Digital Elevation Models – Specific Theory

introduction

The earths surface is a continuous phenomena. There are various ways of representing such surfaces in digital form using a finite amount of storage.

Digital elevation models are used as a way of representing surfaces. A DEM is a quantitative model of a topographic surface in digital form.

The term digital elevation model or DEM is frequently used to refer to any digital representation of a topographic surface, however, most often it is used to refer specifically to a raster or regular grid of spot heights.

Digital terrain model (DTM) is also used to refer to any digital representation of a topographic surface.

The DEM is the simplest form of digital representation of topography and the most common.

The resolution, or the distance between adjacent grid points, is a critical parameter of any DEM. The best resolution commonly available is 30 m.

The data sets should be visualized as continuous surfaces. The operators we will discuss here are designed to work on any continuous surface e.g. map elevations, temperature gradients, or cost surfaces.

Elevation Data

Elevation data is used to create DEMs. A figure showing contour data is shown below. The first shows contour data as a set of lines which connect places of equal height.

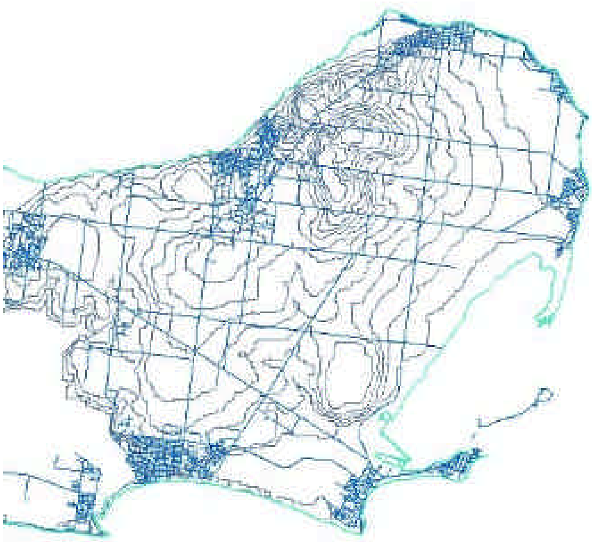


Figure 1. Contour data

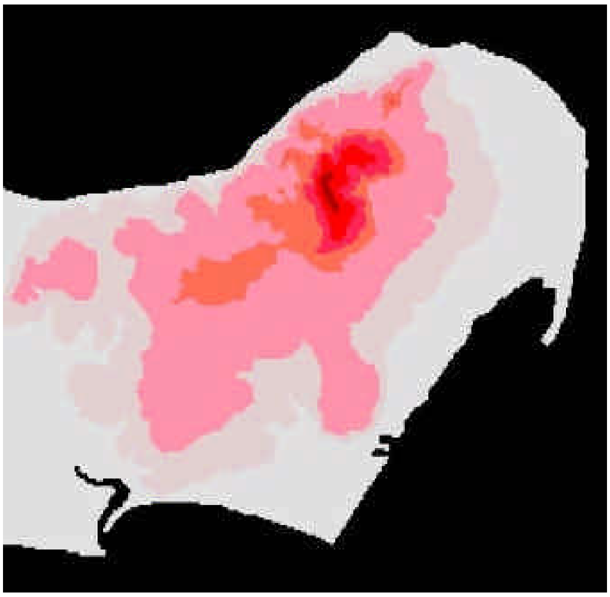


Figure 2 A DEM derived from the contours shown in Figure 1

Surface models are normally stored in either TIN or lattice Format

A TIN (Triangular Irregular Network) model is a continuous mesh of triangles. These vary in size according to need based on the roughness of the terrain. Large triangles are sufficient for flat or smoothly sloping country. Small triangles can model highly variable terrain. This makes TIN modelling accurate and efficient. Slopes, aspects and run-off can be computed directly from TIN models

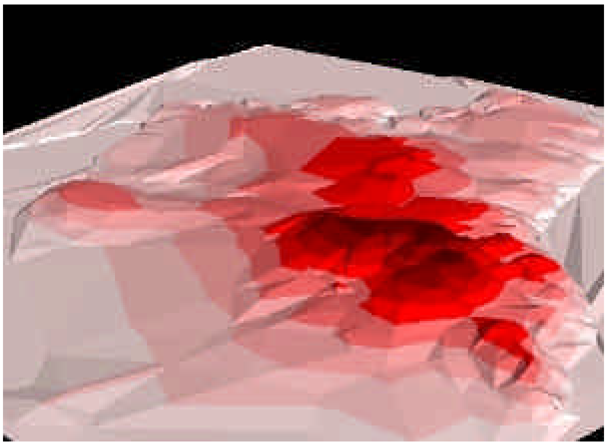


Figure 3 A TIN model derived from the contours shown in Figure 1.

Lattice models of terrain are like other raster data models. Height values are kept in a regular grid. This structure makes algorithms for modelling slope, aspect, run-off, visibility etc very simple.

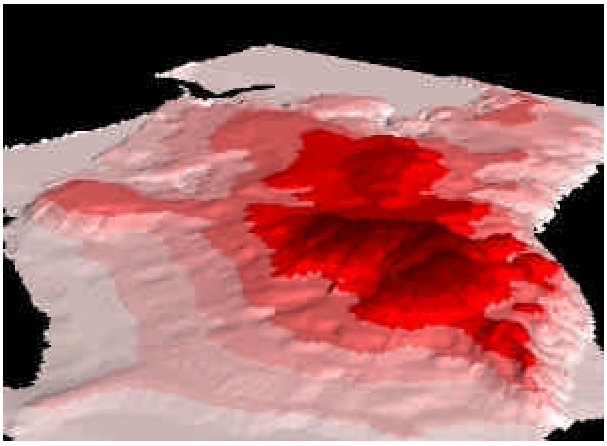


Figure 4 A DEM derived from the contours shown in Figure 1, shown with perspective

Uses of DEMs

DEMs can be used for:

?? determining attributes of terrain, such as elevation at any point, slope and aspect

?? finding features on the terrain, such as drainage basins and watersheds, drainage networks and channels, peaks and pits and other landforms

?? modelling of hydrologic functions, energy flux and forest fires

Slope

The concept of measuring slope from a topographic map is a familiar one for most professionals in the landscape planning/surveying professions. Slope is a measurement of how steep the ground surface is. The steeper the surface the greater the slope. Slope is measured by calculating the tangent of the surface. The tangent is calculated by dividing the vertical change in elevation by the horizontal distance. If we view the surface in cross section we can visualize a right angle triangle:

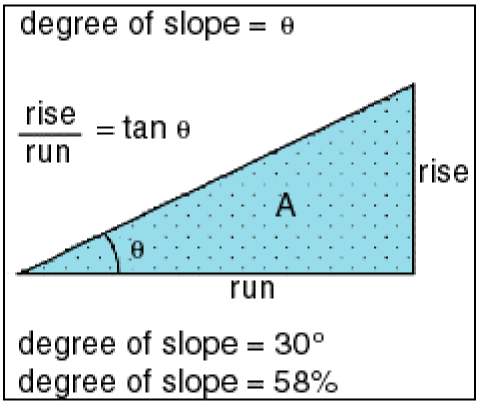


Fig. 1 slope

Slope is normally expressed in planning as a percent slope which is the tangent (slope) multiplied by 100.

Percent Slope = Height / Base * 100

This form of expressing slope is common, though can be confusing since as 100% slope is actually a 45 degree angle due to the fact that the height and base of a 45 degree angle are equal and when divided always equals 1 and when multiplied by 100 equals 100%. In fact slope percent can reach infinity as the slope approaches a vertical surface (the base distance approaches 0). In practice this is impossible in a gridded database since the base is never less that the width of a cell.

Another form of expressing slope is in degrees. To calculate degrees one takes the Arc Tangent of the slope.

Degrees Slope = ArcTangent (Height / Base)

NB. ArcView calculates Slope as degrees

What is important to understand is that we can measure the slope of any surface, defined by measures of topography, temperature, cost or other variables. We can take the slope of the surface defined by air pressure measurements on a weather map to find where the pressure is changing rapidly—this tells us the location of weather fronts. If we take the slope of a slope map it tells us how fast slope is changing. This is equivalent to taking the second derivative of a surface. On a topographic map this is a measure of surface roughness which can be an important factor in estimating the cooling effects of breezes on micro-climates. (Rough surfaces create turbulence and mixing of air masses of different temperatures. This creates better cooling effects at the surface of the ground.) Using these examples it is useful consider slope as a measure of change in a surface.

When measuring slope in a GIS the input map must be an interval map which represents a surface as a set of continuous (floating point) values. The output is interval.

height	base	tangent (height/base)	percent slope	degrees slope
1	100	0.01	1	0.57
5	100	0.05	5	2.86
10	100	0.1	10	5.71
25	100	0.25	25	14.03
50	100	0.5	50	26.56
100	100	1	100	45
150	100	1.5	150	56.30
200	100	2	200	63.43

Methods for calculating slope, aspect and hill shading in a raster GIS

Slope gradient

The gradient of slopes is calculated from a 3 x 3 cell window as shown below. The window below represents the eight neighbouring elevations (Z) surrounding the cell at column i row j. Figure 2 shows the window (kernel) used for computing derivatives of elevation matrices. This 3x3 window is successively moved over the map to give the derivatives slope and aspect.

Zi-1, j+1	**Zi, j+1**	**Zi+1, j+1**
Zi-1, j	**Zi, j**	**Zi+1, j**
Zi-1, j-1	**Zi, j-1**	**Zi+1, j-1**

Fig. 2 the window used for computing derivatives of elevation matrices

If average slope is requested, east west gradients are calculated as follows

?**EW= [(Zi+1,j+1 + 2Zi+1,j + Zi+1,j-1) - (Zi-1,j+1 + 2Zi-1,j + Zi-1,j-1)]/8**?**X**

The north-south gradient is calculated by

?**NS = [(Zi+1,j+1 + 2Zi,j+1 + Zi-1,j+1) - (Zi+1,j-1 + 2Zi,j-1 + Zi-1,j-1)]/8**?**y**

Where

?**x** = the east-west distance across the cell (cell width)

?**y** = the north-south distance across the cell (cell height)

Percent slope is calculated by:

Slope% = 100 * [(?EW)^2*(?NS)^2]^1/2

Degrees slope is calculated by

SlopeDegrees = ArcTangent[(?EW)^2 +(?NS)^2]^1/2

<u>Normal GIS Options</u>

Maximum slope is calculated from the maximum gradient of 8 neighbours.

NB. ArcView calculates Slope this way with the result in degrees

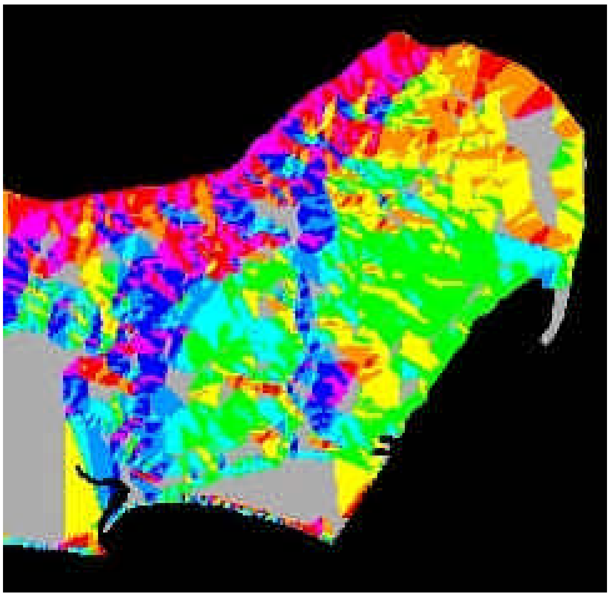
Maximum downhill slope is calculated from the maximum gradient of the cell or cells that are less than or equal in elevation to the central cell. If there is no downhill neighbour the cell is assigned a value of -1.

Aspect

Aspect is calculated using the north-south and east-west gradients as expressed in the above equations using the following equation:

Aspect = ArcTangent (?EW/?NS)

The above equation is adjusted to reflect aspect in degrees in a range from 0 to 360. Where 0 represents a cell with no slope (skyward aspect) and the values from 1 to 360 represent azimuths in clockwise degrees from north. North is 1, East is 90 degrees, South is 180 degrees etc. Optionally, the result is then divided by 22.5 and converted to an integer to derive a set of generalized solar azimuths range from 0 to 8.



0 - represents non-sloping areas;
1 - represents slopes facing the top edge of a map
2 - represents slopes facing the upper right corner of a map
3 - represents slopes facing the right edge of the map
4 - represents slopes facing the lower right corner of the map
5 - represents slopes facing the bottom edge of a map
6 - represents slopes facing the left corner of a map
7 - represents slopes facing the left edge of a map;
8 - represents slopes facing the upper left corner of a map

Hill Shading

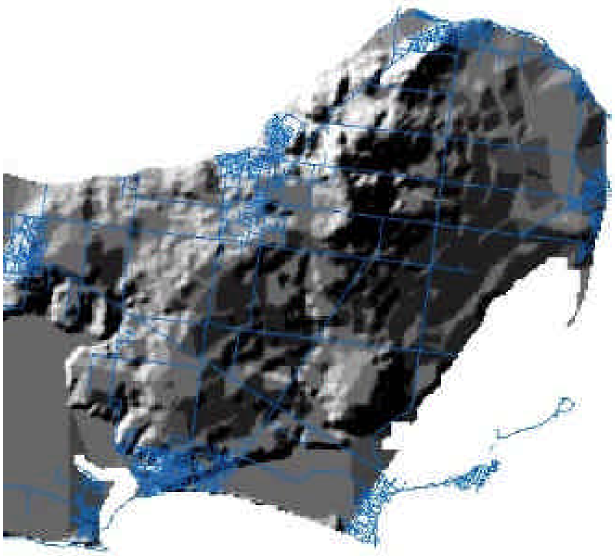
Analytical hillshading is a technique for producing shaded relief maps automatically. Relief shading is used to visually enhance the terrain features by simulating the appearance of the effects of sunlight falling across the surface of the land. Hill Shading estimates surface reflectance from the sun at any altitude and any azimuth. The reflectance is calculated in a range from 0 to 100. The equation for the sun in the northwest sky with a 45 degree altitude is as follows

Reflectance = 1/2 + (p'/2) / SQR(po2 + p'2) * 100

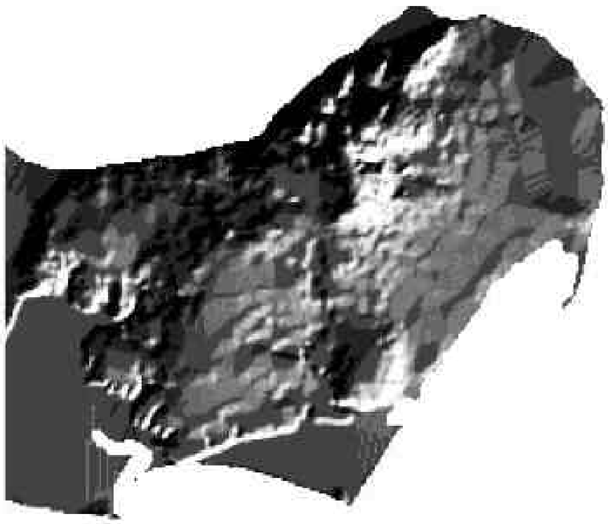
where: **p' = (po * ?EW + qo * d NS) / SQR(po2 + qo2)**

po = 1 / SQR(2)

qo = -po



If you create a hill shade map with the light coming from the 'south' or bottom of the screen the result is not so easily interpreted. It seems that even for people living in the northern hemisphere their 'natural' interpretation of terrain is with the light from 'north'



Viewshed analysis

Viewshed analysis is the study of visibility between points on a terrain surface.

Viewshed analysis is used in visual impact assessment.

In viewshed analysis, the visibility of every cell from the observer cell (or numerous observer cells) is computed.

Visibility is calculated by measuring the tangent from the observer's eye to each cell starting from cells closest to the observer. As long as the tangent increases in the line of site from the observer, the cell is visible. If the tangent decreases, the cell is not visible.

References

Burrough, P.A. (1986) *Principles of Geographic Information Systems for Land Resource Assessment*. Monographs on Soil and Resources Survey No. 12, Oxford Science Publications, New York.

Environmental Systems Research Institute (ESRI) (1996) *Working with the ArcView Spatial Analyst*.

Fisher, P.F. (1996) Extending the applicability of viewsheds in landscape planning. *Photogrammetric Engineering and Remote Sensing*, 62: 297-302.

Hadrian, D.R., Bishop, I.D. and Mitcheltree, R. (1988) Automated mapping of visual impacts in utility corridors. *Landscape and Urban Planning*, 16: 261-282.

Itami, R.M. and Rawlings, R.J. (1993) *SAGE Introductory Guidebook*. Digital Land Systems Research.

Klinkenberg, B. (1990) *Digital Elevation Models*. National Centre for Geographic Information Analysis Unit 38. URL: http://www.geog.ubc.ca/courses/klink/gis.notes/ncgia/u38.html#UNIT38