TOPOLOGY AND LBS APPLICATIONS

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ABSTRACT

Several GIS companies are promoting hybrid technologies and *location engines* for location-aware applications. However, the effective deployment of Location Based Services on the Internet will require topology integrated with the data. While numerous 'topology modules' have been available from Enterprise GIS vendors for some time, these modules are external to the data and are typically found in separate proprietary applications. However, it is apparent to many technology architects that the separate and disconnected origins of these specialized applications may present some 'show-stopping' integration and scalability hurdles in a web environment.

This paper describes the important role played by topology in Location-based Applications and the value of a web enabled database centric solution where all spatial data relationships are maintained and managed directly in the database itself, without the need for any specialized or proprietary GIS application. This solution will provide integrated dynamic topology and spatial analysis from any wireless handheld device.

These capabilities are especially significant for those large enterprise organizations and high-volume commercial services that wish to deploy spatially enabled Location Based Services (LBS) and applications on the Internet, especially where the source data is constantly dynamic.

Our initial development of a Topology Manager provides a best–of–breed software component that dynamically discovers and persistently tracks topological and spatial data relationships within vector geometry models.

With further development, the Topology Manager can be integrated into popular database products such as Microsoft SQL Server; this will provide the capability to dynamically *discover* and persistently *track* all topological and spatial relationships with a *linked* MapPoint 2002 vector geometry model. Therefore, as topologically important events occur in the database i.e. edge intersection, shape creation, point-in-polygon and other dynamic events associated with location based data, the Topology Manager will notify the application, triggering intelligent behaviours required for advanced LBS applications.

INTRODUCTION

The importance of Location Based Services (LBS) and the commercial promise it presents to the emerging wireless industry is now well publicised. Examples are being expounded. Competitive architectures are being promoted and, if activity is a guideline, excitement is growing rapidly; the location bug has taken hold. Both the government and private sectors are recognizing the considerable value of location information as a platform for improved services and business applications.

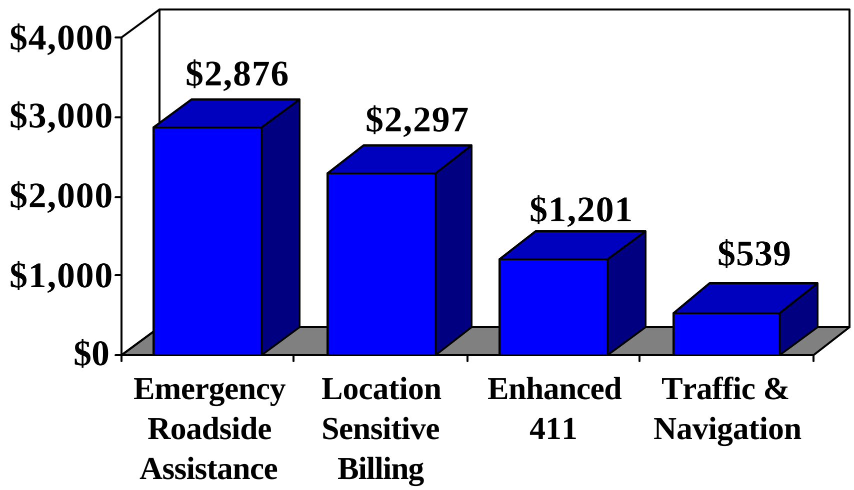

Figure 1 – Revenue (in millions) projected for Location Based Services by 2004

Source: *Wireless Location Services: 1999*, The Strategis Group

As the GIS and mapping industry recognize the possibilities, we're starting to see many increasing examples of the "Where's the nearest bank ATM" application. Such a service uses your present location to deliver ATM addresses that are in close proximity. Similar and more complex examples are being developed for navigation, directions, traffic routing, restaurant finder and enterprise mobile worker applications. However, when we consider the degree of intelligence imbedded in these initial applications, it becomes apparent that some important pieces of the technology are still missing from the overall schema of location-based services. The technology that we're still missing is integrated topology; real-time, dynamic topology and network tracing.

Development platforms for LBS have been brought together by various vendors with labels like "Location Engine" and "Data Engine" however, it is apparent to many technology architects that their separate and disconnected origins may present some 'show-stopping' integration and scalability hurdles in a web environment.

This paper describes the important role played by topology in Location-based Applications and the value of a web enabled database centric solution where all spatial data relationships are maintained and managed directly in the database itself, without the need for any specialized or proprietary GIS application. This solution will provide integrated dynamic topology and spatial analysis from any wireless handheld device.

WHAT IS TOPOLOGY?

What is topology? In its simplest form, topology is the 'shape' of data; the specific physical, *i.e.,* real, or logical, *i.e.,* virtual, arrangement of the elements of a network. Currently, the function of topology management is provided by many software vendors in the form of a specialist proprietary application external to the database. These applications are typically 'run' by the user during data entry, data editing and most spatial queries.

If full topology can be integrated into a database, databases can then control and issue asynchronous events upon the recognition of certain topological (physical relationship) criteria, without the need for an additional specialized application. Examples include notification when certain spatial relationships exist, or when a point passes into or out of a specified region, or when two elements (linear or curved) intersect. Other examples could include database driven events related to dynamic polygons representing business data analysed against dynamic demographic data. This type of application can also serve as a platform for Decision Support Systems (DSS).

While topology is a basic function in many typical GIS applications today, it may not appear immediately relevant to the location based services developer. For example today, several simple LBS applications function without integrated topology. These examples are using the mobile phone relationship to the carrier's 'cell' location to determine a basic level of location awareness. An example of this is the wireless discount coupon application, which recognizes a customer's phone number as it enters the mobile carrier's cell; the application sends a time sensitive electronic coupon to the phone, valid only in a nearby store within the same carrier's cell. This application is confined to the carrier's system and the carrier's customer. Sophisticated applications of the future will draw on dynamic data from wide and varied sources, both government and private data, and will require advanced real time topology. The importance of integrated topology is especially true in commercial enterprise applications where dynamic polygons can represent dynamic business data, which could be analysed in real time against mobile customer data and fixed networks.

While many industry visionaries and technology writers have presented examples of LBS applications that can be enabled by location information, these examples have not been broken down into their constituent technology parts. The Open GIS Consortium (www.opengis.org) however, in its efforts to examine in more detail what exactly will be required to realize the goals presented, has developed a series of examples and their discrete parts for analysis. Through such analysis, a consistent conclusion emerges: real-time, dynamic topology functionality is necessary to effectively realize the full potential offered by most location aware applications.

The examination of the following examples describes some applications that benefit from integrated topology management and real-time topology validation. Many Location Based Service applications also require network tracing and similarly, this functionality must be integrated within the database itself if scalability and rapid deployment is to be realised.

EXAMPLE APPLICATIONS

The Open GIS Consortium (OGC) has identified several examples of location-based applications, which will allow us to examine a more detailed break down of what is entailed in the successful realization of location-based services. These examples will now be examined to identify the role of topology and dynamic topology.

Traffic Information
"You are about to join a ten kilometre traffic queue, turn right on the A3 ahead for a better alternate route."

This was reported as one of the most complicated examples so it shall be examined in depth. The OGC's detailed breakdown goes as follows:
Create a planned route
Periodically get device location
Position device on appropriate transportation network (usually streets)
Examine planned route for obstacles such as traffic delays or weather related problems
Analyze impact on travel plan
Compute work-around if obstacle adds x% to travel time
Process and present a work-around
Obtain background road networks with street and place names with scale and map up date as device moves
Highlight planned route
Highlight work-around route
Explain the obstacle

Step a) requires topological services, although not of a dynamic nature. A static topology engine would suffice for the simplest cases. But consider the task of planning a route subject to dynamic constraints represented by other data sources. Typical constraints are traffic and weather. Or, for commercial vehicles, maybe the route should remain a minimum distance from some fixed or mobile features. Commercial vehicles may also need to respond to changing customer activity or remote transactions, such as calls for service. These constraints imply topological capabilities: proximity zones and containment tests. If routes are subject to on-the-fly update then dynamic topology is required. Either way, topological data models and data structures could assist in representing, storing, and communicating the route.

Step b) requires real-time location positioning such as GeoMode (www.geomode.com) for urban wireless devices or Global Positioning Satellite (GPS) based systems for rural areas.

Step c) brings us right back to topology in the application. Any location that comes out of the previous step will have some error associated with it. In its simplest form this may be modelled as a point in a circle, or with slightly more complexity, a point in an ellipse. In either case it is highly unlikely that the point itself will lie on a unique street in a street network. Instead the point will more likely lie off the streets but the circular or elliptical error envelope will overlap one or more streets. The location algorithm might proceeds as follows:
Locate all the streets that intersect the error envelope
Compute a perpendicular minimum distance to that limited set of streets
Select the closest and/or similar alignment to device movement as the result

Of course, smarter algorithms could be developed that take prior locations into account.

Step d), like step a), could make good use of the data models and algorithms contained in a topological component. The examination of the route for obstacles certainly implies network traversal on a graph that stores the route itself. Definition of obstacle could be a simple topological fact like an open drawbridge. More complete definitions would likely include topological conditions and other attributes as well.

Step e) requires processing of the additional travel time based on delay parameters and requires topology as the location and obstacle parameters change (traffic or weather improves or worsens)

The reasoning implied by computing a work around in step f) again demands a high degree of topological capability. What does “around” mean? Does it mean a route that starts and ends at certain points of an original route, but avoids the region of an “obstacle” in between? Of course direction is critical here as well as a route is assumed to be directed. Care must be taken not to miss any key points on the original route. Missing a delivery because of traffic is not an excuse that people would accept in either domestic or industrial settings.

Step g) requires topology similar to step a) and is one that is repeated in many of the further examples to be examined.

Step (h) will not require immediate application of topological functionality

In the Traffic Information example, topology and dynamic topology have a role to play in 4 of 7 steps as presented in this breakdown. In one of the other steps there may be topological services needed at a level below that of application. It is clear that topology is critical to any intelligent implementation of the Traffic Information scenario.

Emergency Services

“I’ve had an accident.” This scenario is interesting in that it captures the requirements the United States’ Federal Communication Commission (FCC) has placed on mobile operators in the US. Emergency calls must be locatable to within 100 meters. The OGC’s detailed breakdown is as follows:

Get device location (GeoMode or GPS)
Position device location to address or other human location
Communicate request for assistance to closest Emergency Call Desk
Convey response to accident victim (e.g. ETA)

Location positioning for step (a) can be provided by GeoMode for urban areas and areas with adequate wireless coverage or GPS for rural areas. Positioning the device in step (b) will require topology to convert X,Y to a street address. An error envelope a true position has to be determined and topology can refine the X,Y to a street address. Step (c) does not require immediate use of topology, as it is a simple communication step.

Step (d) is a communication step however topological functionality is required to calculate a drive time along a route to the emergency to estimate the time of arrival (ETA). There are many dynamic conditions, which can impact the ETA, which require topology.

Topology also plays a critical role when attempting to coordinate mobile emergency vehicles with the location of the emergency. This coordination requires dynamic topology to manage and select the emergency vehicle that can respond in the shortest time (and not distance) possible.

Public Safety Vehicle Management
“Who is closest to that emergency?” This scenario calls for location positioning from GeoMode or GPS for the location of the emergency, and also requires the dynamic topology described in the introduction. It should be pointed out that this example also represents a taxi dispatch problem, although this is somewhat less dramatic setting.

The OGC breaks this scenario down as follows:
An emergency is communicated to a call centre
Each vehicle in the emergency response fleet receives the location of the emergency
Each vehicle periodically (every few seconds) reports its position and status to the call centre
The call centre computes the response ‘time’ for vehicles to attend the emergency
The call centre assigns the closest vehicle (in the correct status) to the emergency
The call centre sends a route to the vehicle; optionally it sends only the destination, and the vehicle computes the route

In this example, topologically speaking, everything here is dynamic. For this type of ‘real-time’ Location application to be effective, dynamic real-time topology is a requirement.

Vehicle location, in the cases above, requires topology to position a device on a road network given the inevitable errors that can creep into the location positioning process. In steps (d) and (e), rather than calculating all the distances between the vehicles, an alternative approach is to create the Voronoi diagram of the vehicle’s locations as discussed above. Selecting the nearest vehicle/s becomes a simple point containment test to determine which vehicle’s cell contains the location of the emergency. Any refinement of the response time for emergency vehicles (should they’re be more than one emergency vehicle available in the same cell) must include driving conditions, which impact time to the emergency location; this requires dynamic topology.

Further functionality can be achieved through the use of dynamic topology in this scenario. Imagine the taxi dispatch variant. A dynamic topology component at the call centre can monitor continuously and report lack of coverage of certain areas in the region. This would be a clue to the human dispatcher to instruct vehicles to move to a new location. Lack of coverage under a specified time would be determined as a region larger than a tolerance size that lies outside the union of specified time drive time areas of each vehicle. With appropriate algorithms and a real-time topological component even further services can be developed.

Leisure Information

"We want to go to Ronnie Scott's Jazz Club tonight; how do we get there from here?" The detailed break down starts with geo-coding Ronnie Scott's to get a destination address. Then the device's location is determined (GeoMode or GPS). Here the need for topology arises.

The next step consists of determining an optimal path from the device location to the club. This potentially difficult step clearly requires topological data models and data structures for completion. As above, extra constraints on the route, including those that may depend on current traffic or weather conditions, further complicate the task.

Dynamic topology would be required for determining "what live jazz club choices are available within 1 mile of my location tonight". Or, find me a hotel within a specified distance, which also has nearby events for children. Here you are requesting a Boolean operation on separate data types in a spatial context. This requires dynamic topology.

Similar applications apply to finding parking spaces, hotel rooms, events, or nearby buddies

Vehicle Navigation & In-Vehicle services

Currently, we have several available novel examples of in-car navigation products, however these systems are limited to positioning the car location on a static map display stored within the product. The current systems also require the user to input a destination address manually. Simple questions like how do I get from one address to another address are easily supported by current systems, but the question "How do I get back to the Interstate from here" or "what's the fastest way to…" require topological services. Dynamic data sources such as weather and other traffic cannot be considered by current systems. If any sort of update is required before the destination is actually reached, such as testing if the road has been ploughed during a snow condition, then dynamic topology is required. Proximity queries such as "find all of the available hotel rooms less than $80 per night for the night of 12/12/02 along my route" can also be performed quickly and easily. More innovative applications, which integrate vehicle navigation systems with automatic parking systems can be developed whereby locating and purchasing a parking space and being directed to the space, are possible with Topology Manager.

Public Transport Schedules and Tracking

Security applications, where the tracking (www.geomode.com) and disabling of public transit vehicles which stray from pre-set routes, are becoming necessary as public safety comes under threat from terrorist and criminal groups. Additionally, the ability to inform the public of the currently best available options for getting from A to B can increase the commercial use of public transport. Topology Manager can support the integration of transport schedules from different transport systems such as Greyhound and Amtrak. Today, with the current website schedules, it is impossible to find a bus / train combination to get from A to B. With Topology Manager, passengers could type their home or starting address and destination address into a search field on the Amtrak website; their preferred time of departure or arrival and the schedule application would direct the customer to the correct bus and train schedule for the best routing. The need for dynamic topology arises from the need to query separate transport systems and networks related to the customer location and destination.

AN INTEGRATED SOLUTION

Over the years, virtually every industry has evolved sophisticated models to handle complex data objects that make up the heart of their business. By *data objects*, we mean both the structures that relate different units of information to one another and the operations that are performed on them. As seen above, web-based 'location aware' applications include many kinds of complex data objects which, to be effective, will require the topology to be dynamic.

A typical topology application from a GIS 'vendor' requires the user to 'run' the vendor's proprietary topology application against the data from time to time, especially after data maintenance actions i.e. data changes. Our proposed approach is to build the topology logic into the database itself thereby avoiding integration and scalability issues. The ability to extend the database to include complex application-specific data types as well as the business logic associated with these types, offers a more advanced solution for mobile Internet-based applications. Additionally, the inclusion of topological intelligence within the data structure provides dynamic topology, which is better suited to applications where the data is dynamic such as Location-Based Services. Today's database products are becoming more extensible so that advanced software modules and business logic, such as topology, can be incorporated directly into the database.

The notion of adding logic to data in a database has been available for some time by way of stored procedures. With the addition of object-relational extensions, popular database products such as Microsoft SQL Server can be greatly enhanced to support a new generation of data types, processes, and logic in order to model business objects.

Our initial development of a Topology Manager provides a best–of–breed software component that dynamically discovers and persistently tracks topological and spatial data relationships within vector geometry models or any file format that stores vector geometry with integer, single, or double precision, such as AutoCAD DWG or DXF files, MicroStation DGN files, ESRI shape files, simple vector format SVF files or stereo lithography STL files. Such relationships include intersection, adjacency, containment, enclosure, and overlap.

The Topology Manager has been implemented across many operating systems including popular Unix flavours and the Microsoft Windows 32-bit platforms. It is accessible as a native language shared library in C and C++ development environments, from within Java-based applications, or from within visual-based development environments.

Topology Manager provides interactive topology through a rich event-driven paradigm using asynchronous messages and registered *listeners*. As topologically important events occur—edge intersection or shape creation, for instance, the Topology Manager notifies the application, triggering intelligent behaviours that previously had to be performed by end-users. Associated attribute data is easily maintained this way.

With further development, the Topology Manager can be integrated into Microsoft SQL Server; this will provide the capability to dynamically *discover* and persistently *track* all topological and spatial relationships with a *linked* MapPoint 2002 vector geometry model.

Therefore, as topologically important events occur in the database i.e. edge intersection, shape creation, point-in-polygon and other dynamic events associated with location based data, the Topology Manager will notify the application, triggering intelligent behaviours required for advanced LBS applications.

By integrating Topology Manager with Microsoft SQL Server, then MapPoint.Net, using open APIs, can deliver high-performance location-based services (LBS) such as emergency response applications, interactive yellow pages, real-time traffic monitoring, point-of-interest selection, optimal routing and driving directions without the need for any specialized application. Such LBS dependent functionality can rival the sophisticated features typically found only in advanced spatial information systems.

The integration of Topology Manager and SQL Server will allow companies to develop database centric location-based services using spatial datasets from a variety of sources. Ad hoc wireless proximity queries such as “find me all of the available hotel rooms less than $80 per night within 1 mile of my current route” can also be performed quickly and easily.

Such a database centric approach is necessary if we are to build truly scaleable LBS applications without the complexities, which arise from data integration issues. Topology Manager will allow users to integrate, manage, develop and deploy spatial and transactional applications totally within a single, open, database environment, paving the way forward for location-aware decision support systems including advanced wireless transaction applications.

This approach will also solve some of the address matching issues that are emerging in the mobile wireless technology world, where a location-aware device (e.g. a cell phone) will compute X, Y location, with accuracy anywhere from +/-25 m to 100 m (www.geomode.com). However, it will most likely not coincide with existing road alignment geometry. Any location that is computed by a location aware device will have some error associated with it. In its simplest form this may be modelled as a point in a circle or polygon, or with slightly more complexity, a point in an ellipse. In either case, dynamic topology can provide the analysis required to convert the X, Y location into the most probable street address.

The advanced solutions being described here, will allow organizations to develop and deploy spatially enabled e-business and m-commerce applications such as optimal routing, public transit systems, emergency dispatch, intelligent traffic guidance systems and related ‘Locate-me’ applications, within a scalable database centric system, without the need for any proprietary geo-data spatial management application. This approach leads to a more cost effective, open and powerful enterprise wide location aware development platform, suitable for e-business and m-commerce, which can be deployed to provide ubiquitous access to a truly *digital earth*.

CONCLUSION

Web visionary Tim Berners-Lee, stated that the next phase of the Internet would see the development of a "semantic Web," one in which meaning is embedded within the framework of the Internet. This 'meaning' is the sort of intelligence exhibited when humans look at maps… and such intelligence is required for most advanced LBS applications.

Such a semantic Web requires unifying principles in order to organize and embed greater intelligence in the Web, and topology is one such principle. And 'location' positioning, combined with integrated topology is the 'glue' which adds relevance to disparate sets of data.

The implementation of real-time dynamic topology, within a database, is necessary for capturing and managing this intelligence in real-time.

These capabilities are especially significant for the modern enterprise or utility where the enterprise or network is constantly expanding and changing, where the source data is constantly dynamic. This technology provides a solution allowing ubiquitous data collection, posting, analysis and retrieval to be managed in real-time without the need for data translators, application interfaces or data integration concerns. In this solution, all data, both spatial and non-spatial, is managed in a single data model and can be made available, specifically filtered by location, transmitted to mobile workers in the field via any wireless handheld device.

Integrated dynamic topology is especially significant for those organizations that wish to deploy spatially enabled Location Based Services and Applications on the Internet where the source data is constantly dynamic.

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BIOGRAPHICAL INFORMATION

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Mr. McGeough is Founder and CEO of Digital Earth Systems Limited, a privately held software development company and consultancy. His responsibilities include the development of emerging wireless technologies in connection with the company's end-to-end Location-Based Services solution strategy. In this role, Jim initiates and directs the planning and development of the company's technologies, the Digitalearth network of global partnerships, and corporate and business development.

Jim's career commenced in Australia, in the early 70s when, as a graduate surveyor, he and several technology pioneers developed some of the earliest software solutions for automated mapping applications.

Prior to founding Digital Earth Systems, Jim was a vice president of international operations for a major geo-technologies company and previously an executive consultant in the GIS industry. Jim has held a number of management positions in the software and consulting industry in Australia, New Zealand and the USA including Synercom (now part of Logica); Azimuth Consulting (now Silverline Technologies); Wang New Zealand (now Gen-i). His career has focused on the development of applications and services for utilities and local government clients with particular emphasis on location related technologies. More recently, Jim has provided strategic marketing, technical and business development counsel to client companies. His role at Digitalearth includes managing relationships with global partners and technology industry forums. Jim's credits include the creation of GeoMode, MapVoyager, LocateMode, TrafficMode, MapVu, CartoBank, GeoMedic, GeoEye and the TeleMondo LBS phone.

Jim has been a featured speaker at dozens of industry events Worldwide and has been an active spokesperson on wireless location positioning issues. He has also published several articles and papers in numerous industry trade publications and is a frequently utilized industry expert by many trade journalists. Jim's 2002 industry activities include speaking at the Pulver.Com LBS Summit and serving as Chairman of the 2002 Wireless Positioning & LBS Conference.

A native of Ireland, Jim is currently based in Dublin, Ireland with offices in Washington DC where he is an active member of industry groups including the Geospatial Information Technology Association (GITA). As a veteran of the Geographic Information Systems industry, Jim leads a visionary group of strategic technology partners with skills in wireless based mobile computing and location services.