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Location-based services and GIS in perspective

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Abstract

This paper examines location-based services (LBS) from a broad perspective involving definitions, characteristics, and application prospects. We present an overview of LBS modeling regarding users, locations, contexts and data. The LBS modeling endeavors are cross-examined with a research agenda of geographic information science. Some core research themes are briefly speculated.
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1. Location-based services: definitions, characteristics, and application prospects

Nowadays with the rapid development and widespread deployment of information and telecommunication technologies integrated with lightweight mobile devices and terminals, pinpointing location on the move has become a common exercise. The technologies involve geographical information systems (GIS), global positioning systems (GPS), radio frequency identification, and various other location sensing technologies with varying degrees of accuracy, coverage and cost of installation and maintenance. Some most recent location sensing technology based on ultrawideband radio can even achieve accuracies on the order of centimeters in an indoor environment. Meanwhile, the rapid evolution of cell phone industry from initial simple talk services to multiple functions of multimedia

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messaging and voice services with the emergence of broadband wireless infrastructure has created tremendous demands for various location-based services (LBS).

What are LBS? There have been various definitions of LBS from different perspectives. One regards LBS as "any service or application that extends spatial information processing, or GIS capabilities, to end users via the Internet and/or wireless network" (Koeppel, 2000), and another says that LBS are "geographically-oriented data and information services to users across mobile telecommunication networks" (Shiode, Li, Batty, Longley, & Maguire, 2004). From a GIS perspective, the former definition concentrates on the GIS capabilities that are available in networked environments. The latter definition, on the other hand, narrows down specifically to geographic data and information services that are available in a mobile-networked environment. Both definitions emphasize that LBS are services targeted to a wide range of users. According to these definitions, both online map services (e.g. mapquest) and the Internet GIS can be considered important LBS applications, as they provide the kind of geographic information services via the Internet or mobile-networked environments to mobile devices. LBS are indeed partially evolved from the online map services and other Internet GIS applications, whereas current LBS mainly rely on lightweight mobile devices such as personal digital assistants (PDA), smart phones and wearable computers for delivering various services so as to provide added value to users. A true LBS application aims to provide personalised services to mobile users whose locations are in change. Location and context are the key players in LBS which are thereby often called location-ware computing or context-aware services.

Any definition of LBS would overlap partially with some key terms in research fields of GIS and geoinformatics. Instead of presenting a new definition, it is important to capture those distinct characteristics of LBS that differentiate it from other GIS applications. We can compare them in regard to five commonly accepted components of GIS, i.e. hardware, software, data, models, and people. In a comparison with conventional GIS, Karimi (2004) elaborated the distinct characteristics of LBS (he used another term "telegeoinformatics" to refer to LBS). From the hardware and software perspective, LBS are based on diverse platforms and packages which involve the use of Internet, GIS, location-aware devices, and telecommunication technologies. No conventional GIS applications involve so much diversity of hardware and software in an interoperating environment. In regard to data, LBS receive data from various sources such as remote sensing (including micro-sensors), positioning systems, topographic maps, and traffic and transportation data sources. The data from the various sources often need to be handled in LBS simultaneously and dynamically. Thereby LBS are much more heterogeneous in nature comparing to most other GIS applications. Because of various data sources involved, integrating the data and processing them in a real-time fashion seem to be more challenging. Moreover, models for generalization, visualization, and geoprocessing in general would also be imposed further research challenges because the user's locations are in constant change. Finally, human factors should be taken into account for any LBS. Special considerations need to be taken for interface design, visualization methods, and reasoning approaches. More than often, user profiles and requirements need to obtain before and during any design and development.

Basic questions that LBS users are concerned about include: where am I currently? What and where are the nearest locations of interest? How to get there? The questions may arise in different contexts. LBS applications range a wide spectrum from daily life scenarios to specialized applications. A major application of LBS is to accurately position wireless emergence calls through E911 in the United States (or European equivalent E112) for emergency and rescue operations. Other applications include locating friends, locating nearest printer services, tracking staff, monitoring patients for emergency response, military training, asset tracking, and fleet management, to mention a few examples. The various information services can be delivered to the LBS devices in two different modes. The first is "push" mode where services are pushed to the user end automatically without the need of user request. The second is called the "pull" mode in which the user has to voluntarily request the information to be delivered from service centres. The market potential of LBS has been enormous, and thus it represents a new source of revenue opportunity. According to Allied Business Intelligence Research (http://www.abiresearch.com/), the worldwide market for LBS is to reach as high as $40 billion by 2006.

LBS not only can identify locations of human beings who carry location-aware devices, they also can track objects that are equipped with a tiny (and usually inexpensive) sensor identifier for delivering relevant services. For instance, products moving through the supply chain can be dynamically identified with embedded smart sensors, and massive products of such form a large-scale intelligent network (Swartz, 2001). Such a sensor network has a better sense of customer's need and is able to deliver the related services intelligently. The sensor network described may sound very ambitious, but it represents some of current developments in pervasive computing. Pervasive computing (Satyanarayanan, 2001) that reflects Weiser's initial vision on ubiquitous computing (Weiser, 1991) represents the opposite of virtual reality, i.e. instead of letting people and objects immerse into the chips or computers, chips and microprocessors are embedded into human body and objects. This is likely to be a direction for future development of LBS. This paper is not intended to go any further in regard to these future development directions. Instead, it strives to provide a perspective of the interplay between LBS and GIS in terms of modelling for LBS and to discuss research challenges that cut across the two fields.

2. Modeling for LBS

A good collection of models has been proposed in the past to capture important system components such as user, location, context, and data. These models are mostly introduced in a broader context of interaction systems of which LBS is an emerging type. The review that follows is based on the scholarly literature from relevant domains including ubiquitous computing, context-aware computing, general interaction systems, and GIS.

2.1. User needs and modeling

Users are central to LBS and so LBS applications should be designed based on a user-centered view. The user is a starting point for any LBS application design. It is the user who needs location-based services in various situations. User needs, user behaviors, and user profiles are important considerations in the course of designing LBS, since they determine what information should be provided and influence to a large extent the way systems and interfaces should be designed. User modeling sounds a very new subject for LBS, whereas it is an established domain in computer science for interaction systems (e.g. biennial conference series on user modeling since 1994). User modeling is referred to as "…the acquisition or exploitation of explicit, consultable models of either the human users of systems or the computational agents which constitute the system" (Csinger, 1995, p. 32). This definition was given in the context of intent-based authoring that clearly reflects user's purpose of information presentation. Basic questions about the users in LBS are: who are the users? what are their needs? when and where do they need services? etc. Many studies in user modeling (e.g. Jameson, 2001) have examined a wide range of user properties including users' current states, behaviors and even long-term properties.

It is not an easy task to thoroughly understand the users and user needs, as they usually tend to be very diverse. Clustering the users in terms of interests, behaviors and personal profiles is an important step towards a better understanding of the users. For instance, to design a LBS application for a museum, the users can be classified in terms of the viewing habits and interests. Sparacino (2002) developed a wearable computer, so-called the museum wearable, to capture the user's behavior in visiting a museum. Three categories of the users can be identified, i.e. greedy users who need in-depth information on everything, selective users who want in-depth information on selective items, and busy users who see a little bit of everything. The information about users can also be captured by conventional user studies through personal interviews and field evaluations (Kaasinen, 2003; Li, 2006). It is important to note that user needs, interests, and behaviors are not static but rather in constant change. Information of such changes would be valuable for the design of an adaptive LBS system. Ashbrook and Starner (2003) introduced a model for predicting user's future locations based on the user's past locations. The model was verified by two scenarios involving a single user and multiple users respectively; refer also to Liu and Karimi (2006) for more recent advances on the issue. This kind of dynamic models would be highly expected in the future for developing LBS applications with a high level of intelligent responses and adaptation. The discussion of dynamics is probably more related to the next issue: location modeling.

2.2. Location modeling

If we unpack the term "location-based services", it is clear enough that location is an important part of LBS. Location is part of context (which will be further discussed in the following section) and it determines what information and services the user may expect. A location can be represented and perceived in different ways. A location could be represented as geometric or symbolic on the one hand (Leonhardt, 1998), and it could also be absolute or relative on the other (Hightower & Borriello, 2001). In GIS, locations are georeferenced in continuous or discrete georeferencing systems. For instance, a major entry of the University of Gävle is located at 17° 7′ 9.23629″E, 60° 40′ 7.53197″N using the universal reference system, known as World Geodetic System 1984 (WGS84). The location can also be represented as Kungsbäcksvägen 47, 801 76 Gävle, Sweden. The former is represented by coordinates in a continuous georeferencing system (WGS84 in this case) used by the GPS, while the latter is a visiting or post address in a discrete georeferencing system. These two location representations are actually two georeferencing methods in GIS. Most indoor locations are represented in some local (rather than global) reference system. For instance, a robot can be located given a pair of coordinates relative to specific origin in a local reference system. The room numbered as 11:310 could indicate it is in the third floor of the building 11, whereas it is relative to the above university address.

Location modeling deals with the basic issue of representing space (or more precisely geographic space) for LBS. Two dominating methods in geographic representation are emerged from absolute and relative views of space, which arose from Newtonian and Leibnizian physics respectively. The former view regards space as a set of individual locations and objects, while the latter on how the individual locations and objects are interrelated within space. Two distinctive models: geometric and symbolic models (Leonhardt, 1998) are de facto reflection of the above two views of space. The geometric models treat locations and objects as points, areas and volumes within a reference coordinate system, and they can support a range of queries regarding a position, nearest neighbors, and efficient paths among locations. Most existing GIS are actually based on the geometric models. However, the geometric models face some limitations and difficulties for the general public who are more used to linguistic expressions of spatial features, locations, and spatial relations. Research challenges in this regard will be discussed later. On the other hand, with the symbolic models, locations are modeled as sets and located-objects as members of sets, and interrelationships are established among a set of locations and a set of located objects.

Attempts have been made towards integration and extension of the geometric and symbolic models in order to take advantages of both. For instance, Leonhardt (1998) developed a semi-symbolic model in which a located object is represented as both absolute coordinates (as in geometric models) and memberships of named objects, i.e. symbols (as in symbolic models). Hu and Lee (2004) have recently developed a semantic location model that combines both geometric and symbolic aspects of locations based on location and exit hierarchies. A major advantage of this model is that it can automatically create location and exit hierarchy without human intervention. Along the same line of thoughts, we can remark that a street topology based on a graph theoretic representation (Jiang & Claramunt, 2004) can support the kind of location modeling as well, since interconnection of named streets are clearly embedded in the modeling effort. The reader can refer to Becker and Duerr (2005) for a comprehensive overview of various location models.

2.3. Context modeling and adapting

Context is defined, for instance, as "location and the identity of nearby people and objects" (Schilit & Theimer, 1994, quoted in Dourish, 2004), or "location, identity, environment and time" (Ryan, Pascoe, & Morse, 1997, quoted in Dourish, 2004). So location is part of context, but context is far more than location (Schmidt, Beigl, & Gellersen, 1999). Dey (2001) defined context as "any information that can be used to characterize the situation of an entity," where "an entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." Context constitutes an important part, probably also the most difficult part, of LBS, as both the user and location are part of the context. Because of the importance of context, LBS are often given other names, e.g. context-aware computing or context-aware services.

Context has impacts on information retrieval, user actions, and user behaviors with LBS applications. Contexts change persistently with mobile users, so context modeling must be able to capture the changes and reflect current context whenever and wherever the users are. Schmidt et al. (1999) introduced a model to better understand the concept of context for context-aware computing. The model adopts a context feature space, which is hierarchically organized. In the model, context is related to both human factors and physical environments surrounding the user. The human factors can be further subcategorized into user, social environment and task; the physical environments can be subdivided into conditions, infrastructure and location. The context related features can be further subcategorized as well. For instance, location could involve absolute position, relative position and co-location, etc. A similar consideration of context is made towards modeling people's perception of distance in situated contexts (Yao & Thill, 2005). To help context modeling or situation abstraction, a context toolkit was suggested for building context-aware applications (Dey, 2001). Given the complex nature of contexts, it has been argued that an empirical and user-centered approach should be adopted to understand mobile contexts (Tamminen, Oulasvirta, Toiskallio, & Kankainen, 2004). In order to design mobile LBS systems that adapt to the changing contexts, contexts must be captured via sensor technology (Schmidt et al., 1999) or be taught through machine learning techniques (Laerhoven & Aidoo, 2001). More recently Dourish (2004) presents an alternative model that focuses on a view of interaction rather than representation. It presents a new perspective towards a better understanding of contexts, although the model is not explicitly design- and technical-oriented.

2.4. Geospatial data processing and modeling

Geospatial data are one of the key components of LBS, as in essence LBS are a kind of data or information services. There has been increasing availability and continuous update of geospatial data over the past decades due to the advances in geospatial technology. Based on the projection of the National Research Council (2003) of the United States, the volume of geospatial data will increase by several orders of magnitude over the next decade. However the existing geospatial data infrastructure is not particularly suitable for LBS applications. For instance the data collected and maintained by the national mapping agencies do not match very well along the country boundaries. The data management and map symbols are not particularly designed for small mobile devices. All these impose challenges for data processing and modeling for LBS. Because of limited resources of mobile devices (e.g. limited size of screen and storage space), on-the-fly visualization and generalization are inevitable for mobile devices. In this respect, GiMoDig project (http://gimodig.fgi.fi/index.php) made efforts to develop various methods of delivering geospatial data and to provide data service infrastructure for LBS applications, although it is mainly limited to topographic data maintained by national mapping agencies.

While the existing geospatial data provide basic data layers, more data sources are needed depending on specific LBS applications. For instance, for LBS applications designed for tourist guide, all physical attractions including historic sights and shopping locations should be collected. Furthermore, some specific LBS applications have specific requirements for data modeling in some particular contexts. For instance it is found that landmarks are far more required than other information such as distance and street names (May, Ross, Bayer, & Tarkiainen, 2003) in a pedestrian navigation context. Major challenges for geospatial data processing and modeling include how to present information on a small screen in a clearly understandable way, and how to design maps adapting to changing contexts. No single map mode is for everyone, so multiple map modes are essential for various users. A visualization method that combines both 2D view and 3D view for wearable computers with navigation or wayfinding activities seems a solution (Suomela, Roimela, & Lehikoinen, 2003).

For the sake of convenience, we introduced the above modeling attempts from different perspectives involving the user, location, context, and data. Nevertheless, we must be aware of the fact that the considerations from all these perspectives should be integrated in the design and modeling process for any LBS application. For instance, prediction of a user's future location is discussed from both user modeling and location modeling perspectives. Both the user and locations are part of the context, therefore in essence they are inseparable in modeling processes. All in all, the four aspects should be coherently considered with a comprehensive conceptual modeling towards a systematic model for any LBS application.

3. Research challenges for LBS

The modeling attempts outlined in the above sections represent state-of-the-art research around LBS. The models are mainly proposed in the domain of ubiquitous computing with a few exceptions on geospatial data modeling conducted in GIS. LBS continue to be a hot topic in GIS, e.g. three short-term research priorities proposed by University Consortium of Geographic Information Science (UCGIS) are LBS related, i.e. LBS, social implications of LBS, and pervasive computing. In this section, we try to assess how the modeling issues briefed above actually constitute a series of long-term research challenges of geographic information science (GIScience). Table 1 lists the current ten UCGIS long-term research challenges (McMaster & Usery, 2005). We shall first examine the connection between the research agenda and the modeling demands for LBS.

As LBS can be regarded as a special kind of geographic information services, it is no surprise that the UCGIS research agenda clearly has close links to the modeling issues for LBS. For instance, research on *spatial ontologies* with focus on ontological foundations for geographic information has at least two implications to the development of LBS applications. At one level, it can help to set up a common ontology for LBS for knowledge sharing among diverse users. At another level, it can help conceptualize design and modeling processes. Both location modeling and context modeling are related to the fundamental issue of *geographic representation* in GIScience. It concentrates on how geographic space should be represented conceptually and logically. The research issue is more challenging for LBS, because unlike other GIS applications where users' locations are not of particular concern, LBS are targeted to the users with constantly changing locations. Another UCGIS research priority, *spatial data acquisition and integration*, is also directly relevant to LBS. As a matter of fact, spatial data acquisition and integration is an integral part of data processing and modeling in LBS. Moreover, LBS applications often have unique requirements for data collection, integration, and accuracy analysis. Particularly, the issue of *uncertainty of geographic information* is closely linked to the data processing and modeling in LBS.

Table 1
UCGIS long-term research challenges

(1) Spatial ontologies
(2) Geographic representation
(3) Spatial data acquisition and integration
(4) Scale
(5) Spatial cognition
(6) Space and space/time analysis and modeling
(7) Uncertainty in geographic information
(8) Visualization
(9) GIS and society
(10) Geographic information engineering

Source: McMaster and Usery (2005).

A more relevant topic is probably *spatial cognition*, which is inherited from long standing research interests in human environmental perception and cognition, map perception and interpretation, human spatial behavior, and wayfindings in complex built environments. The studies along this line can provide valuable inputs to the design and development of LBS in regard to human-environment interaction, human-map and -system interactions, user interface, and visualization methods. The challenge of *visualization* is closely linked to data modeling, and how geographic information is perceived, either via visual display or audio broadcasting. Due to the size constraint of mobile devices, graphic information should be represented in a simplified way but without loss of overall information. For the basic requirement, generalization linking to *scale* issue can help retain the simplified graphic forms. Furthermore research on *space/time analysis and modeling* could provide a powerful reasoning capability for more innovative value-added services. From a societal aspect, LBS are a key instrument for the improvement of the quality of life and personal productivity. On the other hand, societal impacts of LBS also include surveillance and invasion of personal privacy, and changes in human spatial behavior (Dobson & Fisher, 2003).

Having elaborated on the close links of the research agenda of GIScience and modeling issues in LBS, we want to ask this question: what is special about LBS? Indeed, LBS represent some very special attributes of geospatial technology. For instance, most users of LBS are the general public; the user's behavior, location, and context are in constant change, and the systems must be adaptive to the changes. All these special characteristics are typically not dealt with in conventional GIS. In the rest of the section, we suggest a few research themes for future investigations, whereas the list of research themes is not intended to be exclusive.

3.1. Naïve users and next-generation GIS

A distinct characteristic of LBS is that they are generally oriented to naive users. Potentially everyone may become a user and therefore no assumption can be made about a user's prior knowledge of GIS or the spatial environments. While this fact provides a great opportunity for ubiquitous use of GIS, it also challenges GIS to cater for the particular needs of naive users. An average citizen usually has qualitative abstractions of the environment (Cohn & Hazarika, 2001). Naive users tend to acquire commonsense, often qualitative, knowledge about the spatial structure of the geographical world through experiences without concentrated efforts. The knowledge may be incomplete or inaccurate at times, yet they still can be very powerful in making useful conclusions (Kuipers, 2004). The commonsense geographical knowledge is usually expressed in linguistic terms such as place names (e.g. *Atlanta*, *White House*, *Main street*, etc.) and spatial relations (e.g. *north*, *in*, *near*, etc.). Therefore for the general public, the next-generation GIS not only should have the metric data handling capabilities, but also should be receptive to qualitative information and make best conclusions out of it.

The idea of next-generation GIS for naive users has close ties to several lines of intellectual investigations in the literature. Particularly, naive geography (Egenhofer & Mark, 1995) provides the theoretical foundation for the next-generation GIS for naïve users. Naïve geography concerns with formal modeling of commonsense geographic world and the design of GIS for average citizens without major training in GIS or geography. A considerable amount of research has been made to contribute to naive geography. For example, Yao and Thill (2006) proposed a framework to handle locations referenced by qualitative spatial relations in GIS. Research achievements from a number of associated threads of investigation make direct or indirect contributions to naïve geography. These fields include qualitative spatial reasoning, perception and cognition of space, studies of the relationship between natural language and perceptual representation of space, computational models of spatial cognitive maps, uncertainties in spatial boundaries, as well as research on place names and digital gazatteer (e.g. http://www.alexandria.ucsb.edu/gazetteer/). Researchers from computer science have also shown great interests in dealing with qualitative spatial information (e.g. McGranaghan, 1993; Wang, 2003).

In spite of the research efforts that have been made, current LBS and GIS applications are still in its quantitative-dominant stage. Coherent and consorted research is in great demand towards the realization of the next-generation GIS that cross between qualitative and quantitative paradigms. Research issues include mapping mechanisms between qualitative data and quantitative data, the design of user interface, interpreting semantics of linguistic expressions in LBS, incorporating qualitative spatial and temporal reasoning models in LBS, and visualization of qualitative location information, to name a few examples.

3.2. Spatio-temporal analysis and mining of mobile geospatial data

The geospatial data captured by mobile devices such as PDAs, mobile phones and wearable computers have been proliferating with the rapid development of LBS. This emerging data source has enormous potential to play an important role for our understanding of human activities and human behaviors in the environments. For instance, the Amsterdam RealTime project (http://www.waag.org/realtime/) collected massive data of individuals' whereabouts. From the datasets, researchers can track the spatio-temporal trajectories of the individual's activities. Spatial-temporal data mining algorithms can be used for the extraction of patterns from the datasets. An example of such patterns may be that many individuals in the study area go shopping on the way from work to home. Findings of human activity patterns and other spatial characteristics of human behavior can greatly facilitate the planning and decision-making processes, as these human activities and trajectories are sensitive to physical and cultural infrastructures (Ahas & Mark, 2005). LBS provide a revolutionary data source of such data because they can collect spatio-temporal data that otherwise have to be obtained from very expensive data collection processes. This new data source will certainly stimulate more research towards what Miller (2005) called people-based GIS, with which spatio-temporal analysis and data mining is a major vehicle. Spatio-temporal modeling is likely to gain reviving research interests with the emergence of LBS.

Spatial-temporal analysis and data mining typically involve the use of vast amount of data and high computation load. Thus efficient data structures and algorithms need to be tailored for the LBS devices, which are typically not the top-of-the-notch computing environments in terms of storage volume or computation speed. In this regard, LBS data provide great opportunities as well as challenges for spatial data mining of human behavior data. Future research along this line include the development of data mining algorithms tailored for LBS data, design and implementation of data structures of activity-based location data, exploratory analysis of such data, and knowledge discovery from the data mining practices.

3.3. On-the-fly generalization and visualization

LBS can be characterized as map-centered geographic information services, as location information and services are most likely to be shown in mobile terminals. Conventional cartography, which was initially developed for stationary map displays, is rather insufficient to the particular needs of LBS. Distinct from a stationary cartographic system, the maps for LBS have various constraints such as small screens, persistent change of locations, and egocentric views. Special considerations should be given to these constraints for map rendering. For instance, the small screen constraint means that the conventional map with a great amount of details cannot be directly rendered for LBS applications. Mobile maps must be more simplified or generalized while retaining the necessary information. For this consideration, route maps or schematic maps (Agrawala & Stolte, 2000; Avelar & Mueller, 2000) are highly advantageous developments. Persistent change of locations implies the constant retrieval and update of the base map. Meanwhile, the retrieval and update must be adapted to the user's location and context. These issues have never been researched in conventional cartography, although the research issue of on-the-fly generalization has been explored for web mapping (e.g. Cecconi & Galanda, 2002). In consideration of the abovementioned particular constraints and characteristics of LBS, more efficient algorithms are to be developed for on-the-fly and context-sensitive generalization and visualization.

It will also be interesting to investigate whether other visualization approaches, such as animation, multimedia, and multimodal geographical information presentation, are feasible for designing LBS applications. To adapt to the user's dynamic location, egocentric representations such as fish eye and variable scale maps, and panoramic view of the surrounding from the user's current position are appropriate. A recent book edited by Meng, Zipf, and Reichenbacher (2004) presents a state of the art of the research and development along the line of map-based services. Many issues are still kept open for further research. These issues include human cognition of the new types of mobile maps, the usability of these maps, as well as the effectiveness of the mobile visualization methods. As the devices used for LBS are very compact, they typically do not include powerful input–output peripheries such as keyboards and mice. This brings about extra research challenges to facilitate human-device interactions that are necessary for advanced visualization methods.

3.4. Interoperability issues

Interoperability has been a challenging issue for GIS (Goodchild, Egenhofer, Fegeas, & Kootman, 1999). Heterogeneity is also one important feature of LBS. The heterogeneity can be seen from various perspectives involving network protocols, hardware, software, positioning technologies, users, data sources and formats, and application semantics. Heterogeneity can be achieved through standardization. Currently many organizations are making contributions to the standardization of LBS to facilitate interoperability. Among them two bodies, Location Interoperability Forum (LIF) and Open Geospatial Consortium (OGC), have devoted significantly to location interoperability. LIF approaches location interoperability from the perspective of wireless network, while OGC targets the same issue from a geospatial angle. The two bodies endorse mutually some location interoperability standards. It is important to note that LBS are a collection of services offered by a value chain of interconnected companies from IT and geospatial industries. The companies include data providers, hardware and software providers, service providers, positioning data providers and so forth. The standards and open specifications significantly improve the efficiency of developing some LBS applications. In the future, more work needs to be done in order to achieve cross-standards interoperability.

For the development of LBS, it is rather important to ensure the meanings of concepts and data intended by the designer are effectively communicated from service suppliers to consumers (Kuhn, 1996, cited from Raubal, 2005). These are fundamental for semantic interoperability. Among the various types of interoperability, the semantic one is probably most difficult to achieve because of the linguistic sophistication and delicacy. It is challenging to catch and communicate semantic meanings across systems and among people. Raubal (2005) suggests adopt a people-oriented approach to solve semantic interoperability, as essentially meaning is not independent of people's understanding and cognition. More research along the line is anticipated in the future.

3.5. *Privacy and social issues*

Although LBS indeed have enormous application potential for enhancing safety, convenience, and utility in our daily lives, people are wary of any abuse of the technology and location information. If not well guarded, LBS, like any other technology, may be reversed into the opposite of what was originally designed for (Sui, 2004). LBS, as well as other location related geospatial technologies, threaten people and the society's privacy, or location related privacy to be more specific. The threat has been widely recognized and is vividly termed as "geoslavery" (Dobson & Fisher, 2003). The concern has enormous impacts on people's attitude towards using and adopting LBS. Current research on the issue of relations between the user's conceptions of privacy and intentions to use LBS is important for the development and deployment of LBS (Junglas & Spitzmuller, 2005). Thirteen privacy issues related to the collection, retention, use and disclose of location information and technologies (Minch, 2004) provide a full spectrum of understanding of location privacy. The privacy issues could be used as a foundation to build up a theory of LBS privacy as part of general theory of privacy in the information age (Moor, 1997). Safeguard necessary for protecting rights of individuals must be provided to avoid abuse of location information and technologies, and to further facilitate the healthy development of LBS products and services.

Currently, research towards the privacy of LBS has been sporadic, among them most on conceptual and a few on empirical studies. For instance, the conceptualization of LBS as new media (Sui, 2004) contributes to a complete and holistic perspective on LBS. In particular the detailed tetradic analysis of LBS based on McLuhan's laws of media provides some deep insights into social and spatial impacts of LBS on individuals and society as a whole. To alleviate users privacy fears, industry has started to implement some regulations to get rid of users' privacy concerns. The Privacy Management Code of Practice defined by Vodafone for instance allows the users to anonymize location requests by mapping the cell phone number to an alias (Spiekermann, 2004). It also provides an interface option for the users to turn on or off localization. More research is needed on users' conception of privacy and how they shape their attitude towards LBS products and services. Future development of LBS and the fulfillment of their potential rely much on the advances around study, standards, and legislation about location related privacy.

4. Conclusion

This paper strives to capture the current developments in LBS, an emerging and fast developing field cutting across the boundaries of geospatial, mobile, and information technologies. We have seen from the previous review that increasing efforts have been made by both geospatial scientists and computer scientists towards the advancement of LBS. We have also seen a series of issues and challenges imposed on LBS research from both technological and societal perspectives. The need and importance of many GIScience research topics find more justifications with LBS. Meanwhile these research topics also see new challenges with LBS. More cross-disciplinary endeavors are anticipated in the future particularly at the intersection of information technology, geospatial technology, and increasing awareness of social impacts of the technologies.

There is no a clear-cut boundary of LBS and GIS, as many fundamental research issues of GIScience are those of LBS as well. The boundary could be even more blurry in the future when conventional GIS advances to invisible GIS in which GIS functionalities are embedded in tiny sensors and microprocessors. As speculated by Sui (2005), conventional GIS concepts may disappear, but instead GIS functionalities may appear in a pervasive fashion when the idea of ubiquitous computing comes true. The evolution of GIS concepts clearly reflects the shift of computing platforms from mainframe, to desktop, and nowadays to an increasingly pervasive fashion. It is the shift that makes LBS and GIS research special, challenging, and exciting.

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