Consistent Visualization and Querying of GIS Databases by a Location-Aware Mobile Agent

Suresh K. Lodha, Nikolai M. Faaland, Grant Wong,
Amin P. Charaniya, Srikumar Ramalingam, Arthur M. Keller
{lodha,auldane,gwong,amin,srikumar,ark}@cse.ucsc.edu
Department of Computer Science
University of California, Santa Cruz, CA 95064
Tel: 831-459-3773; Fax: 831-459-4829

Abstract

Location-aware mobile users need to access, query, and visualize, geographic information in a wide variety of applications including tourism, navigation, environmental management, and emergency response. Often they also need to communicate information back and forth with other mobile users or with a central agency. Depending upon the task, the user may have to share or switch between different databases or different views of the same database. In this work, we first describe our efforts to create a consistent visualization of different spatial geographic databases consisting of aerial imagery, AutoCAD drawings, schematic diagrams, and street maps. The location of a mobile user is obtained via GPS (Global Positioning System) and visualized synchronously across different visualizations. Our focus then is to support the mobile user in visually accessing and querying the spatial GIS databases. The mobile or the central user can interact with the the database in real-time and communicate the information to each other over wireless networks. The system supports a variety of queries and tasks ("how far", "where", "closest" etc.) for many different types of geometric primitives (points, lines, polygons etc.) and objects (buildings, metro stops etc.). The output results can then be unobtrusively and consistently displayed to the user across multiple views of the scene.

Keywords: GIS, GPS, mobile visualization, database query, visual user interface.

1 Introduction

Location-aware services to mobile users is emerging as a critical need in several important applications. Examples include cooperation between mobile users working together to study environment or respond to an emergency situation. There are also standalone examples such as a family trying to navigate its way and making the best use of its first time visit to San Francisco, or a disabled individual needing assistance to find a parking spot on the UCSC Campus. Often these users benefit by communicating to a central agency who may have additional, dynamic, time-critical, or global information that may not be available to the mobile user. Equally useful is dynamic input from the mobile user to update the database information.

The emergence of GPS devices and PDAs (Personal Digital Assistants), availability of high resolution spatial data acquired by different sensors, along with advances in hardware capability, sensor technology, and wireless communication have raised the possibility of making mobile computation and visualization ubiquitous.

Several components are needed to deliver effective services to the mobile user. These components include affordable and comfortable hardware devices users can carry, including location and orientation trackers, time-critical wireless communication with other users and a central agency, unobtrusive and effective multimodal human-computer interaction, real-time availability of a rich and consistent geospatial database, and convenient mechanisms for the query of, interaction with, and dynamic update of the information. It is not surprising that a number of researchers are working on different aspects of this problem [13, 4, 6, 7]. Use of a variety of sensors (cameras, LIDAR, etc.) and display devices (head-mounted displays, PDAs, etc.) by mobile users can enhance the utility of context-aware GIS systems in several emerging applications such as augmented reality, cybertour, and situational awareness [5, 3].

In this work, we have integrated many components of a mobile visualization system – GPS devices, wireless communication, and different types of GIS databases of the same region. Our focus is on the visual interaction and input-output querying of spatial databases, and on the consistent synchronous visualization of many different GIS views of the same scenario. As discussed later in Section 2, both these important issues seem to have received little attention in the mobile GIS research community. Challenges in consistent representation of spatial databases (discussed in Section 4) arise since sources and time stamps of these databases differ posing significant problems of registering different views against each other. Similarly visual querying of spatial databases, subsequent understanding of the findings, and regrouping of the results to pose additional queries is a challenging task. We address these issues and present some task-based examples in Section 5. Section 3 presents an overview of the system. Finally, Section 6 presents some conclusions and future work.

2 Related Work

Integration of GPS data embedded within a GIS environment has been discussed by Stockus et al. [13]. They use DGPS (Differential GPS) to acquire position information, a cellular internet connect for access to distant data servers, and exchange of data, and a Java applet for data processing and presentation. The authors mention that appropriate registration of data is a concern.

A mobile context aware GIS system for cooperative work in utility industry has been discussed by Hope et al. [4]. They use IEEE 802.11 networks for communication and mobile access to remote GIS databases. A location aware mobile environment for sharing a graphical bulletin board system is discussed by Leichsenring et al. [6]. They use GPS devices to acquire location information and use this information to compute an influence zone of the mobile user. Information and comments within the influence area are then displayed to the user within a VRML viewer. The importance and extent of the influence area can be controlled by user input regarding local events.

Cyberguide [1] and Touring Machine [2] are early examples of systems using PDAs and HMDs (Head Mounted Displays) by mobile users to tour a local region. Collaboration and information annotation by mobile users for augmented reality type applications are also supported [3]. More recently, situational visualization, where mobile users enhance their understanding and experience of the surrounding world using wearable computing resources has also been envisioned [5].

Our work shares some common components with some of the systems described above – mobile user with GPS devices, access to GIS databases, and IEEE 802.11 networks for communication. However, in contrast to earlier works, here we focus on query and display of spatial database information using visual interfaces and consistent visualization.

3 System Overview

In our system, a mobile user is interacting and querying his/her environment using a visual interface and display on a laptop. The user can view the environment using one or many of the spatial databases that are available. The user has a choice of four views – aerial imagery, AutoCAD drawing, street map, or schematic diagram. Examples of these views are shown in Figures 1, 2b, 3, and 4. Different views have complementary advantages.

The Mobile user is carrying a GPS receiver that is tracking the user's position. We have employed the DGPS (differential GPS) method using an Ashtech Z-12 sensor to find the location of the user. The location of the mobile unit is obtained by the visualization program via communication with the GPS unit and is displayed in real-time on all the views as a black cross as shown in Figure 3b. In contrast to work by Stockus et al. [13], where the distant server processes GPS information and sends Java applets back to the local embedded server, in our system all the processing is done locally in real time. Communication has been established between mobile users using IEEE 802.11 wireless connection. In addition to the visualization of the environment, mobile users have access to hundreds of layers of data associated with the environment and stored in databases. The environment information is stored in database formats supported by PostgreSQL [10] and PostGIS [8].

4 Consistent Visualization

Consistent registration of heterogeneous time-dependent data from various sources is a challenging task. There are at least three different issues that must be dealt with in order to create a consistent visualization: (i) coordinate transformation, (ii) registration, and (iii) accuracy. Of course, extensive cleaning and processing of raw data typically precedes these issues.

In this work we have used digitally ortho-rectified aerial imagery (also referred to as DOQs - Digital Orthophoto Quads), AutoCAD drawings, street maps and schematic drawings. The DOQs are raster while the AutoCAD drawings, street maps and schematic drawings are in vector form. Some of these datasets are geo-spatially referenced using some coordinate system, others are not. The coordinate system can either be a spherical coordinate system such as Geographic (latitude/longitude/height) or a planar coordinate system such as the State Plane Coordinate System (SPCS) or Universal Transverse Mercator (UTM) system. Along with the coordinate system a datum (such as NAD83 or NAD27) is also specified. Consistent visualization of these datasets involves geo-spatial registration of these datasets using a common coordinate system accounting for the misregistration and accuracy of each these datasets.

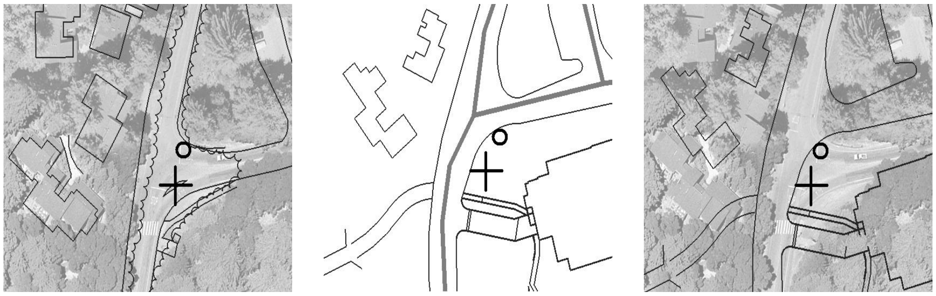


Figure 1. Building footprints and street boundaries match between aerial imagery and AutoCAD drawing in the left diagram, and between schematic diagram and street map in the middle diagram, but not between aerial imagery and schematic diagram. There is also a slight discrepancy between the exact location of the mobile user shown as a circle and the reported location of the mobile user shown as a cross.

The DOQs, AutoCAD drawings, and street maps used in this work are registered using NAD83 California State Plane Coordinate System, Zone 3 (Fipszone 0403). In some cases, this involved a coordinate system conversion accomplished using standard GIS software such as ESRI Arcinfo. Schematic drawings have been registered by applying simple geometric transformations.

Some of these datasets register quite well with respect to each other while others are off either uniformly or non-uniformly. Uniform offsets can be easily corrected while non-uniform misalignment requires complex geometric transformations. Figure 1 shows multiple windows simultaneously displaying the visual output o the query of finding buildings within a certain radius of a mobile user. These figures bring out both the consistent and inconsistent aspects of the output results. In our work, the AutoCAD drawings were derived from the aerial imagery and therefore, these data have been registered consistently with each other as shown in Figure 1a. Although street maps and schematic diagrams are obtained from independent sources, they also registered each other very well after simple geometric transformations, as shown in Figure 1b. However, the registration of the first image (aerial imagery and AutoCAD drawing) with the second image (schematic diagram and street map) does not match very well, as shown in Figure 1c. At least three different types of integrity concerns are visible: the shape and the location of the footprints do not match, the outlines of the streets do not match, and some new objects are visible on the right corner (this arises due to temporal inconsistency: a new parking garage has been built since the aerial imagery was taken).

Finally, we register standalone and differential GPS position information with the abovementioned GIS datasets in real-time using the same California SPCS, Zone 3 coordinate system. The uncertainty issues arising from the registration of GPS data within the GIS systems are discussed later in Section 5.

5 Querying GIS Databases: Visual I/O

We first begin by describing how we support input queries and provide visual feedback, and then illustrate the system by presenting several examples. We then present two specific tasks that can be supported by our system to illustrate the utility of the system.

5.1 Input Query Organization and Visual Feedback

Broadly speaking, the user can provide three types of input for querying the database – spatial, mobile, and query input. The user can supply spatial input via a painting operation applied directly on a GIS view. Different GIS views are coordinated in multiple displays via a common coordinate system discussed previously. The common user, who knows nothing of the underlying coordinate systems, is thus shielded from the underlying complexity of the coordinate system. The GIS platform provides a natural familiar context for the database objects. For example, a user can click near a building on the aerial imagery, query for buildings in that area, and receive information such as the building's name in a schematic view. Currently, we support a variety of database objects such as the building footprints, telephones, metro stops, disabled parking spots, and stop signs.

The user can paint points, lines, and arbitrary polygons on the GIS context with the mouse, and use these primitives as input to queries. Database objects can then be retrieved according to their spatial coordinates. Once retrieved, standard operations such as union, intersection, and filters on attributes can be applied to objects and groups of objects

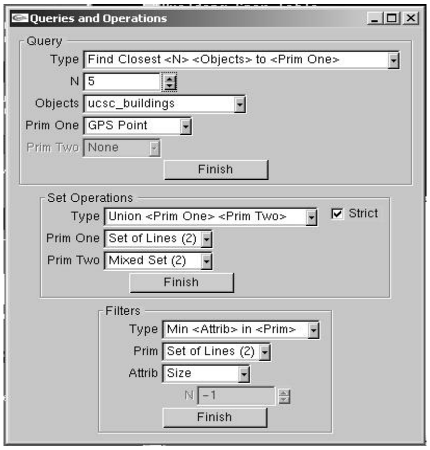


Figure 2. The visual interface for querying spatial databases displays the parametric query box approach with parameters for query, set, and filter operations shown directly underneath.

(sets). An object can also be treated as a primitive. For example, once a building has been retrieved, the polygonal footprint of the building can be used as an input to another query through a simple mouse click. Figure 3a shows the output of the query of intersection of buildings within two polygonal regions.

The second type of input is the location input obtained from GPS devices. This input can be obtained from a previously logged file for post-analysis purposes or can be obtained in real-time. The mobile user can thus view its own location and/or previous trace within the GIS context. Figure 3 shows an example of a query by a mobile user to locate the nearest metro stop and telephone at the end of a path. Buildings close to the user's path ate also shown. In addition to the visual output, textual output regarding the attributes of objects or additional information related to queries can be viewed in a separate output text window. There are consistency and uncertainty issues related to the location input. First, the location of the user shown as a cross is marked consistently in the three images of Figure 1. However, due to uncertainty in the GPS devices, the reported location does not necessarily coincide with the actual location. The actual location (which was obtained in this case through manual observation) is shown as a circle. This information is, of course, not available to the program automatically. However, the discrepancy can be estimated in certain circumstances and can be used to provide a range of answers with varying probabilities or confidences rather than a unique set of answers. We have investigated some GPS uncertainty issues in our previous work [7], but retrieving database results using uncertain input and visualizing resulting output remains an important future task.

The third type of input is the query itself. We have designed a graphical user interface shown in Figure 2 to support input queries visually. The user can choose a pull down menu to pick from a list of queries. Currently supported list of queries include finding some number of objects closest to a geometric primitive (point, line, etc.), finding all objects within a certain radius of a primitive, finding paths between primitives etc. One of the difficult design issues was how to present these choices to the user while keeping it simple and accessible but at the same time flexible and general enough to support a large number of queries. One choice was to use a list of frequently asked questions simply stated in the English Language. However, there is no clear way to extend this approach to a richer set of queries. Incorporating a rich set of queries allowing outputs to be used as input queries, in combination with set and filter operations, is a challenging task. In our approach, we have introduced a *parametric query box* approach where the query presents itself with certain parameters. For example, the query "Find closest N objects to a given point" has three parameters, namely N, the type of object, and the point. Once the user selects this query, the associated parameter boxes become highlighted (to begin with, all parameter boxes are greyed out and inaccessible). These parameter boxes appear right below the main query and the user then simply has to provide these additional inputs in order to complete the query. Furthermore, active or user selected primitives are automatically available to the user through a pull-down menu amongst which the user can conveniently pick and choose. Our experience is that this user interface and query organization is very natural and immediate to most users. Although a large number of base queries can be supported using this mechanism, more work such as hierarchical grouping of queries and parameters is needed to make the world of queries even richer.

Combinations and filters are also supported in a similar manner within the user interface. The user first chooses a set operation such as the union or intersection. The paramaters associated with the operation are highlighted and can then be filled by the user. Wthin the set operations, we have currently supported union, intersection, negation, and split. In particular, we have supported both loose and strict union and intersections where the queries can look for quick results using only the bounding boxes of the primitives or use the actual polygonal shape of the underlying primitives for more accurate results. Supported filter operations include min/max, and comparison operations (less than, equal to, greater than) on object attributes.

Output for all queries are presented both visually and in a textual output window that lists the output objects, and associated attributes or information depending upon the query.

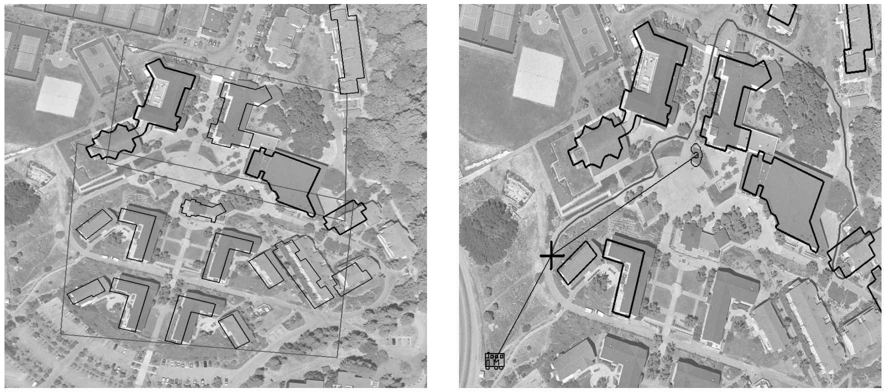


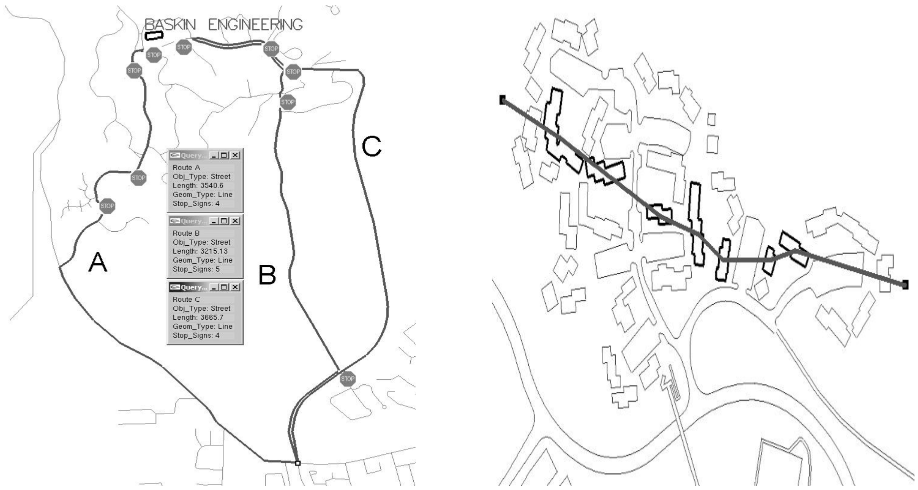
Figure 3. (left): Visual feedback of intersection query for buildings within two polygonal regions; (right): Buildings close to a mobile user's path and the nearest metro stop and telephone from the current position.

For example, the distance between two points will be displayed in the textual box. If there is a list of objects, each object is given a number or letter that appears next to the object in the visual window, and further, individual object attributes can be displayed in a textual popup window (see Figure 4a). We have adopted this approach so as not to clutter the visualization. The split operation (a unary operation) is an important operation for combining and subsetting the results of queries. This operation can be used to ungroup an output some subset of which can then be selected as input. This selected subset of outputs becomes automatically available as input to the user in the input query box and vice-versa.

5.2 Task Support

We now describe two useful tasks that require the combination of several queries. The first task is assistance in finding an optimal driving path between two points using streets. If there is more than one path, all the paths are displayed and labeled. Information associated with different paths are shown in separate textual windows. Figure 4a presents results of such a query when the user wants to get to the Baskin Engineering building from the entrance of the campus. The entrance of the campus is obtained via the GPS unit or can be input by the user directly on any GIS view. The user also has to enter the text primitive "Baskin Engineering" using the visual interface. Since the street maps are graphical networks, all paths between two points on the graph are retrieved. The lengths of the each path are automatically computed, but in this case more information is desired. Additional queries are automatically fired to compute the number of stop signs along each path. It is easy to add additional information such as the driving speed to estimate the travel time and make a recommendation on which path to take based on clear traffic conditions. Annotations added by mobile users regarding traffic updates can be used to enhance the system further in future work.

The second task we discuss is the capability to find the wireless routing of communication between two points using intermediate buildings. Suppose that a user has a wireless networking device that only functions within a certain radius R of a transmitter. Let us say that there are transmitters installed in all the buildings in a certain area. The user may want to travel from one point to another while maintaining transmitter coverage or a software program may need to retrieve this information to be used in routing wireless communication. An answer to this query can be obtained by combining several queries. First, a set of buildings S within the radius R from the starting point P is found. For each of these buildings the sum of the path from P to the building and from the building to the end point Q is computed and the minimum is chosen. The output is a pair of line segments from P to the nearest building B within radius R and another line segment from B to Q. Since the output at this stage is simply a pair of line segments (and not the building itself), the building can be retrieved using the set operation "loose intersection" (rather than "strict intersection") between the set S of buildings (polygons) and a pair of line segments. The loose intersection operation returns the polygon or the building B that intersects the pair of line segments. The result of this query is visually shown in Figure 4b. There are cases in which no path is found for example, when here is no building within the specified radius. Also, the current implementation of greedy algorithm needs to be updated to backtracking algorithm to guarantee results when the greedy approach fails. In fact, further support for graph algorithms in querying the underlying GIS database



(a) Driving alternatives between two points (b) Communication path between two points

Figure 4. Visual feedback on tasks based on combination of simple queries.

is needed to obtain efficient and accurate results.

6 Conclusions and Future Work

We have presented a system for simultaneous visualization and querying of different spatial databases by mobile users and a central agency. We have discussed consistency issues between different spatial data and described a convenient visual user interface that lends itself to easy and natural use. We are currently working on extending the existing system in many ways. First, we are incorporating speech output capability so that the mobile user can hear the answers in addition or instead of viewing them. This is particularly useful when the screen space is limited such as on a PDA. Because of the limited range offered by 802.11 networks, we will be working on creating a network topology consisting of a collection of relays to enhance the range of our mobile communication. In addition to efficient location-based routing, we hope to investigate research issues in consistent reliable wireless communication due to interruptions, inaccuracies, and time delay. Most important perhaps is the integration of a more powerful spatial database, providing capabilities to process more complex queries including advanced path planning [11] and topological queries [9], and further work on hierarchical arrangement of visual querying of spatial databases. Another important future direction is to make the existing system available through the web using standards created by the OpenGIS consortium such as WMS (Web Map Server) and GML (Geographic Markup Language). Further research is required in query processing [12] and visually presenting these results to the user.

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