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SOFTWARE PACKAGE FOR THE CONTOURING OF MASSIVE
DEM IN A MINI-COMPUTER ENVIRONMENT

ABSTRACT

The development of automated photogrammetric systems with capabilities for producing dense digital elevation models (DEM) has opened new vistas for the fast generation of hypsography overlays for topographic mapping. In 1976, in the Topographical Survey, Canada, a computer system was developed for the generation of contours from dense DEM's using a mini-computer in a time shared environment. A linear interpolation technique was adopted. The spacing between grid points is immaterial as far as it can be described mathematically. The basic scanning mechanism allows an optimal number of passes according to cartographic representation. The program uses two virtual arrays; one for the DEM (stored on disk), and the other as a bit matrix to keep track of the contouring to avoid unnecessary searches (core resident). The limitations imposed on the program are those of the disk storage and in some degree on the available core size. The total elapsed time required to generate a hypsography overlay from a DEM containing one million elevation points is one hour on a PDP 11/70 computer in a time shared environment.

INTRODUCTION

Digital Elevation Models (DEM's) may be defined as the digital representation of terrain relief. At present, several automated photogrammetric systems are capable of producing DEM's in the form of terrain elevation profiles or regular elevation grids covering the stereo-model. The Topographical Survey Division of the Surveys and Mapping Branch is currently engaged in a program for digital mapping using DEM's. For this reason a Gestalt Photomapper (GPM-2) system was acquired and is operational since early 1977 (Allam, 1978a).

For the processing of DEM's produced by the GPM-2 system, a software package was developed. The main components of this system were

described in earlier publications (Allam, 1978a). One of the sub-programs in this system was designed for the interpolation of hypsography overlays from a grid of elevations (Global Grid). In our system, the global grid is constructed by interpolating the DEM's produced by the GPM-2 system.

The problem of contouring from DEM's was addressed by the Topographical Survey Division in the early 1970's to find a solution for the metrication of the topographic maps with contours expressed in the English (feet) system. At that time, the contouring was done from elevation data in an irregular pattern. This pattern was obtained by digitizing the hypsography overlay (in the feet unit system) and a new overlay was produced by interpolating this irregular pattern.

Linear interpolation methods were used on the original data and it was soon found that the best approach was to interpolate the irregular pattern into a regular elevation grid and then proceed with the contouring operation.

The contouring program was originally developed on a large frame computer - CDC Cyber 74, and was tested for the interpolation of the global grid, even before acquiring the GPM-2 system.

To accommodate our digital mapping requirements and to minimize the cost incurred in using a large frame computer, a dedicated mini-computer system was acquired for the post-processing operation. A PDP-11/70 computer was selected to accommodate the DEM's post-processing software and the interactive digital map compilation and edit system to support the digital mapping activity (Allam, 1978b).

The implementation of the system on the PDP-11/70 computer, which operates in a time-sharing environment, required the restructuring of the program to accommodate the problems of mass data processing. For example, the standard Fortran I/O operations requiring large buffer space were not used, and we developed our own I/O routines, which uses a fixed number of working buffers and virtual paging techniques.

The contouring program developed in our organization is fully operational since early 1978 on the minicomputer. A description of the basic algorithms, program requirement, limitations, outputs, options and special machine dependency features are given.

BASIC CONCEPT

The contouring program performs two operations: the scanning of the grid and the calculation of the contour coordinates by linear interpolation.

Scanning of the DEM Grid

The DEM elevation grid is searched for contours by scanning, first around the edges as illustrated in Figure 1, and second along the interior of the grid as illustrated in Figure 2.

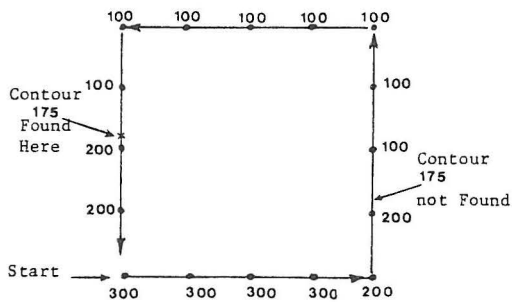


Figure 1. Edge Scanning of DEM Grid.

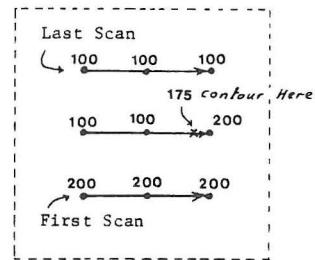


Figure 2. Scanning of DEM Grid Interior.

Any contour starting on an edge terminates on an edge, while a contour starting in the interior of the grid is a closed contour, and the entire contour is traced in one pass.

Edge scanning is conducted in a counter-clockwise direction around the grid. If a contour point passes between two grid points starting from the south-west corner, one of the grid elevations must have a value greater than the contour (reference point) and the other must have a value less than the contour (sub-point). A contour point starting on the edge will be found, only if the sub-point is in the opposite direction from the reference point with reference to the original scan direction. As shown in Figure 1, contour 175 was found on the left edge only. Using this method the bit matrix array need not to be checked during the search, as each edge contour is defined only once. Upon completion of edge scanning the program interpolates for edge contours.

Scanning in the interior of the grid is done from left to right, starting from the bottom and progressing to the top. During scanning, a contour point is found if the sub-point is located to the left of the reference point. As with edge scanning the reference point must have a value greater than the contour and the sub-point a value less than the contour point. If a contour point exists, the bit matrix array will be checked to see if it has already been contoured.

Linear Interpolation for Contours

Using the reference point as centre, the points on a contour are found at successive angles of 45° along the lines extending to the eight points immediately adjacent. For the points on the diagonals, the elevation at the centre point of each grid square is calculated as the average of the values at the corners. With the introduction of the centre point, the grid square may be broken up into four triangles and a contour can pass through each triangle in a unique way. When the contour line does not pass between the points, the reference point is transferred to the second point around which contour points at 45° angles continue to be found. A simple illustrative matrix with one contour line at elevation 175 is shown in Figure 3. Once a reference point has been used for any specific contour, it is flagged to ensure that contours are traced only once.

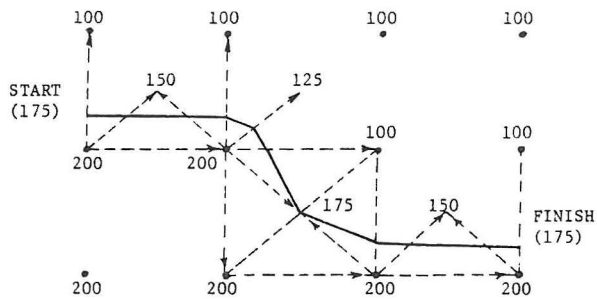


Figure 3. Example of Tracing Contour 175 on a DEM Grid.

SPECIAL MACHINE DEPENDENCY FEATURES

The interpolation of contours from dense DEM's should be addressed in the context of mass data processing. The entire surface of the map must be viewed as a virtual array.

Virtual Memory

Since the program was developed for a mini-computer environment (Digital Equipment PDP-11/70), consideration was given to all the special features of the computer. Program Logical Address Space (PLAS) was used to expand beyond the memory addressable limitation of 32 K Word, as dictated by the 16-bits word machine. This was critical because the program acquires memory dynamically whenever needed.

I/O Operation

Since the I/O operations in any virtual system are numerous, the storage and partitioning of the DEM data contribute much to the efficiency of the program execution. The virtual DEM for the entire map is partitioned into global grid cells. The size of the cell is selected by the user. The cellular partitioning was taken over the profile method for obvious reasons. To contour a surface area, the plotter will travel in the X and Y directions with equal probability. The storage structure of the global grid cells are a fixed size block with no-overlapping of elevations, and whenever possible, although not necessary, the file should be a contiguous file for the minimization of disk head movement.

Since the standard Fortran I/O operation requires large buffer space, we developed our I/O routines, which uses a fixed number of working buffers and virtual paging technique. A paging system using the Least Recent Used (LRU) page swapping algorithm was implemented. By developing our own virtual operating system, we saved buffer spaces and made better utilization of system resources.

Two virtual arrays are utilized by the program. One virtual array is used for the DEM (disk resident) and the other is a bit matrix to keep track of the contouring to avoid unnecessary searches (core resident). Since the virtual array matrix is utilized to tag the direction of the contour from a given reference point, it is imperative that it remains in core due to the high access rate on that portion of the data.

LIMITATIONS

The limitations imposed on the program are those of the disk storage and CPU Core available. The current production program is resident on a PDP-11-70 with 256K-16 bits word CPU and 300 Mega Byte disk. The system operates under the RSX-11M operating system. With the system, it is possible to process a DEM grid consisting of over 3,000,000 elevation points. While large volume of data is acceptable by the program, it may be more economical to utilize a computer of greater capability.

The resource consumption of the system is linear in respect to the number of digital elevation data and the number of contours produced (i.e. the contour interval). The core requirement for the PDP-11/70 under the RSX-11M are 16 K Word, plus 4 K word for each additional 64 K of digital elevation data.

The disk requirements are one additional disk block for every 100 digital elevation data. The elapsed run time is approximately one minute for every 4,000 digital elevation data. This run time was computed based on the operation of the system in a time-shared environment for data acquisition, processing, program development, etc. This time was computed by contouring a very dense DEM, as illustrated in Figure 4. The run time is dependent on the number of contours generated, and may be several times less in the case of moderate topography.

OPTIONS

Several basic options are available. These include, size of global grid cell, contour interval required, coordinate system, scaling, co-ordinate transformation and the generation of the index contour in a format different from that of other contour lines.

Since the system was developed for contouring of hypsography overlays for topographic maps, the program has an option for the trimming of contours outside the map sheet borders. This is necessary because contouring is normally done in DEM's of areas covering more than the area of the map sheet overlay. Another option which may be necessary is the blanking of areas where contouring is not desired.

OUTPUT

The system provides output in several forms as follows:

- a) Display on a CRT graphic display terminal (Tektronix 4014), where a hard copy may be also obtained.
- b) CalComp compatible file for the generation of proof plots.
- c) A data base file in the format of our interactive graphic design system (IGDS). Interactive on-line editing may be performed on this file.

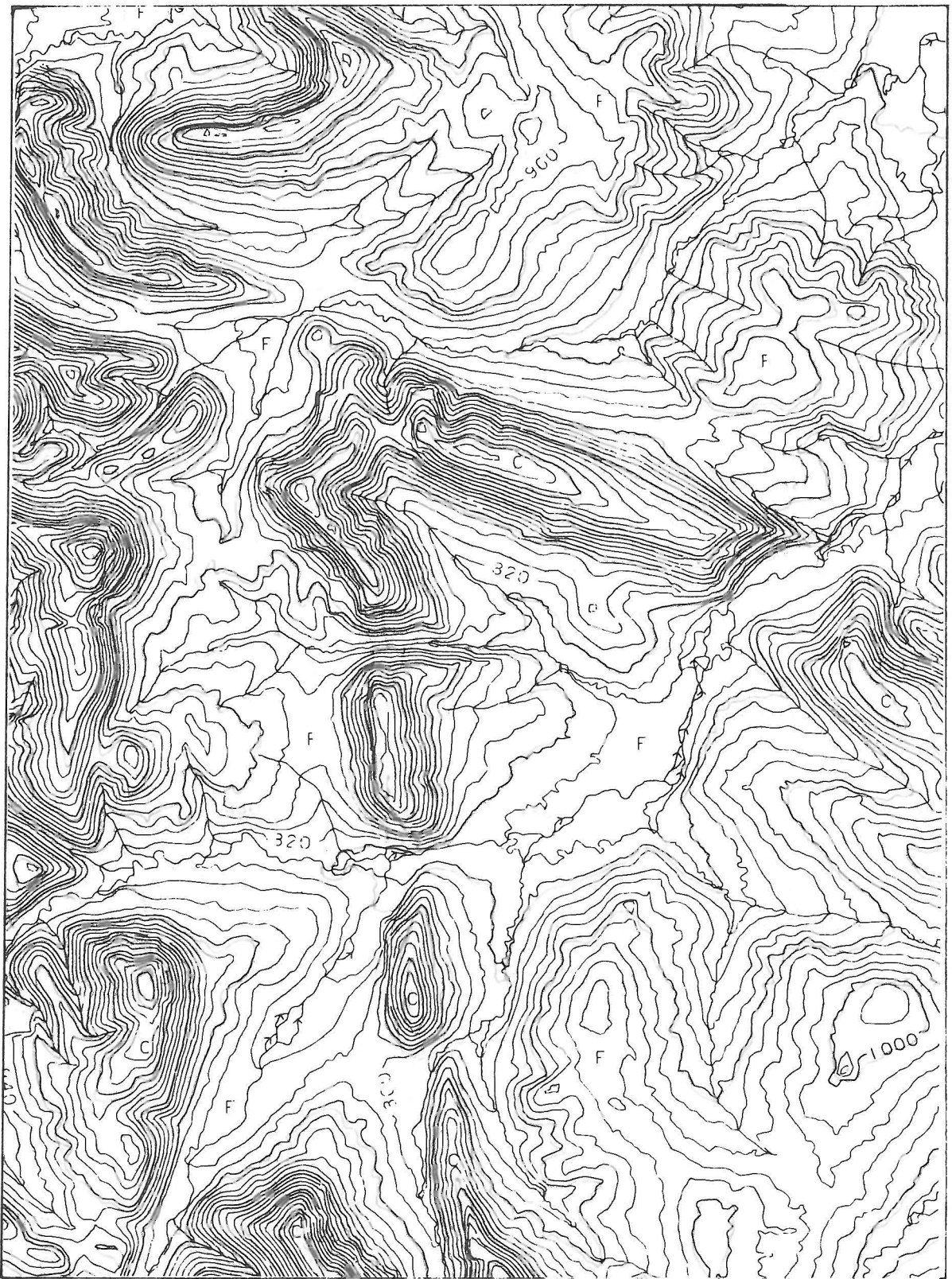


Figure 3. Section of a Hypsography Overlay.
Dark Lines- Contours Interpolated from DEM
and Light Lines- Contours Compiled on a
Photogrammetric Plotter.

Figure 4 illustrates the output of the contouring program (a section of a contour overlay). For comparative purposes, the output from conventional plotting on a photogrammetric instrument, was overlaid on the plot to show the difference between the interpolated and photogrammetrically compiled contours. The dark-lines are the digital interpolated contours and the screened (light) lines are those compiled on the photogrammetric instrument.

CONCLUSIONS

The increased demand for map data in digital form and the development of automated and analytical photogrammetric instruments capable of producing DEM's in an automatic or semi-automatic mode are adding new dimensions to the task of interpolating hypsography overlays. The recent advances in interactive display and editing are contributing to success of the overall integration of DEM data processing in the production environment by ensuring that the generated files are error-free digital data files.

A system for the contouring of DEM's may be integrated, as an entity or subsystem, in an overall digital mapping system consisting of other digital data acquisition and output subsystems (Allam, 1980). The recent trend in digital mapping systems is based on the integration of subsystems in a distributive network. These systems are normally characterized by the use of mini-computers, which may be used as data processors and controllers for other peripherals, such as graphic display CRT's, on-line plotting machines, photogrammetric and manual interactive data acquisition and editing station.

The development of programs operating in a mini-computer environment makes the process of system integration easier, in addition to the savings in operational and processing costs.

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