A UNIFIED SYSTEM FOR TERRAIN ANALYSIS AND MAPPING FROM DEM AND DTM

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Computer technology was originally introduced into terrain analysis and mapping in two distinct developments. In one of these, map production units adopted digitization of terrain features and computer graphics to reduce the costs of production. This development is now proceeding at a very high rate, and has already resulted in some maps that are completely computer-drawn. Engineering plans and cadastral maps have also been completely computerized by a few institutions. The other line of development was inaugurated by geographers, whose original goal was to derive numerical parameters to characterize and describe various terrain types. For this purpose, much work was done on fitting analytical surfaces to digital elevation data, and in such exercises as cluster analysis and trend analysis of thematic data. It now seems reasonable to say that analytical surface-fitting is dead, except perhaps for local smoothing operations. The statistical techniques have some value in mapping such variables as population, traffic patterns and the like, but seem inappropriate for deriving physical terrain properties or combinations of properties.

To an every-increasing degree, the computer is now being used to provide direct and quantitative answers to simple but important questions such as the ones described in this paper. Most of the change in emphasis has arisen from the advance of digital electronic techniques, including more rapid and accurate data capture as well as the tremendous increase in capacity and speed of the computer itself. The present authors happened to adopt this approach from the outset (Collins, 1975), and the result has been the development of a powerful series of programs. All of them are intended for economical processing of terrain information, and some of them produce terrain parameters that are unique and highly useful. (Collins and Moon, 1978; Collins, Moon and Fetter 1979). This paper will describe in a more complete form the approach that is being used by the authors for analysing large amounts of terrain data, typically involving models with 10^6 or more points.

Methods of Data Storage and Analysis

There are two methods of data capture which lead directly and naturally into two different methods of data storage. There has been a tendency to preserve this differentiation into the data-analysis stage. One method of data capture, exemplified by contouring, profiling, and outline drawing in photointerpretation, is the polygon method. Terrain information is digitized in continuous or discontinuous strings of points, each with x and y coordinates and one coded attribute. The other method is the grid-cell method. Coarse grid-cell techniques have been used for many years by geographers, hydrologists and others to record and combine broad terrain features. More recently, remote sensing with its many forms of digitized images has provided new data in a dense-grid form, and dense grids of elevations have been provided by the Gestalt orthophoto system (Brnjac et al, 1976).

Storage in polygon (and isolated single point) form is inherently economical, because it involves storing only the data that are essential to describe each significant terrain feature. Some terrain analyses have been carried out by working directly from the polygon structure, but generally speaking it is difficult to derive terrain descriptions from combinations of several types of data stored in polygon form. In addition, while polygonal and grid data can be mapped on one base easily enough, there are computational difficulties in combining information from the two types of data source.

Storage of data in grid-cell form provides a simple means of stacking many pieces of coded information on each point, and thus allows the application of simple and very fast programs for producing derived thematic maps. In fact, digital image processing and thematic map derivation take on similar characteristics as the grids on which the terrain data are stored are increased in density. Some suggestion will be made in this paper of the speed and power of the programs that can be used for manipulating gridded terrain data.

The obvious drawback of handling terrain data in grid form is the storage problem. The approach used by the authors has nullified this problem for project-sized operations, involving up to one million grid points, but storage in direct grid form for large geo-referencing systems is out of the question. For a single project area, the grid that is fine enough to allow accurate representation of the terrain may be redundant over sections where there is little variety, but the redundancy is not significant compared to the extreme speed of data processing. For large geographic areas the redundancy factor increases rapidly, even though somewhat coarser grids may be used.

About two years ago, it became evident to the authors that the strengths of the polygon and the grid system would have to be united into one comprehensive terrain analysis and mapping system. The examples following will show the steps that have been taken to effect this unification and the potential value of the approach.

Analysis of Dense Digital Elevation Models (DEM)

Dense digital elevation models in grid form (primarily from the Gestalt orthophoto system) have been used to extract quantitative information for hydraulic and hydrologic applications. Watershed analyses have been carried out to quantify the number, areas and potential storage volumes of depressions on scales ranging from small test plots up to very large hydro-electric head lakes. The programs for these purposes have been derived largely from the algorithms described first by one of the authors in 1972 at the Fall Convention of the ASP and published later (Collins, 1975). Only the reservoir storage volume and area program system has been completely developed in fast languages for commercial application (Collins, Moon and Fetter, 1979).

In this system, polygons were added to the grid data to delimit specific areas of interest in order to save computer time and also to represent specific dam sites (Figure 1). The Gestalt data have a spacing at the original photo scale of 0.1816 mm, giving a ground spacing of about 5.5 m at the 1:30,000 scale of the photographs used for this project. The valley chosen for the project was extremely deep with side-slopes up to 70^{o}, and the Gestalt data showed some imperfections. But a comparison with conventionally-plotted contours showed that the grid data represented the terrain very well, and the resulting computations of area and volume were of high precision. The complete process of plotting contours from the DEM, delimiting the study area and including the dam site, computing the flooded volumes and areas for many stages, and plotting the flooded areas at each stage, required just 5 minutes of CPU time on an Amdahl V5 computer. Within the delimiter, about 250,000 points were processed.

It is interesting to note that, using Gestalt data and the present program system, it is reasonable to derive stage-volume data at much closer stage intervals than can be used for contour plotting. The computation time is almost independent of the number of stages that is called up, and the precision of the Gestalt data would permit an interval of about 5 m, much closer than the contour interval that might be used in such mountainous terrain.

Thematic Mapping from DTM

The well-known advantages of using a grid base for the extraction of interactions among several layers of thematic data has led the authors to create fast programs for this purpose. The natural ease of data capture and storage in polygonal form, and the desirability of being able to map the outlines of derived features made it necessary to write programs for converting polygons to grids and vice versa.

The program adapting polygon data for use in grid-cell analysis is especially interesting. Any data source capable of generating closed strings of points in cartesian coordinates may be used. The program creates grid points from the strings, and identifies all interior grid points with the strings. The software carries out this identification without regard to the order in which the string points were digitized, and will handle highly convoluted and multiply-connected strings. This simplifies the process of digitizing because it is not necessary to supply an identifier for the interior of the string or for the direction of digitization.

First Version of THEMAPS

For areas of 'project' size, it is efficient to use the conversion program above to attach all thematic data to every point of a dense grid. Thus each point carries a stack of data cells which carry coded values of the input themes. The process of selection is then, in principal, similar to the common methods where attributes are manually coded to a coarse grid of terrain cells. The selection may be carried out either by logical algebra, which is very fast, or by arithmetic functions which are more flexible but which may take somewhat more computer time.

As an example of the speed of this first version for work on a project scale, five different photointerpreted overlays, some of them highly complex, were combined into a grid data base of 500,000 points. Using logical algebra, any combination of the properties from the overlays could be derived in less than 10 seconds of CPU time on an Amdahl V5 computer. (One combination, for example was: Slope from 15 to 20%, Soil type sand, Vegetation trees $>$ 5', Tree spacing 3', Moisture conditions wet). A shaded plot in black and white or in colour can be drawn of the selected areas. A fast program is also available for drawing outlines of the selected areas.

Second Version of THEMAPS

The second version is one that has important implications for the creation and use of large amounts of geographically-based information. It may be called a 'virtual-grid' method, and it combines the important qualities of the polygon and the grid into a unified system. The input data is stored in the original polygon form or in the form connected to the grid, and can quickly be converted from one to the other. The storage requirements may be one tenth or less than those for the complete grid data base.

The selection process, whether by logical or arithmetical algorithms, proceeds directly from the stored polygons, which are called up only as needed by the selection algorithm. The program will economically select combinations of features from up to 300 polygon files at a time, using less than 64K bytes of main memory. It is thus usable on any minicomputer. The value of this great competence for calling up and combining data will not be realized in most single projects, but will be fully appreciated when large data banks are to be used.

Nobody is going to want to derive thematic maps from 300 data sources for any one job, but the power of this program allows the simultaneous derivation of many thematic maps from such a large data base, at one pass through the computer.

As an example of the economy of the programs of Version 2, multiple derivations have been made in 10 to 20 seconds of CPU time on an Amdahl V5 computer, for the equivalent of an 800,000-point grid data structure.

Display Techniques

A tektronix 4027 colour terminal has been used to display some of the results obtained from the programs above. Individual themes derived from a common data base are displayed in different colours, and it is possible to use special colours where conflicting themes overlap. The instrument allows the operator to modify the colour selection after the display is complete, without replotting, in order to accent the most important features that are shown. The final results can be photographed, recorded on video-cassette, or plotted in continuous-tone or in outline mode.

Comments on Terrain Data Storage

In the light of these developments, it may be instructive to look again at the basic methods of data storage. In most grid cell techniques, the data are stored 'vertically' as a list of attributes attached to each cell. This method was and is used effectively in the first version of Themaps. The amount of data to be stored on every point is determined by the total number of classes of input data, and is thus highly redundant in two senses. Firstly, the terrain variability may be high over part of the area, and low over most of it. Secondly, many of the decision functions to be applied will require only a few classes of information from the data base. Both of these factors mean that most grid cells are loaded with far more data than are required for deriving any one combination.

Storage of features in polygonal form can be considered as 'horizontal' storage, in which each terrain classification can be called up independently. The second version of THEMAPS has this advantage, and only the classes of data or 'overlays' that are necessary for one computer run (which may involve many different derivations) will be addressed.

Summary

Program systems have been developed for producing thematic and engineering maps and data from the most useful data sources, polygons and grid structures. The programs combine the advantages of economical data storage with very high processing speeds, and permit the parallel derivation of several or many types of thematic maps from the same large polygonal data files.

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