Distributed Database Design for Mobile Geographical Applications

MANHOI CHOY1, The Hong Kong University of Science and Technology
MEI-PO KWAN2, Ohio State University, USA
HONG VA LEONG3, The Hong Kong Polytechnic University

Introduction

Advances in geographical information systems (GIS) have brought new impact to the design and application of conventional database systems. This is further enhanced by the ability to locate a user by global tracking technology like the Global Positioning System (GPS) (Zito et al., 1995), which is used by vehicle manufacturers such as Mercedes-Benz. These two technologies find their applications in Intelligent Transportation Systems (ITS) (Tsao, 1995). As a major component of ITS, Advanced Traveler Information Systems (ATIS) (Kwan et al., 1998) aim at assisting drivers in trip planning and decision making on destination selection, departure time, route choice, and congestion avoidance (Khattak et al., 1993). This has greatly relieved transportation planning from the costly approach of providing more freeways and transit routes.

Application requirements of ATIS, however, are quite demanding. In order to provide useful traffic information to travelers, accurate congestion prediction, enroute real-time traffic warning, and alternate routing suggestions are needed. These operations require real-time processing of large data sets on a detailed transportation network. GIS, which allow efficient storage, retrieval and manipulation of spatial and aspatial objects, can provide a basis for ATIS (Kwan, 1997, 1998; Kwan & Hong, 1998). They can provide a realistic representation of the environment for querying and processing. Other information useful for travel decision making can also be integrated into a comprehensive database through geo-referencing.

Kwan et al. (1998) has suggested the requirements of a GIS for modeling human travel behavior in an ATIS context. The system needs to handle not only route information but also a large amount of explicit spatial information about activity locations in the environment. Both activity locations in the objective and subjective environment (preferred activity locations, preferred routes and familiar areas) would be important in modeling travel behavior. A GIS-interfaced computational process model (CPM) called GISICAS is developed and implemented for activity scheduling behavior in ATIS (Kwan, 1997). GISICAS contains a comprehensive geographic database in ARC/INFO format to supply detailed...
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 19.2 kbps per channel upstream to 2 Mbps 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. Interrelated 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