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Digital Terrain Model Data Structures

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Abstract
This paper describes pertinent digital terrain model data structures, namely, grid/raster, quadtree, and triangular irregular network. A basic concept of DTM data structure is also explained. The aspects of TIN storage, TIN data structure conversion, advantages and disadvantages of each structure are discussed. A complete data structure conversion program is also presented.

1.0 INTRODUCTION

Digital Terrain Model (DTM) is used to represent the earth surface or part of the surface digitally. Historically, DTM was introduced by engineers at Massachussetts Institute of Technology (MIT) in the late 1950's. Their definition of DTM is: "digital terrain model (DTM) is simply a statistical representation of continous surface of the ground by a large number of selected points with known x,y,z coordinates in an arbitrary coordinates field" (Kennie and Petrie,(1990)). The definition was based on the nature of the work at that point in time i.e. engineering. Today several terms begin to manifest and can be recognized as Digital Elevation Model (DEM), Digital Height Model (DHM), Digital Ground Model (DGM), Digital Terrain Model (DTM), and Digital Terrain Elevation Data (DTED). Dispite of the differing terms have been used all of them represent the same phenomena i.e. the topography of the earth surface.

2.0 DATA AND STRUCTURES

The pattern of DTM data could be regular or irregular. The regular may be in the form of square or rectangular grid while the irregular one may be based on triangular network of irregular size, shape and orientation. These DTM data could be structured in different ways such as grid/raster, quadtree, and triangular irregular data structure. Mark(1978) defined data structure as a collection of facts or data together with their relations. In DTM, data structure is a way of organizing the XYZ coordinates (e.g. in table form) in such a way that the data can be processed and manipulated efficiently. To make a process more efficient then a data structure may be restructured to another format. One should bare in mind that computer system, programming language, nature of the problem to be solved, nature of the data, and the character of the terrain phenomenon are things that will influence the data structuring. Data structure conversion(i.e. restructuring) may be necessary in order to optimize the processing.

The issue of structuring DTM data now becomes an interesting area to be investigated especially in an integrated environment e.g. DTM+GIS. At this point in time, DTM handling in GIS is not so efficient. Why ? One of the major impediments is due to the data structuring. Thus a 'brilliant' data structure will greatly influences DTM data processing. Mark (1978) suggested that a considerable thought and care has to be taken if a data structure has to be designed or adopted, because, once chosen and implemented, then often will be very difficult or expensive to modify. If they are poorly designed then the system may be less efficient, and may caused some problems. Mark (1978) also suggested that the structures should be tailored to the terrain phenomenon. Another author, Radwan(1989) suggested that the most appropriate DTM structure should be able to support a wide range of DTM applications for terrain analysis, and able to accommodate, use, and explicitly represent critical features of morphological significance in addition to the standard DTM data i.e. spot heights, contours, and regular grid.

The following sections explain the three main DTM data structures in more detail.

2.1 Grid/raster data structure

Tradionally, this is the most frequently used data structure. The points (xyz coordinates) are normally arranged in a series of rows and coloumns or in xy cartisean system. One of the advantages of this structure is that it has an implicit definition of point topology where the neighbouring points can be found without additional computation. Also, offers a relatively compact storage and able to handle a fast data processing algorithm. This structure is widely used in image processing techniques. However, the major drawback is that inability to accommodate relief changes in rough terrain. Thus, in terms of storage space, the structure tend to occupy large space and highly redundant of data in flat terrain. Ambiguous height interpolation occurs in the case where two diagonal points have the same heights(O'Callaghan and Mark,(1984)). This problem is particularly noticeable, for example, when deriving drainage network in hydrological modelling, and also in contour threading.

2.2 Quadtree and DTM data

Recently, quadtree has recieved considerable attention as a data structure in GIS and DTM. Its has several advantages especially in handling a coherent or 'blocky' spatial data, see Samet(1989). The details principle and concept of this structure can be referred to the Samet's vast publications on the quadtree and the related subjects. Quite number of works have been done on the quadtree with GIS 2D spatial data and binary images, but not much for terrain surface representation e.g. Salamanca(1990). She studied how to structure DTM data in quadtree. The quadtree property which allows densification is of great help for DTM. For example, data collected using progressive sampling can be stored and structured in quadtree. Another approach is to use octree, sometimes known as 3D extension of a quadtree(Wen, 1991).

2.3 Advantage and disadvantage of quadtree DTM

Since quadtree is a grid-based structure and has variable resolution, and in many ways related to the progressive sampling, thus redundance of grids data can be avoided particularly in flat terrain and eventually need less storage space. Waugh(1986), Mark et al(1989), and Mark(1986) suggested that quadtree is not very efficient structure to represent grid DTM data, continous surface, and unclassified imagery data. This is due to the fact that the neighbouring cells of these data seldom have identical values. Another major drawback is that difficult to modify any changes to the pattern of the data, requires recalculation of the quadtree. In terms of storage space, quadtree reduces quite significant compared to the normal DTM data structuring e.g. grid.

3.0 TRIANGULAR IRREGULAR NETWORK(TIN)

TIN data structure is increasingly and widely used in terrain modelling. Peucker et al(1978), and Peuquet(1990) worked with this data structure, and noted that all measured data was used directly since these data form triangle's nodes. Then, these nodes are used to interpolate and construct any DTM products e.g. contours. A network of triangles offers a relatively easy way of incorporating breaklines, faultlines, drainage lines, thus tailored to the terrain variations.

3.1 TIN Storage

TIN data can be stored in several methods, namely, triangle-by-triangle, points and the neighbours, and side-based.

- **Triangle-by-triangle.**

It is a record of triangle number, xyz coordinates of the three nodes, and neighbouring triangles.

- **Nodes and their neighbours.**

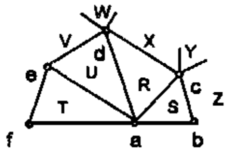
An alternative to the above structure, it is a record of node ID number, the xyz coordinates, and the neighbouring nodes.

- **Triangle sides**

This is another way of storing TIN. The most prefered one for contour threading or any other traversing procedures, and generally needs less storage space in triangle network.

Triangles

ID	Coord			Neighb.		
R	a(xyz)	c(xyz)	d(xyz)	S	X	U
S	a(xyz)	c(xyz)	b(xyz)	Z	R	
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.



Nodes

ID	Coord	Neighbours					
a	xyz	d	c	b	..	f	e
b	xyz	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.

Figure 1 Triangle and node based data structures

Points

#	X	Y	Z
1			
2			
3			
4			

Sides

#	ND1	ND2	Tri1	Tri2
1	1	2	0	1
2	2	7	2	1
3	1	7	1	6
4	2	3	0	2

Triangles

#	Sd1	Sd2	Sd3
1	s1	s2	s12
2	s2	s3	s4
3	s4	s5	s6
4	s6	s7	s8

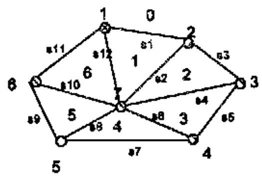
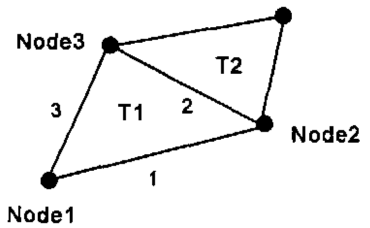


Figure 2 Side based TIN data structure

3.2 Data structure conversion

In certain situations, it is good to have a capability to convert from one data structure to another format e.g. grid to TIN and vice versa. This is due to the fact that not all data structure may satisfy some processing algorithms e.g. contour threading, and able to incorporate some important terrain phenomena. Weibel and Heller(1991) also noted that a flexible DTM system should have an *ability to switch to different data* structure. For example, one may want to produce contours from TIN data which is structured in triangle-by-triangle based. Then, in order to make the threading faster, the structure should be converted to 'triangle sides based'. A data structure conversion program was developed by the author, see a complete source code in Appendix A. This program is able to handle up to 5000 triangles.



Tri

Tri#	Node1	Node2	Node3
1	1	2	3

Nbr

Tri#	NumNbr	Nbr1	Nbr2	Nbr3
1	1	2	0	0

Sid

Sid#	Node1	Node2	RightTri	LeftTri
1	1	2	0	1

Trs

Tri#	Side1	Side2	Side3
1	1	2	3

Figure 3 Triangle-based to Side-based data structure

4.0 CONCLUSION

To summaries, each data structure has its own properties, advantages and disadvantages, thus the selection and adoption of a particular structure is very crucial and has to be tailored to the purpose. The existing data structures e.g. grid/raster, quadtree, and triangular irregular network are applicable and suitable only for certain data model, and data type. Thus, no single data structure is able to satisfy most of the problems related to the digital terrain relief modelling e.g. in the issue of terrain information extraction, handling of large data sets, and also in the issue of incorporating and integrating DTM with other mapping and geoinformation systems.

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