Implementation of a Geospatial Three Dimensional Topology Model

Introduction

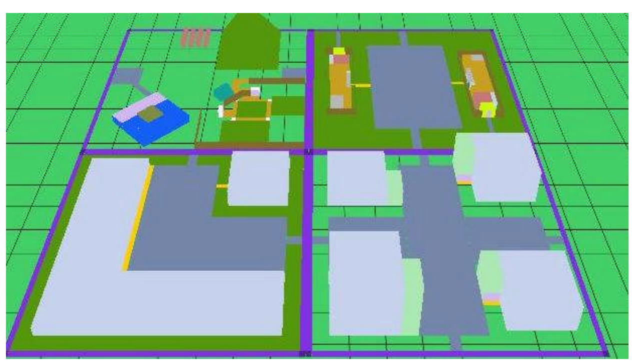
Integration of spatial information into relational database management systems continues to develop both in scope and scale providing application developers, data providers and most importantly data users the ability to explore new opportunities requiring the analysis of multi-dimensional data. In the past, developers and users alike have thought of the spatial world as two dimensional (2D) which supported the needs for effective data representation and display. In certain cases an ability to assign a Z-value to a specific coordinate or series of coordinates would be described as three dimensional (3D) data. In fact, while the typical approach of integrating a 2D model with a 3D surface representation, typically described as 2.5D representation, works for many categories of query, this is not accurate in the context of true 3D data which can support volumetric analysis.

The volumetric character of data often becomes important when considering detailed, through-space interactions between features, such as the interactions that occur in urban environments or complex navigational planning. Volumetric models are the most complex and most expressive tools we have for describing our interaction with the real world.

Value of a True 3D Topology Model

The need for and ability to analyze and manipulate true 3D data is rapidly increasing. While existing GIS functionality provides for data analysis, structuring, management and presentation of 2D and 2.5D data, similar capabilities operating within a true 3D environment do not exist in a mainstream, commercial system. The availability of an efficient, true 3D topology model will allow application developers to better serve users of spatial information and expand the areas and complexities associated with modeling and analyzing real world data. Activities associated with 3D urban planning, defense, medical analysis, monitoring of complex environmental factors, telecommunications, management of utility assets, mining and underground detection are just a sample of pursuits that stand to benefit from the availability of a true 3D data model.

Research and Development



To effectively and efficiently interact with true 3D data, a model that leverages the value of topology in association with feature geometries is required. Topology is the branch of mathematics describing the properties of geometric figures that are invariant under continuous deformation of the embedding coordinate space. The use of topology in computational geometry accelerates spatial query operations such as computing containment or overlap relationships. Because of the explicit nature of topology, an additional benefit is the control of quality associated with the spatial data itself.

Under a Small Business Innovative Research (SBIR) project, Laser Scan Incorporated (LSI) and *1*Spatial assembled a team of experts from the spatial and topology fields which resulted in the development and implementation of a sophisticated 3D topology model. The implementation of the 3D topology model in essence is a group of spatial operators that utilize the Oracle® Spatial database engine. The model was then validated using a combination of methods which included automated test scripts and inspection.

Key Components

Key components of the technology include assurance that the model when implemented is scaleable, capable of storing simple and complex 3D topology, and that the model does not require any modification in order to accommodate the schemas presented in numerous datasets. These capabilities and compliance to ISO 19107 specifications, form the foundation of the LSI 3D topology environment.

To characterize the spatial relationships addressed by the 3D model, all 81 Boolean and all 19,683 Egenhofer intersection patterns have been implemented. These capabilities form the foundation for determining the spatial relationships between two features and records whether the intersection relations between their parts (interior, exterior, boundary) are empty or not. Typical patterns implemented include adjacency, intersection, containment, overlap, equals, etc.

Additionally, it has been determined that even on the computationally intensive frameworks such as those described above, there are significant increases in query speeds utilizing the 3D topology model versus 2D geometries. To compare the speed of query using 3D topology versus 2D geometry, datasets consisting of varying numbers of volumes were employed. Dataset features used in the test range in size comparable to single buildings, residential areas and city blocks. LSI used the *intersects* function, which searches for two geometries that share a common point, to measure the speed of the 3D topology query. The Oracle 2D geometry *touch* function, which searches the geometry where boundaries intersect but the interiors do not intersect, was used in the 2D geometry query. Oracle 2D geometric operations were used since Oracle 10g does not provide 3D geometric operators. (Oracle anticipates including 3D geometry operators in its 11g release).

For each dataset, 100 3D topology and 2D geometry queries were performed, and the response times were recorded in milliseconds. Figure 1. demonstrates a significant increase in time required to perform queries on geometry stored as the topological primitives as opposed to response times using 3D topological queries.

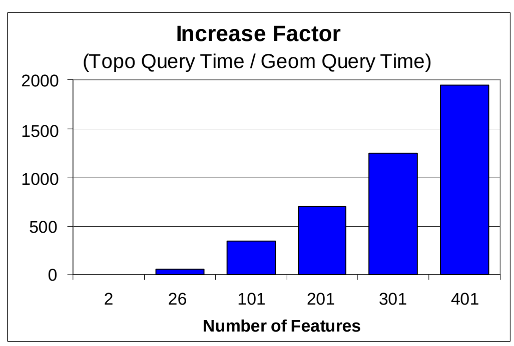


Figure 1. Using 2D geometry to find all Intersecting objects (TOUCH) vs. using 3D topology to find all Intersecting objects (INTERSECT)

Conclusions

The results of the effort are substantial and represent a significant step forward in the exploitation of geospatial data through the utilization of 3D topology. There are however challenges, both technical and business related, when implementing this technology into practical, real-world applications.

Carrying out complex 3D topology queries relies on topologically clean data. A complete package to build, validate, edit, query and display 3D geometry and topology from a variety of input sources requires further integration and development. These activities include:

- creation of a set of robust validation rules based on the descriptions in ISO 19107 defining the relationships between topological primitives across all dimensions of the data;
- dynamic true 3D topology creation supported by a function-rich and well-performing 3D geometry library integrated with the validation rules to determine on the fly valid topology;
- capability to make geometry queries using the 3D geometry library, in combination with topology and attribute queries;
- feature rich display and editing tools for creating and editing 3D data including the viewing and editing of geometrical and attribute data.

Ultimately the success of any technology is directly measured by the value it provides to the market. Commercialization of the technology requires identification of partners with a wide range of expertise focused on activities in which the handling of numerous, geometrically complex features is needed. Approaching various industries with partners well positioned in those markets and whose products complement this technology will expedite market awareness and adoption.

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