LOCATION-BASED SERVICES

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INTRODUCTION

Over the past ten years location-based services (LBS) have been variously touted as the next generation of GIS; as the killer application that will bring the GIS industry to its next level of prosperity; and as a growing threat to human privacy. This chapter attempts to provide a basic introduction to LBS, and a discussion of some of the major issues surrounding them. It begins with basic definitions, and a short history of LBS. This is followed by an overview of the services currently provided by this form of geospatial technology, or likely to be provided in the near future. A major section of the chapter then describes the various methods for determining the location of a device, and significant gaps in current coverage. The penultimate section introduces some of the major social issues associated with LBS, and the final section discusses some broader implications and current research directions.

A location-based service can be defined as an information service provided by a device that knows where it is, and modifies the information it provides accordingly (http://en.wikipedia.org/wiki/Location_based_service; Küpper, 2005). This is a very broad definition, and not surprisingly there are some trivial fits. A human, for example, is capable of knowing his or her location, and of providing information based on that knowledge, but one would not describe a human as “a device” – instead, “a device” is clearly intended to imply something digital, such as a cellphone, laptop computer, desktop computer, ATM (automated teller machine), or PDA (personal digital assistant). Moreover human knowledge of location is often informal (e.g., I am “at the airport”), rather than the formal and precise coordinates demanded by GIS technology.

Early computing devices were designed for the solution of numerical problems such as the equations governing nuclear reactions, for breaking secret codes, and for handling and analyzing massive amounts of data. None of these applications are in any way dependent on knowing the location of the computing device. Location was and is important in GIS, but while it is important in these computing applications to know the locations and attributes of features on the Earth’s surface, the locations of the user and the computing device were largely irrelevant. Indeed, much is still made of the ability of GIS to analyze conditions in parts of the world that are remote from the user, and may never have been visited by the user.

While LBS are defined by their ability to provide information, the recipient of that information may not be the person using the device, and may not be in the same location. To be precise, then, the *user* for the purposes of this discussion will be the person co-

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located with the device, while the term *recipient* will be used in those cases where the information provided by the device is not directed to the user, at least in the first instance. For example, when a cellphone user initiates a 911 emergency call, the service provider will attempt to determine the location of the device by one of a number of techniques described later in the chapter, and will forward that information to the emergency dispatcher. Indeed, in this scenario the user may never know his or her location, but that information is enormously valuable to the dispatcher. U.S. law explicitly authorizes this release of location information by cellphone providers for emergency purposes.

The first truly mobile computing devices began to appear in the 1980s (in my own case, in the form of a Hyperion portable computer with two 5.25 inch floppies, an alphanumeric screen, an Intel 8088 processor, and no hard drive). Since then mobility has become an increasingly important factor in computing, and today we expect to find far more powerful performance available in devices that can fit in a pocket. Mobility has in turn opened up the possibility of providing information about the user's location in space and time, about the user's surroundings, and about features in the environment that are nearby but beyond the user's own sensory perception. This information may be useful to the user, and it may also be useful to someone else, such as the user's employer, bank, parents, or government. The next section reviews examples of LBS, and their value to users and other recipients.

WHY IS LOCATION IMPORTANT, AND WHO WANTS TO KNOW?

GPS provides the simplest and most obvious form of LBS, allowing a user to determine position on the Earth's surface, in the precise coordinates of a formally specified location, to within meters and in some cases centimeters (Kennedy, 2002; Leick, 2004). The U.S. Global Positioning System was originally developed for military purposes, with only a degraded signal available to civilians. But a change of policy in the 1990s opened full accuracy to all, and today GPS is used worldwide as a free, ubiquitous means of determining position. It is based on comparing the timing of signals arriving from that subset of a consellation of 24 satellites that is above the user's horizon. A comparable Russian system is in operation, and a European system known as Galileo will be operational within a few years.

A GPS position alone is not of much value – exact position relative to the Equator and the Greenwich Meridian is not in itself very useful. Position can be determined relative to other features if the GPS signal can be integrated with a digital map, or if a paper map is available and suitably marked with a coordinate graticule. But the real power of GPS comes from its integration into other functions, including those of a GIS with a suitable database. Today, simple GPS devices are available that contain digital maps, databases of features such as hotels, retail stores, and restaurants, and GPS has been integrated into the in-vehicle navigation systems that are increasingly common either as installed features or after-market additions. Such systems are often described as providing an *augmented reality*, by providing the user with information that is beyond his or her sensory perception, in contrast to the *virtual reality* of traditional GIS.

GPS integrated with a database in a mobile device such as a PDA (personal digital assistant) or cellphone can provide a powerful form of augmented reality. But an isolated database is inherently static, since it can be updated only from physical media. For example, many in-vehicle navigation systems must be updated by the cumbersome process of downloading from a CD via a personal computer and a USB connection. A more dynamic approach results when the mobile device is linked wirelessly to the Internet, allowing more-or-less continuous updating. Information on minute-by-minute changes in traffic congestion, the positions of trains and buses, and the real-time locations of flights can be continuously fed from servers, providing a truly dynamic LBS.

For example, in many cities it is now possible to obtain real-time feeds of the actual locations of buses, and to service queries such as “When will the next Number 24 bus arrive at this stop?”, where “this stop” is determined from the user’s current location as determined by the mobile device’s GPS (e.g., http://www.nextbus.com). Several Web services offer real-time data on traffic densities on major roads (e.g., http://local.live.com), and several airlines allow users to query the locations of flights, returning the results in map form (e.g., http://www.alaskaair.com).

Similar technology has been exploited to provide valuable services for emergency response, military operations, and construction. For example, an emergency responder may find it difficult to determine his or her current location, particularly if street signs and house numbers have been obliterated, or if the street pattern itself has become distorted, or if visibility is obscured by smoke or dust (NRC, in press). In such situations it is useful to have a mobile device equipped with GPS and a map database, and if possible to receive real-time feeds of other data sets, including recent post-event imagery. In the construction industry, LBS offers the possibility of on-site access to databases showing the underground locations of infrastructure, allowing workers to dig without risk of interrupting services.

Researchers have also recognized the potential of augmented reality in field work. At Columbia University, Steven Feiner and his group have experimented with head-mounted devices that superimpose historic scenes on the user’s field of view, based on GPS positions and sensors that determine the user’s head orientation (http://www1.cs.columbia.edu/graphics/projects/mars/). At the University of California, Santa Barbara, Reginald Golledge and his group have developed prototypes of a personal navigation system for the visually impaired (http://www.geog.ucsb.edu/pgs/main.htm), while Project Battuta, a collaborative project with Iowa State University, has developed LBS to support researchers working in the field, providing information about the user’s position and the locations of sample sites, and performing real-time spatial analysis of observations as they are gathered by the user (http://dg.statlab.iastate.edu/dg/), and based on wearable devices.

Besides these rather utilitarian applications, LBS are also proving popular in social and recreational activities. Several cellphone operators now provide variations on the theme of mapping friends. For example, the Find Friends service offered in some markets by AT&T prior to its merger with Cingular (http://interactive.usc.edu/archives/000784.html) allows participants to display maps on their cellphones of the locations of friends who are also participants. Geocaching (http://en.wikipedia.org/wiki/Geocaching; http://www.geocaching.com) is a popular and rapidly growing sport that involves players in using GPS and digital maps to find caches where they can exchange interesting objects. A number of *location-based games* have been developed that engage one or more users in fictitious scenarios. In Undercover 2 (http://www.ydreams.com/ydreams_2005/index.php?page=193), for example, players are tracked using cellphones, and maps are displayed on user devices showing the locations of each player.

In all of these examples it is the user who receives the information provided by the LBS. Reference has already been made to 911 calls, when it is the dispatcher rather than the caller who receives the information about the caller's location. However there are many other examples of LBS applications for which the recipient is someone other than the user, and in many of these the user may not be aware that the information is being provided, and may even be disturbed to know that his or her locational privacy is being compromised in this way.

The term *tracking* is often used to refer to real-time acquisition of location information by a third party, often by wireless communication of GPS measurements. Such tracking is common in the transportation industry, and car rental agencies have been known to track their fleets to monitor violations of rental agreements, for example by speeding or by traveling into explicitly prohibited areas such as other countries. Tracking is used by probation officers to monitor compliance, by vehicle owners to detect theft, by researchers and wildlife managers to monitor the movement of animals and birds, and by pet owners and even parents to monitor their charges. The OnStar system (http://en.wikipedia.org/wiki/OnStar; http://www.onstar.com/us_english/jsp/index.jsp) installed in many vehicles initiates tracking when activated by the user, transmitting the user's current location to a dispatcher who can respond to queries, for example for driving directions. The system is automatically activated in the event of airbag deployment, prompting the dispatcher to activate appropriate emergency services.

Tracking devices monitor the location of the device on a fixed interval of time. Often the major constraint on the frequency of sampling and the length of time over which data can be collected is the capacity of batteries, and this is particularly problematic when devices have to be carried by small mammals or birds. But when battery power is not a constraint, for example when tracking devices are carried on vehicles, it is common for sampling intervals to be as short as 1 second. With such rates it is possible to detect stops, starts, and changes of speed, and thus to infer many potentially useful properties. For example, changes of speed can indicate the presence of traffic accidents long before the event is known through more conventional means, such as cellphone calls from drivers.

Other techniques make it possible for third parties to determine the locations of events, and to associate them with individuals. Although no mobile devices are involved, every use by a purchaser of a credit or debit or store affinity card creates a record that is easily referenced in space and time. Card companies use this information to detect fraud, as for example when a card is used for several large purchases in quick succession in an unusual location. Many of us have had the embarrassing experience of having a card refused at a restaurant, store, or hotel that is not within our normal geographic range. Other devices record the passage and identity of vehicles on toll highways, and video cameras increasingly record the presence of individuals in public places. Automated license-plate recognition is now routine, and facial recognition is increasingly effective.

Finally, information on the user's location is of substantial commercial value to the operator of a search service, such as Google or Yahoo!, since it can be used to prioritize hits in geographic proximity to the user. Such prioritization is of value to vendors, who are consequently willing to pay the search service operator accordingly. Although geographic location is not normally known precisely, it can be inferred approximately from the user's IP address, as described in the following section.

LOCATION-DETERMINING TECHNOLOGIES

Mention has already been made of GPS and its analogs, which today constitute the primary means by which a mobile device is able to determine its geographic location. Miniaturization of GPS receivers has made it possible to embed them in cellphones, PCMCIA cards, and even wrist watches (e.g., the Garmin Forerunner 201; http://www.garmin.com/products/forerunner201/). Battery power is currently the major constraint to further miniaturization, however, and the operating times of some devices on a single charge can be disappointingly short.

GPS requires the line-of-sight presence of at least three satellites for horizontal positioning, and at least four for additional vertical positioning. Unfortunately this means that GPS signal is frequently lost by mobile devices, owing to tree cover, steep slopes, and buildings – and is never available within buildings. It is estimated that while an average vehicle driving in the San Francisco area has signal available 80% of the time, in Hong Kong with its urban canyons the proportion drops to 20%. For pedestrians and for vehicles parked in structures the percentages are substantially lower.

Many options for filling these coverage gaps in positioning technology have been explored, especially within buildings, with varying degrees of success. Beacons can be installed at fixed positions, radiating signals in various parts of the spectrum that can be used by mobile devices to determine position (WiFi signals offer one of the more successful options; e.g., http://www.ekahau.com/). At this time, however, no one system appears to be ideal, and to offer smooth interoperability and transition with GPS positioning outdoors. Meanwhile research projects continue to develop prototypes of integrated indoor/outdoor positioning (e.g., http://www.spatialinfocrc.org/pages/project.aspx?projectid=65).

Although GPS provides the positioning capability of many cellphones, other and in some respects simpler techniques are also used. Accurate timing of signals from multiple towers, accurate timing by multiple towers of the signal from a phone, and estimation of distance by measuring signal attenuation, are all used to provide positional information, with accuracies ranging from hundreds to tens of meters (http://www.geog.ucsb.edu/~good/176b/n14.html). In addition the identity of the cell containing the phone is sufficient in some areas to provide positioning to a few hundred meters, particularly with the micro-cell technology now being implemented in some urban environments. Note that these technologies can provide limited coverage beyond the range of GPS signals.

Several other techniques are capable of providing at least approximate locations. For point-of-sale systems and ATMs, geographic location is determined when the system is installed, and is used to georeference any transactions recorded by the system. Mention was made earlier of the potential for approximate determination of location from the IP address of the user, based on the publicly available registration information associated with the address. Several companies specialize in inferring geographic locations from IP addresses (e.g., http://www.digitalenvoy.net/).

Finally, there has been much interest recently in the potential of RFID (Radio-Frequency Identification) as a technique for determining position (Finkenzeller, 2003). RFID is perhaps best thought of as the radio equivalent of a barcode, its major advantage being that no optical device such as a laser needs to be physically pointed at the tag. Instead, tags are detected and read by remote radio-frequency transmitters, which receive and interpret the returned signal. RFID tags are sometimes incorporated into standard optical barcodes, but can also be concealed in articles and made difficult to remove. They are cheap to produce, and easily miniaturized.

RFID tags are now being used by major retailers to keep track of the production, shipment, storage, and sale of goods (e.g., http://www.directionsmag.com/article.php?article_id=629&trv=1). They are being used to identify and track the components of a building during construction, to manage farm animals, and to track containers through ports. A new version of RFID allows tracking of objects enclosed in metal containers (http://www.navsci.com). Several recent news stories have focused on the potential for RFID tracking of individuals, including one in which a school used RFID tags to track its students entering and leaving school property (http://www.msnbc.msn.com/id/6942751/), and one in which a night club used RFID to tag its members (http://technology.guardian.co.uk/online/story/0,3605,1234827,00.html). Another recent news story described the Geo-Spatial Web (http://www.onpointradio.org/shows/2006/01/20060103_b_main.asp), a future world in which many types of objects would be "intelligent" – capable of returning their identity, location, and other properties in response to a radio signal, just as air traffic controllers today can track the identity and properties of aircraft.

SOCIAL ISSUES

It will be apparent already that many forms of LBS raise serious and significant issues of an ethical nature. Many of the applications allow third parties to gain access to information about the location of the user, whether or not such access has been explicitly authorized. Users of credit cards, for example, in effect surrender certain aspects of their locational privacy in return for the convenience of the card, and some degree of assurance that tracking of location will protect them from fraud. U.S. legislation in the form of the Wireless Communication and Public Safety Act of 1999 protects the users of cellphones from unauthorized release of location information by the cellphone operator, allowing such release only in carefully defined circumstances:

“(4) to provide call location information concerning the user of a commercial mobile service (as such term is defined in section 332(d)):

(A) to a public safety answering point, emergency medical service provider or emergency dispatch provider, public safety, fire service, or law enforcement official, or hospital emergency or trauma care facility, in order to respond to the user's call for emergency services;
(B) to inform the user's legal guardian or members of the user's immediate family of the user's location in an emergency situation that involves the risk of death or serious physical harm; or
(C) to providers of information or database management services solely for purposes of assisting in the delivery of emergency services in response to an emergency."

The State of California has aggressively pursued rental car operators who track renters in ways that can be regarded as intrusive (e.g., http://www.bizjournals.com/sanjose/stories/2004/11/08/daily16.html).

Raper defines two distinct contexts of locational privacy (http://www.geoplace.com/ge/2001/0101/0101tt.asp). The *public persona* governs those circumstances in which the individual is willing to surrender locational privacy in return for certain benefits – the convenience of a credit card, or the discounts offered by a store affinity card. The *private persona* governs those circumstances in which the individual demands to keep location private, perhaps because harm or embarrassment might result if location were revealed.

Dobson has defined and written extensively on the concept of *geoslavery* (Dobson, 2003), drawing an analogy between the effects of surveillance and tracking on individual freedom today, and the effects of shackles, branding, and skin color on the freedom of individuals in past centuries. Public debates over the tension between individual freedoms and the need for security have grown in intensity since the events of September 11, 2001, and will likely continue to grow.

A quite different set of social issues arises from the ability of LBS to modify other aspects of human behavior. For example, in the past it has been important for retailers, particularly of fast foods, to locate in the most visible urban sites, notably on retail strips and on street corners. But in a world of augmented reality, when the senses are aided by an array of information sources including LBS, it is no longer necessary to be able to *see* a vendor. In principle, the effects of widespread adoption of LBS on the urban retail landscape could be as profound as those of the Interstate Highway network beginning in the 1950s. At a more immediate level, LBS has the ability to assist drivers in scheduling daily tasks, choosing routes and sequences that avoid the worst congestion (e.g., Garling *et al.*, 1998). Some daily activities, such as the journey to work or to drop children at school, are fixed in time, but others, such as shopping, dry cleaning, or visiting the gym, can be rescheduled in response to real-time and forecasted levels of congestion.

THE BROADER CONTEXT

The growth of LBS in recent years has stimulated a challenging research agenda. A 2001 specialist meeting organized by the Center for Spatially Integrated Social Science at the University of California, Santa Barbara, (www.csiss.org) in conjunction with the University Consortium for Geographic Information Science (www.ucgis.org) identified a series of short- and long-term research issues ranging from three-dimensional positioning indoors and outdoors, to the social impacts of widespread LBS use. Some of the highlights of the research agenda were:

- There is a need for methods of analysis that infer activity types from the form of tracking data, and other potentially available ancillary data such as the characteristics or socioeconomic status of the person being tracked. We need a library of track types, an understanding of the distinguishability of each common form of mobile human activity, and an understanding of the importance of sampling rate and spatial accuracy in each case. Alternatively, we need to define a new set of activity types that are both detectable in tracks and of interest in social science, given the potential abundance of such data from LBS.

- Data mining techniques are already being used to discover misuse of credit cards, based in part on abnormal behavior in space and time. Other data mining tools could be developed for purposes more closely related to social science, including the detection of types of behavior from tracking data.

- There is a pressing need for new theory, to frame the new analytic tools and models. New theory should deal with the types of behavior revealed by tracking, and with the impacts of LBS on behavior of consumers and entrepreneurs.

- LBS has the potential to affect profoundly the spatial organization of society, and the behavior of individuals and groups within it. How rapidly will this occur? Which social groups will lead the process and which will lag?

- Will LBS adoption lead to fundamental change in retailiing structure? Will retail outlets become more dispersed or more concentrated in space, and what impact will LBS have on microscale location strategies (*e.g.*, within malls, or along streets)?

- What factors determine how people react to the intrusiveness of LBS, and their willingness to trade privacy? Are there differences due to gender, age, or ethnicity?

(the full report of the meeting is at http://www.csiss.org/events/meetings/location-based/goodchild_lbs.htm).

At a more technical level, LBS raises issues of user interface design, computational geometry, and network architectures. The small space available on the typical mobile device presents challenges for the cartographer, who is used to much larger display areas (e.g., Dillemuth, 2005; Reichenbacher, 2004). Mobile devices must often be used in conditions that make it difficult to see the device screen (smoke, bright sunlight). Because viewing a small screen and interacting with a keyboard can be distracting, it is desirable that drivers interact with mobile devices using sound and speech, raising additional questions about user interface design. There is a growing literature on the computational problems posed by large numbers of mobile devices querying large spatial databases over wireless connections with limited bandwidth (e.g., Kulik and Tanin, 2006). More broadly, LBS can be seen as part of a growing research interest in sensor networks (e.g., Lesser, Ortiz, and Tambe, 2003), and to pose particular problems due to the mobile nature of the sensors.

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