ACTIVITY-ORIENTED CONTEXT MODEL FOR ADAPTIVE MOBILE GIS SYSTEM DESIGN

A Thesis in
Information Sciences and Technology
by
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Submitted in Partial Fulfillment
of the Requirements
for the Degree of
Master of Science

August 2009
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ABSTRACT

Mobile GIS has been used to support many human activities such as tourism, navigation, and crisis management. One of the challenges of dealing with mobility is the continuous change of contexts, which requires the system to be adaptive. Despite considerable research efforts in context adaptation in the mobile map services, there remain a number of limitations. First, context models are inadequate in a sense that they merely deal with physical factors and fail to take into account the dynamics of cognitive factors. Second, the adaptation mechanisms for geovisualization often deal with context changes in isolation to user’s activity resulting in missing the target of adaptation.

In this study, I believe that geovisualization should be situated in user’s ongoing activities and dynamically present the most relevant information to the user. This thesis advances the science of context-adaptive map services in two related areas. First, I describe an activity-oriented context model and its computational representation based on the theories of situated activity and SharedPlan. The model binds contextual factors with the plans of the ongoing activity and enables the system to reason the effect of a context change on the advances of the whole activity. Second, I present a method to adapt cartographic visualization based on the above context model. The principles of adapting a mobile map to context change are demonstrated through an analysis of a hypothetical scenario.
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Chapter 1

Introduction

1.1 Motivation

Mobile GIS system is an integrated software/hardware framework for accessing geospatial data and services through wireless network (Tsou, 2004). It brought a whole new variety of possibilities of utilizing geospatial information to support real-time mobile activities. It could range from basic information services that merely present location-based information to more complex ones that provide functional spatial-related analysis. Currently, the main applications of Location-Based Services include tourism, navigation and crisis management.

Despite the great potential of mobile GIS system in supporting multiple user mobile activities, the design of mobile GIS remains to be a difficult task due to the mobility of users, the restriction of mobile devices, the difference contexts of users, and the various user profiles and requirements. To address this challenge, adaptive mobile GIS, as a new field of research, has gained increasing attention from multiple research disciplines, including Geographical Information Science (GIS), Cartography, Artificial Intelligence (AI) and Human Computer Interaction (HCI); and the knowledge from these disciplines needs to be combined in order to pursue the approach of designing a well-behaved adaptive mobile GIS system.
1.2 Statement of the Problem

Context awareness is a key feature of adaptive mobile GIS system. It refers to the idea that the system should be aware of and adapt to context factors that are related to the ongoing activity. Towards context awareness, considerable efforts have been made to develop mechanisms to capture and model context (Strang & Linnhoff-Popien, 2004). Most of them focus on isolated context factors of single actions but fail to consider the effects of these contexts to the whole embedded activity. As a result, the adaptation is likely to be simple and rigid and the target of the whole activity is missed during the process of adaptive geovisualization. To address this challenge, several research questions need to be answered.

1) What is the scope of context that should be considered for mobile context adaptation?
Context is information describing the situation of an entity. Two main categories of context include environmental and human context. So far, many context factors have been recognized and utilized for mobile context adaptation, such as location, human preference and history. However, besides of these well-known and frequently used contextual factors, I assume other context should also be important for consideration. As mobile activities are always driven and influenced by cognitive states of mobile users, I regards human cognitive state can be an important piece of context for mobile adaptation.

2) How to capture key context factors and model them in computational system?
The usage of context should be analyzed under certain situations. For an activity, there are potentially a large number of factors influencing the accomplishment of an activity. It is important to understand how to select and model those significant contextual factors according to the activity in focus.

3) How to utilize context for adaptive geovisualization?
Geovisualization is an integral component of mobile GIS system. It should be adaptive to the continuously changing context and
presents geo-related information according to the current state of an activity. Due to different context surroundings related to an activity, the information to provide to the user should be adaptive and dynamically changing. As for geovisualization, it is important to know how to provide appropriate geographical information for mobile users.

1.3 Objective

The main object of this study is to generate tailored visual representations to support ongoing user activities. Current systems have not been fully developed to achieve this goal, because their adaptations focus on environmental context but rarely consider the target of the activity (Abowd, et al, 1997; Amendola, et al, 2004; Malaka and Zipf, 2000; Pospischil, 2002). By maintaining the context awareness of ongoing activities, this study aims to make an improvement to generate activity-situated visual representation. To approach this main goal, several sub-objectives can be identified corresponding to the identified questions:

1) Human intention should be captured and modeled as a piece of context for adaptation to an activity. During a mobile activity, context continuously changes including both environmental and human context. It is important to detect this change to trigger the process of context adaptation. Human intentions help the system to be aware of the influence of the change to the activity. By capturing human intentions, the system can better understand the user’s requirement and hence enables itself to select appropriate strategies for adaptation.

2) An activity-oriented context modeling mechanism should be developed to maintain the awareness of the ongoing activities. Single actions are always embedded in activities and their executions should be conducted according to the current state of activity. An action should comply with updated constraints of the activity, such as time left for the rest of the activity. Besides, its execution should consider the influence from previous/subsequent actions. Therefore,
to support adaptation to a current action, the adaptive system should be capable of tracking the whole activity and maintain the updated contextual information of activities.

3) *An adaptive methods for geovisualization should be developed based on activity-oriented context model and generate tailored visual representations.* To support the user activity, it is essential for the system to provide appropriate geographical contents to the user at real-time. From this standpoint, this study will work on the selection of layers, that is, what geographical content should be provided to mobile users to support their activities.

### 1.3 Method and Expected Outcome

To approach the objectives, this study follows two steps. First, an activity-oriented context model is developed with supports from two theories: 1) Activity theory is used to understand the mobile activity. It introduces the hierarchical structure of mobile activity; declares mobile activity as a goal-directed developmental process; and helps identify the related context factors of the mobile activity. 2) Then, coherent to Activity Theory, the SharedPlan theory is utilized to model the mobile activity in computational system. By adopting a mental state view, it helps the system to analyze and capture both environment and human context according to the activity.

Based on the activity-oriented context model, the adaptive geovisualization can be achieved through a rule-based approach. According to the rules, the contextual information in the context model can be linked to the decision-making of the geovisualization. The system can obtain the information through tracing back the context model and the rule is selected by matching the obtained information with the conditions of the rule. In the large scope of issues of
geovisualization, this study focuses on the adaptive selection of geographical content (map layers) for the activity; so specific rules are designed for selecting the layers.

According to method of activity-centric adaptation supported by the context model, the process of geovisualization is expected to be coherent with the ongoing activity, dynamically adapt its geographical content to the user’s need at real-time.

1.4 Thesis Outline

This thesis is organized into five chapters. Chapter 1 (this chapter) aims to provide a big view of this study. It identifies the research question; illustrates the object of this study; and briefly demonstrates the method and expected outcome.

Chapter 2 reviews the related studies to this work. A basic structure of adaptive system is introduced, and based on it, an in-depth discussion on existing adaptive mobile GIS system are made to demonstrate why the existing approaches of adaptation among the systems are insufficient to support user mobile activities.

Chapter 3 describes the method of activity-oriented context adaptation for mobile geovisualization. Activity theory and SharedPlan theory are introduced to build an activity-oriented context model. Then based on the model, the process of adaptive geovisualization is illustrated.

Chapter 4 introduces a scenario to test the feasibility of this study and demonstrates the advantages of this study compared to existing ones.

Finally, Chapter 5 makes a conclusion of this study with suggestion for future research.
Chapter 2

State of the Art

The objective of this chapter is to review the existing works related to this study. Section 2.1 introduces the basic concepts and principles for adaptation and adaptive systems. Based on a generic framework for adaptive system, each of the embedded components is discussed, including adaptation target, adaptation information, adaptation object and adaptation process (section 2.2). The final section makes the conclusion by stating the insufficiency of current adaptation approaches in achieving the claimed research objects.

2.1 Adaptation and Adaptive mobile system

Computing systems were always regarded as passive tools, and their designs were mostly driven by advances in technologies. Lacking of awareness of human context during user activities, the usability of such systems are ignored (Reichenbacher, 2004). To overcome this, the concept of adaptation is proposed (Browne, 1990; Sanderson, 1993; Oppermann, 1994). It is meant to increase the suitability of the system for specific tasks; facilitate handling the system for specific users, and so enhance user productivity; optimize workloads, and increase user satisfaction (Oppermann, 1994). Rather than a passive tool, the adaptive system is expected to actively participate in the user activity and provides user with timely support.

An adaptation system includes three components: adaptation target, adaptation object and adaptation process. The adaptation object is adapted to the adaptation target through adaptation process; the adaptation process involves the utilization of the adaptation information, which is analyzed from adaptation target (e.g. useful contextual information) (Reichenbacher, 2004)(Figure 2.1). In the situation of mobile GIS usage, each component of the structure and their
co-relationships needs to be identified and enriched. To do this, three questions need to be answered (Brusilovsky, 1996): “what to adapt, to what to adapt, and how to adapt.”

Figure 2-1: Basic structure of adaptation system (T. Reichenbacher, 2004).

To what to adapt – The motivation of integrating adaptation into mobile GIS system is to support mobile activities, therefore, mobile GIS system should adapt to the user activity it aims to support. A classification of mobile activities has been provided by (Reichenbacher, 2004), in which the main category refers to the application of tourism.

How to adapt – Mobile GIS systems should adopt certain adaptive mechanism to adapt itself to the activity. During this process, adaptation information needs to be selected and utilized. In the mobile situation, the adaptation information refers to contextual information including both environmental/physical context (e.g. location, weather) and cognitive/human context (e.g. goal, intention). In mobile situations, environmental context keeps changing while the user moves from one place to another. This change of environmental context may results in the change of human context such as user intentions and goals. The mobile GIS system should be aware of both changes of these factors. For different applications, the adaptation processes should be different because of the different contextual situations of activities.

What to adapt – During the adaptation process, several components should be adjusted to respond to the change of activity-related context, such as geovisualization and mobile devices.
2.2 Adaptive mobile GIS system

In this section, I examine the adaptation for the mobile GIS usage. Each elementary components of the adaptation system will be investigated, including adaptation target, adaptation information, adaptation object, and adaptation process. The review of current adaptive mobile GIS systems will be framed by this basic adaptation structure. First, as adaptation target, the concept of mobile activity is introduced. It helps to provide a big view of the application domains of mobile GIS usage. Then, as adaptation information, the mobile context is discussed. When the mobile context is described formally in relation to the mobile activity, it helps the system to understand the state of the activity and adopt appropriate adaptation strategies. Then, based on the introduction of mobile context, the adaptation object is introduced. As a component of adaptation object, geovisualization will be highlighted because this study mainly focuses on the adaptive geovisualization. Finally, taken as a whole, the adaptation process of current systems is introduced. That is, how the mobile context is utilized by the systems to adapt their geovisualization to their supported applications.

2.2.1 Mobile activity

Mobile activity is a kind of activity that is conducted in continuously changing environment. With the advance in mobile technologies, more and more activities have been involved in this category, such as daily planning, tourism and crisis management. A mobile activity is always composed by several complementary actions, five types of which are identified as locating, navigating, searching, identifying and checking (Reichenbacher, 2004).
The nature of mobility makes mobile activity different from other kinds of activities. First, the environmental situations of mobile activities keep changing. Second, the mental states of the participants towards activities tend to change with the situated environment.

2.2.2 Mobile Contexts and Context Awareness

Mobile context is information describing the contextual surrounding in which a mobile activity situates. It helps the system to understand the current state of an activity and provide tailored support to the user. The utilization of mobile context is directly influencing the effectiveness of adaptive systems in supporting their aimed activity. For the usage the context usage, the key concern refers to the context model, which defines the process of context captures and reasoning. From this standpoint, the object of this section is to investigate current context modeling mechanisms and reveals their insufficiencies to achieve our objectives.

2.2.2.1 Definition of context

Any human activities are embedded in a context and can be shaped by it. To provide better support to human activities, computer systems should keep monitoring their real-time context. Schilit et al (1994) defines context as where you are, who you are with, and what resources are nearby; and Dey and Abowd (2000) stated: “Context is any information that can be used to characterize the situation of an entity.” These definitions of context are declared from a general perspective; however, a vague notation is not sufficient for real applications. In order to make full use of context, it is necessary to obtain a better understanding of what context is. For the purpose of this study, I adopt the definition from Chen and Kotz (2000), who defined context as a set of environmental states and settings that either determines an application’s behavior or in
which an application event occurs and is interesting to the user. This definition implies that the relevant context should be defined coherent to the user’s activity.

### 2.2.2.2 Dimension of mobile context

So far, several means have been proposed to organize and classify the context. Schilit (1994) classified context into three categories: computing context, user context, and physical context. Baldauf et al (2007) classified context into physical context, virtual context and logical context. Gwizdka (2000) divided context into internal context and external context. Based on complexity of functionality, Chen and Kotz (2000) defined context by different levels - low-level contexts consisting of time, location, bandwidth and orientation, and high-level ones consisting of users’ current activity and complex social context.

The above classifications of context are from a generic perspective. In the mobile situation, context should be categorized in more detail and specified to certain usage in mobile activities. Kahkonen et al (1999) defined the dimension of mobile context including location, system, purpose of use, time, physical surroundings, navigation history, orientation, cultural and social, and user.

![Figure 2-2 Topologies of context for mobile cartography usage (Sarjakoski, 2004)](image-url)
• **Physical surroundings**: In mobile activities, the physical surrounding is continuously changing, such as location, lightening, noise, temperature, surrounding landscape and weather conditions. The change of this physical surrounding information may influence the process of the accomplishment of user activities. For example, if the weather is raining, visitors may cancel the outdoor activities; if surrounding landscape is sharply changed, the routing system should recalculate the optimized route.

• **Location**: Given the mobility of mobile devices and varying situations of mobile usage, the location context has been the focus of mobile context (Pascoe, 1999). It enables users to be aware of their positions. Besides, it can be used to deduce other important context such as surroundings, weather, traffic, and so on. Location context can be obtained through mainly three means: 1) GSM (Global system for mobile communications), 2) Wireless-LAN, and 3) GPS (Global positioning system).

• **System**: To support mobile activities, it is necessary to know the properties of users’ devices, including the size of display, input method, and processing and storing capabilities.

• **Purpose of use**: In mobile situation, most activities are in real-time and have clear target. The mobile GIS system should be aware of such targets and provides the corresponding service. Just as defined in (Schmidt, 1999): Mobile systems are operational and operated while on the move, and should be characterized by a shift from general-purpose computing to task-specific support.

• **Time**: The context information of time includes time of day, time of week, time of season, time of month and time of year. The awareness of time can help to detect any changes happened that may influence user’s activities, for example, the open and close time of attractions; the time for a coming bus; and the changing weather during time.

• **Navigation history**: Navigation is an essential mobile application for users to observe
different spaces on maps. It has two-dimensional characters: spatial and historical. By recording navigation history, the system can track user’s activity, and reveal other information, such as users interest.

- **Orientation**: The mobile map should be displayed in the right position according to user’s movement direction. Map, as a metaphor of real world, when matching with its corresponding one, can decrease the possibility of misperception of spatial information.

- **Culture and social**: The usage situations of mobile maps can differ due to user’s current social and culture context. Culture and social context should be notified for users if there are changes. One example is transportation system; and another may be racial related issue such as habits and local festival.

- **User**: The significance of contextual information of user has been realized and emphasized in recent works (Zipf, 2002; Freksa, 1997). The idea is to provide egocentric mobile services to the users considering their own characters. The characters include: physical abilities such as height, age, swiftness and left- or right handedness; cognitive and perceptual abilities such as memory, learning, problem-solving and decision-making; and personality differences, consisting of gender, attitudes, habits, emotional states and so on. The user context can be obtained through two means: 1) through user’s explicit input or 2) through learning from previous history of interaction.

Mobile context has multiple dimensions, however not all of them need to be captured for certain applications. Location information is adopted in almost all the systems, but other context factors are also considered. Orientation information is captured in the Cyberguide project (Long, 1996; Abowd, 1997) to avoid users’ disorder of spatial relationships. Navigation history is recorded in the LOL@ (Pospischil, 2002) and UbiquiTO (Amendola, 2004) to make touring suggestions. User preference is captured in the GUIDE(Cheverst, 2000), DEEP MAP (Malaka & Zipf, 2000), and CRUMPET (Poslad, 2001) projects to help customize GIS systems. And time is
considered in GUIDE (Cheverst, 2000) and UbiquiTO (Amendola, 2004) project to support dynamic interactions.

### 2.2.2.3 Context Modeling

Context modeling refers to the question about how to organize and structure context factors in computational environment. A well-designed model is a key access to the context in any context-aware system. A context modeling survey has been done by (Strang & Linnhoff-Popien, 2004). Six basic modeling approaches are introduced, including *Key-Value Models, Markup Scheme Models, Graphical Models, Object Oriented Models, Logic Based Models and Ontology Based Models.*

- **The Key-value model** is the simplest modeling methods, constructed by a list of attribute-value pairs. Currently, most of the mobile GIS systems use this modeling method to structure the context factors. However, as context factors are organized separately, the relationships among context cannot be maintained. This model cannot support sophisticated context reasoning.

- **The markup scheme model** is a hierarchical data structure consisting of markup tags with attributes and content. Typical representatives of this kind of context modeling approach usually base on a serialization of a derivative of Standard Generic Markup Language. There are several context-modeling approaches in the markup scheme category, such as *Composition Capabilities/Preference Profile (W3C), Comprehensive Structured Context Profiles* (Held, 2002), and *Pervasive Profile Description Language* (Chtcherbina, 2003). The markup scheme model has the advantages to organize a set of inherently hierarchical context factors such as user profile, however, when context is inherently complex, the model would be inconvenient to use. Among the current mobile GIS systems, this model is used in
GinisMobile (Predic, 2006) following XML scheme.

- **The Graphical model** uses diagrams to represent the structure of context. Two well-known approaches of this model include the *Unified Modeling Language* and *Object-Role Modeling* (Halpin, 2001). The main focus of the graphical context model is on the structure of context, and it is hard to use for context reasoning.

- **The Object oriented model** organizes context by the unit of object. It inherits the benefits of object-oriented techniques, such as encapsulation and reusability. It lends a good method to model the context, however, it cannot assure an efficient means for context reasoning if the relationship among objects is ignored for an activity. In current systems, the object-oriented model is employed in GUIDE system (Cheverst, 2000).

- **The Logic based models** defines context as facts, expressions and rules. The emphasis of this model is on the conditions enabling the transitions from one fact to another. Two famous approach of this model are *Multicontext Systems* and *Extended Situation Theory* (Akman, 1997). This model has the strength for context reasoning; however, it does not provide efficient mechanisms for modeling context, especially in dynamic situation.

- The Ontology based model organizes context based on facts and concepts in formalized structures. Typical examples in this category include *Aspect-Scale-ContextInformation (ASC) model*, *Context Ontology Language (CoOL) model* (Strang, 2004), and *CoBrA* system (Chen, 2003). In the situation of mobile usage, this model have been investigated and used among researchers (McCullough, 2001; Zipf, 2003). The ontology-based model owns a high level of formality, however, once it is structured, it cannot be changed dynamically. Therefore, it lacks of flexibility of adapting to the changing context.

As a supplementary to the context models mentioned above, the activity-based context model is investigated (Kaenamprnpan, 2004; Petersen, 2005). This model takes *context as a matter of user activity*, aiming to understand how context information is related to, and affects user activities.
Compared with other models, the activity-based context model provides an effective to organize and reason about context 1) taking activity as basic analysis unit, it helps to identify the key context factors that influence human activities; 2) with a tree hierarchical structure, the model helps to reveal the internal interlaced relationships of an activity and track the whole process of the activity.

2.2.3 Adaptation objects

During the process of adaptation, several adaptation objects need to be adapted to the activity to provide the tailored support. In this study, I focus on the geovisualization as the main adaptation object. It includes two sub-components – geographical content and map representation. The geographical content reflects information requirements from users: what user’s need in which level of detail; and Map representation acts as the interface through which users can obtain information for their activities.

2.2.4 Adaptation process

In a process of adaptation, adaptation objects should adapt to activities through adaptation mechanisms. This section seeks how adaptive methods and techniques are employed to adapt each adaptation object to certain context factors.

Geographical content – Adaptive mobile GIS systems should provide users with tailored geographical content to the activities. In order to do this, context-reasoning mechanisms should be launched for analyzing the context factors. Implementation of this process in the current adaptive systems is rather simple and straight: the selection of geographical content is only decided by one or two predefined context factors. For example, the DEEP MAP employed user
preference to suggest the navigating route (Malaka, 2000); the UbiquiTO system utilizes user’s interest to suggest traveling places (Amendola, 2004); and the CRUMPET utilizes user’s preference and knowledge to provide tailored traveling information (Poslad, 2001).

**Map representation** – Map, as an integral component of the mobile GIS system (Kraak, 1996). It supports user-activities from two aspects: first, as a display tools, a map provides a user with spatial information; second, as an interactive component, a map can enable a user to explore spatial-related information. When regarding the usability of a map, the key concern is to generate adaptive map representation according to the user need. The map representation should adapt to the external context factors, such as environmental and human factors; besides, it also should be internally adapted, such as the symbol placement. So far, considerable efforts have been paid, including intelligent maps (Frank, 2004), egocentric maps (Meng, 2005), focus maps (Richter, 2002), aspect maps (Freksa, 1997) and activity-based maps (Zipf, 2003). In these studies, main adaptation techniques include:

- **Adaptive panning**: the process to adapt map to user’s positions.
- **Adaptive rotating**: the process of rotating the map in accordance with the user’s position and orientation.
- **Adaptive zooming**: the process of changing map scale based on the context of user, such as entities of interest, and motion speed. A similar idea with this is the adaptive distortion. By using different scaling granularity, distortion enables different levels of information to be represented in a map (Rauschenbach, 1999; Richter, 2002).
- **Adaptive symbolization**: the process of changing the presentation of symbol according to culture, user or situational context. Symbols of object are represented with different opacities according to the relevance level. Besides, the symbols are represented with different colors according to different user profile. Moreover, the size of symbol can dynamically change according to the placements of other symbols.
Table 2-1: A Summery for Current Adaptive Mobile GIS System

<table>
<thead>
<tr>
<th>Mobile System</th>
<th>Application</th>
<th>Adaptive Target</th>
<th>Adaptive Process</th>
<th>Adaptive Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOL@</td>
<td>Tourist Guide</td>
<td>Location, history</td>
<td>Use GPS and user input to identify location</td>
<td>Geographical content</td>
</tr>
<tr>
<td>(Pospieschil, 2002)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEEP Map</td>
<td>Tourist Information</td>
<td>Preference, Interest, mode of transportation</td>
<td>Preference and interest to make route proposal</td>
<td>Geographical content</td>
</tr>
<tr>
<td>(Malaka, 2000)</td>
<td>System</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyberguide</td>
<td>Tourist Guide</td>
<td>Location, Orientation</td>
<td>Use location and speed to pan the map</td>
<td>Map Representation</td>
</tr>
<tr>
<td>(Abowd, 1997)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UbiquiTO</td>
<td>Tourist Guide</td>
<td>Location, Profile, Movement, History</td>
<td>Use user’s interest to make suggestion; Use user profile to customize user interface</td>
<td>Geographical content</td>
</tr>
<tr>
<td>(Amendola, 2004)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRUMPET</td>
<td>Tourist service portal</td>
<td>Location, Preference, Knowledge</td>
<td>Use user preference to adjust the map contents, and symbols</td>
<td>Geographical content</td>
</tr>
<tr>
<td>(Poslad, 2001)</td>
<td></td>
<td></td>
<td></td>
<td>Map Representation</td>
</tr>
<tr>
<td>GinisMobile</td>
<td>Tourist Guide</td>
<td>Location, Moving speed</td>
<td>Use location and speed to adjust the map scale</td>
<td>Map Representation</td>
</tr>
<tr>
<td>(Predie, 2006)</td>
<td></td>
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</tr>
</tbody>
</table>

2.3 Conclusion

Table 2.1 summarizes the progress made in the literature along the three dimensions of the adaptation processes of mobile systems. I would like to make a few observations on the insufficiency of current approaches of adaptation in achieving our objectives.
First, though human factors are considered by the current context adaptation, such as user preference and interest, user cognitive context is rarely taken into consideration. User cognitive context is essential for the system to understand the state of activity at real time. So, it is still necessary to think of how to model and use the human cognitive factors for context adaptation.

Second, among the systems, the process of adaptation considers context factors separately. However, in real situation, the adaptation should be result from the interplay of multiple context factors. This arise the requirements that a comprehensive context modeling mechanisms should be pursued to organize the activity-relevant context.

Besides, in these systems, the context factors are fixed. However, as the mobile activity is the process under changing contextual situations, it is hard to prescribe what context are relevant and what to adapt to during the design time (Greenberg, 2001). Therefore, it would be important for the system to track the whole activity, indicating which context should be considered under current situations.
Chapter 3

Methodology

The objective of this chapter is to present a method of designing adaptive mobile GIS systems as an improvement of existing systems. This chapter is organized as following: First, Activity theory will be used as a conceptual framework to understand mobile activities (3.1). Then, consistent with Activity Theory, SharedPlan is presented as a computational model of mobile activities (3.2). This model can be implemented as a PlanGraph context model (3.3). Then, based on the PlanGraph, the adaptive process of mobile geovisualization can be introduced (3.4). At last, architecture for implementation is introduced for demonstrating the feasibility of this study.

3.1 Understanding Mobile Activities

Activity theory was developed by Russian psychologists Vygotsky, Rubinshtein, and others in the 1920’s (Kaptelinin, 1997). Its central focus is human activities. Different from other opinions, which regard activities as purely goal-bounded, Activity Theory places activities in a more comprehensive framework of analysis. An original version of the framework of Activity Theory involves three main components: subject, object and tools. Later, three other components - rule, community and role, are grafted, which aims to cover the fact that activities are carried out under certain social and culture contexts (Figure 3-1).
Activity Theory provides the framework to present key dimensions of context factors related to an activity. More important, it introduces several principles to describe how these factors motivate and influence the activity. These principles can be utilized to understand the mobile activity.

**Mobile activity as a goal-directed activity process**

Activity theory states that activities are goal-oriented processes that must be carried out to fulfill the goals. “The goal can be both material thing, or less tangible (like a plan) or totally intangible (like a common idea) as long as it can be shared for manipulation and transformation by the participants of the activity (Kuutti, 1996).” Transforming the goal into an outcome motivates the existence of an activity. To approach a goal, internal activities are firstly emerged as a thinking process. Then, by consideration of the external constraints such as rules, roles and tools, the internal activities lead to external activities, which can be defined as using tools to act on real objects.

**Mobile activity as a hierarchical action-tree**

Action theory states that an activity follows a hierarchical structure (Figure 3-2). An activity can be decomposed into actions; actions can be divided into lower-level actions or operations. The operations can be directly executed by participants.
Mobile activity as a developing process

The activity moves forward to approach the goal by taking a plan. In mobile situations, the planning of mobile activity is an evolving process rather than pre-defined. Because mobile context is dynamic and unpredictable, participants need continuously update their internal states about the current situation and take actions.

Mobile activity as a collaborative performing process

By employing adaptive mechanisms, a mobile GIS system is not merely a passive tool executing user demand, but should act as an active agent participating the planning process of the mobile activity. During this process, users and agents should have mutual initiatives and understandings of actions; they need negotiate with each other in order to reach a consensus of a plan and all of them should have the capability of interfering with the activity process, pushing the activity forward in an interlaced manner.

3.2 Modeling Mobile Activities as SharedPlan

Consistent with Activity theory, a computational model, SharedPlan (Grosz, 1993), is adopted to model mobile activities in this study. Extending the initial mental state model of plans (Pollack, 1990), SharedPlan theory adopts a mental state view to describe the process of the
activity. It claims that an activity is a process that a shared plan is established and executed based on the participants’ mutual understanding and knowledge. To support the modeling of activities, a complex structure of supportive definitions and notation are included in the theory. Some key elements include:

**Action:** An action refers to the user behavior that is taken to achieve the goal of that action. It can be either basic or complex. A basic action can be executed by individuals directly whereas a complex action cannot. To perform a complex action, agents need separate it into sub-actions. During this process, the knowledge pre-conditions of the action have to be identified, responsibilities among agents have to be divided, and mutual commitment should be achieved.

**Recipe:** A recipe defines the detail about how to carry out an action, defining the sub-actions and related pre-conditional knowledge as parameters. There may be multiple recipes for each action in case the goal an action is carried out in different contextual situations. The recipe defines how the hierarchical structure of activity can be formed, and the selection of recipe is based on the analysis of the current context.

**Plan:** Compared with the recipe that represents external knowledge about how to conduct an action, a plan mainly focuses on the internal mental states of agents. The major component is the intention operator, including Int.To and Int.Th. Int.To is used to represent an agent’s intention to do some action, and Int.Th is used to represent an agent’s intention that some proposition is hold (Grosz, 1993). Except for the intent operator, there are also belief operators and commitment operators. The belief operator helps to represent a belief of a proposition and the commitment operator indicates whether the collaborative agents have committed to the success of an action.

Based on these supported definitions and notations, the SharedPlan model provides a good modeling framework for approaching the objectives of this study.

First, the SharedPlan model enables the system to maintain the whole structure of the activity by modeling activities with this hierarchical structure. This structure provides a
mechanism to organize the context factors related to the activity. Besides, itself can be regarded as a part of context as it helps to represent the developmental path of the activity and reveal the inner relationships of it.

Second, by considering an activity as a planning process, the SharedPlan model enables the system to capture human factors as intentions and beliefs. As discussed, the human factors can be important for context adaptation as they enable the system to understand the activity, and hence to provide user with fitted information and services.

Third, by modeling the activity-related context in a comprehensive manner, the SharedPlan model supports the process of geovisualization to adapt to the whole activity. With the developmental character of the SharedPlan model, the geovisualization can be consistent with the updated state of the activity.

3.3 PlanGraph-Based Context Model

The SharedPlan model describes the activity-oriented context modeling mechanism from a generic view. Based on the specification of SharedPlan model, a PlanGraph model (Cai, 2005) can be developed to model the activity-related context for the real use. In this section, the basic structure of PlanGraph is introduced first. Then, the PlanGraph-based modeling and reasoning mechanisms are deliberated.

3.3.1 Structure of the PlanGraph

PlanGraph is composed of two basic components: plan in the shape of rectangle and parameter in the shape of oval: 1) for the node of plan, it represents the planning-related information for a certain action. Such information includes agents for an action (who are
responsible for the action; what about their roles), mental states towards the action (what are their intentions and beliefs during the activity planning process), and recipes to execute the action (how to accomplish the action); 2) for the node of parameter, it indicates the knowledge preconditions for the action.

Composed by these two components, a PlanGraph is displayed as a set of hierarchically organized plans (Figure 3-4). The root of a PlanGraph represents the plan for the overall mobile activity. It can be decomposed to multiple parameters and sub-plans; the sub-plan can also be separated into other parameters and sub-plans. This division process of an activity is carried out according to the recipes, which is chosen based on the consensus of the joined participants towards the current situation of activity.

This hierarchical structure of PlanGraph provides a set of effective mechanisms to model mobile context. Three kinds of context factors can be plugged into this structure (Figure 3-4) (Cai & Xue, 2006):
• **Social context** of mobile activities is represented in PlanGraph as “agents”. It indicates who the participants of the attached plan are. “Agents” involves coordination among the participants, their responsibility, their capabilities, and their communications. In this study, I assume the social context would be stable across all the mobile activities, involving two participants: user and system agent. This assumption is based on the fact that an adaptive mobile GIS system is always operated by a single person.

• **Cognitive context** is represented in PlanGraph as “Mental_state”. It contains cognitive factors of participants to initiate a shared plan. Such cognitive factors include *intentions, beliefs* and *commitments*. For cognitive context it can be captured through the externalization of the user’s cognitive state through interactions with the system. Through capturing user cognitive context, the system is capable of understanding the state of activity and hence providing appropriate information to the user.

• A plan of an action often involves the identification of some parameters as **Pre-conditional knowledge**. It is not defined as a specific type of context but decided by the concrete action in progress. Different types of context factors may be included in this category because of different requirements of actions. For example, in a navigating activity, the orientation is a pre-conditional knowledge; but in a searching activity, user interest may become a pre-conditional knowledge.

• The **constraint** in the above diagram represents any constraints of the activity, which can be environmental factors or other factors. For example, the weather may be a constraint for visiting an outdoor attraction; a set of tools may be a constraint for carrying out an action.

  Activities cannot be understood at a time point but should be considered in the history of development. As the PlanGraph model develops during the time while the activity proceeds, the **historical development** of activity is also recorded in the model. By continuous updating itself according to the progress of activity, PlanGraph enables the system to analyze the current states
of the activity based on understanding of the whole developmental history of the activity.

### 3.3.2 PlanGraph-based context capturing

During the process of mobile activity, the system captures context by two means: through the user interaction and remote information services.

1) Supported by adaptive mobile GIS system, a mobile activity is accomplished through collaborative efforts from both the user and the system. During this process, a user can provide the system with contextual information through interactions. One of the functions of the user interaction is to express the cognitive states towards the current activity, indicating what s/he wants to do and what information and services s/he needs. Second, when the system lacks of knowledge for identifying the pre-conditional knowledge for executing an action, external intervention from the user should be required. Furthermore, the process of mobile activities is always constraint by multiple contextual factors. The user is responsible for informing the system with those constraints in order to get right response.

2) Besides capturing context through user’s directly interactions, in mobile situation, context can also be captured by accessing remote information services, such as weather, transportation and location.

### 3.3.3 PlanGraph-based context reasoning

During the process of a mobile activity, the PlanGraph model is dynamically developed based on a context reasoning mechanism. This reasoning mechanism is composed of two steps: *explanation* and *elaboration*.

- **Explanation**: The mobile activity is pushed forward by interlaced efforts from users and
adaptive mobile GIS systems. During this process, the system needs to explain about users’ inputs and understand how the user intentions may exert influence to the current plan. The intention derived can be classified into three categories: first, *to initiate an activity*; second, *to identify the parameter*; and third, *to express the mental state towards the activity*. If the user’s input can be successfully explained by the system, the reasoning mechanism will step to the second phase.

- **Elaboration**: After successfully explaining user’s input, PlanGraph needs to elaborate the intention of users to update the most current state of the mobile activity. The system can elaborate the PlanGraph in multiple ways: 1) *Choose a recipe to accomplish the action*. When the intended actions are not developed in the PlanGraph, the system will introduce a recipe to achieve the goal of that action, which defines the parameters to be identified and the sub-actions to be fulfilled. For each action, there may be several recipes for use. A recipe can be selected by a ranking algorithm and it can be replaced by another when the user think the recipe is not feasible in current situation. 2) *Identify parameters for the intended action*. To accomplish an intended action, multiple parameters identified by a recipe need to be identified. During the elaborating process, the system will try to contribute to the identification of certain parameters. 3) *Execute any sub-plans that have been fully developed*. When the system believes that a sub-action included in the recipe of the action in focus can be fully developed, the system should accomplish the sub-action.

### 3.4 PlanGraph-based Adaptive Mobile GeoVisualization Process

The main goal of adaptive mobile GIS system is to generate suitable and tailored visual representations to provide users with activity-relevant information. The PlanGraph can provide support to approach this goal by modeling the activity-centric context, according to which the
adaptive map representation can be generated. In this section, a demonstration is made to show how the PlanGraph context model can be utilized for adaptive mobile geovisualization.

To introduce the adaptation visualization process, two steps should be steered through. First, the structure of PlanGraph for mobile visualization is introduced. Then, the PlanGraph-based reasoning process of adaptive visualization is discussed.

### 3.4.1 Basic structure of PlanGraph for mobile visualization

To build PlanGraph to describe the process of mobile visualization, first we need to identify the actions during this process. This study adopts an action-based hierarchy (Cai, 2005), including four levels of actions. The first level is tagged as domain action, describing the domain of the activity such as “planning for travel” in a touring domain. The second level is cartographic and visualization actions, dealing with the visualization techniques for map representation, such as add/delete layers, zoom in/zoom out, highlighting, symbolizing and panning. The third level action is the spatial analytical actions, referring to geoinformation-based analysis, such as buffering. Finally, the fourth level deals with spatial data retrieval actions. Figure 3-6 shows an example of the PlanGraph representation based on these definitions.
3.4.2 PlanGraph-based adaptive geovisualization

According to the above figure, the adaptive geovisualization is carried out to support the user’s domain action. In this process, the user intention is always the starting point to trigger the process of adaptive geovisualization. Therefore, I will first talk about the generation of user intentions. Then, a discussion will be made on how the intention can be elaborated leading to the process of adaptive geovisualization.
3.4.2.1 Generation of User Intentions

The user intention is the key factor to motivate the process of adaptive geovisualization. According to the specification of SharedPlan, intentions can be classified into real intentions and potential intentions. The real intention represents what the users aim to do and the potential intention represents the potential action a user may work on. A potential intention can change to a real intention when the user intends to do the potential action. For example, in a tour, there are two potential actions as visiting a museum and having a lunch. Each of these actions represents a potential intention. When the user informs the system that s/he wants to visit a museum, the corresponding potential intention becomes a real intention.

A real intention can be obtained through explanation of the user interaction with the system. The generation of real intention is significant for the process of adaptive geovisualization, as it provides the current knowledge about the state of activity to the system and enables system to response correctly to the user.

The user intention mentioned above refers to the domain intention, which describes the goal of the user activity. Besides of domain intention, there is also visualization intention, which directly leads to the generation of map representation. In the mobile situation, the visualization intention refers the cartographic action as showing a map. The visualization intention is generated by the system when the system finds that a map should be generated to support the domain action, which is always referring to identify a route or identify a location.

3.4.2.2 PlanGraph-based Adaptive Mobile Geovisualization

The coming intention from a user interaction triggers the development of a PlanGraph. When the visualization intention is generated, the process of geovisualization is triggered in
which the parameters of generating a map should be identified. To identify these parameters, the system needs to obtain and reason about the activity-related context.

The hierarchical structure of PlanGraph enables the system to access the captured context by backtracing the whole structure. In each step of backtracing, three complementary actions are involved in this step: go back to the upper-level action, check the constraints of the action and read the recipe for that action. As shown in figure 3-5, the process of backtracing begins when a system starts to execute the cartographic action “ShowMap”. At the first step, the system traces back to the upper-level action “Identify Restaurant” and reads the recipe of this action by traversing its composed parameters and sub-actions. In this step, the system captures the domain intention “Identify Restaurant” and a pre-conditional knowledge for this intended action “Type of food”. After this step, the system continues tracing back to the higher-level action “Have lunch”. It checks the constraints of this action and knows this action has time constraints. Then, by traversing the recipe, the system can be aware of the identified restaurant and the intended subsequent action “Route Selection”.

Figure 3-5: Structure of a PlanGraph for mobile visualization
PlanGraph enables the system to obtain captured contexts by backtracking the hierarchical context modeling structure. Based on the PlanGraph, the key concern is to reason about the context and to make decisions for geovisualization. In this study, I focus on the adaptive selection of layers. The aim of selection of layers is to provide tailored geographical content for mobile users. To approach this object, it is essential for the system to understand the current state of the activity and analyze about the user requirements of the geographical information. The PlanGraph-based context modeling mechanism can support the selection of layers from two perspectives: 1) users intention can be used to directly indicate their requirements of geographical information for the mobile activity; 2) by maintaining the inner relationship of an activity, the whole structure of the activity helps to reveal the geographical information that are potentially support subsequent actions, hence the whole activity.

The rule-based approach is adopted to utilize the captured context for adaptive selection of layers, which can be represented as $F(Context) \rightarrow Layers$. Three types of rules are introduced including:

1) Rules on the Action-Level: To generate a map to support a user activity, it is important to know what information the user requires for the current action. The system can deduce the required information from two parts of the PlanGraph:

First, the user intention of the action in focus can be used by the system to recognize the thematic layer to add to the map. For example, in figure 3-6, by being aware the user identifies a restaurant, the information of restaurant should be the focusing theme of the map.

Second, the pre-conditional knowledge as parameter can be used by the system to produce adaptive map representation. A parameter may have two functions. First, a parameter may be used to specify the information consistent with the theme. For example, in figure 3-6, “types of food” indicates the preferred food type of a user. According to this information, rather than adding the layer of restaurant, the corresponding layer of the identified type of restaurant is
added to the map. Second, the parameter can also be used to imply other supportive layers except for the thematic layer. For example, if a user needs landmark to identify a restaurant, then the layer of landmark can be a supportive layer for the action.

To formalize the rule from above discussion, I use \textit{Int} to represent the current intention, and \textit{para} to represent the parameter. The rule is composed by “if ... else ....” conditional statements:

\begin{verbatim}
If (Int equals A) {Thematic_Layer = Theme(A);} 
For (para in Recipe)
{
If (para can be used to specify the thematic information) {Add specified thematic layer}
If (para can be used to derive supportive information) {Add supportive layer}
}
\end{verbatim}

Figure 3-7: Formalization of action-based rule

2) \textit{Rules on the Activity-Level}: Rather than merely targeting on the current action, the geovisualization should also consider the accomplishment of the whole activity. From this standpoint, the system should be aware of the influence from other actions to the current action,
especially the subsequent action. For example, in figure 3-7, because the location of church may influence the decision of picking up the restaurant for lunch, the layer of church may be useful if added on the map.

The question here is how to position the influencing subsequent actions in the PlanGraph. To address this problem, the system needs to backtrack the structure, as well as check the subsequent-action at each step. This process ends till the system realizes that both the action and the subsequent-action are registered in different application domains. For example, in figure 3-8, when the system backtracks to the action “identify restaurant” and checks the subsequent action is “route selection”, it continues the process of backtracking because the later action is dependent to the identified restaurant, and they are in the same application domain as “Have Lunch”. Then, the system backtracks to the action “have lunch” and checks the subsequent action as “visit church”, therefore it can reveal the influencing subsequent actions.

Figure 3-8: Activity-based rules for selection of layers
To generalize the rule from above discussion, I describe it by “if ... else ....” conditional statements:

```plaintext
Do

\{Backtrack to the upper-level action and checks the subsequent action
If(two actions are for the same application) {Continue backtracking}
Else(Add the supportive layer)
\}

While{Backtrack to the end of PlanGraph}

Figure 3-9: Formalization of activity-based rule
```

3) **Rules based on the constraint:** While the activity progresses, the constraints of the activity should be checked all the time, such as the weather condition and time. According to the result of checking, certain specified layers can be selected. For example, if there is a *time* constraint of the action “Have lunch”, the layer of fast-food may be added on the map; if there is a *weather* constraint of the activity “tourism”, when it rains, the layer of outdoor attractions should be filtered out.

![Diagram](image-url)

Figure 3-10: Constraint-based rules for selection of layers
To generalize the rule from above discussion, I use *constra* to represent the constraints of the activity. The rule is composed by “if ... else ....” conditional statements:

```
Do
{
  Backtrack PlanGraph and collect the constra
  If (constra can be used to select a layer) {add the specified layer}
}
While{Backtrack to the end of PlanGraph}
```

Figure 3-11: Action-based rule

According to the rules, the adaptive layers can be selected. However, except for these layers, the map should have a default background to enable the mobile users to be aware of the landscape and geographical objects around them. This default background can be static including a set of layers, such as the layer of main road, and the layer of city subdistrict. This map background is important for users to execute their activities, because it helps users to memorize and understanding the spatial relationships among the geographical entities, thus directly minimize the thinking load of mobile users.

### 3.5 The Architecture for System implementation

For later implementation, the system can be developed with a modular architecture (Figure 3-8). It consists of three major components: a knowledge base, a system agent, and the geographical information portal. This system follows the client/service framework.
The system agent is a programmed logic that handles the interaction between user and the system meanwhile coordinates the data transmission among different modules. It explains the user input and contributes to the elaboration of PlanGraph by selecting the recipe. It identifies the complementary components of geovisualization based on the PlanGraph-based context.

The knowledge base provides general knowledge for the system to make decisions to complete the activity. In this architecture the knowledge base consists of two components. The first is the recipe library, including the recipes for conducting actions. Another is the visualization rule-based system, which contains the rules for identifying the layers according to the PlanGraph.

The geographical information portal in the infrastructure is to provide remote data and services in order for the system to generate the tailored information for user activities. We assume that the mobile client system can access these portals through wireless communications.

In this architecture, PlanGraph is used to maintain the context awareness and activity structure. We use the tree data structure to model the PlanGraph, and each tree node is represented by an instance of a plan class. To be consistent with PlanGraph, a class of plan

Figure 3-12: Basic architecture of adaptive mobile GIS system
includes an array of plan to store the sub-plans, an array of constraints and an array of parameter. These parameters can be initiated by parsing the recipe selected from Recipe function. By adopting this data structure, the system can both maintain the context awareness and track the whole activity.
Chapter 4

A Sample Scenario of Adaptive Mobile Adaptation

This chapter presents a scenario to illustrate the process of PlanGraph-based adaptive geovisualization. The scenario is selected with two considerations: first, the scenario should be involved in a mobile environment; second, the scenario should be understandable that most of people are familiar with. According to these criteria, a touring scenario is developed. In section 4.1, the scenario will be introduced. Then in section 4.2, the process of mobile GIS adaptation will be illustrated.

4.1 Deliberation of scenario

The scenario involves an application of mobile map systems in tourism. Jim is the traveler who plans to have a tour in the city of Chicago. During this tour, Jim uses a mobile GIS system (Tourist Guide System). Figure 4-1 presents the interactive process between Jim and the system during the activity.
### Adaptive Geovisualization

**Action: Visit the Sear Tower**

<table>
<thead>
<tr>
<th>Step</th>
<th>Process of the mobile activity</th>
<th>Adaptive Geovisualization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>[Jim]: “I plan to have a tour in the city of Chicago”</td>
<td><img src="image1" alt="Map showing Layers: Places of interests" /></td>
</tr>
<tr>
<td>2</td>
<td>[System]: “What do you want to do during the tour?”</td>
<td><img src="image2" alt="Map showing Layers: Places of interests" /></td>
</tr>
<tr>
<td>3</td>
<td>[Jim]: “I want to visit a famous tower.”</td>
<td><img src="image3" alt="Map showing Layers: Places of interests" /></td>
</tr>
<tr>
<td>4</td>
<td>[System]: “Ok, please identify the attraction”</td>
<td><img src="image4" alt="Map showing Layers: Landmark, Places of interests" /></td>
</tr>
<tr>
<td>5</td>
<td>[Jim]: ”I do not know the exactly location of that tower.”</td>
<td><img src="image5" alt="Map showing Layers: Landmark, Places of interests" /></td>
</tr>
<tr>
<td>6</td>
<td>[System]: “Please identify landmarks near the tower.”</td>
<td><img src="image6" alt="Map showing Layers: Landmark, Places of interests" /></td>
</tr>
<tr>
<td>7</td>
<td>[Jim]: “It is near to the Cheap Hotel and Gage Restaurant.”</td>
<td><img src="image7" alt="Map showing Layers: Landmark, Places of interests" /></td>
</tr>
<tr>
<td>Line</td>
<td>Conversation</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>--------------</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>[System]: “Please identify the tower.”</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>[Jim]: “Only one tower is near to the Gage Restaurant. I should try that Tower.”</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>[System]: “How will you go to the tower?”</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>[Jim]: “I will take the bus.”</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>[System]: “Please identify the bus route.”</td>
<td></td>
</tr>
</tbody>
</table>
13  | [Jim]: “I will take the bus on W Lake St.”

14  | [Jim]: I have visited the tower and want to have lunch now, after that I may go to a museum.

15  | [System]: “Ok, which type of food do you like?”

16  | [Jim]: “Seafood.”

17  | [System]: “Please identify the seafood restaurant ”

18  | [Jim]: “I would like to select the restaurant near a church.”

19  | [System]: “Please identify the transportation mode?”

20  | [Jim]: “Seems the place is near; I would like to walk there.”
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>
| 21 | [System]: “Ok, please select a sidewalk.” | ![Map](image1.png)  
**Layers:** Sidewalk, Restroom |
| 22 | [Jim]: “Ok” |   |
|   | **Action: Visit a museum** |   |
| 23 | [Jim]: “I have finished the lunch and want to visit museum now.” | ![Map](image2.png)  
**Layers:** Museum |
| 24 | [System]: “Please identify the museum.” |   |
| 25 | [Jim]: “I am go to the nearest one.” | ![Map](image3.png)  
Layer2: Sidewalk, the identified museum |
<p>| 26 | [System]: “Please follow the sidewalk” |   |
| 27 | [Jim]: “Ok.” |   |</p>
<table>
<thead>
<tr>
<th>28</th>
<th>[Jim]: “I have visited the museum and want to finish this tour”.</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>[System]: “Ok.”</td>
</tr>
</tbody>
</table>

**Figure 4-1** The interactions between Jim and the system during the tour

By observing the scenario, some characteristics can be revealed to assure that the scenario is applicable to validate this study; these characters match well with the conceptualization of the planning process defined by Activity theory and SharedPlan.

- **Activity as multiple interlaced actions**: The entire activity as touring is handled by addressing a series of smaller actions. In this scenario, the whole activity is separated into sub-actions including have a lunch and visit a museum, and these actions are further elaborated other sub-actions until to the ones that can be executed by the system directly, for example, selection of feature from geo-database.

- **Mutual contribution to the shared plan**: The planning activity is accomplished through mutual collaborations between Jim and system. The system is cooperative with Jim in addressing the issue in focus and proactively presents relevant information.

- **The participants must make consensus on each action in order to achieve the accomplishment of the whole activity**: In this scenario, by capturing the cognitive states of Jim, the system is capable of understanding the current states of the activity, modifying the plan, and facilitating the build of common ground among participants for the subsequent steps.

- **Evolutionary path of activity planning**: To approach the expectation of the tour, the planning process between Jim and the system is carried out step by step rather than pre-defined. This evolving planning process enables the system to cope with situations in which uncertainties exist.
4.2 Mobile GIS Adaptation Process Based on PlanGraph

In this section, the scenario will be walked through to illustrate the process of adaptive geovisualization. The developmental process of PlanGraph will be illustrated to understand this process.

**Step 1:** [Jim]: “I plan to have a tour in the city of Chicago”

**Step 2:** [System]: “What do you want to do during the tour?”

The activity of tour planning is initiated by the original intention of Jim. When the system successfully explains the intention, the Plan node “Tour Planning” is added to the PlanGraph and is elaborated by selecting a recipe. In this recipe, all the potential touring actions are listed representing potential intentions. When the system realizes the need of generating a map for identification of user’s touring actions, a default map is displayed as background including layers of landscape and city sub-districts. At this stage, the current PlanGraph is developed as Figure 4-2.
Step 3: [Jim]: “I want to visit a famous attraction.”

Step 4: [System]: “Please input the name of the attraction”?  

The system asks Jim to identify his first touring action. As a response, Jim informs the system that he wants to visit a famous attraction. Then, the system starts to explain this interaction. The explanation is carried out by the system agent, which actually is a coded program. When this interaction is successfully recognized by the system agent, the system can generate an intention. In this case, the system generates the intention that Jim wants to visit an attraction, so it changes the potential intention of Visit an attraction to a real intention. Then, the system starts to elaborate this intention to PlanGraph. In this case, a recipe is selected for the intended action, which defines two sub actions: identify the attraction and select a route. According to this recipe, the system first starts identify the attraction. Because the system does not know the place of interest Jim plans to visit, so an invention from Jim is required. At this stage, the PlanGraph is developed as Figure 4-3. The dotted area P helps to illustrate the developed PlanGraph. In this case, the system is carrying out the cartographic intended action “ShowMap” and aims to support the domain action “identify the attraction”. As mentioned in the

Figure 4-2: Map for selecting touring actions
previous section (section 3.4.2.1), the cartographic intention “ShowMap” is a derived intention when a map is considered necessary for supporting an intended domain action.

A map is presented to Jim for identifying the attraction. The layer of attraction is added on the map based on the current intended domain action. Based on the map, the system asks Jim to identify the attraction he wants to visit.

Figure 4-3: Map for selection of an attraction
Step 5: [Jim]: "I do not know the exactly location of that tower."

Step 6: [System]: “Please identify the landmark near the tower? ”

Jim wants to visit the attraction as a famous tower in Chicago, but he does not know the exactly location of it. So he informs that the generated map cannot support his identification of the attraction. When the system realizes this condition, the PlanGraph needs to be updated and the current recipe to identify the place of interest has to be replaced by another one (Figure 4-4). In this new recipe, the system decides to use some landmarks to facilitate the identification of the place of interest. A map is generated for Jim to identify the landmark. By backtracking the PlanGraph, the system realizes the action of identification of landmark is in focus, so the layer of landmark is added to the map.
Step 7: [Jim]: “It is near to the Cheap Hotel and Gage Restaurant.”

Step 8: [System]: “Please identify the tower.”

To use the layer of landmark to locate the place of interest, the system asks Jim to input the landmark that may help the identification. In this case, Jim informs the system that the place he wants to visit is near to the Cheap Hotel and Gage Restaurant. Both of these two objects are included in the layer of landmark. Then, the system starts to generate a map that shows the place of these landmarks in order for Jim to identify the attraction (Figure 4-5). The system knows the current map is for identification of the attraction, so the layer of attraction is added to the map. Then, according to the rules for selecting layers, the system obtains the pre-conditional knowledge of landmark to support the current domain action, so it adds the layer of identified landmark to the map.
Step 9: [Jim]: “Only one tower is near to the Gage Restaurant. I should try that Tower.”

Step 10: [System]: “How will you go to the tower?”

Figure 4-5: Adaptive mobile visualization for selecting the restaurant
After obtaining the landmark that may be helpful for current action, a map is shown to let Jim identify the attraction. By observing the map, Jim finds that only one attraction is near to both the landmarks, so he regards that place as the attraction to visit. The identification of the tower is finished when Jim picks up that place and then the system believes that the action of identification of the attraction is finished. Then, the system continues the action of visit an attraction by moving its focus to the action identify a route. To do this, a recipe for route selection is selected: the system needs to know the transportation mode of Jim and then generates a map for selecting a route. To identify the transportation mode Jim would take, a route map is displayed on the map (Figure 4-6). The routes layers are added to the map because the system obtains the pre-conditional knowledge “Types of transportation”. According to this parameter, the layer of bus route and the layer of sidewalk are added to the map. Coupled with the layer of bus route, the layer of bus station is also added to the map.
Step 11: [Jim]: “I will take the bus.”

Step 12: [System]: “Please identify the bus route.”

Based on the understanding of possible transportations, Jim informs the system that he would like to take a bus to the attraction and believes the system can help him to show the bus routes. Therefore, the layer of bus route is selected according to the pre-conditional knowledge “Transportation mode” provided by Jim.
Step 13: [Jim]: “I will take the bus on W Lake St.”

Step 14: [System]: “Ok.”

By observing the map, the Jim decides to take the bus on W Lake St because the bus station of this line is near to his current location. By receiving the identification of this bus route, the system believes that the current action of selecting a route is finished.
**Step 15:** [Jim]: “I want to have lunch now, after that I may go to a museum”.

**Step 16:** [System]: “Which types of food do you prefer.”

After visiting the attraction, Jim plans to have a lunch and then go to a museum. On detecting the user input, the system generates two sequential actions by changing the potential intention of *have a lunch* and *visit a museum* to real intentions. Because Jim declares that he wants to have a lunch first, the system moves the focus of the activity to the action have a lunch and starts to elaborate this intention in PlanGraph. A recipe for this action is selected, following which the system helps Jim identify the restaurant. According to the selected recipe, the system needs to know the food type Jim is interested in. Then, a map is generated for Jim to select the food type (Figure 4-8). The layers of different food types are displayed on the map because the system obtains the pre-conditional knowledge “Types of food” for generating the map.
Step 17: [Jim]: “Seafood.”

Step 18: [System]: “Please identify the seafood restaurant.”

Based on the generated map, Jim decides to have seafood for lunch. Based on the identified food type, the system shows a map for Jim to identify a seafood restaurant. The layer of seafood is added to the map according to the identified food type. Except for the layer of seafood restaurant, because the system traces back the whole PlanGraph and finds the subsequent action “Visit a museum”, the layer of museum is added to the map based on the assumption that the locations of museums may be useful for selection of restaurant, because Jim will visit a museum after the lunch. In this case, the layer of museum does really help for the identification of the seafood restaurant because Jim would like to go to a restaurant near a museum.

Figure 4-8: The default map for identifying a food type
Step 19: [Jim]: “I would like to select the restaurant near a museum.”

Step 20: [System]: “Please identify the transportation mode?”

Supported by the generated map, Jim selects the restaurant near a museum. Then, the system starts to identify the route heading to the destination. In order to do that, the system needs information about the transportation mode Jim would take. The same as before, to identify the
transportation Jim would take, the layers of two types of routes are displayed on the map according to the pre-conditional knowledge “Types of transportation”.

Figure 4-10: An adaptive map to identify the transportation mode

Step 21: [Jim]: “Seems the place is near; I would like to walk there.”
Step 22: [System]: “Please select a route”

By observing the map, Jim thinks that the restaurant is near to the current location, so he decides to walk there. Then the system generates a map for Jim to select a route. The layer of sidewalk is added to the map because of the identified transportation mode.

Figure 4-11: An adaptive mobile visualization for selecting a sidewalk
With the support of the adaptive map representation, Jim identifies the route and finishes the lunch. Then, the system believes in the accomplishment of the action “have a lunch” and moves to the following action: visit a museum. Because Jim selects the restaurant near to the museum, he identifies that museum and then a map will be generated to show the route for heading to the museum. At the end, when the system is informed that the action of “visit a museum” is finished, the whole activity is done.

4.3 Summarization of the scenario

Through this scenario, several characters of our approach of adaptive geovisualization can be revealed:

1) *The process of geovisualization is motivated by the intention of user.* During the touring scenario, each step of geovisualization is triggered by Jim’s intention. By being aware of Jim’s intention, the system can updates the understanding of the activity on time and provide information and services that are consistent with the ongoing activity.

2) *By maintaining the whole structure of an activity, the geovisualization is coherent with the target of the whole activity.* During the tour, Jim informs the system that he wants to go for a lunch and then visit a museum. When the system generates a supportive map for the action “have a lunch”, the influence of the subsequent action “visit a museum” is considered. By assuming the location of the museum may exert effect on identifying a place for food, the layer of museum is added to the map. In this case, this assumption really helps as Jim picks up the seafood restaurant close to a museum.
Chapter 5

Conclusion

This thesis describes a method of designing the adaptive mobile GIS system, which enables the process of geovisualization to be consistent with the ongoing activity. In this chapter, I make a summarization of this study and introduce some areas for further research.

5.1 Research Summary

Context awareness is a main approach for a system to be adaptive. In this study, I investigate the mobile context adaptation for mobile activities, claiming the necessity of human intention in motivating the context capturing, that is, the context should be captured and modeled according to the current user intention.

With understanding the significance of user intention, this study presents an activity-oriented context model from a mental state view, which is developed based on Activity theory and SharedPlan theory. This context model aims to describe the collaborative process of the activities between the user and the adaptive system. As it borrows the hierarchical structure to represent an activity, it is capable of dynamically tracking the whole activity and maintaining the up-to-date context awareness to the activity.

Based on this context model, the adaptive method of selection of layers is developed. In this study, different levels of rules are designed to utilize the captured context for selecting layers. The action-level rules is defined to obtain the requirement of geographical content to support the
current action, and the activity-level rule is for the whole activity. With this method of adaptation, the map content can be consistent with the whole activity rather than merely the single action, hence can support the accomplishment of the whole activity.

5.2 Research Contribution

The main contribution of this study is to introduce an activity-oriented context modeling mechanism for adaptive mobile geovisualization. This contribution is obtained based on several enhancements to existing studies.

1) The utilization of the user intention for mobile context adaptation. This study emphasizes the significance of human intention in the process of an activity. It advocates that the system should track the user intention in order to better understand the user requirement of information.

2) Moving the focus of adaptation from action to activity. This study considers activity as the unit of adaptation rather than single actions. By revealing the truth that an action can be always connected and effected by other actions, this activity-oriented adaptation can be better support mobile activities as a whole.

3) A PlanGraph–based mechanism for adaptive geovisualization. In current systems, context factors are always analyzed and utilized separately. However, this study captures and reasons context in a combined manner. By adopting the PlanGraph-based context modeling mechanism, the context factors related to the activity can be analyzed as a whole, which enables the process of geovisualization to be more tailored to the activity.
5.3 Future Study and Discussion

This study is assumed to have promising usefulness for mobile applications, but there are still some challenges for further research. The main challenge is the design of the knowledge base. Especially, because of the very diversified contextual surroundings related to mobile applications, the design of recipe is hard. It is ideal if there is some existing summarized knowledge to handle this problem. However, as a relative new research domain, this work still need to be further investigated.

5.4 Conclusion

This thesis explored the potential of adopting Activity and SharedPlan theory to develop an activity-based context model to support adaptive geovisualization for mobile activities. This method allows the adaptive geovisualization consistent with the target of the whole activity and dynamically adaptive to the activity.
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