Advances in wireless networks and mobile devices have motivated an intensive research effort in mobile computing and mobile data services. The goal is to provide users with anywhere, anytime connectivity to the Internet and access to services that are valuable depending on users’ context. One of the most interesting context factors is user location. Thus, context-awareness, and particularly location-based services (LBSs), have attracted great interest. Moreover, rapid progress in developing Semantic Web standards, tools, and techniques (see www.w3.org/2001/sw/), including applications that are rich in spatial and temporal dimensions, and the vision of the geospatial Semantic Web enable the development of more intelligent LBSs.

The Importance of Location-Based Services

A key driver for LBSs and context-aware services is their economic value. Strategy Analytics predicts that the consumer and advertiser expenditure on LBSs will approach US$10 billion by 2016 (see www.strategyanalytics.com/default.aspx?mod=reportabstractviewer&a0=6355). The importance of location-based social networking is also expected to increase; ABI Research estimates that such social networking will generate revenues up to $3.3 billion by 2013 (see www.4psmarketing.com/the-rise-of-location-based-social-networks.html). One reason for this will be the ever-growing availability of embedded GPS devices. According to Berg Insight, the global number of GPS-enabled handsets will have grown from 175 million units in 2007 to 560 million in 2012 (www.berginsight.com/News.aspx?m_m=6&s_m=1). New positioning systems such as Galileo (www.esa.int/esaNA/galileo.html), which is expected to provide “positioning accuracy down to the meter range” and work indoors, will also contribute to an increased interest in LBSs.

These market trends have motivated the development of many interesting applications, such as tracking, emergency, navigation, and information services (for example, vehicle monitoring, roadside assistance, digital travel assistants,
and location-dependent yellow pages), as well as location-dependent advertising and even games (for instance, location-based offers and coupons, and geocaching [www.geocaching.com]).

Within LBSs, the ability to efficiently process location-dependent queries, whose answers depend on certain objects’ location, is an important research issue. Consider a user who is searching for a taxi. A taxi-finder LBS could provide the user with information about available nearby taxis by submitting a location-dependent query that retrieves taxis in his or her vicinity. This is also an example of a continuous query, given that the objects that can affect its result (both the mobile user and the taxis) can move constantly; thus the answer becomes obsolete very quickly.

Managing Semantics in LBSs
Using semantic technologies in software application development has been a clear trend in recent years. Numerous advances in Semantic Web technologies — which facilitate the development of systems that enable machines to understand and respond to human requests based on their meaning — can have an interesting application to LBS development. (Note that the rapid emergence of the Web of data, or linked open data, lets us transform unstructured and heterogeneous data into semantically annotated structured data that’s more machine-processable and understandable.) Thus, semantic technologies can enable software to automatically process information and users to search more accurately for services (for instance, using semantic search engines rather than traditional syntactic-based ones).

So, several research challenges and opportunities aim toward developing semantic LBSs. One key element in the Semantic Web area is using ontologies (a formal, explicit specification of a shared conceptualization) for knowledge representation, which can be encoded in languages such as the Web Ontology Language (OWL). Ontologies can provide LBSs with knowledge about context, leading to software applications that know how to behave in certain, sometimes unexpected, situations (a capability until now restricted to humans). Thus, by linking LBSs and semantics, we can enable reasoning and develop intelligent services.

Linking LBSs and Semantics
LBSs’ main attraction is that users don’t have to enter location or movement information manually — rather, the services automatically pinpoint and track such data to provide information relevant to users’ locations. Besides, in information services, we can apply semantic technologies to provide natural interpretations of the information available and the users’ information needs. These two worlds are complementary and can benefit from each other. Let’s look at some areas in which semantic techniques could lead to smarter LBSs.

Flexible Querying
Information access in existing LBSs is constrained to a predefined data schema that mobile users (or end-user applications) must manage in order to submit information requests. It would be much more interesting to enable some form of keyword-based searching or an intelligent query-answering approach that takes the user’s context into account.

Supporting this kind of flexible querying necessitates semantic techniques. For example, we’d need a semantic approach to disambiguate the keywords or terms the user introduces. Moreover, we’d need to categorize the accessible information somehow, such that if users search for “transportation means,” they’ll find information about the different available alternatives (for example, taxis, buses, trains, or even donkeys in some more remote areas), depending on users’ location and context. When different data sources are involved, the LBS should infer the relationships between the data at those different sources. Finally, in some cases, it might need to automatically match the user query with an appropriate information service.

Managing Semantic Locations and Trajectories
Users should be able to use the location terminology they require, so access to information shouldn’t be limited to requests regarding objects’ current geographic locations. Rather, LBSs should support any concept of location that might be interesting (semantic locations), such as a neighborhood, city, province, building, or room. An LBS developer could represent these symbolic locations using ontologies, making explicit the properties and relationships of the locations.
Moreover, a system that supports semantic locations should also manage transparently the location information provided by the different positioning mechanisms available, which might offer different accuracy. The challenge is how to efficiently exploit such semantic location information to offer users better access to the data they require.

In addition, applications should understand the trajectory of a moving object as an important element that characterizes its spatio-temporal behavior, which goes beyond just a raw sequence of locations. So, in various scenarios (location-based social applications, tourism, geofencing, and so on), LBSs might need semantic abstractions of the trajectories (semantic trajectories). The idea is to enrich the raw data of a trajectory with higher-level information (semantic annotations) that’s useful for a given application (for instance, if a tourist is in a touristic place for a certain amount of time, an application or service can infer that he or she is probably visiting that place; or, if the tourist is following a typical touristic route, then he or she will likely continue following that route).

**Interoperability among LBSs and Providers**

LBSs should provide users with location-independent, wide-area access, meaning that the use of a service should be the same regardless of the user’s location. Thus, sharing and exchanging data among different LBSs should be possible. Interoperability issues and the integration of similar services in different geographic areas are important challenges. Additionally, LBS developers should have a means to transparently handle positioning mechanisms (such as GPS, cell-ID positioning, and Wi-Fi-based positioning).

Some standardization initiatives have tried to solve these problems. The Mobile Location Protocol (MLP), supported by the Open Mobile Alliance (OMA; www.openmobilealliance.org), defines a set of rules for querying and representing location information. Similar approaches exist for location modeling. In this context, semantic technologies could play an important role — for example, as a means of representing the information managed in an unambiguous way or trying to save the existing differences between different location services via semantic matching. Indeed, some works have proposed using semantics to address interoperability issues in an LBS context.

**Protecting Personal Location Information**

Location privacy is an important requirement for LBSs. A common strategy for protecting location privacy is based on forwarding to the LBS provider the user’s coarse location (obfuscated) instead of his or her actual and precise location. Obfuscation methods are generally based on geometric methods, which don’t take into account geographical knowledge that could enable a malicious entity to infer semantic locations; thus a risk exists of disclosing sensitive location information which might lead to privacy leaks.

New proposals try to avoid this situation by taking into account the semantic context in which users are located. In this vein is a framework that manages a semantics-aware obfuscation model. Significant progress in geospatial semantics and widely usable geographic data in linked open data are likely to expedite such capabilities’ deployment.

**Reasoning in Complex and Dynamic Contexts**

A key research issue is how to effectively exploit available semantic information to provide intelligent LBSs. This implies performing reasoning with such information. In some cases, simple spatial reasoning might be all that’s necessary (for instance, if the user is in a certain room, and that room is within a certain building, then the user is in that building). In others, a more sophisticated reasoning involving other elements could be required. For example, a user might ask for a good and convenient place to eat, and an LBS could infer what “good” and “convenient” mean for that user at that particular moment and location, as well as the most suitable type of “place” (restaurant, bistro, bar, and so on) the LBS could consider. In a more complex scenario, the user could even just say “I’m hungry,” and the system would infer that he or she needs a certain place to eat (according to preferences and context).

Scenarios like those just described require modeling and reasoning with elements such as location, user preferences based on a user profile, user context, and the context related to potential targets. Some researchers have
proposed models for spatio-temporal reasoning with ontologies.\textsuperscript{19} Besides providing more accurate information to users, reasoning in the context of LBSs could help detect inconsistencies in the available data or unsatisfiable user requests (due to contradictory requirements, for example).

**In this Issue**

With this special issue, we wish to highlight research that joins advances in mobile computing and the Semantic Web to build new semantic LBSs.

Emanuele Della Valle, Irene Celino, Daniele Dell’Aglio, Ralph Grothmann, Florian Steinke, and Volker Tresp present the article “Semantic Traffic-Aware Routing Using the LarKC Platform.” They propose integrating statistical learning techniques (for traffic prediction), operational research algorithms (for routing), and conceptual query answering. As an application scenario, they present a service that offers traffic-aware routing services for the city of Milano.

“A Framework for Integrating, Exploring, and Searching Location-Based Web Data,” by Alessandro Bozzon, Marco Brambilla, Stefano Ceri, and Silvia Quarteroni, presents a framework for searching and exploring resources based on the notion of nearness. This framework lets users navigate through resources based on their location, closeness, and other semantic relationships. The authors have implemented a prototype that supports different forms of visualization and ranks query results according to different criteria.

Finally, “Mobile Querying of Online Semantic Web Data for Context-Aware Applications,” by William Van Woensel, Sven Casteleyen, Elien Paret, and Olga De Troyer, presents the mobile application framework SCOUT. This framework facilitates the development of location-based and context-aware applications. It supports linking physical entities with online semantic sources available on the Web and provides a service that manages, integrates, and queries data transparently.

The three articles in this special issue address only some topics in semantics for location-based services. As semantic technologies become more mature and experience regarding their application in different contexts grows, we can expect an increasing amount of research that will try to merge both worlds.

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**References**


Sergio Ilarri is an associate professor in the Department of Computer Science and Systems Engineering at the University of Zaragoza, Spain. His research interests include data management for mobile computing, distributed systems, vehicular networks, mobile agents, and the Semantic Web. Ilarri has a PhD in computer science from the University of Zaragoza. Contact him at silarri@unizar.es; http://webdiis.unizar.es/~silarri/.

Arantza Illarramendi is a full professor at the University of the Basque Country, Spain. Her main research interests are data management in mobile environments and semantic interoperability among information systems. Illarramendi has a PhD in computer science from the University of the Basque Country. Contact her at a.illarramendi@ehu.es; http://bdi.si.ehu.es/~arantza/.

Eduardo Mena is an associate professor in the Department of Computer Science and Systems Engineering at the University of Zaragoza, Spain. His research interests include interoperable, heterogeneous, and distributed information systems, the Semantic Web, and mobile computing. Mena has a PhD in computer science from the University of Zaragoza. Contact him at emena@unizar.es; http://webdiis.unizar.es/~mena/.

Amit Sheth is the director of the Ohio Center of Excellence in Knowledge-enabled Computing (Kno.e.sis) at Wright State University. His focus is on developing semantic approaches and background knowledge to process, integrate, analyze, understand, and make actionable a wide variety of sources, including scientific experiments and literature, social media, and sensors. Sheth has a PhD in computer and information science from Ohio State University. He’s a fellow of IEEE and a LexisNexis Ohio Eminent Scholar. Contact him at amit@knoesis.org; http://knoesis.org/amit.

Selected CS articles and columns are also available for free at http://ComputingNow.computer.org.