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Introduction

Data modeling is an effective design and communication tool used for the development of relational databases and associated applications. A fully developed data model includes a rich set of information on tables; fields; relationships; and, most importantly, the organization's business rules. Data models facilitate communication between developers and clients and, in modern development environments, CASE tools can be used to translate many model specifications directly into the physical database. Whether implemented in the physical database or enforced at the application level, the vision of the relationship between data and its uses that is expressed in the data model becomes a crucial contributor to the usability of the resulting database and suite of applications.

This paper addresses a data modeling problem inherent in the use of geographic information systems (GIS) which is not adequately covered by traditional modeling techniques. GIS are computer-based systems designed to capture, store, integrate, update, modify, create, display, and analyze geographic data. GIS technology has only recently begun to be used by a large number of businesses; therefore, much needs to be done to develop procedures for modeling GIS data and applications in a business context. This situation is partially a result of the fact that GIS developers have traditionally been knowledgeable end users or facilitators and they have generally been called on to build stand-alone systems for experienced end users; not "enterprise-wide systems" or systems for use by decision makers not familiar with GIS technology. Changes in these patterns have made the modeling issue much more important, yet we still lack standards for representing and communicating the use of and relationships between tables when one or more contain geographic coverages.

To address these issues, we begin the next section by discussing the important characteristics of spatial data and several of the modeling problems that are inherent in working with this data. Following this, a methodology for modeling spatial relationships as part of a comprehensive data model is developed and demonstrated using graphical modeling techniques.

Illustrating Spatial Data

In traditional database designs relationships are formed between entities when the primary key of one entity serves as a foreign key in another. Multi-table queries are almost always made along these paths using joins to select records in one table with key values matching selected records in another. These relationships are modeled using a number of techniques.

In a GIS, however, a new kind of join, the spatial join, is possible. The GIS engine is 'aware' of the area occupied by objects (records) in coverages and is able to tell when a record in one coverage overlaps the area occupied by a record in another. Further, while joins in conventional systems typically test for equality of key values, spatial joins can be accomplished using a number of different criteria. Keywords in spatial joins include, "intersect," "are completely within," "completely contain," "have their center in," "nearest," "contain the center of," and "are within distance of." Finally, GIS loaded with appropriate matchable street themes have the capability of estimating the x-y coordinates of an object such as a street address.

With these capabilities, queries such as the following are possible:

- Select all customers whose addresses are within one mile of the store's location.
- Select the nearest store to a customer's location.
- Select the hospital emergency room which is closest to 123 Elm Street and which has a cardiac intensive care unit.
- Select all employees whose zip codes fall within the service area of the XYZ HMO.

These capabilities highlight the modeling problem addressed by this paper. Whenever there are two geographic coverages in a system there is *automatically* a relationship between them. No matter where the coverages lie with respect to each other, a "Select the Nearest..." query will yield related records. When the coverages overlap spatially then any of the spatial join types can be expected to yield related records.

Since any two coverages are automatically related, it is essential that the database designer distinguish between *accidental* relationships and those relationships having fundamental importance to the use of the system. Further, when spatial relationships are part of the system, rules for maintaining data integrity, especially rules enforcing standards for 'orphaned' records (insert and delete rules) must be established. Finally, the modeling technique must provide for the representation of 'traditional' data in the system. An overall approach for modeling data in a GS requires a method for representing spatial coverages; for distinguishing between intended and incidental relationships between coverages; for documenting the characteristics, including data integrity rules, of spatial relationships; and for documenting relationships between coverages and conventional tables. A methodology for accomplishing these goals is developed in the remainder of this section. The methodology is illustrated using the traditional ERD first proposed by Chen but the techniques can easily be adapted to other modeling techniques.

Illustrating Spatial Coverages in a GS

When a system includes both conventional tables and spatial coverages, the illustration should clearly distinguish between these two data structures and it should allow the user to see the class of objects in each coverage. These goals may be accomplished by taking the following steps.

1. Use a rectangle or other shape as a metaphor for the ground and place coverage entities inside this area. Entities shown outside this area will be implemented as conventional tables rather than coverages. In the case of complex or multi-page GDMs where all of the coverage shapes cannot reasonably be drawn in proximity to each other, the spatial indication boundary can be repeated in multiple parts of the GDM. It would be understood that each of these individual areas is actually representing the entire spatial area of interest.
2. Annotate each spatial entity with a symbol to indicate the type of objects it contains. Symbols should be easy to construct with any graphics program capable of creating the basic symbology of the GDM itself and should bear some resemblance to the type of object being represented.

Figure 1 illustrates the application of these techniques in a simple GDM. The model pertains to a company with sales representatives (SalesRep entity) assigned exclusive rights to a sales territory (SalesTer). Each sales territory lies entirely within a sales district. Customers are assigned to sales representatives and territories according to the territory in which they reside. Customers receive after sales repair services according to the service area in which they reside but there service areas have no correspondence to sales territories and districts.

Illustrating Spatial Relationships

As discussed previously, the inclusion of spatial coverages in a bounding box illustrates the natural spatial relationships which exist between records in any two coverages sharing a common coordinate system. It is likely, however, that business rules similar to those applied to relationships between conventional tables may apply to relationships between geographic coverages. A method must be adopted to distinguish between 'accidental' relationships which exist between all spatial coverages and intended relationships which implement some business rule of the organization.

For example, it may be company policy that each sales territory falls within just one sales district but that each district contain many sales territories. On one hand it is clear that this relationship has the characteristics of a conventional One-to-Many relationship between tables but there is a geographic component to the relationship which must also be enforced. Each record or object in the SalesTer coverage must therefore satisfy the spatial criteria as well as the traditional referential integrity requirement.

Illustrating intentional relationships between coverages in a geographic system can be accomplished by connecting each coverage in the relationship with a line. Annotate the line with a short descriptive name and the cardinality of the relationship. This technique is illustrated in Figure 1 for the example relationship as well as some others.

Documenting Spatial Data Integrity Rules

This section covers the enforcement of data integrity rules as they pertain to spatial coverages. While many of these rules are similar to those found in conventional database design the spatial aspects of the data present some additional challenges to the designer. These challenges are in the area of enforcing existential integrity, referential integrity, and triggering operations.

Documenting Existential Integrity Rules

Existential integrity in conventional systems requires that each record be unique and this requirement is enforced by guaranteeing the uniqueness of the primary and alternate keys of each record in a table and the existence of values in each field of a primary key (nulls are not allowed). Spatial coverages may have the same rules for their attribute data but must also consider the spatial uniqueness and completeness of each record. Since the enforcement of rules in these areas will vary with the application, or even between coverages in the same database, these rules must be specified at design time and enforced within the database or the using application.

Spatial uniqueness determines whether a record in a coverage is allowed to overlap the area occupied by another record in the same coverage. For example, in a polygon database containing the legal descriptions of property records it is not legal for the area of one parcel of land to overlap the area of another. Each area of land must be within a unique parcel and each parcel must have an ownership status. On the other hand, a polyline coverage mapping bus lines in a city may have different routes intersecting or occupying the same streets on portions of their routes.

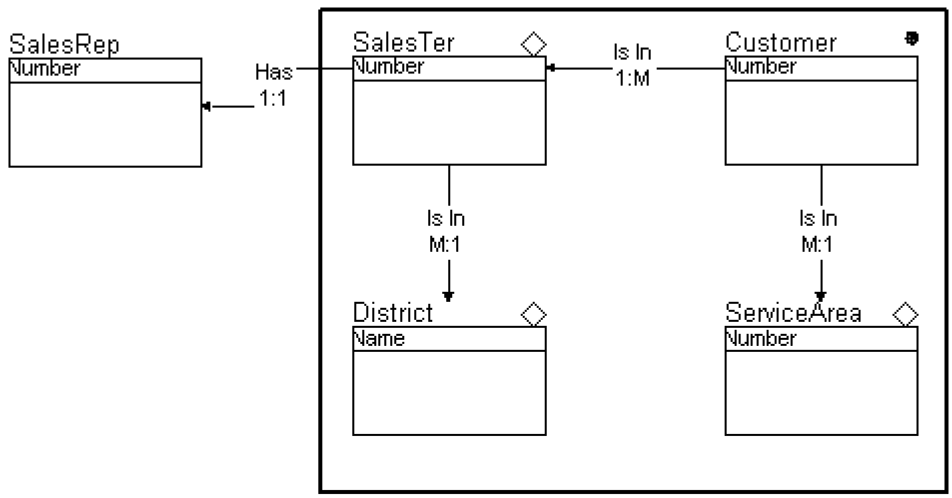

Figure 1: Relationships in a GDM

Spatial completeness determines whether or not records in a polygon coverage must completely fill the bounding area of the coverage. In the property records mentioned above it would make no sense to have an area of land not belonging to a legally described parcel. Such an area would be ownerless and the system must therefore enforce the completeness of the coverage. On the other hand it would be acceptable for a coverage of city boundaries to have gaps in it representing unincorporated areas of a county.

Uniqueness and completeness of the coverage must be specified in the coverage's entry in the data dictionary.

Documenting Referential Integrity

It is also necessary to document the nature of each intended spatial relationship in the data dictionary. This documentation should include conventional referential integrity rules for the relationship (insert and delete rules) as well as any spatial restrictions on the nature of the relationship. These last may be thought of as rules which must be enforced by the GIS engine.

These rules must be derived from the spatial selection capabilities of the GIS engine as it is the engine which must perform validity checking on the spatial objects. For example, according to the example business rules given earlier the relationship between SalesTer and District in Figure 1 would be an "Is Wholly Enclosed By" relationship. All sales territory relationships must be wholly enclosed by a single sales district. On the other hand, the company may have a rule that says that new customers are automatically assigned to the closest sales representative as determined by their sales territories. With this rule customers will automatically be assigned to the appropriate sales representative if they happen to live within an established sales territory but will be assigned to the closest representative if no territory contains their address.

Documenting Triggering Operations

Triggering operations (or triggers) are data integrity rules which may not be specified using the earlier methods. Triggers frequently require calculations, reference to additional fields (other than primary or foreign keys), or summaries of values in multiple records for determining the validity of a proposed action.

Actions requiring integrity enforcement through triggering operations are common when dealing with geographic records. One example of a trigger could be created by an ordnance which prohibits certain land use (e.g., liquor stores) within a specified radius of property designated for a different use (e.g., schools).

While it is simple to detect whether or not an object exists within this radius reference must be made to additional information to determine the types of the two objects to enable detection of a violation of the trigger condition.

Conclusions

GIS are becoming ever more popular for transaction processing, management support, and decision support systems. As they become integrated with other organizational systems their design must reflect the same considerations for data integrity protection found in other systems. This paper has proposed a methodology for identifying and documenting data integrity considerations for geographic systems. The methodology is an extension of techniques already in use and can be implemented with tools likely to be found in any programming shop.

An expanded version of this paper with additional illustrations, references, and expanded coverage of this topic is available from the authors at **lwest@garnet.acns.fsu.edu**.