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Information Representation for Driver Decision Support Systems

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Abstract:

The successful development of Intelligent Transportation Systems (ITS) depends on the capability of incorporating a vast amount of information about the location of facilities which generate travel as well as a realistic representation of elements of the transportation network in which travel occurs. An integral part of this system is an Advanced Traveler Information System (ATIS) . Such a system can be based on an innovative and comprehensive Geographic Information System (GIS). Whereas current ITS primarily use simplified transportation networks as their basis, using an object-oriented GIS allows us to provide a more realistic representation of elements of the network and the ways that people perceive them. We can represent the network by defining roads or street hierarchies and by storing environmental data as layers which can be overlain, aggregated, or decomposed at will. Storing the transportation network as a hierarchy facilitates the calculation of different paths through the network and allows the introduction of different path selection criteria. A long-run aim of ITS is to develop a real time multi-strategy travel decision support system over a multi-modal network. We examine the advantages of an object-oriented system over the link-node system in pursing such a goal. We also identify the shortcomings of link-node technology that are overcome by using an object-oriented data model. And finally, we discuss some of the theoretical and applied implications of our suggestions.

Purpose

Intelligent Transportation Systems (ITS) utilize advanced communication and transportation technologies to achieve traffic efficiency and safety. There are different components of ITS, including Advanced Traveler Information Systems (ATIS), Automated Highway Systems (AHS), Advanced Traffic Management Systems (ATMS), Advanced Vehicle Control Systems (AVCS) and Advanced Public Transportation Systems (APTS). Development of a system for ITS depends on our ability to deal with a vast amount of information about the locations of places as well as with the complex representation of the transportation network linking those places, and to incorporate these into a geographic database. The system therefore needs to be constructed based upon the foundation of an integrated and comprehensive Geographic Information System (GIS). As compared to the simplified node-link graph theory representations of transport networks used by current ITS, GIS are able to provide more realistic representations of elements of the complex environment.

Transportation Science has an expressed goal of increasing accessibility for all groups of people with regard to the environments in which they live and interact. A significant component of these goals is to further develop Intelligent Transportation Systems (ITS) through multi-level and multi-modal research and testing. This includes contributing to research and transportation system architecture, technology development, policy formation, and operational tests of various systems including ATMS, ATIS and APTS. In this paper we focus on ATIS.

ATIS Characteristics

Traffic congestion is a problem that appears to be increasing in a world-wide context. In recent years considerable effort has been paid to the investigation of methods to reduce such congestion and the accidents and hazards that are usually associated with it. Collectively these efforts come under the aegis of Intelligent Transportation Systems (ITS). A critical part of ITS are the Advanced Traveler Information Systems (ATIS). Essentially these consist of in-vehicle information and guidance systems which help the driver to select routes which will reduce congestion, to find parking in areas where it is sparse, and to facilitate rescheduling of activities when congestion makes this a feasible alternative. It is argued that such assistive information will benefit individual drivers in terms of helping to achieve their scheduled behaviors and activities as well as benefiting the system by improving traffic flow.

The objective of an in-vehicle guidance system is to assist the driver to select routes which will help reduce congestion. Such a move will benefit both drivers in terms of helping to achieve their scheduled behaviors and activities, as well as benefiting the system by improving traffic flow. Before the information given by the in-route guidance system can be effective, however, it must be perceived as being valuable by the driver, the driver must recognize that information so obtained is valid and reliable, the driver must accept that the action if taken will not increase stress levels or route him through fearful or dangerous places, and the driver must be willing to execute an appropriate action promptly.

The continuing increase in vehicle miles of travel and the corresponding environmental degradation, personnel time loss, increased congestion, and decreases in safety, have lead to the suggestion that ATIS may represent a feasible solution to many of these problems. The ATIS is usually conceived as an in-vehicle route guidance system with supplementary information that allows changes in activity scheduling. The objective of an ATIS is to reduce the impacts of congestion by offering information to drivers that will help them select alternate routes that should benefit them individually as well as benefiting the operation of the system as a whole. While there is no doubt that drivers may respond in markedly different ways to in-vehicle information and route-guidance data, it is still suggested that a versatile ATIS will be capable of being personalized by each driver by acting as a decision support system and informative supplement to the driver's knowledge base.

ATIS as a Decision Support System for Travel

Decision Support Systems (DSSs) are integrated sets of tangible and intangible information that are designed to supplement a decision maker's personal knowledge base during problem solving activities.. The principal objective of a DSS is to support decision making by humans, not to replace it completely with computerized recommendations. Use of such a system is presumed to bring to bear on a problem the strengths of personalized expert knowledge and comprehensive exogenous knowledge that may not normally be available to the decision maker. The result should be an informed and intelligent decision.

An ATIS can be considered a DSS that is designed to provide a set of information to a driver while on-route to help solve problems (e.g., what to do when faced with congestion, hazards, or other barriers to movement such as construction). To achieve this goal, the ATIS should not provide just a single set of commands or directions, but rather allow a driver to use whatever criteria is most acceptable in terms of deciding whether to wait out the delay effects, or to undertake travel changes such as rerouting, rescheduling activities, replacing activities, changing destinations, and so on. But ATIS should be considered as a supportive tool designed to help the user, without automating the total decision process according to previously established sets of objectives or by imposing solutions which may be unacceptable to the driver (e.g., recommending rerouting that takes the driver through what may be imaged as a dangerous neighborhood). When using an ATIS as a DSS, it must be designed to be easy to use, it must have a user friendly in-car interface, it must help drivers achieve travel objectives and not divert them from attaining those objectives, and they must be designed to enable a user to benefit fully from the types of information dispensed. The ATIS then becomes a decision aid which might allow a user to generate a series of alternatives prior to making a critical decision. It thus provides the traveler with an opportunity to find a good or satisfactory solution without imposing the need to seek an optimal solution.

In the domain of surface travel by road, implementing an ATIS as a DSS can be complicated. The first problem arises in determining whether the information dispensed is most relevant to solving a system problem (e.g., clearing a point of congestion, hazard, or traffic delay) in as timely a way as possible, or providing information to allow drivers to make their own decisions on rerouting, rescheduling, and so on. Up until this time, the best quality and most quantity of information that has been geocoded and stored has related to the environmental base (i.e. transport network). Given this emphasis, information has been available to handle a system problem in a timely way, by determining alternate routes around a barrier or obstacle.

In recent years, however, there has been an increasing effort to focus on the driver as a recipient of advanced traveler information by developing a series of simulators which allow manipulation of environments and observation of different driver behaviors (see Koutsopoulos, et al. 1995). The use of such simulators is most helpful when attempting to decide the likelihood that drivers will accept information dispensed through their in-vehicle guidance system.

The development of driver simulators and the consequent modeling of driver behavior has been an attempt to enrich the potential of ATIS methodology. Simulators themselves range from PC based pseudo game systems in which a participant moves a cursor on the screen (representing a vehicle) through a two-dimensional network or maze in attempts to achieve some goal that is constrained by *à priori* determined barriers. Other simulators are more comprehensive and involve video or time-sliced slide displays of actual road conditions. Of significant importance, however, is the increased acknowledgment that these simulations work best if the environment is designed to have as many important real-world features as possible (e.g., traffic lanes instead of undifferentiated network arcs; signalized or otherwise controlled intersections instead of unconstrained nodes in a graph theoretic representation of a system; indicators of traffic speed and driving headway; etc.). Emphasis on driver behavior has also developed beyond simple observation of actions to the stage of providing supplementary information to the driver so that normally considered criteria can be used in decisions concerning rerouting, rescheduling, destination substitution, and so on. The most productive driver simulations are those in which the supplemental information allows decision makers to use their personal skills and expert knowledge in a flexible and adaptable way. But, while acknowledging these needs, it is also necessary to realize that an interactive system (e.g., in-vehicle guidance) can only be effective if it works in a realistic time frame and does not delay the decision making process of a potential traveler. Thus, not only do our drivers require timely decision support, but they must also be able to comprehend the information provided, integrate it with their goals and objectives as they exist at a given time and place, and make a decision that will benefit both the driver and the system.

Regarding an ATIS as a driver decision support system provides a framework for developing a potentially useful ATIS. The first filter provided by this framework is whether a driver is capable of synthesizing the information provided in such a way that personal and system-wide benefit will occur after a decision has been made. A second component of this framework concerns the system's construction, which involves selection of a type of database, a user interface, the type of display for distributed information, the amount and type of information, the range of alternatives that may be considered to replace current actions, the user friendliness of the display system, the complexity of the information provided, and the probability that a driver will use such information. With these guiding principles in mind, we now turn to suggest one way of developing such an ATIS using a Geographic Information System (GIS) as a host. We will also discuss the relative advantages and disadvantages of two different types of GIS - the longer existing relational based GIS which uses link-node network structures, and the more recently emphasized object-oriented database and data model.

Development of a GIS for ATIS

Fig. 1

The first requirement of a GIS for ATIS is focused on the ability to represent the transportation network in detail in order to apply different routing algorithms for both modeling of movement and simulations of flows. In the real world, a transportation network has different types of roads, (e.g. highway, arterials, local streets, etc.) and different types of intersections (e.g. signalized and non-signalized) that are of interest to ITS builders (Figure 1). For some applications, information on intersections, lanes and lane changes such as turn lanes and merging lanes, highway exits, etc. may be important. We may also require geometric representation for road curvature and incline.

Current GIS data models usually represent the network as a collection of links and nodes. Whenever two links intersect, a node is created. Unless additional structure is added, the link-node nature of topological data models is basically planar and cannot distinguish an intersection at grade from an intersection with an overpass or underpass which does not cross at grade. It is difficult to accurately represent overpasses/underpasses and this situation may lead to problems when running various routing algorithms.

There are other situations in which we may want to differentiate types of nodes. First, if there is a decision point that the traveler needs for movement, the node-link model usually slaps that point to the nearest node regardless of type. Thus, this approach ignores the different types of links and nodes making up the complex network. Moreover, when the traveler needs to make a decision to move in the network, there are many decision points that he/she needs to encounter in addition to intersections (e.g. merging lanes, divided lanes). Sometimes, different nodes may lead to different behaviors. For example, we usually make a U-turn at a dead-end node. This behavior is commonly not available in much of the link-node software.

Second, since ITS have to operate at various spatial scales, a multi-level representation of a transportation network is needed. At the local level (i.e., city or county), the transportation network needs to be represented in very great detail for navigational purposes, whereas only the major elements such as the interstate on of state highways need to be represented in the case of regional, state or interstate travel. Further, relationships between data at different levels have to be established (e.g., solving the aggregation problem). Only through the use of a more efficient geographic data model can we hope to overcome these and other related problems (Roberts, Gahegan, Hoff, & Hoyle, 1991). Several recent attempts to tackle this problem have focused on the object-oriented approach (e.g. Mainguenaud, 1995; van Oosterom and Schenkelaars, 1995).

A third problem concerns a system's ability to handle the real-time update of traffic patterns and transmission of information . To provide travelers with timely decision support, an ATIS needs to receive and transmit data in real-time through a communications network connecting a vast number of system elements, such as traffic sensors and location-tracking devices. Even for a small city like Santa Barbara, which has about 14,000 segments and approximately 28,000 nodes in its street network, the real-time update and transmission of data is a very challenging problem. To keep information on the dynamic environment current and self-consistent even in the presence of concurrent updates and queries from around the network, we need to go beyond existing data handling technologies. The system has to be interoperated with other transportation software and requires certain spatial partitioning for effective access.

To overcome these limitations, we explore some of the problems that must be faced when building a multi-strategy travel decision support system using object-oriented data modeling and database technologies. In such a system, the realistic representation of elements of the real world travel environment will be handled by an object-oriented GIS data model. In another paper we explore how the system can handle transit routes in addition to highway traffic in a multi-modal environment.

Implications of Using GIS in an ATIS Context

Geocoded data systems are complex. Incorporating such systems into a dynamic real-time multilevel ATIS system makes them even more so. Objects, when geocoded, have both geographically and temporally referenced geometry. That is, objects are located in time and in space. These spatio-temporal characteristics tie all the geocoded data together. But, spatial databases are usually extremely large. For example, in the Santa Barbara area, with a population of about 180,000, the street system consists of 14,000 arcs and 28,000 nodes. When we add descriptor and attribute information to every segment and node, the size of the database escalates by many orders of magnitude. In geocoded data accuracy and relative accuracy are important. Relative accuracy is more important than global accuracy because the real-world activities that are modeled or simulated within the database are usually local in nature.

In databases of transportation networks that are tied to link-node representations, real-world accuracies (e.g., curved streets and multi-path intersections) are not always represented accurately, but are stylized into graph theoretic renderings. And, with respect to the current state of knowledge, we have very little idea of the amount of inaccuracy and error that may be present in many of these large databases. The presence of such error will, of course, give unreasonably bad performance when attempting to either model travel behavior or to send information that will cause revision of activity schedules and consequent changes in spatial behavior. However, it appears that, when considering these problems, the use of object-oriented database systems and object-oriented data modeling strategies now have the greatest potential for use when attempting accurate and usable information transmission and the consequent modification of travel behavior.

Helping the Traveler Resolve Conflicts

We have suggested that one of the most common uses of an ATIS will be to provide information that will help a traveler overcome the problems associated with congestion. These problems can be summarized as: rerouting; rescheduling; destination substitution; activity compression; and activity deletion.

Rerouting decisions require information on the nature of the roads that make up the path selected as an alternative to that currently being traveled. The database must therefore have the capability of incorporating all levels of a road hierarchy, from highways to local streets. In addition, information must be available on the type of flow (e.g., one-way or two-way flows) and the directionality of the flow (i.e., towards or away from a potential destination). Data such as the number of lanes, whether on-street parking exists, the type of neighborhood the selected streets pass through, and the location of facilities (e.g., commercial, business, or other establishments) must also be accessible. In addition, access to information concerning the expected time of travel along the new route requires accumulation of expected travel times on each level and segment of the general road hierarchy making up the selected path. Other features that might be captured in a visual display (e.g., whether the ultimate route parallels the new one or proceeds orthogonally or diagonally away from it, as might be expected if the alternate route represents a shortcut), is required.

The occurrence of congestion may cause gridlock. In that case rerouting may not be a feasible alternative. If the driver is locked in a tightly linked lane of traffic with no immediate chance of escape (e.g., on an interior lane of a multi-lane highway), it makes little sense to provide information about alternate routes that could be taken. Rescheduling of activities then becomes a possible alternative. Most drivers do this mentally. However, an ATIS option that assist in rescheduling. Such an option has been offered elsewhere by Gärling, Kwan, and Golledge (1994), and Kwan (1995), in the form of a Computational Process Model linked to a Geographic Information System (GIS). These devices, called SCHEDULER and GISICAS respectively, allow conflict resolution in both temporal and spatial domains by rescheduling prioritized activities to give precedence to those with the greatest needs, providing temporal constraints are not violated.

Along with potential rescheduling of activities comes the possibility for substituting among destinations. Rescheduling, in fact, might encourage the traveler to exit the congested area at the earliest opportunity and to undertake travel to a new destination which is in a vastly different locale that the original one. To make these destination substitutions, the ATIS must contain sufficient information to allow choice of alternative places to go. Destination substitution may have only a limited possibility with respect to work trips, but for many other trips it can become a viable alternative (e.g., substituting a different restaurant for the one originally planned to patronize).

Congestion invariably involves time loss. Time loss may prevent extensive rescheduling, just as the nature of the surrounding road system may make rerouting a less desirable alternative. One option, therefore, is to undertake activity compression. This would simply maintain the original activity schedule but reduce the amount of time allocated to each remaining activity. Thus, a two hour recreational period might be reduced to forty-five minutes, a one hour shopping trip reduced to fifteen minutes, and so on. Often activity compression is also associated with destination substitution. For example, one may have planned to visit a specialty food store to pick up goods for an evening meal; after experiencing traffic congestion and the need for activity compression, a destination such as a fast-food restaurant may be chosen as an alternative to the original one.

If time loss because of congestion or barriers is significant, a final option is activity deletion. In this case the ATIS would need to provide sufficient information (or to have sufficient information contained within its programming) to allow the decision maker (or to recommend to the decision maker) that low priority activities be deleted. For example, if at lunch time one was planning to get a haircut, but was caught up in congestion while traveling to the barber, that activity could simply be deleted from the day's schedule and reinserted at some later appropriate time. Again, however, information necessary to allow deletion to take place must be provided in a timely, clear, and usable manner.

Requirements of a GIS for use in an ATIS context.

Perhaps the most fundamental requirement when considering building a GIS for use in an ATIS context is the degree to which it is a realistic representation of existing network elements. Such a representation would need to include a road hierarchy, directionality of traffic flow, number of lanes, turn restrictions at intersections, signaling and signage (e.g., traffic lights and stop signs), existence of pedestrian crossings (particularly school crossings), presence or absence of bicycle lanes and on-street parking, the presence or absence of dividing strips, the opportunity for making U-turns, the nature of the road's surface, allowable and safe speeds, street gradients, driveway access from streets, whether or not through traffic is possible, and so on. Many existing transportation networks used in ATIS simulations and model building have been developed simply as node-link graphs, and while some of the above attributes are included, many of them are not.

In addition to the realistic representation of the street network, information is needed concerning the multimodality of each system element. In other words, the potential for linking with other transportation modes (e.g., busses, trains) must be included. In addition, the ATIS and its GIS components must be amenable to spatial and temporal update as permanent changes occur in the environment or as significant temporary barriers or changing circumstances come into existence (e.g., closure of entrance or exit ramps on freeways for certain time periods to allow widening, change of grade, or other features).

Perhaps the main purpose, however, of having a good GIS in an ATIS is to provide alternative models for vehicular routing and navigation. Any existing ATIS, whether designed for use in practice or in simulated conditions, contains only a restricted number of routing algorithms. These are usually based on minimum distance considerations and are most easily implemented in a simple node-link network. However, unless a very comprehensive set of attributes are associated with each node or link, this simplified graphical solution to navigation and routing may prove not so simple after all. For example, if one is being allocated to a route segment which has a lane divider that prevents U-turning, and U-turning is impossible at the next intersection, how does one access a destination on the other side of the road? Similarly, in the simplified graph theoretic network representation, a route may require turning at a node which in reality is not an intersection but an overpass or underpass. Obviously without knowing the constraints of traffic flow directionality, one may further come up with a routing solution that indicates travel should occur against the legal direction of flow. Or simply, the driver may wish to implement a routing algorithm that uses a path selection criteria other than shortest path. This alternative may depend on trip purpose (which may change if activity rescheduling occurs), and has been examined elsewhere (Golledge, 1995).

Obviously many of the existing GIS that rely on link-node structures have difficulty in meeting the various informational needs mentioned above. Their information base is incomplete, their potential for conflict resolution is limited, and their ability to use human perceptions is likewise limited.

In comparison to the link-node systems, object-oriented Geographic Information Systems (OOGIS) allow for class hierarchies among objects and provide for the possibility of the inheritance of attributes among different levels of a class. For example, a general level of the class "road" might be "highway". Many of the characteristics of a highway can be inherited by the "children" or lower level members of the general class of roads - such as arterial streets or neighborhood streets.

An object-oriented database allows a map to be divided into layers, each defined by a common set of attributes. Each layer may consist of entities encoded as circles, lines, points, polylines, nodes, links and line attributes. Object-orientation also provides a means of partitioning a map and of displaying the zoomed-in partition. Partitioning allows the rendering of only those sections of the map which overlap with a currently defined viewing box. As the viewing box expands to incorporate more layers, it also incorporates adjacent partitions. Attribute lists relevant only to each partition (partitioned entity lists) can be displayed and consequently the time and effort of examining unnecessary data is conserved. Partitioning can take place in a number of different ways; we have used quad-trees.

Our object-oriented GIS can also undertake hierarchical layering. For example, if we define a road layer class we may then be able to derive more specific types of roads from this class (e.g., highway, local street). This establishes a kind of "parent-child" relation between objects. The "child" class inherits the properties of the "parent" class including the parent class' attributes and its associated functions. For example, a relation might be established between a class labeled "car" and a class labeled "vehicle." It could then be said that "car" is derived from "vehicle" and that "car" is a type of "vehicle." As a type of vehicle it would inherit many of the attributes associated with the class vehicle.

An additional favorable characteristic of an object-oriented GIS is called "polymorphism." This represents the quality or state of being an object which is able to assume different forms. In a programming context it means the same construct can be used to manipulate objects of different types. For example, one can conduct "overloading" in which the same operator ("+" or "print") can perform different functions depending on the recipient's object class.

In the link-node GIS structure there is an assumption that the transportation network is represented as links and nodes and there is no differentiation between these links and nodes. Consequently the delay function at intersections, for example, cannot be easily modeling differently for signalized intersections versus non-signalized intersections, or highways versus local streets. With polymorphism in an object-oriented context, these different elements in a network can be modeled using different functions, but with the same operator ("cost") used to calculate the delay function in all circumstance (Khoshafian and Abnous, 1990). An object-oriented system also allows for parametric polymorphism. This provides for the construction of abstract classes, with different type parameters. For example, a delay function can be formulated as COST(D) with D as a parameter of different type of distance measures. In transportation research, distance is often measured either as travel time or over-the-road distance. So the parameter D can be implemented as a type of integer (when used in terms of minutes of travel time) or as a type of real number (when used in terms of meters of physical distance). Both sets share the code as it is implemented in COST(D).

The relevance and reliability of the information contained in an ATIS is a key component of such travel aids. Thus, for both travel behavior simulations and for real world applications, the need for development of a database and data model that reflects complexities of real-world conditions is essential. It is in this context that we argue for the development of Geographic Information Systems (GIS) as an appropriate host technology. In the remainder of this paper we will examine some of the characteristics of existing and potential GIS databases for ATIS use. And, finally, we will discuss the theoretical implications and model building implications of having access to more comprehensive and more realistic databases that reflect transport network conditions and driver behavior conditions in ways that are closer to real-world situations.

Koutsopoulous, Polydoropolou, and Ben-Akiva (1995, 144) have raised a number of questions concerning the benefits and effectiveness of ATIS. Since our paper similarly addresses some of these questions and tries to suggest how GIS can play a role in such matters, we repeat their questions as follows:

- "What role can ATIS play in alleviating traffic congestion?"
- "What impact can ATIS have in altering traveler's decisions concerning their trip and destination?"
- "What impact can ATIS have in model shifts?"
- "What impact can ATIS have on departure time and parking choices?"
- "How much are users going to pay to gain access to different ATIS services?"

- "How do users evaluate different ATIS features?"

Their suggested answers to these questions include concerns such as the degree of awareness or level of knowledge of a traveler about the existence of ATIS services; the traveler's willingness to acquire equipment or subscribe to services providing ATIS information; the probable frequency of usage of ATIS services; the probability that a traveler will make a response requiring a change in travel behavior after receipt of information; and the degree to which multiple exposures to an ATIS system and the consequent learning experiences, are evaluated as useful and favorable. They also further argue that because of the difficulty of collecting data in real-world environments, travel simulators have become more popular. However, their design and usefulness depends to a large degree on the user interfaces representing travel, network, and information environments.

It is our contention that by developing the capabilities of GIS, particularly using object oriented databases and data models, that some of these disadvantages and limitations, relating to the traveler environment, the network structure, and the activity schedules and travel behaviors of individuals, will be positively enhanced.

Towards an Object-oriented GIS

Worboys (1992a & b, 1994a & b), and Worboys, Hernshaw, & Maguire (1990), surveyed the current state of the object-oriented paradigm as it applies to the handling of geo-referenced information. He outlined the major concepts behind the approach and its application in handling spatial information. These concepts have also been presented in many of the pure research papers, some of which will be discussed below.

Worboys defined a geo-object, which unifies spatial, temporal, graphical and textual/numerical objects in his conceptualization. He also pointed out the little use of proprietary object-oriented systems, except in cases like Milne, Milton & Smith (1993) and David, Raynal, Schorter & Mansart (1993). Research on the extended relational system has also faced difficulties. Projects in extended relation DBMS on applications of geo-referenced information include work by Lohman, Lindsay, Pirahech, & Schiefer (1991), and Rowe & Stonebraker (1987).

Some object-oriented systems have been implemented using object-oriented modeling and commercial OODBMS. Williamson & Stucky (1991) developed a generic GIS supporting Earth resource imaging analysis. The system consists of (1) a graphic, raster and text interface; (2) a database containing maps, images, and graphical and textual descriptors; and (3) a collection of processes which transform the representation and content of the data objects in the GIS. The system purportedly improved quality of reports, database updates, and analysis and more timely access to widely dispersed information. They argue that a more intuitive interface with the information in the database also reduces the necessary minimum training level for analysis.

Comparison of object-oriented and relational approaches

Typical modeling approaches use relational databases for data modeling and as the base for programming languages they use to model different transportation processes. However, the object-oriented approach has been said to have superior modeling power because the DDL and DML are merged with the OO programming language. Because of this there is a tendency for the use of OODBMS to expand in comparison to relational models. While the latter models simply describe system states, object-oriented models can describe both system states for data and system processes or behaviors in an integrated context (Booch, 1991; Rumbaugh, et al 1991)

Some limitations of existing DBMS (relational) have been identified by various writers such as Herring (1992). First, relational RDBMS lack extensibility to provide for special application needs (e.g., provisions for the user to add new data types and methods, addition of user-defined code, design of new storage methods, and access to standard packages). A table is created for each entity type, a row corresponds to an entity and columns contain the attribute values. However, a relational schema ends up with many additional tables because an attribute is restricted to being a simple built-in type. An attribute may not be a set of values, and relationships are also modeled using tables. For GIS spatial and non-spatial data, they are complex enough that spreading entities and attributes into numerous tables is undesirable (Wiegand & Adams, 1994).

Some of the advantages of OO modeling are that related data can be kept together and relationships can be directly modeled (Medeiros & Pires, 1994). The new geographic data models based on a set of feature objects provide the needed framework for a scaleless and seamless database (Mainguenaud, 1995; Guptill, 1989). It also has the DBMS characteristic of extensibility needed by GIS (Haas & Cody, 1991). For example, the ability to add new data types (e.g., points) and operations on them (e.g., distance functions) and the ability to have a new set of operations as part of the query language (e.g., overlay) are added benefits (Gunther & Lamberts, 1994).

The use of relational databases has been popular in the past and because of this, a set of reliable and working software tools have been developed. This software includes the core database engine, modeling tools, and application development utilities. It usually incorporates a powerful query language (SQL) which has a sound mathematical basis in relational calculus (Date, 1985) and, usually operating on collections of fixed format tables. As opposed to this, the tools in an object-oriented approach draw on a semantically richer background. Unfortunately this has allowed greater personalization of the approach and a standard query language has not yet emerged. As a result, two different types of object-databases have developed, one of them following many of the ideas of the relational model and the other designed to be integrated with an OO programming language (such as VERSANT). The goal of VERSANT's type of OODBMS is to transparently provide persistence to the classes set in the OO programming language. Ties to the relational model provide enhanced relational databases with an object interface. Those tied to VERSANT or other similar languages emphasize persistent objects. Other tools include translators between objects on the program side and relational sets on the storage side. Regardless of the tools selected, there is a need for more application oriented technology. The development of this software, however, must focus on questions of its modularity, its performance, its scaleability, its openness, its robustness, and its ease of use (Göllü, 1995).

The advantages and capabilities of object-oriented systems include: (a) The representation of elements in the object-based environment can be categorized into a hierarchy of object classes. The ability to perform various functions on different classes through polymorphism can further differentiate network elements and modal choices in ITS applications. This ability is not readily available without adding additional structure in the existing relational GIS. (b) An object-oriented representation will be more congenial to the perceived travel decision environment of an individual. It will therefore provide a more intuitive and user friendly environment for the implementation of an ITS. (c) It overcomes the difficulties of the planar data structure and will allow for a finer differentiation of various geographic objects in the system. Running routing and spatial search algorithms will become less problematic. (d) It will facilitate the representation and processing of a multi-level transportation network through introducing new classes across different levels and new functions for these classes; spatial search and queries will be handled more efficiently. (e) It will facilitate the integration of a wide variety of geographic objects and relations within a comprehensive geographic database.

There are also important advantages when implementing such object-oriented systems in the real world: (a) Less costly data integration - Because of the costs of acquiring and maintaining geographical data, the cost of developing an ITS can be greatly reduced if part of the data can be shared and integrated across many other applications. An object-oriented approach can greatly facilitate this through a unified scheme of object abstraction and classification. (b) Less costly maintenance and expansion - The modularity of object-oriented systems renders them highly extensible, reusable and maintainable. (c) Higher data access efficiency and reliability of the system.

The major objectives when building an object-oriented system include the establishment of an object-oriented data model through constructing the key abstractions, class structure and functions that are required. Thus, we suggest that it is possible to build up an object-oriented GIS for ITS applications by generating a set of high-level abstractions of the ITS environment through domain analysis. These abstractions may include the transportation network, the mobile and non-mobile users of the systems, and the activity schedules and the adjustment strategies of travelers. Key mechanisms involved in the system would include processes like data acquisition, message parsing, activity scheduling, routing, spatial search and information display. The class structure and the module architecture of the system will then be constructed based upon the above analysis. Specifically, elements of the complex transportation network (including routes that utilize various modes such as transit routes) at various spatial scales could be represented in terms of abstract data types supporting inheritance, polymorphism and dynamic binding.

Experimenting with an Object-Oriented ATIS

The first step in this experiment was to conceptualize the class hierarchy that could be applied to an ATIS, and develop an object-oriented GIS that could handle inheritance, polymorphism and dynamic binding. We then developed a script language associated with this object system using C++ and C language; it can handle various mathematical and conditional statements, as well as defining classes and functions. The system is designed to be fully functional within the IBM PC environment.

Based on this preliminary work, we tried to utilize a real world transportation network and operate it in our object-oriented system. We used an ETAK database of the Santa Barbara area as the primary host for our efforts. This is a comprehensive database available commercially.

Our first step was to read the ETAK mapbase file structure for the Santa Barbara network into our object class hierarchy. Next, we undertook the following steps: (1) completing modification of the ETAK database to include attributes such as travel times and splits, weights or penalties on turns at signed or lighted intersections, one-way streeting, lane changes, and temporal summaries of traffic volumes; and (2) expanding the class hierarchy in order to accommodate these realistic traffic characteristics.

Methods

A. Layering:

The first task was to divide the base map of the Santa Barbara area into layers. Most of the layers can be defined according to the attribute types defined within the ETAK MapBase format. Each L-record attaches information to a point, line or region and has a code which determines the type of attribute. A layer is created for each type of attribute; and each layer contains lists of the following types of entities: circles, lines, points, polylines, nodes, links and line attributes. The first four are the graphical entities common to most CAD and GIS systems. The nodes and links are the entities used to define the street network and will be described below. The line attributes are records used to describe the line and link entities. They contain a subset of the information attached to each line element within the MapBase format: they include the left and right street addresses, census block numbers, topological information, etc.

Because the MapBase format defines many more attribute types than actually occur within the Santa Barbara County Map, most of the layers ended up empty. An important work that was to add in some of the detailed attributes in the ETAK database and build the layers. Transit routes were stored in another layer with pointers referring to the street network in order to perform routing. Space will be conserved by allocating only the entity lists which actually contain items in order to minimize storage.

B. Partitioning:

The major purpose of partitioning is to enhance the efficiency of spatial search. Some means of partitioning the map is required if displaying the zoomed-in map takes nearly as long as displaying the entire map. The reason is that storing the map as a "flat" file requires comparing each entity to the viewing box. The extent of the viewing box is determined by a translatable origin and axes scale factors. This problem can be alleviated by partitioning the contents of each layer. Partitioning allows the rendering of only those sections of the map which overlap with the viewing box without "touching" all of the entities. The increase in performance resulting from accessing only the necessary entities can be observed whenever a spatially localized subset of the map is to be referenced. This will occur not only during the tasks of displaying the map but during many other analyses, including route computation.

The description given above of a "layer" stated that each layer contained a set of entity lists, one for each type of entity. The partitioned entity lists replace that description. Each layer consists of either the lists of entities or a set of partitioned entity lists. A hierarchical spatial tree can be used to implement the partitioning. The tree consists of a set of hierarchically arranged bounding boxes. The bounding box for the entire map is used as the boundary of the "root." In a sense, the unpartitioned entities are stored at the root of the tree because all of the entities are contained within its associated bounding box (by definition). The root bounding box is divided into N-by-N quadrants to define the 1st level. The original box is the "parent" and the smaller N-by-N boxes are the "children." Each child is itself subdivided into N-by-N boxes. This recursive subdivision is repeated until a specified "depth" is achieved. The bounding boxes at the first level define the tree's "leaves." The contents of each layer is partitioned by deciding which leaf's bounding box contains the entity. This decision is made using the entity centroid. The entity is copied to the appropriate entity list in the leaf and is subsequently removed from the unpartitioned list. Although it is possible to use a different spatial partitioning for each layer, the same spatial quadtree is used for all layers.

In the first phase of building the system, only the leaves of the tree will be used to determine whether to draw each partition's entities. The more sophisticated and efficient approach (to be pursued later) would be to compare the bounding boxes at each level of the tree to the viewing box. A saving in processing time would arise whenever the remaining depth of the tree could be ignored because the bounding box at the given level did not overlap the viewing box.

C. Hierarchical layering:

We require the capability to hierarchically relate different road types for use in route selection. In a multi-modal situation, we also require the different layers of routes to be related. Code can be written to create these relations at the "layer" level. We build on the recent work of Göllü (1995) for this purpose. The first step is to define a "road-layer" class and then to "derive" more specific types of roads from this class. "Derive" is the object-oriented term meaning to establish a "kind-of" or "parent-child" relation between objects (Egenhofer & Frank, 1989). The derived or "child" class is said to "inherit" the properties of its "parent" class, including the parent class's attributes and its associated functions. A relation might be established between a class "car" and a class "vehicle." It could then be said that "car is derived from vehicle" and that "a car is a type of vehicle."

The class definitions are stored in text files which, when processed, define the layer hierarchy. The class definitions describe both the hierarchical relation as well as the attributes attached to "instances" of each class. In our case, the "instances" correspond to items placed into the given layer. Defining the layer hierarchy is taken care of by the first line, "class road : layer". It is useful at the same time to define the potential attributes of entities contained by the layer. The attributes are only "potential" because the entities are not required to have defined attributes.

D. Associations between entities and attributes:

There seem to be several approaches to associating entities and attributes, each having different drawbacks. One is for each entity to contain a pointer to its attribute. When the entity possesses an attribute, the pointer would be set to the attribute's memory address; when the entity doe not, the pointer would be set to NULL. A second method, similar to the first, would be to place a pointer to an entity within each attribute. A third method would b e to assign a unique identification code (i.e., "handle" or "object identifier") to each entity. Attributes would then refer to their entity using this code. A single-bit flag might be set within an entity to indicate that an entity possesses an attribute.

The first two of these approaches are pointer-based. They have the drawback that they allow only a single attribute to be associated with each entity (unless a more complicated scheme is implemented to allow lists of attribute pointers for each entity). One or the other approach would be preferred depending on from which side most of the computation would be done. If most computation involved only the attributes with infrequent reference to the entities, then the pointers might be better placed within the attributes. An additional consideration is whether the entity-attribute relations will be sparse or dense. The space consumed by NULL pointers under sparse conditions might be unacceptable. For the third method, actually associating an entity with its attribute requires searching the attribute list for the attribute having the entity's identification code. This required computation is what is made implicit within the pointer-based approaches.

E. Generic attribute hierarchies

The capability to define class hierarchies is not specific to layers, but may also be used to define hierarchies of any information (e.g., types of activities, types of destinations). The use of the word "layer" in the road-class definition causes some special handling that creates internal data structures related to the map. Another way to say this is that the keyword "layer" acts as a built-in "base" class. The trick will b e to decide what we want hierarchies of, what the attributes should be, and how we will fill in the attributes.

Theoretical and Applied Implications of Using OOGIS in ATIS

Transportation Science is host to a variety of theories concerning (among others) network structure, routing algorithms, traveler activity patterns, mode choice, demand forecasting, vehicle or traffic assignment, trip allocation, and traveler behavior. Our paper today has direct relevance for trip allocation and prediction, activity scheduling, and traveler behavior, and indirect relevance to other theories.

Most transportation models derive basic assumptions from econometric models. These include assumptions of economic rationality and utility maximization of travel related choices. Simplified spatial assumptions include those of shortest-path route selection and selection of closest alternatives for interaction purposes. In addition, travelers are assumed to be low risk takers, creatures of habit (i.e. invariably repeat behaviors), and to have perfect information. such assumptions are often necessary to produce normative or optimal solutions for transportation problems.

In practice, information is usually partial or incomplete, is not available instantaneously, and may be difficult to interpret or integrate into an existing knowledge base. Knowledge bases are imperfect, as are our mental models (i.e. cognitive maps) of environments through which travel takes place. Environments are partially represented. Drivers often have well formed habits that are difficult to change; these are easy to model. But much driver behavior is not habituated, but is better described in terms of problem solving. Driver decisions may be rational, but often we don't know the appropriate criteria to judge them. Consequently we limit those criteria to a few that are mathematically tractable. Sometimes we develop theories or models and assumptions that are sensible for dealing with freight traffic, or for dealing with fleet vehicular movements that have little or no driver independence involved, then assume that individualized vehicular traffic can be likewise constrained.

When discussing ATIS, we must remember that we are dealing with individual drivers pursuing their own activity schedules, rather than fleet operators seeking cost minimization solutions to driving problems. There is, therefore, a need to work in a more realistic rather than a more abstract and simplified environment; there is a need to incorporate more realistic assumptions of driver behavior and even network structure; there is a need to consider individual differences in risk taking propensity and stated preferences for travel. Allowance must be made for both active movers (those seeking solutions to traffic problems) and passive stayers (those waiting *in situ* for someone else to solve the problem).

A viable ATIS must be more realistic than normative. As such it is difficult to imagine a good usable and practical ATIS being driven by existing theoretical principles or concerns. The potential for developing a real-world real-time ATIS may be significantly increased by using a GIS as a host.

A host GIS can allow different levels or classes of objects. Starting with the most basic feature - the transport network - a GIS can share an accurate geocoded database complete with curves, gradients, non-planar intersections, and movement controls; or it could develop cognitively warped and viewpoint specific systems. This introduces versatility into the network representation.

A GIS should provide alternative path selection algorithms with a variety of route selection criteria (e.g. shortest path, fastest path, longest leg first, most aesthetic route, etc.). Such criteria may be most important in selecting alternate routes and alternate destinations after experiencing congestion, hazards, construction, or other travel delay scenarios.

By more faithfully and realistically encoding routes and linking sets of attributes to them, rerouting and changing destinations should become more acceptable procedures. There is little sense in recommending an alternative route that is restricted to local streets with numerous stop signs, if a traveler's criteria for path selection is "fastest route". It makes little sense to recommend an alternative route that crosses many arterials if a traveler wishes to avoid traffic signals or wants to minimize left turns. Most ATIS to date provide only one alternative routing model (often a modified Dijkstra algorithm): many of today's GIS offer a set of alternative route selection models which allow individuals to express their preferences for different controlling criteria.

Object-oriented GIS in particular allows for detailed attributes to be attached to routes. Routes can be conceptualized as continuous lanes over the entire length of a street, rather than as multiple arcs with beginning and ending intersection nodes. And, as shown previously, features such as hierarchical layering, class structures, inheritance of attributes, polymorphisms, and encapsulation processes give much versatility and considerable replication of how we perceive the reality of transportation systems.

Thus, as technology (such as GIS) allows us to model and describe transportation systems more completely, there emerges a need to re-think existing models and theories which were developed in times of sparser knowledge and understanding of both system complexity and human behavior. While not denying the continued usefulness of (normative) theories and models as ways to formalize the state of our knowledge, there is also little doubt that as we enter this new age of information distribution, new sets of constraining assumptions are needed. As we develop more comprehensive tools for obtaining environmental information (e.g. remote sensing, satellite imagery) our need to simplify for the sake of mathematical elegance may be reduced . And as we develop technologies for detailed examination of driver activities and behavior (e.g. traffic and driver simulators) our knowledge of the range of feasible and likely behaviors should escalate - again requiring revisions of limiting behavioral assumptions.

Thus, as we explore the use of current and future technology, there should be direct and immediate feedback to the domains of theory and model building.

Conclusion

We expect that this research will have important significance on both basic and applied levels. We have conceptualized and developed an object-oriented geographic information system. Our continuing effort will focus on the data modeling issues of a multi-modal network, and the implementation of a multi-strategy travel decision support system built on this object-oriented system. We have discussed the advantages and disadvantages of an object-oriented approach to transportation modeling. Apart from its improved capability of handling the transport network as more of a perceptually accurate system, the object-oriented data model allows us to incorporate hierarchical layering within the basic network that ties to the normal engineering way of interpreting road systems. Polymorphism allows us to perform ITS functions on various classes of objects in the transportation network, an ability that is not easily obtained in existing systems. The approach also appears likely to substantially decrease the time involved in interacting with the database particularly by using partitioning and inheritance characteristics. Cost of operation should consequently be reduced. Both these factors are important when considering the primary aim of the ATIS component of an ITS is to get useful information to travelers in as timely a manner as possible so that on-route decision making can be undertaken.

There are many basic research problems relating to the development of workable object-oriented data models for use in transportation planning and this research has examined some of these. We also expect that the data model as developed will greatly facilitate the implementation of ITS by more quickly resolving conflicts with respect to ultimate selection of routes, substituting destinations, changing activity patterns, and rescheduling activities.

Our project was designed to contribute to the next generation of traffic management technology, particularly in terms of dispensing information to travelers in a pre-planning or on-route phase via an ATIS. ITS generally appears to be moving more towards

Object-Oriented data structures and models and we believe our work is in line with these nationwide trends.

Some of the critical features involved in evaluating the worth of any object-oriented data model or object-oriented data structure include its ease of use, the relevance of the attributes defined in the system, whether or not the model deals with real or artificial concepts, the degree to which there is a clear translation between model entities and the actual objects, and whether or not there are acceptable matches between those activities undertaken in the real world and those activities incorporated into the model. Other criteria relate to the number of modules embedded in the system that have to be changed in order to work in a real environment, the number of steps that operation of the system requires, the degree to which one must know and accept a process model of the system, and the time that is required to integrate changes in the system to ensure it is a dynamic real time one.

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