THE OBJECT-ORIENTED HEIGHT MODEL AND
ITS APPLICATION

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ABSTRACT:

Object-oriented height models are defined and their advantages and disadvantages are explained. The advantages are based on a higher "intelligence" which allows for validation of the input data and the models, on the data structure which enables the integration in Geographic Information Systems, and on numerous applications. Some of the new applications are explained in detail and tested, for example, the generation of height models using additional breaklines or data from a situation model, and the generation of slope and soil erosivity maps. The tests were made with Intergraph's "MODELER" and "ANALYST" programs on the TIGRIS platform.

KEY WORDS: Object-oriented Height Model, Geographic Information System, Topology, DTM, Slope Map, Soil Erosivity Map, TIGRIS.

1. INTRODUCTION

For many years, height models and situation models were treated separately. The appearance of Geographic Information Systems (GIS) requires the integration of height models and situation models. Modern Geographic Information Systems are also object-oriented. The objects are houses, roads, etc. or breaklines, peaks in the terrain. They can have attributes (e.g. the number of floors in the house, the width of the road, etc.) and the relation to other objects can be established. This means, the objects are attributed and topologically structured. Thus, advantages and new possibilities are created. It is the purpose of this paper to investigate the potential of object-oriented height models. The experiments and tests are carried out by means of the program "MODELER" on the Intergraph TIGRIS platform.

2. THE OBJECT-ORIENTED HEIGHT MODEL

Height models are a collection of height values which are arranged in grids, triangles, or contours. The height values of the model should describe the surface of the terrain in an optimal way. Height values for points in-between can be interpolated. The application of height models covers the derivation of profiles, contour lines, volumes, orthophotos, and 3 D-presentation of the terrain. The data for height models are acquired by photogrammetric measurements or by digitizing contours in existing maps. Height models can also be integrated into Geographic Information Systems. Various authors have dealt with this topic, e.g. (Göpfert, 1987), (Sandgaard, 1988), (Fritsch, 1991). The elements of modern GIS are objects which contain geometric and thematic components (attributes). Several objects can form a theme (compare fig. 1). This means, a hierarchy will be established. True GIS data are also topologically structured which means, that they are additionally described by nodes, edges, and faces. This coordinate-free geometry or topology is essential, when the data of the informationsystem have to be analyzed according to their neighbourhood relations. For example, one can query a GIS system: "Which object is adjacent to another object?" Subsequently, the height information integrated into a GIS can be analyzed

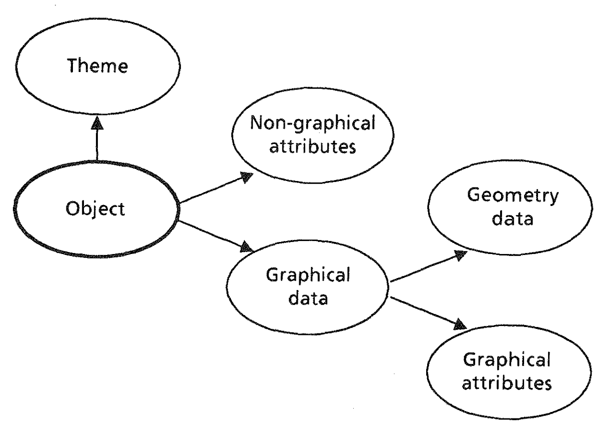

Fig. 1 Objects and their components in a Geographic Information System.

Several objects form a theme. Geometry data are the coordinates of points, the graphical attributes include information about,how line elements are formed and how all elements are symbolized for presentation.

as well and the results of the analysis can be combined with other information. In this way, many new applications can be created. For example, thematic maps with areas for potential risk for soil erosivity can be created. For this purpose, the height (or slope) informations have to be combined with those of the soil type. More details about this application can be found in chapter 3.4. Height models can also be generated from objects of a situation map. Their geometric data should have x-, y-, and z-coordinates. The objects, however, should be part of the terrain surface. One can also collect data which characterize the terrain. The objects can be devided into point objects, line objects, and area objects. Table 1 contains typical objects for height models and their definition. All of them form the Theme "Height model" (compare Fig. 2).

type	objects	definition
point objects	regular	xyz coordinate triplets
	spot	Local high and low points; no assumptions on the slope of the surrounding terrain are made
	peak	Specific local high z-value
	pit	Specific local low z-value
linear objects	break	A three-dimensional line which defines a change in slope or a surface discontinuity
	drain	A specific form for the breakline; this type assumes that the surface on either side of the linear object has an increasing slope. The height values increase or decrease monotonically along the line
	ridge	A specific form of the breakline; this type assumes that the surface on either side of the linear object has a decreasing slope
	contour	All heigt values along the contour line are the same
area objects	double-line drain	An area which consists of a series of planes with various slopes A drainage object which at the map scale is large enough to be represented as two short lines
	edge	It defines a boundary. Only objects inside the boundary are considered as part of the model
	lake	It maintains a constant height value
	obscure	It bounds or limits the extent of a region. No restrictions are made about the height value of any point within the interior

Table 1 Typical objects of height models

There can be additional objects or themes. For example, a theme "verify" can contain all check points. These points (objects)

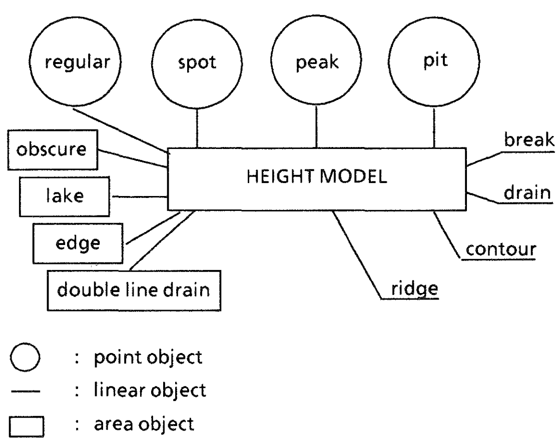

Fig. 2 Objects of the theme "Height model"

can be used for the assessment of the accuracy of the height models. Furthermore, a theme "slope" with the object "polygon" and attributed with slope values can be created. Then one can derive areas (polygons) for slope classes from the height model (see fig. 3). In an object-oriented height model one can create, verify, manipulate, and analyze the objects as well as the height models (see Fig. 4). The height models can be represented as height matrices (GRID), triangulated irregular networks

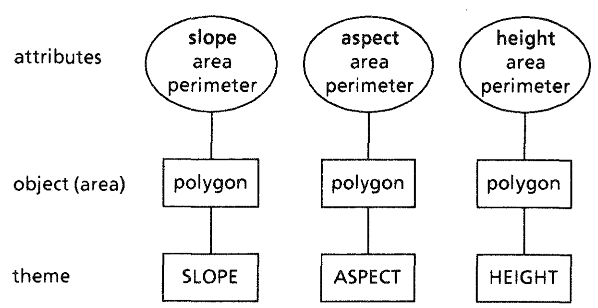

Fig. 3 Topologically structured themes of polygons derived from TIN models

(TIN) , or topologically structured contours (CONTOUR). A GRID model or better its points carry attributes such as height, slope, grey values, etc. The CONTOUR model (which is derived from contours) is topologically structured. Its objects are height zones (polygons) which have attributs (e.g. the bounding height values, area, etc.). From a TIN model one can derive area objects (polygons) which are attributed and topologically structured.

In TIGRIS "MODELER" all objects and height models are part of a large design file (object space). This design file as well as the program "MODELER" reside in the memory of the computer. The objects and their different models can therefore be edited, manipulated, and analyzed interactively. During digitizing of new objects the topology is built up in realtime. The program

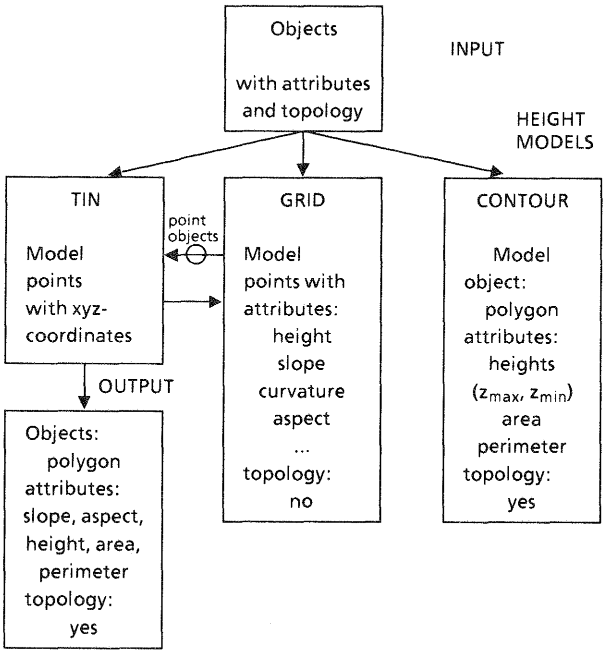

Fig. 4 The object-oriented height model uses objects in input and output. Various height models (TIN, GRID, CONTOUR) which contain objects and attributes can be derived.

"MODELER" can be used in combination with the programs for image processing ("IMAGER"), for mapping ("MAPPER"), and for analyzing ("ANALYST"). All of these programs are of the same size and relatively big (ca. 13 Mb). The hierarchy of objects is designed graphically by means of the program "ADMINISTRATOR".

The advantages of the object-oriented and topologically structured height model are based on its higher "intelligence". The input data as well as the derived results can be automatically validated.For example, the height values of drains shall decrease continuously, or the generated height model should not have unrealistic peaks, or the digitized contours should not cross. The height models can be generated with less blunders and are more accurate. The possibility of working either with GRID models or with TIN models allows an adaption to the task to be fulfilled. For example, a TIN model allows a more accurate modelling of the terrain, but the generation of a slope map is best done by means of a GRID model. The conversion from GRID models to TIN models is solved via the generation of point-objects; redundant height data are then eliminated without altering the height model significantly. The editing of topologically structured data, e.g. contour lines, is much simpler. And the most important is, that the objects (with their attributes) can be analyzed and new applications can be created. For example, one can easily derive slope maps from GRID models or shade contours. From TIN models one can generate a thematic output such as height or slope polygons. The area for a slope class will be topologically structured and attributed with slope values. Furthermore, by means of general functions in "MODELER" one can convert 2 D-objects into 3 D-objects, or height values can be manipulated. In this way, a flooding can be simulated, and the extent of the water body can be mapped, or a dam can be designed, and the extension of the reservoir can be displayed.

It can be seen from the description above, that the term "object-oriented" relates to the management of data or the way the user classifies and manipulates the data. Therefore, it is sometimes called object-oriented management (Fritsch, 1991). There are also object-oriented data bases which are based on "object-oriented" programming. Such data base models are first under development. These two things should not be mixed up.

3. SOME PRACTICAL EXAMPLES

These practical examples are carried out on the GIS workstation of the University of Aalborg. It consists of an INTERPRO 6280 computer with 48 Mb memory and 600 Mb harddisc, it allows processing with 14 MIPS. The 2 Mb pixel screen has a high performance graphic processor (EDGE II) which allows fast displays and millions of colours at a large screen (68.6 cm-diagonal).

3.1 Generation of a height model from photogrammetric data

A height model is required, when orthophotos have to be produced. Today photogrammetric companies (as well as other institutions involved in the production of photogrammetric data) use analytical plotters and collect height data by profiling. The distance between profiles corresponds to the slit length used in the analytical orthoprojectors, e.g. 16 mm in the scale of the analog orthophoto. Within the profile data are recorded in shorter intervals. The accuracy of the collected heights can be relatively high (σ_h = 0.1 o/oo of the flying height when static measurements are used), but the heights between the collected points will be found by interpolation only. It now depends on the shape of the terrain and the method of interpolation, how big the errors in the generated height model will be. These errors will show up in the orthophoto, especially when several orthophotos have to be assembled into a mosaic. In order to improve the accuracy of the height model additional breaklines can be collected in the stereoplotter and then be used for the generation of the height model.

In the first part of the test about 8000 regularly distributed pointsfrom a photogrammetric model were collected for a 2 km x 3 km area. The photoscale was 1 : 18 000, the distances between the points were 24 m (within the profile) and 32 m (between the profiles). The accuracy of the measured points was about σ_h = 0.3m. All these points were used to produce a height model. The matrix of points is then oriented to north, and the distances between points are 50 m. Figure 5 shows a 3-D presentation of the generated height model.

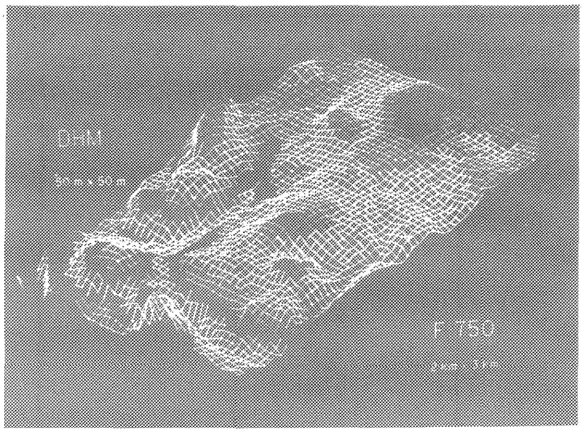

Fig. 5 Isometric representation of a height model. Profile lines are colour-coded according to their height. The height model is used to produce a digital orthophoto.

In this form the height model can be used for the generation of digital orthophotos. More details about this application can be found in (Höhle, 1991). In the second part of the test breaklines were also collected in the analytical plotter, again by an experienced operator. The breakpoints and the regularly distributed points as well as some check points were treated as "objects". The input of all these points requires a conversion from ASCII to binary format. These so-called xyz-files which are established for each object can then be read in "MODELER". The ASCII input files have to be of a certain format as well, where the units of measurements, the sequence of coordinates, the sequence of point numbers for a line have to be added and arranged in a certain way. The conversion from the photogrammetric data file to the ASCII input file has been solved by a newly established program. A TIN model was first generated from the regularly distributed points and from the breaklines and later converted to the final GRID model. A display of the differences between the two generated models revealed that the improvements (when using additional breaklines for modelling) reached up to 3 m. This confirms the assumption, that additionally collected breaklines considerably improved the quality of the height model.

3.2 Generation of a height model from digital map data

Digital maps which are produced by photogrammetry have also z-coordinates for the individual objects and their elements (points). Objects which are on the surface of the terrain can be used for the generation of a height model. In Denmark, digital maps are available for the whole country (T0, T1, T2, T3 data).

T0-data covering the rural areas are produced from photography 1 : 20 000 to 1 : 30 000. This means, that objects of about 1 m x 1 m on the ground can be identified. The produced data base has 14 different objects, their heights have an accuracy of σ_h = 1 m for well defined points or σ_h = 1.5 m for all other points and lines. These data can be bought for a very modest price. The main application of this data base is the recording and updating of utilities (gas, telefon, etc.). The exchange of all these data occurs by means of the Danish Exchange Format (DSFL, 1986), (Alexandersen, 1991). The format is object-oriented as well. In the data files header are also information about the used photography and control points. In built-up areas more detailed map data are produced (T1, T2, T3 data). The scale of photography is between 1 : 4 000 to 1 : 20 000 which means that objects down to 15 cm x 15 cm on the ground can be identified and the accuracy of the heights of well defined points is σ_h = 0.15 m at the best. The number of the recorded objects differs from 16 (T0) to 60 (T3). In order to take advantage of these easily available T-data for the generation of a height model in TIGRIS "MODELER", a conversion program was created (DSFL2ADF). By means of this program the objects in the National Exchange Format (DSFL-format) are translated into the objects of the height model. A cross reference table like in table 2 had to be established. The output of the conversion program are files which contain all the data for one object type (e.g. breakline). In this way some height models have been created. Their accuracy, however, is not homogenious. It depends on the density of the planimetric data and the purpose of the application. For the generation of orthophotos this may sometimes be sufficient, because a higher accuracy is required for areas where objects, especially man made ones, are. In this context it may be mentioned, that in Denmark scanned and rectified aerial photographs are available on CD-ROMs (Jydsk Telefon, 1992). The application of the digital photographs (pixel size 2.5 m x 2.5 m on the ground, 64 grey values) is within Geographic Information Systems. Their rectification is done by means of digital map data (T0 data).

3.3 Display of height model by means of grey values

The attribute of a GRID model can be heights, but also many other parameters (e.g. slope, aspect, temperature, etc.). The heights can be converted into grey values. Such a display can be seen in fig.6. It is used for visual inspection in the orthophoto production, in order to make sure, that there are no positional displacements or other blunders.

3.4 Thematic maps for slope and soil erosivity

The inclination of the terrain surface at a particular point is called slope. Slope values can be computed for the entire height model. From TIN models, for example, areas (polygons) of slope classes can be derived. These polygons are the objects, their attributes are slope values. At the beginning of the process one specifies the interval, e.g. 15°, and the range, e.g. 0° - 90°. All polygons for the defined slope class are calculated and displayed.

National Exchange Format (DSFL - Format)				Digital Height Model-Program (Intergraph "MODELER")		
class	code	object	code	theme	object	type
road system	KG3	sideline of road	U13	DHM	break	L
		unpaved way	U21		break	L
		parking	U24		break	L
		local road	U27		break	L
		path	U31		break	L
buildings & constructions	KG4	house - roofline	U1		-	-
		greenhouse	U31		-	-
fences	KG5	hedge	U1		-	-
		land use border	U32		break	L
area symbols	KG6	coniferous forest (symbol)	U12		spot	P
special objects	KG8	high voltage line - base	U33		spot	P

Table 2 Crossreference table for conversion of database data (T3-data) in the Danish National Format into objects of a height model (P...point, L...line, -...not used)

By means of a simple analysis-function, "Built Query", one can query the data base

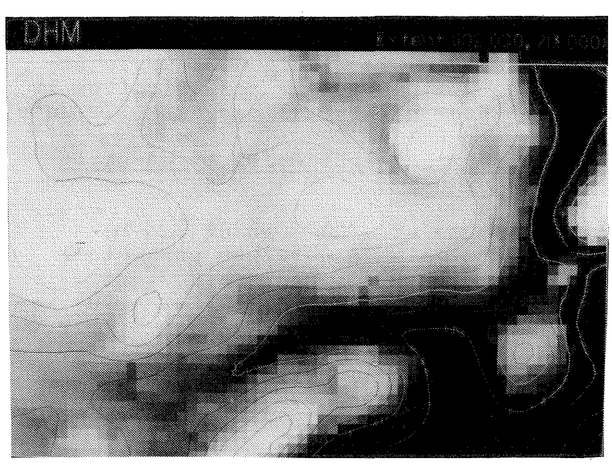

Figure 6 Height model displayed by means of grey values. This representation is used in quality control.

by Structured Query Language (SQL). For example, one can find and display the areas for a certain slope range (see fig.7). With other ANALYST functions one can automatically derive the area or the perimeter of the slope polygons. Slope information can be overlapped with other area related information, for example the soil type. The result of such a spatial query can be a new map of polygons which displays the risk for soil erosivity. Soil erosivity maps are used in landmanagement. A similar application is described in (Sigle, 1991).

Figure 7 Polygons for the slope range 0^{o} - 2^{o} together with contours.

In figure 8 the generation of a soil erosivity map is presented schematically. A new object (soil erosivity) and a new attribute (potential soil erosivity risk (PSER)) are synthesized. Spatial operators such as "overlap", "meet", "within distance", "contain", "touches", etc. can be used to create new objects. Attributes can be updated by means of a mathematical formular. This means, that object-oriented

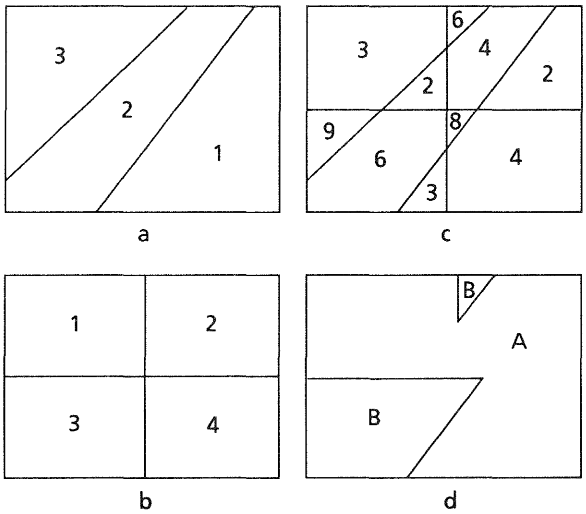

Figure 8 Creation of a soil erosivity map
a slope map with 3 classes
b map for soil type with 4 classes
c map created by overlapping a and b, the classes are derived by multiplying the class-indexes(t=slope x soil)
d soil erosivity map with 2 risk factors (A and B), they are derived from the relation t : 1-5 → A, t : 6-11 → B

and topologically structured data allow query and analysis, they also enable the creation of new objects. They are the prerequisites for a true Geographic Information System (Herring, 1990).

4. CONCLUSION

The concept of objects which are topologically structured and attributed makes the height model more "intelligent". It results in more accurate modelling and allows manipulation and analyzing of the height data. The height models can then be used in Geographic Information Systems which makes GIS much more valuable.
New applications and products can be created, such as
- slope maps
- shaded contours
- generalisation of contours
- flood plane modelling
- dam placement studies
- intervisibility analysis for the telecommunication industry
- landslide and erosivity studies
- creation of surface water drain areas, etc.

The problems with the higher sophistication in using and trouble shooting the software packages have to be overcome by better training and improvement of the user interface.

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