INTEGRATION OF DTM DATA STRUCTURES INTO GIS DATA MODELS

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ABSTRACT:

Most of the Geographical Information Systems (GIS) used in practice have been designed for management and analyses of planimetric data. In the most recent 2D+1D approach the 1D is given by a digital terrain model (DTM) more or less isolated from the planimetric data (2D). On the contrary there is an increasing demand for 3D data models and analyses. This requires the unification of planimetric and height data management within one GIS data model.
A possible way is the integration of DTM data structures into GIS data models which is treated by this paper. It starts with an overview of DTM data structures and DTM data storage. With regard to GIS data models concepts for the efficient integration of DTM data structures into GIS are given. The paper concludes with first assessments considering system response, data consistencies and data analyses.

Key words: digital terrain model, geographical information system, data models, data analyses.

1. INTRODUCTION

Since more than 30 years digital terrain modelling is under research not only at photogrammetric institutions but also in civil engineering and in industry. Digital terrain models (DTM) represent the earth surface by boundary descriptions in different data structures. The terrain heights z are variables of fixed planimetric data x,y, thus the three-dimensional problem is shrinked to a one-dimensional one. Corresponding data models are very simple: topology is maintained by grid and triangle structures, and object semantics characterizes only the nodes within terrain.

When looking into the history of GIS these systems evolved mainly from classical two-dimensional mapping problems (Bill/Fritsch,1991). The reference surface is given by the projection surface of the underlying coordinate system, onto which the three-dimensional data is projected. Therefore, they are restricted in geometry on two variable dimensions (e.g. x,y). Height data, if at all, are supplementary information of the situation data.
But the earth is not flat. So, GIS and DTM should not longer be seen isolated. One way out of the dilemma is to interface DTM program packages with GIS which is described in Ebner et al. (1990), Fritsch (1990b,1991), and Reinhardt (1991). However, the use of two separated databases rises the problem of data consistency, which can only be solved if data structures for both, DTM and GIS are integrated in one data model.
The integration of a DTM into a GIS demands for a total unification of the underlying data sets as well as the methods being applied. Two main procedures can be used which may also be combined with each other (Fritsch,1990a)

- three-dimensional coordinates for all geographic elements
- digital terrain models as constituents of a geographic database

While the first approach is costly in terms of storage elements - the situation elements have to be supplemented by means of additional height elements - the latter one is easier in concept and realization. Furthermore, situation data are dense only in densely populated regions, however, in agricultural areas as well as poor populated regions coarse distribution of planimetry must be overcomed. Therefore the integration of a DTM into a GIS is also more pragmatic from this point of view.
The following constraints have to be considered: On the one hand data storage should be not redundant leading

to a data set of minimum size and, on the other hand, the response time of a system should be reasonable. In order to develop three-dimensional data structures terrain information must be connected with situation information (figure 1). In terms of height integration geometry can be represented by 2D data (situation), 1D data (terrain) and a combination of both which leads to closed 3D data models. However, the integration of DTM into GIS is only a first stage in 3D modelling - the final objective should be a 3D boundary representation of the earth surface as reference not only for man-made constructions above and underneath the terrain but also for complex 3D natural terrain phenomena.

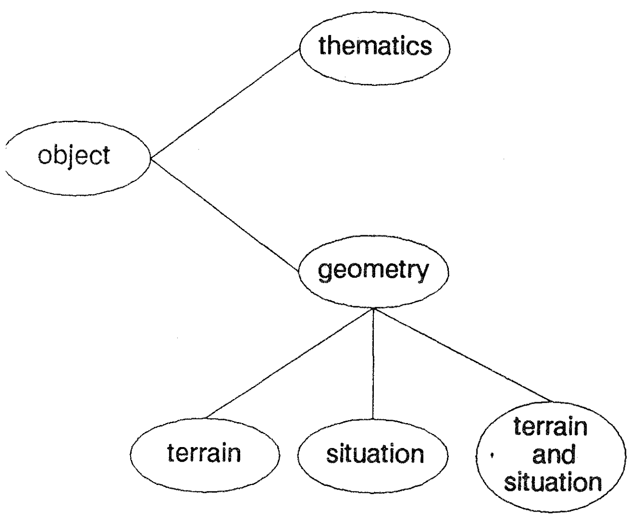


Figure 1: GIS data model

2. DTM DATA STRUCTURES

Digital terrain models are represented by three different data structures (Ebner,Fritsch,1986). These data structures may evolve during data acquisition and data approximation, respectively. For that reason we can differentiate between:

- an irregular structure, which is triangulated and therefore forms a network being called triangular irregular network (TIN). The triangulation should care for constraints between nodes, for instance, to integrate breaklines, and ridge lines (figure 2). Obviously this is the most direct representation of the primary data. It is suited best for all tasks where strong reference to the measured data is required (e.g. volume calculation) or if a fast and rigorous revision of the DTM surface is necessary.

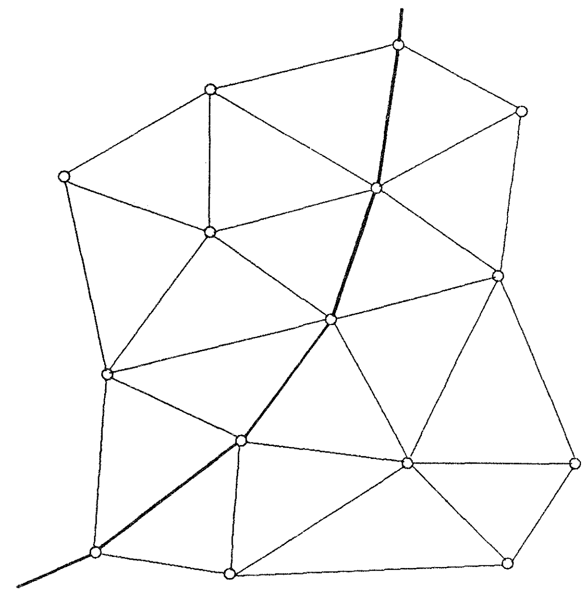


Figure 2: TIN data structure

- a regular data structure, in which the data is organized by a GRID of fixed or variable grid size. For the generation of the GRID methods for interpolation and filtering are used (Kraus,1972; Koch,1973; Ebner,Reiß,1978; Reiß,1985). With regard to better quality terrain representation the grid is often intersected with geomorphological information (figure 3).

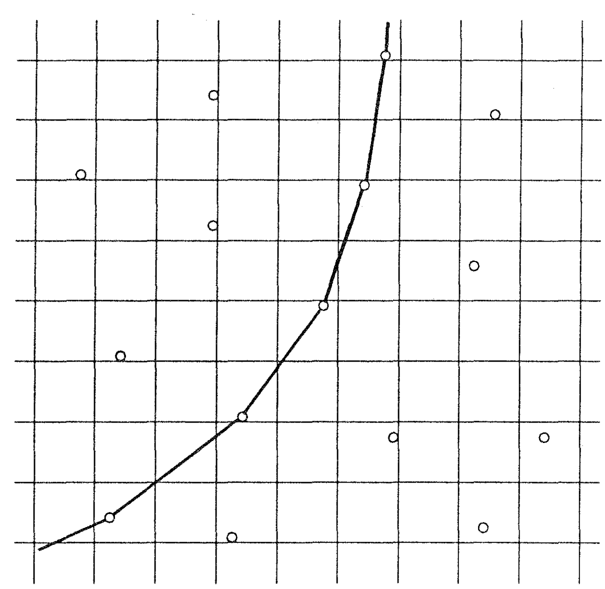


Figure 3: GRID data structure

- a combination of both data structures resulting from the integration of additional geomorphological information. This information is considered by local TIN's in a GRID. With regard to merging two different data types this is called a HYBRID data structure (figure 4).

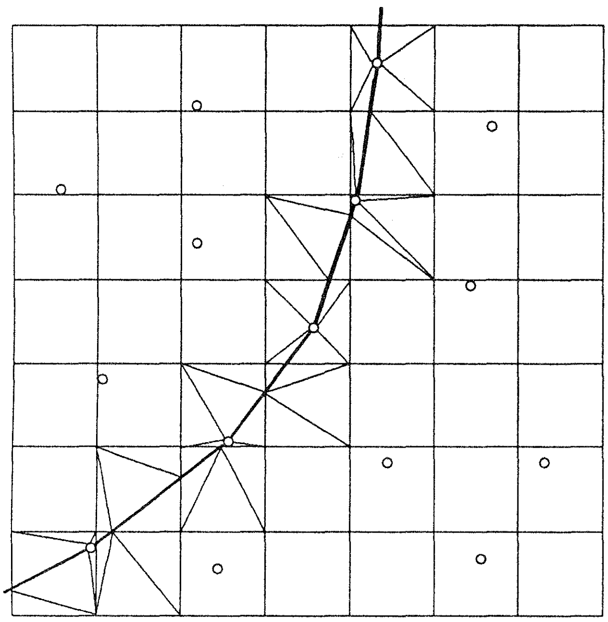


Figure 4: HYBRID data structure

Practical experience has shown that the user should have the opportunity to choose one of the above mentioned data structures, according to the requirements of the project concerned.

3. DTM DATA STORAGE

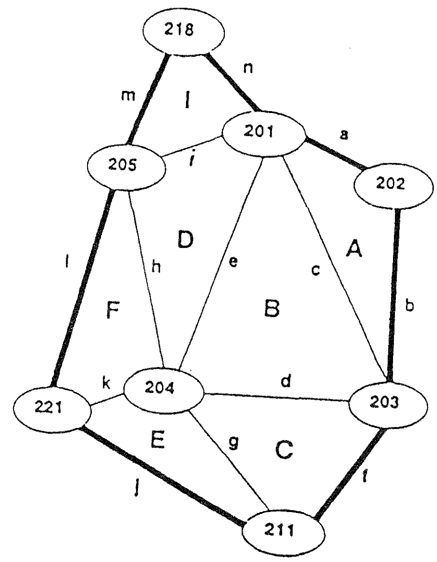
The storage of DTM data can be organized by sequential files, direct access files, and list structures in which position and topology is maintained. Up to now less importance was given to object thematics, however, this is a postulate for a successful integration as explained later on in more detail. An existing data model of a DTM should be extended such that it should not be primarily position oriented but to be topological and thematic as well.

3.1. TIN data organization

As far as TIN is concerned different modes for data storage may be used (Fritsch,1991):

- an organization with respect to triangles and neighboring triangles
- an organization with respect to edges
- an organization with respect to edges and triangles and complete maintainance of topology

The latter one is demonstrated by figure 5, in which linear lists are used for position and topology.



nodes			
node	x	y	z
201	x_{201}	y_{201}	z_{201}
202	x_{202}	y_{202}	z_{202}
203	x_{203}	y_{203}	z_{203}
204	x_{204}	y_{204}	z_{204}
205	x_{205}	y_{205}	z_{205}
211	x_{211}	y_{211}	z_{211}
218	x_{218}	y_{218}	z_{218}
221	x_{221}	y_{221}	z_{221}

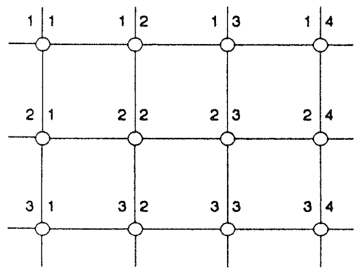
edges	
edge	nodes
a	201, 202
b	202, 203
c	201, 203
d	203, 204
e	201, 204
f	203, 211
g	204, 211
h	204, 205
i	201, 205
j	211, 221
k	204, 221
l	205, 221
m	205, 218
n	201, 218

triangles	
triangle	edges
A	a,b,c
B	c,d,e
C	d,f,g
D	e,h,i
E	g,j,k
F	h,k,l
I	i,m,n

Figure 5: TIN data organization

3.2. GRID data organization

The advantage of a grid data structure is its simple topology. The data is arranged like a matrix with rows and columns describing planimetric data x,y; the matrix elements are the z-values. For example, the grid of figure 6 is organized in a (3,4)-matrix. Because of its regular topology grid data can be accessed directly. An improvement of terrain description is mostly assured by extra sequential files with x,y,z-coordinates of breaklines and other geomorphological information.

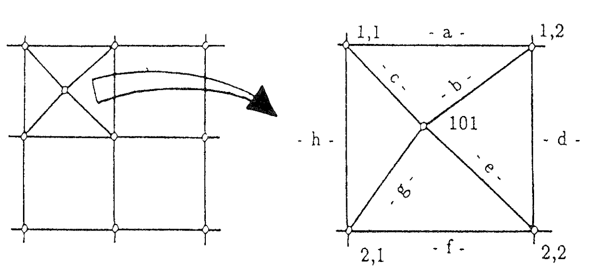


i \ j	1	2	3	4
1	z_{11}	z_{12}	z_{13}	z_{14}
2	z_{21}	z_{22}	z_{23}	z_{24}
3	z_{31}	z_{32}	z_{33}	z_{34}

Figure 6: GRID data organization

3.3. HYBRID data organization

Hybrid data structures make use of the advantage of regular data organization on the different modes of triangulation. In order to have easy data access the grid organization is to prefer being dominant; the result is that the hull nodes of the triangulation are nodes of the grid. Figure 7 gives an example for the structure HYBRID, in which the triangles are organized with respect to edges.



TIN			
nodes	x	y	z
101	x_{101}	y_{101}	z_{101}

GRID			
i \ j	1	2	3
1	z_{11}	z_{12}	z_{13}
2	z_{21}	z_{22}	z_{23}
3	z_{31}	z_{32}	z_{33}

TIN		
edges	B-node	E-node
a	1,1	1,2
b	101	1,2
c	101	1,1
d	2,2	1,2
e	2,2	101
f	2,2	2,1
g	101	2,1
h	1,1	2,1

Figure 7: HYBRID data organization

3.4. Overall data organization

In some cases it is desirable to have an overall data organization especially for the handling of a large amount of data. In this overall organization a contiguous geographic region is splitted into subregions (level 1). This subregions (cells) can be of fixed or variable size. Every subregion may again be subdivided into sub-sub-regions (level 2) and so on (level n) leading to a hierarchic data path (figure 8). This overall organization cares for fast access of regions of special interest. A DTM program package which realized such a data organization is the HIFI package (Düsedau et al.,1987).

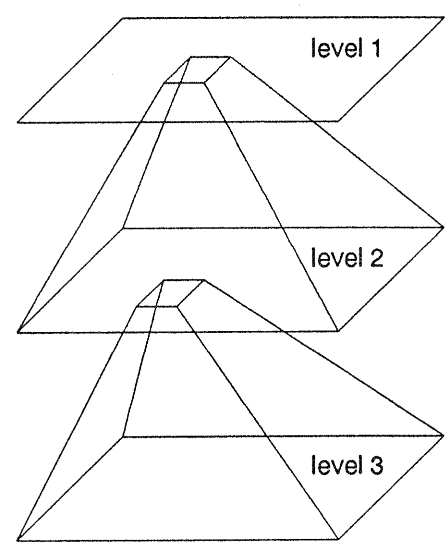


Figure 8: Overall data organization

4. MERGING DTM WITH GIS

4.1. Strategies for DTM integration

When merging terrain data with situation data of a GIS three models can be applied which are realized to some extend in practice. In all three cases the topology within the GIS data model is a two-dimensional one.

4.1.1. Height attributing

In this case it is posssible to add heights to all existing situation data. But this very simple approach has two main disadvantages:

- incomplete height description; there don't exist height data for all situation data, in general.
- dependent on the density of planimetry.

Figure 9 shows a possible GIS data model for height attributing.

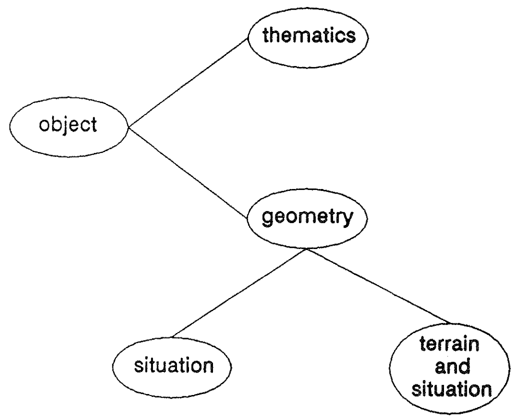


Figure 9: GIS data model for height attributing

The generation of a DTM or, in other words, of an object "height model" whould be possible but does not make sense; the heights are supplementary information for the objects they are attributed to and therefore in most cases not suited for a sufficient description of the earth surface. In consequence, the query space for data analyses is reduced to a 2.5D query space for the situation objects only.

4.1.2. DTM interfaces

DTM interfaces extend the methods of GIS data presentation such that also DTM products in vector and raster form can be some layers of a GIS. The underlying data structures are not changed; there is also no link between the situation data of the GIS and the terrain data of the DTM (figure 10). The worse approach in this case is a separated data management in two different data base management systems (DBMS) when data consistency is not guaranteed within both systems.Up to now there exists two realisations for DTM interfaces (Ebner et al.,1990):

- data file interface; the instructions of the GIS are sent to the DTM program package via files. In the same way the results, produced by the DTM package are sent to the GIS. This data file interface can be realized without much effort because almost nothing has to be changed in the two existing program systems. A disadvantage, however, is that the operator has to work with two different user interfaces. Additionally the data exchange between the two programs via files is rather slow.
- subroutine interface; in this case all data processing and transfer is done in main memory without any disc access and the user works with one user interface only. This interface is much comfortable and faster than a data file interface, but requires a higher programming effort.

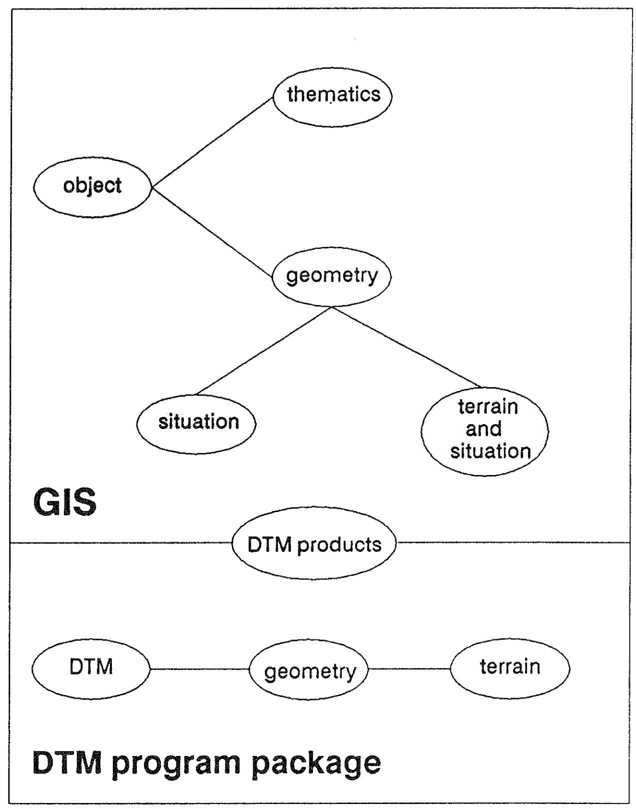


Figure 10: Data model for DTM interface

4.1.3. Total integration of DTM

Total integration of DTM into GIS means at first the recovery of data by only one DBMS. The underlying data structures can be 3D. However, terrain data must not neccessarily be merged with situation data in one positional data set, if they are only essential for the description of the earth surface; with regard to an accelaration of data access it is in most cases suitable to have situation and terrain data as separated data sets. But for an existing relation between situation and terrain data (e.g.a lake) a combination of both should be possible to avoid redundant data storage. In case of separated geometry the terrain elements (nodes, edges, areas) should contain further thematic identifiers to allow for separated questions in terms of situation and terrain. Figure 11 indicates possible thematic attributes for a DTM edge;

the same holds for DTM nodes and DTM areas (Fritsch, 1991). A more detailed description of the attributes for these primitives is given in Höhle (1991).

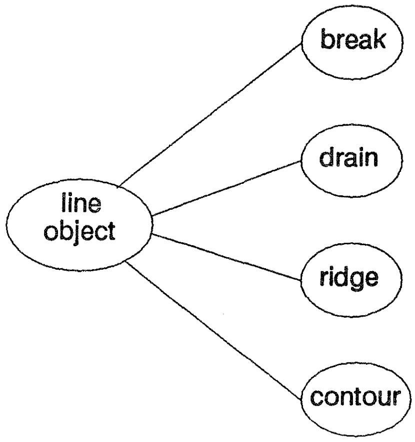


Figure 11: Attributes for DTM edges

Using the data model of figure 1 a DTM can be generated from objects which are characteristic for terrain only and which are characteristic for terrain and situation. The total integration of DTM allows 3D presentation and analyses of the terrain in combination with the situation data what extends considerably the query space of a GIS based on 2D topology.

4.2. DTM data structures in GIS

In the following, problems of integrated data management, according to the different DTM data structures will be discussed in more detail. It is differentiated in DTM generation, data management and data analyses under the aspect of using a GIS.

4.2.1. GRID and GIS

The generation of a GRID as DTM data structure is solved by approximation and interpolation using the original terrain data. The result is a new data set with a regular structure which forms the surface of the terrain. Furthermore, if geomorphological line information is integrated into the GRID this information can be handled objectwise. Thus the object "height model" is to subdivide in raster cells and additional line information. Within data management two different data sets for the terrain have to be stored and managed what causes some problems. A DTM update can only be done when the original data set is accessable and on the other hand every update in the original terrain data set requires a new DTM generation to be consistent in the 1D GRID presentation. But there remains still an other consistency problem using situation data which serve also as terrain information because there is normally a difference between the height resulting from the DTM and the original height. In this sense consistency problems exist a priori. A way out of this dilemma whould be a rigorous separation of situation (2D) and terrain data (1D). But this reduces the possibilities for data analyses provided by the data model of figure 1 and makes redundant data storage unavoidable.

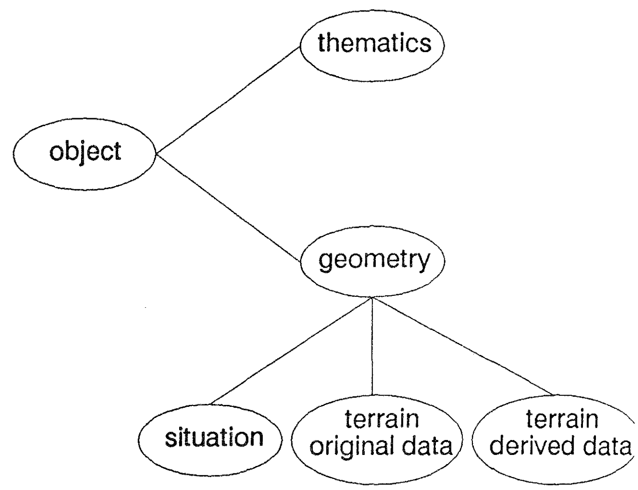


Figure 12: GIS data model for GRID integration

4.2.2. TIN and GIS

Within a TIN the original data represent the DTM. Updating the terrain surface within a TIN is much easier than in a GRID because changes in the original data have only local influence on topology and position; there is no recomputation of large parts of the DTM. The TIN contains implicitely all accessable terrain information without any approximation therefore the complete data model of figure 1 can be used for data analyses in contrary to GRID. Consistency problems will not occur, when it is guaranteed that all 3D information takes part of the object "height model".

4.2.3. HYBRID and GIS

In the HYBRID data model the driving force is a GRID. The advantage of HYBRID is the better fidelity of non-regular phenomena such as break lines and ridges, spot, peak and pit points within the derived DTM what makes it better suited for data analyses which includes height information. However it has all the disadvantages of the GRID in terms of data consistency and DTM generation.

5. CONCLUSIONS AND OUTLOOK

Integration of DTM into GIS is a difficult task which should be solved in near future. In this way the query space of the GIS can be extended considerably. DTM management and DTM generation within a GIS should objectwise be carried out. Separated data sets in situation and terrain make sense if the DTM is introduced as reference surface of the GIS. This separation allows for fast GIS response when queries relate to only one of both data sets. However, these conclusions are only valid for boundary representations.
As far as other geometric modelling techniques are used, it becomes more difficult. In this case, a lot of research should be done on three-dimensional data structures including three-dimensional topology. The experience we get during the introduction of a DTM as reference surface in a GIS can be the basis for more advanced three-dimensional data models.

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