Deriving Spatial Integrity Constraints from Geographic Application Schemas

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INTRODUCTION

Integrity constraints of various kinds must be observed when creating or updating a database in order to preserve the semantics and the quality of stored data (Elmasri & Navathe, 2000). Within the scope of geographic applications, integrity assurance requires special attention from the designer, since most geographic applications use data that depend on spatial relationships (Egenhofer & Franzosa, 1991), thereby requiring the specification of spatial integrity constraints.

In the traditional database approach, there is a relationship between conceptual, logical, and physical design, in which, through mapping operations, constraints that are identified in the conceptual schema are inherited and transformed into implicit constraints expressed by the data definition language (DDL) or into explicit constraints coded in the application programs (Elmasri & Navathe, 2000). This relationship also exists in spatial information systems; therefore, spatial constraints can be likewise identified and implemented. However, even though there is a very active research area interested in the design of robust and efficient spatial databases, there are still shortcomings with respect to spatial integrity constraints (Borges, Davis & Laender, 2002; Plumber & Groger, 1997). This happens mostly because a simple geometric modification in a single object in a spatial database may generate the need to check for possible integrity violations throughout many object classes, using computationally intensive geometric and topologic algorithms.

Most spatial integrity constraints are, in fact, semantic integrity constraints applied to the spatial representation of objects and to the relationships among object instances that are based on spatial representations. In order to be able to adequately represent such representa-

BACKGROUND

Every data model has a set of built-in constraints associated with its constructs (Elmasri & Navathe, 2000). Accordingly, the OMT-G model allows several spatial integrity rules to be derived from its primitives. These rules constitute a set of constraints that must be observed in the operations that update a geographic database. Ideally, these rules should be implemented by the spatially-enabled database management system (DBMS) in its data definition language (DDL), along with the necessary expansions to the data manipulation language (DML) and the implementation of geographic data types and access methods. However, the approach employed by current commercial products is rather different. Since current spatial DBMSs do not implement spatial integrity constraints, the task of ensuring consistency ends up in the application, usually developed as a geographic information system (GIS). In general, GIS tools allow inconsistent
information to enter the database; later on, a range of correction functions is used to “clean up” the data, verifying its consistency.

Regardless of whether the implementation of integrity constraints is to be performed by the DBMS or by the GIS, the required constraints can be determined at the conceptual level of spatial databases design. In order to show how this can be done, we will use conceptual schema primitives from the OMT-G model (Borges et al., 2001), showing how the semantics embedded in the primitives leads to the spatial integrity constraints. Such an exercise can be performed on any other spatial data model.

**SPATIAL INTEGRITY CONSTRAINTS AND THE OMT-G MODEL**

OMT-G is a conceptual data model based on the primitives of the UML class diagram (Rational, 1997), enhancing it with geographic primitives. It is based on three main concepts: classes, relationships, and spatial integrity constraints. Classes and relationships are the basic primitives that are used to create application schemas with OMT-G. From these primitives, spatial integrity constraints can be obtained, as presented next.

*Classes*, in OMT-G, represent the three main groups of data (continuous, discrete, and non-spatial) that can be found in geographic applications. Non-spatial data are represented using conventional classes, which can relate to spatial objects but have no geometric or geographic properties. Georeferenced classes describe a set of objects that have spatial representation and are associated to features on Earth (Câmara, 1995). Assuming the fields and objects view (Frank & Goodchild, 1990), georeferenced classes are specialized into geo-field and geo-object classes. Geo-field classes represent objects and phenomena that are continuously distributed over the space, corresponding to variables such as soil type, relief, and mineral contents. Geo-object classes represent individual, particular geographic objects, which can usually be traced back to real-world elements, such as buildings, rivers, and trees. The notation employed by OMT-G is shown in Figure 1.

There are five geo-field descendant classes in OMT-G: isoline, planar subdivision, tesselation, sampling, and triangular irregular network (Figure 2). From the semantics involved in the concept of geo-fields and from the specific definition of these classes, some spatial integrity rules can be deduced (Table 1).

Geo-object classes are classified into geo-object with geometry classes, representing objects which have only geometric properties (points, lines, and polygons), and geo-object with geometry and topology, which represents objects which also have topological connectivity properties, and are thus specifically suited to the representation of spatial network structures. Topological properties are present in objects that are either nodes or arcs in a graph-theoretic approach, thereby forming Node, Unidirectional Line, and Bidirectional Line classes (Figure 3). Geo-objects with geometry and topology are not subject to a set of integrity constraints by themselves, but their use is conditioned to the existence of network relationships (Table 4).

The geometric concepts used in the definition of points, lines (including lines with a topological role), and polygons lead to some integrity constraints. The geometric definitions adopted in OMT-G admit the existence of geo-objects that are formed by several polygons, establishing one of them as the “basic” polygon and considering the others as islands or holes. Polygons that are composed of multiple parts (or polygonal regions) are important, since there is no guarantee that the results of traditional operations, such as buffer creation, union, intersection, and difference between simple polygons, are always formed with simple polygons. Constraints regarding lines and polygons are presented in Table 2.

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**Figure 1.** Graphic notation for the basic classes

**Figure 2.** Geo-field classes

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