LOCAL UPDATING OF TIN
FOR
THE INTEGRATED DTM AND GIS DATA STRUCTURE

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ABSTRACT

Aiming at an integrated system of "DTM and GIS", we investigate the aspects of data updating. The integrated terrain model uses TIN as a basic concept. To be applicable to large data sets, local retriangulation is of particular interest. Since we are using a relational database structure for implementation, TIN updating needs to be studied in terms of geometry and consistency in changing the relational tables. The user should be charged only with entering the desired change object change, not with taking care of all of the consequences. The paper reviews the approach to integration, the data model, and the unified data structure (UNS). It elaborates on the principles and procedures of updating data in UNS and gives an account of its implementation.

1. INTRODUCTION

The increasing demand for reliable and comprehensive multi-purpose geoinformation governs the need for integration of diverse geographic information. This need stimulates the development of an integrated data model and data structure, as well as corresponding tools for data handling. Integration is more than just a collection of data and tools. Data must be stored and maintained in an appropriate structure, ready for fast interaction with the user.

Two major components of terrain-related geoinformation can be distinguished. The first one is information about terrain features. Topographic entities, such as rivers, lakes, footpaths, railroads, airfields, cemeteries, water towers, etc., are terrain features, and the relevant information is usually made available in the form of maps or a two-dimensional GIS. Types of entity and geometric abstraction (point, line, area) are issues of concern in representing terrain features. The second component is terrain relief. The description of the shape of the ground surface--DTM--is not concerned with feature types. Instead, it is concerned with interpolation, i.e., reconstructing a continuous surface from discrete data. Traditionally, information about terrain features and terrain relief is handled separately in terms of data acquisition, data structure, database management, data storage and maintenance, and the corresponding tools and systems. Integrating the two systems, GIS and DTM, by facilitating mutual data exchange (e.g., Ebner et al (1990), Mark et al (1989), Arc/Info (1991)) still implies that both data sets are stored and maintained separately. Both sets contain information pertaining to the same location, but the topologic relationships existing between them are not dealt with. This has several drawbacks. Many applications require access to and use of both data sets at the same time. If only available in a "collection manner", much human intervention is needed to establish the links and obtain the answer to a query. Updating one data set does not automatically modify the other one accordingly. This increases the risk of inconsistencies and as a consequence can cause problems of integrity of terrain representation, reliability of derived height and slope information, and low efficiency when both sets of information have to be used to facilitate better spatial analysis and graphic presentation.

Integrating information about terrain relief and terrain features, let us say DTM and GIS, is the subject of research at various places, e.g., Sandgaard (1988), Ebner et al (1990), Fritsch and Pfannenstein (1992), Pfannenstein and Reinhardt (1993), Wiebel (1993). Pilouk and Tempfli (1993) suggested a data model valid for both aspects of terrain, thus aiming at integration at the conceptional level. The integrated terrain model (ITM) can be translated into the unified data structure (UNS) using either a relational database structure or an object-oriented approach (see also Pilouk and Tempfli (1994b)). UNS supports all common functions of a DTM (i.e., interpolation, contour lines, slope and aspect, perspective views, etc.) as well as those of a GIS (in particular querying). An important building-block of UNS is the triangular irregular network (TIN) concept. After reviewing ITM and UNS, this paper describes the various aspects of updating TIN within the relational UNS.

2. THE INTEGRATED TERRAIN MODEL AND ITS DATA STRUCTURE

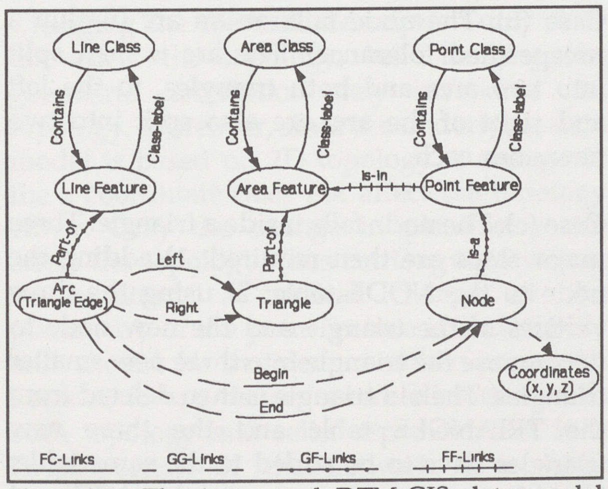

Figure 1 : The integrated DTM-GIS data model (ITM)

ITM can be seen as both an extension of Molenaar's (1988) data model for single-valued maps and an application of the concept of simplicial complex (see Egenhofer et al (1989)). ITM distinguishes three geometric primitives, i.e., node, arc and triangle (see figure 1). Any geographic object, being represented as point, line, or area feature, can be decomposed into a set of geometric primitives and assigned to a single class (theme). An area feature (e.g., lake) is decomposed into a set of triangles and so is terrain relief. A point feature (e.g., water tower) is "decomposed" to one node only. Nevertheless, the identifier "point feature" is needed to be able to separate thematic and geometric properties. As regards topology, we can state: nodes are triangle vertices and may, but need not, belong to a point feature; arcs are triangle edges and may, but need not, be part of a line feature; a triangle can be situated either at the left or the right side of an arc and may be part of an area feature. Terrain elevation can be computed at any point by interpolation in the TIN (see, e.g., Abdul Rahman (1994)). Since terrain features--including breaklines and salient points--are incorporated in the TIN structure, high fidelity surface reconstruction can be achieved.

Mapping ITM to a relational database structure yields fully normalized tables as shown in figure 2 (see Pilouk and Tempfli (1993) for details). Three tables (POINT, LINE, AREA) provide access to the thematic properties, the other five define geometry and topology. The three feature tables are designed to interface with the user for e.g., updating purposes. UNS supports a wide range of queries (including queries about relief) as well as 3D visualization. It can be implemented on any relational DBMS, e.g., dBASE IV; in addition, however, tools have to be developed for graphic display and triangulation. The developed algorithm for constrained Delaunay triangulation is outlined in Pilouk and Tempfli (1994a).

3. UPDATING OF UNS

Updating integrated terrain information means altering the data elements that are contained in the tables of figure 2. The user has the possibility to do so via the three feature tables. The remaining five should only be altered by the system or the database

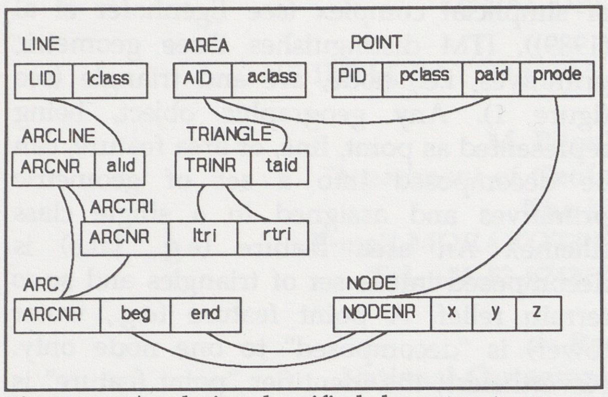

Figure 2 : A relational unified data structure

administrator. Alteration of these five tables must depend on a set of algorithms and procedures provided by the database designer. Integrity rules and constraints should be taken into account during the design of algorithms and be well implemented in the procedures. The system takes the user's action as input, uses this set of procedures to evaluate and decide on the appropriate action and eventually gives feedback to the user. With this kind of constraint, the user's updating actions can be anticipated and differentiated into three major types with respect to each feature: insertion, deletion, and modification. The following subsections elaborate on each of the operations per type of feature. The updating scheme, which is based on the idea of local updating of TIN, is similar to the one presented by Egenhofer et al (1989). Local TIN updating is preferred to global updating because of computational efficiency. Implications for triangulation criteria, however, still need to be studied.

3.1 Updating point feature

Altering the geometry of a point feature affects directly its primitive, a node, and indirectly the arcs and triangles that are associated with this node. We can distinguish three cases:

3.1.1 Insertion of a point feature

When inserting a new point feature into the database, for example, the user may issue a command like "INSERT POINT A with identifier = 1234, class label = 'Town B', X = 1234.350, Y = 3845.230, Z = 750.245". The POINT table is then the first one that is subject to change. The system needs to evaluate whether the point identifier or these coordinates already exist. If this is not the case, the point can be inserted. Figure 3 shows all three possible situations that can occur.

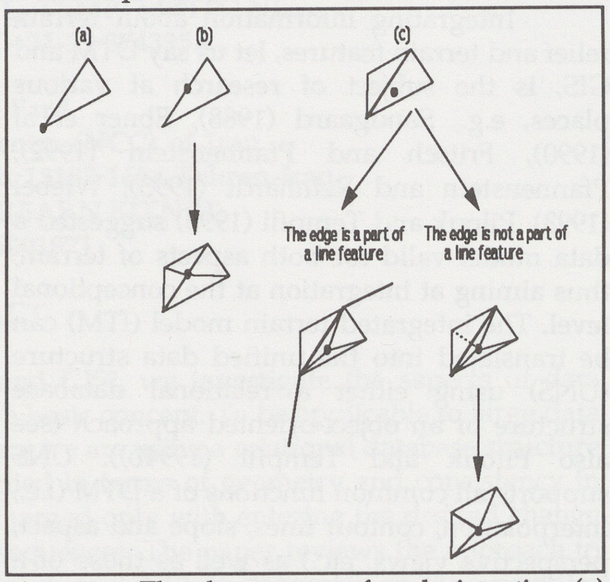

Figure 3 : The three cases of node insertion (a) node coincide, (b) node on edge, (c) node in triangle (adapted from Egenhofer et al (1989)).

Case (a): The coordinates of the new node coincide with those of an existing node (within a prespecified tolerance). The insertion attempt is rejected.

Case (b): The node falls on an arc (within a prespecified tolerance). The arc is then split into two arcs and both triangles, to the left and right of the arc, are also split into two new ones each.

Case (c): The node falls inside a triangle. Three major steps are then required: 1) adding the node to the NODE table; 2) using the three vertices of the triangle and the new node to decompose the triangle into three new smaller triangles. The old triangle is then deleted from the TRIANGLE table and the three new triangles have to be added to the same table; 3) adding three new arcs to the ARC and ARCTRI table. After this, if there is a requirement to follow Delaunay triangulation, further refinement like swapping some of the edges among the neighbours of the old triangle may be necessary. However, when an edge of the old triangle is a part of a line feature, this edge must remain unchanged; otherwise, the chain of the line feature would be destroyed, implying loss of integrity.

3.1.2 Deletion of a point feature

When the user decides to delete a point feature, the point feature must first be correctly identified. This can be done by using an SQL statement with search criteria (e.g., delete where pclass = 'town B') or using a pointing device to pick up the point feature from the displayed graphics. The point feature can be deleted immediately from the POINT table. Then the status of the node associated with this point feature needs to be evaluated. If the node is not a component of any line or area feature, then this node is subject to deletion upon the decision of the user. The user may consider maintaining this node for the purpose of surface representation. If not, the node will be deleted from the NODE table. Subsequently, all arcs and all triangles linked to this node should be deleted. This results in a polygon which needs to be locally retriangulated. Figure 4 illustrates this operation.

3.1.3 Modification of a point feature

Modification can pertain to a change of the thematic description, to a change of the z-coordinate (elevation) or to a change of (x,y). Changing the thematic description only does not affect the topology, but changing the geometric description may invalidate the topology. Moreover, since the underlying data model is based on 2D topology, a change in the z-coordinate does not affect the topology either. Only the change in planimetry can affect the topology, thus retriangulation may be required. A radical change of the planimetry of the point feature is undesirable and should be avoided or either prevented because it can cause severe disturbance to both topology and relief representation in a large portion of the network. If a large planimetric discrepancy in the location of the point is found, it is better to delete the original point and insert a new one. Changing the planimetric location of a point feature may be permitted only in the case of a small change

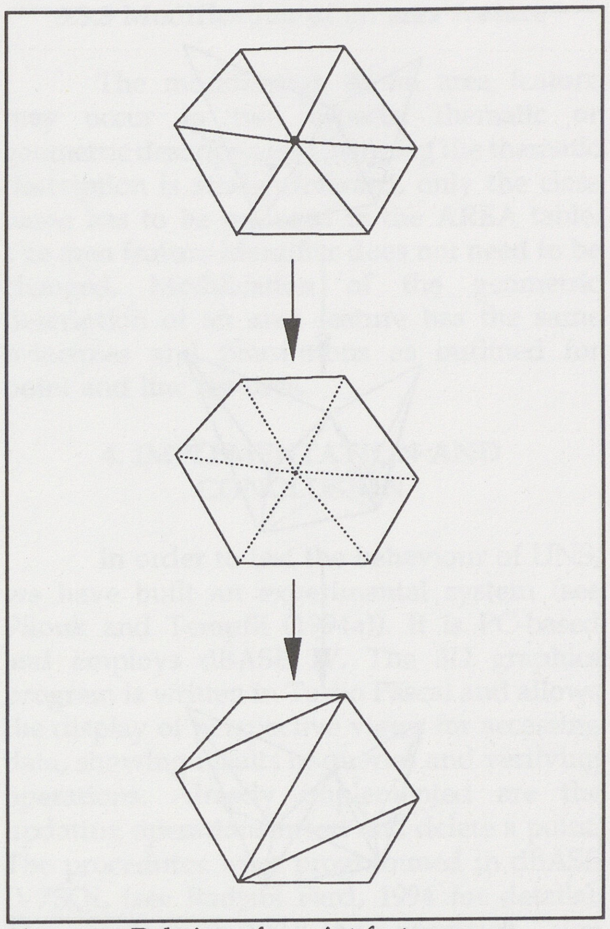

Figure 4 : Deletion of a point feature

and in such a way that topology is not disturbed. The respective tolerance can be derived from given accuracy specifications of the database.

3.2 Updating line feature

Geometrically changing a line feature affects all arcs and nodes that are components of the line feature. Also triangles that share these arcs and nodes are inevitably subject to retriangulation.

3.2.1 Insertion of a line feature

Insertion of a line feature first requires insertion of all the nodes that constitute the new line. A straightforward procedure is to first insert each node, as described in section 3.1.1, and then the intersection points of the new line with the existing arcs (see figure 5). Subsequent simple local retriangulation, however, does not necessarily produce optimal

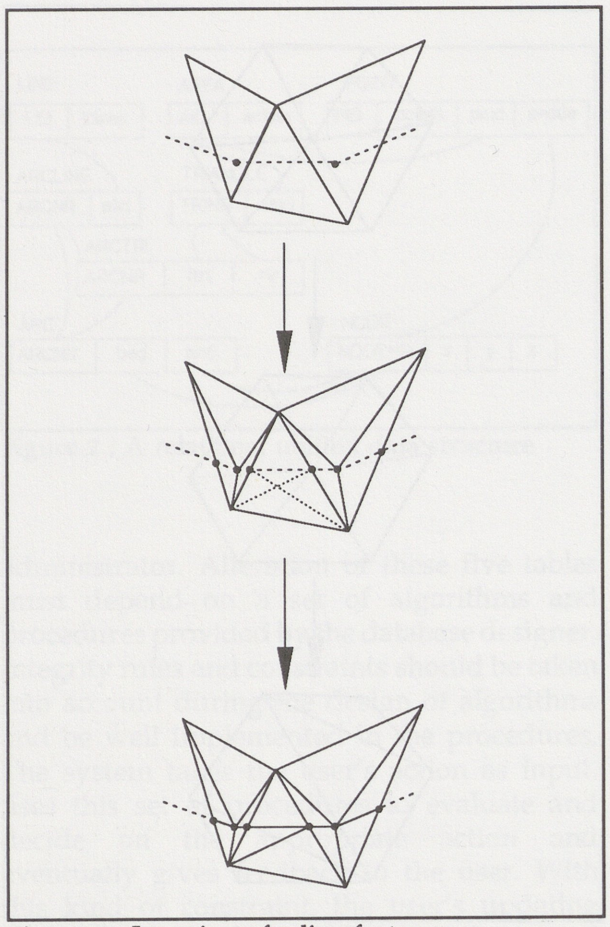

Figure 5 : Insertion of a line feature

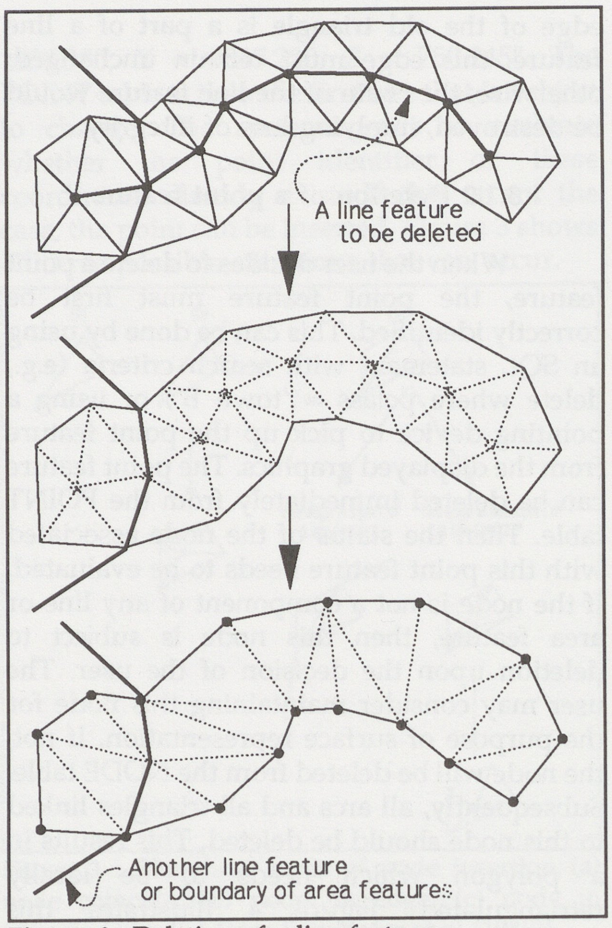

Figure 6 : Deletion of a line feature

triangles (e.g., according to the Delaunay criterion). Retriangulation must ensure that existing line features are not disturbed.

3.2.2 Deletion of a line feature

When deleting a line feature we can distinguish between deleting the thematic and the geometric descriptions. First the identification of the line feature is required, then the line feature is deleted from the LINE table. The next step is to delete from the ARCLINE tables every record indicating the arc as part of the line feature. The deletion from the ARCLINE table means detaching the thematic description from an arc. After this operation, the geometric description is still maintained in the ARC table (i.e., the vertices of the line are still there, but the linking arcs do not compose a line feature anymore). If the user also decides to remove the geometric description of the line feature from the database (e.g., if it is not considered necessary for relief representation), this set of arcs should be deleted from the ARC table. As a consequence, this set of arcs is also deleted from the ARCTRI table and all triangles that are situated on the left and right sides of these arcs are deleted from the TRIANGLE table. Last, all nodes that are components of these arcs must be deleted from the NODE table. This results in a polygon bounded by those arcs which are components of the deleted triangles. This leads to a situation comparable to that described in the last part of section 3.1.2 (see also figure 6). Thus, retriangulation is done accordingly.

3.2.3 Modification of a line feature

The same considerations hold for modifying a line feature as described for a point feature in section 3.1.3. Modifying the thematic description does not affect topology or the relief representation, thus it can be done directly in the LINE table. Modifying the geometric description concerns the nodes that are components of the line feature and is carried out according to the explanation in section 3.1.3.

3.3 Updating area feature

An area feature is defined by its thematic description and its boundary polygon. The boundary has a chain of arcs and nodes as its components.

3.3.1 Insertion of an area feature

After the user has issued a command to insert an area feature into the database, first the AREA table is updated. The identifier and the name of the area feature will be added. Next, all new nodes (and arcs) that are components of the boundary have to be inserted, following the procedure described in section 3.2.1. The TRIANGLE table is the last to be updated, in such a way that all triangles that lie completely inside the boundary of the area feature have to be reclassified into the new area feature.

3.3.2 Deletion of an area feature

To delete an area feature, the user needs to identify the area feature first. The considerations are the same as for the deletion of a point or a line feature. Deleting the thematic description of an area feature does not disturb the topology. The record of the area feature can be deleted directly from the AREA table. Consequently, all triangles that are part of the area feature have to be reclassified into 'unclassified'. This update is done using the TRIANGLE table. The geometric description remains unchanged. If there is the need to delete the boundary nodes of the area feature (if considered irrelevant to the relief representation), the procedure described in section 3.2.2 can readily be applied. If the two adjacent areas need to be resolved into one, the common boundary of the two areas need not be deleted; only the reclassification into the new designated class is required. The procedure is described in the next subsection.

3.3.3 Modification of an area feature

The modification of an area feature may occur in two aspects: thematic or geometric descriptions. Changing the thematic description is straightforward, only the class name has to be replaced in the AREA table. The area feature identifier does not need to be changed. Modification of the geometric description of an area feature has the same principles and precautions as outlined for point and line features.

4. IMPLEMENTATION AND CONCLUSION

In order to test the behaviour of UNS, we have built an experimental system (see Pilouk and Tempfli (1994a)). It is PC-based and employs dBASE IV. The 3D graphics program is written in Turbo Pascal and allows the display of perspective views for accessing data, showing results of queries and verifying operations. Already implemented are the updating operations insert and delete a point. The procedures were programmed in dBASE IV/SQL (see Radjabi Fard, 1994 for details). The correctness of the approach was experimentally verified. We still have to implement the other procedures, but we already dare to state that ITM and the corresponding UNS allow for consistent updating of terrain relief and terrain feature data.

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