Semantic Enrichment of Location-Based Services

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INTRODUCTION

Location-based services (LBS) are considered the most popular mobile telecommunication services besides the traditional ones, for example, SMS and MMS. They are believed to constitute the *killer applications* for next generation mobile networks, since they enable adaptive location-driven content provision. Such services can be provided wherever the location of mobile users can be determined. Nowadays, there is a wide range of methods for estimating the location of users in both *indoor* (i.e., in-building areas) and *outdoor* environments (Schiller & Voisard, 2004).

Outdoor LBS are more developed than their indoor counterparts due to the existence of positioning and topological information systems, GPS (global positioning system) and GIS (geographic information system) respectively. However, almost all known LBS provide their functionality irrespectively of the actual *user context*, which may consist of user's location, physical capabilities, and/or cognitive status. Furthermore, most services ignore the semantic information of the spatial elements (e.g., stairs, elevators, and physical obstacles), other than the Euclidean distance.

In this article, we describe issues related to the development of *intelligent* and *human-centered* LBS for indoor environments. We focus on the navigation service. Navigation is probably the most challenging LBS since it involves relatively complex algorithms and many cognitive processes (e.g., combining known paths for reaching unknown destinations, minimizing path length). With the proposed system, we try to incorporate intelligence to navigation services by enriching them with the semantics of users and navigation spaces. Such semantic information is represented and reasoned using state-of-the-art semantic Web technologies (Berners-Lee, Hendler, & Lassila, 2001).

BACKGROUND

LBS offer location-aware content provision. Apparently, a key enabler of LBS is the positioning infrastructure. As far as outdoor environments are concerned, the most commonly used positioning method is GPS, which provides spatial information with high accuracy and availability at low cost. On the other hand, there exist many alternative positioning solutions for indoor spaces, but with none of them having been standardized yet. Among these solutions are: WLAN (wireless local area network) triangulation, dead-reckoning techniques (implemented with accelerometers and digital compasses), RFID (radio frequency identification) tags, and infrared/ultrasound beacons. The authors in Hightower and Borriello (2001) provide an extensive survey of indoor positioning techniques. A basic assumption for developing our system is that we have an indoor positioning system at our disposal. Such system can locate users with "adequate" accuracy.

This article deals with indoor navigation. Former indoor navigation research focused on robot navigation. As the positioning systems have matured, more effort has been put on developing indoor navigation services for pedestrians, such as museum guides aiding the sightseeing of tourists. An indicative system in this category is CyberGuide (Abowd, Atkeson, Hong, Long, Kooper, & Pinkerton, 1997). Another, more recent and more sophisticated, navigation system is Navio (Gartner, Frank, & Retscher, 2004). Navio aims at developing a route modeling ontology, which provides both outdoor and indoor routing instructions to humans by identifying and formally defining the criteria, the actions and the reference objects used by pedestrians in their reasoning for routes. However, Navio research emphasizes on location fusion (i.e., the aggregation of location information from multiple sensing elements) and user interfaces and, thus, does not contribute significantly to the issue of path selection. This latter issue is of utmost importance for human-centered LBS, but it is often ignored or handled in trivial ways. In general, such systems focus on the path presentation to users and on the hardware/positioning infrastructure used.

Additionally, some systems have been developed for addressing the special needs of certain user categories, such as navigation for blind people. Such systems, however, lack a holistic approach to the navigation process. This means that their approaches are not considered general enough to address the whole range of potential application requirements. This drawback of existing solutions, as well as their deficiencies that will be identified in the following subsections, have motivated the present research in user- and space-modeling, path selection and navigation algorithms.

Navigation Algorithms

Since navigation is a path-searching algorithmic problem, the decision on the *path-searching* algorithm used is vital for the quality of the provided service. Most of the existing navigation systems, either indoor or outdoor, make use of *traditional* shortest path algorithms (e.g., Dijkstra, A-star), thus, recognizing the minimization of Euclidian distance as the only objective in the path selection process. However, such approach overlooks the significance of other objectives more relevant to the context of the user. Hence, significant research on that topic has identified that pedestrian navigation needs more sophisticated and human-centered path-searching algorithms. Authors in Duckham and Kulik (2003) have proposed the "simplest path algorithm." In this algorithm, the selected path is the one with the lowest possible complexity in navigation instructions. This work belongs to the category of approaches that introduce modifications of well-known graph routing algorithms like the aforementioned shortest path algorithms. A rather similar approach is discussed in Grum (2005), where the proposed navigation algorithm computes the "least risk path." The term *risk* refers to the possibility of the user getting lost.

The aforementioned algorithms, although providing more "intuitively-correct" paths than the conventional shortest paths algorithms, do not take into consideration the user semantics, as dictated by the modern design paradigm "Design for All" (European Institute for Design and Disability, 2005) (a.k.a., inclusive design). This paradigm promotes the design and implementation of services and products so that they can be used by any user, without any further adaptation. The implementation of such a paradigm, in the LBS domain, would lead to services that can be consumed (in an optimal way) by any user, regardless of her special characteristics.

Spatial Models and Ontologies

The quality of *path-searching* algorithms also depends on the spatial modeling of the navigation space. Many approaches have been proposed for spatial modeling with different data representations and expressiveness. Specifically, *geometric* models represent the navigation space using a certain coordination system and mainly support geometric queries (e.g., where is the nearest coffee machine?). On the other hand, *symbolic* models represent the navigation space through sets of symbols (i.e., names) and inter-symbol relationships capturing the topological semantics (e.g., part-of and overlaps spatial relations). Finally, *hybrid* models are combinations of the two former categories, aiming at maximizing the overall expressiveness of the spatial model. An interesting comparison of spatial models is presented in Leonhardt (1998). As far as indoor navigation is concerned, only a few researchers have proposed practical, yet expressive, models. To our opinion, the most important is presented in Hu and Lee (2004). It is a hybrid model, which represents the space as semantic hierarchies of "locations" and "exits" that also carry geometric information (e.g., coordinates).

The use of semantics-based spatial models results in what has been called *semantic location-based services*. However, we claim that actual semantic LBS should not only exploit semantically enriched spatial models (symbolic or hybrid), but also take into consideration the *navigation context* (i.e., user context and instantiation of spatial model). Hence, we propose a refinement of the term *semantic LBS*, or better, *human-centered LBS*, so that it supports the following requirements:

- Awareness of spatial semantics (e.g., hybrid model)
- Awareness of navigation context
- Adherence to the Design-for-All paradigm
- Reaction to dynamic user or space status changes

As will be shown in a following section, such services can be built with a knowledge-based system architecture. This architecture exploits knowledge representation methods to model the various components, and reasoning/inference techniques in order to implement the actual path selection process. The most popular and practical technology for representing models is the ontologies. Ontology is defined as "an explicit and formal specification of a shared conceptualization" (Studer, 1998, p. 185). In other words, it is a method for describing models of application domains that can be understood by machines. Knowledge reasoning is the process of inferring new implied knowledge from explicit knowledge assertions. Such reasoning can be based either on logic-based methods (i.e., resolution) or production rules (Brachman & Levesque, 2004).

SEMANTIC INDOOR NAVIGATION

In this article, we propose a framework for human-centered semantic indoor navigation, which meets the aforementioned

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