate the potential foci of the driver. We can see just two buildings fall into this area as the salient candidates.

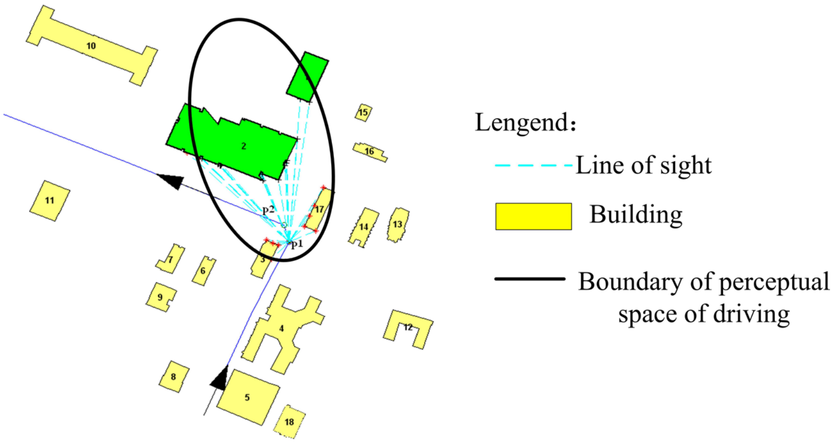


Figure 4.12 Lines of sight during driving

The values of perceptual parameters and PDS of the two salient building objects for driver are summarized in Table 4.3. The weights of shape, area and distance are empirically set as 0.2, 0.6 and 0.2 respectively.

Table 4.3 PDS for driving

Building ID	PDS_p	PDS_{shape}	PDS_{area}	PDS_d	**PDS**
1	11.36	0.09	217.32	188.06	**0.61**
2	60.60	0.26	1197.21	116.30	**0.83**
$w_{shap} = 0.2, w_{area} = 0.6, w_d = 0.2$					

It's obvious that the building 2 reveals the largest perception salience, which is also the landmark for the first turn point.

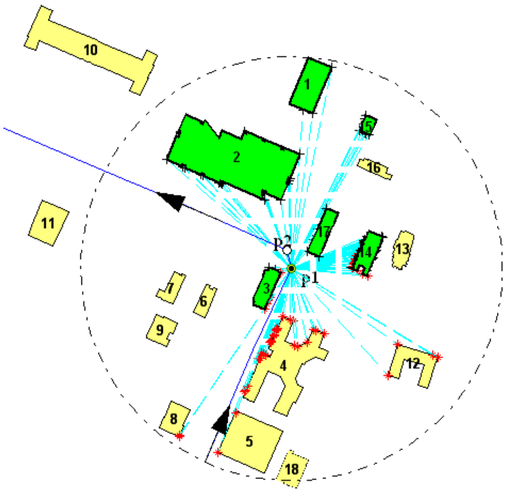


Figure 4.13 Lines of sight for walking

For pedestrian, however, there is a much larger potential perception area within which all buildings can be identified during walking. As shown in Figure 4.13, there are 16 buildings falling into the circled area. Based on the discussion in Section 3.2, the 6 buildings in green which fall into the useful view filed are supposed to be the focus of pedestrians. The corresponding values of PDS with the same parameters as those for driving are summarized in Table 4.4.

Table 4.4 PDS for walking

Building ID	PDS_p	PDS_{shape}	PDS_{area}	PDS_d	PDS
1	70.53	0.03	1349.06	186.38	0.71
2	104.52	0.31	2065.56	85.01	0.81
3	8.77	0.11	209.29	27.19	0.73
14	12.26	2.04	176.69	57.46	0.76
15	32.62	0.21	727.08	189.53	0.66
17	71.10	0.08	1903.27	53.16	0.83
$w_{shape} = 0.2, w_{area} = 0.6, w_d = 0.2$					

Comparing the results for driving and walking as shown in the histogram in Figure 4.14, building 17 has the largest salience, although it does not have the largest area. This can be explained by the fact that it rests closest to the turn point.

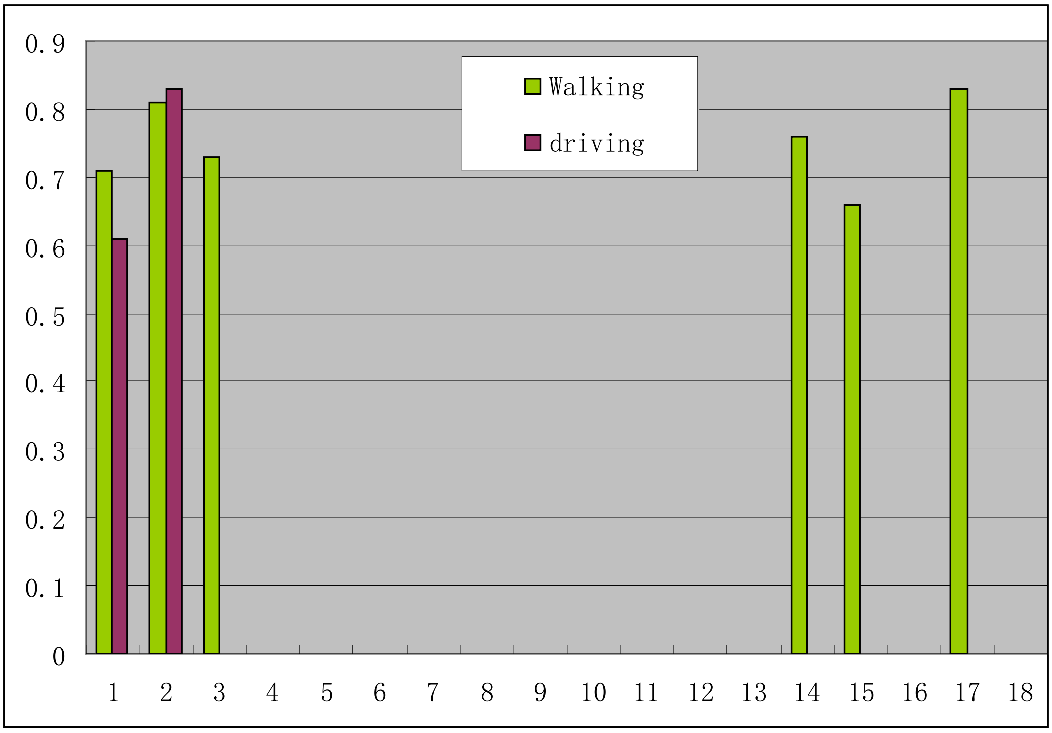


Figure 4.14 The relative PDS for walking and driving

Since the PDS of building 2 is close to that of building 17, we provide both of them as landmarks for pedestrian. This is in line with the suggestion that the granularity level of landmark for a pedestrian should be higher than a driver (Caduff and Timpf 2008).

Since the salience value is influenced by the weights of the individual parameters, the same dataset is tested using another set of weights $w_{\mathrm{shape}} = 0.5, w_{area} = 0.5, w_d = 0.0$. The result is shown in Table 4.5. The most salient building is now building 14 due to its prominent shape (2.04) and the second most salient building is building 2 with a prominent area (2065.56).

Table 4.5 PDS for walking with a different set of weights

Building ID	PDS_{p}	PDS_{shape}	PDS_{area}	PDS_d	PDS
1	70.53	0.03	1349.06	186.38	0.66
2	104.52	0.31	2065.56	85.01	0.78
3	8.77	0.11	209.29	27.19	0.57
14	12.26	2.04	176.69	57.46	0.89
15	32.62	0.21	727.08	189.53	0.67
17	71.10	0.08	1903.27	53.16	0.74
$w_{\mathrm{shape}} = 0.5, w_{area} = 0.5, w_d = 0.0$					

The salience result of each viewing point can be displayed dynamically. As Figure 4.15 shows, while the user moves forward, the dynamic salience could be measured and visualized. For example, we initialize all salience to zero, and the saturation of the color for each spatial object will be then changed in proportion to the measured value during the movement.

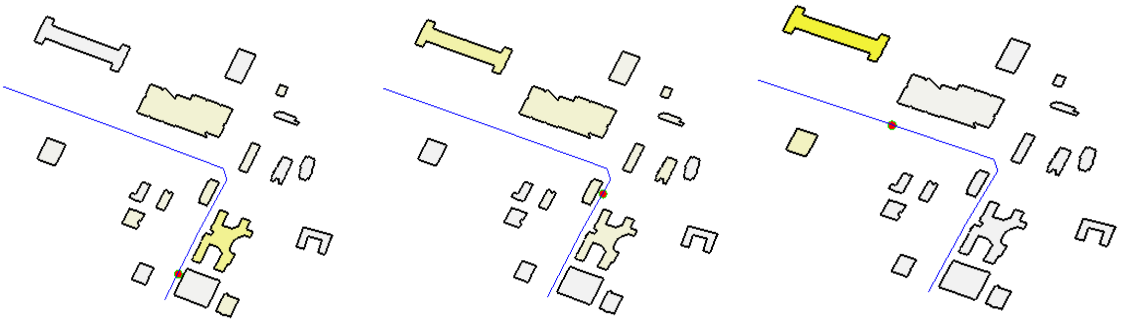


Figure 4.15 Dynamic salience during driving (30°)

In the second experiment, we focus on the PDS measurement through the combination of a series of viewpoints. We choose the same route but with a larger dataset consisting of 80 buildings. As shown in Figure 4.16, the dark blue line indicates the route, the black dots along the route represent the viewing points, the yellow polygons are the original buildings, and the green polygons with the center points (red dots) are building outlines which fall into the user's useful view field. The light blue lines are lines of sight from the individual observer points. Figure 4.16 demonstrates the salient buildings during driving towards two opposite directions with 30° as the maximal useful view field, while Figure 4.17 shows the salient buildings during walking in two directions with 90° as the maximal useful view field.

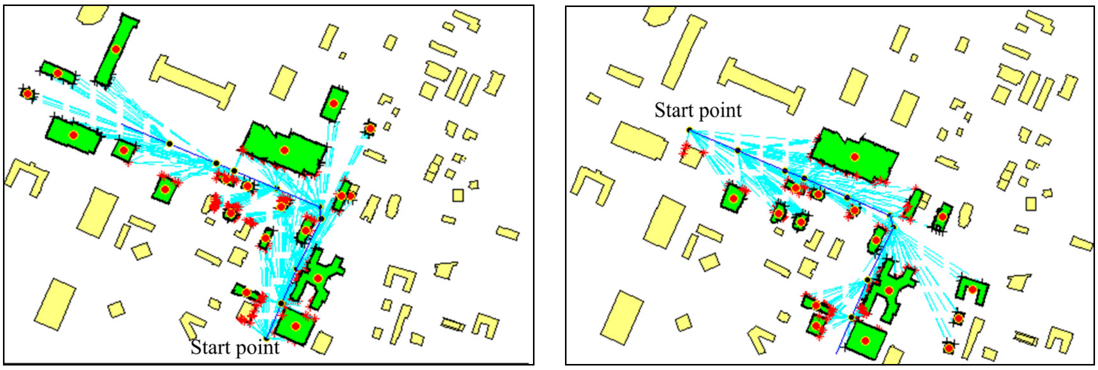


Figure 4.16 The salient buildings in green during driving (30°)

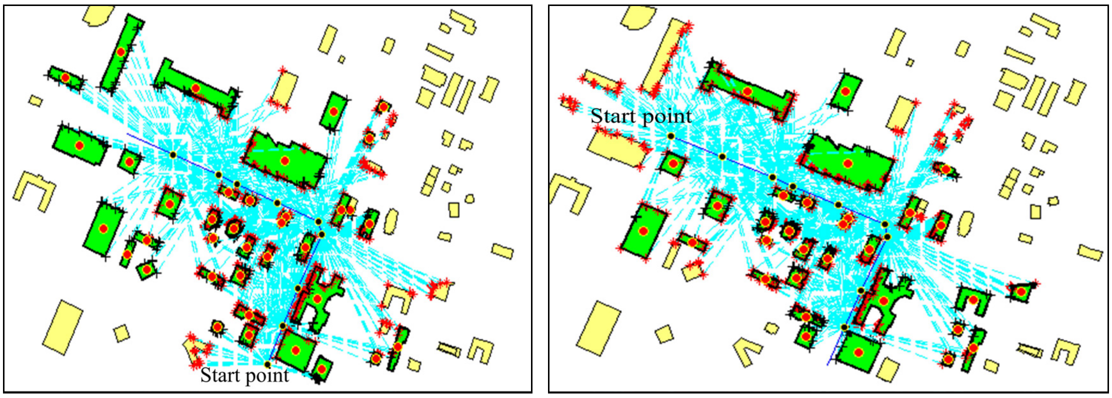


Figure 4.17 The salient buildings in green during walking (90°)

Figure 4.18 and 4.19 highlight the rated salient building objects from Figure 4.16 and Figure 4.17 respectively. The PDS changes obviously for different directions, different travel modalities. The driver usually focuses on the objects in the front of the car, and the salient objects are centered along both sides of the road in front of each position. The pedestrian has a larger cognitive space, the salient objects lie on two sides of the road near each position. The objects in the front of the walker have higher salience than those behind. Moreover, objects around turning points are more salient as well.

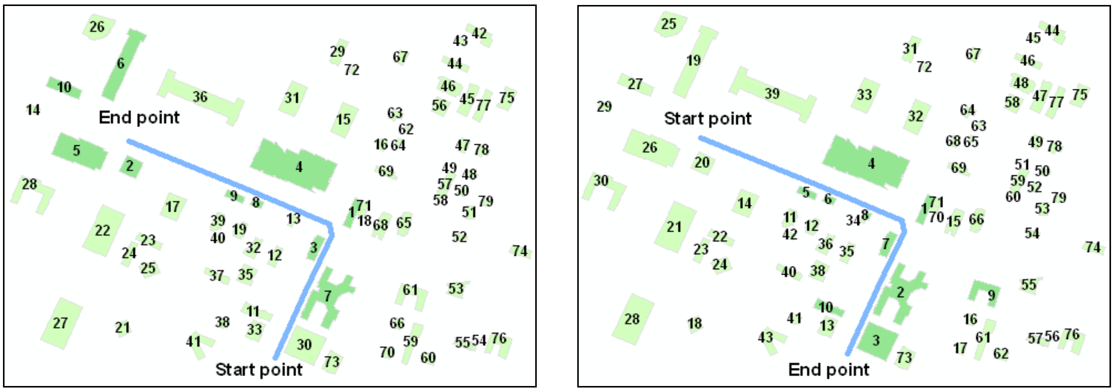


Figure 4.18 Rated salience for driving

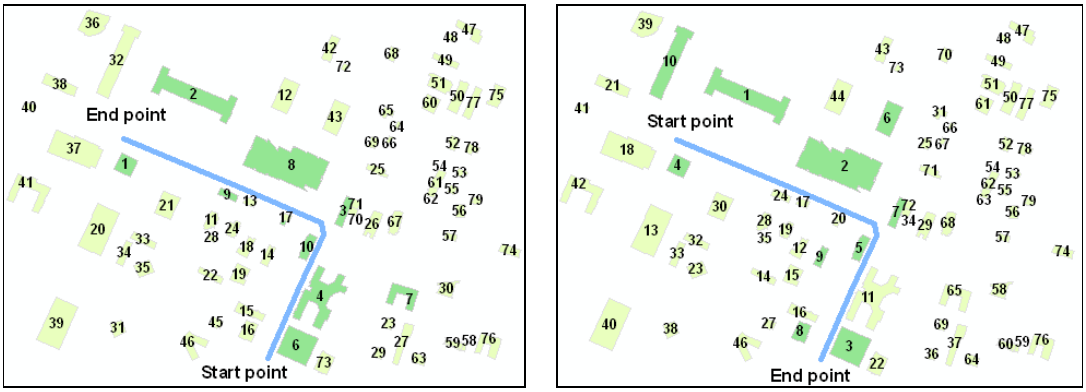


Figure 4.19 Rated salience for walking

4.4 Integration of passive and active salience

As mentioned in previous sections, the salience of a spatial object for routing task is composed of a passive part and an active part. The passive part in turn is treated as a weighted sum of ISS, SDS and RDS. In this section, we try to integrate the passive part with the active part by means of a linear function by Eq.4.10.

Additionally, as discussed in Chapter 3, for a static viewing point, we define its context area based on the visibility from the egocentric perspective. From an exocentric perspective, the context area is independent of the visibility analysis. The passive salience for an object *i* within the context area can be expressed as:

$$S_i = ISS(i) \cdot w_{iss} + SDS(i) \cdot w_{sds} + RDS(i) \cdot w_{rds} + PDS(i) \cdot w_{pds} (i \in [1, N], N \in R) \tag{4.10}$$

The overall salience $S(i, j)$ of object i from each viewing point j can be calculated by Eq 4.11.

$$\begin{aligned} S(i, j) = ISS(i, j) \cdot w_{iss} + SDS(i, j) \cdot w_{sds} + RDS(i, j) \cdot w_{rds} + PDS(i, j) \cdot w_{pds} \\ (i \in [1, N], N \in R, j \in [1, m], m \in R) \end{aligned} \tag{4.11}$$

Using the same test data with 18 buildings from the pervious sections, the individual salience parts and their integrated effects from a static viewing point are computed and summarized in Table 4.6.

Table 4.6 Multiple salience parts and their combined effects from a static viewing point

Building object	ISS	SDS	RDS	PDS driving	PDS walking	Combination driving	Combination walking
1	0.12	0.13	0.8	0.61	0.71	0.87	0.97
2	1.02	0.11	0.84	0.83	0.81	1.45	1.43
3	0.06	0.06	0.79	0	0.73	0.21	0.94
4	0.42	0.15	0.69	0	0	0.36	0.36
5	0.11	0.09	0.63	0	0	0.21	0.21
6	0.08	0.19	0.77	0	0	0.26	0.26
7	0.03	0.10	0.77	0	0	0.21	0.21
8	0.13	0.28	0.66	0	0	0.30	0.30
9	0.03	0.21	0.73	0	0	0.24	0.24
10	0.32	1.21	0.71	0	0	0.75	0.75
11	0.20	0.14	0.69	0	0	0.28	0.28
12	0.14	0.39	0.67	0	0	0.35	0.35
13	0.16	0.13	0.76	0	0	0.27	0.27
14	0.05	0.32	0.78	0	0.76	0.31	1.07
15	0.07	0.10	0.79	0	0.66	0.23	0.89
16	0.03	0.11	0.79	0	0	0.22	0.22
17	0.01	0.02	0.84	0	0.82	0.18	1.0
18	0.14	0.17	0.59	0	0	0.24	0.24

$$w_{iss}=0.2, w_{sds}=0.1, w_{rds}=0.2, w_{pds}=0.5$$

In Figure 4.20 (left), the green labels indicate the top five salient objects when the driver reaches the point P_1, while Figure 4.20 (right) shows the changed top five salient objects when the driver arrives at viewing point P_2. In a similar way, Figure 4.21 (left) and (right) illustrates the top five salience objects for walking at P1 and P2 respectively.

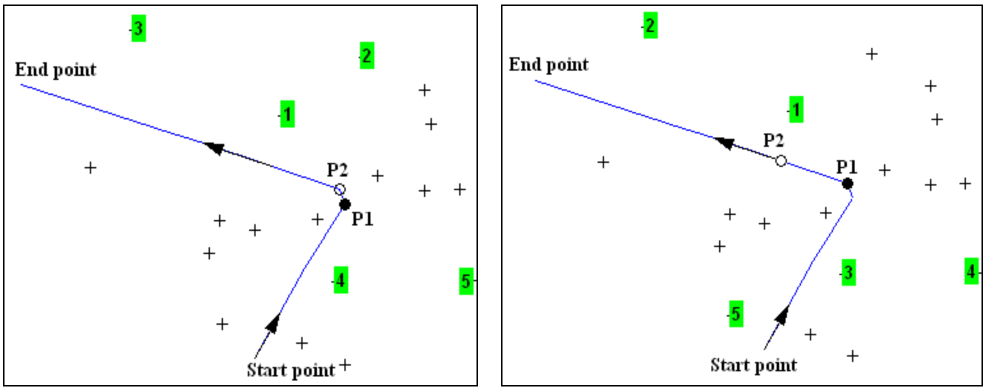


Figure 4.20 Two viewing points of driving and the changing top five salient objects

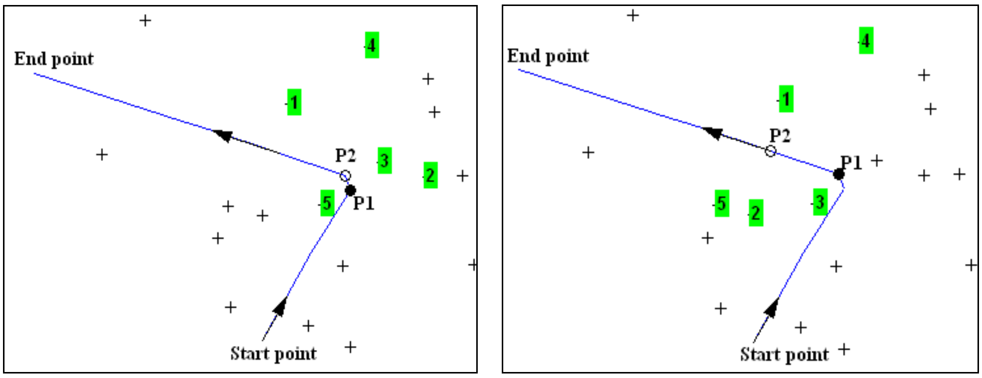


Figure 4.21 Two viewing points of walking and the changing top five salient objects

The top five salient objects (filled by green dots) computed with the larger test dataset are shown in Figure 4.22 and Figure 4.23. Obviously, the objects near the route are more salient for both driving and walking although the salient objects are spread in a larger view field for walking than for driving. The salience rating of all individual objects may guide the generation of the route map at multiple scales. It is also important to change the weights for different routing situations. For instance, the weight of the PDS may be reduced by bad weather and increased to relax the mental effort of the traveler. Likewise, we can adapt the weights depending on the age of the traveler.

It is worthwhile to note, that the passive and the active part of salience can be integrated in other computational ways. For example, it is possible to identify salient objects based on their frequency of becoming salient from different viewing points. Those objects which are deemed salient very frequently should be considered as more important than others for the routing task.

Figure 4.22 Integrated salience for driving in two directions

Figure 4.23 Integrated salience for walking in two directions

Chaper 5

Selective rendering of routing map

5.1 Cognitive elements for rendering

5.1.1 Rendering strategy

The salient objects extracted by using the method described in Chapter 4 need to be visualized as map features for individual routing task. In our context, we limit the task for two travelling modalities –walking and driving, and will answer the basic question of how to visualize the route-related geographic information in an appropriate and efficient way. This seemingly straightforward question involves two complex aspects: 1) how to visualize as many salient objects as possible; 2) how to minimize the workload of the user's decision-making with the right amount of supporting information. Both issues have been comprehensively studied in a separate way in the literature. However, we need to integrate the findings into our study.

The routing map is assumed in two typical scenarios: a static routing map and a dynamic view of the route during the travel. In practice, more and more users, especially the mobile users, need both scenarios in advance and/or during the travel. Being aware of various categories of routing map as reviewed in Chapter 2, we emphasize in this chapter various aspects of landmark visualization and their applications. Landmark visualization is related with a number of research topics ranging from cartographic method, computational geometry, information visualization to human cognition (Luboschik et al., 2008; Karnick et al., 2010). Visualizing landmarks along the route can be thought as a special case of a thematic map, which requires suitable cartographic design to symbolize label landmarks and highlight the important information without overlap for the given task.

This elementary problem of automatic label placement has been studied since decades. To deal with different application scenarios, various strategies for automatic labeling have been presented, e.g. expert system (Ahn and Freeman, 1984), zero-one integer programming (Zoraster, 1990), approximation algorithm (Agarwal et al., 1998, Kreveld et al. 1999, Strijk and van Kreveld, 2002), simulated annealing (Christensen et al., 1995), force-driven algorithms (Hirsch, 1982), and tabu search (Yamamoto et al., 2002). The conventional automatic label-placement problem has been proved to be a NP-hardness problem (Formann and Wagner, 1991; Marks and Shieber, 1991; Kakoulis and Tollis, 1996), and it was identified by the ACM Computational Geometry Impact Task Force (Chazelle et al., 1996) as an important research area. The relentless effort of pursuing automated approach is motivated by the intention to reduce the tedious and time-consuming work of manual labeling, which is estimated to take 50% of total map production time (Morrison, 1980). Depending on the geometric extension of spatial objects, the labeling can be conducted on point, line and polygon map features. Point labels are preferably positioned above and to the right of the object. Fig.5.1 shows two examples of labeling positions. Additional positions in connection with the map feature can also be considered, for example, the continuous positioning along a so-called slider model (Hirsch, 1982). Labels for line features should be placed near the line feature and the unoccupied space. For polygon labeling, it’s important to keep the label inside the area and stretch it to represent the whole area (Imhof, 1975; Dorschlag et al., 2003). Landmarks along the route are usually visualized as point features with distinct labels, which can facilitate the user to get apt information for orientation. Therefore, we focus on the labeling problem for point features in this chapter, and the line and polygon features should be transformed into points before rendering. To avoid the distortion during the transformation, we make use of the feature's shape and the font size of the label according to (Dorschlag et al., 2003; Guo et al., 2004).

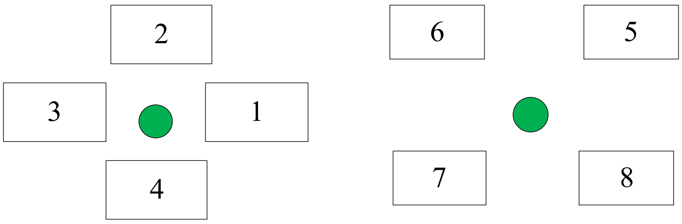


Figure 5.1 Preferred positions for labels on maps

The labeling process is divided into three stages (Petzold, 2003):

(1) Identify the possible positions of the label;

(2) Place the label near the feature according to cartography laws, and then evaluate the rate of these positions;

(3) Decide the final label position for each feature that can minimize the overlap with other labels and at the same time increase the rating of the global solution.

In case of labeling point feature, the orientation of a label can be approximated by its axis-aligned bounding rectangle, while the possible labeling positions and their ranking can be determined in a straightforward way according to the given preferences as shown in Figure 5.1. This labeling approach is intended to provide high legibility of maps on different media, however, most of the mentioned methods focus on finding a solution which can maximize the number of the labels at a given map scale, little attention is paid to rendering time for the labels. Dynamic and interactive methods are needed to satisfy the demand for fast visualization (Petzold et al., 2004, Been et al., 2006).

The research of interactive and dynamic labeling with time constraint started from the 1990's. Tools such as interactive zooming function are available, which requires the complete labeling to be constantly refreshed whenever the display scale is changed in the interactive environment. Fekete and Plaisant (1999) reported the exocentric labeling, where all features in a circular neighborhood of the mouse are labeled by listing the labels vertically to the right and left of the neighborhood, and drawing lines from each label to its associated feature.

In order to enhance the visualization speed, Petzold et al. (1999, 2003a, 2003b, 2004) separated the dynamic labeling procedure into two phases: the pre-processing phase and the interaction phase. The potential complication was computed beforehand and stored in a data structure called the 'reactive conflict graph', and then in the interaction phase, the graph was repeatedly queried to obtain a static conflict graph: the nodes were the map features within the current view, and the edges indicated potential conflict for labels of these nodes. A subset of labels were selected from the conflict graph and placed at the current scale. To avoid conflicts among the labels, they employed a greedy method according to which a priority order for labels guides the selection or rejection of the labels.

Poon and Shin (2005) introduced the adaptive zooming over a set of point labels, and they assumed only axis-parallel, rectangular labels, which mean that the point feature must be located at the left boundary of the label. During zooming out, the labels grew to the right vertically. The one-dimensional version of this task can be solved for a given scale with greedy interval scheduling. A hierarchy where each level represents one resolution was built to allow the zooming operation, the lowest level has the finest resolution, and the resolutions become coarser and coarser when the levels in the hierarchy increase. When a feature should be rendered, the most appropriate level in the hierarchy is identified and an optimal solution for this specific level is then chosen.

More approaches for interactive and dynamic labeling can be found in (Zhang and Harrie, 2004; Yamamoto et al., 2005; Been et al., 2006; Mote, 2007; Ladniak and Kalamucki, 2007; Kramers, 2008; Nivala et al., 2008; Luboschik et al., 2008). They were developed especially for users who can easily acquire the web-based map information via Internet or mobile service.

$$V_d = \int_{s=0}^{\infty} v_s \tag{5.1}$$

The fundamental difference between the dynamic and static labeling problem is the number of rendering stages. The dynamic labeling problem can be regarded as integration of the static labeling problem along the map scale or time as shown in Eq. 5.1. Petzold et al. (1999) recognized the obvious differences between the two strategies as coming from the media. They suggested the dynamic labeling for screen map and the static labeling for paper map. It is well known that the minimum pixel size of a paper map is about 0.1mm (even smaller), but the minimum pixel size of a computer monitor is about 0.2mm. To get the same quality, the symbols in screen maps must be made less filigree and have a lower density of symbols than that of the paper map.

The disadvantage of coarser monitor resolution can be compensated to a certain extent by means of interactive operations such as scrolling (changing the map clipping), zooming (free choice of scale) and dynamic combination of thematic layers. However, these operations do not solve the conflicts among labels on screen maps when the display scale is reduced beyond a certain limit. Two examples that demonstrate the overcrowded labeling are shown in Figure 5.2.

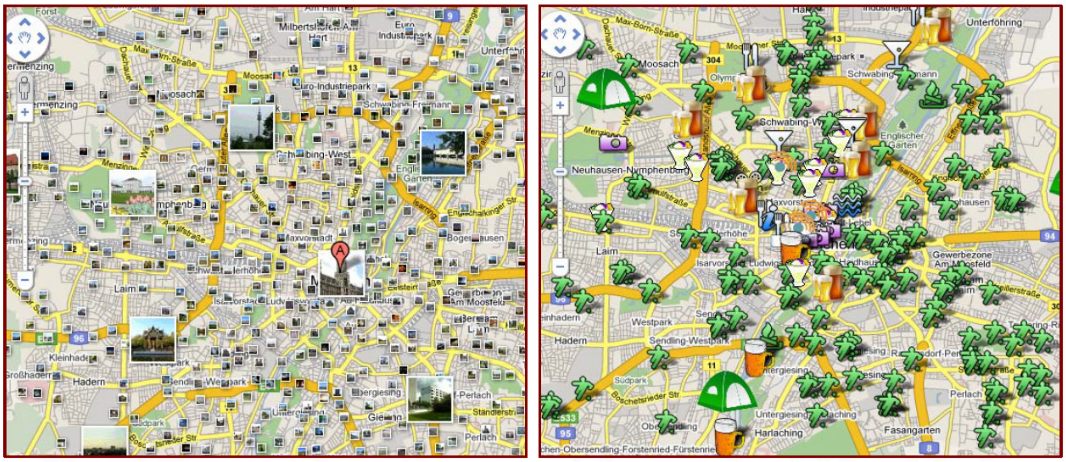


Photo features User-created symbols

Figure 5.2 Two screenshots with overcrowded geo-tagged photos or labels

At the same time of research on optimizing the label placement, cognitive factors have been considered and evaluated for the dynamic labeling problem. Agrawala (2001) proposed two criteria - the usability and fidelity for the routing map, and indicated that the important information, e.g. road name, address of the origin and destination and landmark should be labeled on the map. Similar to Agrawala's work, Swienty (2008) studied the visual information processing and biological mechanisms involved in visual attention, and suggested an attention-guiding geo-visualization approach. Moreover, he proposed two criteria, i.e. utility and usability, to evaluate the acceptability of a visualization system. Kristien et al., (2009) tested the usability of geo-visualization, especially the label placement method on dynamic and interactive map. The entire labels as well as their abbreviations were used. According to user's evaluation, reducing the number of labels will drastically improve the interaction efficiency.

Previous works suggest that all geometric types of map features - points, lines and areas can be displayed on the routing map. For way finding or navigation, the most important features are landmarks of various types which could be derived from tangible geographic objects such as buildings, rivers, forests, POIs and so on. No matter how many spatial objects or layers the original spatial data is composed of, the routing map should always keep its legibility. Therefore, a compromise between the static routing map and dynamic routing map is necessary during the navigation. Being inspired by related research works, we propose in the subsequent sections a novel approach to generate a dynamic route map by simplifying salient spatial objects.

5.1.2 Guidelines of routing map labeling

The development of an automatic method for landmark labeling on a routing map requires systematic formulation of the conflicting criteria related to graphic variables of labels such as location, orientation, shape, size, and typography. Yeoli (1972) and Imhof (1975) summarized the general cartographic principles for map labels for the efficient and automatic design of routing map. Moreover, Imhof illustrated around 100 labeling examples to show good or bad criteria. Agrawala (2001) studied position and style of the label in the following aspects:

(1) Legibility: the label should be easily read, easily discriminated and easily located. This is a basic requirement dependent not only on the style of the label, e.g. the colour and size, but also on the spatial location.

(2) Associability: The label should have a clear graphic association with the object, and the label should be easily recognized with the belonged object.

(3) Unambiguity: The label should disturb other map content as little as possible, and it's important to avoid covering, overlapping so as to increase the identifiability. Each object should have an exclusive label if there is enough space for the label, and the label should assist directly in revealing spatial situation, territorial extent, connection, importance, and differentiation of objects.

(4) Monotonicity: the label should not be evenly dispersed over the map, nor should names be densely clustered.

(5) Priority: the type of the label should reflect the classification or hierarchy of objects on the map.

These general principles have been widely accepted not only for map production, but also for some visualization research topics such as virtual reality. However, they have been targeted only for static maps. Moreover, the principles implicitly emphasize on the manual labeling work. So it needs some extensions to generate the dynamic screen map. In a navigation scenario, for instance, it is a crucial task for the dynamic map to avoid the behavior that is distracting or jarring, such as labels popping or moving in unexpected ways (Been et al., 2006).

Interactive maps are extensively used in Internet or professional GIS systems. The landmark visualization follows the prevailing strategy of ‘All or None’, which allows the user to choose one or more types of landmarks at the same time to display without pre-processing of relevance or salience. No wonder that a map will be cluttered when the users choose all types. Another strategy to control the visualization is to show the features within a fixed scale range when the users need the zooming operation. However, this may only reduce the cluttering problem within the given scale range. As mentioned in Section 5.1, dynamic maps need to incorporate user interactions such as zooming and panning, which habitually violate the conventional principles. The classical labeling task is to optimize the relation between the completeness of the labeled features and the legibility of the route map; however, the dynamic labeling task is about the compromises between the completeness and the speed of the visualization. It has to follow three additional guidelines related to the changing scale.

(1) Continuity (dynamic): The labels should change continuously under the zooming and panning operations, which indicate the labelling problem is a function of the current state. To be more specific, the size and location of the labels vary with the map scale. Moreover, the labels should remain visible and consistent for a preset scale. Simultaneity, the type of label must be considered, for example, for the text labels, there are lots of potential locations can be used to represent them, on the contrast, for a symbol label which represents an object itself, the location should be accurately positioned to avoid the misapprehending of the reader.

(2) Relative completeness: The labels should reflect not all, but the most relevant spatial objects. The labels should be ordered according to their priority and legibility so that they can be visualized on-demand and on-the-fly.

(3) Convenience: the label should consider the scenario of the application, which means the user might have different requirements when the usage context for his task changes. For instance, a routing map should contain much more focused labels during a travel than during the planning stage.

Considering these additional guidelines, we reformulate the labeling problem for routing purpose as a task with focused goals and salient landmarks which can be detected using the method introduced in Chapter 4. Furthermore, we assume that the dynamic routing maps are a set of the static maps for each scale, although the labeling should be computed dynamically for the current scale. The route on the map could be partially overlapped by the landmarks. The dynamic parameters can be the display scale, the size of the label and the characteristics of the route etc. We choose the display scale as the guiding variable for navigation.

5.1.3 Labeling maximization

The global labeling problem is a typical NP-Hard problem. The number of possible solutions increases exponentially with the increasing number of spatial objects to be labeled. Therefore, a compromise between the performance and quality is needed for the interactive usage context. We introduced several constraints to reduce the search space for labeling locations.

We assume that each label of a given set of landmarks has a known priority which can be derived, for example, from the relative salience of its corresponding landmark. The landmarks have their locations without conflicts in the real world. With the decreasing map scale, however, they may become increasingly close to each other and their labeling may cross each other. A reasonable labeling approach aims therefore at minimizing the number of scale-dependent conflicts.

Definition 5.1 (Dynamic Landmark Visualization Problem DLVP):

Given the initial map domain M, the distinct points $P=\{|p_1,p_2,...p_n,n\in I\}$ are the datasets to be labeled $L=\{|l_1,l_2,...l_n,n\in I\}$, and each point is related to a known weight factor and the label size $l_i^s=[length,width]$, which changes continuously with the map scale. For each point in P, there exists a scale range $r_i=[s_{\min},s_i]$, within which there is no overlap with other labels, but the overlap emerges beyond this range, therefore, the prior weight decides which label should be deactivated in the current scale. At each scale, the number of the non-overlapping labels should be maximized and visualized.

Labels may overlap with others only if the scale has been changed because the size of the label changes with the zooming operation, whereas the panning operation only changes the center of the focus. During zooming, the distance among features is scaled by a constant factor which also guides the scaling of the label size. The scaling process was simulated by a planar affine function in Been et al., (2006).

In practice, the conflicts are detected in a pre-processing procedure and stored as a semantic property of the spatial object. This pre-computation can dramatically improve the performance of the interactive process. Unlike the classical sequential procedure from filtering, selection to label placement, our strategy is to compute the scale ranges within which they can be visualized for each spatial object. The subsequent interactive operations apply the maximum distance and visible scale range to generate the screen map. However, to generate such a series of maximum distances for each display scale is a complex and screen-dependent issue which is addressed in the following section.

5.2 Labeling landmarks on routing map

5.2.1 Conflict detection

The label placement for the landmarks free of conflicts can be regarded as a fundamental issue in map generalization which serves the purpose of deriving small-scale maps from large scale maps. The selection of landmarks is scale-driven (Meng, 1997) whereas the visualization is also related to the usage context. The interactive operations such as zooming and online queries, for instance, require instant visualization of landmarks and their labels. The user faces the same time pressure for navigation task. We choose to pre-process landmarks and labels in an off-line manner and then render them in real time.

The main task in the pre-processing is to detect the conflicts among the labels which are characterized by the spatial relationships among the labeling objects and the sizes of the labels. Obviously, the label size and the distance between the map features are related to the map scale. However, the changing ratio of the size needs to be estimated during the pre-processing procedure which can simulate the actual scenarios and record the scale limit beyond which the conflicts occur. Changing the scale may introduce conflicts. For each display scale, we can compute the minimum distance at which no conflict occurs with the legible symbol sizes. It depends on the minimum dimensions of map elements of specific display screen and the display scale.

The minimum dimensions of map elements could be the minimum values for the perception (or legibility) of map elements and the space between under normal conditions of perception. They depend on two factors: the aligning power (resolution) of the human eye and the restriction of the display screen. The aligning power is the distance at which two points can still be perceived separately, which is a function of the reading distance, the wavelength of the surrounding light and the visual ability of the user. The well acceptable values of the aligning power in case of normal daylight are shown in Table 5.1.

Table 5.1 The aligning power of the human eye depending on the reading distance (Neudeck, 2001; Lechthaler, 2006; Jenny, 2009)

Reading distance	**Aligning power (alternative one)**	**Aligning power (alternative two)**
30cm	0.05mm	0.09mm
60cm	0.10mm	0.17mm

Whereas the resolution of a screen is its resolving power: the number of pixel per surface unit commonly expressed in dots or pixels per inch (dpi). The resolution determines the degree of detail visible on the screen and it is almost always given as a pair of numbers that indicate the screen setting's width and height in pixels. For example, a monitor may be specified as being a low-resolution of 640 * 480, a medium resolution of 800 * 600, or a high-resolution of 1024 * 768 or more. Given the display resolution and the size of the display screen as Figure 5.3 shows, the size of pixel can be calculated with Eq.5.2.

$$\text{Size of pixel} = \frac{MS \cdot 25.4}{\sqrt{DSH^2 + DSV^2}} \tag{5.2}$$

Where

1) *DSH* is the width of monitor’s drawing area (unit：pixel)
2) *DSV* is the height of monitor’s drawing area (unit：pixel)
3) *MS* is the monitor's diagonal size (unit: inch)

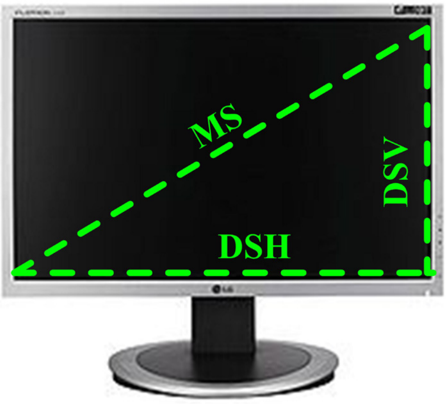


Figure 5.3 A display screen and its size

For example, given the resolution of 800*600 and the size of 12.2 inch, the size of pixel of the screen is 0.3mm, whereas given the resolution of 1280*800 and the size of 5.3 inch, the size of pixel of the screen is 0.089mm.

It is obvious that if the aligning power of the human eye is smaller than the pixel size, the latter is a suitable minimum dimension under average viewing condition, however, for a higher resolution, for example, 1280*800 and the screen size of 5.3 inch, the pixel size is smaller than the aligning power of the human eye, therefor, the suitable minimum dimension should be the aligning power of the human eye rather than the pixel size. This principle is adopted in our study expressed D_s in Eq.5.3.

$$D_s = \begin{cases} \dfrac{MS \cdot 25.4}{\sqrt{DSH^2 + DSV^2}} & if\ (size \quad of \quad pixel > 0.1) \quad (unit : mm) \\ 0.1 \quad if\ (size \quad of \quad pixel < 0.1) \quad (unit : mm) & \end{cases} \tag{5.3}$$

On screen map, icons and symbols are often used to represent the spatial objects and their meanings in an integrative way. For instance, a university is usually depicted by a university symbol and a name label. The suitable size for the symbol and label is dependent on the display scale. Lots of researches and various strategies about the relationship between the size and the scale have been reported. A typical example is the non-proportional relation proposed by (Petzold et al., 2003a). In (Harrie et al., 2004), a series of discrete label sizes was used for web maps. In our study, we take the size of the symbol or label as a variable to control the conflict. Although a map symbol may take various styles, its size can be approximately described by a circle or a rectangle.

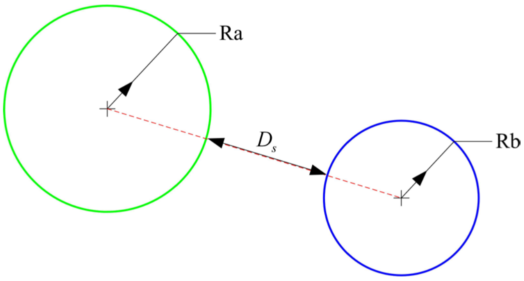


Figure 5.4 Two circle symbols and their sizes

As shown in Figure 5.4, R_a and R_b represent the radios of two neighboring circles, D_s is the minimum spacing between them for a given display screen, the minimum Euclidean distance Min_d can be computed by Eq.5.4

$$Min_d = (D_s + R_a + R_b) \cdot LM \qquad (5.4)`$$

where LM is the denominator of the display scale.

In case of rectangles as shown in Figure 5.5, the minimum Euclidean distance Min_d is expressed by Eq.5.5.

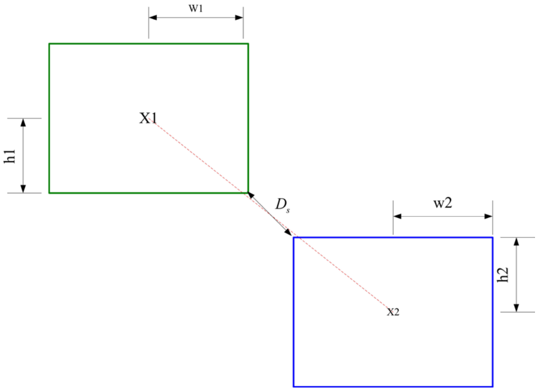


Figure 5.5 Two rectangular symbols and their sizes

$$Min_d = \min\{(LM\cdot(D_s+h_1+h_2)),(LM\cdot(D_s+w_1+w_2))\} \tag{5.5}$$

Based on the minimum Euclidean distance (Min_d), the potential conflicts between symbols or labels can be detected on the given display screen.

5.2.2 Conflict management

We choose the cost-efficient 4-neighbor model to express the candidate position for each point, or the label space (Yamamoto et al., 2005). As shown in Figure 5.1(left), the rectangular bounding box around the map feature contains four grids. The label can be freely placed in one of the four grids as long as no conflict occurs.

In order to simplify the labeling problem, we assume that all labels keep the same direction on the map. The labels start to clutter when the display scale is reduced below a threshold. The threshold scale can be pre-calculated and stored for each map feature. For each individual landmark, we can calculate its smallest display scale and store its display scale range as a property for the visualization.

A favorite data structure that can store the overlap information for the labels is called conflict graph proposed by Kakoulis and I. G. Tollis (2003). Instead of using the intersection testing approach, we use the distance between labels to estimate the intersection. This kind of conflict takes into account the minimum discernible distance on the screen.

Definition 5.2: In the point dataset N, let the label space for point i be l_i, the conflict between the point j and point i is dependent on their Euclidean distance at the current scale as expressed in Eq.5.6.

$$D_{curr}^{H} > \frac{l_i^w + l_j^w}{2} + D_s\cdot LM \text{ or } D_{curr}^{H} > \frac{l_i^h + l_j^h}{2} + D_s\cdot LM \tag{5.6}$$

with

1) D_{curr}^{H} is the current horizontal distance between the two labels;
2) D_{curr}^{V} is the current vertical distance between the two labels;
3) I_i^w is the width of label i;
4) I_i^h is the height of label i;
5) The suitable minimum dimension of display monitor;
6) *LM* is the denominator of the display scale.

The distance between two map features is the scaled-down ground distance between the corresponding objects, whereas the label size is also dependent on the rendering strategy and the available space and therefore each individual label needs to be examined in terms of conflict detection. The adjacency matrix of map features is a suitable data structure to store the distance information which varies with the change of map scale. It is easier to get the proximate objects and derive conflicting situations from the adjacency matrix.

The label of a map feature may have one or more conflicts at each scale. We address the conflicts at the reference scale where all map features can be displayed but their labels could have conflicts. A heuristic approach is required to deal with labels with more than one conflict. We first compute the adjacency matrix for all potential label points. A conflict graph is then derived from the 4-neighbor model. In the example as shown in Figure 5.6, each node of the conflict graph of *P1* and *P2* represents a candidate label position in Figure 5.7, where every point occupies four label positions and the edges of the graph connect the conflicting label positions. Two nodes are adjacent if they are connected by an edge. The higher the degree of a node, the more conflicts occur to the label at this position. For example, the node *P1-L1 or P2-L3,* if the labels on this position, there will 2 potential conflicts (one conflict is between *P1-L1* and *P2-L3;* another is between the P1-L1 and P2-L2). We employed the yellow dot to represent the nodes in conflict and the red line to denote the edge. The number of conflicts for each node equals to the number of links in the conflict graph from this node to the nodes of neighboring features, e.g. *P1-L1* has 2 conflicts with *P2-L2* and *P2-L3*, while *P2-L2* has 1 conflict with *P1-L1*.

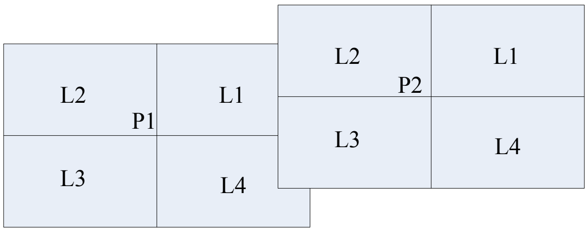


Figure 5.6 Candidate label positions for two point symbols

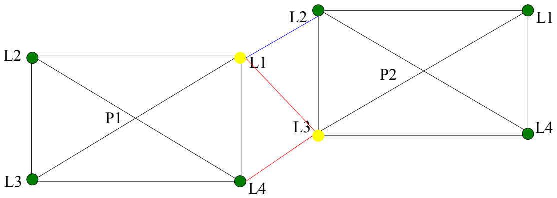


Figure 5.7 Conflict graph of each label position

In another way, the conflict graph is projected to an adjacency matrix, where rows and columns represent nodes (label positions), and each value is either *1* for conflict or *0* for non-conflict. Table 5.2 demonstrates the adjacency matrix of for map features *P1* and *P2*.

Table 5.2 Adjacency conflict matrixes of *P1* and *P2*

	P1-L1	P1-L2	P1-L3	P1-L4
P2-L1	0	0	0	0
P2-L2	1	0	0	0
P2-L3	1	0	0	1
P2-L4	0	0	0	0

On this basis, we can get a list of conflicts. Since the purpose of our work is to label salient objects on the routing map, which means that the priority of each spatial object is already known, we keep the same priority to treat conflicts among labels.

The optimal solution would be maximizing the label size while satisfying the given constraints and avoiding conflicts. In practice we may simplify the requirements and determine the legible label sizes corresponding to the salience of their associated spatial objects. To be more specific, we start to label the most salient spatial object. In case of conflicts, labels of objects with lower salience and their labels may be ignored. The iterative process runs until no conflict exists. We term the computational routine as Subordinate Sacrificed Labeling Algorithm (SSLA) which can be described as follows:

Algorithm 5-1: Subordinate Sacrificed Labeling Algorithm (SSLA)

Input:

(1) The salience order of the spatial objects
(2) The conflict list for each object
(3) The display scale range

Output:

(1) Labels without conflict
(2) The maximum number of labels at each display scale

Main steps:

(1) Sort the salience of all involved objects in descending order
(2) Start from the object with the largest salience; store the ideal labelling position if no conflict occurs in any of the four positions. Otherwise, traversing the conflicting positions in an ascending order. If a free position is available, assign it to the point and store the position as the ideal labelling position. If not, no labelling would take place at that position, and go on with the check of other conflicting positions till the conflict list is exhausted;
(3) Repeat Step 2 for the object with the second largest salience and so on, until all objects in the dataset have been visited.

5.2.3 Selective labeling

The proposed approach in the preceding section serves the general purpose of acquiring the information about graphic conflicts. According to the approach, graphic conflicts with the nearest valid neighbors appear at a specific scale when the spacing between map features becomes too narrow and/or the label size becomes too large. In other words, the label size alone can cause graphic conflicts. For example, if a label begins to have conflict with its neighbors at 1:20,000, it will have more conflicts at smaller scales. Therefore, we can set 1:20,000 as the threshold scale for the visualization of this particular label.

It’s reasonable to regard the conflicts as a constraint for the visualization. The scale of the base map as well as the threshold scale for visualization is stored as additional properties of the individual spatial objects. This is essentially a similar strategy to the dynamic map generalization during which only an appropriate number of map features are selected for the display on the map. The visualization of the selected features and their labels has to take additional constraints into account, especially the time constraint raised by users for their special tasks. In our work, we focus on the navigation task.

In conventional GIS solutions, an active display range for the map features is defined, for example, the layers are made visible in a certain scale range, whereas they're invisible for other scales. We adopt this strategy to visualize the labels for landmarks in real-time by means of stored scale ranges for each individual labels. We apply the 'Level of Details' (LoD) approach to discretize the scale range into a number of scale intervals and fix the number of visible landmarks in each interval. In this section, we discuss the general case for the LoD-based visualization and introduce its detailed algorithm.

Whether a label should be made visible or not is generally dependent on the map scale. Whenever the zooming operation is activated, the system will search all the label candidates for which the new scale is within their visibility scale range and then render them along with the selected landmarks. We divide the scale range S into n different intervals (as shown in Eq. 5.7). When the zooming operation varies within a predefined interval, no change would happen to the labels in terms of their visibility and size.

$$S = \{ f(s_1), f(s_2), \cdots, f(s_n) \} \quad n \in I \tag{5.7}$$

where $f(s_i)$ is a discrete scale interval within the overall scale range.

The scale intervals can be stored as an additional attribute along with the threshold scale for the map features and labels. In this way, the process of conflict detection has been transferred to filtering the landmarks with specific attribute by means of an interactive query.

Our approach is essentially composed of a time-consuming pre-processing and a fast rendering. This is an ideal strategy for applications that require real-time visualization, especially when a great number of labels need to be treated and rendered. An additional optimization is possible in terms of managing the space for labeling. The available space for a label can be rather large. After one position has been decided for a label, the remaining free space can be utilized for the neighboring labels. However, more constraints for these neighboring labels are needed. In this thesis, the multiple possible placements are not considered. More information about how to calculate the unbound labels can be found in Petzold (2003a).

Unlike the classical labeling problem, the labeling of a routing map aims to provide the user with clear and useful information along the route, thus efficiently help him to reach the destination or get the relative location during the journey. Besides the salience information used to select the labels, more route-related information should be integrated. Therefore, other rendering strategies are required to display and highlight the vital route information for navigation purposes. For example, the attention-guiding visualization approach (Swienty, 2008) provides guidelines for the rendering of point, line and polygon features based on the study of user reaction on color, intensity and orientation. In order to increase the utility and usability of the route map, more parameters than just map scale need to be considered in our optimization procedure, which is the future work of this study.

5.3 Evaluation and discussion

Three experiments have been conducted to test our proposed labeling method. The first is to render points using test data (POIs in center of Munich) by two rendering strategies for label and icon. Figure 5.8(left) shows the original labels, some conflict areas are highlighted within the dashed area. Figure 5.8(right) reveals their corresponding bounding boxes (rectangles). The number of each rectangle reflects its ranking order of the Inherent Spatial Salience introduced in Chapter 4. The dashed red circles are also employed to express the conflict area.

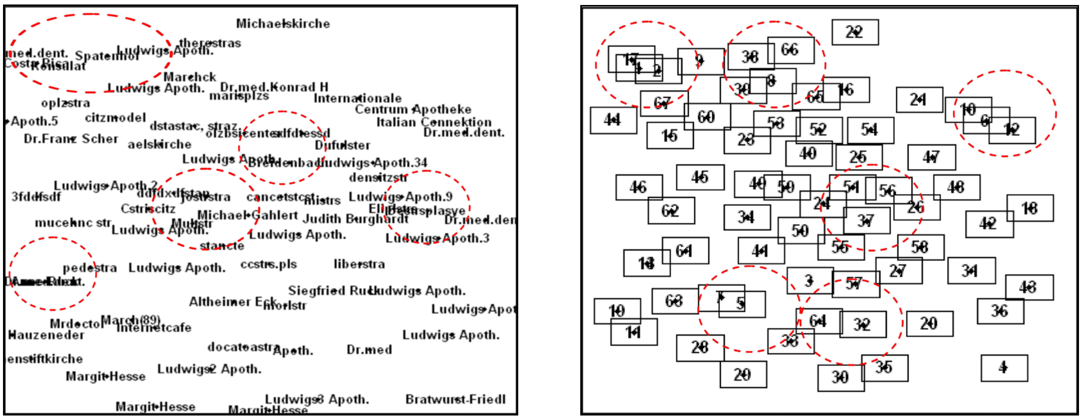


Figure 5.8 Conflicting labels of POIs around center of Munich

Figure 5.9 shows our labeling result of the Subordinate Sacrificed Labeling algorithm; it is obvious that the conflicts have been solved by selective labeling. Labels with low salience are marked by the red points and ignored. For example, in the conflict area A around labels ranked as 1, 2 and 17 is resolved by rendering the labels ranked as 1 and 2 and ignoring the rank 17. The conflict area C around labels ranked as 10,6,12 is spatially extended to its vacant vicinity. The conflict area D around labels ranked as 24, 54, 56 is resolved by rendering only the label ranked as 24.

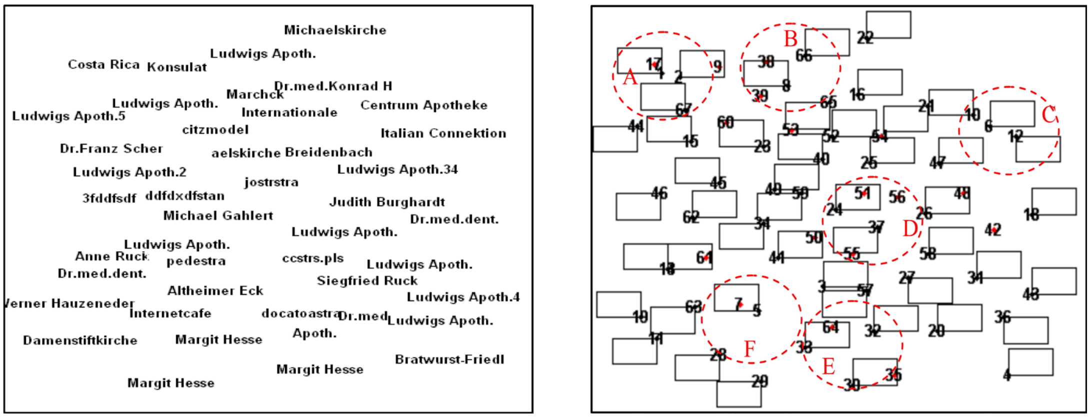
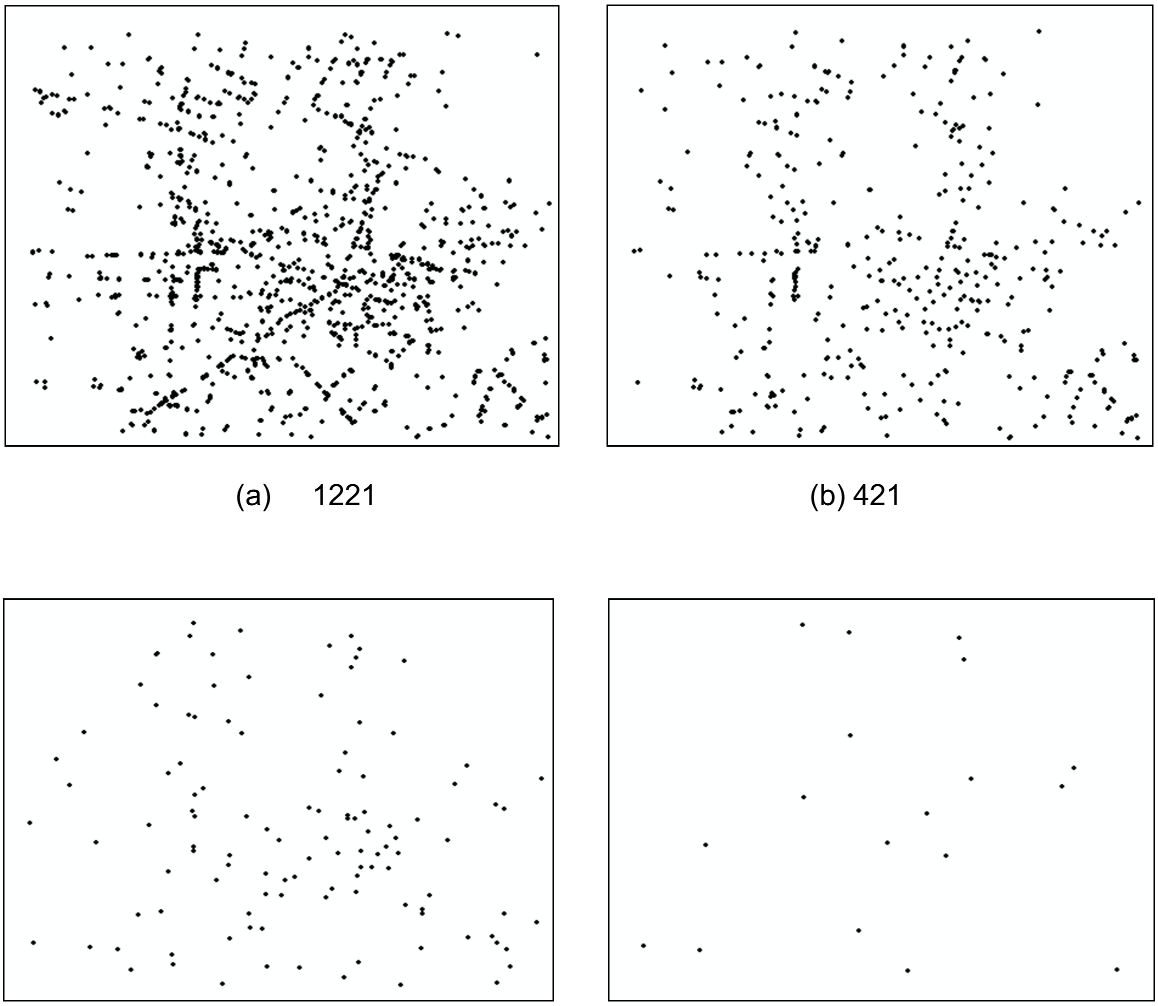


Figure 5.9 Results created by the Subordinate Sacrificed Labeling Algorithm

In the second experiment, we use the dynamic labeling algorithm to select POIs. As mentioned in Chapter 1, POIs do not have salient geometrical information, but bear some prominent thematic information. We may select POIs based on other constraints such as preservation of the thematic distribution. We may also generalize them based on symbol size. For example, when the display scale is reduced, we need to increase the symbol size to keep the legibility. The smallest distance among POIs must be increased accordingly to avoid overlaps. Figure 5.10 (a)-(d) shows the positions of original POIs in a test area and the selected positions for three different symbol sizes.



(a) 1221

(b) 421

(c) 114

(d) 18

Figure 5.10 Test data and three generalized distributions with the number of POIs

Chaper 6

Experiments and discussions

This chapter is dedicated to the technical implementations of our approaches introduced in previous chapters. With experiments on selected test datasets from navigation databases representing three different cities, Munich in Germany, Nanjing in China and Auckland in New Zealand, we want to prove: 1) the salience estimation model; and 2) the selective rendering of landmarks on routing maps.

From Section 6.1 to Section 6.3, a web-based prototype system with cartographic web map services is described. The emphasis is laid on pre-computation of the passive salience. As a result of the passive salience computation, web map services are enriched with POIs and tested with data from the urban area of Munich.

In the section 6.4, we address the active salience computation, landmark extraction and visualization. A series of landmarks for different travel modalities and different study areas are extracted. Our results are evaluated and discussed in Section 6.5.

6.1 Initialization

We choose the test data from Munich city to illustrate the data initialization process. The dataset contains integrated and routing-capable road information of NAVTEQ and ATKIS. It was resulted from the matching approach developed by Zhang (2009) and is accessible for travel modality driving and walking. Using the dataset, Liu (2011) developed and realized a number of multimodal route planning algorithms. The test area is shown in Figure 6.1 which is around 64 km2. The raw data is provided in shape file format with 5 different layers – classified streets, public transport network, pedestrian roads, buildings and outbuildings. The land parcels contains 74165 buildings (gray polygons), and 7678 POIs (green dots) which fall into 56 types.

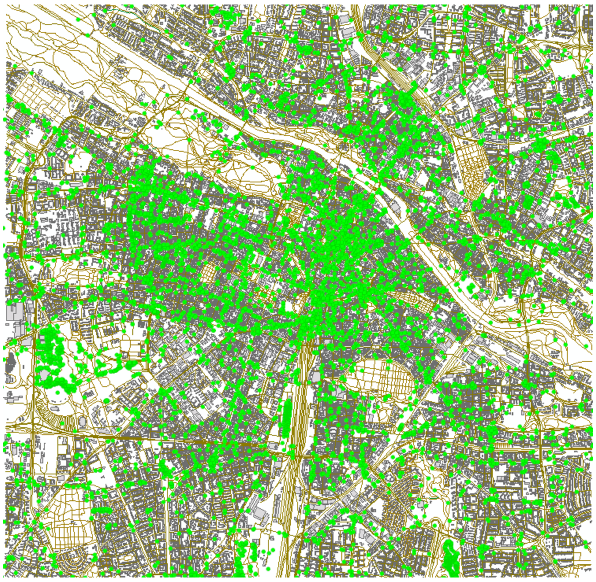


Figure 6.1 Test area of Munich

Although the feasibility of our approaches has been demonstrated with small datasets in previous chapters, it is necessary to verify the model with large test datasets. We will first present the salience detection of cognitive elements for route applications, and then demonstrate the effects of our visualization algorithm in a web-based prototype system. Finally, we will discuss the results in detail.

From the related works we know that both the geometric and non-geometric attributes of the spatial objects may influence the detection of landmarks and their relative salience. The relevant attributes of buildings include footprint area, footprint perimeter, and location of the gravity centre of the building, building height and building function.

The POIs are characterized by their locations, feature types, names, typicality and frequency and so on. As discussed in the chapter 4, the typicality of each type denotes the characteristics of a POI type (e.g. the social important, the geometry characteristic and etc). It can have a weight for landmark ranging from ideal, highly suitable, good suitable, suitable, somewhat suitable, seldom suitable to never (details can be found in Appendix). Likewise, the weight of frequency ranges from always, most, many, some, few and never (details can be found in Appendix). A university, for example, has an ideal typicality if it is unique in a region. On the contrast, telephone cabinets or traffic lights occur repeatedly and are therefore seldom suitable as landmarks. It is not a trivial task to capture the suitable typicality weights. Moreover, the typicality of each POI type may vary with different areas and cultures. There are two ways to get typicality weights. One is based on an expert system as proposed by Winter (2010). The other is based on empirical investigations. In our experiments, we adopted the first way, but with an additional distinction between typicality and frequency (see section 6.3).

A route is known as the computing output of multimodal routing algorithms developed by Liu (2011). The salience measurement is based on the given route incl. the involved travel modalities. Before we conduct the salience measurement, the routing information is prepared in specific formats. Based on the single route graph (Kippel, 2003) and multimodal route graph (Liu, 2011), we describe the routing information as being composed of the following elements:

1) Start point – The starting point of a route.
2) Destination – The endpoint of a route.
3) Viewing point – any intermediate point along the route of a certain travel modality at a certain travel speed, the Origin and Destination are two special viewing points
4) Turning point – any viewing point where a significant change of direction takes place
5) Route segment – a monomodal route as part of a moultimodal route
6) Switch point - a transfer point where a change of the travel modality can take place

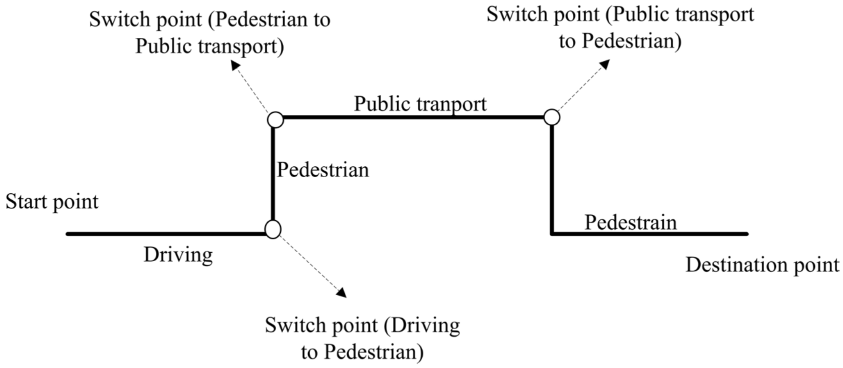


Figure 6.2 Components of a typical route

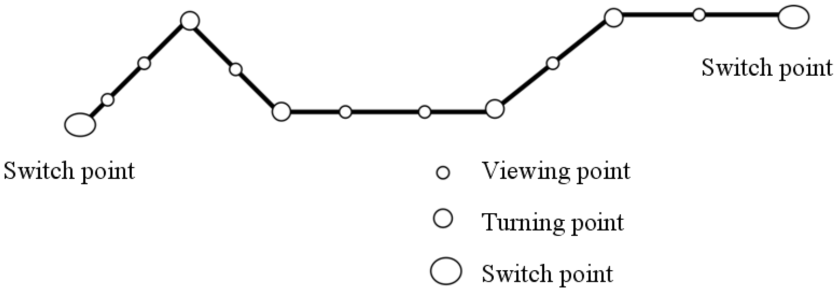


Figure 6.3 Paths along two neighboring route segments

Figure 6.2 and 6.3 demonstrate the components of a typical route and paths connecting two neighboring viewing points. In a practical navigation scenario, the user is the protagonist. His personal characters, skills and experiences will all influence his interaction with the environment and his routing task. Instead of considering all the factors, we only take the general ability of human perception in relation with the travel modality into account. A rather general spatial dataset is required for the experiment which aims to identify the important cognitive elements in the data which should raise the performance of navigation.

6.2 Web-based prototype system

Due to the easy connection to the wireless Internet, more and more location-bases services, especially the navigation services, are provided via Internet and can be accessed by travelers during their movement. A multimodal navigation system requires various datasets containing the information about road network, traffic flow, traffic accidents, parking lots, public transport schedule and public transport stations etc. These heterogeneous datasets are distributed and maintained separately by different data suppliers. They need to be merged into our web-based prototype system for multimodal routing map services. The architecture of the prototype is illustrated in Figure 6.4. Its output should be the routing map services targeted for various stationary and mobile clients.

The architecture is composed of three interrelated levels: spatial data, routing services and applications:

1) Spatial data: At this first level the spatial datasets, static or dynamic, are integrated and managed. The raw datasets are stored in the shape format, can be requested via a data portal, bundled by means of integration algorithms and returned as integrated data services for different applications.

2) Routing service: The integrated datasets are processed at this second level. On the one hand, standard requests are generated and can be sent to the first level for the retrieval of certain parts of the spatial datasets. On the other hand, routing solutions and their salience-oriented visualization are computed in response to the specific requirements from users.

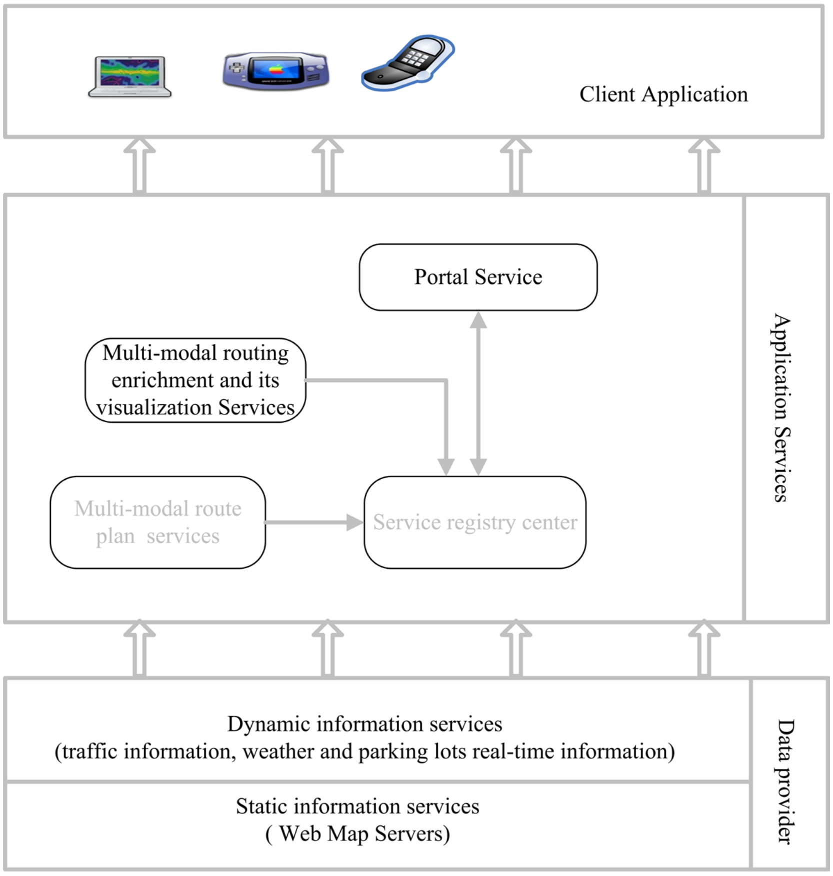


Figure 6.4 Architecture of the prototype system for multimodal routing map services

3) Application: at this third level the routing services are delivered to various clients through a human-machine interface. These services can then be presented on different devices in an easily understandable way. In our prototype system, we use Open Layers API (2.0) to integrate all application services and display the maps accessible through web browsers.

Three services have been implemented at the second level: the multimodal route plan services, multimodal route enrichment and its visualization and portal services. The multimodal route plan services are essentially developed in the thesis from Liu (2011). Therefore, the emphasis of this thesis is laid on the communication of the routing information. The enrichment and visualization services of multimodal routes are achieved in two steps: design of the scale-driven web map services; derivation of routing map services from the web map services. Three different rendering engines and technologies were investigated and implemented for the generation of the web map services enriched with POIs. We treat POIs separately due to two reasons: POIs represent dynamic semantic information and should be better separately updated without having to influence other data; POIs have prominent properties not necessarily in spatial or geometric sense. Therefore, their salience should be estimated by means of different criteria instead of spatial attributes. Four services have been implemented in our prototype system. Table 6.1 summarizes these services along with their input, applied technology and output.

Table 6.1 Detailed information of implemented services

Name	Original data	Technology	Output
Cartographic web map	DLM De	Mapnik(0.6.1)/IIS(5.0)/python(2.7)VS2008.net/IIS	Web map services and map image (png)
Semantic map	POIs DLM De	Mapnik/IIS/python VS2008.net/IIS	Web map services and map image (png)
Routing map	Route, DLM De layers	Map server(6.0) /Apache tomcat Matlab/Matlab Builder NE for.NET Framework, Visual studio 2008 (c#)	Web map services
Routing	Route	Map server (6.0) /Apache tomcat	Web map services

In spite of different applied technologies, these services are provided as standard web map services with the same or a similar work flow as depicted in Figure 6.5, and they publish spatial data and interactive maps in the web.

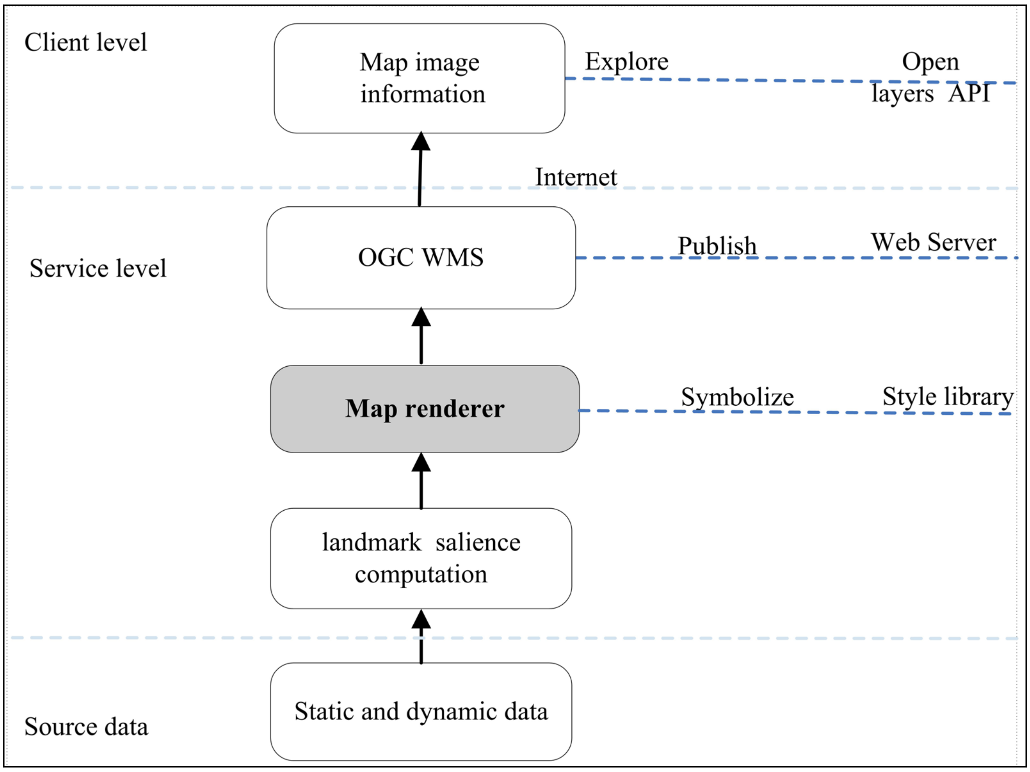


Figure 6.5 Workflow of the web map services

The generation and implementation of routing map services is characterized by two special aspects. One is related with the computing methods about the salience assessment of cognitive elements and LoDs. The other is the source data along the value chain. Instead of taking the navigation-relevant raw datasets as our starting point, our work begins with a specific route created from multimodal routing algorithms and further information related to this route. The software routines and tests in our prototype system are implemented on a Windows XP SP3 system. An XML c parser (libxml2) and a python imaging library (PIL 1.1.7) were installed to store the various results for a Mapnik OGC server. In order to increase the server-side processing speed for each request from the client, we adopted the FastCGI as our web server interface. At the same time, we employed the technology of Mat lab Builder NE (for Microsoft.NET Framework, Visual studio 2008(c#).) to connect the salience assessment program which is needed for the implementation of dynamic routing map services. Moreover, the gnumex 2.0.1 and MinGW 5.1.4 were installed to carry out the visibility analysis and allow the visiLibity (www.visiLibity.org, c++ library) to run with Matlab in MS windows systems. Figure 6.6 shows a base map for routing services at 1:5000 available under http://129.187.175.27:81/routingmapsevices/MultWMSHybid.html.The base map can be overlaid with routes and route-related semantic information.

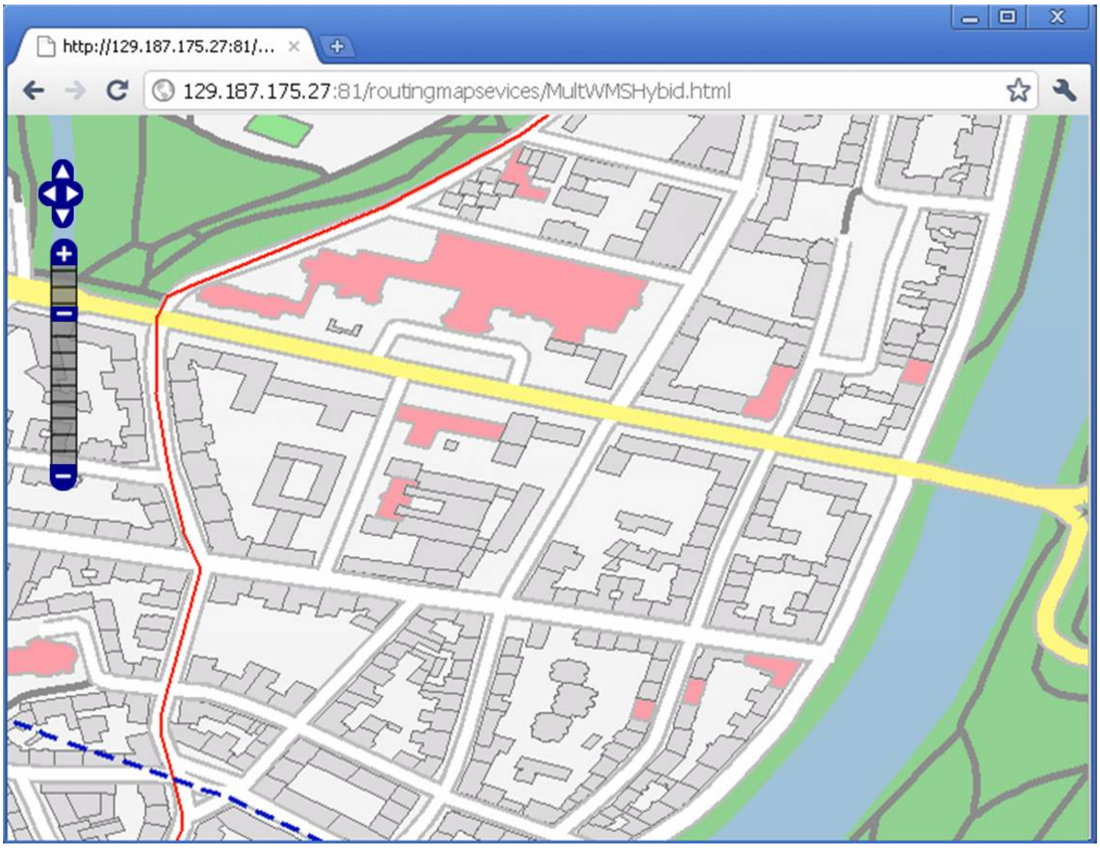


Figure 6.6 An example of web map services (display scale 1:5000)

6.3 Cartographic rendering of web map services

Web Map Service (WMS) is an international standard which defines a "map" to be a portrayal of geographic information as a digital image file suitable for display on a computer screen. Besides the spatial data, WMS are rendered in a pictorial format such as PNG, GIF or JPEG, or occasionally as vector-based graphical elements in Scalable Vector Graphics (SVG) or Web Computer Graphics Metafile (Web CGM) formats. When a WMS client requests a map service via the Internet, the corresponding map will be retrieved at server side and rendered in a browser accessible to the client. Among many complex procedures that are necessary for web map generalization and representation, the ranking of LoDs and the selection of a suitable WMS rendering engine are particularly important for our approach.

6.3.1 Adaptive hierarchical strategies

To satisfy the demand on a web map which can be zoomed in and out, we need to rank the information to be rendered in an order. Up to 20 zooming levels are realized in currently popular WMS. For example, 20, 19 and 17 zooming levels are possible with Google Maps, Live Search Maps and Yahoo! Maps respectively. Most of the current ranking or classification methods are only based on geometric or topological properties of the map features. In our prototype we choose three different strategies to rank or generate the different levels for different data types.

The first strategy is the conventional one based only on the Inherent Spatial Salience derived from geometric or topological properties. It is useful to rank some information with legible geometric or topological properties, for example, the road network, lakes, rivers, buildings and so on. There is a well-accepted classification derived from this strategy (Table 6.2 shows an example of the road classes in Germany). In our work, we also use this strategy to classify our test buildings.

Table 6.2 Road classes

Class	Road layers	Function
1	3106 Road	-
2	3101 Street	2301 Road traffic
3	3101 Street	1808 Pedestrian zone
4	3102 Way	1701 Main agricultural road
		1706 Cycle
5	3102 Way	1703 Foot
		1704 Park
		1709 Mountains
		1710 Cycling and walking
		1707 Riding Trail
7	3105 Road Way	-
8	others	

The second strategy is based on the Semantic Dependent Salience (SDS). On certain occasions, the semantic of POIs is more significant than geometric information. Although many researchers have indicated the necessity of taking into account the semantic information for the generation of LoDs, little practical work has been reported. In our prototype, we use SDS to rank the POIs for two purposes. The first purpose is to generate the semantically enriched web map services; the second is to generate the routing map. The SDS has been automatically computed using the algorithms introduced in chapter 4. With regard to the weight system, we separately adapted the typicality for the web map services and the combination of the typicality and frequency to the routing web map services.

In the third strategy the geometric, topological and semantic properties are combined to generate the ranking order. We adopted this strategy for POIs which are an important information source for the generation of different routing maps. In order to compute the geometric properties for each POI, we first find the building footprint, within which the POI is located in, then take the geometric salience of the building as the Inherent Spatial Salience (ISS) of the POI, and finally combine the ISS with the SDS as the overall salience of the POI. These steps are illustrated in Figure 6.7.

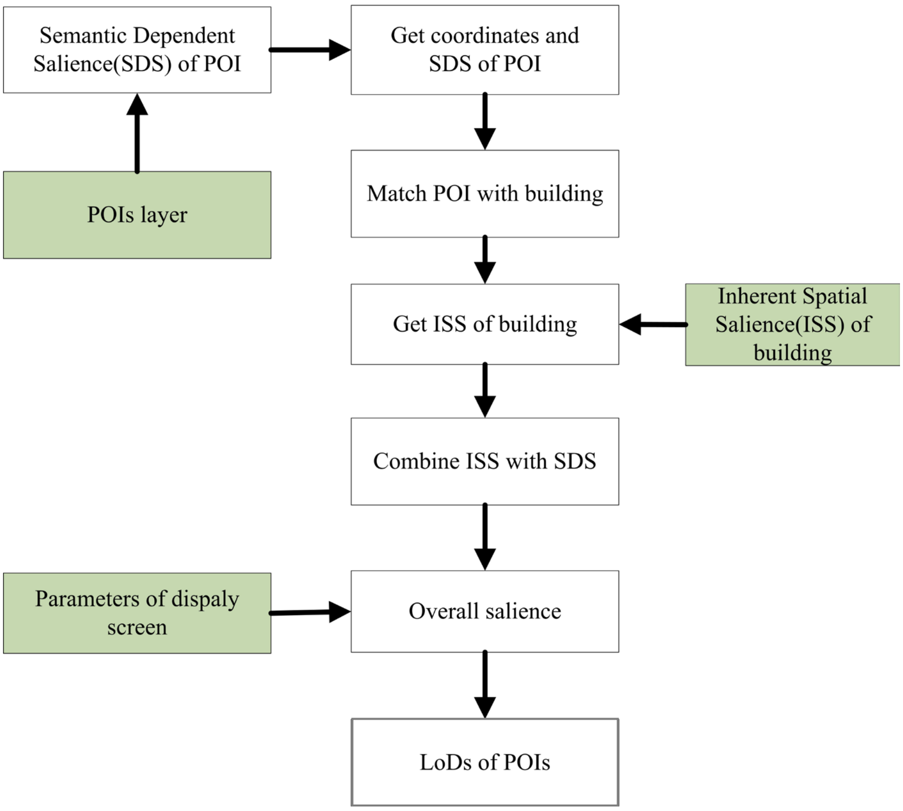


Figure 6.7 LoDs generation steps for POIs

Figure 6.9 shows two examples. The ISS of a hospital symbol can be set the same as the ISS of the building (polygon in red) computed using the geometric attributes (Figure 6.8 left). The ISS of a bus stop as POI located along the street is set to zero because it is not located within the footprint of a building (Figure 6.8 right).

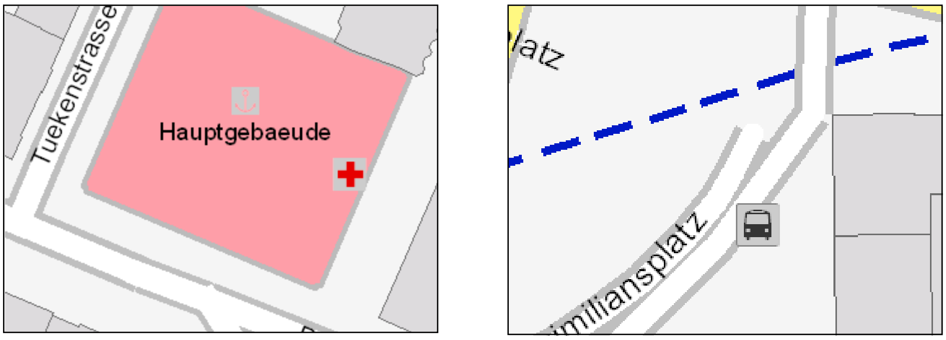


Figure 6.8 Different POIs located within or outside of a building

6.3.2 Generation of LoDs for representation

In order to classify the salience degree and to represent them at multiple LoDs, we apply our dynamic labeling method guided by the salience of individual map features. In our experiments, the icon size of symbol size is set to a constant value (e.g., 24 pixels), and the resolution is 96 dpi (the diagonal size is 17 inch, 1400*1050). The size of each pixel is 0.246 mm which is larger than the aligning power of the human eye. Detailed sizes and minimum distances between the neighboring icons for the individual LoDs are listed in Table 6.3.

Table 6.3 Different LoDs for display

LoDs	Level 5	Level 4	Level 3	Level 2	Level 1
Display scale	1:5000	1:10,000	1:20,000	1:50,000	1:100,000
Icon size (unit: pixel)	24	24	24	24	24
Font size	12	12	12	12	12
Min_d	30.75	61.5	123	300.75	615
The number of icons	6114	3575	1823	639	199
The number of labels	5223	2342	1290	512	168
Number of POIs by ArcGIS 9.3	3778	1971	913	255	39

To demonstrate this process, we visualize the first LoD level with 39 semantically salient POIs from our test dataset. Figure 6.9 are the render results. As shown in Figure 6.9, there are overlapping conflicts even through the icon size is reduced from 24 pixels (left) to 12 pixels (right). Figure 6.10 shows the result of our dynamic labeling algorithm. Each red dot represents an object while each icon represents POI at a dynamically identified location free of conflict.

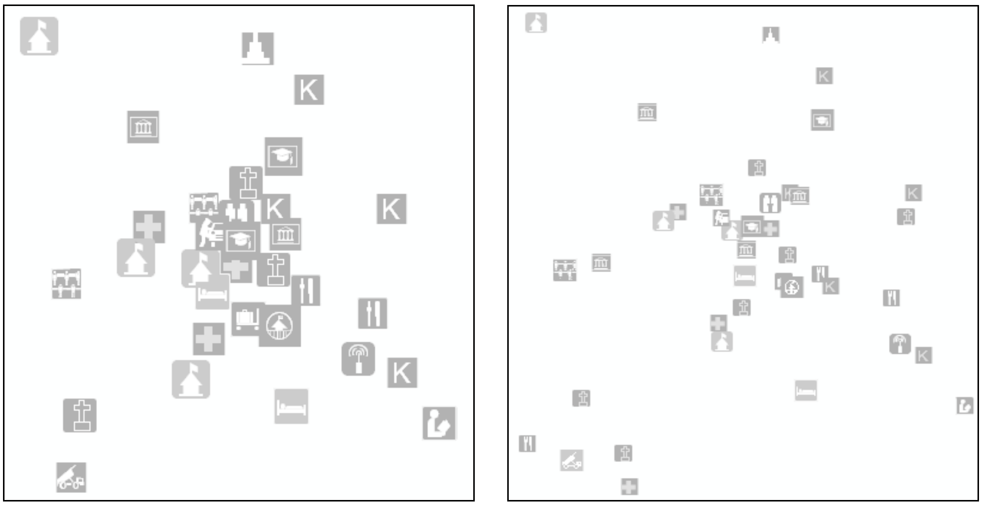


Figure 6.9 Rendering of 39 semantically salient POIs from the original dataset

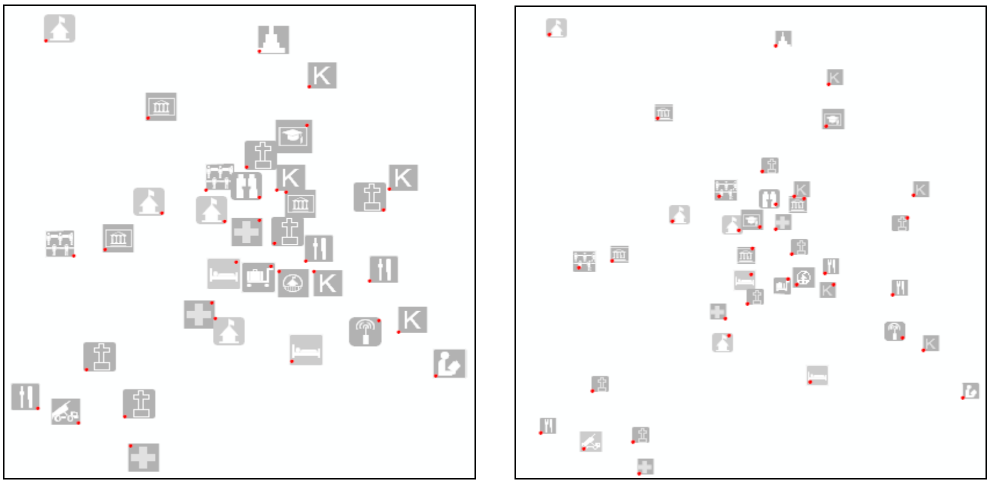


Figure 6.10 The result of the dynamic labeling algorithm

In our prototype system, the LoDs are pre-computed and recorded as two controlling variables – display scale and display location. The display location is marked with the number 1, 2, 3 or 4 indicating the favorite labeling position around the map feature. During the rendering, the number can be automatically converted to the real location. When the user operates the map with the zooming function, thus changes the display scale, the server will automatically extract those labels along with their sizes and locations that can be accommodated at that display scale and send them to the rendering engine. The user will then see the refreshed visualization results free of overlap.

6.3.3 Cartographic rendering and WMS implementation

Currently, many software and tools such as ArcGIS, MapServer, GeoServer, and Mapnik etc. support the publishing of web map services. In addition to their different underling technologies of Internet services such as Apache, IIS (Internet Information Server) etc., they are driven by different rendering engines. The rendering engine is a software component which provides the basic computer graphical functionalities. Different rendering engines produce different maps from the same spatial data. Figure 6.11 demonstrates the visualization results of two rendering engines – Osmarender and Mapnik - from the same dataset of OpenStreetMap. Figure 6.12 demonstrates the visualization difference between Mapnik and ArcGIS 9.3.1.

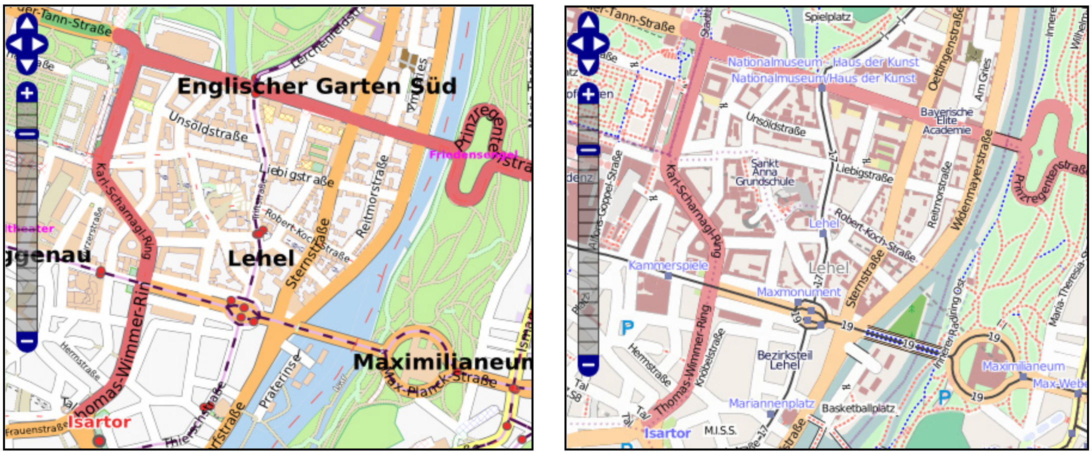


Figure.6.11 Screenshots from Osmarender (left) and Mapnik (right)

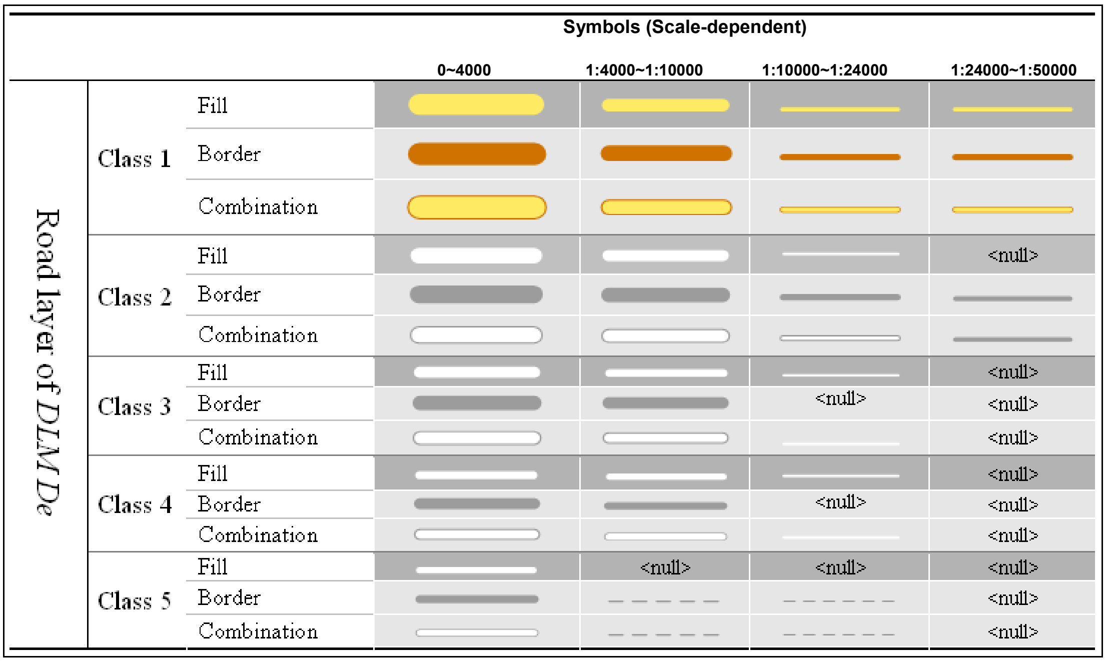
Figure.6.12 Screenshots from Mapnik (left) and ArcGIS (right)

From the cartographic point of view, Mapnik is able to produce a better graphic quality in terms of color use, anti-aliasing, label alignment etc. Moreover, Mapnik supports more graphic variables of its map symbolization. For instance, transparency is used in Mapnik to render different geospatial objects, which is so far not possible in ArcGIS. For these reasons, we choose Mapnik as the most suitable rendering engine in our prototype system and have implemented it in the following three steps:

Step 1: Design of rendering styles

In order to achieve the cartographic quality, each class of spatial objects needs to be symbolized as map features. We established a style library to store the symbols. Each style corresponds to a specified scale interval (e.g. from 1:10000 to 1:50000) in line with the widespread web map services such as Google Maps, LiveSearch, Map 24, OpenStreetMap and the standard symbol design of the paper map in Germany. Table 6.4 shows an example for the road classes from Table 6.2, while Table 6.5 contains examples for point symbols in our style library.

Table 6.4 Symbolization of different road classes



			Symbols (Scale-dependent)			
			0~4000	1:4000~1:10000	1:10000~1:24000	1:24000~1:50000
Road layer of *DLM De*	Class 1	Fill	━	━	━	━
		Border	━	━	━	━
		Combination	━	━	━	━
	Class 2	Fill	━	━	━	<null>
		Border	━	━	━	━
		Combination	━	━	━	━
	Class 3	Fill	━	━	━	<null>
		Border	━	━	<null>	<null>
		Combination	━	━	━	<null>
	Class 4	Fill	━	━	━	<null>
		Border	━	━	<null>	<null>
		Combination	━	━	━	<null>
	Class 5	Fill	━	<null>	<null>	<null>
		Border	━	– – – – –	– – – – – –	<null>
		Combination	━	– – – – –	– – – – – –	<null>

Table 6.5 Symbolization of POIs

Step 2: Creation of an XML file

The description of our rendering styles can be stored in a XML file that obeys the syntax of Mapnik (https://github.com/mapnik/mapnik/wiki/XMLConfigReference), contains the path of the data to be rendered (e.g. the shape files) and a list of the visual variables, such as color, size, transparency etc. During the rendering process, the features are made visible at given locations on the screen.

Step 3: Creation of a python script

A python script is created that allows the rendering engine to handle the style descriptions, the output format, the optimal scale and other information, thus execute the rendering process and send the result to the user.

Step 4: Creation of a configuration file and publishing of the WMS

With the python script, the geo-data can be only rendered off-line. To realize an on-the-fly rendering process based on Mapnik, the python script needs to be integrated into the web server (e.g., IIS) with a configuration file.

Step 5: Establishment of a web application to access the WMS via OpenLayers APIs

Figure 6.13 illustrates the labeling result of a semantically enriched map with 168 POI labels at the first level.

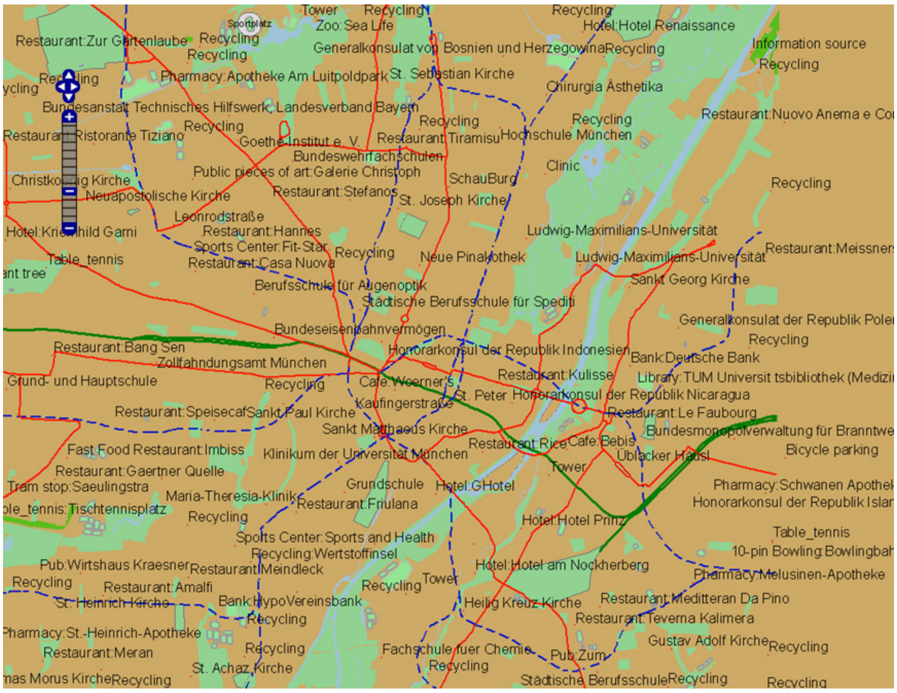


Figure 6.13 Screenshot of a semantically enriched map at 1:50,000 with 168 POI labels

6.4 Case studies of multimodal routing maps

The visualization of multi-modal routes as a web map service can be separately developed or incorporated with other services such as route planning services. In our work, we have designed it as a separate service. Since the generation of LoD is more complex than the cartographic web map services in the preceding section, we first tested our approach for three cases and then should combine them in the prototype system of multimodal routing map services in the future work. We choose three different areas to test the robustness of our methods. For each route, we designed two routing modalities i.e., walking and for driving with two directions. The useful visual field of 90° is initialized for walking, and 30° for driving. 100 meters is used as the interval distance to generate the observer points. Theoretically; every turning point is an observer point. To simplify the computation, we set a threshold angle (5°) to control the observer point. All routes are randomly generated from road networks.

Three types of salience could be calculated: passive, active, and the combinational salience. On the average, three landmarks between two neighboring observer points are extracted. And the passive salience is computed using two parameters - footprint area and building height. The active salience of building is computed on the basis of the visible area from all observer points. The computation of active salience of POI is based on the number of times the POI remains visible from all observer points. In our work, the weight of passive and active salience is set to 0.5. To highlight the extracted landmarks, we employed different visualization strategies. All landmarks extracted from POIs were visualized at their default position with a red dot and a label. The position of each label is determined by implementing the dynamic label algorithms. The building has been highlighted by assigning different transparences (e.g. 70% for background and 0 for landmark).

These experiments serve three purposes: to generate landmarks for different travel modalities, to generate different LoDs for the routing map; and to compare and evaluate the results from three test areas. In the first study area, we emphasized the evaluation of semantic information salience and its impact on the routing task. We generate the landmarks and LoDs based on both passive and active salience of POIs and building objects. In the second study area, we adopted a 2.5D visibility analysis for the detection of landmarks in comparison with the results based on the 2D visibility analysis. In the third area, a 3D visibility analysis was conducted on the basis of the computation of visible surface area. The distinction between active salience and passive salience was reiterated. Further, we discussed the different weight systems for active and passive salience and the associated attributes.

6.4.1 Study area 1: Munich

A section of the test area of Munich is chosen as the representation context for the routing map. It involves 2723 buildings and 344 POIs. The heights of buildings range from 1 to 58m. Their footprint areas range from 0.6 to 8572 m2. The frequency distribution of the building heights and their footprint areas is shown in Figure 6.14.

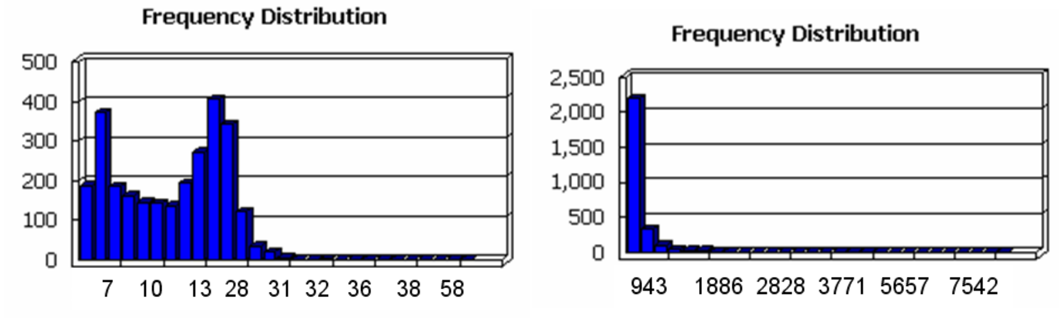


Figure 6.14 Frequency distribution of building heights (left) and footprint areas (right) in the study area

A route from Karlstrasse to Amalienstrasse is designed in random. Along this route, there are 14 viewing points. The landmarks from viewing points for driving and walking (labeled POIs as red dots and buildings) are demonstrated in Figure 6.15 - 6.17. The weights of typicality and frequency for driving and walking are documented in Appendix Table 6.1 and Table 6.3.

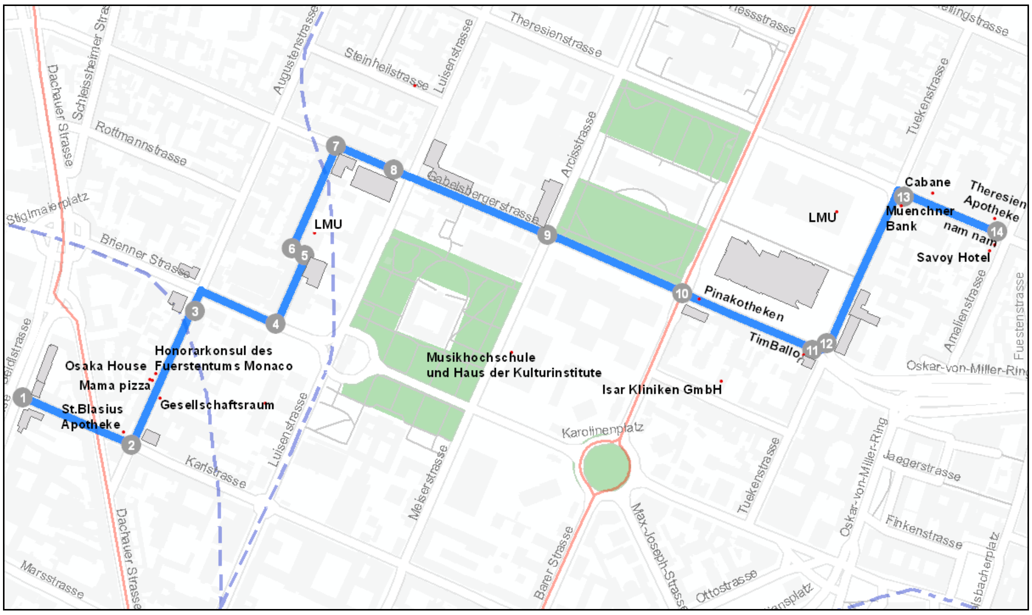


Figure 6.15 Landmarks (building footprints and labeled POIs) along a route in blue for driving

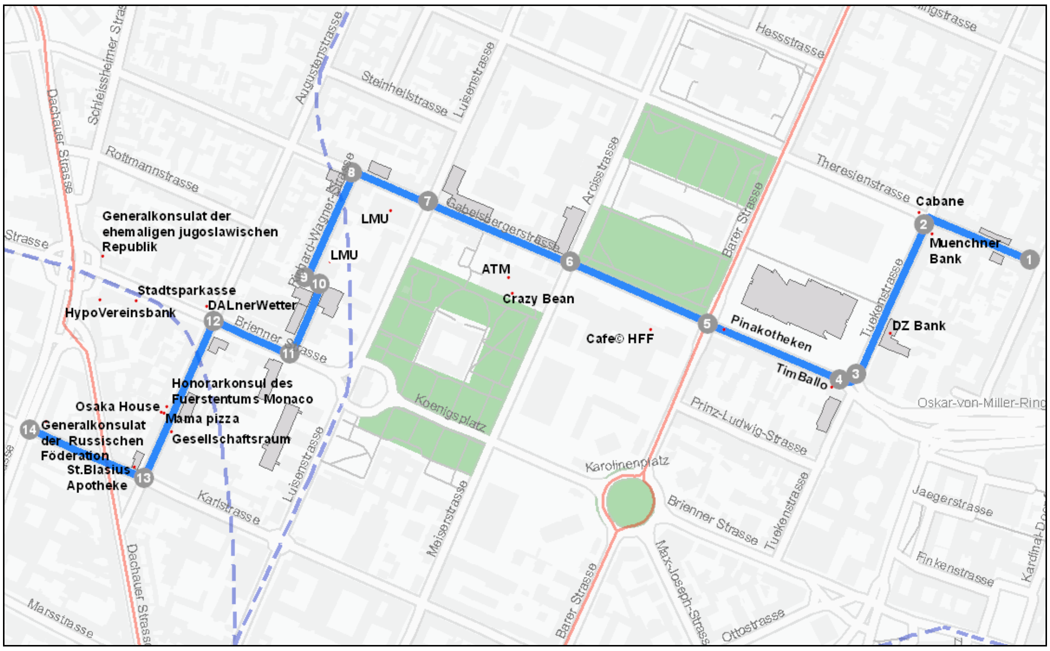


Figure 6.16 Landmarks (building footprints and labeled POIs) along the same route for driving as in Figure 6.15 in a reverse direction

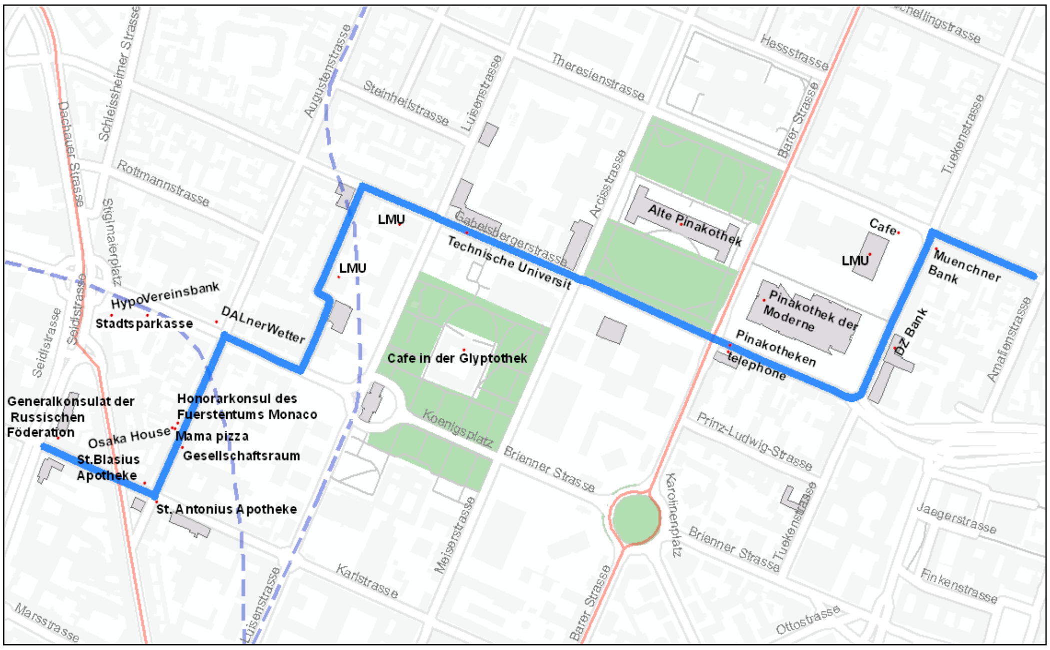


Figure 6.17 Landmarks (building footprints and labeled POIs) along the same route as in Figure 6.15 but for walking

6.4.2 Study area 2: Nanjing

Figure 6.18 shows a 3D city model of the second study area from Nanjing city. It contains 2842 buildings in the representation context of the route. The heights of buildings range from 3 to 105m. Their footprint areas range from 0.5 to 4085 m2. The frequency distribution of the building heights and their footprint areas is shown in Figure 6.19. A route from Yihe business building to restaurant of Fenghuangtai is demonstrated in red as shown in Figure 6.21. Along this particular route, there are 15 viewing points.

Figure 6.18 3D city model showing part of Nanjing city

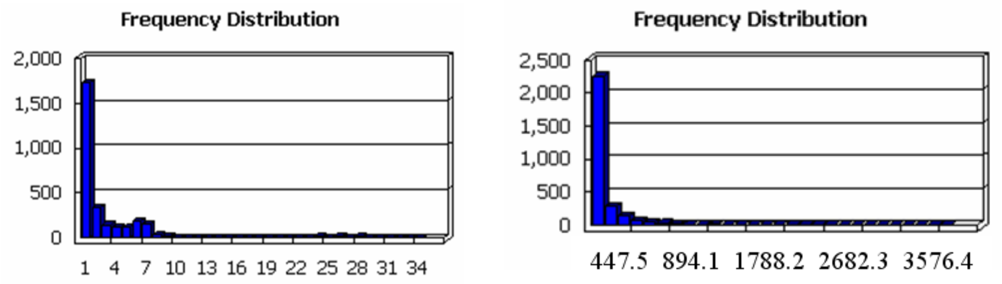


Figure 6.19 Frequency distribution of building heights (left) and footprint areas (right) in the study area

In this study area, we conducted visibility analysis in 2.5D and 2D for the computation of the active salience. The 2.5D visibility is calculated using the methods introduced in chapter 4 and illustrated in Figure 6.20. The green surfaces are visible from the viewing points along the route from both moving directions. The visibility was computed without additional constraints on the field of view. Taking into account the varying perception space for different travel modalities, the landmarks for walking and driving were respectively detected and illustrated in Figure 6.21-6.23.

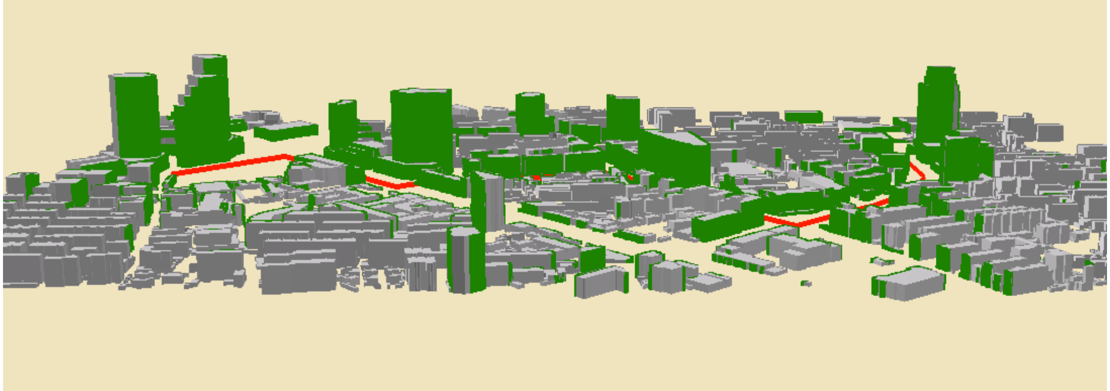


Figure 6.20 Surfaces in green are visible from the route in red

Figure 6.21 Detected landmarks in 2D along the route from viewing point 1 to 15 in blue (the same route as in Figure 6.21) for driving

Figure 6.22 Detected landmarks in 2D along the same route as in Figure 6.21 for driving, but in a reverse direction

Figure 6.23 Detected landmarks in 2D along the same route as in Figure 6.21 but for walking

6.4.3 Study area 3: Auckland

Figure 6.24 shows the study area 3 - the Central Business District (CBD) of Auckland. The raw data contains buildings and the Digital Elevation Model (DEM) of the area. A route between Sky Tower and Ferry Building is depicted in red. It involves 13 viewing points. There are 3409 buildings (without the Sky Tower) in the representation context of the routing map.

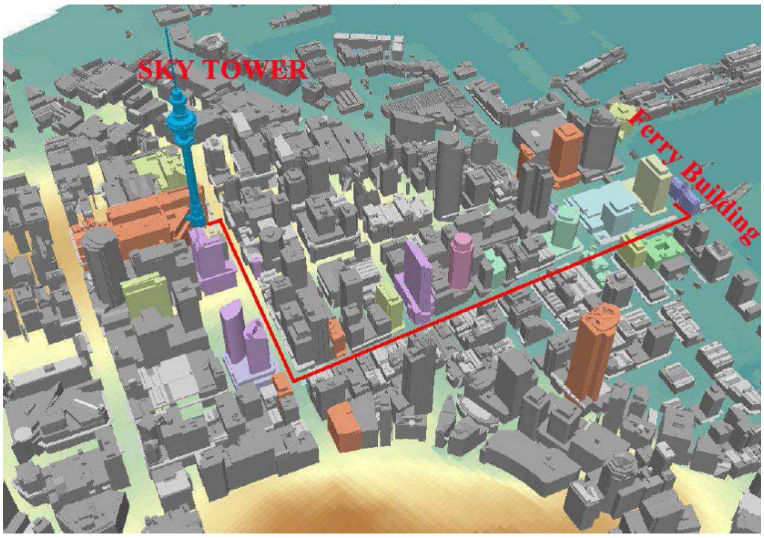


Figure 6.24 Study route between Sky Tower and Ferry Building

The building heights range from 3, 28 to 160m, while their footprint areas are between 0.22 and 6649 m2. Their frequency distribution is shown in Figure 6.25.

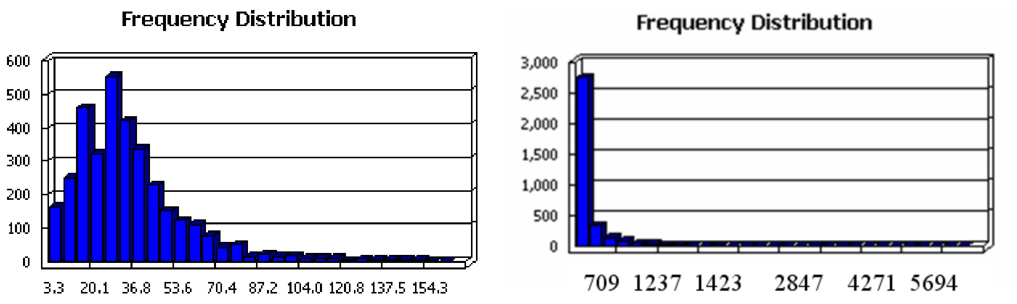


Figure 6.25 Frequency distribution of building heights (left) and their footprint areas (right) in the study area

The active salience is computed by implementing the 3D Viewshed analysis in a free filed of view. Figure 6.26 illustrates the visible building surfaces using ESRI's ArcScene. Figure 6.27-6.29 demonstrates the results of 3D active salience measurement.

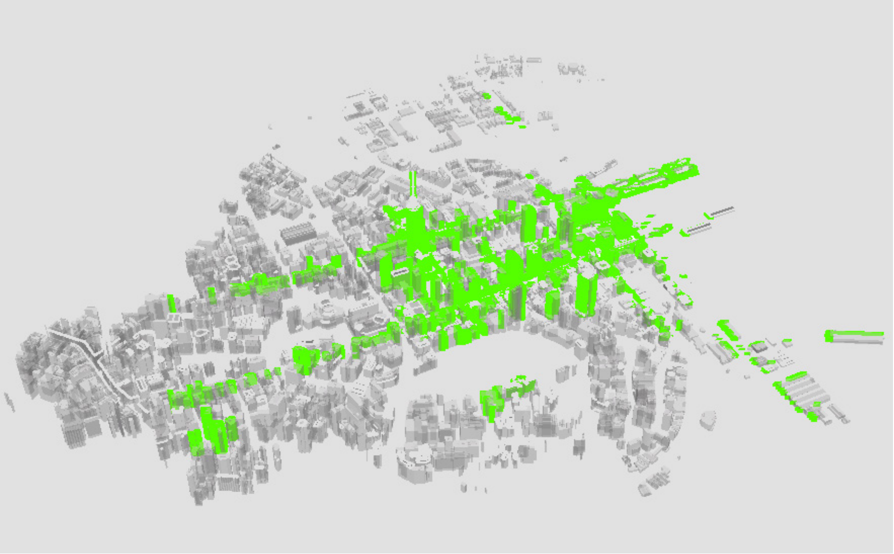


Figure 6.26 3D visibility of the study route 3 in Auckland

Figure 6.27 3D landmarks in green for driving

Figure 6.28 3D landmarks in green for driving in a reverse direction

Figure 6.29 3D landmarks for walking along the route

6.5 Evaluation and discussions of results

Keeping in mind that this work attempts to establish a model for the automatic extraction of different landmarks for different travel modalities, we proposed an analytical salience measurement method to separate different salience factors based on the available attributes of spatial objects. This section is dedicated to the evaluation of the results.

6.5.1 Passive salience and active salience

The passive salience is derived from the Inherent Spatial Salience (ISS), the Semantic Dependent Salience (SDS) and the Route Dependent Salience (RDS). A building with higher passive salience could be extracted as a landmark, but whether it is finally qualified as a landmark depends on its active salience in the perceptional space that varies with travel modality along a certain route. The active salience is based on the visibility analysis (2.5D and 2D). The buildings which possess more visible surface are perceptually more salient. The overall salience of a building is therefore a function of its position relative to the observer and its attributes that include not only the geometric and distributional information but also semantic attributes. In our active salience computation, we assigned the frequency for each travel modality as a weight. This weight system makes the active salience and passive salience of a building more distinctive. We compared the active salience and passive salience in the first and second study area by using the overlap percentage (the number of buildings which are both actively and passively salient / the total number of the landmarks) with the aim to quantify the difference. The results of the comparison are shown in Table 6.6.

Table 6.6 Comparison of buildings which are both actively and passively salient under different conditions

Conditions	Free view field	Driving 1	Driving 2	Walking
Overlap of 3D buildings in study area 2	13%	23%	16%	16%
Overlap of 2D buildings in study area 2	13%	13%	16%	20%
Overlap of 2D buildings in study area 1	-	30%	27%	30%
Overlap of 2D POIs (free view field) in study areas 1	-	73%	43%	50%
Overlap of 2D POIs in study area 1	-	76%	43%	53%

The reasons for a little higher overlap percentage (2D visibility) in study area 1 (Munich) might lie in its relatively low height difference of buildings than in study area 2 (Nanjing). The lower overlap percentage for the free view field than for other perceptional spaces indicates the distinctive influence of the perception space on the landmark extraction. In addition, the higher overlap percentages of POIs than those of buildings indicate the necessity of integrating more semantic information in the active salience assessment of building objects.

6.5.2 Comparative analysis between 2D and 3D visibility

As discussed in previous chapters and sections, the measurement of the active salience mainly depends on the visibility analysis which can take place in 2D, 2.5D (without surface elevation) and 3D (with surface elevation) for different travel modalities. Figure 6.30-6.33

shows the visible buildings in 2D and 2.5D from the study area 2 during driving and walking. The number on each landmark building is the number of the floor from which the height of the building can be inferred.

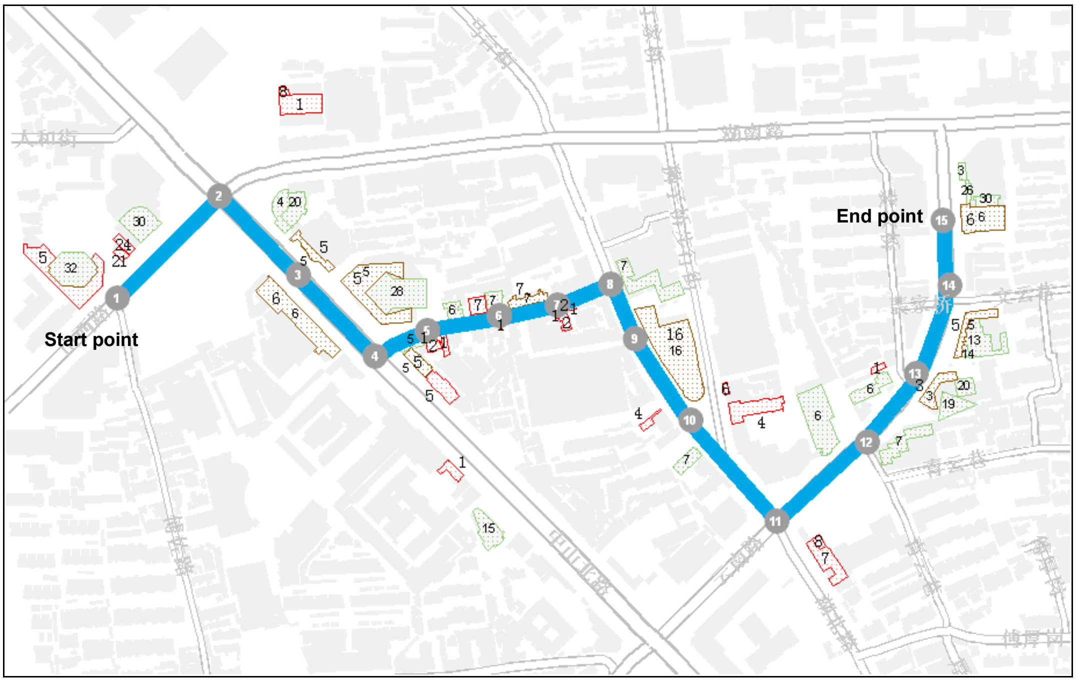


Figure 6.30 Active landmarks for driving (2.5D and 2D) (see the legend in Figure 6.33)

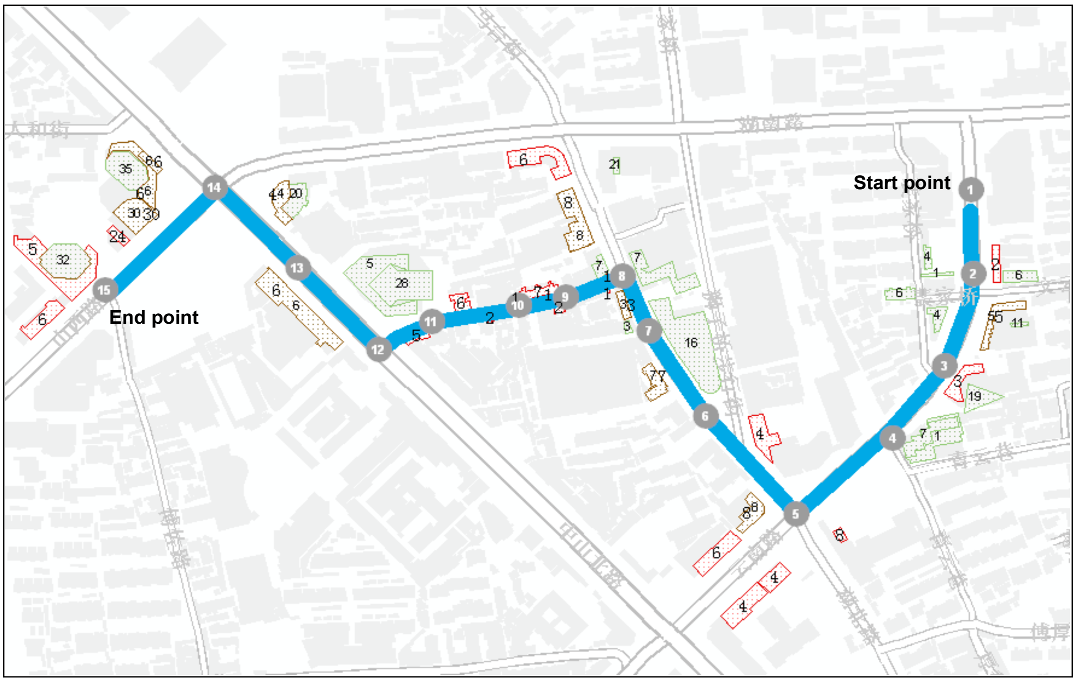


Figure 6.31 Active landmarks for driving in a reverse direction (2.5D and 2D)

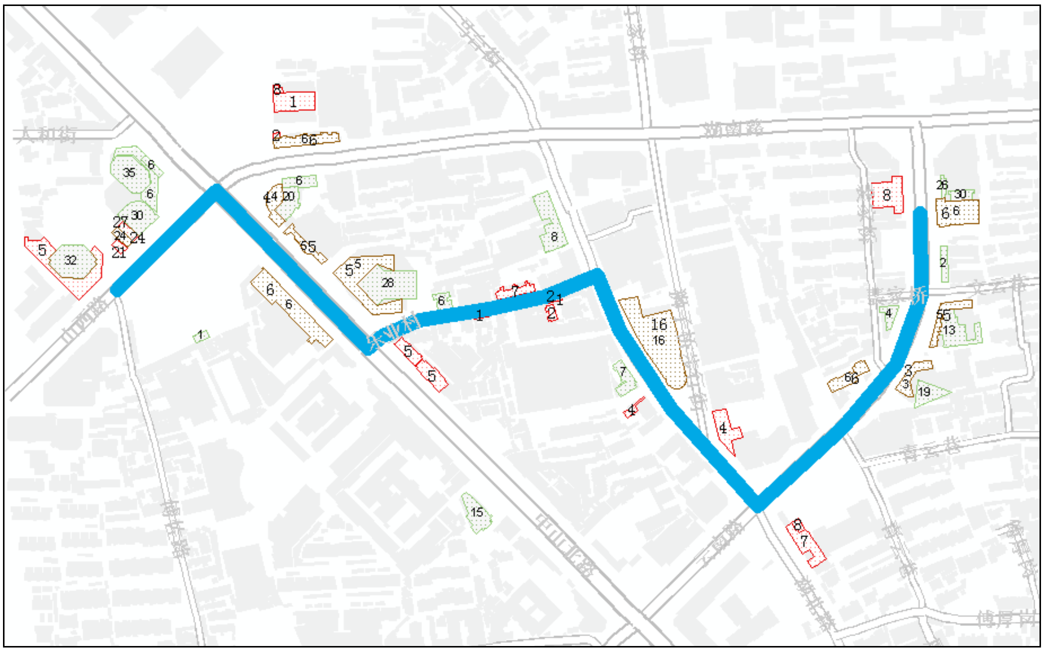


Figure 6.32 Active landmarks for walking (2.5D and 2D)

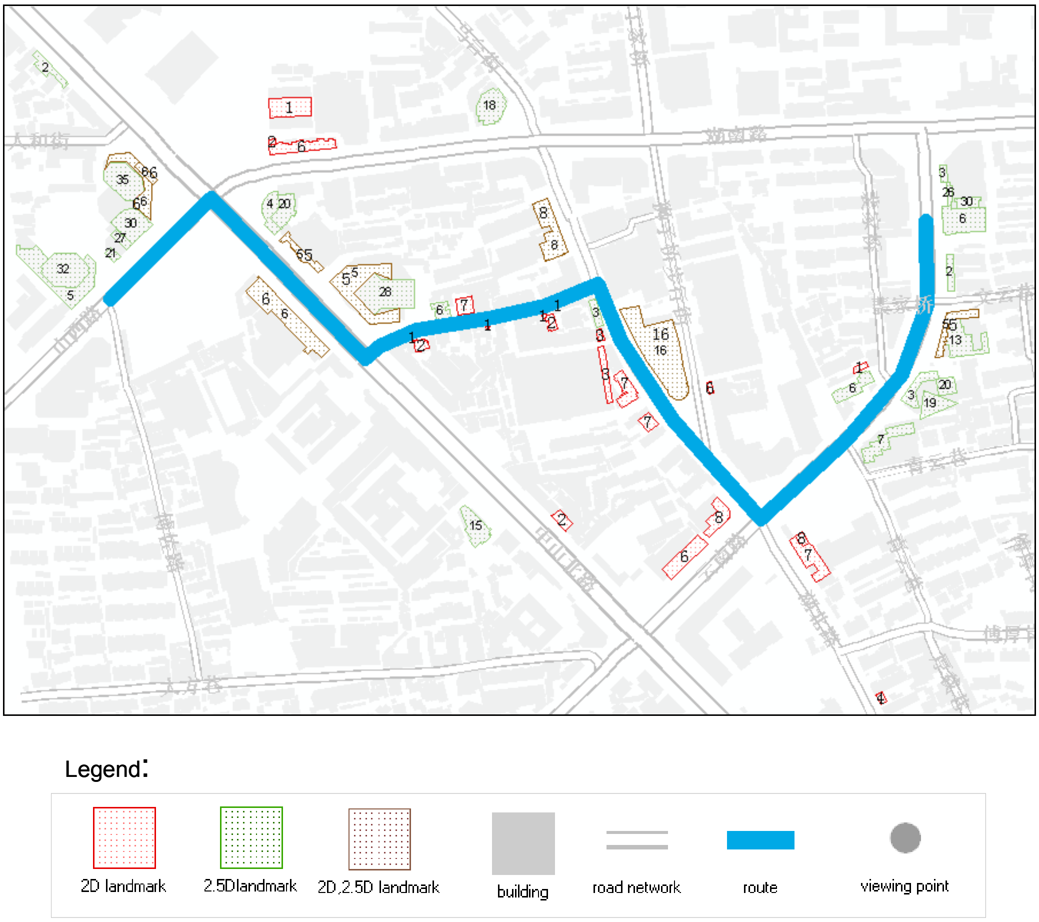


Figure 6.33 Active landmarks in the free view field (2.5D and 2D)

The distinction of active building landmarks between 2D and 2.5D lies in the relative height of the building. In 2D visibility analysis, some buildings are identified as landmarks even if they may be hidden behind higher front buildings. Table 6.7 shows the comparative result.

Table 6.7 Visibility analysis by 2D and 3D comparison

Conditions	Free view field	Driving 1	Driving 2	Walking
Overlap percentage between 2D and 2.5D	26%	33%	36%	43%

The larger discrepancy or lower overlap percentage between the 2D and 2.5D building landmarks in the free view field(the visible range of human is unbounded) suggests that the detected number of visible object in 2D is smaller than that in 3D. The difference increases with the increasing density of the buildings for example, in the center of city. Theoretically, the visibility analysis in 2.5D or 3D leads to better results than in 2D. However, with regard to the computational complexity, the 2D visibility analysis has its advantage, especially for a city where the heights of buildings do not vary very much or the density of buildings is rather low.

6.5.3 Combination of ISS and SDS

Without sufficient redundant and complementary information it is complex and difficult to extract the suitable landmarks using the currently available methods. Therefore, we have introduced the Semantic Dependent Salience (SDS) differentiate in addition to Inherent Spatial Salience (ISS) to tackle this problem.

By means of the semantic web map services, the passive salience of buildings and POIs can be easily computed and combined. The details of the results are demonstrated in Figure 6.34-6.36. Both the ISS and SDS are pre-computed and can then be integrated in the process of generating the dynamic routing map. This enables on-the-fly extraction of landmarks and on-the-fly generalization of POIs in web map services.

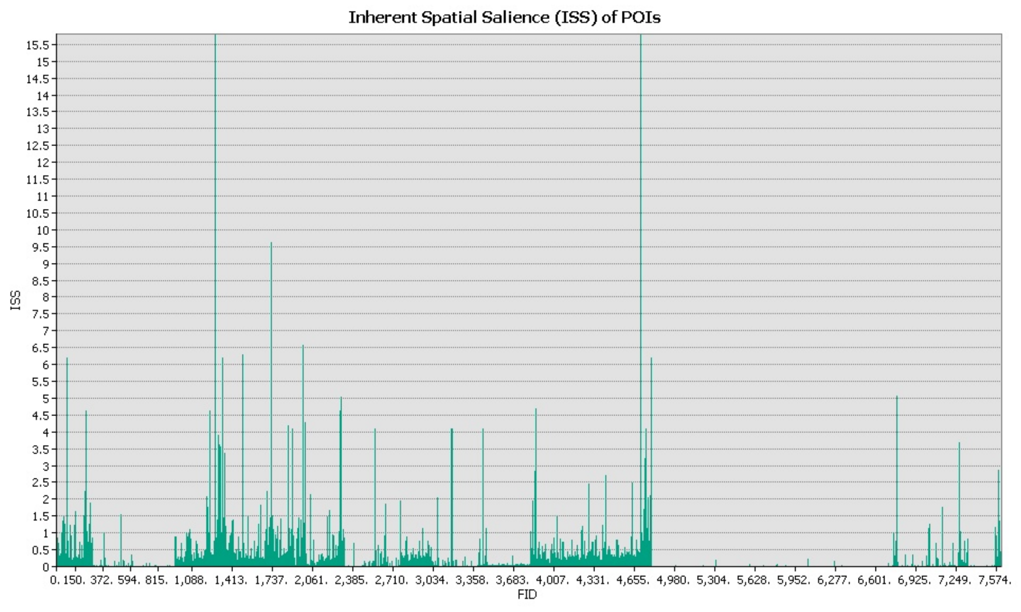


Figure 6.34 Distribution of ISS of POIs

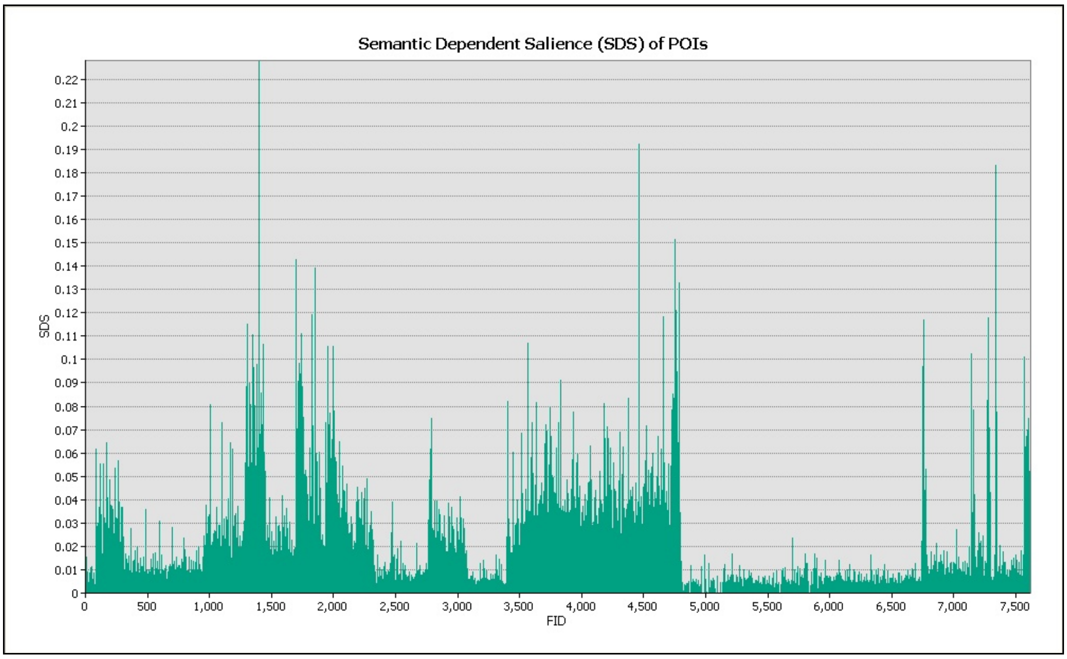


Figure 6.35 Distribution of SDS of POIs

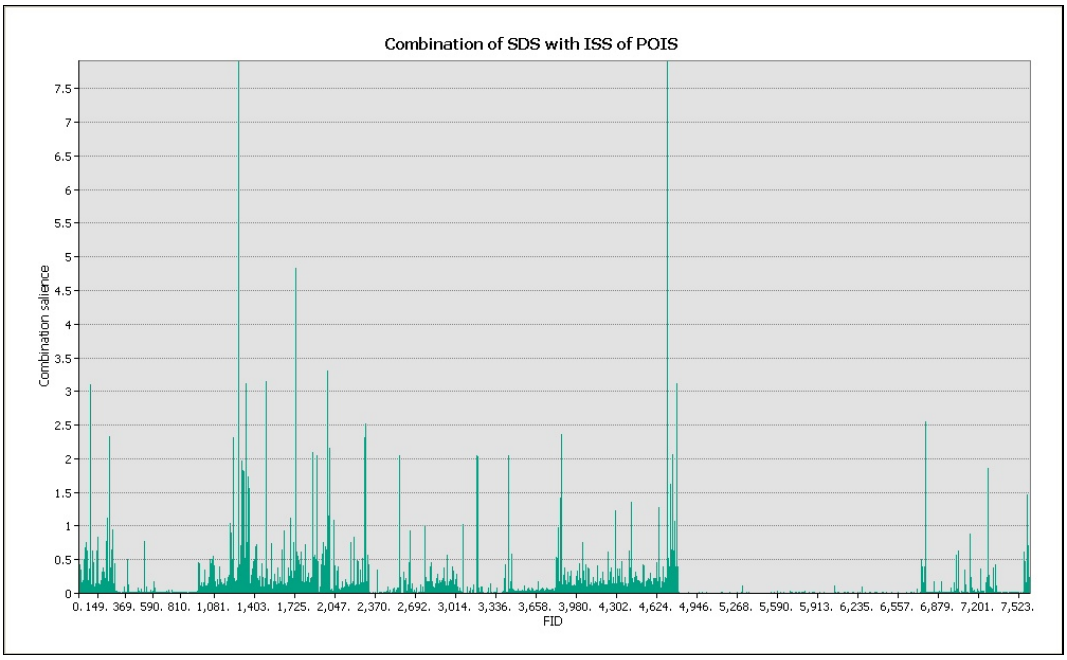


Figure 6.36 Combination of SDS and ISS of POIs

The weights of different salience components can be freely tuned for different travel modalities. The weights for the typicality and frequency of POIs also need to be fine tuned for different travel modalities and study areas.

Chaper 7

Conclusions and Outlook

Routing maps provide the useful information for their users who are traveling through an unfamiliar environment. A customized routing map that not only shows the route itself but also introduces additional landmarks around the route can help decrease the uncertainty during the travel. The automatic generation of customized routing maps requires interdisciplinary knowledge from cartography, spatial cognition and spatial data mining. For example, the derivation of the minimum distance between geospatial objects in the reality for the legible display on the screen for a given map scale is related with human vision system and cartographic semiotics.

7.1 Main contributions

By combining the passive salience that reflects the inherent characteristics of spatial objects and the active salience that is dependent on the cognitive capacity of travelers for the given routing task, the author developed a comprehensive approach of salience estimation and generation of web-based routing maps for two traveling modalities - walking and driving.

The cognition-based model of routing maps introduced in this thesis has essentially combined the cognitive spaces of both the cartographer and the traveler. The cartographer's cognitive space is characterized by the passive salience which includes Inherent Spatial Salience (ISS), Semantic-Dependent Salience (SDS) and Route-Dependent Salience (RDS), whereas the traveler's cognitive space mainly deals with the active salience - Perception Dependent Salience (PDS) from his individual perception while moving through the environment. In this work, a hierarchical salience structure is constructed for the dynamic rendering of the routing map. The main contributions can be summarized in the following aspects:

1) A cognition-based model for routing map generation

With the increasing awareness of user's behavioral abilities, the generation of personalized routing map which aims not only to satisfy cartographer's requirements (to provide a precise map) but also to maximize the benefit of the user (to match the personal capability for a specific routing task) becomes more important. In order to generate such a routing map, we proposed a cognition-based model of routing map generation. A hybrid conceptual space derived from two conceptual spaces of the cartographer and the user is employed

In each conceptual space, the various salience elements are evaluated with regard to two aspects: user's stimuli ignorance and perception ability. The ignorance is influenced by the task, and the perception ability is simulated by the proposed dynamic perception space. Accordingly, the salience elements are divided into passive and active salience.

The distinction between the active salience and the passive salience allows the generation of routing maps for different contexts. For instance, depending on how we determine the relative weights for the active salience and passive salience, we may generate either a more data-driven routing map which aims to provide the user a comprehensive image of the environment or a more cognition-driven routing map that provides the most needed information to an individual traveler.

2) Salience formalization and measurement

It is well known that the salience is related to spatial objects, the environment, and the traveler. However, its quantification in a specific context remains a challenging task. In our salience measurement model, four components are formalized: Inherent Spatial Salience (ISS), Semantic-Dependent Salience (SDS), Route-Dependent Salience (RDS) and Perception Dependent Salience (PDS).

The ISS is reflected in the spatial distribution of the objects, and each object has a unique value in that environment, which is determined in contrast to its neighborhood, i.e. the intrinsic properties and the context-dependent properties. The ISS is independent of the route information or the users' perception. It is usually applied for general cartographic visualization instead of being specially designed for navigation. The pre-computation of salience for each spatial object not only reduces the computational complexity, but also provides relevant information for specific routing as a priori parameter.

The SDS suggested that an object may have a larger semantic salience than other objects if it has a significant meaning. For the users in a familiar environment, objects become landmarks based on semantic salience and contribute significantly for routing. SDS is usually separately treated because the semantic information is difficult to acquire and may not influence the outlook of the spatial objects. The application of SDS of POIs in our experiments has proved the significance of the semantic salience. According to our tests, it is possible and practicable to extract some landmarks from accessible and dynamic POIs.

The Route-Dependent Salience (RDS) focuses on the route information in the environment. The characteristics of the route, especially the route direction, play an important role for the determination of landmarks. That is, the assessment of RDS is based more on intrinsic properties of spatial object in relation to the route which is usually abstracted as a directed graph.

The Perception-Dependent Salience (PDS) focuses on the participant of the routing task which is the most difficult part of the salience measurement model due to human interferences. In our work, the perception space is considered for the salience assessment and it varies with the travel direction, travel modality and current location. The changing illumination and weather condition during routing may also influence the perception space.

3) Adaptive hierarchical strategies and dynamic rendering

The salience of the spatial objects defined in this work is an integration of the passive salience and active salience for a given task. To combine the various salience vectors into a unique vector, we employed two strategies to adopt the different data types and applications. The first is to combine all salience vectors (ISS, SDS, RDS, and PDS) to generate the routing map. We used this strategy to classify our building objects. The second strategy is to combine the SDS of POIs with the ISS of the building within which the POI is located to generate the cartographic web map services. In the third strategy, the combined SDS and ISS of POIs are integrated with the PDS to generate the routing maps.

The consideration of the task-related salience is useful for web and mobile applications where, for instance, the various display screens constrain the visualization of salient objects. In order to legibly visualize the routing specific landmarks on different mediums, we employ an adaptive rendering strategy according to which landmarks are ranked by their relative salience in a hierarchy and brought into view without graphic conflicts at a right level of detail.

The adaptive visualization is a function of the screen resolution, the display scale and the salience degree of the spatial objects. Our experiments with the cognitively adequate and legible web map services enriched with landmarks in different study areas have verified the feasibility of proposed rendering strategy. This will benefit further generalization approaches on POIs or other semantic information.

4) Landmark extraction for multimodal navigation

The study on the nature of routing map and its evolution shows that the landmark-based orientation is regarded as the most important routing support, but largely ignored in current web-based routing plans and map services. At the same time, the largest challenge for the design of the customized routing map lies in the difficulties to derive the suitable parameters for a given traveling modality.

Although many researchers have indicated the necessity of taking into account the modality for the extraction of landmarks, little practical work has been reported. In our prototype, we used our proposed salience measurement model to extract the different landmarks for different travel modalities as well as different moving directions.

This work has not only provided a comprehensive and comparative investigation of the research works which involve the definition, categorization, detection and quantitative evaluation of landmarks, it has also filled a gap with regard to the active salience computation. The currently available route planning system can benefit from the proposed approach and be extended to embrace the personalized routing map for the real-time routing applications.

5) Two attention assessment strategies combination in routing map

An attention-guided map is referred to as a map with salient information. However, the computation of attention is a complex process which contains both object-inferred model and traveler-inferred model, or their combinational model. The most important object-inferred model is also termed as bottom-up model for attention computation by calculating the visual salience. On the contrast, the traveler-inferred model is also termed as top-down model for attention computation by calculating the relevance. Our work has combined both models in the generation of routing maps, i.e., we introduced the frequency of each POI type to denote the relevance degree for a given travel modality, then computed SDS by using the value of frequency as weight and integrated it with others salience factors. We can also generate other types of web map services, for example, by using the typicality as the weight of POI. It must be noted, however, that it is not a trivial task to capture the suitable typicality and frequality weights. Moreover, the typicality of each POI type may vary with different areas and cultures. In our work, we adopted an expert system to generate the typicality and frequency. A more elaborated weight system of typicality and frequency should be investigated by extensive empirical studies.

7.2 Outlook

1) Extension of the perception space model

Our modality-related parameters need to be extended to cope with more travel modalities such as the bicycle and public transport. This requires the understanding and description of the traveler's visual perceptual space, preferences and perceptual ability ifferent context, e.g. for each of these further travel modalities. Moreover, further studies on the assessment and comparison of the perception space in 2D and 3D and the measurement of passive and active salience are necessary. Currently, our web-based routing map system can only allow the 2D visibility analysis. The computation of 3D vision field in our current prototype system is based on raster information and should be extended to allow the vector-based and web-based implementation. The constraint of view field in the vertical dimension for different travel modalities should be continued.

In addition to the travel modality, many other parameters about the mobile environment and the profile of traveler should be included in the computational model for the active salience estimation. Although specific researches have been reported for a certain parameter, the integration of all these parameters is necessary which should allow the comparison of the different impacts of these parameters on various contexts.

The proposed dynamic perception space can also be extended to generate other maps such as the “here-you-are” map, build the adaptive nearest neighborhood for query purposes. Furthermore, our experimental results can serve as the input for the cognition-based robot navigation.

2) Adaptive determination of the relative weights

In our salience model, various influence parameters have been so far empirically weighted. An automatic assignment of a suitable weight for each parameter in a given context is a complex work which should be addressed in further empirical studies or in an expert system. Especially, we need to pay more attention to the varying human preferences and perceptional abilities for different mobile contexts, such as motionless situation, self-motion (driver), co-driver or fellow passenger. According to Bertin's theory, the perceptual influence of size is stronger than color, but this theory assumes that the viewing point is static. Since a moving traveller perceives his surroundings in a dynamic way, he may experience the changing perceptual influences of the visual variables. The same issue should be considered in visualization by identifying the most powerful visual variables for the real-time use of routing maps.

3) Model simplification and modification

Our current algorithm, especially which for the estimation of active salience estimation is still quite complex and has to be executed in preprocessing stage. Its computing efficiency needs to be improved for real-time applications. Moreover, the linear function applied in the current salience model should be verified or modified with extensive experiments. Likewise, a quantitative estimation of salience needs to be combined with further criteria to evaluate the usability of customized routing maps.

4) Usability and utility of the routing map evaluation

The usability and utility of the routing map should be evaluated in extensive user studies in the future. In addition, the applicability of our approach for further applications such as voice navigation and the combination of directions with the text description needs future studies as well. Especially, the number of the landmarks and the hierarchy of salience information along a specific route that match the different zooming requirements should be implemented by means of the dynamic routing map services.

5) Cognitively adequate visualization methods

In our current prototype system, the landmarks are visualized with the dynamic labels. The evaluation of this visualization method should be conducted in the future and compared with other existing methods. For cartographic web map services, the icons of different POIs are just symbolized using different formats with the same background. Other visualization methods, for example, by using different backgrounds and different colors or transparencies should be studied. Furthermore, the adoption of different graphic variables for different travel modalities remains an interesting topic for the future study.

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Abbreviations

CSR	Conceptual Spatial Representations
CRM	Classic Route Map
DDA	Data-Driven Approach
DT	Delaunay Triangulation
GIS	Geographical Information System
GIS-T	Geographic Information System for Transportation
GPS	Global Positioning System
HBI	High Belief Information
ISS	Inherent Spatial Salience
KVA	Kinetic Visual Acuity
PNA	Personal Navigation Assistant
PDS	Perception-Dependent Salience
POI	Point of Interest
PRM	Perceptual Route Map
RDS	Route-Dependent Salience
SDS	Semantic Dependent Salience
SVA	Visual Acuity
UFOV	Useful Field of View

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Appendix

Typicality of POIs

Ideal	Highly	Good Suitable	Suitable	Somewhat suitable	Seldom suitable	Never
University	Castle	Library	Pharmacy	Attraction	Tram stop	Post box
Federal government	Church	Parking lot	Café	Information source	Bus stop	Toilets
Zoo	Theater	Gas station	Pub		Attraction	Fountain
Hospital	Museum	Post office	Garden		Stop sign	Significant tree
Consulate	School	Police station	Motel		Traffic light	Public telephone
Regional Government	Shopping center	Basketball playground	Fast food restaurant		Subway entrance	Automatic Teller Machine
Tower	Sports center	Skating ground	Beer garden		Taxi station	
TV, Radio studio	Look-out	Swimming pool	Railway station		Bicycle parking	
Administration	Recycling station	Pin bowling station				
District-government	Park	Hotel				
	Fire station	Restaurant				
		Table tennis playground				
		Bank				

Frequency for driving

All	Most	Many	Some	Seldom	Never
Regional government	Castle	Library	Pharmacy	Stop sign	Post box
Federal government	Church	Post office	Café	Subway entrance	Significant tree
University	Museum	Police station	Pub	Tram stop	Bicycle parking
Hospital	School	Bank	Garden	Bus stop	Automatic Teller Machine
Consulate	Fire station	Skating	Beer garden	Tourist information	Public telephone
Zoo	Sports center	Theater	Fast food	Attraction	Toilets
Tower	Look-out	Basketball playground	Motel	Public pieces of art	Traffic light
TV, Radio studio	Shopping center	Swimming pool			
	Park	Pin bowling station			
	Restaurant	Gas station			
	Hotel	Parking lot			
	Railway station	Table tennis playground			

Frequency for walking

All	Most	Many	Some	Seldom	Never
Regional government	Castle	Hotel	Pharmacy	Public telephone	Post box
Federal government	Church	School	Subway entrance	Tourist information	Significant tree
University	Sports center	Café	Tram stop	Toilets	Bicycle parking
Hospital	Museum	Post office	Bus stop	Public pieces of art	Automatic Teller Machine
Consulate	Motel	Police station	Garden	Attraction	
Zoo	Railway station	Bank	Taxi station	Stop sign	
Tower	Parking lot	Fast food restaurant	Library	Traffic light	
TV, Radio studio	Gas station	Pub	Skating		
	Restaurant	Beer garden	Table tennis playground		
	Railway station	Sight boards	Basketball playground		
	Fire station		Swimming pool		
	Shopping center		Pin bowling station		
			Theater		