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SUPPORTING PLACE SENSEMAKING WITH MULTIDIMENSIONAL INFORMATION REPRESENTATION ON MOBILE DEVICES

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ABSTRACT

Knowing the living environments is an intrinsic part of human development for building self-confidence and meeting social requirements. Proliferation of mobile devices has greatly changed our interaction with the physical environments. The problem for existing mobile navigation tools is that it only emphasizes the spatial factor by offering step-by-step route directions, not helps us better understand the place. Such approach is inadequate in situations like moving to a new city where people need to build comprehensive awareness, rather than a one-shot solution to the problem. In this research, I propose a view to see navigation as a sensemaking process. I coined the term "*place sensemaking*" to refer to the process of maintaining awareness and building comprehensive knowledge of the environment. Specifically, this work represents my effort in representing information that could transform our understanding of a physical *space* into a vivid *place* by taking advantage of mobile technology and online resources.

To interrogate this topic, this work practiced a holistic set of research methods:

First, I applied works in sensemaking from information science in the context of physical navigation and proposed a place sensemaking framework. Based on the existing literature and my empirical work on spatial information representation, I have developed a theoretical framework that identifies the core components in making sense of a place, such as a person's ongoing spatial task, internal spatial mental model, and external environmental information, and emphasizes the role of interactive information visualization and exploration in mediating the relationships among the above components.

Second, based on this framework and empirical users' requirement analysis, I proposed design goals to support place sensemaking by providing not only spatial information, but also the social and temporal aspects of the place.

Third, targeting the design goals, I designed and implemented a mobile application on the Android platform to facilitate place sensemaking by integrating multiple online resources, such as Facebook, Foursquare, Panoramio, and Wikipedia.

Finally, results from a field evaluation with 18 participants in several weeks showed the benefits of our approach in support of comprehensive space exploration and elevation from *space*, a concept that focuses more on the objective and geographical properties of a physical environment, to *place*, a notion that embodies the physical features, individual spatial sense, and social aspects of the environment.

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Chapter 1

Introduction

Knowing the living environments is a basic survival skill for human beings. Being physically and cognitively capable of reaching a desired location is a fundamental source of confidence for living creatures. Mobility is an intrinsic part of human development and is essential to modern life. Finding our way around or being able to navigate our physical environment is necessary for an easy life. However, modern civilization has complicated our ability to navigate by building complex architectures and city plans. In comparison, our innate wayfinding ability has not evolved much (Morville, 2005; Silverman et al., 2000). More than 30 years ago, Passini suggested that navigation is a spatial problem (Passini, 1977); nowadays, this problem has become increasingly difficult.

Besides spatial features, as our travel range expands from small towns to the whole world, quickly adapting to a new environment and knowing non-spatial features of the place is no longer an unreasonable demand. The notion of *Place* differs from *Space* for its recognizable social meanings in the course of interaction (Dourish, 2006; Harrison & Dourish, 1996). The intimate relationships between people and their physical environment make each place unique. In addition to the geographic characteristics of a space, social, cultural, economic, and political activity create a dynamic sense of place that evolves over time.

Various external navigational aids have been developed to support us to know the space, including maps, signage, and other digital aids. Traditional paper maps are the most familiar navigation artifacts created and have been in use for thousands of years. With the development of personal computing, networking, and Geographic Information Systems (GIS), digital maps enable map-readers more interactive actions than paper maps. Features such as zoom, pan, and dynamic queries, provide an efficient and convenient user experience. Online digital map products, such as Google Maps, Yahoo Maps, and MapQuest, are widely used. Maps on mobile devices enabled with positioning technology cater to the requirement of mobility and become an inevitable trend of permeation today as personal computers were ten years ago. It is reported that 33.9 million units sold in 2007 and now 10% of US drivers and 20% of European drivers own a navigation device (Sterling, 2008). While maps, in general, provide the symbolic representation of the environment with spatial context, how to connect such abstract symbols to the real world objects is still a challenge for many people (Streeter, Vitello, & Wonsiewicz, 1985).

Though mobile guidance enabled by Global Position System (GPS) claims to ultimately solve the wayfinding problem and emancipate people from “engagement of the environment” (Leshed, Velden, Rieger, Kot, & Sengers, 2008), detrimental effects of such electronic mediation on our sense of place have been observed. GPS devices removed much of the cognitive effort required to travel between two locations. With that, they also removed much of the enjoyment and fulfillment experienced by many who interacted with maps and the route to learn their way from point A to Point B. By following the step-by-step direction on the small screen of the device, an active explorer is actually degenerated into a passive follower. The problem created through such cognitive easiness is the “mindless of the environment” (Parush, Ahuvia, & Erev, 2007). We become detached from and unappreciative of our physical environment (Kupfer, 2007; Relph, 1976). Empirical research suggested that the slavery of automatic tools could results in degeneration in acquisition of spatial knowledge (Parush et al., 2007). In extreme situations, such habitually mental un-readiness may even cause safety concerns. In situations where GPS devices are out of access, malfunction, or simply give wrong directions, people may not be well prepared to react to unexpected environmental conditions and find alternative action plans.

Rather than view the electronic mediation as monster, I see the mobile devices providing an opportunity that can help us better explore the environment through its variety of sensors, computation power, and connection to other information resources. Thus, this dissertation work represents my effort in using current mobile technology to support making sense of a place by providing information from social, temporal, and spatial channels.

Challenges and opportunities

Sensemaking, a concept first proposed in 1980s (Dervin, 1983), was re-proposed and has become a serious field of study (Klein, Moon, & Hoffman, 2006; P Pirolli & Card, 2005; Russell, Stefik, Pirolli, & Card, 1993; Weick, 1995) triggered by an information explosion: we need to find meaning of the world as quickly as possible regardless of the increasing data volume. The challenge is the same for modern navigation. Several models have been proposed to capture sensemaking processes at both the individual and organizational level (Russell et al., 1993; Weick, 1995). Though varying in details, most of these models agree that sensemaking is an iteratively engaging process that tries to bridge the gap between observed information and structured concepts (e.g. encoding data with schema, instantiating structure) to form a coherent understanding. In such iterations, computational tools that provide proper external representations are believed to facilitate sensemaking processes by reducing transaction memory, influencing the level of participation, providing manageable artifacts, and helping pattern recognition, which is highly desired currently (Faisal, Attfield, & Blandford, 2009; Klein, Phillips, Rall, & Peluso, 2006).

Despite physical navigation as a direct metaphor for making sense out of massive information, few researchers approach navigation from the perspective of sensemaking and rarely have designs been implemented from this aspect. Analysis of previous work in sensemaking and navigation design indicates three major challenges where this work can contribute:

- Theoretically, no proper model exists for sensemaking in the context of physical navigation. Sensemaking, as a concept or a set of theory, still lacks a widely accepted definition, which blurs its application boundary. Klein wrote two papers on what is not sensemaking (Klein, 2006) and what is sensemaking according to him (Klein, Moon, et al., 2006). Though currently, there are several models and many research groups are working on this huge umbrella, they are either too broad or focusing on text-based information analysis. Applying sensemaking into physical navigation (referred as *Place Sensemaking*) is a novel attempt to extend the sensemaking application area.

- Practically, when it comes to design, though various mobile applications are available on the market, not a single application aims to provide direct support for place sensemaking. Similarly, vast information resources exist online, but there is little information that indicates what kinds of resources are useful to help people understand the place. Balancing cognitive cost and spatial awareness of the physical environment in mobile design is believed to be a notorious problem as it will not help building spatial awareness if just providing turn-by-turn directions like GPS and the users will not use the mobile guidance if it is difficult to use or ineffective (Forbes, 2006; Parush et al., 2007). Can sensemaking theory provide the guidance to solve such problem? If the answer is positive, then in what way? This work exemplifies the practice of this procedure by applying the derived place sensemaking theories and findings in the structured study into concrete design goals, and most importantly, materializing the design goals into a functional mobile application by integrating selective information online resources.

- Empirically, the outcome of sensemaking is difficult to evaluate, even in the traditional textual analysis domain. No explicit ending point exists in the sensemaking process. This differs from problem-solving, which could be tested by the appearance/correctness of the solution. For example, designs for a traditional navigation guide that results shorter completion time in searching tasks could indicate a better support. For sensemaking, the goal of sensemaking is not well-defined and is evolving as the sensemaking process continues. This work adopts both quantitative analysis and qualitative analysis on objective and subjective data to describe the richness (the true value) of the place sensemaking process. The functional prototype serves as a test bed, on which sets of multiple metrics are derived to validate the place sensemaking theory in practice.

Dissertation objectives and scope

The overall objective of this work is trying to answer this question:

How to support "Place Sensemaking" on mobile devices? More specifically, in the case when acquiring knowledge of a place is important (as opposed to a one-time visit), how can we use properly selected online information, such as salient entities, temporally updated information, and comments from social network sites, to help people create sense of place?

Grounded in the cognitive sciences of wayfinding, sensemaking, and human-computer interaction, this research advances our understanding of situated spatial cognition in navigation and informs the design of mobile navigational tools. This research included establishing a conceptual model, which views physical navigation in unfamiliar places for exploration purpose as a sensemaking process, and from this perspective, developing design guidelines for mobile navigation guidance. Next, a prototype that instantiates such ideas with a concrete artifact to support making “sense” of place was developed. Finally, the prototype was tested and evaluated by human subjects in the real world.

Merriam Webster’s dictionary[1] provides 12 main definitions and 23 sub-definitions for the noun “*place”*. Rather than purely linguistic (e.g. “new ones will take their place”) or spatial aspects (e.g. “all over the place”), I am interested in the geographical aspects of “place” that can be traced to ancient Greek philosophers, like Aristotle. According to Aristotle’s theory of place, the place of x is the first motionless boundary of the thing that contains x (Casey, 1993). This container view of place is too broad as everything is embodied by itself and all the thing we care about is embodied in the universe. Such a philosophical definition of place is not practical to help us understand the environment. A more methodological definition given by Casati and Varzi defines place as a region in space having an address, which could be occupied by an extensional entity (Casati & Achille C. Varzi, 1999). Relph (1976, p. 31) emphasized the experiential flavor of a place by adding the concept of “time” and the associational memory with it. Similarly, discussion of “public space” (e.g. Garcia-Ramon, Ortiz, & Prats, 2004) connects the notion of “place” with a small settlement, such as a “city”. The socio-cultural perspective of “public space” in a certain place constitutes the identity associated: placeness gives public space a coherent intelligible meaning; public space serves as a medium for producing explicit expressions of the place. As we can see here, “place” is a fundamental concept but impossible to give any straightforward definition of it. To constrain the focus of our study, I adopt the definition from the Merriam-Webster dictionary, item 3a: “a particular region, center of population, or location, e.g. a nice place to visit” as my definition of the place.

[1] www.m-w.com

The focus of this research is on investigating proper information representations with limited display estate in a dynamic mobile context. The scenarios of interests here are those that require navigating an unfamiliar physical environment and a rich and quick understanding of place. This research is not concerned with one-time visits to a place when physical guidance is enough. The activity of interest in this work, physical navigation, is not whether or not arriving at a named place successfully, but the exploring process. Thus, we care more about how people differentiate information from the surrounding environment to make sense of the place during an active exploration, rather than the result of physical movement. By physical navigation, I refer to the cognitive process that people rely on to develop specific actions plans suitable to move through a given environment. Usually, wayfinding refers to finding a named place from origin, while navigation has a broader meaning, which is the case in this work. Though most of the time, these two terms can be used interchangeably (Golledge, 1999; Montello, 2005). During navigation, both internal factors, such as cognitive capabilities and acquired knowledge, and external factors, such as spatial layout of environment, semantic relationships between objects (e.g., street naming schema) and navigational aids, are important to the learning process. Emphasis of this work is on the support of building navigational knowledge by offering interpretive and non-intrusive information on mobile devices.

Dissertation structure

The remainder of the thesis is structured as follows: Chapter 2 reviews related theoretical works in sensemaking and physical navigation. Chapter 3 establishes the validity of navigation as a sensemaking process by connecting the key concepts in traditional sensemaking theory to the navigation process. Chapter 4 derives the design goals based on current technical solutions and our user requirement analysis, which identifies the gap and reveals possible opportunities for a new generation design. Chapter 5 describes the iterative process of technical implementation and user interface design of a mobile application, Proximity Explorer, which is used to materialize the design goals. Chapter 6 reports the field evaluation of the mobile application practice, which provides empirical studies to elaborate the framework. Finally, Chapter 7 concludes the dissertation work and points out future directions.

Chapter 2

Theoretical Foundation

Understanding theories and empirical results from related fields may provide top-down guidance for designing mobile navigation systems. This chapter will review current theoretical research in sensemaking and navigation (the information aspect), and try to find connections between these two separate domains. Popular models and concepts in sensemaking will be compared for their assumptions, coverage, and application fields. Empirical studies of navigation in various contexts, such as virtual and real environments, indoor or outdoor, familiar or unfamiliar, and naïve search or return travel, provide conceptual models of how human beings perform the tasks and thus give direct references for designs.

Sensemaking theories and models

Sensemaking was first raised by Dervin in 1983 (Dervin, 1983). According to her, sensemaking is how people make sense of their worlds by bridging the knowledge gap so that people can approach progress in time and space (Dervin, 1998). To her, it is an approach, or methodology. This definition is broad in the sense that everything in our personal experience and interaction to the external environment is treated as sensemaking. However, such a definition is too general to provide manipulable components that could assist in concrete analysis or relevance to design.

Later, Weick (1995) studied the phenomenon of sensemaking in the context of organization level from behavior studies. The significance of this work suggests that sensemaking not only happens on individual level, it also exists in-group activities, and researchers have called for new designs to support collaborative sensemaking because of its importance to group activities. Research has shown that group sensemaking often involves a team of people who analyze, share, and synthesize relevant information (Robinson, 2008; Schafer, Carroll, Haynes, & Abrams, 2008). Paul and Reddy (2008) argued the need for flexible representation switching tools to address the gaps in sensemaking between individuals and groups. Qu and Hansen (2008) suggested that shared representations among group members are important to collaborative sensemaking. For the interest of this work, I will take the perspective that collaborative information sharing is an important aspect in group sensemaking and not further investigate the sensemaking work between different individuals.

In addition to this methodological and behavior perspective, some groups define sensemaking from a cognitive perspective, which is my interest here. PARC researchers defined sensemaking as “the process by which individuals (or organizations) create an understanding so that they can act in a principled and informed manner.” Such a task-oriented definition was also suggested by Klein, who defined sensemaking as “a motivated, continuous effort to understand connections (which can be among people, places, and events) in order to anticipate their trajectories and act effectively” (Klein, Moon, et al., 2006). An early paper by Russell et al. (1993) studies how people learn new laser printers and defines sensemaking as a process of searching for presentation and encoding data in that representation with the aim to question answering.

However, in contrast to Dervin’s general embracement, most of these studies constrain the scope of sensemaking studies only within the documentation analysis domain (Bodnar, 2005; Qu & Furnas, 2005; Russell et al., 1993) and thus their understanding of sensemaking is strictly constrained with these settings. For example, PARC’s understanding of sensemaking tasks “often involve searching for documents that are relevant for a purpose and then extracting and reformulating information so that it can be used."[1] Qu and Furnas studied a topic comprehensive task where participants were asked to collect information for preparing a talk on certain topics (2005). "Topic comprehensive tasks" are a dominant type of sensemaking scenario in lab studies. In these studies, either participants are asked to study massive amounts of information, given beforehand or the participants are asked to self-collect information to learn about an event or a fixed topic. The participants are then either interviewed or asked to develop a description of the learning results without a specified format. In these tasks, the topic should be clearly stated and the sensemaking equals information seeking, filtering, categorizing, comparing, synthesizing, etc.

These definitions of sensemaking vary in scope and perspectives, which raised a widely discussed question of what is sensemaking and what is not sensemaking, e.g. (Klein, 2006; Klein, Moon, et al., 2006). When sensemaking happened? Some researchers suggest that unexpectation triggers sensemaking, e.g. sensemaking is "the process by which people develop their understanding in the face of surprise information" (Klein, 2007); or, when there is a gap of knowledge, people will begin to learn to bridge the gap, while others believe people encounter sensemaking tasks everyday (Zhang, Soergel, Klavans, & Oard, 2008). No taxonomy exists for sensemaking tasks to indicate when and where sensemaking takes place. For example, as indicated above, most of current sensemaking research investigated tasks that could be measured using textual analysis. None of them systematically studied sensemaking during physical navigation. Thus, there is a need to propose a working definition that could include other application areas and my work will contribute to extend sensemaking studies to a new area: physical navigation.

[1] http://www2.parc.com/istl/groups/hdi/sensemaking/glossary.htm

Sensemaking: A two-way loop

Before proposing my working definition for sensemaking, I will review existing models. For the interest of this study, I will only review sensemaking models raised from cognitive perspectives.

Two kinds of conventional sensemaking models have been proposed: top-down and bottom-up. Russell et al.(Russell et al., 1993) generalized the structure of sensemaking as an evolutionary process of building (if the observation fits), or modifying (if there are many 'residues') a schema and encoding the current observation into that schema. It is a process of developing representations (schema) to organize information seeking behavior (encoding). This top-down approach is guided by previous knowledge (such as a schema). The work is one of the fundamental theoretical works in sensemaking for two reasons: it identified key subprocesses in creating representations for a given task and it suggested that finding the proper representations, both externally and internally, is critical for the success of sensemaking. In contrast, bottom-up approaches de-emphasize the role of a priori representations in guiding sensemaking, and adopt a "from data to wisdom" method focused on information exploration and inductive construction of knowledge schemata (Ackoff, 1989). The strength of bottom-up approaches is in the possibility of new insights and discoveries of structures and relationships in data.

However, single direction, either deductive top-down or inductive bottom-up, will not work in most practical sensemaking processes. With the overwhelming increase of information, most of the time, we search and learn only because we have a clearly defined goal in mind and need to find related information for solutions. In such situation, the intermediation between action and understanding process happens. For example, when nurses take care of patients, they label them according to their knowledge but also confirm their judgment with recursive observation and reflective thinking (Teekman, 2000).

More recently developed models argue that neither pure top-down nor bottom-up approaches are capable of describing the dynamics in sensemaking. For example, it has been suggested that sensemaking is not a one-way process that encodes information pieces into existing schemas, but rather a tightly integrated process between searching and structuring (Qu & Furnas, 2005; Qu & Hansen, 2008). Thus, some hybrid approaches were proposed. Researchers at PARC (e.g. Pirolli & Card, 2005) presented a Think Loop Model for analytical process that involves massive data in intelligence communities. The top-down approach starts with "why" that a "sensemaker" tries to establish a reasoning logics by searching evidences to either support or reject presumable hypothesis; the bottom-up approach starts with "how" when the sensemaker connects the collected data into hypothesis/theory building. According to this Thinking Loop Model, "action" and "thinking" are two ends within which sub-loops consisting collecting new data and testing hypothesis transit between different states, like external data source, shoebox, evidence, schema, theory, see **Figure 2-1**. Similarly, Klein et al. proposed a data-frame model (2006) where "frames shape and define the relevant data, and data mandate that frames change in nontrivial ways". They carried out a three-year research project studying experienced and novice Information Operation officers sensemaking behavior in given scenarios in depth with transcript coding (inferences, speculations, and explanations) and Cognitive Task Analysis method (Sieck, Klein, Peluso, Smith, & Harris-Thompson, 2004). More importantly, this model indicates that sensemaking is actually a closed-loop between mental model formation and mental simulation, which signals that the result of sensemaking is to create a mental model that can lead to problem-solving. These hybrid models address sensemaking as a process involving both finding appropriate information to suit given structures and developing structures based on available information.

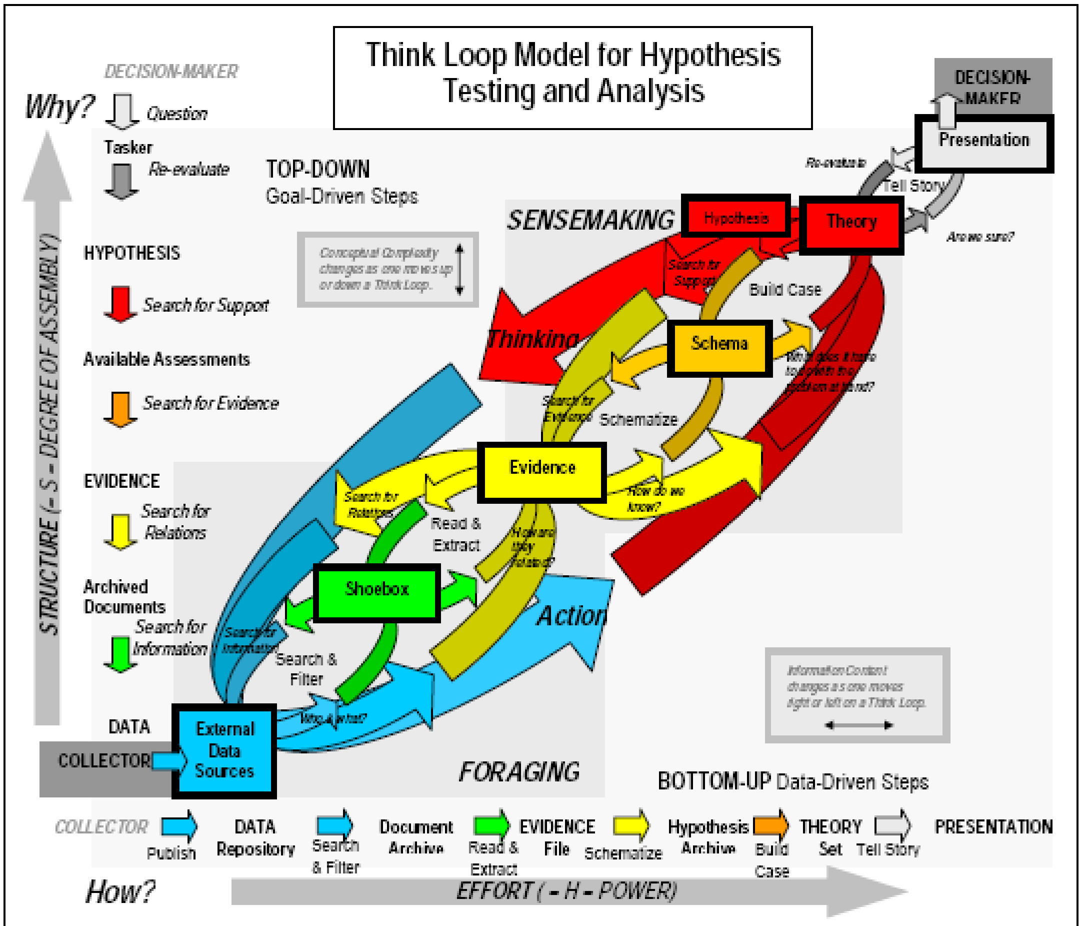


Figure 1. The Think Loop Model for the Analytical Process. In doing hypothesis testing, the analyst operates within multiple nested "think loops" that integrate a bottom-up data-driven strategy with a top-down hypothesis-driven strategy. At any point in the process, the analyst must decide whether to accumulate and collate data and evidence and assemble it into a theory or to search for new evidence in support of the hypothesis being tested.

Figure 2-1 Think-loop model (from (Bodnar, 2005))

Zhang extended sensemaking with learning theories and created a comprehensive model (Zhang & Soergel, 2009; Zhang et al., 2008). This model is a combination of Russell et al.'s (1993) and Klein et al.'s sensemaking model (2006) and adds input task/knowledge with output updated knowledge. The core of this model is the two-way hybrid iteration between structure and data, which happened after identification of gaps. Tasks and existing knowledge influences gap identification. The ultimate outcome is the updated knowledge in three forms: accretion, tuning and restructuring (Rumelhart & Norman, 1976). Accretion means gradual addition within existing schema; tuning means tailoring existing schema to fit or interpret data; restructuring means radical change of existing schema or new structure creation. Zhang also considers the update knowledge as mental model changes in front of situated new information. This model is the first attempt to consider the long-term effect, e.g. learning and knowledge, rather than only short-term cognitive activity in sensemaking.

Working definition of sensemaking

Based on existing sensemaking models, especially the extended one, I view sensemaking as **an active exploration process, influenced by existing knowledge and social background, to create a mental model of the given data by connecting fragmented information pieces that could lead to efficient action towards given tasks**. Here, I adopt the broad meaning of sensemaking which includes the whole process of searching information, interpreting and structuring information (the sensemaking loop), and finally transferring to knowledge, or an updated knowledge. This view of sensemaking contrasts with the narrow definitions of sensemaking that only includes information interpretation.

Cognitive perspective of physical navigation

Literature on navigation and wayfinding is massive. I will only cover the spatial cognition studies that focus on building cognitive maps in real world. Finding a named place, the most common task in physical navigation, is defined as problem-solving by Passini (1977) and coined it as “wayfinding”. Completing navigation task requires a person’s ability to mentally construct a representation of an environmental setting and put herself into this representation

(Passini, 1996). In one of his pioneer works, Passini (1984a), identified three stages in wayfinding:

1) spatial information gathering and processing;

2) decision making and wayfinding plan; and

3) decision executing;

In the first stage, a navigator looks around for environmental cues to serve as the starting point to make a decision, e.g. “I see a big intersection, which should lead me to the destination.” In the second stage, the navigator will make the actual traveling plan based on the spatial information collected, e.g. “I should turn right on this intersection.” In the third stage, the navigator performs the plan by either by using the real transportation tool or by interacting in the virtual world, which results in physical movement. Later researchers found that these three stages could not be clearly segregated as it was first proposed. For example, Hayes-Roth & Hayes-Roth disagreed on this order and they defined planning as “the predetermination of a course of action aimed at achieving some goal”, which is the first stage of the problem-solving process (1979). The second stage is to modify and execute the plan according to the actual situation by collecting environmental information. Montello et al. (2004) indicate the development of these three kinds of spatial knowledge is in parallel rather than in strict order. However, these three stages still serve as a helpful schema for computationally modeling human wayfinding behavior.

For the spatial information needed in the first step, it could be collected in two ways classified by the perceptive view: a) can be constructed from one standpoint; b) needs a series of views gained from different points. Spatial knowledge collected from the second view is regarded as cognitive map, a mental structure process (Passini, 1996), or an internal representation of the physical environment (Golledge, 1999). Tolman used the term “cognitive map” in 1948 (1948). This work considered to be a classic in psychology and has been cited more than 1000 times. By studying the maze behavior of rats, Tolman suggests that animals, including human, form a "tentative, cognitive-like map" of the environment by repeated acquisition. This cognitive map indicates "routes and paths and environmental relationships, which finally determines what responses." He contrasted this theory to stimulus-response connections for animals that need to build up a more comprehensive understanding of the spatial relationship. Downs and Stea formally defined the concept of cognitive mapping as "a process composed of a series of psychological transformations by which an individual acquires, codes, stores, recalls, and decodes information about the relative locations and attributes of phenomena in everyday spatial environment" imagery (1973).

The Landmark-Route-Survey (LRS) model is the classic theory to explain how to build a cognitive map. Three levels of spatial knowledge in navigation were identified (Downs & Stea, 1973; Siegel & White, 1975): a) landmark knowledge is the memory of salient objects for their particular shapes or individuals' preference; b) route knowledge (or procedural knowledge) is formed by integration of these landmarks into a path or a sensorimotor sequence as the navigator travels a route; c) survey knowledge is a spatial model of the space formed from many sequential navigational experiences or abstraction from map-learning integration. Spatial learning was also described as a process in which subjects move from an egocentric (referring to the body) to a fixed (referring to fixed external landmarks) and then to an abstract or exocentric (referring to the space coordinates) reference. Then another commonly used way of distinguish spatial knowledge is: a) sequential egocentric knowledge gained by a first-person view movement; b) survey knowledge structured by repetition and coordination. Lloyd et al. distinguished these two representations as internal perspective and external perspective with the respect of reference point (Lloyd, Cammack, & Holliday, 1995).

A landmark is a salient object that is used as a reference to help people memorize and recognize routes, and locate themselves in terms of their ultimate destination (Sorrows & Hirtle, 1999). Landmarks function as anchor points in an arbitrary path. Traditional definitions of landmarks usually refer to an individual salient building that is in contrast to its background. According to different perspective of this saliency, Sorrows and Hirtle proposed three kinds of landmarks: visual, cognitive, or structural landmark (1999). The visual salient landmarks often draw navigators' attention by its staring shape, color, or height, such as a big building with flashing billboard; the cognitive salient landmarks often have important or unusual function that makes it stand out from the environment, such as the city hall in a small town; the structural landmarks have a critical role or location in the structure of the environment, such as a big intersection of two main roads. Landmark saliency of a feature is a relative property, which does not depend on its individual attributes but on the distinction from attributes of close features (Raubal & Winter, 2002a). For a certain object, the more it possesses these characteristics, the more it qualifies as a landmark. Another classification based on the location of a landmark includes choice point landmarks (at the decision points), potential choice point landmarks (at traversing intersections), on-route landmarks, and off-route landmarks (distant but visible from the route). A more general definition for landmarks does not necessarily require landmarks to be only dot-like entities. Hansen et al. (2006) incorporate point, linear, and areal entities that stick out of from the background as landmarks as long as they serve to organize spatial knowledge for understanding or planning routes in the environments.

To facilitate constructing cognitive map, structural repetition should be avoid and identifiable principle for three dimensional cues is needed (Passini, 1996). Landmarks serve as navigational tools and helps concept organization in wayfinding (Montello, Lovelace, Golledge, & Self, 1999). It is necessary to include landmarks into the design of navigation supports to enforce the function of landmarks. There are already calls and implementation of adding landmarks into current route directions. For example, Vinson (Vinson, 1999) pointed out that landmarks should be kept visible at all scales when he proposed guidelines for using landmarks to support wayfinding in virtual environments (VEs). Similarly, Steck and Mallot (2000) emphasized that both global and local landmarks can facilitate the decision making process in wayfinding in VEs. Raubal and Winter (2002a) addressed the problem of only providing single instructions at each decision point by supplementing the instructions with local landmarks. They conducted a case study in Vienna, Austria where they automatically extracted local landmarks from a database based on the measures of landmark saliency: visual, semantic, and structural attraction. The instruction was given by describing the appearance of a local landmark which has a highest value calculated by above parameters. However, this paper only addressed how landmarks were useful but did not point out why single direction instruction is ineffective.

According to the LRS model, more conscious direct navigation experience leads to more survey knowledge while less experience leads to route knowledge (Golledge, 1999). In fact, survey knowledge can be obtained by both direct navigation experience and indirect learning phases (Thorndyke & Hayes-Roth, 1982). However, repeated exposure to the actual environment (repeated route knowledge) will result in more accurate and finer survey knowledge than learning from maps (Thorndyke & Hayes-Roth, 1982). The process of creating a cognitive map directly from route knowledge is called environmental mapping, while the process of creating a cognitive map from maps is called survey mapping (Lobben, 2004). For a one-time experiment with limited time, the results of two processes depend on specific tasks for the measurement. Generally, map learning can produce better performance in tasks such as direction pointing and map drawing in a short time, while direct navigation experience results better in orienting to unseen targets, route distance estimation, and route description (Ruddle, Payne, & Jones, 1997; Thorndyke & Hayes-Roth, 1982).

Another distinction related to route knowledge and survey knowledge are two types of structures in visual cognition: perspective structure and invariant structure (Gibson, 1986). These two structures were derived from theories of wayfinding with visions. Perspective structure was interpreted as “the constant patterns in the changing mosaic of the solid visual angles produced by body movement” (Sholl, 1999), or the perceived person-to-object relationship from an ego-centric perspective. Invariant structure was information about environmental objects of which the relationships do not change as the navigator moves, or the object-to-object relationship from exo-centric perspective (Sholl, 1999). Exploration is a process to gain information about perspective structure, while a good understanding of the space requires the invariant structure as well. Changing from knowledge of perspective structure to invariant structure is challenging. Computational tools that support such transition could be helpful (e.g. coordination transformation).

Maps, in either paper or digital formats, are designed from the viewpoint outside the world, the exo-centric perspective. Cognitive mapping from maps only will get object-to-object relationship. However, when traveling in the 3D environment, a navigator usually needs to execute the spatial decision by using the body as reference, such as “go forwards/backwards,” “turn right/lef.t” Static map reading requires a considerable cognitive effort. This expenditure in effort may be inefficient when compared to some well-designed verbal instructions (Streeter et al., 1985). A dominant causation for such inefficiency is the translation from exocentric reference in the map to egocentric reference of wayfinding action. Most verbal direction is given from the individuals’ view point, such as “turn left/right, go straight”, which shares the same referential point as wayfinding activities and thus provides more direct affordance for completing a given wayfinding task. In contrast, the translation from an external world to an internal ego asks for an extra workload on spatial transformation besides the main wayfinding tasks and results in less efficiency in map use. To reduce this effect, mobile navigation systems usually allow users to orientate the map-up with the approaching direction either manually or automatically (Arhippainen, Rantakokko, & Tahti, 2005).

Chapter 3

Place Sensemaking: A Theoretical Framework

With the help of regular GPS systems, navigating to a destination is nothing more than reaching a goal, which is normally solvable. Another value of reaching a goal as a process of problem solving is to enhance the learning experience even though the problem is not efficiently solved. Many theories and studies on navigation focus on the goal-reaching perspective of spatial problem solving as indicated above, but the contribution of the navigation process to knowledge accumulation is under-investigated. Sensemaking is an essential part of the learning process. The result of sensemaking, as defined above, is to create a mental model that can direct people's behavior. In this chapter, I define *Place Sensemaking* by applying the sensemaking theory into physical navigation and propose a framework that identifies the core components.

Physical navigation as metaphor for sensemaking

Physical navigation is a direct metaphor for making sense out of massive information. For example, Dervin uses a central metaphor of sensemaking as "human beings traveling through time-space, coming out of situations with history and partial instruction, arriving at new situations, facing gaps, building bridges across those gaps, evaluating outcomes and moving on" (Dervin, 1998, p.p. 39). A similar metaphor is the "berrypicking" in information searching. Bates describes users' evolve-search behavior as picking berries on the bush (1989). According to her observation of how people search online information, end users begin with one relevant reference and move through various sources. New information pieces will change the ideas and direction for the next step in the query (reframing process). Thus, the search result is a collection of individual useful references identified at each stage, rather than a final retrieval dataset. The activity is typical sensemaking with iterative, a-bit-at-time nature. Picking berries scattered on the bushes as finding place of interest in different places is a typical tourist activity as well.

Information foraging theory is another example using physical navigation to help explain human's information seeking behavior as following a promising path. Not all spatial information is equally useful. Pirolli and Card (1995) proposed information foraging theory for information seeking based on anthropologists' optimal foraging theory, which was developed to understand animals' behavior of food seeking in the environments. This theory shows that foragers use similar strategies to seek abstract information (such as online websites) as real food: allocating their attention to the resources based on the perspective value of "cues." These cues are "information scents" that foragers used for "diet selection" and "patch selection" by analyzing them on a balance of cost-benefit. An assumption of cost-benefit is that people tend to stay at a place until they consume all the supplies before moving to another place. This theory is used to evaluate tools that are designed to facilitate information collections. For example, does the interface provide enough "nutrition" and present it in an obvious manner, or satisfied the user's immediate needs?

Navigation: a form of sensemaking process

This section will compare the core concepts defined in traditional sensemaking studies (e.g. document analysis) with navigation practice. The following analysis highlights the direct mapping relationships.

First, like typical sensemaking activities, navigation is a process of mentally conceptualizing related information into imagery representations. Some previous researchers already indicated that the result of sensemaking is a mental model (J. R. Anderson, 1996; Gentner

& Stevens, 1983). The mental model is an imagery representation of linked concepts, like pictures that share the same structure of the objects represented, but in a symbolic manner. A cognitive map is an abstract, or symbolic, representation of the surrounding environment. Lynch (1960) used "cognitive maps" to explain how inhabitants interpret the environment with his pioneering work on imageability. Cognitive maps characterize the way people create mental pictures, which consist of spatial primitives (paths, edges, districts, nodes, and landmarks). Navigators improve their cognitive maps with more accuracy and completeness as they gain more knowledge of the environment. Downs and Stea (1973, p.9) defined such cognitive mapping as "a process composed of a series of psychological transformations by which an individual acquires, stores, recalls, and decodes information about the relative locations and attributes of the phenomena in his every day spatial environment." Levine et al. (1982) suggested that the cognitive mapping process places a mental copy of sequentially experienced landmarks and preserves the metric information of the landmarks in relations to each other. According to Johnson-Laird (1983), a mental model works through manipulating internal representation as symbols to understand external reality. The reasoning process is the derivation or inference based on currently available information (mapped as internal symbols), or retranslation of new information (e.g. confirmation). Such internal representations is intrigued by visual imagery (vision, diagram) or propositional representation (verbal, discourse) and formulized by reasoning. Thus, his idea of a mental model has same structure of the modeling objects or processes. In the case of physical navigation, the mental representation of the place, or cognitive map, is shaped by the environment itself (Tolman, 1948). Another similarity between a mental model and a cognitive map is their power for prediction. Mental models differ from mental simulation in that whether a good model is necessary for a good prediction. A representationally accurate mental model of the objects/processes (Norman, 1983) could predict better for the subsequent behavior, but both Johnson-Laird and Norman agree that an incomplete, or an inaccurate mental model can produce a correct outcome as long as the user has empirical experience. In navigation, having complete survey knowledge of the environment improves navigational behavior, but simply being there is good enough for giving directions.

Second, existing models for physical navigation shows that navigators' exploration is a staged-learning process, which occurs in sensemaking activities as well. For example, the LRS model mentioned above (Downs & Stea, 1973; Siegel & White, 1975) suggests that navigators first recognize individual landmark information, as sensemakers identify discrete information pieces; then navigators learn individual routes that link landmarks along the way so that they can arrive from one location to another, which is to make a connection among data points; finally, as navigators experience multiple routes and form a network-like survey knowledge, which enables them to navigate to places they have never visited. This process is similar to forming a mental model of information for guiding future behavior.

Third, previous knowledge constrains navigation behaviors in the same ways as prior knowledge does to other sensemaking tasks. People's assumptions of meta-environmental knowledge may influence formation of their cognitive maps. Dijkink asked children to plan a city layout as they wished (Dijkink & Elbers, 1981). Some children placed farms in the center city streets and other children placed public buildings on city skirts. Children younger than 12 years old, who had less previous knowledge of what a city should looks like, could hardly have helpful presumable knowledge of what a city should look like. Navigation produces an abstract, imaginary indexing of the original, massive data, to guide future behavior. Mental representation of the environment provides a symbolic model as a reference that could lead further behavior or even help to make predications. In sensemaking, information collection and cue selection could be highly based on individual preference, or bias. The ultimate goal of sensemaking is to find some sort of frame that plausibly links the events that are being explained.

Finally, from a macro-cognitive view, the aim of navigation in most of the cases is not only to find the place, but also to be able to navigate with confidence and engage in the travelling environment, which goes along with sensemaking as a method to gap the knowledge bridge. A basic purpose of sensemaking is to reduce uncertainty and cause emotional evanescence, a native desire of human being (Wilson, Gilbert, & Centerbar, 2003). Such uncertainty aversion indicates the preference of a known risk over unknown ones. As the Ellsberg paradox suggests, people do not make choice on possibilities, as expected utility theory indicated, but just choose options with less uncertainty (e.g. bet on 30 red out of 90, rather than unknown number yellow out of 90) to maintain high robustness against variation (Yakov, 2006). Getting more information to fill the info-gap results in the satisfaction of being explainable and self-confident, this, in turn, serves the purpose of obtaining pleasure and reducing unexpected pain. For example, when an individual suddenly loses a family member, she feels depressed and deeply pained. Then, she may come to understand why and how this happened. After she learns that her beloved had severe heart disease, which eventually caused the tragedy, she is relieved and soothed because of the explanation of inevitability. People feel anxious when they are not sure where to go. Similarly, navigators make decisions with “less than perfect” strategies when they feel anxious. The option chosen, at least, has an obvious advantage compared to other alternatives from the view of the decision maker. It is reported that during emergencies, people tend to take familiar routes (the route when they come in) instead making use of marked exits designed for these situations (Canter, 1980). Another rule applied in emergency selection is “the less risky choice”. People put more weight on negative dimension of information than positive ones, which usually causes more attention in normal activities (Wright, 1974). For example, it is reported that in fires, people do not concentrating on positive aspects of options in comparison, such as the nearest path or less crowded, but the negative aspect, such as prohibition of exit, or hazards signs (Ozel, 2001). A more advanced benefit of navigation as a sensemaking process is to engage in the environment.

As the scenario presented earlier, interacting with the environment consciously and constructing a mental model of the environment is a social experience of the living environment for a valuable life journey. Benford et al. (2009) defined such a journey through places, times, roles and especially with interfaces facilitated as “trajectory”. The embedded digital media should help human become more engaged in the environment as indicated in Ingold’s arguments (2007) that it is the experience of the journey that matters more than the final destination. Such difference goes back to the difference of problem-solving and sensemaking with a distinction between the relatively clearly characterized problem spaces of the simple search-type problems and the less well understood mental representations of more abstract conceptual domains (Millward, 1983).

Definition and framework of place sensemaking

Based on the working definition of sensemaking proposed in Chapter 2, and the above justification, I view knowing a place through navigation is a valid sensemaking process and specifically, I coin a term, Place Sensemaking, and define it as **an active exploration process, influenced by existing knowledge and background, to create a mental model of the gained information about the environment by filtering, connecting, analyzing, and synthesizing fragmented information pieces**.

As defined previously, sensemaking is a two-way iteration starting from tasks and existing knowledge and ending with mental models of the information studied for the given task. A working framework derived from earlier work is proposed for analysis purpose, as shown in Figure 3-1. The cognitive processes happened in sensemaking loops are two ways: the bottom-up (inductive, data driven) approach includes information selection and cue identification, options comparison, schematization and integration, while the top-down (deductive, structure driven) approach includes fragmentation, hypothesis testing, and strategy applying. Analogy and inference sit in the middle of these two directions, which is influenced by existing frame and encountered data. Other than the sensemaking loop, task requirement interpretation, hypothesis formation, and model construction are also key components.

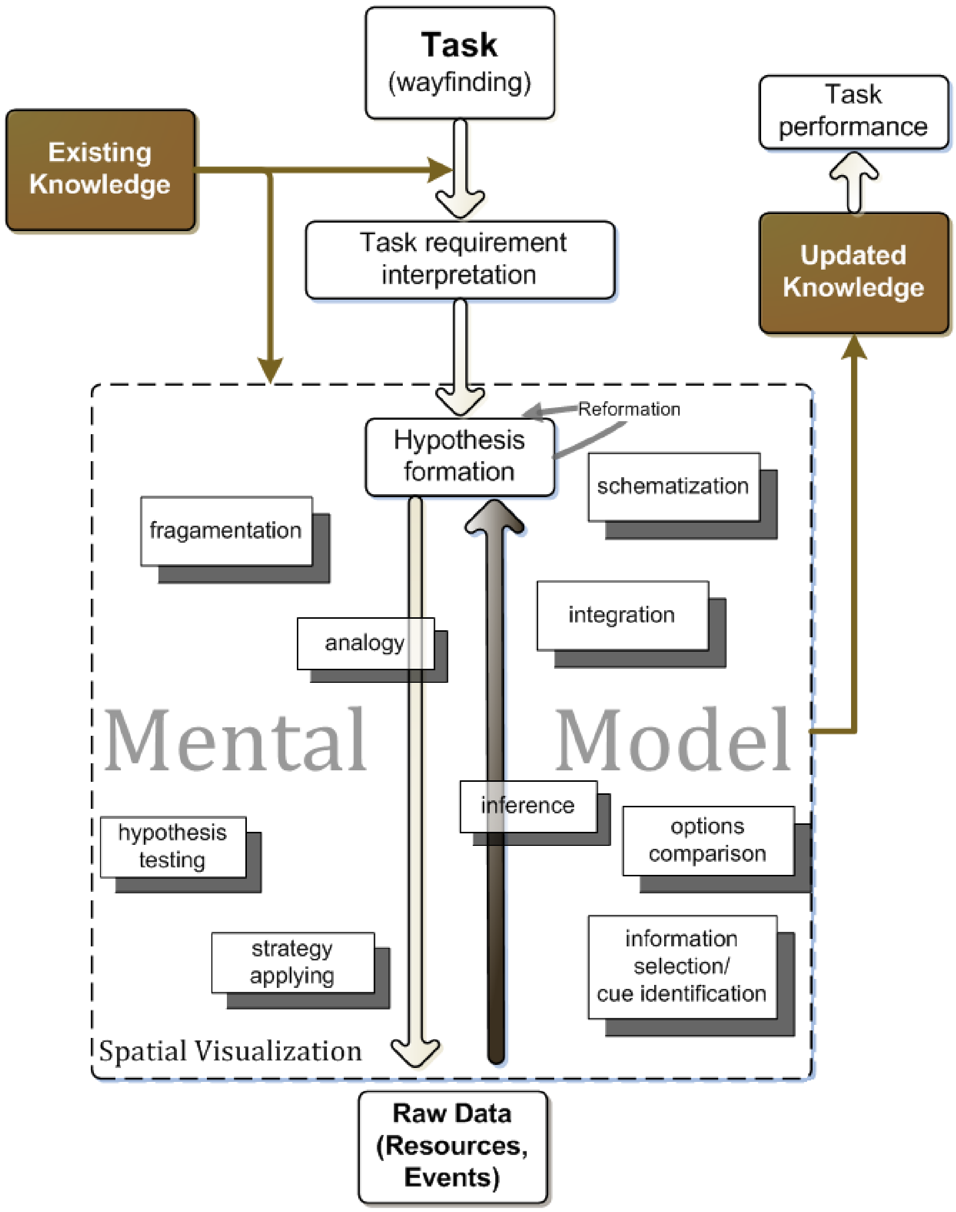


Figure 3-1 A working framework of sensemaking

The first explicit investigation of navigation as sensemaking process was done by Klein, who argued that the lost and recovery stage in navigation could be treated as sensemaking processes based on his study using semi-formal interviews (Klein, 2007). However, this investigation is constrained to the lost and recovery stage of the navigation process and is preliminary in both depth and breadth of the study design and data collection. I will analyze the similarity in this information process with respect to spatial information acquisition and internal representation by decomposing the core components as information selection and clue collection, options comparison at decision-making points, analogy and inference, fragmentation and integration, schematization, strategy applying, and hypothesis testing.

- *Information selection and cue detection:* The most obvious cues in navigation are landmarks. Reorganization of landmarks could be based on the objects' saliency. As mentioned above, objects' saliency could be in different perspectives (visual, cognitive, and structural saliency) (Sorrows & Hirtle, 1999) for different purposes. The relative property of saliency (Raubal & Winter, 2002a) holds true in common sensemaking task. For example, contrast of distinctions with close features makes the landmarks standout while reoccurrence or emphasis make important means pops out in textual sensemaking.
- *Options comparison:* An action-driven perspective of navigation could be making decisions at each decision point (Passini, 1977). Picking the right route at each intersection from other candidates is exactly the case described in information forage theory: people pick promising paths based on their judgment either from current comparison, or from previous memory. The strategy originally made by the navigator has an important impact on their later performance. Since external environmental information is overwhelming, navigators usually only select those instantly useful clues based on their perception of the task. Several wayfinding strategies have been proposed by previous studies, especially by assistance of Virtual Reality technology. Least

angle strategy is one of the commonly used strategies for route planning. According to this strategy, navigator tries to shorten the travel distance by choosing local directions that have the least deviation from the direction of the target (Homchmair & Rank, 2000). This strategy usually leads to heading straight to the destination, which will reduce a detour. However, to ensure this, one needs to have a good sense of direction while moving and to have a comparatively clear sense of the local network. For example, when finding ways within multi-level architectures, people may apply different strategies based on different situations (Hölscher et al. 2006). The central point strategy involves finding ones' way based on well-known locations within the building. The direction strategy, which is similar to the least angle strategy, is used to choose the route closest to the direction of target horizontally first. The floor strategy is to get to the right floor at which the target is located. It is found that the floor strategy is most useful in a multi-level indoor environment.

- *Analogy and inference:* People build abstract, symbolic representations to structure the data based on the analogues of familiar, existing models. Previous experience in similar places may help navigation in an unfamiliar place by providing valid assumptions of the layout of the environment. For example, major shopping centers and train stations are always presumably located in the center of the city, while airports and shopping outlets are typically located in suburban areas. Devlin (1976) found that wives of military personnel, who move frequently to similar places, were better and quicker to learn new environments.
- *Fragmentation and integration:* Fragmentation and integration are employed for efficient short-term memory in navigation, a phenomenon also seen in sensemaking. In sensemaking, fragmentation reduces the number of information

pieces to be recalled and processed at each time, while integration combines these segments after being temporally processed. Similarly, navigators also use various strategies to segment the information. “Fine to coarse” strategy suggests navigator will first segment the environment based on region and start from local judgment to make the decision (Wiener & Mallot, 2003). Contrast this with “coarse to fine” route planning that suggests that navigators generate a coarse plan using higher levels of spatial representations and before producing detailed plans for each subsequent step. Both of these two strategies support the idea that spatial knowledge is hierarchically structured and stored (Chown, Kaplan, & Kortenkamp, 1995). When Bailenson et al. (1998) found that when the origin and destination are reversed, the navigator will select a different route. To explain this, they propose a “Road climbing” principle which indicates that people plan their route to leave the region containing the origin as fast as possible. The fragmentation and integration happened subconsciously by appearance of overload and obvious/subtle connections. Detection of these signs is subjective and highly contextualized. Such idea of decomposition and synthesis occurs in route learning and route integration: navigation depends on associative links between landmarks (Kuipers, 1982).

- *Schematization:* originally, schematization is defined from information processing that involves three sub-processes: abstraction, idealization, and selection (Herskovits, 1998). Klippel (2009) defines schematization as the process of intentionally simplifying a representation beyond technical needs to achieve cognitive adequacy. During schematization, topological relationships and hinge points are the key elements reserved in connecting route knowledge or fragmented local survey knowledge into a complete image of the environment.

Finally, we should note that schematization is not a universal process; instead, it is highly contextualized (Freksa, 1999).

- *Strategy applying:* Linked landmarks (Siegel & White, 1975) and remembering continuous transformations of overlapping scenes (Cornell & Heth, 2000) are the most popular strategies to memorize the decision sequence and facilitate route learning. According to linked landmark strategy, when one landmark is visited and recognized in a cognitive map, actions towards related landmarks could be triggered because they are linked on the same route. Continuous scenes strategy suggests vivid landmarks are not necessary as long as the navigator remember the sequence or has triggerable memory by onsite interaction. Sensemaking happens in situated-context: though people can plan beforehand, they often cannot or do not plan every action in a pre-defined sequence. Instead, they improvise to local situations. Navigators need route-planning, but also response to local information, e.g. a one-way street.
- *Hypothesis testing:* iteratively testing and modifying hypothesis happens in navigation, especially for exploration purposes. When people have certain hypothesis, they will intentionally collect evidence for support or rejection. They set up expectations to see the next intersection or a landmark to confirm whether we are on the right track. Finding an expected object could be regarded as hypothesis confirmation and detecting the absence of an expected environmental feature could be considered as hypothesis violation/rejection (Spiers & Maguire, 2008). Inspecting the surrounding environment either intentionally or subconsciously as we travel through the space is a way of acquiring information and testing hypotheses. Such testing periods often start after turning into a street.

Summary

Based on the related literatures in sensemaking, spatial cognition and wayfinding behavior summarized in Chapter 2, this chapter argued that navigation could be a form of sensemaking and proposed a framework that maps the core components in classic sensemaking theories into physical navigation. On the one hand, earlier researchers have drawn empirical experience of navigating in the physical worlds to develop sensemaking theories in the abstract information world. On the other hand, both in mental conceptualization, individual's learning, and macro-cognitive perspective, making sense with documents and understanding of the physical environments have many similarities. Hence, I defined place sensemaking as **an active exploration process, influenced by existing knowledge and background, to create a mental model of the gained information about the environment by filtering, connecting, analyzing, and synthesizing fragmented information pieces**. I also proposed a framework to model how people get insight of the environment as they navigate around through a lens of sensemaking theory.

Chapter 4

Design Goals for Supporting Place Sensemaking

This chapter describes the procedure to derive design goals to support place sensemaking based on existing technical solutions and a structured study that provides understanding for developing mobile applications. I conclude that to support place sensemaking, computational tools need to provide information from social, temporal, and spatial dimensions. In each dimension, I identify the factors that need to be considered, which will be used as direct reference to identify the information resources.

Existing design solution

There are too many mobile navigation systems to be covered in a single review. I will only select those with significant influence, or unique characters that are related to or could inspire our design in supporting place sensemaking. Research and applications in context-aware mobile computing and geospatial visualization fall into this category. Mobile navigational aids have practical impact on users' daily life that not only draws attention of researchers, but also attract booming of various commercial products. Thus, available commercial technology and services related to mobile navigation will also be reviewed in this section.

Spatial information in place sensemaking

Following the primitives of cognitive maps in the environments, I will review current visual representations for landmarks, route, and surrounding information.

Visual representation for landmarks

Landmarks, as an anchor point, are an important concept in forming mental representations of the environment. Properly represented, such information could efficiently support place sensemaking in navigation. Elias et al. (2005) implemented a navigation system based on a database by “route-dependent generation of landmarks”. Two steps were implemented: detecting what objects are landmarks from a database and given a route and only extracting those landmarks on this route. However, in their implementation, whether an object is a landmark or not is predefined, which is difficult in real practice since different people may regard different objects as landmarks. Also, Elias et al.’s idea of scale-dependent visualization is just set LOD to models and links different representation of a certain model, which is also difficult for real working system because it is complex to divide scale levels.

Elias et al. (2005) also proposed the following design protocols to make landmarks more identifiable.

1. Using color to highlight the landmarks;
2. Simplifying the background objects and preserving the original shape of the landmarks;
3. Merging the background objects and separating the landmarks;
4. Reducing background and enlarging landmarks; and
5. Assigning a height to the landmark and decreasing the height of background with increasing height.

These design ideas took advantage of existing theories in visualization, such as color is the most dominant factor in visual perception for normal people. However, some of these may not be proper in practice. For example, using color to highlight the landmarks may cause confusion when users try to match the represented objects with a bright color to the real world building that is usually textured. A similar problem arises from assigning height to the landmarks, which may also present confusion if the change is not well determined.

People tend to pay attention to objects with structural coherence and distinctive appearance on the screen. By studying the dynamic processing demand for animations, Lowe (2003) used animated weather maps and asked participants to predict future meteorological patterns. Their results show that animation and static graphics share the same visuospatial characteristics. The author also classified three types of changes in animation: form changes (“transformations”), position changes (“translations”), and inclusion changes (“transitions” appearance/disappearance).

As seen, literatures suggest the design of navigation systems provide proper landmarks to help users internally conceptualize the environment. However, the relationship of salient object selection with the represented environmental features and devices’ screen size has not been well studied.

To identify what salient objects people may need and what environmental features make relevant objects stand out in different scales, I have conducted an experiment on subjective feature selection in an environmental exploration task with 42 participants. Participants marked and ranked the objects that they considered most helpful on maps of different environments with different scales. The results show that point-like landmarks (e.g., objects with distinct appearance, intersections) are the most selected spatial references in wayfinding, though degree of preference varies by map scale and environmental features. The results also show that line-like landmarks (e.g., streets with distinguishable features, buildings exhibiting linear patterns) are regarded most valuable in wayfinding tasks. These results deepen our understanding of landmark selection on small screens and provide design implications for mobile navigation systems. For the details of this study, see (Wu, Li, Klippel, & Zhang, 2012).

Visual representation for routes

Directional guidance can be given in either pictorial format, such as maps, or verbal instruction, such as GPS. By following the guidance, users want continuously to keep track of where they are and find their location on the navigation aid to use the tools as references. These two formats may produce different results in helping wayfinding performance. Researchers suggest that pictorial guidance facilitates the formation of survey knowledge better, while verbal description facilitates the formation of route knowledge (Tversky & Lee, 1999). Descriptive instruction does not work well on maps. Map readers rely on visual memory to learn and retrieve spatial information. Kullhavy et al. (1983) have compared three versions of maps: text-only, text with mimetic symbols, and text with geometric symbols, in a recall task. Their result showed that subjects performed better with text plus mimetic symbols or geometric symbols than text-only maps. In scenarios where the main task requires considerable visual occupancy, such as driving, verbal description is desirable because it does not require users to allocate limited visual attention to the guidance. Audio recordings of verbal instruction are more effective and efficient in terms of travel distance, travel time and number of navigation errors, for guiding driving in an unfamiliar environment (Streeter et al., 1985).

With the proliferation of GPS-based mobile navigation units, step-by-step directions are the most commonly used verbal description in navigation support. Such directions can largely reduce workload of drivers and efficiently help people find their way. However, over automation causes concern of taking the main actor—the human navigator “out of the control loop” (Parush et al., 2007). It deprives the decision making stage in wayfinding process. Users’ reliance and trust on the automated guidance could reduce the subjective monitoring of the system’s performance and result in poor situational awareness. If automation fails, users who lose the skills may be impossible to take over the task.

Parush et al. (2007) carried out an experiment in a virtual desktop world. The task was to find out a target in a four-story building. The experiment tested two between-subject factors: continuous/by-request position indication, with/without orientation quizzes. The position indication was on a 2D overview map with a current position mark. The orientation quiz asked the subject to indicate his current position on the 2D map. Each participant completed 16 trials in one of these four conditions. There was an extra trial without any position indicator to test the transitional effect at the end of the experiment. Excess distance, orientation quiz performance, and judgment of relative direction after the experiment were used as measurements. Results show that wayfinding performance (measured by excess distance) is consistently better in conditions where the participants' continuous position was indicated. However, the excess distance and the number of times that a participant requests their position decreases with more trials suggesting that participants acquire more spatial knowledge and need less assistance in the process. The performance in the orientation quizzes also improves as a function of wayfinding trials. The extra trial in the final confirms the hypothesis that performance degradation will happen when automation navigation disappears. With both position indication requested and orientation quiz, participants showed the highest level of acquired spatial knowledge. This paper proves the importance of direct and active experience in effective spatial knowledge acquisition and suggests two strategies to keep the users in loop: providing position indicator only by request and asking orientation occasionally.

Admittedly, it is unreasonable to add this laborious enforcement all the time for occasional navigators, but as Parush et al. (2007) suggest that it may be important for some professionals, such as taxi drivers, military personnel, pilots, search and rescue operators, etc. For them, it is not just an exercise to complete this task but should be a learning experience supported for further work. In the case of an emergency, professional rescuers need to enforce the long-term retention and performance rather than just finish this one. To keep their own positional awareness and increase the “storage strength” as well as “retrieval strength” (Bjork & Bjork, 1992) is critical to their future success of their duties.

Visual representation for surroundings

Route Aware Maps (Schmid, Peters, & Richter, 2008) is a combination of providing only route information and classic maps that present global information uniformly. Design of such maps is intend to help navigator recovering from lost by showing the alternative route at error-prone intersections, the regions along the route and essential landmarks. Implementation of Route Aware Maps starts from the route itself and provide alternative routes at intersections that may have two kinds of ambiguity. The first one is local ambiguity, when an intersection has multiple outlets that heading to the same direction as the route indicates. The second is global ambiguity, when other similar intersections occur before or after the relevant decision point. Choreme Analysis (A Klippel, 2003) is used to determine the degree of ambiguity for each intersection.

Region is an important conceptualized object in spatial recognition. Wiener and Mallot (2003) have identified other than fine-space based place-connectivity, navigation strategies are based on region-connectivity as well. Their experimental investigation in virtual environments suggests that regions are perceived and encoded in the very early stage of exploration and regions serve as a higher level object in the hieratical structure of the place (Wiener & Mallot, 2003; Wiener, Schnee, & Mallot, 2004).

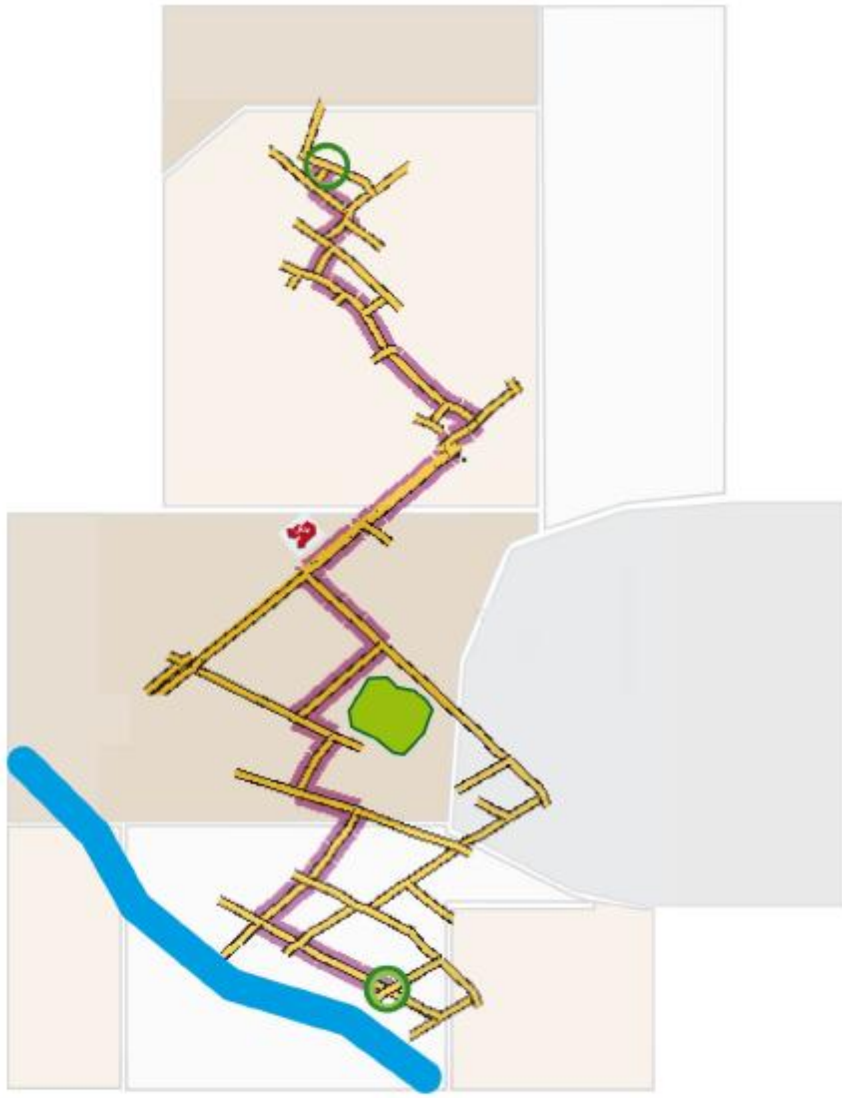


Figure 4-1 Route Aware Maps, from (Schmid et al., 2008)

Another approach to address this content-context issue is applying different scales. In contrast to conventional maps, which have uniform scales across the whole map, usage of variable-scales can enlarge area of interest with a larger scale while keeping the surrounding areas present in the smaller screen. Harrie et al. (2002) demonstrate this idea by using a fisheye view in the GiMoDig project, as shown in Figure **4-2**. To avoid the clustering problem on the edge, Rappo (2003) further simplified the objects represented with radial generalization from the center towards the surroundings.

Figure 4-2 Variable-scale map, from (Harrie et al., 2002)

Social information in place sensemaking

The knowledge of a place is socially constructed. As indicated earlier, place has been defined in human-computer interaction (HCI) as "a space with something added – social meaning, conventions, cultural understandings about role, function and nature…" (Harrison & Dourish, 1996, p.3). "What begins as undifferentiated space becomes place as we get to know it better and endow it with value" (Tuan, 2001, p. 6). Human experiences and associate social attributes are the main characters to differentiate place from space. The general social and experiential concept in building the sense of place has a long history. Throughout the years, various metrics to measure the sense of place have been proposed by human geography, environmental psychology, and landscape architecture, such as place attachment, place identity, place dependency, and place meaning. As some of these concepts require long-term residential interaction with the environments, the analysis here focuses on place meaning, which could be developed quickly in certain “chosen places” with dramatic landscapes or intense experiences (Tuan, 2001). Steele (1981) treats place from the point of a landscape architect and believes that place is “created by the setting combined with what a person brings to it. In other words, to some degree we create our own places, they do not exist independent of us” (Steele, 1981, p.9).

Currently, as the amount of information exponentially increases online, people are connected with powerful personal devices to create a virtual community beyond the physical space. With the maturity of spatial information representation that facilitates individual’s understanding and pervasive connectivity, there is a trend toward information sharing among individuals. The vision of ambient intelligence and ubiquitous computing that incorporates sensors, human actors, and social knowledge infuses novel experiences into a place. Mobile computing allows users to engage in activities in different physical locations even though they are not physically present, to access resources specific to the location, and to communicate with others.

Social navigation, a concept first raised by Dourish and Chalmers (1994), was described as “movement from one item to another is provoked as an artifact of the activity of another or a group of others... moving ‘towards’ a cluster of other people, or selecting objects because others have been examining them would both be examples of social navigation.” The original definition of social navigation was clearly associated with spatial navigation as it was first examined in virtual reality, where the decision that some information might be interesting as a result of seeing the clustering of like-minded individuals around it. In a familiar real-world situation, similar exploiting pattern can be observed as well. HCI researchers in Cornell University extends Dourish and Chalmers’ work and proposed social, spatial, and semantic modes of navigation. Specifically, they developed MobiTags (Cosley, Baxter, & Lee, 2009), a web-based application on an iPod Touch using a CIYU JavaScript Library, to integrate social tagging into an art museum’s space. MobiTags presents social tagging of museum objects, interactive mapping, and extra information about art objects to allow museum visitors to make sense of and collaboratively explore the displayed artifacts. They examined how space and social tagging influenced navigation and experience in a public space by analyzing data from tagged objects and users’ reaction to the art, which could be used to enrich further museum visits.

Online social network information can inform navigation design in three ways: First, friends’ comments and visiting history can influence users’ travel plans. Studies in social influence suggests that people ’s opinions and behaviors can be swung by others (Handl, 2006). With increasing online social interaction, network members influence each other’s opinions by sharing comments and reviews. Unlike reviews generated by strangers, comments and visiting history from people within one’s social network are considered more trustworthy. Thus, users are more likely to modify their behavior to bring them closer to their friends’ behavior. For example, large scale data shows that people tend to have close friends who live in the same geographical regions on their online social network (Backstrom, Sun, & Marlow, 2010), which suggests it is quite possible that people may find useful local information from their friends’ online behavior. Second, to some extent, people’s aggregated, explicit expression of their physical presence can be used as measurements of the physical place. The number of check-ins reflects the real-time popularity/crowdedness of a certain place (especially true for entertainments venues like bars and restaurants), which cannot be reflected in a traditional tour guide. Among various Location-based social network (LBSN) mobile applications proliferated, Foursquare is a widely adopted one with 10 million registered users (as of June 2011) and 3 million check-ins daily (TechCrunch, 2011). Users “check-in” to share their location for serendipity, connection, or personal history. Third, virtual indicators of physical presence bridge online social network with real world life, which may expose potential conversations or interactions among the “lurker” and the “blabber”. Pultar and Raubal (2009) show that new real world connections are created through LBSNs based on their study of CouchSurfing, a social network for exchange free lodging between travelers cross the world.

Temporal information in place sensemaking

All activity is enacted in space as well as in time (Bardram & Bossen, 2005). Historical events are important for understanding the current situation and predicting future developments. Such understanding and predictions can be used to make informed decisions. People are attracted by significant and/or interesting events to make decisions on whether to attend event to pursue further interests. It is quite common nowadays that people leave traces of their attendance electronically, such as geo-referenced tweets, “check-in”, or sharing geo-tagged photos on web sites or through mobile phones. By mining such digital records related to the presence of people in different places at different time, one can discover interesting facts from the modern history of places. For example, Andrienko and Andrienko (2010) proposed a suite of visual analytics methods for detecting and reconstructing events by combining geocomputations, interactive geovisualizations and statistical methods to enable integrated analysis of the spatial, temporal, and thematic components of the data.

Context-aware mobile computing

Empowered by various types of sensors and connectivity, mobile devices can detect the contextual information in real-time and infuse the online resources into the spot. In this section, I will review existing works that leverage such power to provide information other than traditional guides that emphasize spatial information representation.

The notion of context awareness is related to place sensemaking. The general idea of context is surroundings, the surrounding that defines a place where people can do certain things but cannot do something tacitly. However, as Dransch indicated, it is difficult to define ‘context’ since there are too many dimensions and parameters (Dransch, 2005). Sarjakoski and Nivala (Sarjakoski & Nivala, 2005) presents a framework to embody various factors related to mobile navigation context besides location, such as time, purpose of use, physical surroundings, navigation history, and user/cultural/social elements. Some context-aware systems developed to support navigators perform properly in that time, place, state of people, and the physical surroundings.

When one has access to massive spatial information, what should be presented and what should not is the key issue. Providing the proper amount of information is the first step to reduce processing workload and help users focusing on crucial data that may help them understand the main features of the environment. Schematized maps are developed based on cartographic generalization and cognitive adequacy with the aim of simplifying information on maps so that map-readers can quickly get the main topological relationship of spatial objects. Examples of schematization procedures and algorithms have been proposed to convert normal cartographic maps into schematic maps, as seen in (Barkowsky, Latecki, & Richter, 2000). Some basic schematization principles are summarized in (Meilinger, Holscher, Buchner, & Brosamle, 2007), as shown in Figure 4-3.

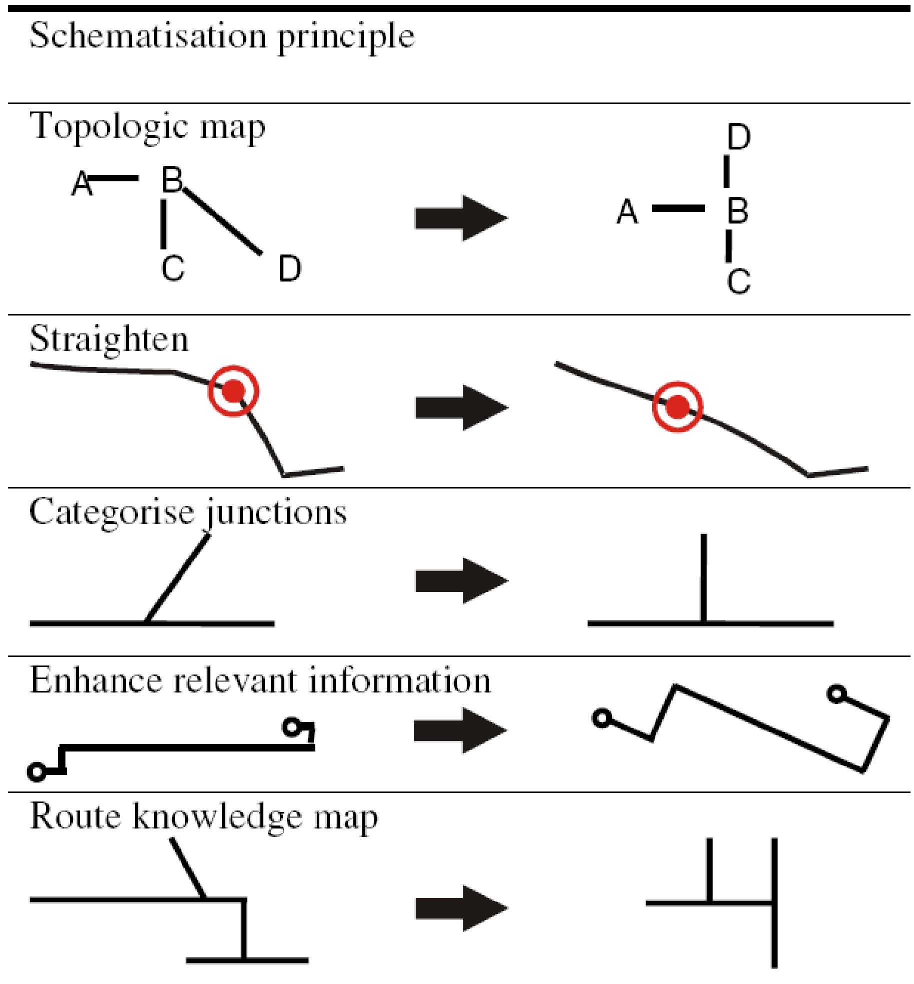


Figure 4-3 Selected schematization principles, from (Meilinger et al., 2007)

In fact, back in mid-1990s, Cyberguide (Abowd et al., 1997) first adopted such schematic black and white maps with related information for predefined for navigation in indoor and outdoor locations, shown in Figure **4-3**. Though primitive in data collection and representation, Cyberguide is regarded as the first attempt of supplying related information based on mobile device's current location. The maps are static and preloaded in Cyberguide. To provide dynamic information in a browser instead of individually installed application, GUIDE project (Cheverst, Davies, Mitchell, Friday, & Efstratiou, 2000) is one of the examples that adopts server-client infrastructure with wireless LAN to provide geospatial information for tourist purposes at Lancaster, UK, see Figure **4-5**. This design employs multimedia information such as pictures and verbal instruction.

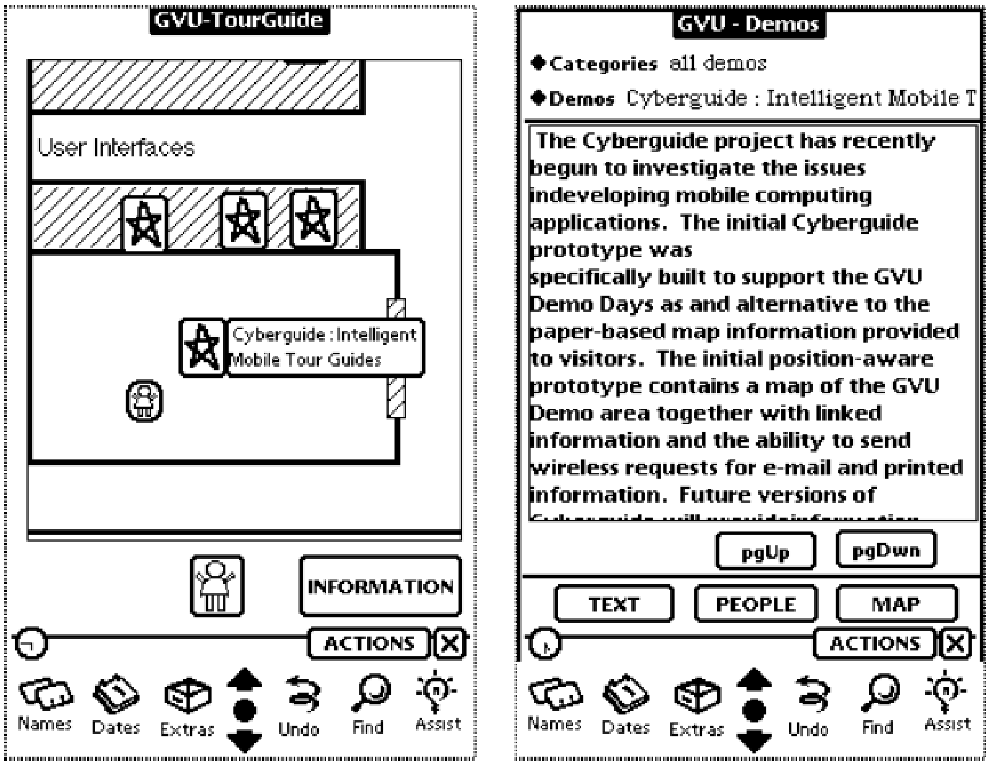


Figure 4-4 Cyberguide interface, from (Abowd et al., 1997)

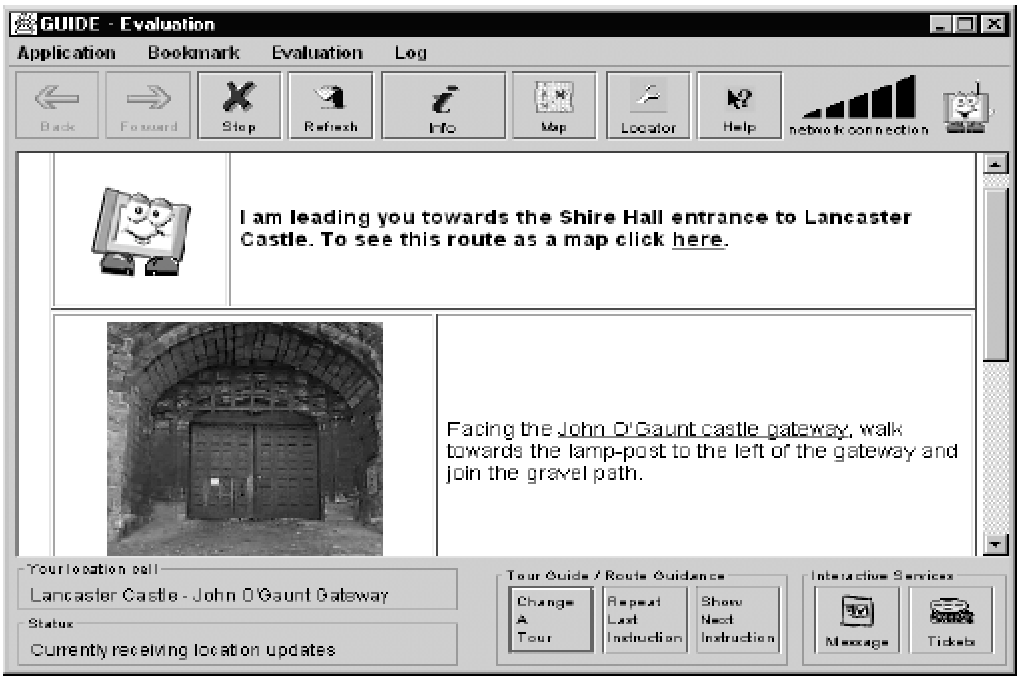


Figure 4-5 GUIDE interface, from (Cheverst et al., 2000)

However, survey knowledge and route knowledge gained from such schematic maps are constrained (Meilinger et al., 2007). Sacrifice of Euclidean distance may result in less accurate mental image of the environment, which may be necessary when accurate estimation of time and distance is desirable.

Another disadvantage of such schematic maps is the cognitive workload since users have to bridge the perceptual gap between abstract representations on the device with real-world objects. Some navigation designs are designed to increase richness of the representation, e.g. the street view and satellite view of Google Maps. This kind of design aims to reduce the workload in connecting symbolic representation on maps to the real objects in the world, which is one of the main challenges for map-reading. Some early attempts already include 3D models on mobile maps. For example, TellMaris developed by Nokia Research Center (Kray, Elting, Laakso, & Coors, 2003) stores 3D models of Tonsberg, Norway locally. This prototype was designed to help boat tourists find locations of interest. In their evaluation, a laptop with 800*600 resolution display running a mobile phone emulator is used to avoid computational limitation.

Figure 4-6 TellMaris interface, from (Kray et al., 2003)

Later, a series of studies compared 2D and 3D representations for navigational tasks. Oulasvirta et al. (2007) constructed a working model of situated interaction for mapping problem by comparing 2D and 3D maps. They asked participants to point the correspondent objects between virtual and real world, they compared the source of orientation (from virtual to real or reverse), representation of maps (2D vs. 3D), task scale (proximal mapping to recognize a target from the immediately perceivable surrounding vs. remote navigation that needed to find a target in out-of-sight areas). Measured by wayfinding performance, verbal protocol and subjective workload report. Their results show that 3D is superior to 2D maps, especially in remote navigation tasks. The model that establishes connection between the source environment and target environment is presented. In this model, users identify 'cues' (a perceptual entity used to establish the connection) in the source environment, encode it, match it with stored representation in mind and search it in the target environment. This loop can be itinerated until the user successfully makes the connection. The authors indicate that mobile maps should provide maps with different dimensions.

Some other studies suggest that 2D still results in better navigation performance. For example, Dilemuth (2005) has compared aerial photos with simplified maps for pedestrians with a handheld computer in route-following tasks. The results show that more generalized map results in quicker route completion and fewer navigation errors.

Simply comparing the results is not fair for the effectiveness of 2D and 3D representation because the difference in interface setting and task requirement. However, from these studies, we can summarize their differences in three aspects:

- Alignment of representation and the represented space: 2D map readers need to transform or rotate the representation to correspond the objects on maps to the objects in the world, which needs mental or physical effort.
- Spatial updating: 2D maps could provide better references for users to update their location awareness at different span level, while 3D maps allow users to be better aware of their current location.
- Focus and context: 2D maps provide information of both objects and its surrounding areas, which facilitates users to recognize the landmarks and understand the relationship, and thus helps mapping and orientation in navigation.

Selecting the proper representation for the corresponding task is still a challenging question (Oulasvirta et al., 2007). From a recent observation, Oulasvirta et al. (2009) get the general conclusion that 2D maps lead users to use reliable cues like street names and crossings while 3D maps could assist rapid identification of objects and ego-centric alignment.

Data-rich multimedia and 3D transmissions require high speed networks that have less constrains now. In 2001, the LoL@ project (Gartner & Uhlirz, 2001) developed a prototype for tourists in inner Vienna using a 3G network. Universal Mobile Telecommunications System (UMTS) is used for map-service. Map size could be adjusted automatically to fit the screen size.

Real-time location is the most important factor in mobile service for navigation. Location Based Service (LBS) provide informational services based on a user's current location through the mobile network's identification of device terminals. There are already commercial products to enable location and orientation- aware in mobile devices, such as mobile phones with integrated GPS chips/A-GPS and compass, with accelerometer-based tilt sensors (e.g. iPhone). Most LBS assumes a stable connection to a server, while in fact, there is no perfect technical positioning solution for this. For example, the most popular GPS only works outdoors with vast enough area where it can get satellite signals. Compasses and accelerometers based on electromagnetic could be severely interfered with other nearby electronics. Wireless LAN is limited because of the current wireless coverage and they poorly overlap. Positioning base on cell tower triangulation (http://searchengineland.com/cell-phone-triangulation-accuracy-is-all-over-the-map-14790) seems to be promising for its comparatively wide coverage, but the position accuracy still depends on the density of base stations. For a full comparison of different positioning techniques, see http://www.gps-practice-and-fun.com/positioning-systems.html.

Interaction with the physical objects is another aspect of context-aware design. Numerous researchers in tourist design focus on this aspect. Kenteris et al. (2008) compares selected tourist guides (some of them I mentioned earlier) from the perspectives of architecture, information models, network infrastructure, positioning technology, map technology, input/output modality, and unique services.

When the major task is important compared to learning the environment, such as driving, current designs for in-vehicle tried to minimize the cognitive load by providing turn-by-turn direction, as shown in Figure 4-7. Tomtom announced IQ Routes techniques to calculate shortest route calculated by the real-time speed on the road, which may be influenced by traffic situation (http://www.tomtom.com/whytomtom/topic.php?topic=5&subject=3).

Figure 4-7 Tomtom GPS GO520 interface

According to Milgram’s virtuality continuum (Milgram & Kishino, 1994), objects represented in any particular display could be mapped onto an axis with one end as real environments and the other end as virtual environment. For those environments created by combining the two, the mixed information may facilitate the understanding of real world by leveraging virtual computational power. Recently announced 3D GPS Mapping systems by Gizmodo is designed to better provide the connection of abstract representation with 3D landmarks[3]. Augmented Reality (AP) puts the idea of using 3D objects into the extreme. Augmented reality mixes the real world with the virtual world to enhance the experience in a uniform representation, which can reduce the split attention effect (Chandler & Sweller, 1992).

[3] http://gizmodo.com/345907/3d-gps-mapping-to-come-to-us-at-last

Recently, Mobilizy announced Wikitude Drive (http://www.mobilizy.com/drive). Wikitude Drive is a mobile AR navigation system which overlays point-to-point directions on a camera-view, without the need for maps. It has integrated voice command, like normal GPS, and now are available for most mobile platforms.

Figure 4-8 Wikitude Drive preview, from http://www.flickr.com/photos/wikitude/3873848623/in/set-72157622416440954/

Mashup applications and information integration

Information overload is significant on mobile devices considering the small screen, the cumbersome interaction, and the moving context. Defined as "a combination of pre-existing, integrated units of technology, glued together to achieve new functionality, as opposed to creating that functionality from the scratch" (Hartmann, Doorley, & Klemmer, 2008), mashup design resolves information overload with tailored services. iGoogle and Netvibes are examples of existing products on the desktop.

Studies through interviews suggest that users desire mashups both on the desktop and mobile devices (Väänänen-Vainio-Mattila & Wäljas, 2011). Some researchers have proposed a dashboard design to aggregate information, which provides inspiration to our approach to ground explorations into a unified platform. PROTEUS (C. Anderson, 2001) is a mobile version of Montage, a desktop application which consolidates information from different web pages based on user preference and interactions. More recently, both researchers and practitioners have created mobile “social dashboards” that combine information from multiple social streams into a single application, (e.g. Cui, Honkala, Pihkala, Kinnunen, & Grassel, 2010; Sohn et al., 2010). For example, Linked Internet UI (Cui et al., 2010) aggregates social events from various social networking services in a hub, and links to the original service through hypertexts. Users can navigate to different information resources within a single UI through “clicking links” and “back”. The current work contributes to this body of research by extending the idea of information integration into spatial navigation. This is useful when users need a unified solution as they have limited time and less cognitive resources to switch between multiple specialized applications in order to get a coherent idea of their environment.

Google Place exemplifies the idea of information fusion by integrating contact information, addresses, directions, reviews, photos, operating hours and a link to the official website (when available) into a single application, which provides a one-time shop for such information. This app is the most relevant to our research. However, the design of Google Place does not provide personalized information about space, which is critical to establishing personal connection with space in place sensemaking.

Dietze et al. (2009) proposed using Semantic Web Services (SWS) to address the context-adaptation by enabling the comprehensive semantic capability descriptions. They defined Mobile Situation Spaces (MSS), which describes the mobile situation as members in geometrical vector spaces and compares the similarity between situational contexts through Euclidean distance calculation. They exemplified this idea with a web-based prototype, which allows users to visit the potential point of interests for its historical facts.

Tomaszewski and MacEachren (2010) proposed a framework to support sensemaking of documents in crisis management and humanitarian relief with geographical, historical, and thematic contexts. Their framework, called Geo-Historical Context (GHC), has three sub-models (geographic, historical, and conceptual/thematic) in different forms as per the ideas of locality (different view on the same world) and compatibility (interconnections existing with varying degrees of detail). Geographic, historical (temporal), and thematic cover the aspect of information sources, while locality and compatibility describe the range of information needs in different contexts. Context, as a formal structure for reasoning, is based on "local" facts derived from a global knowledge base and used for reasoning about a given task (Giunchiglia & Bouquet, 1997). Contrast this with other applications in ubiquitous computing, context here not only provided filtering function as predefined input, it also actively involved and thus determined how users forage information throughout the reasoning process. They also distinguished contextual information with contextualized information: while the former is the relevant information provided, the latter emphasizes on users' internalized meaning. The value of this framework includes providing a formal structure for the theoretical and conceptual components to describe a definition of the context and serving as a conceptual template for structuring and representing information instances in the sensemaking process. They also designed a typical GIS prototype application, called Context Discovery Application (CDA), which integrates maps (e.g. Google Earth) and annotation tools, and evaluated the tool with focus group and expertise evaluation (5 grads in the lab and 5 UN workers). A Consolidate Appeal Project scenario in Sudan was used. Subjects were asked to review predefined material with the CDA tool and complete a list of 5 tasks. In a later task used to evaluate the GHC framework, other than the listed tasks, the subjects needed to complete an executive summary report that outlines the context information regarding to the three aspects. Comments and transcripts are analyzed using Krueger's method (Morgan & Krueger, 1998), also used by (Kessler, 2000). This work greatly inspired our design goals, which will be introduced in the next section, but it still focuses on traditional tasks like document analysis in stationary settings.

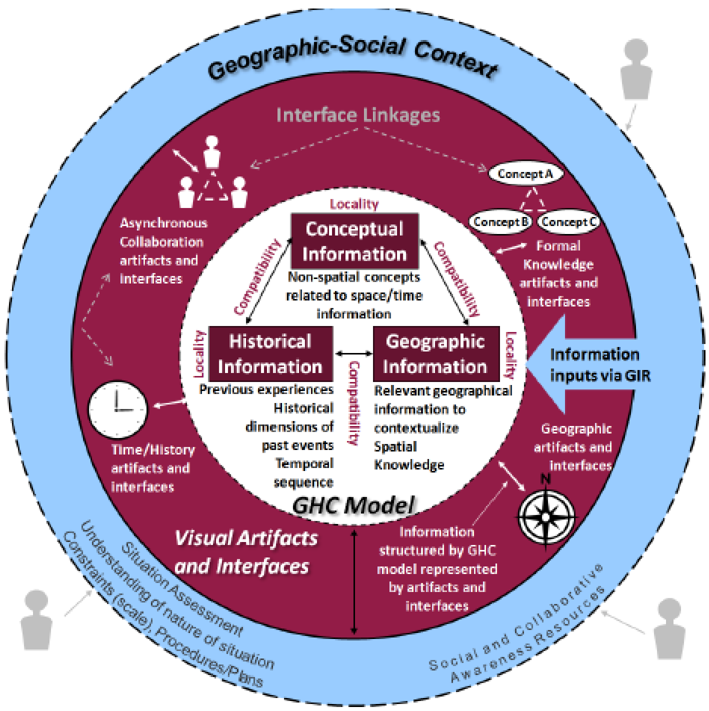


Figure 4-9 GHC model, from (Tomaszewski & MacEachren, 2010)

Design Requirements

To further our understanding of users' practice and requirements in exploring novel environments, I conducted a structured study asking college students about their current practices to get to know a new place and their desired functionality of a mobile application.

Sample and data collection

The sample for the study was drawn from undergraduate students in the College of Information Science and Technology (IST) at Penn State University. Compared to students in other majors, such participants are trained with considerable technical background and not yet primed with domain knowledge. The sample selection was based on an attempt to survey a subset of gender-balanced college students representing the young generation, who are open to new technology with mid-level education. This survey was my exploratory effort seeking to develop initial hunches or insights, which could be used to provide direction for design, rather than generating conclusive claims.

I made the announcement through a presentation for the recruiting in three classes given in the College of IST, introducing the study background and survey questions. Students who were interested in the study were welcomed to participate and being compensated with extra credits for their voluntary participation. Twenty undergraduate (9 female and 11 male) students were recruited in class from three courses. Each participant was asked in-depth questions and was required to provide at least a 2-page long written response that covers all the questions. The questions related to their current strategies, technology used, and information resources accessed to know a new place. The questionnaire also asked about the challenges in this process, their personal experiences, and attitudes towards current mobile navigation tools. Their future vision of desired functionality on mobile assistance was collected as well. For details of these questions, see **Appendix A.**

Summative Findings

The majority of our respondents are familiar with all kinds of mobile applications for exploration purposes (18 out of 20). Google Maps is the most popular one for its credibility. For directions, traditional in-vehicle GPS devices or GPS software on mobile phones are on the lists. Yelp, Urban Scoop, One School, Around Here, and HopStop are popular apps mentioned for more specific purposes.

Getting prepared before setting out and seeking detailed information on locations are routines for information seeking practices. Our participants identified three major resources to get information for trip planning: a) online resources, including Google search (query as destination name plus “attractions” or “things to do”), various travel forums, personal blogs, and reviews; b) traditional paper media, like paper maps or travel guides; and c) people in their social networks who have visited or currently live at the place. Regarding the online resources, Wikipedia is the second choice after Google search. The participants use Wikipedia to get a concise description of a location. As one participant shared, *“Google just gives too many results, while you can get it from the first few lines on Wiki…”*

After arriving at a place, in addition to the above three mediums, ten respondents like to talk to local residents (e.g. hotel, gas station staff), as they know the place better and can always give “good tips that you cannot find online”, or “have the best scoop that lead me on awesome adventures.” Three correspondents also mentioned that they like driving around to explore the places by themselves from time to time. When comparing these three channels for information quality, traditional guidance material is more targeted, while internet resource is searchable and vast, but could be biased. Our participants believe that reviews from real people and responses from local people are more trustworthy.

Both unique local treasures and familiar venues are what people look for when they get to a new place. Popular tourist attractions (e.g. museums, landmarks, outdoors), shopping zones, local cuisine, and entertainments (e.g. clubs, bars, and theatres) are common places to visit for their newness, excitement, and experiential value. People also look for familiar places, such as Burger King, Starbucks, Gold's gym, to get ensured service.

When asked what kind of information they want to know about a point of interest, we do get confirmation that people want information from multiple dimensions. Geographically, they definitely want to know the address and direction. One respondent described his requirement of building a mental representation of the new environment like this: "*one of the things I try to do is to come up with a mental map of my new surroundings… I want to form a conceptualization of my physical surroundings… I often want to know the functionality of neighboring buildings, restaurant zones, street names and layout…*" Three participants mentioned weather information as well. Temporally, timely information is also desired. Examples would be on-going events or events in the near future, specials of the day. Updated information (e.g. open hours, address changes) is highly helpful as well for the actual visit. For those who would like to visit cultural sites, historical stories in the long run will also attract their attention. Regarding the social aspects of the POI, our respondents indicate that they want to know the significance of the place to the whole society as well as to the local community. Reviews, tips, and ratings from people who have been there reflect diverse opinions.

When asked about the desired functionality of novel applications, YAH is always helpful to construct self-confidence. One participant has the vision that the future GPS should be color-coded buildings by their category, with additional information available on request. Capability of showing the pictorial representation and reviews of a place for a preview purpose is also desirable. In terms of information consumption on the site, a digital, knowledgeable, personal tour guide is the spirit. For example, one of the respondents wishes an application could have some of these features: a) can tell interesting things nearby in voice; b) can recommend places based on request; and c) can provide reviews from other people who have been here. Limited information creation is also welcomed, as sharing, posting, commenting to the social network sites. A student who characterized himself as someone who rarely travels to new places, mentioned that asking information from someone else who might be more familiar with that environment (friends, instructor, store clerks) rather than self-reliance is a more common practice for him. He held slightly negative attitudes toward mobile technology as no software that is “comprehensive, easy to use, and most important very quick” ever exists.

Design Goals

Based on users’ requirements, I propose a framework of design goals on building a holistic understanding of a certain place (Figure **4-10**). This framework views the sensemaking of a space as a process to integrate different types of information about the space.

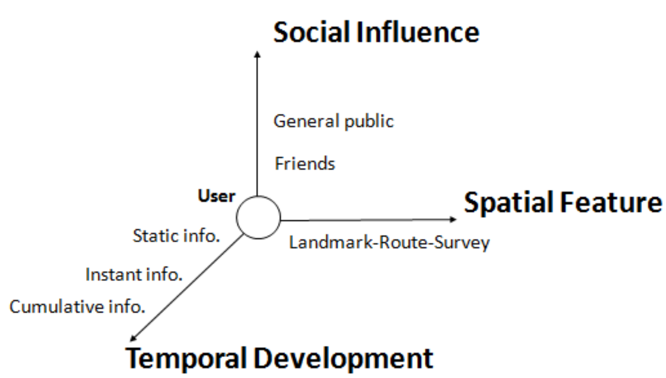


Figure 4-10 Design framework

Here, my focus is on three types of information: spatial, temporal, and social. In the *spatial* dimension, three levels of spatial knowledge are required to establish a mature mental structure of a place: landmarks, route and survey knowledge (Passini, 1984b). Vast research has investigated how to present these three kinds of knowledge effectively. For example, visual representation of the landmark is known to help users build spatial memory (Tversky & Lee, 1999) and only including distance and time make it difficult for users understand and remember directions (Raubal & Winter, 2002b). In the *temporal* dimension, while some information tends to be static across time (e.g. address, place categories), others fluctuate with time (e.g. crowdedness), and knowledge of a place's development can create historical sensation, foster personal reflection, and stimulates cultural exchange (Van Dijk, Kerstens, & Kresin, 2009). *Social* influence on the interest in a place can be dramatic, and from two levels: general public level and friends in social networks. Reviews from the public provide diverse opinions about the place (e.g. "a great lunch place for the Thur sub"), while visiting histories from friends tend to be more trustworthy and verifiable. Based on this framework, three design goals are generated for mobile tools that support place sensemaking (further illustrated on Figure **4-11**):

- Support geographical information exploration with proper representations to build landmark, route, and survey knowledge in the vicinity.
- Support social navigation by getting opinions from the general public and social networks.
- Support instant decision making by providing temporal information changes in the short term (now) and in the long term (historically).

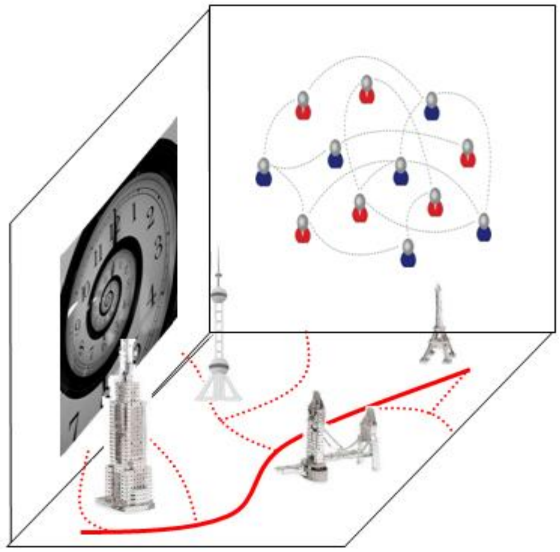


Figure 4-11 Illustration of information representation based on the design goals

Chapter 5

Proximity Explorer: A Mobile Application to Support Place Sensemaking

As reviewed earlier, supporting navigation and spatial knowledge acquisition on mobile devices is a rapidly developing area and much effort has been made in both academia and industry. As such, Proximity Explorer, a mobile application that aggregates content across multiple online services to support exploration of a place, only represents my effort in developing a functional mobile prototype to materialize our design concept by taking advantage of cutting-edge technologies. The current system is the result of nearly two years of investigation through much user requirement analysis and design iterations. Three early adopters actively involved through the whole process and their feedbacks are discussed during the weekly design sessions. This chapter presents the design consideration, technical implementation and user interface design of the application, and finally highlights its key features through a scenario of making sense of a novel environment. The current application installation file and a supplementary demo are available online[4].

System design consideration

To materialize the design goals, which require providing information from spatial, social, and temporal perspectives on mobile devices, several factors need to be considered into the system design:

1. **Where to get relevant information?**
2. **How should the information be presented?**

[4] http://vis.ist.psu.edu/phpFolder/ProximityExplorer.apk

Information resource identification and selection

Common users' generated information provides an opportunity to get richer information about a place. "Volunteered geographical information" (VGI) (Goodchild, 2007) refers to the geographic information created by individuals that can be used as resources for designs. Numerous websites annotate digital information with related geographic identifiers from common users. Such annotation could be in various formats. For example, Flickr (http://www.flickr.com/) and Panoramio (http://www.panoramio.com/) have hundreds of thousands of geotagged user submitted photos. Many Location-Based Social Network (LBSN) sites like Facebook (http://www.facebook.com/), Google Latitude (http://www.google.com/latitude/), and Foursquare (https://foursquare.com/), allow users to explicit express their current location through "check-ins" and make associated comments. Wikimapia (http://wikimapia.org/) connects Wikipedia (http://www.wikipedia.org/) articles to the place of action. Even mobile commercial navigation solutions, such as TomTom, encourage users' contributions to update their map content.

Regarding the three information resources identified earlier to support place sensemaking, especially on mobile devices, I first identified the possible online information services and made selections based on their data quality, user coverage, service stability, and API documentation completeness (shown in Table **5-1**).

Table 5-1 Comparison of POI APIs (As of Apr 20, 2012)

Service	Users	API quality	Pros/Cons
Facebook	800 Million	Well documented, provides multiple access methods (e.g. Graph API, Fql), users' two layer authentication	Good coverage of users' data; Place feature is new and incomplete
Foursquare	20 Million	Well documented, data quality vary by endpoints, limited access, authentication is not required unless for users' data	User created content (15 Million POIs), data density covered well in North America, with users' comments; Websites, address information is not necessary complete for each POI
Gowalla	2 Million before acquired by Facebook Mar 11, 2012	Not well documented, unlimited data access	Similar to Foursquare
Factual	Designed for developers	Well documented, great data quality, free limited access	Official data construction, has crosswalk API to map third-party (Yelp, Foursquare, etc.) identifiers for businesses or points of interest to each other where each ID represents the same place, but not complete enough.
Yelp	61 Million	Well documented, free access	Great reviews and comments, but only focuses on business POI
Google Maps	1 Billion	Well documented, nearly unlimited access	Comparatively complete POI coverage with complete address and contact info; no access to review data

Table **5-2** shows the results of information source selection after comparison. To provide social information of a place from different level of acquaintance, the implementation selected Facebook for friends' check-in and Foursquare for public tips. To provide temporal information, the implementation used Foursquare checked here now and accumulative check-in count. To provide spatial information, the implementation combined POI information from Foursquare with Google Place API for landmarks' basic descriptions like addresses, contact information, tags, or websites; Wikipedia for background description, Google route direction and significant POIs from Foursquare for route; and Foursquare POI categories and 3D Google Streetview for survey information.

Table 5-2 Selected information resources and corresponding channels

Social information	Friends	Facebook friends' check-in
	General Public	Foursquare users' tips
Temporal information	Now	Count of check-in Here now on Foursquare
	Past	Count of accumulative check-in on Foursquare
Spatial information	Landmark	Coordinates from Foursquare POI. Address, website, contact info from Google Place, or Foursquare. Background description from Wikipedia
	Route	Direction from Google Maps plus most checked in POI in Foursquare
	Survey	POI category from Foursquare. 3D view from Google Streetview

To summarize (Figure 5-1), conceptually, to support place sensemaking, the system needs to provide information from social, temporal, and spatial dimension; technically, Google Maps, Facebook, Foursquare, Wikipedia, and Panoramio are used to provide the data.

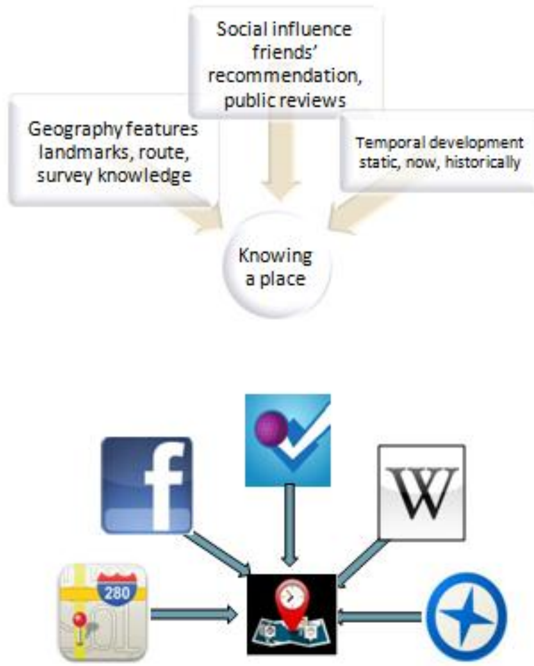


Figure 5-1 Information integration under a unified application.

Information integration and representation under a unified application

The online services collected information of POIs from different GIS vendors, or from users' manual input and contain different detailed information of certain POI in different formats. Problems dealing with such heterogeneity are well known obstacles in developing applications with GIS data (Cruz, Xiao, & Hsu, 2004; Suryana & Sahib, 2009). The information can be merged to form a single comprehensive data set to provide a holistic description of a place. Techniques in ontology merging and database schema integration are usually used in this process (Suryana & Sahib, 2009).

Figure **5-2** shows an example of ontology merging. Here, O1 and O2 represent two separate ontology structures from two services for the same POI (share same head node). The left two nodes in O2 (circled) can be further merged with the left node in O1 (underlined) for their data compliment. For example, the circled two nodes in O2 could be telephone number and Twitter for a POI, while the underlined node in O1 could be contact information, which results in a 3-node, 2-layer sub tree (squared) in the merged ontology O.

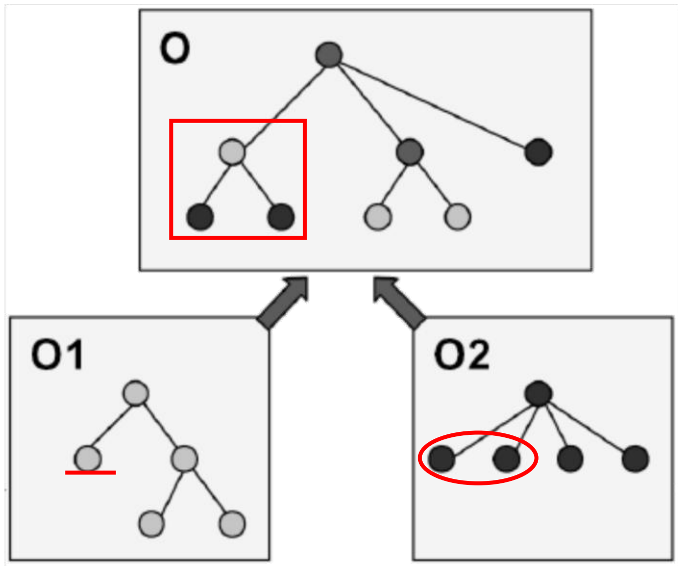


Figure 5-2 Ontology merging

Ontology mapping and alignment are prerequisites before merging, when a relation between two or more entities is identified. However, due to the different index systems used in different online services, such mapping is not straight forwards. In general, merging processes can be conducted either manually or automatically. For the manual methods, domain experts identified the relationship between different datasets and merged the results. For the automatic methods, computational algorithms define the mapping schema, which directs the mapping procedure. For more detail and the classification of matching and merging methods on geographic information, which is related to our research, please see Navarrete (2006).

Considering the large datasets of POIs that may be retrieved, I applied two mapping methods. All of the services involved in this research have place name and coordinates fields.

These two mapping methods are heuristic, and use string-based mapping and spatial mapping, respectively.

String-based mapping heuristic

Various string-based similarity functions exist to compare two strings, which could be place names in the focus context. The parameters in these functions are either pre-defined or determined through training process. For example, Stoilos (2005) considers the similarity of two strings with both the common and different parts that could be calculated through various distance measurements (Jaro, 1995; Winkler, 1999). Machine learning techniques are used to determine the weight of parameters through processing large data. Probabilistic models based on Hidden Markov Models (Bilenko & Mooney, 2003; Cohen, Ravikumar, & Fienberg, 2003) or undirected graphs (Bilenko & Mooney, 2005) are typical approaches. Due to the lack of ground truth and training data for the learning approach, I choose the pre-defined approach. Specially, I adopt the classic string-based mapping algorithms, Q-gram (Sutinen & Tarhio, 1995), to calculate the similarity of two place names and used it to map different representations across services of the same place.

Two main assumptions are used in this algorithm here:

1. POIs with same names are usually the same place; and
2. Adding words usually specifies meaning, thus a larger overlap of defined words may also suggest the same place. A similarity measurement can indicate how a name in one service is included in another.

Each word in place names can be viewed as a string and comparing place names can be seen as comparing multiple strings. For individual strings, string similarity can be calculated with Q-gram distance (Sutinen & Tarhio, 1995):

$$tsim(u,v) = \frac{2length(x)}{length(u) + length(v)}$$

where *u* and *v* are two strings for comparison; and *x* is the longest common substring between *u* and *v* beginning at the first character of both and containing at least *q* characters. In our computation, I adopt q=3, a number mostly used for English strings (Sutinen & Tarhio, 1995).

For place names as composite words, string similarity is calculated with a token-based method (Salton & M. J. McGil, 1986). Given two place names *n1*=$\{s_1, s_2, \ldots s_{c1}\}$ and *n2*=$\{t_1, t_2, \ldots t_{c2}\}$, constructed from the term number of c_1 and c_2, respectively. The token-based method first segments the names into individual words, or tokens. Then, name similarity can be calculated with this formula:

$$sim(n1, n2) = \frac{1}{2}\left(\frac{\sum_{i=0}^{c_1} \max_{t \in n2}\left(tsim(s_{i,} t)\right)}{c_1} + \frac{\sum_{j=0}^{c_2} \max_{s \in n1}\left(tsim(t_j, s)\right)}{c_2}\right)$$

Spatial mapping heuristic

Spatial mapping rules use the spatial distance of two candidates for the mapping. Two main assumptions here are:

1. The coordinates of the same POI in different service should be within a certain tolerance region.
2. POIs that are too close to be different places are usually the same place.

The distance between two places can be directly calculated based on their coordinates.

With the name similarity score and the distance of two places, ontology matching can be conducted. Figure **5-3** illustrates the procedure of the ontology matching algorithm used in this research. For two given ontologies *O1* and *O2* with name *n1* and *n2*, spatial coordinates *s1* and *s2*. If the similarity of their name strings is higher than threshold *t1* and their distance is within threshold *d1*, then they are the same POI and information will be merged. If the string similarity is lower than *t1*but higher than *t2*, then the spatial threshold will shrink to a smaller region to see if they satisfied this criterion. If they do, they will still be matched. Finally, if the names do not match, but geographically, they are too close to be different places, they are considered as the same POI.

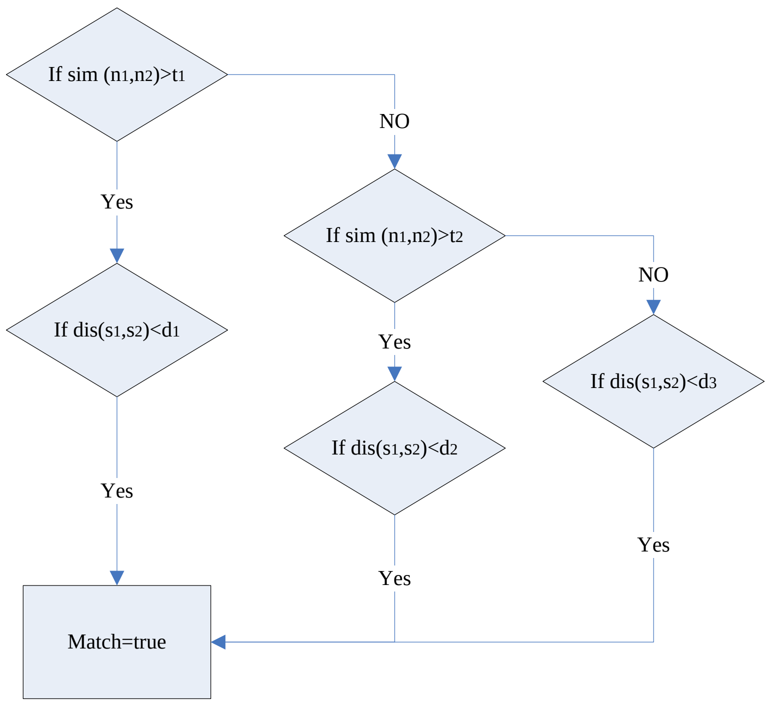


Figure 5-3 Ontology Mapping Algorithm

The thresholds used in the prototype are listed in Table **5-3**. These thresholds are defined by heuristics-based experiments. For example, given two place names, “Starbuck’s” and “Starbucks Coffee”, a string “Starbuck” out of one-word matches. According to the above formula, the resulting similarity will equal to 0.75. Given “Pattee Library” and “Pattee & Paterno Library”, two words, “Pattee” and “Library” match, the resulting similarity will equal to 0.89. Similarly, for the distance thresholds, 30 meter is an estimate of the distance between two buildings in state college; a distance of 300 meter is an estimated tolerance of coordinate errors among services for the same place; and 10 kilometer is an estimated diameter for the focus area. Note that the purpose of such implementation is to demonstrate the idea of information integration in the georeference context. The accuracy of ontology merging is not the core interest. Thus, no systematic study was conducted to evaluate the merging accuracy.

Table 5-3 Threshold used in the mapping algorithm

Parameter	Value
t1	0.89
t2	0.75
d1 (m)	10000
d2 (m)	300
d3 (m)	30

Proximity Explorer aggregates content across multiple internet services, merges service-specific data structures and forms a complete ontology that describes a place from spatial, temporal and social dimensions. Earlier work suggests that visiting multiple applications on mobile devices is not an efficient method of information gathering or processing as it requires users to be familiar with different UI designs and much information usually gets lost between different applications (Cui et al., 2010). Integrating information within a unified application allows users to examine places of interest from multiple aspects without visiting multiple applications.

By analyzing users' requirements collected in the structured study and the continuous feedback from the earlier adopters, I identified some essential functionality for the prototype design. For example, it is expected that information consumption is the major task in the exploration context, considering the limited time. The early adopters of the application suggested that the capability of creating new content actually motivates them to use the application. When they saw an interesting place and made comments, or took pictures, they wanted to make them visible to a larger audience (e.g. Facebook friends) rather than only the users of Proximity Explorer. Thus, the current version enables content creation as well. It allows users to take pictures of the POI and comment on them and share route directions. Another required functionality is allowing exploration on the spot as well as remotely. To satisfy this requirement, the application allows users to refocus the interest region by long-pressing a certain point of interest on the map.

User interface design

The UI design was performed on Android phones hardware specifications, including 3G/Wifi network, GPS module, camera, and 3.7 inch or 4 inch screen. All the views were created for portrait mode except in the camera activity for taking pictures. On the login page (**Figure 5-4**), users will see the logo of Proximity Explorer and login the application with their Facebook credentials. The logo is designed to reflect the design goals of integrating social (smiley faces), temporal (clock) and spatial (map) information into a single application.

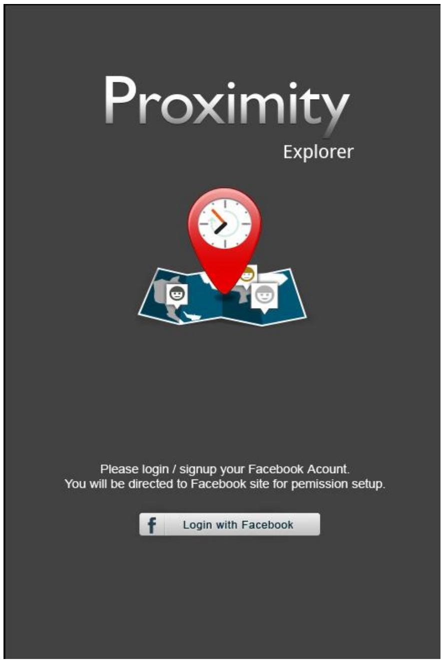
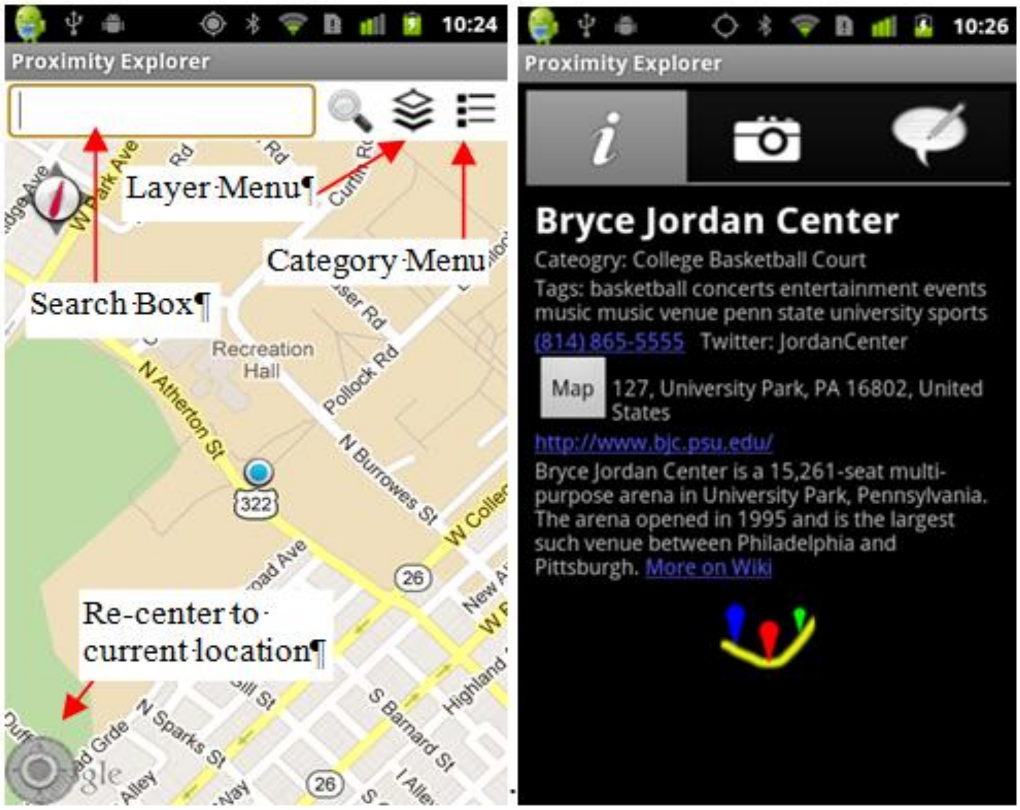


Figure 5-4 Login page

The major part of the Proximity Explorer user interface is composed of two layered views: the Home View and POI View. As depicted in Figure **5-5** (a), the home view provides several means for the user to explore nearby environment from a higher level. Users can see a home view with a search box, a layer selection button, a category button, and a Google Maps view underneath. Like regular navigation tools, users can search location by keywords in the input box. Users can initiate exploration by selecting a category of POI in mind by pressing the category button, e.g. food. Users can also select different overlays by clicking the layer button to switch among regular map views (Google Maps, Satellite Map, Traffic Map) with popular places and friends check-ins. Popular places show the popularity of a set of POIs (either filtered by category, or search results) in the area by visualizing Foursquare check-in counts on a heatmap (Figure **5-7**). Users can also see their Facebook friends' check-ins in a list (Figure **5-6**).

Further detailed information of certain POIs can be examined in the POI View, as shown in Figure **5-5** (b), by clicking on either the friends' check-in item or markers on the map. The POI View contains three tabs: the basic information tab includes place name, category, users' tags, address, telephone, email, twitter, website, and Wikipedia page. Users can also add the POI to a shopping cart-like route-planner. The visual tab has a Panoramio photo gallery and Google Streetview of that place to allow visual exploration of the POI (Figure **5-8**). Users can contribute their own pictures to our server, which are automatically added to the gallery collection for other users to review. In the view tab, users can read Foursquare tips, Facebook Friends' comments, and check-ins (Figure **5-9**).



(a) Home View (b) POI View

Figure 5-5 Two main layers UI of Proximity Explorer

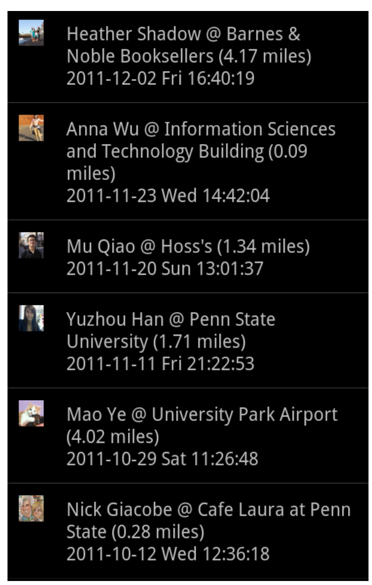


Figure 5-6 Friends' check-in list

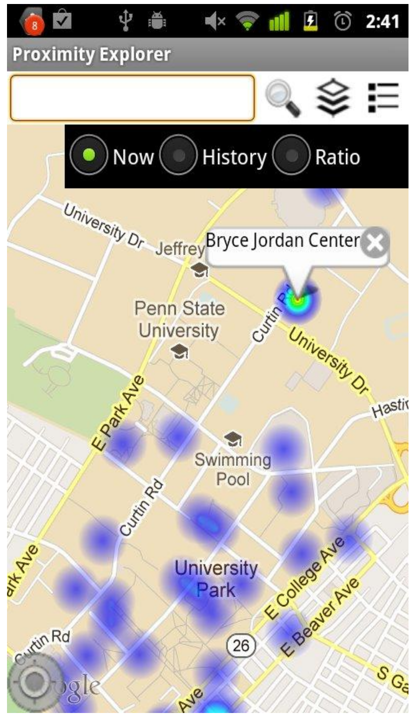


Figure 5-7 Popular places (Taken at Jan 26, 2012, 2:41pm--when Joe Paterno’s memorial service was on-going at Penn State)

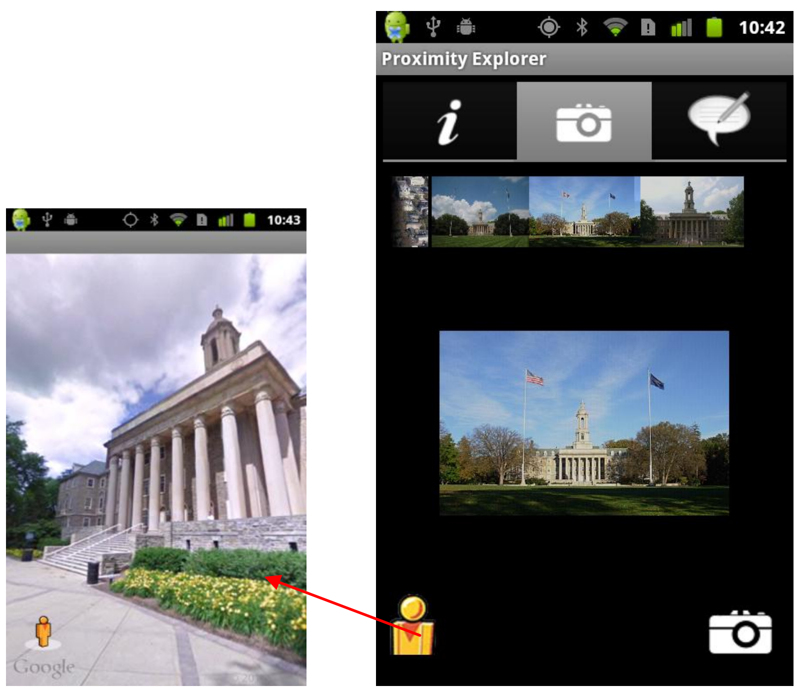


Figure 5-8 Photo Tab

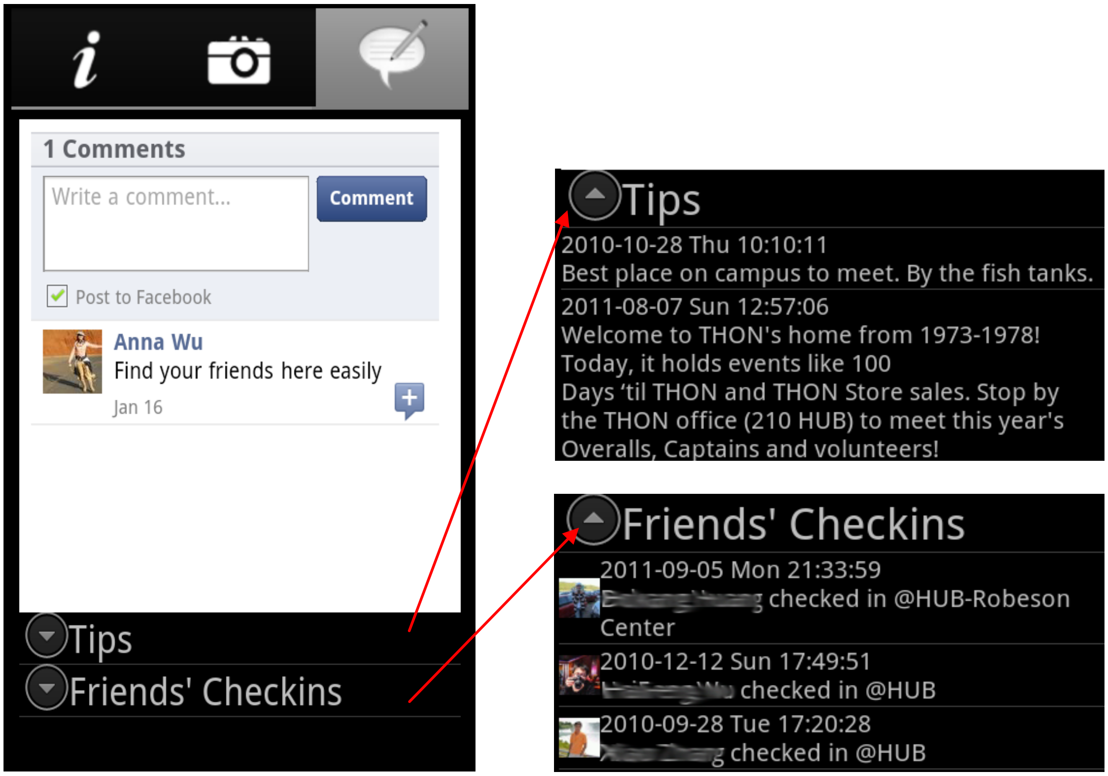


Figure 5-9 Social Tab

A usage scenario and design features

This section shows how Proximity Explorer works through a campus visit scenario when a perspective student tries to explore the spatial, temporal, and social aspects of a college town before she decides to come to this university. Jen, our hypothetical potential student, uses her mobile assistant as she is walking on campus to examine whether the potential new environment will support her college life. This scenario requires active exploration of a new environment from multiple aspects within limited timeframe. Throughout the description of this scenario, the interaction flow and major features of Proximity Explorer will be introduced, and how different information sources integrate to support place sensemaking will be highlighted.

After logging in the application with her Facebook credentials, Jen sees her current location at the center of a regular Google Maps. She explores the nearby area by clicking the Category Menu, which prompts a list of POI categories for selection. By selecting "College & University," Jen finds quite a few academic buildings marked on the map. Tapping on a marker pops up the place name in a callout (Figure **5-10**). Tapping the callout, Jen can get a POI view similar to Figure **5-5**b.

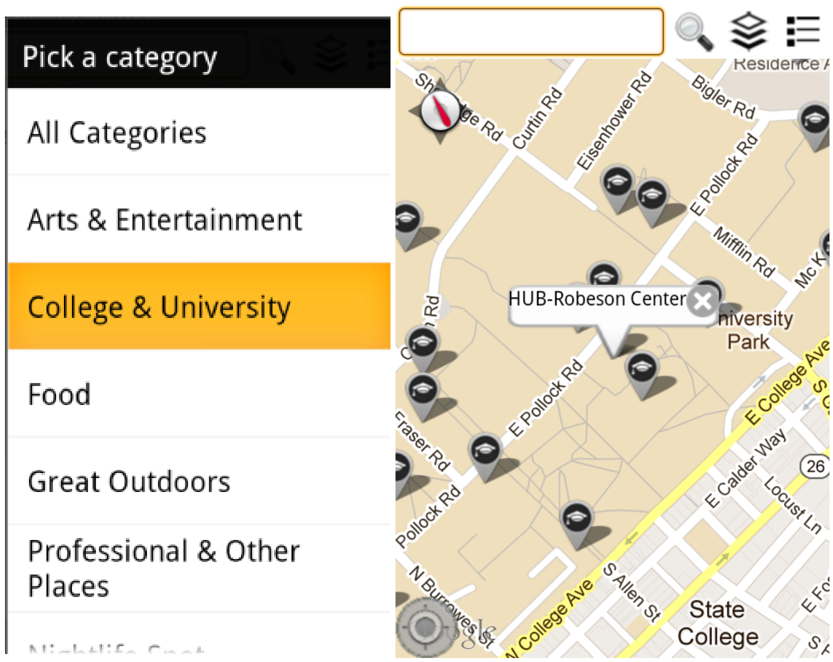


Figure 5-10. Categories of POIs.

Jen can also explore the campus by choosing different map layers. She opens the Layer Menu and chooses the option of "Popular Places". A heatmap visualization shows the popularity of nearby places. The heatmap takes check-in counts from Foursquare to map the heat of a specific POI. Right now, the Thomas Building is pretty crowded, as many mathematics courses are held in that building. She switches to the history view of the heatmap, which indicates that the HUB-Robeson Center is a hotspot on a regular basis.

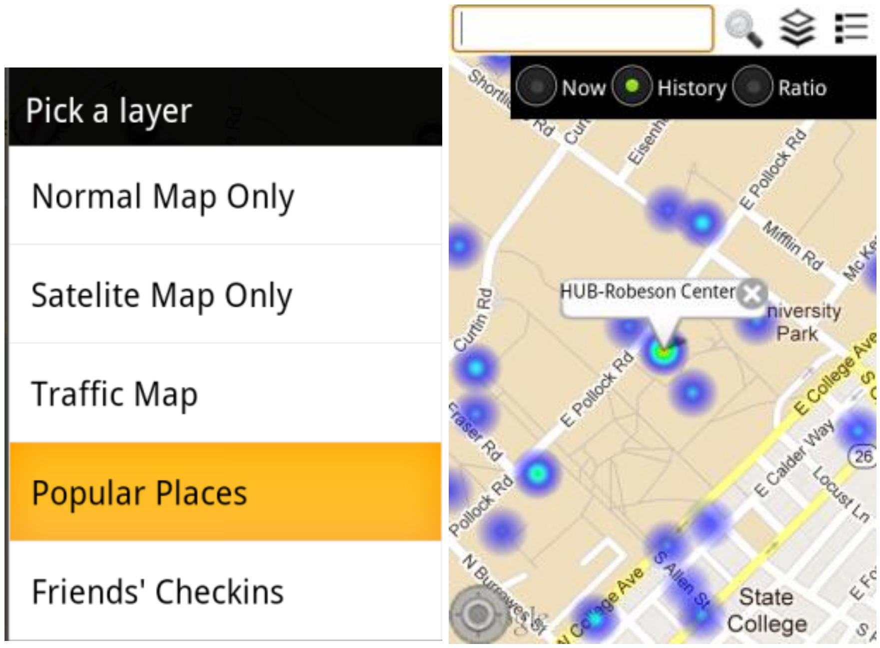
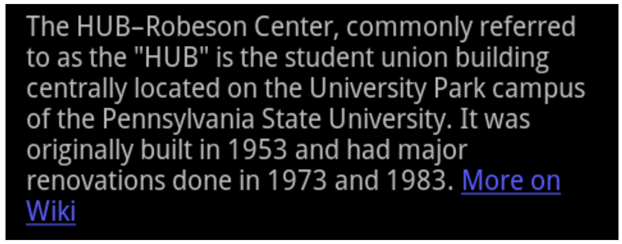


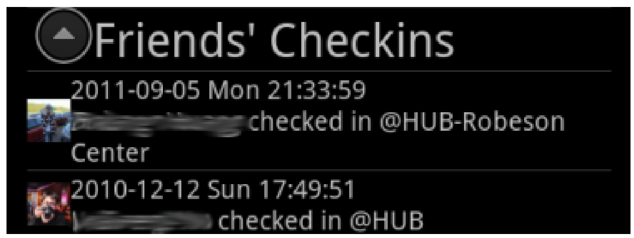
Figure 5-11. “Popular Places” on a heatmap.

Jen wonders why the HUB is so popular, so she taps on the callout and switches to the POI View. After reading the Wiki snippet (Figure **5-12**a), Jen realizes that the HUB is the student union on campus and tips from Foursquare suggest it is the best place for people to meet on campus (Figure **5-12**b). She also finds out a few of her Facebook friends from her high school have checked in there (Figure **5-12**c). She recalls that two of them are students at the university, so she calls them.



(a) Wikipedia Snippet

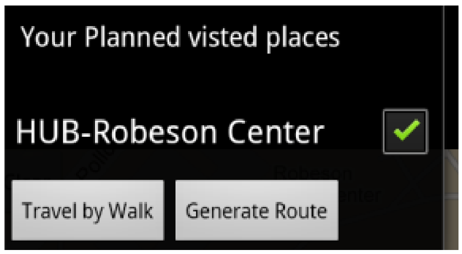
(b) Foursquare Tips



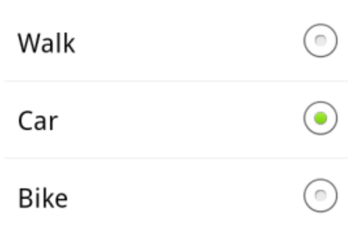
(c) Friends' Check-in

Figure 5-12. Information of a place on the POI View.

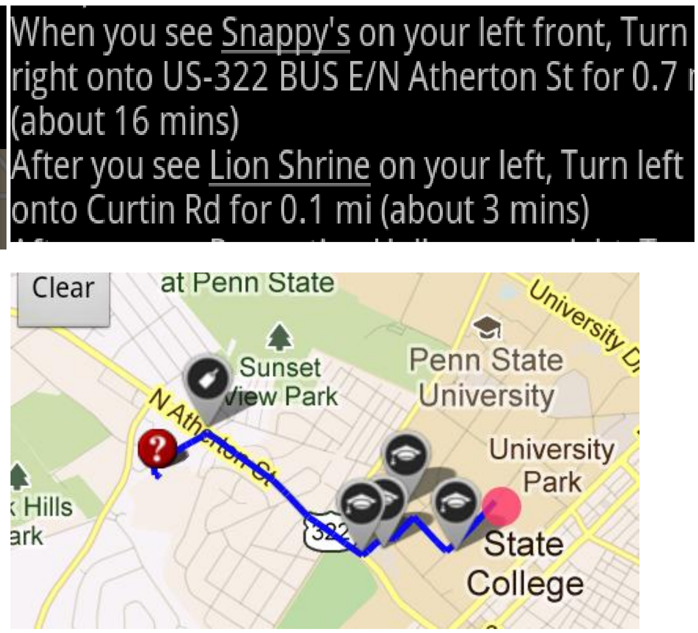
After talking to her friend, Tom, who is currently studying at this university, Jen sets up a meeting with him to have lunch at the HUB. She adds HUB to a shopping cart-like trip planner in Proximity Explorer and sets up the mode of traveling to get directions. Proximity Explorer generates a route on the map with memorable landmark information and emphasizes these landmarks in the textual direction above the map (Figure **5-13**). Landmarks are selected within a100-meter radius region with the highest accumulative check-in count.



(a) Trip planner



(b) Mode switch



(c) Direction and route on the map

Figure 5-13. Trip-planning and route direction with landmarks.

By following the navigation directions, Jen arrives at the HUB a few minutes earlier. To kill some time, she explores more information about the HUB with Proximity Explorer and finds a set of pictures of it on the visual tab. Jen looks through the Panoramio pictures in the photo gallery about the HUB and decides to contribute one as well. She takes a picture of the front entrance of the HUB by pressing the camera button on the right button corner and comments on the picture as “Excited to see my old friend at HUB” (Figure **5-14**). The photo and comment is immediately uploaded to Proximity Explorer server and it becomes public to other users.

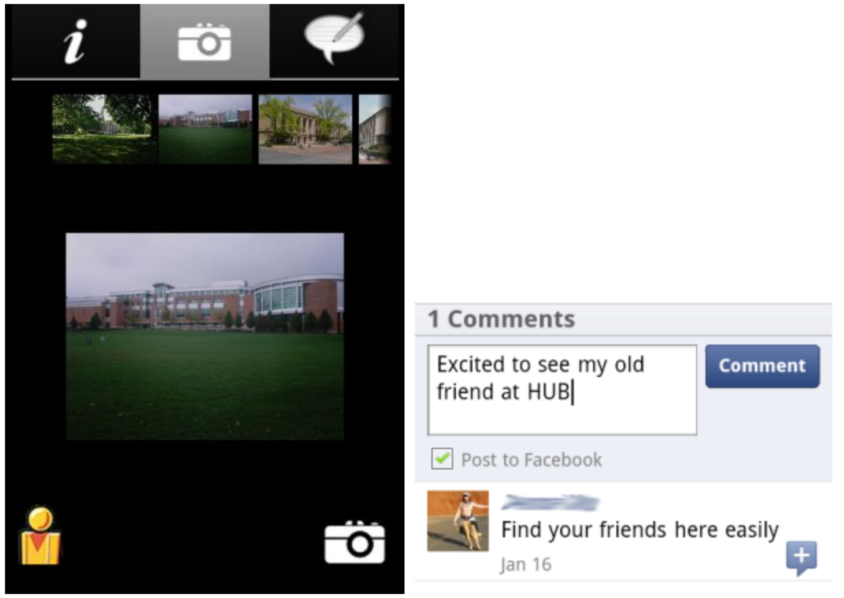


Figure 5-14. Upload picture and comment.

Responding to design goals

Proximity Explorer is a proof of idea implementation for the design goals proposed in Chapter 4. Specifically, it aims to provide information from the three aspects in different levels.

For spatial information, Proximity Explorer presents information to support building landmarks, route and survey knowledge. Users can read textual description (Figure **5-5**b), view the 2D pictorial representation, and 3D Streetview of a certain landmark (Figure **5-8**). Unlike regular computational route directions, Proximity Explorer incorporates salient landmarks in the directions by selecting the most popular places near the decision points. The route directions are presented both textually (which can be shared) and on the map (Figure **5-13**). Users can also explore the surroundings by categorized POIs.

For social information, users can view where their friends have recently been in a Facebook friends' check-in list (Figure **5-6**), which might trigger the discovery of potential interesting places. For a specific POI, users can review tips contributed by the public to gain a sense of the place and to check if any of their friends have been there (Figure **5-9**).

The heatmap presents the temporal dynamics of popularity in a region. Users can view what is now popular, historically popular and the ratio between the now and historic popularity.

System architecture and implementation

Proximity Explorer adopts the client-server architecture (Figure **5-15**). The client side includes four modules: *network*, *location*, *user interface* and *logger*.

- **Network module** monitors the network status, sends client parameters (e.g. location, users' information, interface request), and uploads user-taken pictures and log files to the server. It also receives responses (e.g. information about POIs, friends' check-ins, and directions) from server and passes them to the user interface module.
- **Location module** gets the updated location information using Android internal LocationManager Class and feeds received coordinates to other modules. The location module updates every 1-minute or 10 meters, whichever occurs first.
- **User interface module** is responsible for interaction between users and the mobile devices. It receives users' request, sends commands to corresponding modules, and presents the returned results to the users. See UI design section for details.
- **Logger** records users' interaction with the interfaces (e.g. clicks, views), usage of the application (e.g. session), created artifacts, and location. The logger filters and stores Android internal Logcat output in a local file. It also uploads and processes new logs to the database on each fresh start of the application.

The server side consists of an application server and a data server. The application server has four main components: *service connector, service-specific ontology, ontology merger,* and *Proximity Explorer ontology.*

- The **Service connector** authenticates and connects to external internet services (Foursquare, Google, Panoramio, Wikipedia, Facebook) through their REST-based APIs, and gets the HTTP/HTTPS response as JSON objects.
- The response is parsed into a **service-specific ontology.**

The **Ontology Merger** integrates geographical information from different web-services. Currently, vicinity and placename match are two methods to unify references across services. See the section in this chapter (Information integration and representation under a unified application) for details. Venue category can also be used to improve data quality for location-based information fusion, which I have not implemented yet.

- A unified **Proximity Explorer Ontology** is the result of the merging of information three formats: Abstract POI, which is used to show a cluster of the nearby venues on map view; friends' Facebook check-ins, and a complete POI for the detailed View. The later two are generated only when users click the POI with consideration of network traffic and responsive performance.

The data server stores users' interaction logs, GPS trajectories, and generated contents, such as photos. Users' photos are uploaded and stored in a Tomcat server with metadata extracted and stored in MySQL (user id, poi id, location, time).

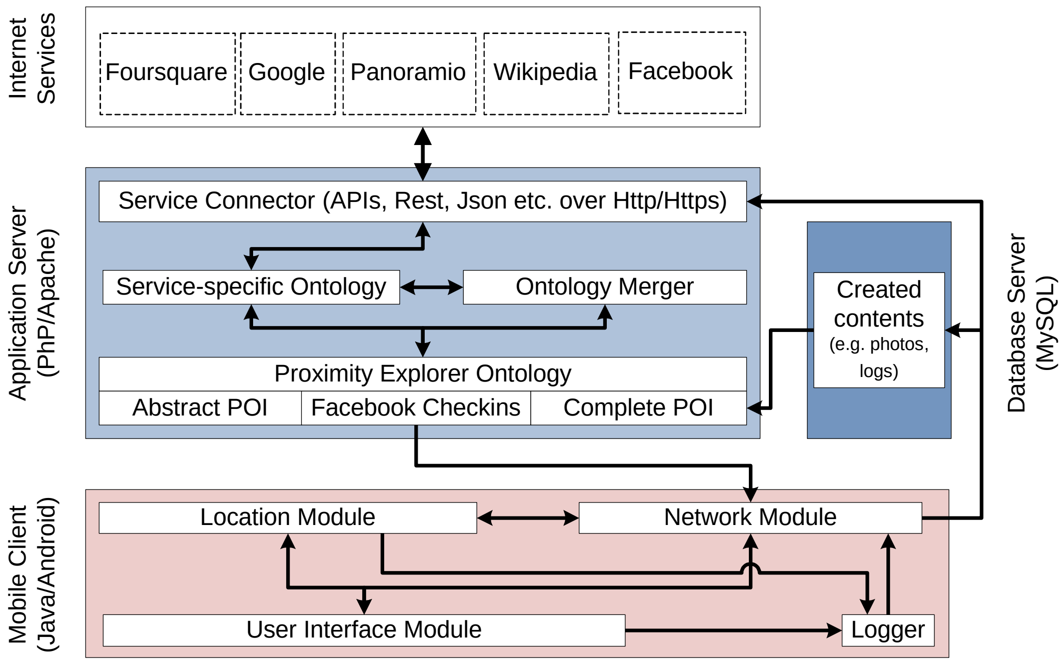


Figure 5-15. System architecture of Proximity Explorer.

The client part is written in Java using the Google SDK API level 8, which runs on Android platform 2.2 and above. Transition of different views is implemented through an Android mechanism for launching activities, aka *Intents*. Server side uses PHP to parse responses through various open APIs: from Foursquare for venue information, DBpedia for corresponding Wikipage, Panoramio for nearby photos, and Facebook for friends' check-ins. The application has been tested to be compatible with most recent Android devices, including but not limited to HTC Nexus One, HTC Nexus S, Samsung Galaxy, Samsung Galaxy S, Motorola Droid, and Motorola Cliq. Figure **5-16** provides an overview of the class association and inheritance relationship among classes for the Java implementation part.

Distribution of the work between clients and architectures are well designed to ensure the responsiveness and stability of the application. For example, the computational heavy task in the POI merging process is performed on the server side and the merged results is stored on the file server, so the next client that visits the POI does not need to wait for the data to merge again. On the client side, when a user take a picture, she will see the picture instantly on the gallery in the photo tab, which is drawn directly from the local external storage, while a back-end thread is uploading the picture to the server, where the photos in the gallery is actually downloaded from.

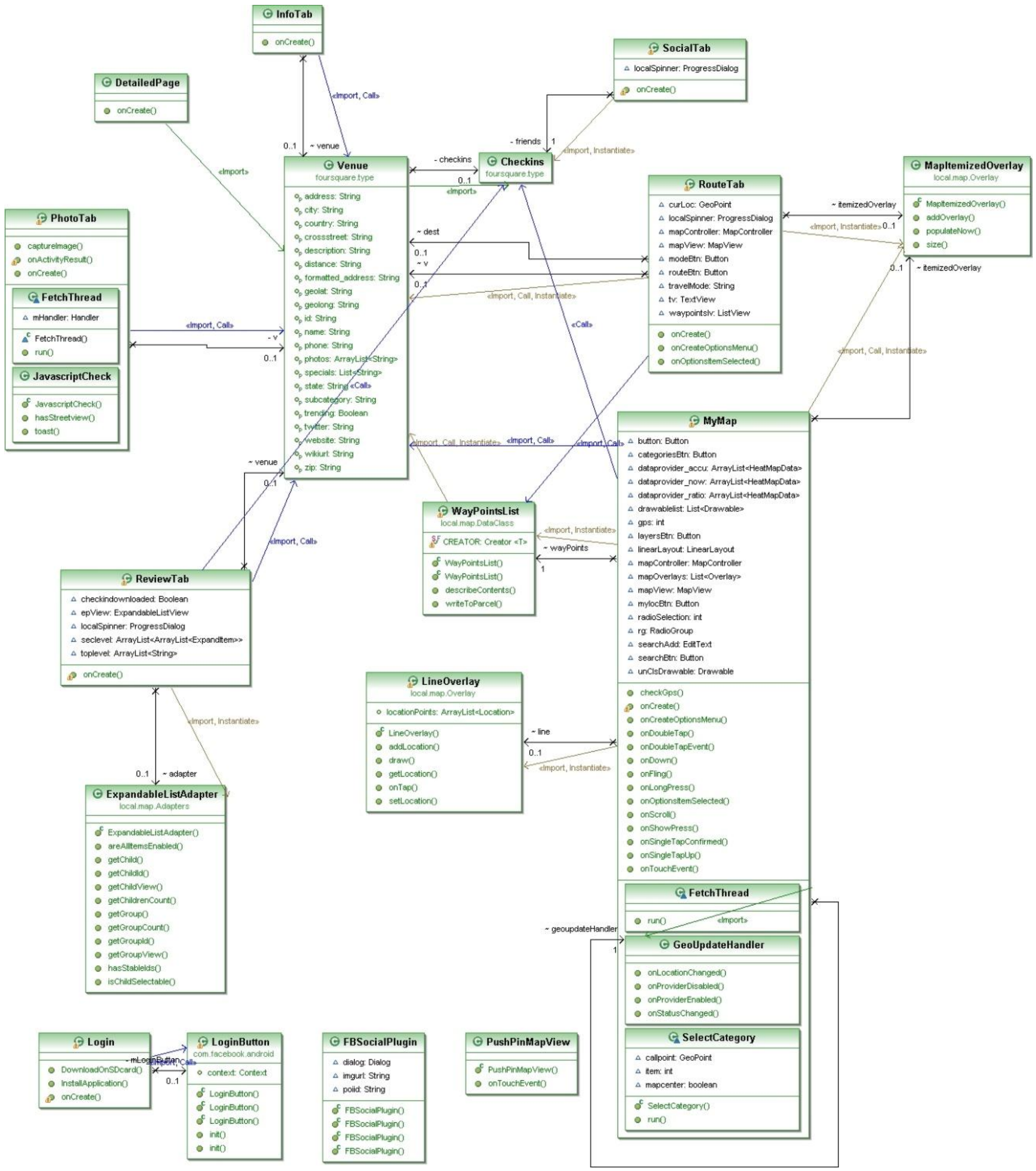


Figure 5-16 Class diagram of the client Java code

Chapter 6

Field Evaluation

This chapter reports a study of evaluating Proximity Explorer. The complexity and richness in the field provide better opportunities to test our design of integrating multiple information resources to support place sensemaking. The study collected both subjective feedbacks through in-depth interviews as well as objective instrumental data from usage logs to provide a complete assessment. College students who are open to novel technology and possess smartphones were recruited to conduct a field evaluation either in their familiar university campus, or on trips. A post-questionnaire regarding usability and effectiveness of supporting place sensemaking suggests that Proximity Explorer fulfills its design purpose.

Evaluation Setup

I conducted a field study to understand how people used Proximity Explorer by inviting college students to use Proximity Explorer on their own Android devices for 2-3 weeks. Participants were asked to use the application with their own devices in their everyday tasks to make the application live in the rich mobile context, and through recruitment (rather than launching to Android Market) gives us accessibility of users for further inquiry.

Participants

Eighteen students (8 undergraduates and 10 graduates) were recruited to use Proximity Explorer for 2-3 weeks. Participants' ages ranged from 21 to 32 (11 males and 7 females). I conducted a background survey to understand our participant's information seeking behavior on mobile devices. See Appendix C for the questionnaire.

The results of the background survey suggests that 67% of our participants owned Android devices for more than one year, 17% between 6 months to 1 year and 17% between 1-6 months (Figure **6-1**). All of our participants use Android applications daily and have installed more than five applications from the Android Market by themselves (78% installed more than 10 applications, Figure **6-2**). These numbers indicate that our participants are experienced Smartphone users who are open to new mobile applications.

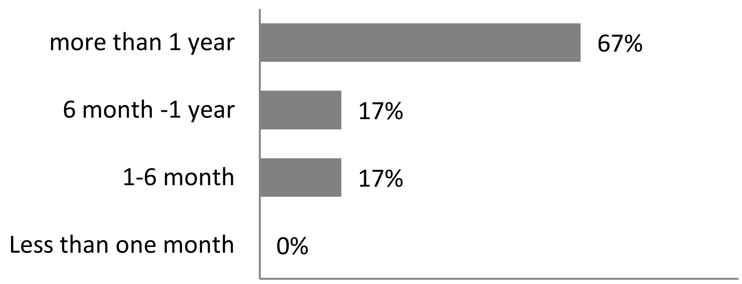


Figure 6-1. Distribution of the Android phone ownership length

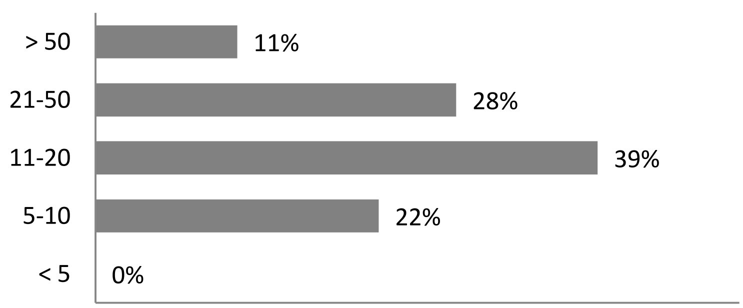


Figure 6-2. Distribution of number of application installed from Android Market

The survey also asked participants to rank the top three types of information accessed from their mobile phones to detect their information seeking behavior in general. Travel/navigation, mails/messages, and social networks are the three most often used application categories by our participants in general (Figure **6-3**). The rank suggests that our participants want to keep connected with their friends, keep informed, and like to travel or move around.

Regarding the application usage on travel, the survey asked users to list the top three applications that they used most often. Google Maps, Facebook, and Gmail/messages are the top three applications used when they are away. Such results indicate that our participants want to be connected with their friends and keep informed no matter where they go. Thirteen participants listed Google Maps in response to this question. The survey also asked them to check all the information resources they used to get to know a new place. Google Maps, Web Search, and Friends are the top three information resources accessed (Figure **6-4**).

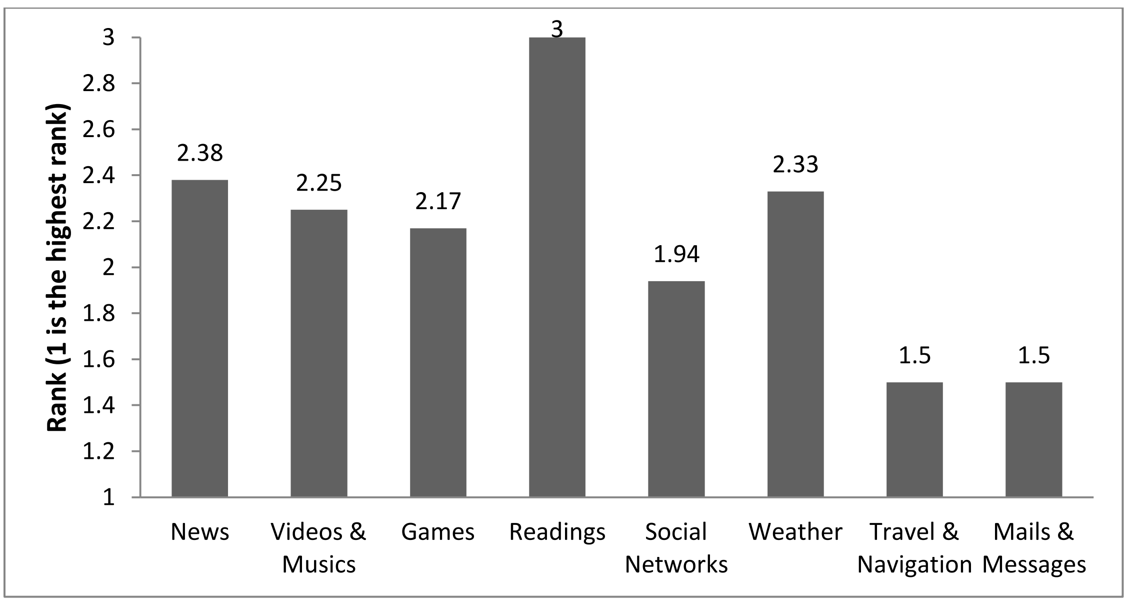


Figure 6-3. Most visited information resources on regular basis.

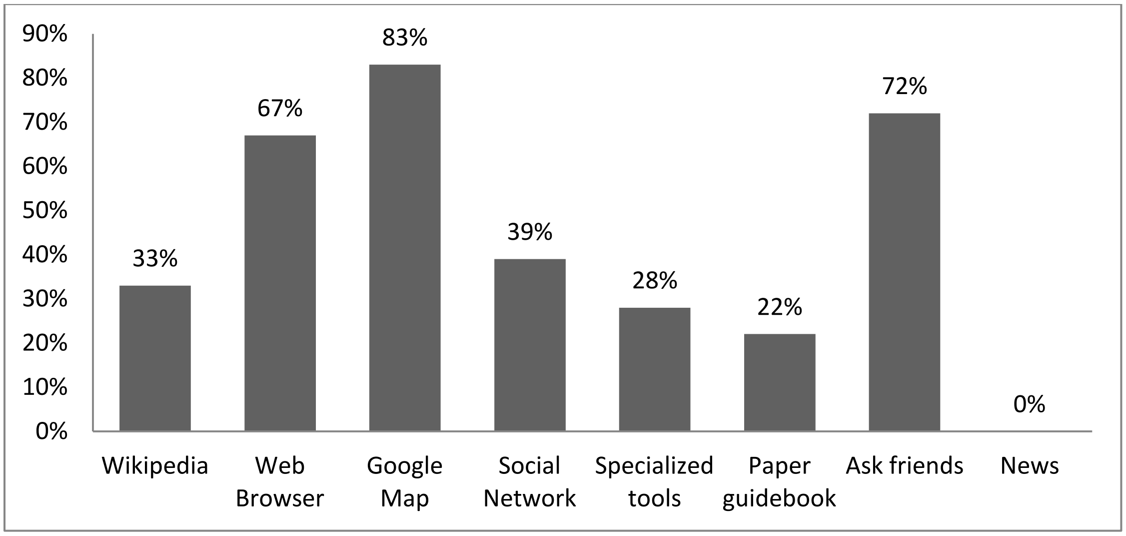


Figure 6-4. Information resources accessed to know a new place.

Data collection

The study was carried out during the 2011 winter break. Half of the participants took at least one trip away from State College during the study. Multiple research methods were used for data collection. Questionnaires tackled users' experience through a pre-specified list to get the profile of mobile device usage of the users. Interviews offered an interactive method of acquiring data from users to investigate what actually happened. Field tests were useful to observe actual service usage in a real context.

Before the study, participants filled out a background questionnaire to provide their familiarity and usage pattern of Smartphone applications. The questions used are listed in Appendix C.

The study logged users' interaction, location (only when using Proximity Explorer), and created artifacts on our server for data analysis. The interaction was logged through Android Logcat and stored temporally in a text file on the external storage (e.g. SD card) until the next usage of Proximity Explorer, when the log file was uploaded to our server. Interaction actions (e.g. clicks, long-press) and the targeted items (e.g. menus, markers, tabs, directions) were stored in the log files. Users' location and timestamps were periodically (either 5 second, or 10 meters whichever occurred first) tracked by either GPS signal or wireless position, whichever was more accurate. Users' photos were uploaded to the file server and metadata (e.g. time, location, user id) was stored in the database server. Users' comments of the POIs and associated photos were stored on Facebook servers, which are accessible and managed through the developer's account on the Facebook Social API.

A 20-minute semi-structured interview was conducted for each participant after the trial. The questions focused on users' feedback on the application (e.g. general impression, likes and dislikes of the features) and reflection of the usage scenarios with the assistance of a usage log-visualization. As shown in Figure **6-5**, a web-based map-centered user interface was developed to help users recall the actual usage scenario. By selecting a session, the time and major interaction is shown on the interface. The red line shows the participants' trajectory, the red ballon indicates that the participant did view the POI view of that place, and the green balloon indicates that the participant only clicked the marker of that place without seeking additional information. Notes were taken during the interviews.

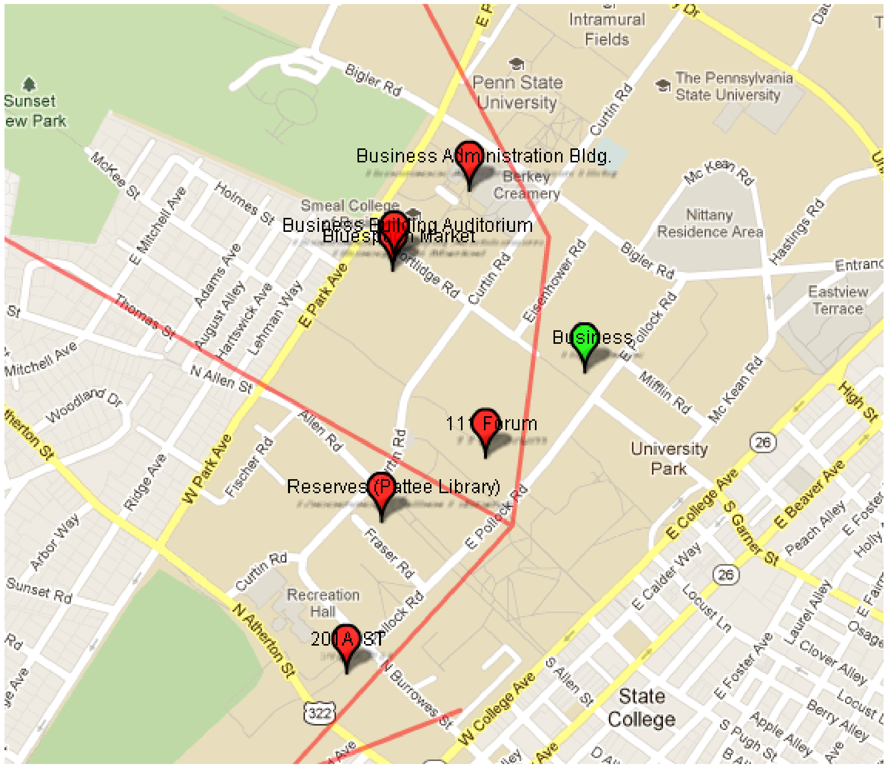


Figure 6-5. A user interface of the log data to assist usage recall.

I also asked participants to provide subjective ratings comparing Proximity Explorer with Google Maps in terms of usability and functionality after the trial. See Appendix D for the survey questions.

The log data, users' description of what actually happened, and their subjective ratings provide both subjective and objective evaluations of how Proximity Explorer works in practice.

Results

Verkasalo (2009) has summarized empirical evaluation approaches for mobile services, including analysis of application adoption, research on stickiness of application usage, measurement of technical performance, evaluation of end-user experience, and collection of end-user feedback. The purpose of this evaluation was threefold:

The first purpose is to demonstrate that the design goal is feasible. I expect to prove that the development of a user-friendly tool is practical by following the design guidelines.

The second purpose is to validate the design goal is the right direction to support place sensemaking. Earlier, I claimed that to support place sensemaking required information not only from spatial dimensions, but also from social and temporal dimensions. In the evaluation, I want to see if this is necessary, whether users will use such information, and if they do, will this help them to sense the place?

The third purpose is to increase our understanding of place sensemaking practice with mobile devices. By analyzing the data from real usage scenarios, I want to know how users actually make sense of the place when they have mobile applications like Proximity Explorer.

In this section, I will apply quantitative data analysis method for the log data and users' subjective ratings and qualitative data analysis methods for the interview data.

Quantitative analysis

Log analysis

I am interested in understanding how individual users' interact with the application, rather than to evaluate the infrastructure of the service. Thus, the analysis here concentrates on the clients' logs (in contrast to the server logs), which reflect the usage pattern and interaction flow.

Data cleaning was conducted before the analysis. Unreasonable short sessions (less than 5 seconds), trial sessions (when users are learning how to use the application during recruiting), and crashed sessions were removed in the data cleaning process. A session is defined from the start of a users' intentional action to the last action, which is defined if idle for 10 minute. (Due to the auto application launching on Android OS, the launch time cannot be used as the starting time.) After data cleaning, participants generated 17.3 sessions on average individually (SD=15.6) and 312 sessions in total. The median session length is 54 seconds. Distribution of the session length (Figure **6-6**) indicates that short visits (less than 3 minutes) are dominant (74.3%), which fits the mobile practice—for a quick look up. It is worth noting that compared to desktop applications, quick interactions with mobile devices are reasonable, considering the dominant task in mobile contexts is to interact with the physical world.

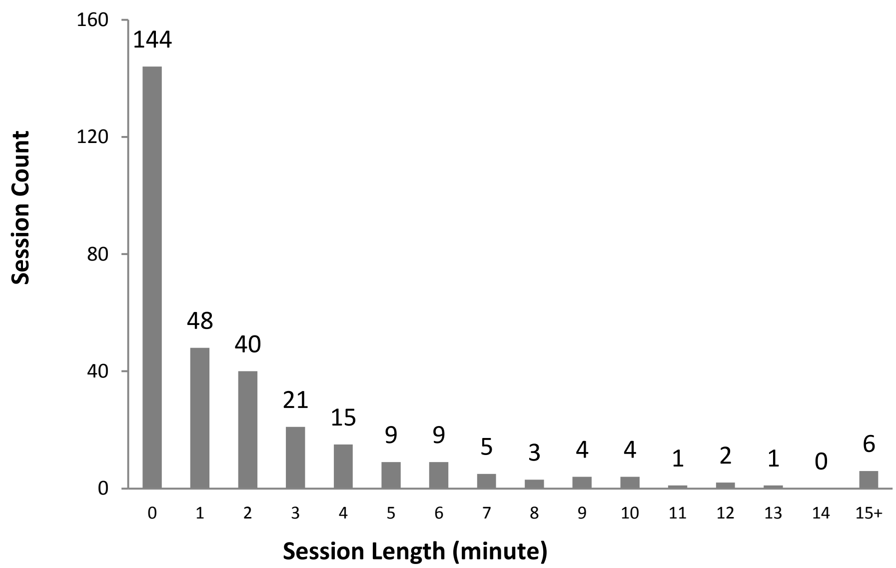


Figure 6-6. Distribution of session length.

Most activities (71.6%) happened during the daytime, 9am - 11pm, especially in the afternoon and earlier evening (Figure **6-7**). Note that some of the activities occurred after the required three-week study period (25.2%), which indicated that our participants would still like to use the application even after they were not required to do so.

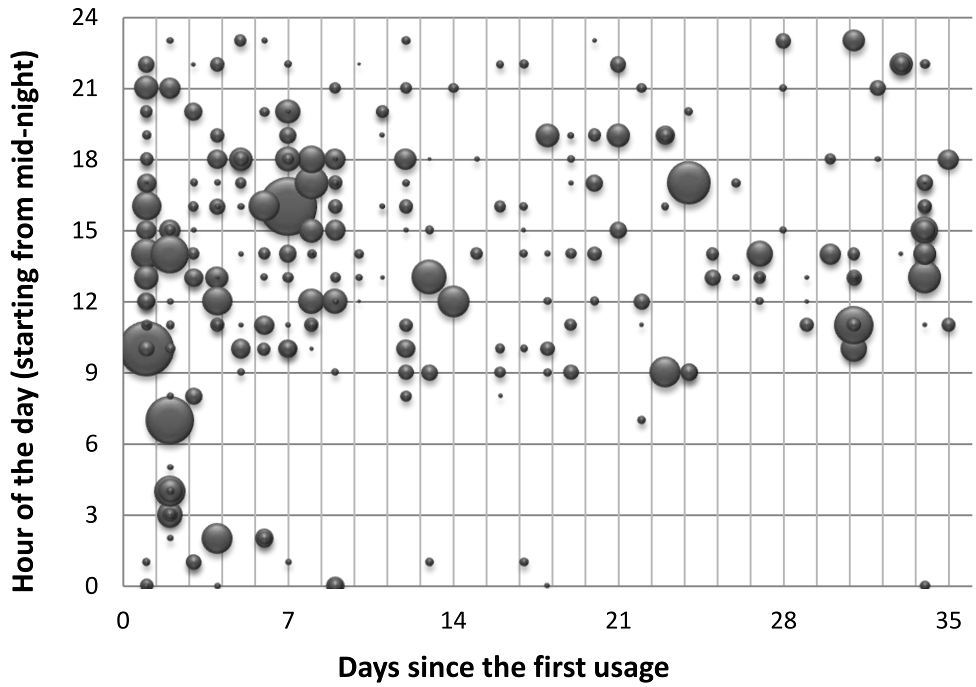


Figure 6-7. Temporal pattern of the usage (bubble size represents session duration).

Interaction logs can help to understand whether people actually need information from different resources, and if they do, what resources are requested. Figure **6-8** shows the transition diagram of aggregated interaction activities of all participants on the Home View. In this diagram, each circle represents a state (or a page) that is derived from the Home View. A link and link direction between two states indicate a transition from one state to another and transition direction. The thickness of a link corresponds to the frequency of a transition. As shown, every UI component has been visited somehow, suggesting that participants did request multiple information resources throughout their usage. It can also be seen that almost each two components are connected with each other, suggesting diverse ways participants interact with the view. Specifically, the search and category menu are two tools that participants used most.

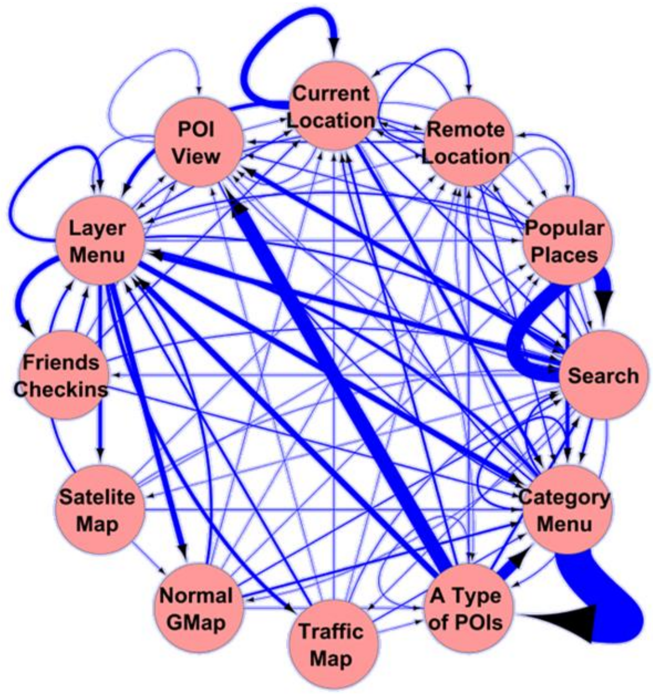
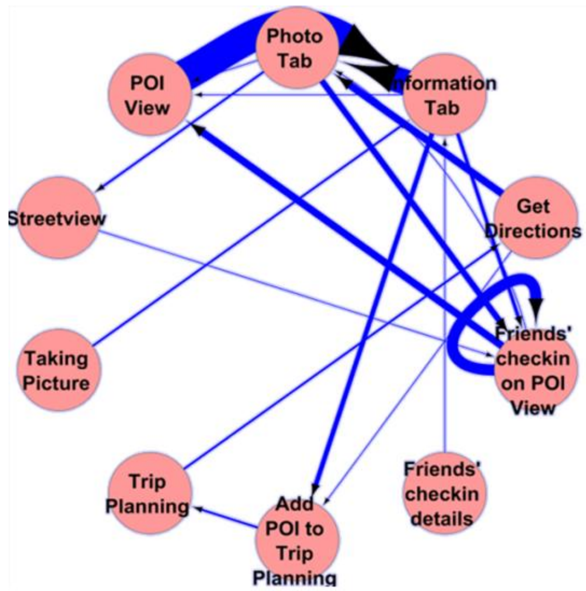
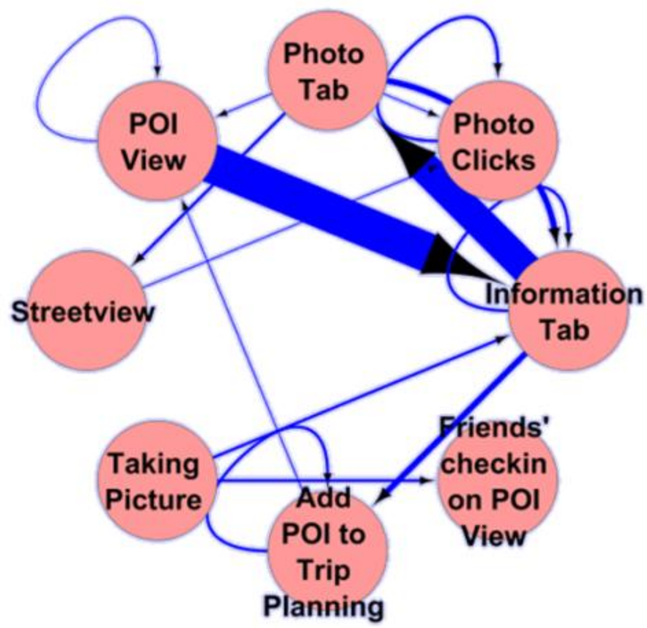


Figure 6-8. Transition diagram of aggregated activities on the Home View.

Individual preferences of tools can also be observed with the state transition diagram. Figure **6-9** shows the aggregated activities of two participants on the POI view. As shown, while a participant was more interested in route planning and where friends have been (Figure **6-9**a), the other primarily focused on browsing pictures of individual POIs (Figure **6-9**b). Such difference suggests further personalized representation of information resource desirable.



(a) Direction and social fan



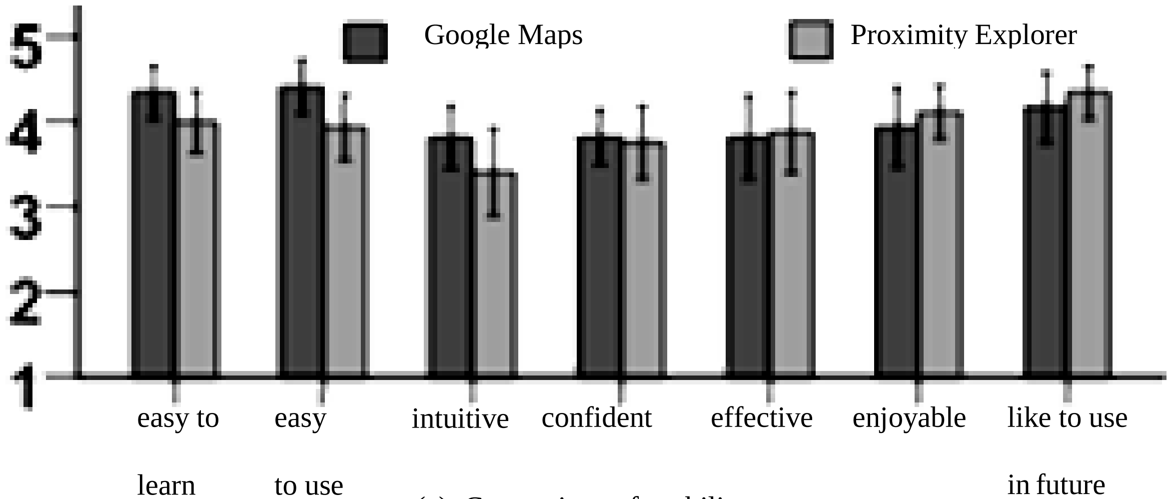
(b) Photo viewer

Figure 6-9. Interaction flow on the POI View (aggregated activity transition of all the sessions for two users).

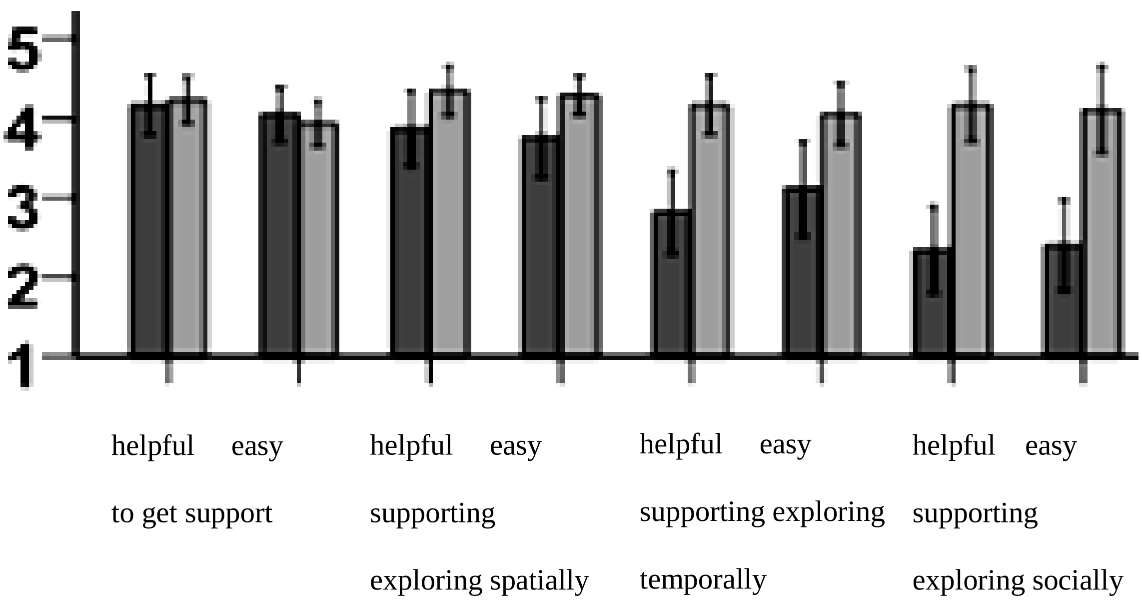
Subjective ratings

Wilcoxon signed rank tests (2-sided test) find no difference between Proximity Explorer with Google Maps in the helpfulness and easiness to get support to know a new place in general. No significant difference in getting the help of spatial information is observed either. However, when comparing the other two dimensions, Proximity Explorer provides significant helpfulness and easiness in getting social information (helpful: $Z=2.355$, $p=0.019$; easy: $Z=3.572$, $p<0.001$) and temporal information (helpful: $Z=2.179$, $p=0.029$; easy: $Z=2.961$, $p=0.003$) of the new place. These results suggest that our participants are well aware that Proximity Explorer can perform as well as Google Maps in supporting exploration of new places, and can offer temporal and social information, which is not provided by Google Maps.

Wilcoxon signed rank tests suggest that Google Maps is still easier to learn ($Z=-2.121$, $p=0.034$), and easier to use ($Z=-2.828$, $p=0.005$), while all the other comparisons did not reflect any significant difference. Such results suggest that Proximity Explorer can provide the confidence, efficiency, joyfulness as well as Google Maps does and our participants would like to use it in the future (Figure **6-10**).



(a) Comparison of usability



(b) Comparison of supporting place sensemaking

Figure 6-10. Subjective ratings comparing Proximity Explorer with Google Maps (1: Strongly Disagree, 5: Strongly Agree).

Qualitative analysis

The purpose of post-study interview is to help us understand how users actually use the Proximity Explorer in the process of place sensemaking. During the interview, the interviewer took notes to highlight examples given by the interviewee. The interviewer recorded these examples and the descriptions of the users' experiences into the actual transcripts.

Usage scenarios

Participants used the application differently. Some simply saw the application as a replacement for applications like Google Maps and Google Place. For example, some participants found the category menu useful to explore nearby surroundings spatially as it shows clusters of POI of a certain type on the map.

"We were driving down to Florida on I-95 and stopped at Savannah for lunch. By clicking food, you can see clearly the food zone is between the Bay St. and the Liberty…" (NW)

The participants also found additional values for the information integration feature in supporting place sensemaking. The findings of the qualitative analysis indicate that the way of Proximity Explorer application supports place sensemaking can be grouped into the following themes.

- **Allow users to explore the place of others' favorite.**

Figure **6-11** shows a usage session of a participant, YX, when visiting to the New York City. From the visualization, we can see that she clicked the marker for Elysian Café near where she was (the red trajectory). Figure **6-12** shows the logged activities retrieved from the database, and it can be seen that she checked the social tab. She told us how she virtually caught up with an old friend during the trip when seeing the visualization of logged interaction:

"We were college mates. … I know she studies in NYC, but do not know where exactly. Her check-in at a coffee shop, near our hotel, 3 months ago makes me think she might not be far away. … I called her and confirmed she was nearby! ... I even took her advice of a great local

restaurant for lunch that day, which I would never found, otherwise. …We did not meet in person, because I had other companies during the trip. Otherwise, we would." (YX)

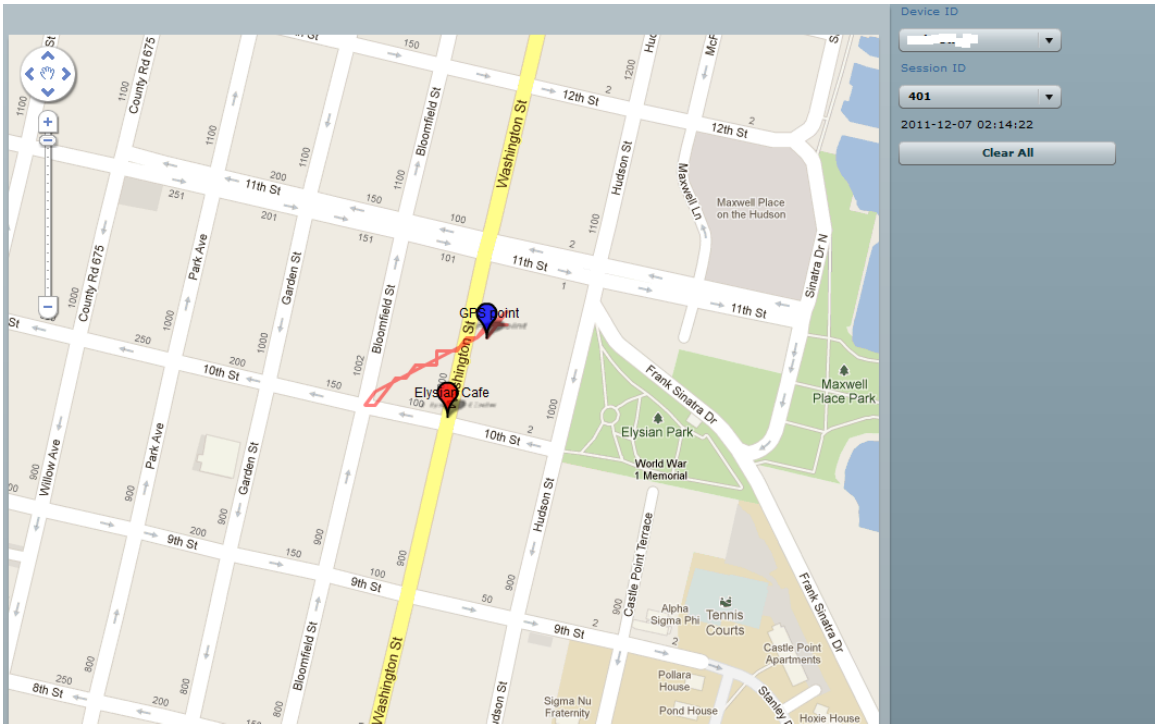


Figure 6-11 Screenshot of visualizing user YX's log for a session in New York City

idactivity	idsession	startdate	starttime	activity	content
5322	401	2011-12-07	02:14:30	click	marker:4b22b45cf964a520244c24e3
5323	401	2011-12-07	02:14:40	info view poi	4b22b45cf964a520244c24e3
5324	401	2011-12-07	02:14:46	click	Friends checkin

Figure 6-12 Snippets of YX's log data corresponding to the discussed session

With the support of Proximity Explorer, several components of place sensemaking happened in this usage:

- YX *detected the cue* of potential information resource as she saw a friends' check-in at a nearby coffee shop;
- She *inferred* that this friend might not be far away; and
- She *tested her hypothesis* by actually calling her friend and got the confirmation.

The result of this scenario suggests that the tool provided a chance to explore the user's friends' favorite restaurant and to enjoy the food there without even meeting that people in person, which will be hard to accomplish without the social information presented on the application.

- **Create potential social interaction.**

The above scenario also suggests the potential social interaction that triggered with the visibility and acknowledgement of a certain visit, which was suggested by the participants but is not actually being used yet.

"I think it might serve as icebreaker on a party. Suppose I saw a friend checked at a beer place before, I may ask him 'how was it?' … Just to kick off the conversations." (ZX)

- **Support place sensemaking with schemas of POIs**

Participants indicated that the application provided richer information on the categories of places and their features, which is very helpful to explore new places. As can be seen from the logs shown in Figure **6-13**, a participant, WN, used the application in a foreign territory and explained the benefits of the application:

"The cruise stopped at Charlotte Amalie, one of the British Virgin Islands. We had no idea where to go, so I used Proximity Explorer and went to the outdoor category. I found quite a few of places, like SkyRide to Pradise Point, Blackbeard's Castle... The one "Hello Kitty's lane", a hiking trial, looks especially interesting to me as we can see gorgeous pictures taken from there…"(WN)

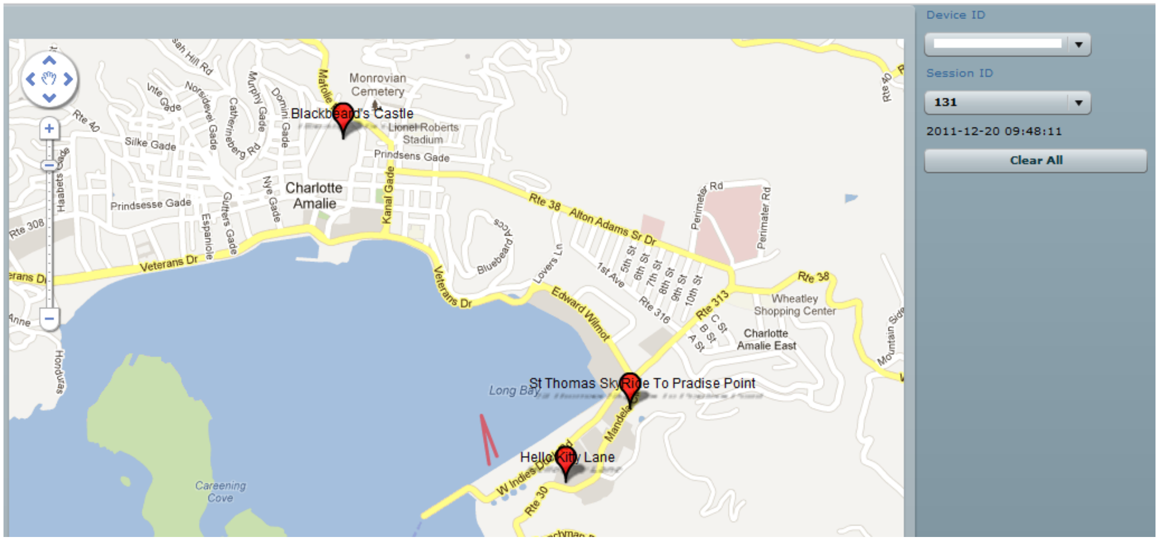


Figure 6-13 Screenshot of visualizing user WN's log for a session in British Virgin Islands

idactivity	idsession	startdate	starttime	activity	content
1967	131	2011-12-20	09:48:11	click	mylocation
1968	131	2011-12-20	09:48:17	click	layers
1969	131	2011-12-20	09:48:22	click	Popular Places
1970	131	2011-12-20	09:49:32	click	category
1971	131	2011-12-20	09:49:40	click	Great Outdoors
1972	131	2011-12-20	09:49:49	click	marker:4eb83e4ccc2143e8292a890c
1973	131	2011-12-20	09:49:57	StartIntent	cmp=local.map/.Views.DetailedPage (has extras) }
1974	131	2011-12-20	09:50:47	info view poi	4d3744d9c47db1f70552eea5
1975	131	2011-12-20	09:50:49	photo view poi	4d3744d9c47db1f70552eea5
1976	131	2011-12-20	09:50:38	click	marker:4d3744d9c47db1f70552eea5
1977	131	2011-12-20	09:50:46	StartIntent	cmp=local.map/.Views.DetailedPage (has extras) }
1978	131	2011-12-20	09:50:47	info view poi	4eb83e4ccc2143e8292a890c
1979	131	2011-12-20	09:50:50	photo view poi	4eb83e4ccc2143e8292a890c
1980	131	2011-12-20	09:50:58	click	marker:4cd2c629df88a35d37cb6aa0
1981	131	2011-12-20	09:51:59	StartIntent	cmp=local.map/.Views.DetailedPage (has extras) }
1982	131	2011-12-20	09:52:02	info view poi	4cd2c629df88a35d37cb6aa0
1983	131	2011-12-20	09:52:09	photo view poi	4cd2c629df88a35d37cb6aa0

Figure 6-14 Snippets of WN's log data corresponding to the discussed session

The logged activities (Figure **6-14**) tell us what WN did. She clicked the category menu (idactivity 1970) and then selected the Great Outdoors category (idactivity 1971). After seeing potential options on the maps and comparing three POIs individually by checking the photos (idactivity 1972 – 1983), she thought the last POI, Hello Kitty Lane marked in Figure **6-13**, was interesting based on the viewable pictures. This process exemplified how users make sense of the place guided by a category of POIs in mind, a top-down approach, and applied *option comparison*, to make sense of the surroundings.

- **Support understanding and communicating the spatial knowledge with the imbedded landmarks in route directions.**

One participant, DS, used the application for route directions very frequently. DS's job involves many interactions with students and parents asking for directions on campus. When asked what he liked about the route directions by Proximity Explorer, he indicated that compared with other navigation tools, the app gives the directions and anchor points *"that you can remember"*:

"Yes, I did use the direction part a lot. When someone is approaching me for direction, I always get the app out and it helps me wording the directions… I like the direction given by the app, with anchor points that you can remember…I can never remember how many miles, or minutes, to make turns after you get onto a road, not even with the direction on hand. So do others…"(DS)

By digging the activity logs of DA, we found that 8 out of the totally 14 sessions (57.1%) involved generating directions for POIs. Figure **6-15** is the logged data for a typical session, which was only being used for the purpose of generating the direction to a POI.

idactivity	idsession	startdate	starttime	activity	content
3667	273	2012-02-10	11:35:32	click	category
3668	273	2012-02-10	11:35:33	click	Arts & Entertainment
3669	273	2012-02-10	11:35:43	click	marker:4b22ff78f964a520db5124e3
3670	273	2012-02-10	11:35:44	StartIntent	cmp=local.map/.Views.DetailedPage (has extras) }
3671	273	2012-02-10	11:35:44	info view poi	4b22ff78f964a520db5124e3
3672	273	2012-02-10	11:35:46	add poi to list	4b22ff78f964a520db5124e3
3673	273	2012-02-10	11:35:46	StartIntent	cmp=local.map/.Views.RouteTab (has extras) }
3674	273	2012-02-10	11:35:46	route view poi	4b22ff78f964a520db5124e3
3675	273	2012-02-10	11:35:54	dir	After you see <u>Atherton Hotel</u> on your left, Tur…

Figure 6-15 A typical session of DS's usage to get the direction of POIs

His usage scenario confirms the importance of both spatial and social saliency of landmark. Landmarks with spatial and social features not only help people remember directions better, but also enhance knowledge sharing (spatial knowledge in this case) among people, which is a key factor of sensemaking according to Weick (1993).

- **Support deeper exploration of familiar places with information integration.**

In addition to standard spatial information on the map, participants also took advantage of the availability of temporal and social information when exploring new POIs even in the familiar environments and making decisions on where to go. One participant, HK, who has lived in State College for three years, said:

"… last Wednesday, I was with several friends. We were talking about where to go for food. Found out Jersey Mikes' Subs seems to be a recently-opened restaurant, really hot at that point…I've never been there before, but from the pictures, it seems nice…From the tips, we also found they have daily specials. We decided to give it a try and now it is on my list."(HK)

Figure **6-16** shows that HK was near Davey Laboratory and checked out several places including Jersey Mike's Subs. The logged data shown in Figure **6-17** confirmed that he got to the Jersey Mike's Sub from the heatmap view and further knowing the place by *integrating* information from the info page, pictures and comments from others. Integration, a core component of place sensemaking was exemplified in this usage.

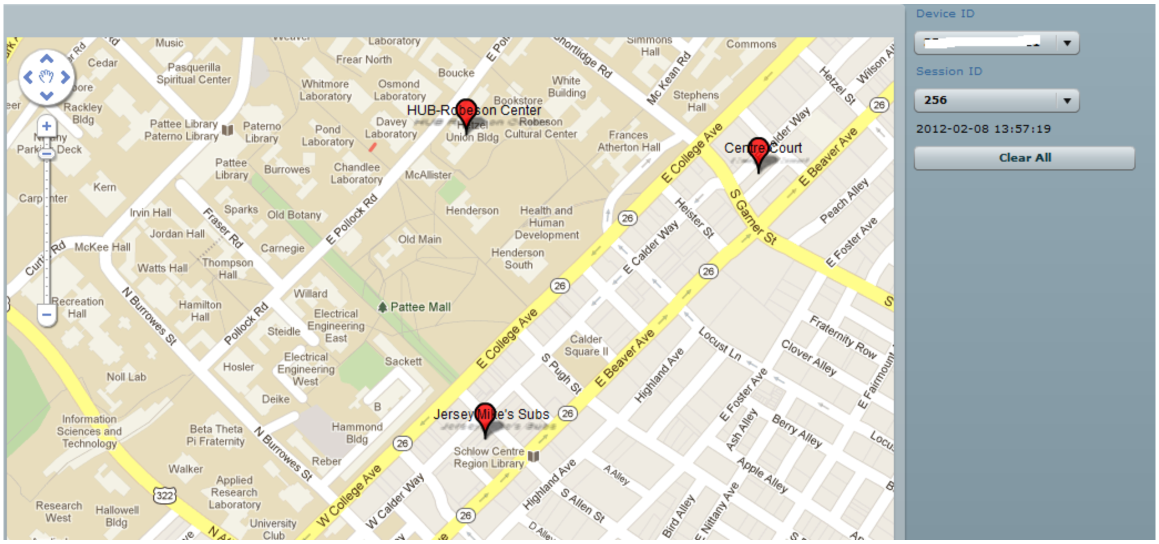


Figure 6-16 Screenshot of visualizing user HBK's log for a session of finding new restaurants at university campus

idacti...	idsession	startdate	starttime	activity	content
3211	256	2012-02-08	13:57:35	click	layers
3212	256	2012-02-08	13:57:37	click	Popular Places
3213	256	2012-02-08	13:57:39	click	marker:4e75f907e4cd3254378a754d
3214	256	2012-02-08	13:57:41	StartIntent	cmp=local.map/.Views.DetailedPage (has extras) }
3215	256	2012-02-08	13:57:42	info view poi	4e75f907e4cd3254378a754d
3216	256	2012-02-08	13:57:47	photo view poi	4e75f907e4cd3254378a754d
3217	256	2012-02-08	13:58:05	click	Friends checkin

Figure 6-17 Snippets of HBK's log data corresponding to the discussed session

The popularity heatmap is one of the favorite features of the application to know a place. A participant DS used the heatmap specifically to find out the popularity of places he wanted to go:

"… Before I went, I always check to see if there are a lot of people on the popular place view…I have checked it once with my friend, who was already there, and he is impressed by how accurate it is…"(DS)

By digging the logs, 3 sessions out of DS' 14 sessions usage (21.4%) involve checking crowdedness of Rec Hall or Pattee Library. Figure **6-18** is the logged data showing one of the heatmap view check.

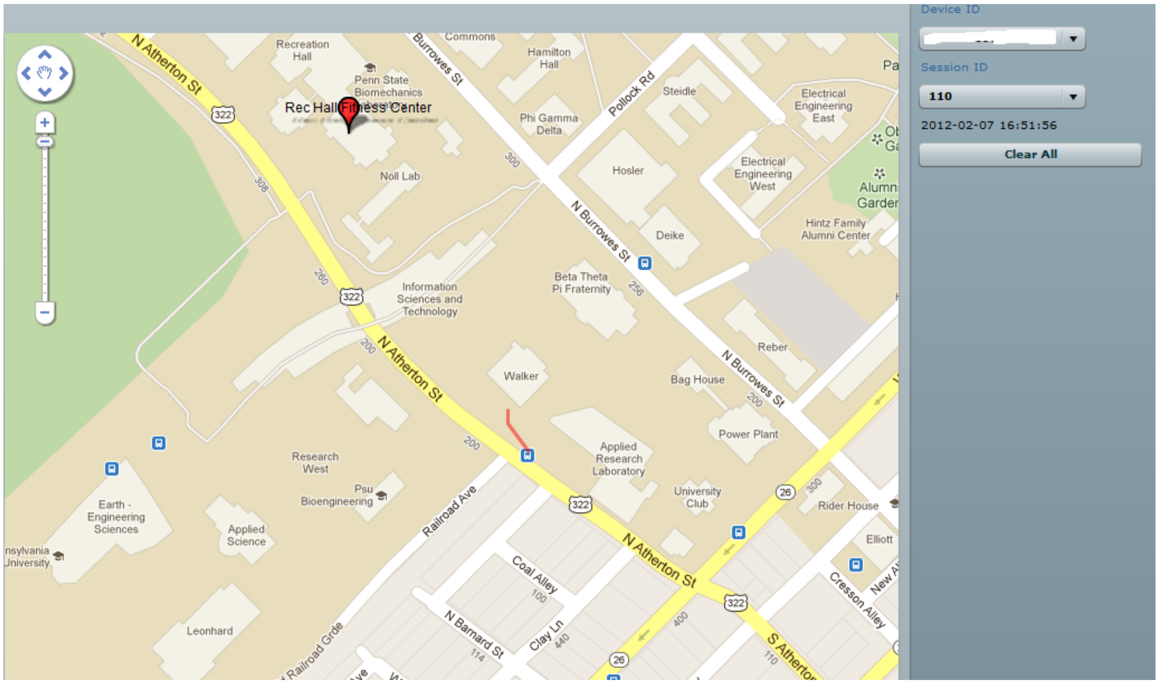


Figure 6-18 Screenshot of visualizing user DS's log for a session of checking crowdedness of Rec Hall

idacti...	idsession	startdate	starttime	activity	content
1648	110	2012-02-07	16:51:56	click	layers
1649	110	2012-02-07	16:51:58	click	Popular Places
1650	110	2012-02-07	16:52:00	click	marker:4b077550f964a520c6fd22e3
1651	110	2012-02-07	16:52:01	StartIntent	cmp=local.map/.Views.DetailedPage (has extras) }
1652	110	2012-02-07	16:52:02	info view poi	4b077550f964a520c6fd22e3
1653	110	2012-02-07	16:52:04	photo view poi	4b077550f964a520c6fd22e3

Figure 6-19 Snippets of DS's log data corresponding to the discussed session

The participants also confirmed the added value of providing online resources (e.g. Wikipedia) about a place. Some participants pointed out that having rich background information about a place increased their interest in the place and made them more engaged with the place. With log visualization as seen on Figure **6-20**, MJ told a usage scenario:

"My sister was visiting the town and I gave her a treat at the Creamery. … Everybody knows Creamery on campus, but I just knew it has been moved from an old place to the current

food science building from the wiki page of the app. I also showed her the old place on the map, which has a marker on the app, like I already knew that, (laugh), very interesting. …"

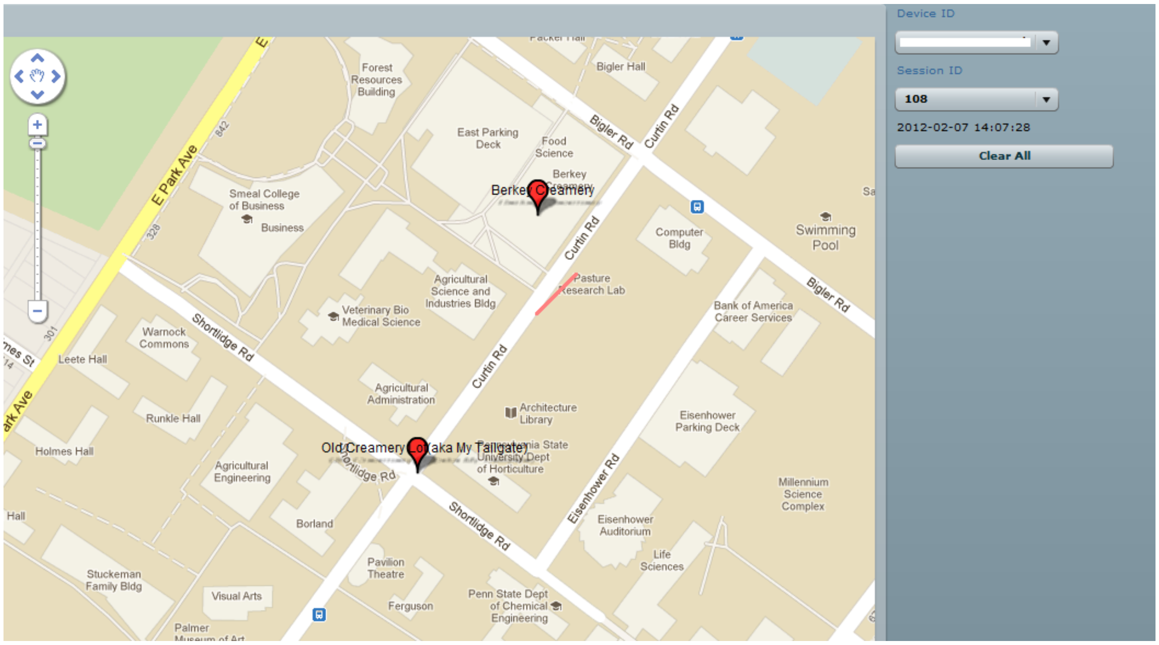


Figure 6-20 Screenshot of visualizing user MCJ's log for a session of visiting Creamery with his sister

idactivity	idsession	startdate	starttime	activity	content
1655	108	2012-02-07	14:08:10	click	search:
1656	108	2012-02-07	14:08:17	click	marker:4afeed73f964a520c13122e3
1657	108	2012-02-07	14:08:18	StartIntent	cmp=local.map/.Views.DetailedPage (has extras) }
1658	108	2012-02-07	14:08:18	info view poi	4afeed73f964a520c13122e3
1659	108	2012-02-07	14:08:20	StartIntent	cmp=com.android.browser/.BrowserActivity (has extras) }
1660	108	2012-02-07	14:08:48	click	marker:4e6b6585d164c37bf4fd61d2
1661	108	2012-02-07	14:08:52	StartIntent	cmp=local.map/.Views.DetailedPage (has extras) }
1662	108	2012-02-07	14:08:52	info view poi	4e6b6585d164c37bf4fd61d2
1663	108	2012-02-07	14:08:55	photo view poi	4e6b6585d164c37bf4fd61d2

Figure 6-21 Snippets of MCJ's log data corresponding to the discussed session

Figure **6-21** shows the Wikipedia page visit initiated from Proximity Explorer (idactivity 1659) and two POI view visits of both the current Creamery and Old Creamery. In this usage, MJ *integrated* the historical development of Creamery from Wikipedia visit into the navigation and selected the next visiting point based on this.

Feature comments

In terms of the three likes and dislikes about the features, the popular places, directions with landmarks, and friends' check-ins are the top three favorite features. The participants provided suggestions for improvement of the application, including making search radius (the size of area) more customizable, adding more refined sub-categories under particular place category (e.g. Outdoors), integrating more online services (e.g. Yelp, campus bus tracker), and synchronizing users activities on Proximity Explorer with Facebook (e.g., sharing trajectory and pictures on Facebook wall).

Most participants confirmed that they were using the application once or twice a day (16 out of 18), with two participants using it less (~ once every other day). Participants used the application when they were walking on the campus between classes, making plans for the next time slot, needing directions for a new place, or waiting for something. All participants explicitly stated that they found the integrated information valuable.

Overall assessment and discussion

The overall assessment was completed based on users' survey, features of the system, users' feedback and their usage. Based on the demographic and mobile usage survey, the participants are a sample of the targeted population in this research—young, experienced mobile device users (especially familiar with various kinds of mobile applications), who are open to novel technology, want to be connected all the time, and are eager to try the most recent devices. Earlier analysis for the literature review suggests that the application design should take advantage of the development of hardware (e.g. lager screen display, high fidelity camera) and online resources (e.g. various kinds of social network sites) into the consideration of designing new applications. This is confirmed by the demographic and behavioral results of the pre-study survey.

The log analysis and users interviews indicate that people do need information from multiple aspects and providing information from multiple aspects is helpful to support place sensemaking. The interaction log data shows that participants often visited different types of information (spatial, social, and temporal) and switched among these types of information frequently. The interviews on usage scenarios further provide qualitative explanations about the ways the application supports users in making sense of the places, such as:

- Supporting the exploration of others' favorite places;
- Creating potential social interaction;
- Guiding the exploration with schemas of POIs nearby;
- Improving the understanding and communication of spatial knowledge; and
- Enhancing the knowledge of already familiar places.

Though one of the earlier adopters of the application suggested adding some features for content contribution to the application, very limited commenting and photo sharing have occurred in the current evaluation. In the post-study questionnaire, I asked participants why they did not use such features. Besides those who seldom do this in normal practice, here are some other explanations:

- No additional value, but extra effort. Some participants admitted that while they enjoyed reading information from the application, they did not see the benefits in adding comments or sharing photos for themselves other than improving the application due to the lack of audience. Commenting is mainly about information correction, such as "it is not library, it is the HUB".
- Concern of the self-image. For some of those who thought of expressing themselves at the first place, they were worried about the impact of such commenting when it

goes to Facebook (even though the sharing to Facebook Wall is optional in Proximity Explorer). According to one participant, he wanted his Facebook post “meaningful”, not filled with the “polluted testing” data.

Chapter 7

Conclusion

Making sense of the place is becoming increasingly important. This trend is partially being driven by two factors: the increasing demand to know a new place in a timely manner and the over-reliance on the deeply penetrating digital devices. While the former reflects the reasonable and inevitable requirement in the modern society, the later brings in low-cost, portable hardware with incredible computational capacity that provides the means to access a broad wealth of shared data online.

This dissertation has shown that with the proper design that considers multidimensional information, these mobile clients can be useful to bridge the gap between information collected online with a requirement for place sensemaking on the spot. Proximity Explorer is the first implementation to demonstrate the feasibility of location-based information fusion, and the results of an evaluation study on the use of the prototype indicate the effectiveness of this approach to support place sensemaking.

Contribution

As shown in **Figure 7-1**, I have actively shared my findings in peer-reviewed conferences and journals throughout the work. The overall contribution to the research field was the proposition of a new design framework of place sensemaking and the realization of the theory through a novel application. The application was designed to support place sensemaking on mobile devices, which could direct the future designs for similar mobile applications. The work represents my effort in bridging information in the cyberspace into the physical world with integrating multiple online resources into designing mobile applications to enhance people’s life in the real world. A combination of mobile computing technology with online services can create new solutions to balance the experiential sensation of the surroundings with rich resources provided by current technologies.

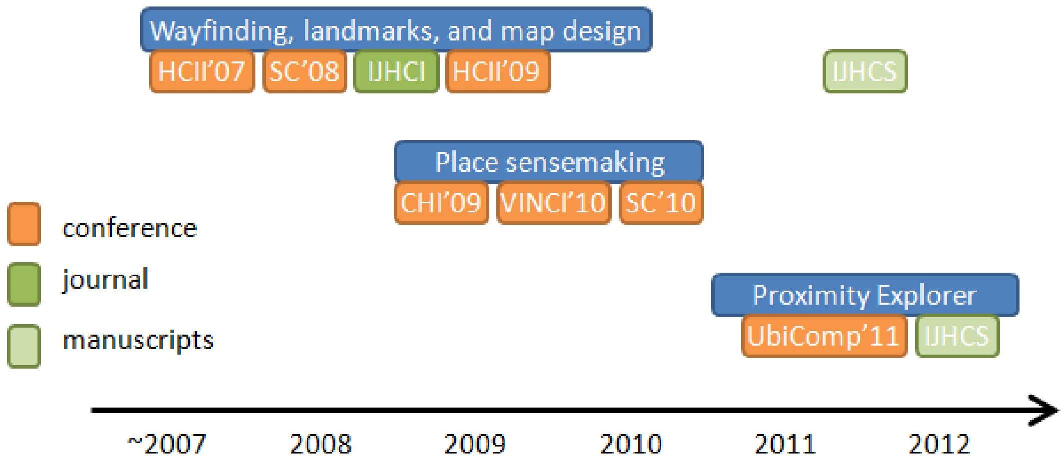


Figure 7-1 Research roadmap and selective publications related to this dissertation work

This work contributes to three broad areas. The first consists of the theoretical ideas underpinning the work. The second consists of the artifacts, served as proof of concept and testbeds, developed in the course of the dissertation. The third set includes the empirical lessons taken from the qualitative and quantitative evaluation of the artifact. The following sections discuss these areas in detail.

Theoretical contribution

Sensemaking theory has been well examined and adopted in many domains and approved to be a well structured analytical foundation. This work is the first to apply the classic sensemaking theories to the domain of navigation, and formalizes a notion of *Place Sensemaking*. More specially, the core components of sensemaking have been used to understand the process of knowing a place in navigation. Such analysis validates that getting to know a new place through physical navigation is also a form of sensemaking and thus, the hybrid two-way approach (top-down and bottom-up) can be used to guide the design on navigational tools.

The second theoretical contribution of this dissertation is the design goals derived from existing work and a structured study. The top-down approach in sensemaking suggests that schema is required to guide information collection and formalization. Directed by this, the design goals identified three dimensions to know a place, namely, spatial, social and temporal. The interview study suggests that for each dimension, some information recourses are particularly useful. For example, in the social dimension, users usually not only want reviews generated from the public, they also prefer visiting history from people in their social networks, which is verifiable, useful for further query, and also could serve as potential social interaction.

The final theoretical contribution is the location-based information fusion. This work exemplified the effort in creating an inference engine by pooling and parsing information from various services to create metadata about a place. String-based and spatial mapping heuristics are implemented as proof of concept, while other mapping algorithms are suggested (e.g. venue category).

Artifacts

This dissertation has produced a novel mobile application and a set of tools for data logging and analysis. The mobile application, Proximity Explorer, differentiates itself from existing mobile applications for its emphasis on the idea of location-based integration among spatial, social and temporal information resources. It demonstrates the feasibility of supporting place sensemaking by integrating online information resources on mobile devices and provides a valuable testbed for understanding the implications of place sensemaking.

Functional wise, the mobile application provides support for typical tasks in knowing a place in both information consumption and content creation. Guided by the design goals, the application presents social, temporal and spatial information of the place of interest with specific levels in each dimension. It also processes popular features that exist in many social network mobile applications, like allowing users contributing their comments/photos, and collecting/sharing directions. People are already familiar with these features that could be used to encourage individual creation of a personal space that could be further enhanced by the social commenting on the space.

Performance wise, Proximity Explorer adopts the client-server architecture, which takes advantages of cooperative processing of both mobile devices and servers. The client side is implemented on Android platform, which leverages the local computational and sensor resources and could be used for potential customization (see future work sections). The server side composes of a web server, a file server and a data base server. These servers have the computational power and storage capacity to provide the service requested by clients, store the interaction logs and the artifacts created by the users. Distribution of the work between the client and servers is well designed to ensure the responsiveness and stability of the application.

A set of tools have been developed to collect and analyze the logged data, which could be used to evaluate data collected in other similar mobile applications. The interaction logs are collected through a filter modified on the native Logcat on Android platform. Logs are uploaded to the server, which will be further parsed and processed to generate both individual and aggregated metrics and stored in the database. A web-based visualization platform has been developed to view the logged data to assist scenario recall from participants.

Empirical evaluation

This work has contributed several important findings and lessons from qualitative and quantitative evaluation.

First, both subjective and objective data empirically validates the design goals of supporting place sensemaking by integrating information from social, temporal and spatial perspectives. Frequent visits of each information resource and the diverse transition among different UI components suggest users did access multiple information resources. The scenario recall interviews further expose how such information resources have been used and under what circumstances.

Second, as suggested earlier, empirical evaluation of sensemaking tasks is difficult as it has no explicit ending point. In the reported evaluation, scenario recall was used to help better understand how the application actually assisted in the knowledge updating of a certain place of interest. Specifically, five major themes of how the application helped people exploring the places of interest have been identified: through exploration of friends' favorites, creation of potential social interaction, sensemaking with POI schemas, remembering and communication with spatial knowledge, and deeper venture of familiar places with information integration.

Third, feedback from users confirms that Proximity Explorer is a functional and user-friendly application. Subjective ratings comparing Proximity Explorer with Google Maps provide promising results in terms of usability and clearly show the advantage of incorporating social and temporal information into similar navigational tools. Users' feedback and usage logs suggest that the participants are likely to use the application in the future, which is encouraging for further development.

Limitation and future direction

This dissertation has a few limitations, which in return open many venues of future work. Improvement can be made to each area of the work: the framework, the design, the implementation, and the evaluation. Some of these are modest and could be achieved in a short-term study, while others will largely depend on the development of relevant technology.

Theoretical extensions

While current design goals suggest integrating information from the spatial, social and temporal dimensions by identifying certain levels of information in each dimension, other levels are possible for extensions. For example, in the temporal dimension, now and historical information has been studied in the current work. The future events, which have direct impact on the decision of making a real visit, are not included yet.

The current place sensemaking framework has identified several components that derived from the classic sensemaking theory, but operational metrics have not been explicitly identified for empirical testing. By analyzing our participants' recall, we can notice certain sensemaking have occurred with the help of computational tools. The analysis could serve as ground for derived measurements for further studies. Controlled experiments with pre-defined tasks, independent and dependent variables can be designed to examine the occurrence of these components individually.

The evaluation results have suggested the occurrence of sensemaking process through participants' recall, but not directly through immediate measurements. To maximize the completeness and accuracy of the data collection, we use the log visualization to help participants' recall and compare what they said with the usage logs. However, we should aware that memory contamination is still an issue using the current method. Other research methods, like dairy studies, field observations, or controlled experiments, can provide direct data for further validation of the framework.

Design improvements

Several limitations in the current design have been observed. From the perspective of information presentation, UI design should be more customizable. As the evaluation results suggest, individual difference of the preferred information resources exists. The current design does not support the quick access to these preferred resources. Future work on user interface customization, either allows users to adjust the welcome view manually, or automatically rearrange the views based on usage history will be helpful to assist quick information access.

From the perspective information selection, current design of Proximity Explorer presents all the POIs nearby (or filtered by a certain category) to allows users to explore the surroundings without any prime. Personalized recommendation of POIs is an active area in recommendation system and mobile services, and can be incorporated into the design in the future. User's preference, social influence, and geographical influence are considered as important factors to provide recommendation (Mülligann & Janowicz, 2011; Ye, Liu, & Lee, 2011) and such data are either available or easily collected with the current application.

The heatmap is a novel design to reflect the popular places and received great appreciation from the participants. However, more functions need to be incorporated. First, in the temporal dimension, the current design only shows the past and present, but no future data, which may have more direct influence on a real visit. To meet this perspective requirement, a visualization graph shows the temporal changes using the past data, or calendar with forthcoming events, specials, and activities, will be useful (though the availability of such data needs participatory contribution). The other shortcoming of the current heatmap is that it only shows the popularity of a certain place, but provides no explanation about why it is popular. Further aggregation of local news and location-based data from social media (e.g. Twitter) could supplement the contextual aspect of the heatmap.

System extensions

The integration implementation takes advantage of the data availability in different services, but also poses constrains on the system. For example, due to the limitation of the Foursquare API, which is used by Proximity Explorer to initiate searching POIs nearby, the balance between search range and number of results is not well adjusted based on the density of existing POIs. As a result, the returned POIs could be spatially concentrated in those highly saturated areas, like New York, or any big city with a high density of restaurants and bars. This problem occurs even though a larger radius is set. A potential solution would be either to fire multiple queries, combine and rank the resulted POIs once the application detects a high concentration, or to expect Foursquare to fix the problem. The current design works well in a college town, where the POIs are literally horizontally distributed, but will be problematic in big cities that POIs could be in the same building but on different floors. As the spatial mapping heuristics only takes latitude and longitudes into consideration, altitude is missing from the current analysis. Reliance on existing services where the lack of latitude data will also impact the merging results.

To get the merged metadata of a POI, two heuristics-based mapping algorithms are used currently, which may results in false results. To improve the data quality of the merging result, other algorithms, either heuristic based (e.g. merging POIs with the similar category) or learning based, can be applied. The other way of improving the data quality is to allow users to contribute corrections once they spot errors. Quality control methods such as peer review or self-regulation could be used to ensure the content production.

Android OS is selected as the mobile platform for the current implementation for its openness, Java programming language, and potential for application distribution, while it also constrains the user group considering the large population of other mobile platforms users, especially iOS. If I had more developer resources or time, applications on other mobile platforms should also be considered.

Only a few dozen users have been invited to use the current application, while the scalability of the system has not been well considered and designed for large number of visits simultaneously or in a short time window. Such challenges go to the data access to various APIs, response computation, and log storage.

Evaluation

The sample of eighteen college students was used in this study. However, I acknowledge it is only a subgroup of the potential users for this application. Including demographics with different ages and occupations will benefit the generalizability of the findings. Example of such groups could be business people who travel constantly, or military families who move a lot.

Though half of the participants have travelled at least once during the evaluation period, the majority of the evaluation was still conducted on campus. Though effort has been made to recruit participants in the spring campus visit event, due to the lack of ownership for Android devices, no valid data has been collected. Future work of deploying the application to new students or employees, who have never been to the area, will provide a better understanding of how people use the application in unfamiliar environments.

Finally yet importantly, the current application is only privately deployed for the purpose of data collection and further verification; distribution on a public platform, like the Android Playstore, will get responses in a larger quantity to further evaluate the usage pattern, stability, and scalability of the application.

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Appendix A

Questions for User Requirement Collection

When you get to a new environment (e.g. moving to a new places, travel out of town), how do you seek information to know that place?

- Describe typical routines of your strategies to know the new place before and during the travel, in general.
- What kind of places you want to know about?
- Describe typical challenges you are facing when get to a new environment in terms of information seeking.
- What types of information you usually gather to know a POI? (e.g. historical, social, geographical…)
- How can you get the information you need, from what information channels and using what tools? (e.g. asking friends, read tour guide…)
- Are you using any mobile navigation tools (e.g. GPS, mobile applications) to help you know the new environment? If yes, list them and describe some typical usage scenarios. If no, explain why not and your attitudes and opinions towards application of these electronic tools.

Describe functions of a mobile application (given the availability of current technology) that can help you knowing the environment.

Appendix B

Example Response from Online Services used in Proximity Explorer (Bryce Jordan Center)

1. Foursquare POI data format

{
- **id**: "4afee83ff964a5207a3122e3"
- **name**: "Bryce Jordan Center"
- **contact**: {
  - **phone**: "8148635500"
  - **formattedPhone**: "(814) 863-5500"
  - **twitter**: "JordanCenter"

  }
- **location**: {
  - **address**: "127 Bryce Jordan Center"
  - **lat**: 40.808888336586634
  - **lng**: -77.85635232925415
  - **distance**: 3808
  - **postalCode**: "16802"
  - **city**: "University Park"
  - **state**: "PA"
  - **country**: "United States"

  }
- **categories**: [
  - {
    - **id**: "4bf58dd8d48988d1ba941735"
    - **name**: "College Basketball Court"
    - **pluralName**: "College Basketball Courts"
    - **shortName**: "Basketball"
    - **icon**: {
      - **prefix**: "https://foursquare.com/img/categories/education/stadium_basketball_"
      - **sizes**: [
        - 32
        - 44
        - 64
        - 88
        - 256

        ]
      - **name**: ".png"

      }
    - **primary**: true

    }
-]
- **verified**: true

- **stats**: {
  - **check-insCount**: 7142
  - **usersCount**: 2829
  - **tipCount**: 40

  }
- **url**: "http://www.bjc.psu.edu"
- **specials**: {
  - **count**: 0
  - **items**: [ ]

  }
- **hereNow**: {
  - **count**: 1

  }

}

2. Google Place API POI data format

- **html_attributions**: [ ],
- **result**:
  {
  - **address_components**:
    [
    - {
      - **long_name**: "127",
      - **short_name**: "127",
      - **types**:
        [
        - "street_number"
        ]
    - },
    - {
      - **long_name**: "University Park",
      - **short_name**: "University Park",
      - **types**:
        [
        - "route"
        ]
    - },
    - {
      - **long_name**: "State College",
      - **short_name**: "State College",
      - **types**:
        [
        - "locality",
        - "political"
        ]
    - },
    - {
      - **long_name**: "PA",
      - **short_name**: "PA",
      - **types**:
        [
        - "administrative_area_level_1",
        - "political"
        ]
    - },
    - {
      - **long_name**: "US",
      - **short_name**: "US",
      - **types**:
        [
        - "country",
        - "political"
        ]
    - },
    - {
      - **long_name**: "16801",
      - **short_name**: "16801",
      - **types**:
        [

            ▪ "postal_code"
              ]
        ▪ }
          ],
    ○ **formatted_address**: "127 University Park, State College, PA 16801, United States",
    ○ **formatted_phone_number**: "(814) 863-5500",
    ○ **geometry**:
          {
        ▪ **location**:
              {
            ▪ **lat**: 40.808869,
            ▪ **lng**: -77.855381
              }
          },
    ○ **icon**: "http://maps.gstatic.com/mapfiles/place_api/icons/stadium-71.png",
    ○ **id**: "19d14622394ae5c199121d17983dec1e19d559a0",
    ○ **international_phone_number**: "+1 814-863-5500",
    ○ **name**: "Bryce Jordan Center: Administrative Office",
    ○ **rating**: 4.3,
    ○ **reference**: "CpQBgQAAAGblEmXKrDuFwTNbbc4HzoMIh-B7jcsNfvR6Q5q6OyOoIudWTR9TuFGSTwmzJwlsZOGwcXejBhH7WqvXHqVyI2BStbvWq4ZWMSZjbkXNRA2qzEBNWSxNn032ZJwZMaA_WDAczgl4wJSezAKpiYLfQy0AZVh1kxEAzegR3ZW1_AD0QIx2mzI3-tUhC99pjdrttBIQNx6XKvMCeWgBWk7v0o-yahoU9RAfev0tL2-WHyQNiQC4PdL89jE",
    ○ **types**:
          [
        ▪ "stadium",
        ▪ "establishment"
          ],
    ○ **url**: "http://maps.google.com/maps/place?cid=533175494886111376",
    ○ **vicinity**: "127 University Park, State College",
    ○ **website**: "http://www.bjc.psu.edu/"
      },
- **status**: "OK"
  }

3. DBpedia data format

dbpedia-owl:abstract	Bryce Jordan Center is a 15,261-seat multi-purpose arena in University Park, Pennsylvania. The arena opened in 1995 and is the largest such venue between Philadelphia and Pittsburgh. It replaced Rec Hall as the home to the Penn State University Nittany Lions men's and women's basketball team, the Pride of the Lions Pep Band, and for the men, its student section, Nittany Nation. It also plays host to a number of events such as music concerts, circuses, and commencement ceremonies for colleges within the university. The arena is named after former Penn State University president Bryce Jordan who was instrumental in acquiring the funding needed to build it. The arena is associated with the Arena Network, a marketing and scheduling group of 38 arenas. http://www. collegian. psu. edu/archive/2004/04/04-23-04tdc/04-23-04dnews-09. asp Le Bryce Jordan Center (surnommé The Big Joint) est une salle omnisports située sur le campus de l'Université d'État de Pennsylvanie à University Park en Pennsylvanie. C'est le domicile des équipes masculine et féminine de basket-ball de l'université. Le Bryce Jordan Center a une capacité de 15 261 places.
dbpedia-owl:buildingStartDate	1993-04-07 (xsd:date)
dbpedia-owl:cost	5.5E7
dbpedia-owl:location	dbpedia:University_Park,_Pennsylvania
dbpedia-owl:openingDate	1996-01-11 (xsd:date)
dbpedia-owl:operator	dbpedia:Pennsylvania_State_University
dbpedia-owl:owner	dbpedia:Pennsylvania_State_University
dbpedia-owl:tenant	dbpedia:Penn_State_Nittany_Lions_basketball
dbpedia-owl:thumbnail	http://upload.wikimedia.org/wikipedia/commons/thumb/8/88/Bryce_Jordan_Center.JPG/200px-

	Bryce_Jordan_Center.JPG
dbpedia-owl:wikiPageExternalLink	http://www.collegian.psu.edu/archive/2004/04/04-23-04tdc/04-23-04dnews-09.asp http://www.gopsusports.com/basketballMfacilities/brycejordancenter.cfm http://www.gopsusports.com/pressreleases/pressrelease.cfm?anncid=10335 http://www.bjc.psu.edu
dbpprop:architect	Rosser Int'l. Inc.
dbpprop:brokeGround	1993-04-07 (xsd:date)
dbpprop:constructionCost	5.5E7
dbpprop:location	University Dr. & Curtin Rd, University Park, PA 16802
dbpprop:nickname	The Big Joint
dbpprop:opened	1996-01-11 (xsd:date)
dbpprop:operator	Pennsylvania State University
dbpprop:owner	dbpedia:Pennsylvania_State_University
dbpprop:seatingCapacity	Concerts: 16,000+ Basketball: 15,261
dbpprop:stadiumName	Bryce Jordan Center
dbpprop:tenants	dbpedia:Penn_State_Nittany_Lions_basketball Penn State Lady Lions basketball
dbpprop:wikiPageUsesTemplate	dbpedia:Template:Infobox_stadium
dbpprop:wordnet_type	http://www.w3.org/2006/03/wn/wn20/instances/synset-stadium-noun-1
dcterms:subject	category:Penn_State_Nittany_Lions_and_Lady_Lions_basketball_venues category:Music_venues_in_Pennsylvania category:Buildings_and_structures_in_Centre_County,_Pe

	nnsylvania category:College_basketball_venues_in_the_United_State s category:Indoor_arenas_in_the_United_States category:Sports_venues_in_Pennsylvania
grs:point	40.80888888888889 -77.85583333333334
rdf:type	owl:Thing dbpedia-owl:Building dbpedia-owl:Stadium dbpedia-owl:Place schema:StadiumOrArena dbpedia-owl:ArchitecturalStructure schema:Place gml:_Feature yago:MusicVenuEsInPennsylvania http://umbel.org/umbel/rc/Stadium yago:SportsVenuEsInPennsylvania yago:CollegeBasketballVenuEsInTheUnitedStates yago:PennStateBasketballVenuEs
rdfs:comment	Bryce Jordan Center is a 15,261-seat multi-purpose arena in University Park, Pennsylvania. The arena opened in 1995 and is the largest such venue between Philadelphia and Pittsburgh. It replaced Rec Hall as the home to the Penn State University Nittany Lions men's and women's basketball team, the Pride of the Lions Pep Band, and for the men, its student section, Nittany Nation. Le Bryce Jordan Center (surnommé The Big Joint) est une salle omnisports située sur le campus de l'Université d'État de Pennsylvanie à University Park en Pennsylvanie. C'est le domicile des équipes masculine et féminine de basket-ball de l'université. Le Bryce Jordan Center a une capacité de 15 261 places.
rdfs:label	Bryce Jordan Center Bryce Jordan Center
owl:sameAs	fbase:Bryce Jordan Center

geo:geometry	POINT(-77.8558 40.8089)
geo:lat	40.808887 (xsd:float)
geo:long	-77.855835 (xsd:float)
foaf:depiction	http://upload.wikimedia.org/wikipedia/commons/8/88/Bryce_Jordan_Center.JPG
foaf:homepage	http://www.bjc.psu.edu
foaf:name	Bryce Jordan Center
foaf:nick	The Big Joint
foaf:page	http://en.wikipedia.org/wiki/Bryce_Jordan_Center
is dbpedia-owl:headquarter of	dbpedia:Nittany_Nation
is dbpedia-owl:recordedIn of	dbpedia:5/3/03_-_State_College,_Pennsylvania
is dbpedia-owl:wikiPageDisambiguates of	dbpedia:BJC
is dbpedia-owl:wikiPageRedirects of	dbpedia:Jordan_Center
is dbpprop:arena of	dbpedia:Penn_State_Nittany_Lions dbpedia:Penn_State_Nittany_Lions_basketball
is dbpprop:headquarters of	dbpedia:Nittany_Nation
is dbpprop:siteStadium of	dbpedia:2009-10_Wisconsin_Badgers_men's_basketball_team dbpedia:2007-08_Ohio_State_Buckeyes_men's_basketball_team dbpedia:2010-11_Purdue_Boilermakers_men's_basketball_team dbpedia:2009-10_Ohio_State_Buckeyes_men's_basketball_team dbpedia:2009-10_Michigan_State_Spartans_men's_basketball_team dbpedia:2009-

	10_Northwestern_Wildcats_men's_basketball_team dbpedia:2007-08_Wisconsin_Badgers_men's_basketball_team dbpedia:2009-10_Virginia_Tech_Hokies_men's_basketball_team dbpedia:2006-07_Ohio_State_Buckeyes_men's_basketball_team dbpedia:2009-10_Purdue_Boilermakers_men's_basketball_team dbpedia:2007-08_Illinois_Fighting_Illini_men's_basketball_team dbpedia:2007-08_Michigan_State_Spartans_men's_basketball_team dbpedia:2010-11_Illinois_Fighting_Illini_men's_basketball_team dbpedia:2008-09_George_Mason_Patriots_men's_basketball_team dbpedia:2009-10_Indiana_Hoosiers_men's_basketball_team dbpedia:2009-10_Pittsburgh_Panthers_women's_basketball_team dbpedia:2010-11_Penn_State_Nittany_Lions_basketball_team dbpedia:2008-09_Wisconsin_Badgers_men's_basketball_team dbpedia:2007-08_Indiana_Hoosiers_men's_basketball_team dbpedia:2008-09_Iowa_Hawkeyes_men's_basketball_team dbpedia:2009-10_Michigan_Wolverines_men's_basketball_team dbpedia:2008-09_Minnesota_Golden_Gophers_men's_basketball_team dbpedia:2010-11_Michigan_Wolverines_men's_basketball_team dbpedia:2008-09_Illinois_Fighting_Illini_men's_basketball_team dbpedia:2008-09_Michigan_State_Spartans_men's_basketball_team dbpedia:2009-10_Minnesota_Golden_Gophers_men's_basketball_team dbpedia:2010-11_Ohio_State_Buckeyes_men's_basketball_team dbpedia:2007-08_Iowa_Hawkeyes_men's_basketball_team dbpedia:2010-11_Wisconsin_Badgers_men's_basketball_team

	dbpedia:2008-09_Indiana_Hoosiers_men's_basketball_team dbpedia:2008-09_Purdue_Boilermakers_men's_basketball_team dbpedia:2007-08_Minnesota_Golden_Gophers_men's_basketball_team dbpedia:2009-10_Illinois_Fighting_Illini_men's_basketball_team dbpedia:2010-11_Maryland_Terrapins_men's_basketball_team dbpedia:2010-11_Minnesota_Golden_Gophers_men's_basketball_team dbpedia:2010-11_Iowa_Hawkeyes_men's_basketball_team dbpedia:2009-10_Robert_Morris_Colonials_men's_basketball_team dbpedia:2010-11_Fairfield_Stags_men's_basketball_team dbpedia:2010-11_Michigan_State_Spartans_men's_basketball_team dbpedia:2010-11_Northwestern_Wildcats_men's_basketball_team
is dbpprop:space of	dbpedia:List_of_licensed_and_localized_editions_of_Monopoly:_USA
is dbpprop:stadiumarena of	dbpedia:2009-10_Penn_State_Lady_Lions_basketball_team dbpedia:2010-11_Penn_State_Nittany_Lions_basketball_team dbpedia:2008-09_Penn_State_Nittany_Lions_basketball_team dbpedia:2009-10_Penn_State_Nittany_Lions_basketball_team
is owl:sameAs of	http://www4.wiwiss.fu-berlin.de/flickrwrappr/photos/Bryce_Jordan_Center yago-res:Bryce Jordan Center
is foaf:primaryTopic of	http://en.wikipedia.org/wiki/Bryce_Jordan_Center

4. Facebook POI


```
{
 "id": "153624551333586",
 "name": "Bryce Jordan Towers",
 "picture": "http://profile.ak.fbcdn.net/static-
ak/rsrc.php/v1/yN/r/cDKJtvtlYv5.png",
 "link": "http://www.facebook.com/pages/Bryce-Jordan-
Towers/153624551333586",
 "likes": 2,
 "category": "Local business",
 "is_published": true,
 "is_community_page": true,
 "location": {
  "street": "463 East Beaver Ave",
  "city": "State College",
  "state": "PA",
  "country": "United States",
  "zip": "16801",
  "latitude": 40.798286894222,
  "longitude": -77.854678236963
 },
 "check-ins": 32,
 "talking_about_count": 1,
 "type": "page"
}
```

Appendix C

Background survey of mobile device usage

Q1 How long have you used the Android device?

- Less than one month (1)
- 1-6 month (2)
- 6 month -1 year (3)
- more than 1 year (4)

Q2 How often do you use Android applications (Exclude email check-ing, text messaging)?

- Never (1)
- Less than Once a Month (2)
- Once a Month (3)
- 2-3 Times a Month (4)
- Once a Week (5)
- 2-3 Times a Week (6)
- Daily (7)

Q3 How many Android applications you have installed (by yourself) on your devices so far?

- < 5 (1)
- 5-10 (2)
- 10-20 (3)
- 20-50 (4)
- > 50 (5)

Q4 Drag the top three types of Android application you used most often?

The top 3 (rank from top as the most often)
______ News (1)

_______ Videos & Musics (2)

_______ Games (3)

_______ Readings(e.g. Books) (4)

_______ Social Networks (e.g. Facebook, Twitter) (5)

_______ Weather (6)

_______ Travel & Navigation (7)

_______ Mails & Messages (8)

_______ Others (9)

Q7 List the top three mobile applications you use on travel?

Top 1 (1)

Top 2 (2)

Top 3 (3)

Q8 What are the information resources you usually access to get to know a new place? (Check all that apply)

- ❑ Wikipedia (1)
- ❑ Web Browser (2)
- ❑ Google Maps (3)
- ❑ Social Network (e.g. Facebook, twitter, Foursquare) (4)
- ❑ Specialized search tools (e.g. Yelp, Priceline) (5)
- ❑ Local guide (e.g. yellow book, travel guide) (6)
- ❑ Ask friends (e.g. msg, call, email) (7)
- ❑ News (8)
- ❑ Others (9) ____________________

Q5 Gender

- ❍ Male (1)
- ❍ Female (2)

Q6 Your age

- ❍ 18-20 (1)
- ❍ 21-25 (2)
- ❍ 26-30 (3)
- ❍ 30-40 (4)

Q9 Your Penn State id (e.g. abc123)

Q10 Course for extra credit

- ❍ IST 220 (1)
- ❍ IST 210 (2)
- ❍ IST413 (3)

Appendix D

Post-study interview questions

1. How often have you been used it?
2. When do you use it?
3. How do you like it? (name three features that you like and three features that you do not like, any suggestion?)

    Good 1:

    Good 2:

    Good 3:

    Bad 1:

    Bad 2:

    Bad 3:

    Suggestion:

    (adding questions regarding their usage of the camera, commenting for some participants)

4. Describe a scenario that this application works for you.
5. Looking at the interface of usage sessions and tell me what happened (where you were, why you looked at certain POI, after you use the application, what you had learned).
6. How do you think the idea of information integration in mobile application in general?
7. Is the information integration of this app adding values?
8. Other data resources would be useful?

Appendix E

Subjective Rating of Proximity Explorer and Google Maps

	Strongly Agree (5), Agree(4), Neutral (3), Disagree (2), Strongly Disagree (1)					
	Proximity Explorer			Google Maps		
	Mean	Median	STD	Mean	Median	STDEV
• easy to learn	4	4	0.71	4.35	4	0.61
• easy to use	3.94	4	0.75	4.41	4	0.62
• Confused to use (results were transformed by minus from 6)	3.41	4	1.00	3.82	4	0.73
• I feel confident to use it to know the details of a place	3.76	4	0.83	3.82	4	0.64
• It improves my exploration efficiency	3.88	4	0.93	3.82	4	0.95
• I enjoyed using it	4.12	4	0.60	3.94	4	0.90
• I would like to use similar application in the future	4.35	4	0.61	4.18	4	0.81
• helpful in supporting exploration of new environments	4.24	4	0.56	4.18	4	0.73
• easy to get support when explore new environments	3.94	4	0.56	4.06	4	0.66
• helpful to know the place of interest spatially	4.35	4	0.61	3.88	4	0.93
• easy to know the place of interest spatially	4.29	4	0.47	3.76	4	0.97
• helpful to get temporal information of the place of interest other than directions	4.18	4	0.73	2.82	3	1.01
• easy to get temporal information of the place of interest other than directions	4.06	4	0.75	3.12	3	1.17
• easy to know the temporal change of the place of interest	4.18	4	0.88	2.35	2	1.06
• helpful to get social information other than directions	4.12	4	1.05	2.41	2	1.12
• easy to get social information other than directions	4.24	4	0.56	4.18	4	0.73

VITA

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EDUCATION

Pennsylvania State University 08/2012 (Expected)
PhD in Information Science & Technology, Minor in Statistics, GPA: 3.9/4

Tsinghua University 2007
M.E. in Management Science and Engineering, GPA: 87.3/100

Tsinghua University 2005
B.E. in Mechanical Engineering and Automation , GPA: 88.3/100

CORE RESEARCH INTEREST

- Mobile user interface design and evaluation
- Spatial information visualization and sensemaking
- Spatial cognition and wayfinding, 3D virtual environments

RESEARCH EXPERIENCE

Pennsylvania State University 07/2007 - Present
Graduate Research Assistant
Palo Alto Research Center PARC) 08/2010 – Present
Visiting Research Scientist Host: Eric Bier (Principle scientist at KLI lab)
IBM Research – Almaden Research Center 05/2011 - 08/2011
Research Intern Mentor: Jeff Pierce (Manager of Mobile Computing Group)
Palo Alto Research Center (PARC) 05/2010 – 08/2010
Research Intern Mentor: Eric Bier
IBM Research – Watson Research Center 05/2009 - 08/2009
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Tsinghua University 09/2005 - 07/2007
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