Distributed Database Design for Mobile Geographical Applications

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Introduction

Advanced Traveler Information Systems (ATIS) require efficient information retrieval and updating in a dynamic environment at different geographical scales. ATIS applications are useful in yielding a better utilization of the limited costly transportation arteries and providing value-added traveler information. Many ATIS applications are built on the functionalities provided by Geographical Information Systems (GIS), which often cannot meet extra requirements like real-time response. We investigate GIS-based systems in ATIS and propose a system architecture based on GIS and distributed database technology. Issues on data modeling, data representation, storage and retrieval, data aggregation, and parallel processing of queries are discussed. This paper introduces a distributed system architecture for ATIS based on recent technology. It presents new data models for information representation and proposes data shipping for efficient query processing and function shipping for reducing communication overhead. The paper also examines the use of a network of computers for solving complex problems more timely and privacy protection for sensitive data.

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spatial information about the potential activity opportunities. It models how the traveler processes the spatial information supplied and makes complex decisions in real-time using spatial search algorithms. The spatial information is stored in a comprehensive geographic database containing a detailed street topological network and activity locations.

The commonly used GIS data models, however, have serious limitations for ATIS applications. For example, the raster data model divides space into regularly shaped and sized pixels, whereas the topological data model subdivides space into irregularly shaped regions, links and nodes (Frank, 1992). None of them, however, represents traffic movement very well, and the problem of connectivity is not taken into account. Although some GIS packages such as TransCAD (Caliper Corporation, 1996) and ARC/INFO (ESRI, 1996) implement transportation functions like routing algorithms using the topological data model, they are not without problems. First, the planar link-node structure cannot distinguish an intersection with an overpass that does not cross at grade. This would induce problems for routing unless additional structures are added to the data model. Second, the topological model does not replicate how a human perceives the street network. We usually do not think of the street network as segments of links with intersections, but more as the street as a whole. As such, the topological data model is not a naturally navigable database (Kwan et al., 1997). In addition, ATIS applications require operations at both the regional and local levels, and information may need to be transmitted between different levels. Mainguenaud (1995) used an object-oriented (OO) approach with graph theory to show how hierarchical relationships can be incorporated into networks. His approach, although very useful, does not deal with the dynamic information needed in ATIS.

For ATIS applications in which large volumes of data and real-time response for accessing data are the critical issues, an acceptable performance can be achieved through the use of spatial indexing and clustering. Many schemes have been proposed including point and regional quadtrees for spatial data partitioning and indexing(Samet, 1989), and R-trees (Guttman, 1984). With respect to object-oriented database (OODB) research, efforts are also dedicated to indexing and related issues. Cobb et al. (1995) developed a self-adjusting indexing scheme for vector data product. Stefanakis and Sellis (1998) dealt with spatial access methods to enhance spatial operations in database management systems. Based on the Morton code sequence and R-tree, Nickerson and Gao (1998) introduced a new hierarchical data structure that supports efficient insertion, deletion and two-dimensional range query operations on swath data. These schemes avoid a serial search of the entire database when handling spatial queries.

In view of the demanding computation for answering queries in ATIS, especially routing problems like the traveling salesperson problem (TSP), parallel computing is regarded as one solution. Chang et al. (1993) presented a traffic network simulation model for real-time applications in ATIS. The proposed simulation model is implemented on a parallel computer for an efficient cost/performance ratio. Their model is implemented with a parallel data structure design and a parallel logic. Preliminary research results show that the running time varies with different levels of model complexities but the parallel simulation methodologies offer a promising alternative in implementing real-time ATIS applications. Furthermore, Imielinski and Badrinath (1992) discussed the use of mobile computers in distributed systems. It was noted that the use of mobile computers in the area of ATIS has not been fully investigated. To utilize the mobile computers owned by users effectively, the problem of communication should be addressed, since the bandwidth of a wireless communication channel is in general quite low, ranging from 19.2kbps per channel upstream to 2Mbps per channel downstream. It is therefore necessary to utilize wisely the scarce wireless bandwidth. The two paradigms for communication in a mobile environment include point-to-point and broadcast. Whenever possible, the more scalable and efficient broadcast paradigm should be employed for a collection of mobile clients. We proposed function shipping to address this bandwidth problem.

In ATIS, information provided to travelers may be affected by decisions made by others in the system. Inter-related decisions for pre-trip planners include the decisions by household members. For enroute travelers, decisions made by other drivers in the system would affect predicted traffic conditions. As a result, some form of consistency control is needed. Kayser et al. (1993) suggested a consistency check in the system design. However, the consistency issue is not directly dealt with in the database design. In addition to the quality of traffic information provided to travelers, the assurance of privacy is also important and should be integrated in the design of the database.

This paper aims at developing a comprehensive GIS-based system for handling the data representation and data modeling problems in ATIS applications. The system implements spatial and temporal data aggregations, uses the technologies of parallel processing and mobile computing, and incorporates concurrency control and privacy protection. Its design is application specific and is targeted at ATIS users. Applications include congestion prediction and routing for pre-trip planners, enroute travelers and emergency vehicles. Data useful for travel behavior research and planning purposes are collected constantly by the system. In addition, locations such as tourist attractions, restaurants, and hospitals are geo-referenced in the system. As a result, value-added information like yellow page information, tourist information and shopping and dining places suggestions is readily available to the users.

The main contributions of this paper include: (a) the proposition of a hierarchical distributed system architecture...

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