Geography 4203 / 5203

GIS Modeling

Class 6: Terrain Analysis

Last Lecture(s)

- So we had a very broad overview of **Map Algebra**
- You know now the **basic principles**, **perators** and **functions** of Map Algebra
- You have seen that they create the basis for all **raster analysis** and thus **grid-based modeling** tasks
- You are familiar with important **terms** such as local/focal/zonal/block/global functions and you know what **Kernels** are…

Today‘s Outline

- We are starting with **terrain analysis** and will have a first look into the **terrain variables** available to us
- Surprisingly, you will see how complex the derivation of variables such as slope or aspect can become since we are working on **(2D) surfaces with elevation information**
- So we will look at some **mathematical approaches** to calculate them

Learning Objectives

- You will understand the **concepts** behind the computation of terrain variables and you will see some **computation examples**
- You will understand the term **SLOPE** from different perspectives and how it can be understood in **mathematical** terms
- You will see different **approaches** for **slope computation** and for **aspect** derivation as well as hear something about the **other terrain variables**

Why Terrain Matters…

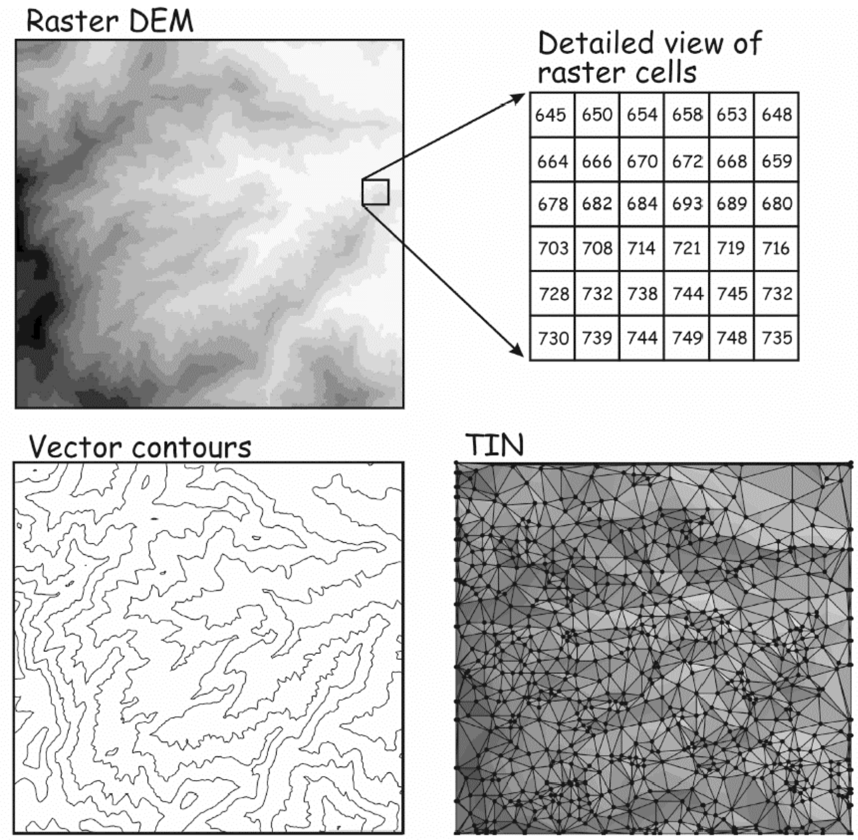
- Terrain variables influence our everyday life
- **Resource** availability, radiation, vegetation growth
- **Natural hazards** (flooding, avalanches,…)
- **Transportation** and **Hydrological** conditions

Representing Terrain

- What is the “conceptual model” you are thinking of when representing terrain?
- Any ideas of appropriate data models?

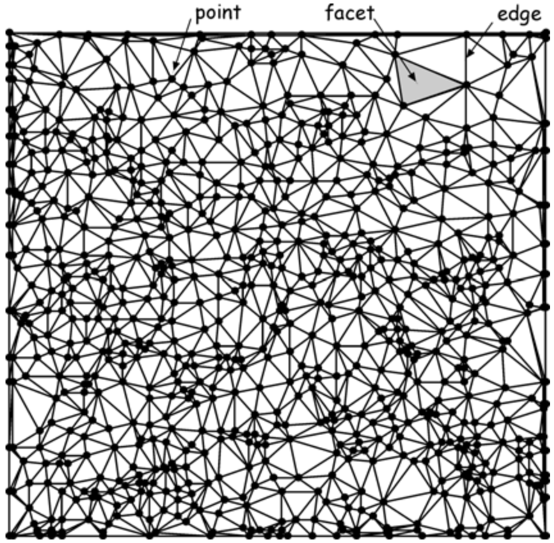
Terrain and Raster Datasets

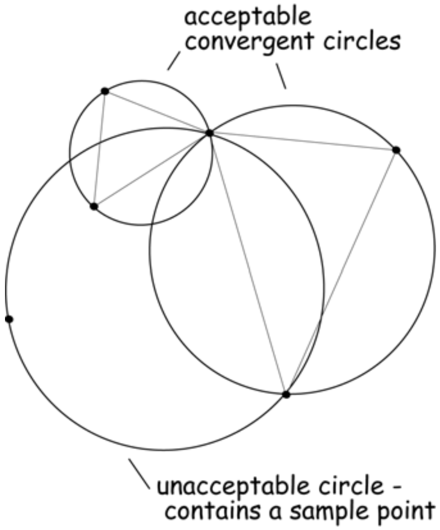
- The simple structure of raster data supports their use for terrain analysis
- Other data models such as TIN useful for specific purposes…



Just aside: Understanding TIN

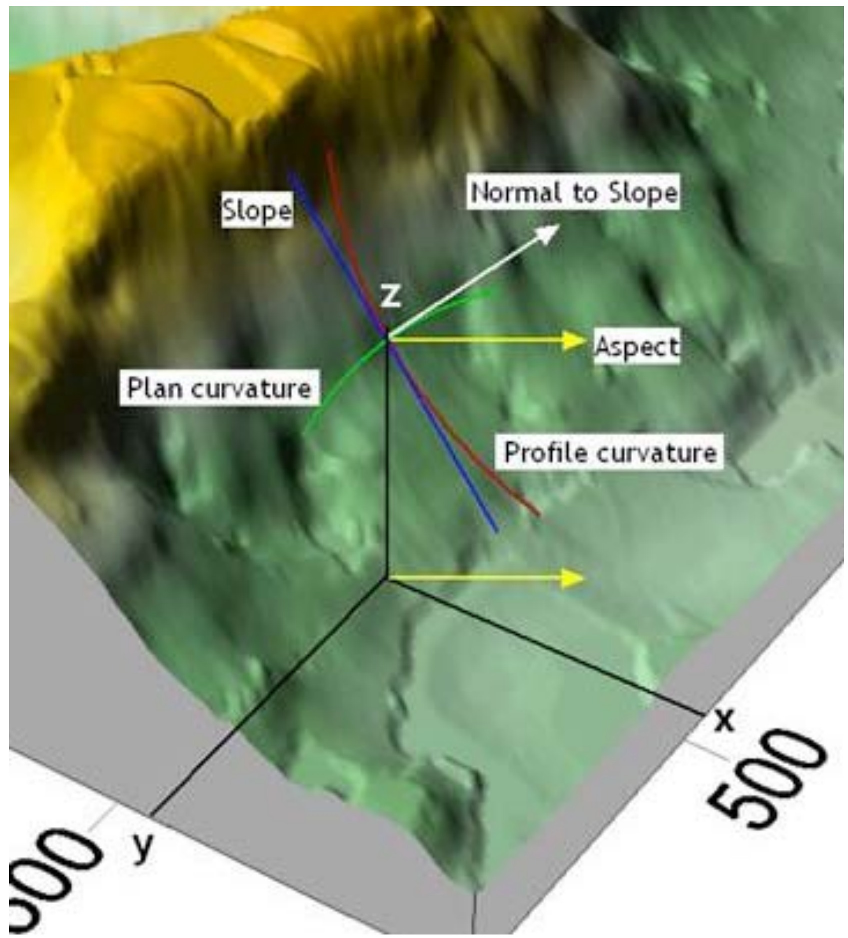
- Measure points connected such that the **smallest triangle** can be constructed from any three points
- Connected **network of triangles** (**facets** that are assumed to be uniform in slope and aspect)
- Lines do **not cross**: **Convergent circles** passing through all three points; triangle drawn if no other point is inside the circle





What are Terrain Variables

- Elevation
- Slope
- Aspect
- Profile curvature
- Plan curvature
- Upslope area
- Flow length
- Upslope length
- Viewsheds/visibility

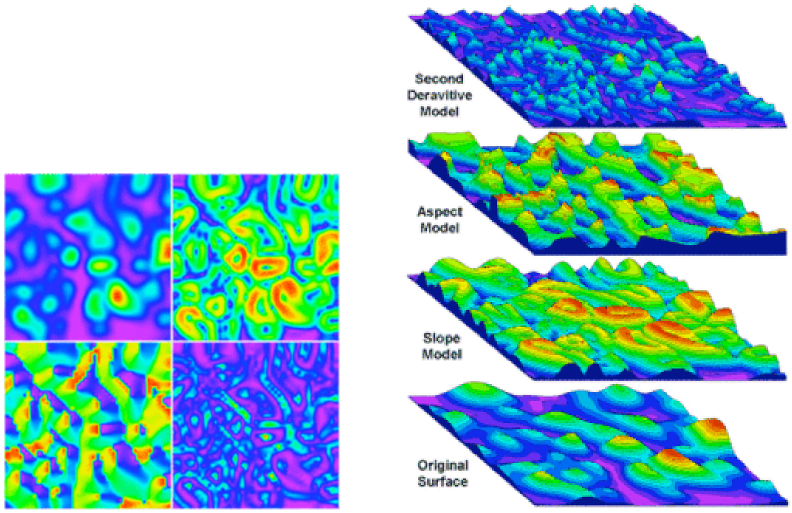


Modeling Surfaces

- Levels (or degrees) of **Continuity** (to have a value at every point)
- **Step-wise continuous**, cont. with **abrupt changes** in slope, cont. with **cont. rate of change** in slope
- Important to understand when creating derivatives
- GIS surfaces have **implicit** continuity - what do I mean with that?? Depending on Interpolator

Slope and Aspect

- Have their importance in hydrology, conservation, site planning or infrastructure development. Why?



Slope Basics

- Change in elevation (a **rise** - A) with a change in horizontal position (a **run** - B)
- In **degrees** [0,90] or in **percent** (45° = 100%)
- …the **tangent of the slope angle** is the ratio of the rise over the run
- `S(%) = (rise/run) * 100`
- $S(^\circ) = \tan^{-1}(rise/run)$
- **Conversion**:

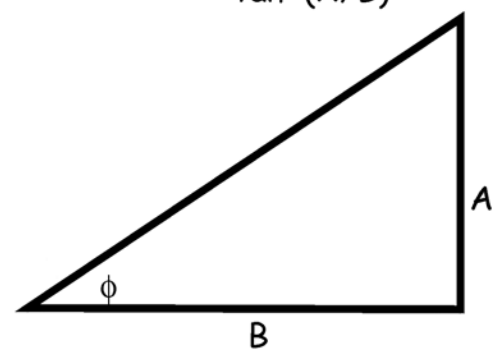
  $S(^\circ) = \tan^{-1}(S(\%) / 100)$

Slope as percent = $\frac{rise}{run}$ *100

= A/B * 100

Slope as degrees = ϕ

= $\tan^{-1}(A/B)$



To convert from percent slope to degrees, apply formula,
e.g. 3% = how many degrees?

A/B * 100 = 3, then A/B = 3/100 = 0.03

= $\tan^{-1}$ (0.03) = 1.72 degrees

Slope Basics Once More

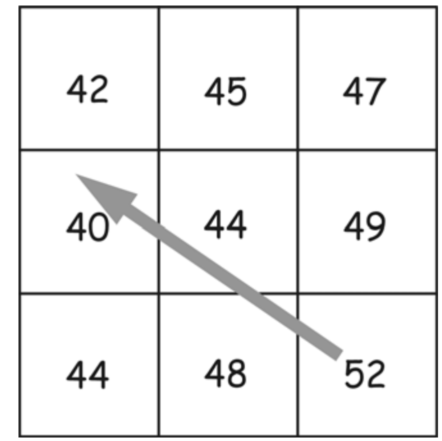
- Slope can be described by a **plane** at a **tangent** to a point on the surface
- Two components of slope:

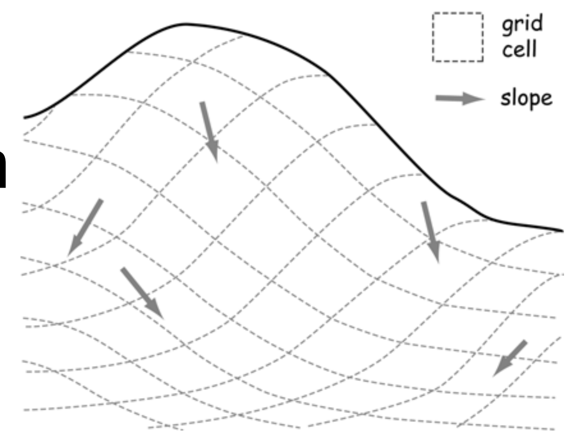
  Gradient: maximum rate of change of the elevation of the plane (the angle that the plane makes with a horizontal surface)

  Aspect: the direction of the plane with respect to some arbitrary zero (north)

Slope Computation is Complex…

- **Slope direction** is calculated in the steepest direction of elevation change - BUT direction often **not parallel** to x,y & not through the **cell center**
- **Relative elevation changes** in neighboring cells are important
- Thus we need some **combined change** in elevation measure within the **vicinity** of the cell





How to Compute Slope?

- "**Combined**" change in elevation in x and y direction
- Much research has been done on this (see Dunn et al., 1998 or Skidmore 1989)

$$S(^\circ) = \operatorname{atan}\sqrt{\left(\Delta Z_x / \Delta d_x\right)^2 + \left(\Delta Z_y / \Delta d_y\right)^2}$$

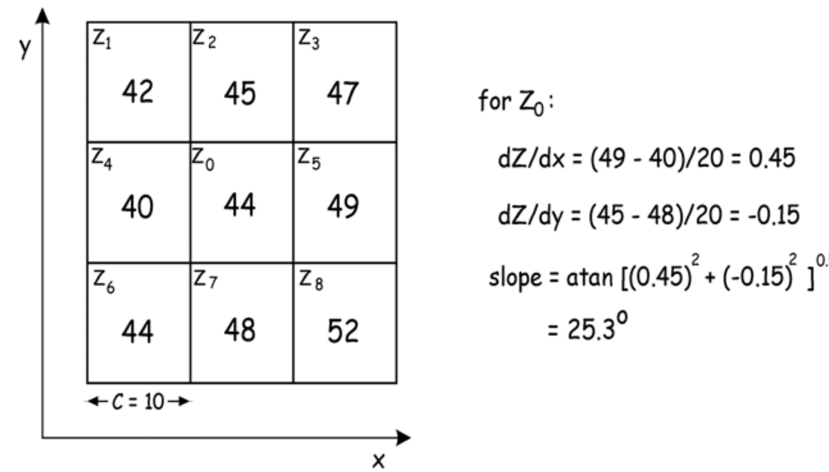
- **dZ/dx**: rise over the run in x direction
- **dZ/dy**: rise over the run in y direction
- Guess! What **kind of MA function** are we using?

How to Compute Slope? - Smooth Terrain

- Guess! What **kind of MA function** are we using?
- …how to compute **dZ/dx and dZ/dy**? Is there THE METHOD?
- "**Four nearest**" method (largest common border with the center) for **smooth** terrain:

  dZ / dx = (z5 - z4) / 2C

  dZ / dy = (z2 - z7) / 2C



$$S(^{\circ}) = \mathrm{atan}\sqrt{\left(\Delta Z_x / \Delta d_x\right)^2 + \left(\Delta Z_y / \Delta d_y\right)^2}$$

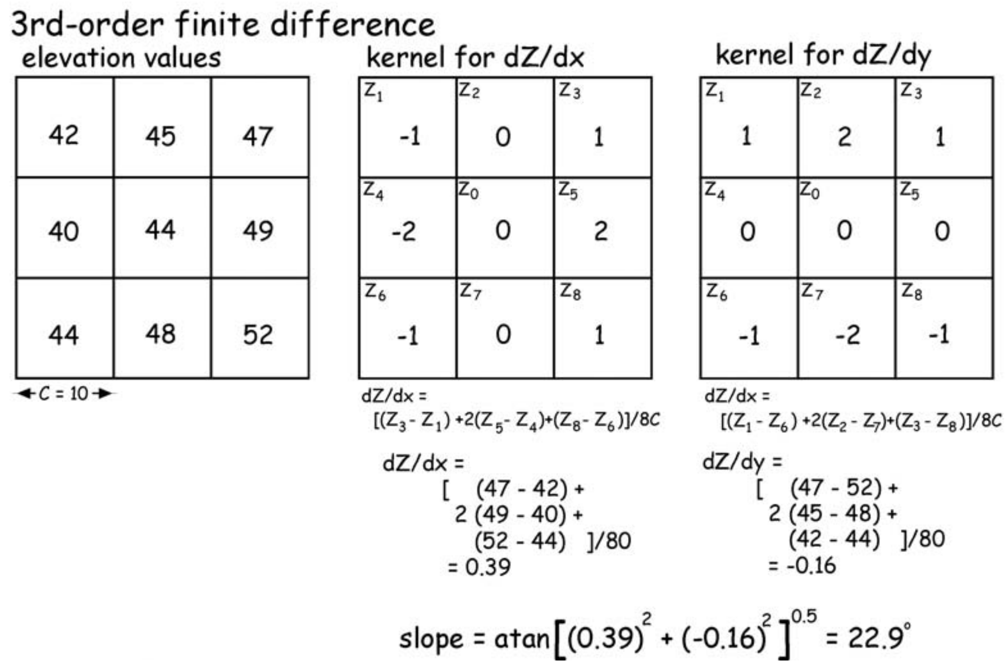
Remember what a **Kernel** is?

How to Compute Slope? - Rough Terrain

- **3rd-order finite difference** approach (all neighbors included but weighted differently)
- **Appropriate** for **rough** terrain (variation is included)
- **Local errors** and their consequences…
- Kernel for the former method?

$$dZ / dx = [(z3 - z1) + 2(z5 - z4) + (z8 - z6)]/ 8C$$

$$dZ / dy = [(z1 - z6) + 2(z2 - z7) + (z3 - z8)]/ 8C$$



Yepp!!

Four nearest cells

elevation values

42	45	47
40	44	49
44	48	52

← $C = 10$ →

kernel for dZ/dx

Z_1 0	Z_2 0	Z_3 0
Z_4 -1	Z_0 0	Z_5 1
Z_6 0	Z_7 0	Z_8 0

$dZ/dx = (Z_5 - Z_4)/2C$

$dZ/dx = (49 - 40)/20 = 0.45$

kernel for dZ/dy

Z_1 0	Z_2 1	Z_3 0
Z_4 0	Z_0 0	Z_5 0
Z_6 0	Z_7 -1	Z_8 0

$dZ/dy = (Z_2 - Z_1)/2C$

$dZ/dy = (45 - 48)/20 = -0.15$

$$\text{slope} = \operatorname{atan}\left[(0.45)^2 + (-0.15)^2\right]^{0.5} = 25.3^\circ$$

3rd-order finite difference

elevation values

42	45	47
40	44	49
44	48	52

← $C = 10$ →

kernel for dZ/dx

Z_1 -1	Z_2 0	Z_3 1
Z_4 -2	Z_0 0	Z_5 2
Z_6 -1	Z_7 0	Z_8 1

$dZ/dx = [(Z_3 - Z_1) + 2(Z_5 - Z_4) + (Z_8 - Z_6)]/8C$

$$dZ/dx = [\ (47 - 42) + 2\,(49 - 40) + (52 - 44)\ ]/80 = 0.39$$

kernel for dZ/dy

Z_1 1	Z_2 2	Z_3 1
Z_4 0	Z_0 0	Z_5 0
Z_6 -1	Z_7 -2	Z_8 -1

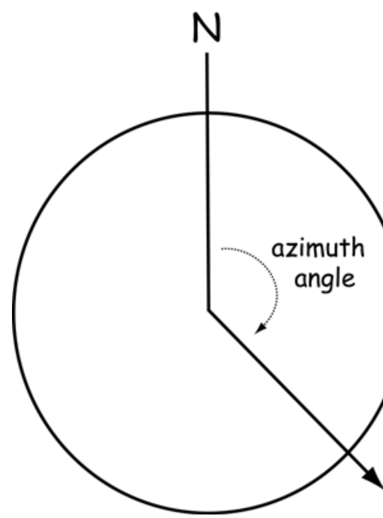
$dZ/dx = [(Z_1 - Z_6) + 2(Z_2 - Z_7) + (Z_3 - Z_8)]/8C$

$$dZ/dy = [\ (47 - 52) + 2\,(45 - 48) + (42 - 44)\ ]/80 = -0.16$$

$$\text{slope} = \operatorname{atan}\left[(0.39)^2 + (-0.16)^2\right]^{0.5} = 22.9^\circ$$

Aspect

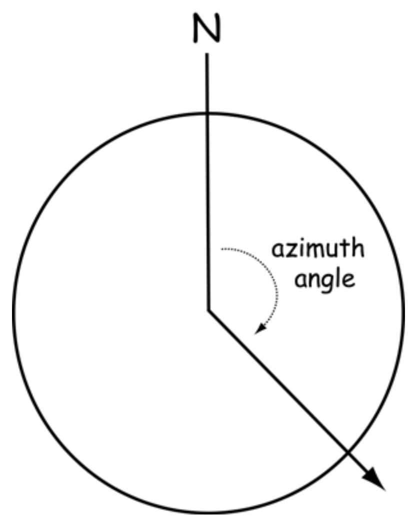
- Aspect at a point is the **steepest downhill direction** given as an azimuth angle (N = 0˚) or called “**orientation**”
- Direction in which **water** will **flow**
- Amount of **sunlight** a site may receive
- What is **visible** from a certain point?
- **Flat areas** have no aspect, obviously…



Aspect Computation

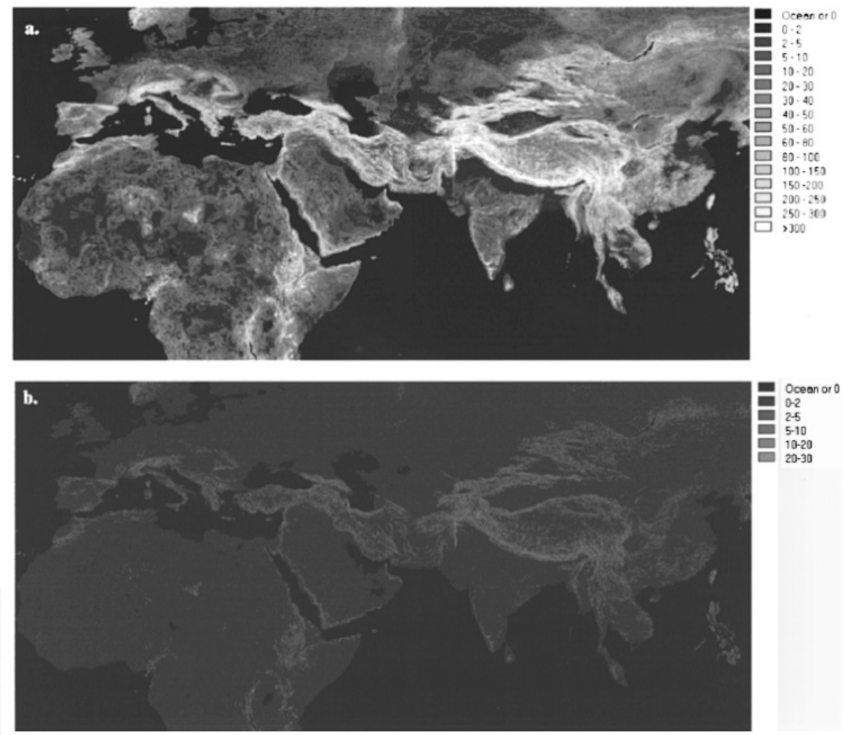
$$A = a\tan\left[\frac{\Delta z_y / \Delta d_y}{\Delta z_x / \Delta d_x}\right]$$

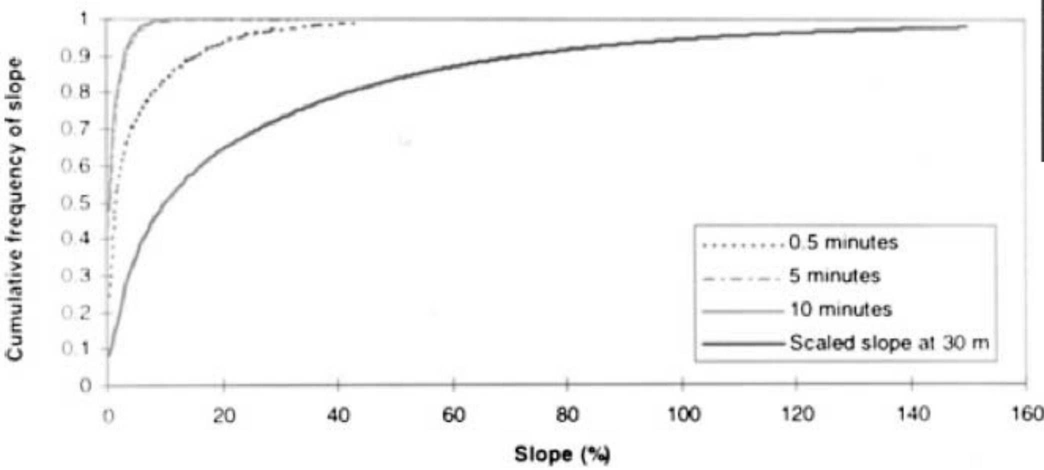
- "**Four nearest**" method and **3rd-order finite difference** methods the most common, similarly as for slope computations



Scale and Resolution

- Think about how slope and aspect computations might be influenced bei varying resolution and / or scale





Cumulative frequency distribution of estimated slope at different scales for the Eurasia and northern Africa DEM

Zhang et al., 1999

Scale and Resolution

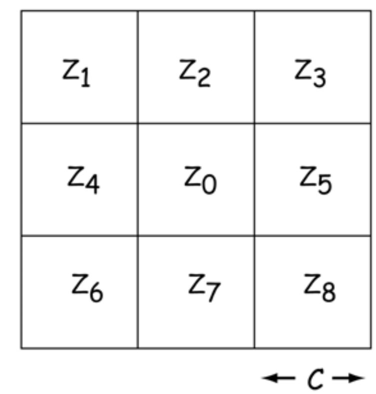
- Reducing the resolution will:
- … the **maximum value** of gradients!
- … the **smoothness** of the data (of neighboring classes) esp. in aspect
- Result in a … of **detail**
- … the **distribution** of the values in a histogram
- So for this reason **resolution** is critical for Slope computation regarding the purpose!

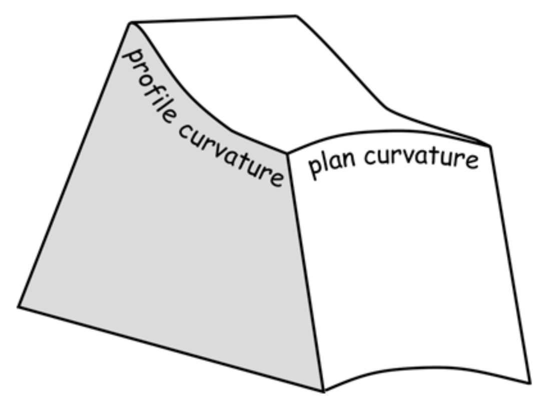
Profile and Plan Curvature

- Estimating the **local terrain shape**
- Deriving information about **soil water content**, **overland flow**, **rainfall-runoff** response, **vegetation distributions** etc.
- Derived from **gridded elevation data**
- Depending on the **method**, **cell dimension** and number of **neighbor** cells involved
- What kind of MA function do you expect?

Profile Curvature

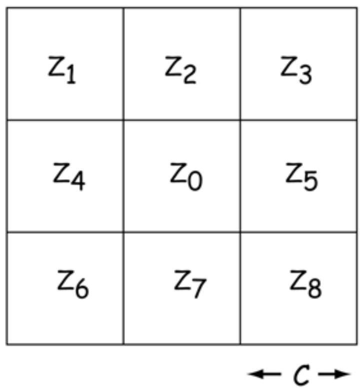
- Index of the **surface shape in the steepest downhill direction**
- Small values = **concave** surface (bowled)
- Large values = **convex** surface (peaked)

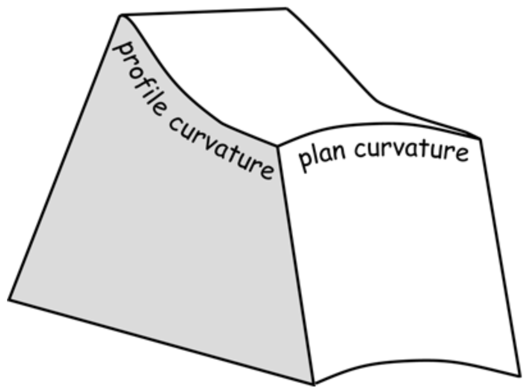




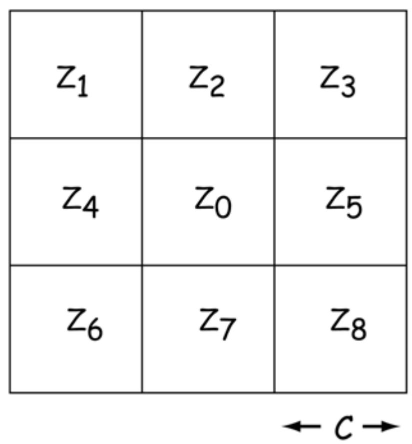
Plan Curvature

- Profile shape in the **direction of the contour**, at right angle to the steepest downhill direction (profile curvature)
- Small values = **concave** surface (bowled)
- Large values = **convex** surface (peaked)





Curvature Computation



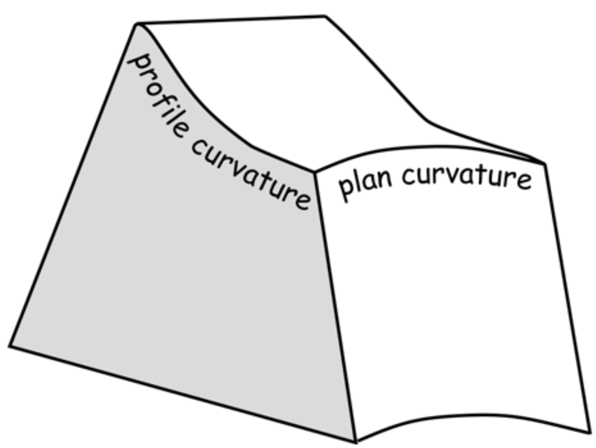
$$D = [\,(Z_4 + Z_5)/2 - Z_0\,] / C^2$$

$$E = [\,(Z_2 + Z_7)/2 - Z_0\,] / C^2$$

$$F = (Z_3 - Z_1 + Z_6 - Z_8) / 4C^2$$

$$G = (Z_5 - Z_4) / 2C$$

$$H = (Z_2 - Z_7) / 2C$$



plan curvature

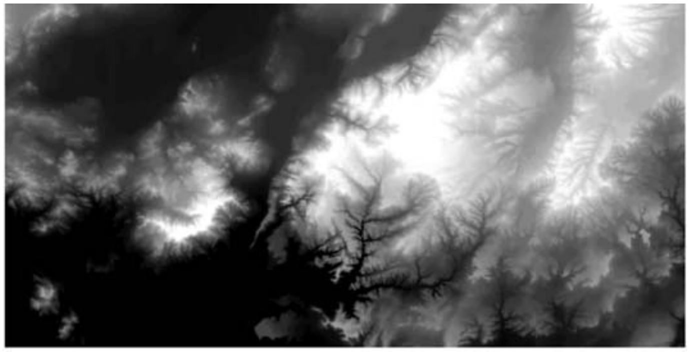
$$\frac{2\,(DH^2 + EG^2 - FGH)}{G^2 + H^2}$$

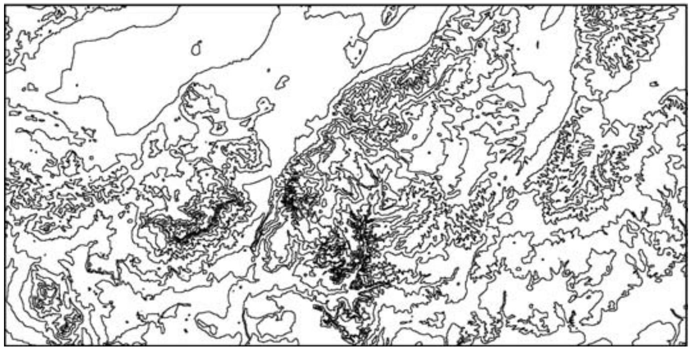
profile curvature

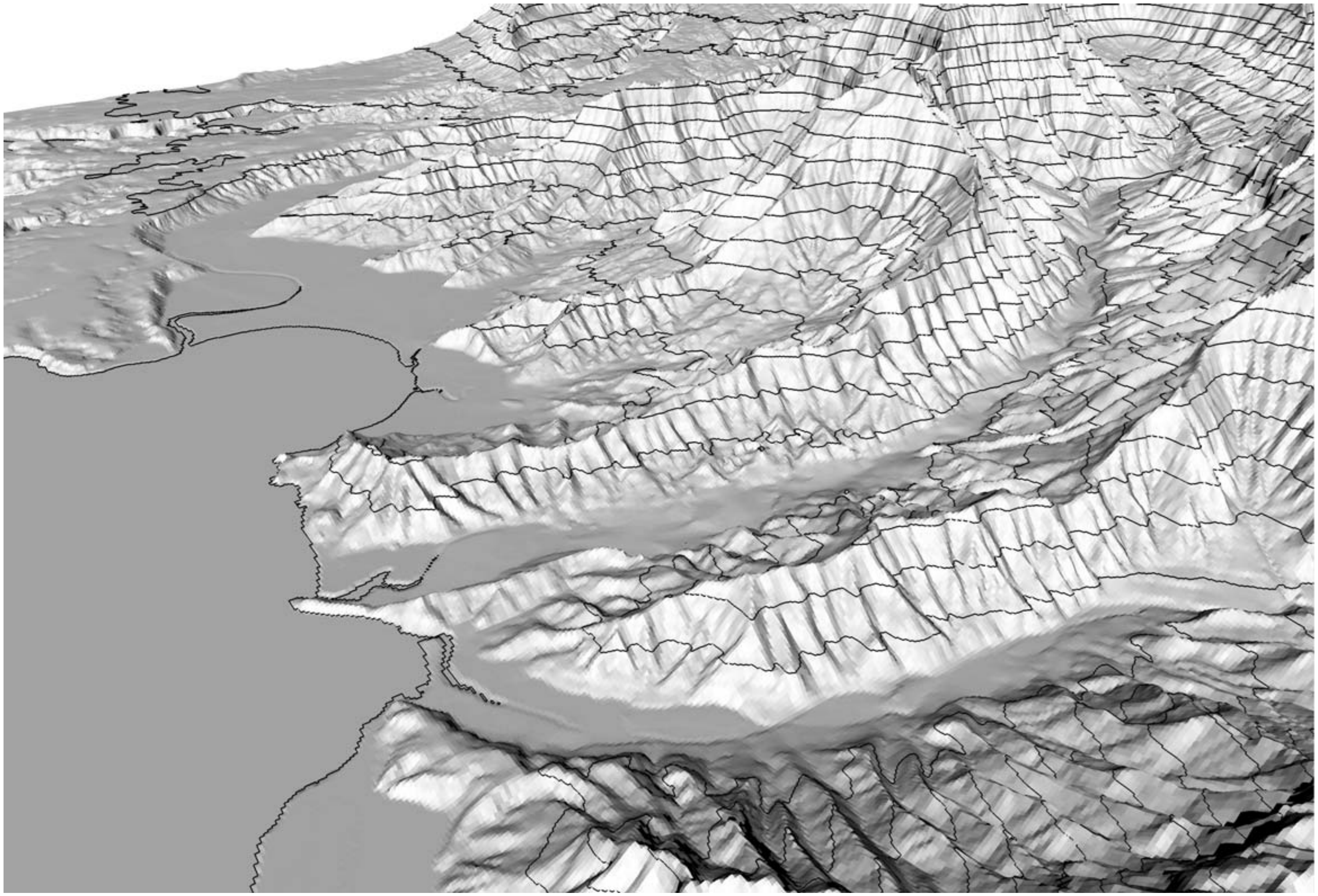
$$\frac{-2\,(DG^2 + EH^2 + FGH)}{G^2 + H^2}$$

(Topographic) Contours

- Connected lines of **uniform elevation** running at **right angles** to the local slope
- Fixed **contour intervals** (where do you see them often as geographers?)
- Most methods to derive contours are based on **interpolation**
- Identify the location of a contour value **between adjacent cells**







Summary I

- We met “**Terrain**” as the core of our existence: water availability, sunlight reception, visibility of human-made objects and activities
- We had some closer insights into **slope** and **aspect**: derived using **trigonometric functions** based on **moving window** operations (local functions!) in DEMs
- We have seen some applications of **Kernels** for deriving terrain variables and **weighting** different values within the local neighborhood
- **Curvatures** for **profiles** and **plans** to derive the relative **convexity** and **concavity** in the terrain (the local shape) in different directions

Further References

- Xiaoyang Zhang, Nick A. Drake *, John Wainwright, Mark Mulligan. 1999. Comparison of slope estimates from low resolution DEMs: scaling issues and a fractal method for their solution. Earth Surface Processes and Landforms 24(9), pp. 763-779
- A.K. Skidmore. 1989. A comparison of techniques for calculating gradient and aspect from a gridded DEM. IJGIS, 3(4), pp. 323-334.
- Dunn, M. and R. Hickey. 1998. The effect of slope algorithms on slope estimates within a GIS. Cartography, 27(1), pp. 9-15.