ISA

Geographic Information Systems 2025/2026

Lesson 17 - Digital Terrain Modelling

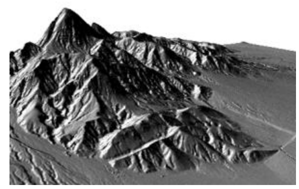
Digital Terrain Modelling

- Main characteristics of terrain surfaces
  - streams and ridges
- Digital Terrain modelling (DTM)
  - Traditional mapping (Contours and spot heights)
  - Digital elevation model (DEM)
    - Creating a DEM using the TIN method
- Derived data
  - contours
  - slope
  - aspect
  - profile, visibility, hillshade

Terrain surface

Relief is mainly defined by:

- **streams** – lines defined by the local lowest points of valleys
  - between 2 streams there is, at least, one hill
- **ridges** – lines defined by the local highest points of hills
  - between 2 ridges there is, at least, one valley
- other defining elements:
  - summits
  - roads
  - dams
  - railways
  - ...



Digital terrain model (DTM)

In the GIS context, a digital terrain model (**DTM**) for a given study area is a **geographic dataset that enables the height knowledge at any location**.

DTM involves 3 main problems:

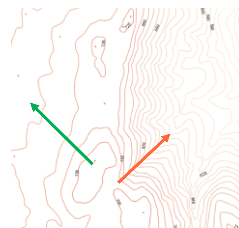
1. modelling a geographic phenomena with continuous distribution
2. high volume of data
3. high volume of data processing

DTM - Traditional mapping

Traditional mapping represents terrain using **contours** and **spot elevations** (at remarkable points)

- **contours** (or isolines) are lines that connect points of equal value concerning a given variable
  - such as **elevation**, temperature, precipitation, pollution, atmospheric pressure, …

- location of lines shows how values change across a surface
  - where there is little change in a value, the lines are spaced farther apart
  - where the values rise or fall rapidly, the lines are closer together



Contours and spot elevations in GIS

Elevation is the attribute of contours (2D lines) and spots (2D points)

Elevation is the 3rd coordinate of contours (3D lines) and spots (3D points) – truthfully, 3D vector gds

DTM - Digital Elevation Model (DEM)

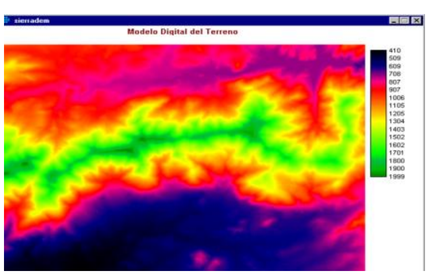
- A DEM is a raster representation of relief
  - **pixel values** are the height at the pixel center (or the average of the eights at the 4 cell corners)

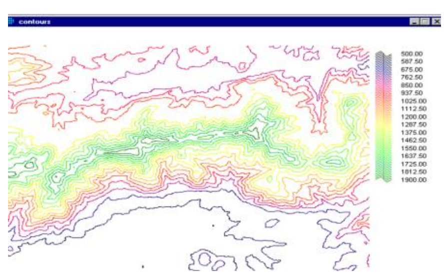
DEM vs. Contours

Continuous fields
DEM (raster data)

vs.

Discrete objects
Contours (vector data)





Techniques contributing to DEM creation

- Topographic maps (contours, spot elevations, waterlines, ...)
- Theodolite or total station

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- Topographic maps (contours, spot elevations, waterlines, ...)
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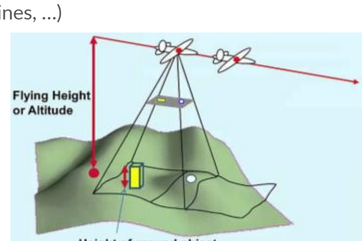
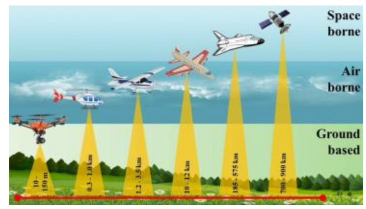
- GPS
- Stereo photogrammetry from aerial surveys



Techniques contributing to DEM creation

- Topographic maps (contours, spot elevations, waterlines, ...)
- Theodolite or total station
- GPS
- Stereo photogrammetry from aerial surveys
- Remote sensing



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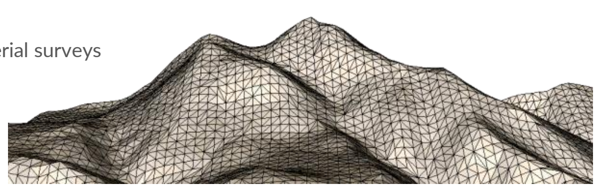

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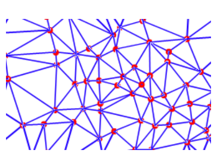
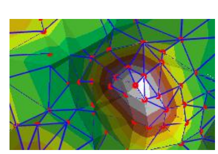
Geographic data are only as good as

the sampling scheme used to create them

Triangulated irregular network (TIN)

- TINs are a special kind of vector data:
  - constructed by triangulating a set of 3D vertexes
  - vertexes are connected by edges to form a network of 3D triangles
- There are different methods of spatial interpolation to form these triangles
  - the Delaunay triangulation method assures that no vertex lies within the interior of any of the circumcircles of the triangles in the network





Triangulated irregular network (TIN)

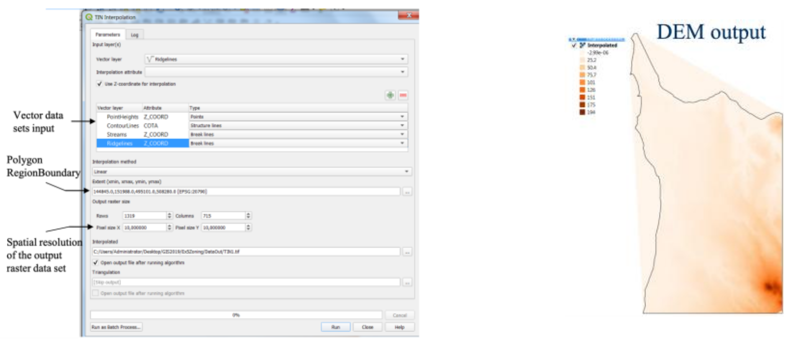
- 3D edges of TINs form contiguous & non-overlapping triangular facets
  - can be used to capture the position of linear features that play an important role in a surface, such as ridgelines or stream courses.
- Each facet has a constant slope & aspect
  - but height is not constant
  - at each location height can be estimated using an analytical method (equation of a plane defined by 3 non-collinear points, the triangle vertices)
- TIN can be easily converted to (raster) DEM

TIN (main) inputs

- **Mass points**
  - are point height measurements (2D or 3D points); they become vertexes in the TIN network
- **Breaklines**
  - lines typically with height measurements; they become triangle 3D edges representing either natural features, such as ridgelines or streams, or man-made features, such as roadways, railways, …
  - **hard breaklines** represent a discontinuity in the slope of the surface; for example, streams & road cuts (3D lines)
  - **soft breaklines** are features that do not alter the local slope of a surface; for example, contours (2D or 3D lines)
- **Clip polygon** (optional, but mostly necessary)
  - defines a boundary for the TIN surface; it can be a 2D or 3D polygon

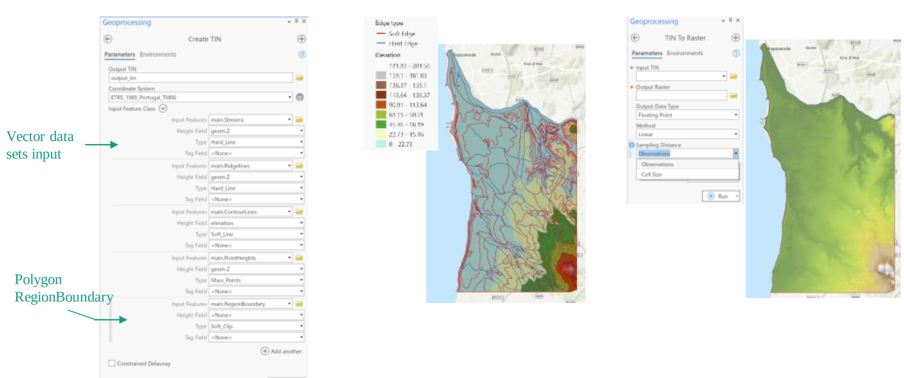
DEM creation using QGIS

Use the menu Processing / Toolbox / Interpolation / TIN interpolation



DEM creation using ArcGIS Pro

Use the tools **Create TIN** (3D Analyst) and **Tin to Raster** (3D Analyst)

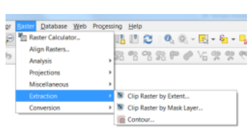


DEM accuracy

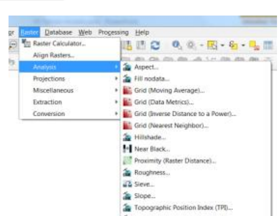
- The **quality of a DEM is a measure of how accurate elevation is at each pixel** (absolute accuracy) and **how accurately is the morphology presented** (relative accuracy); it depends on:
  - terrain roughness
  - sampling density (elevation data collection method)
  - grid resolution or pixel size
  - interpolation algorithm
  - vertical resolution
  - terrain analysis algorithms
  - …

Derived data from DEM/TIN (QGIS)

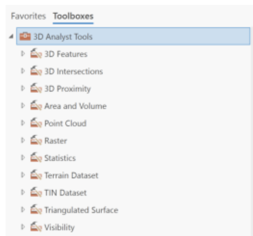
- **Contour**

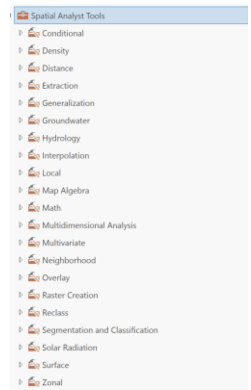


- **Slope** (either % or degrees)
- **Aspect**
- **Visualization:**
  - Hillshade
  - Ruggedness Index



Derived data from DEM/TIN





Slope in GIS

From:

https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-slope-works.htm#:~:text=Available%20with%203D%20Analyst%20license,or%20percent%20(percent%20rise)

Planar slope calculation example

As an example, the slope value of the center cell of the moving window shown below will be calculated.

50	45	50
30	30	30
8	10	10

Slope example input

a	b	c
d	e	f
g	h	i

Surface scanning window

The rate of change in the x direction for the center cell *e* is:

```
[dz/dx] = ((c + 2f + i)*4/wght1 - (a + 2d + g)*4/wght2) / (8 * x_cellsize)
        = ((50 + 60 + 10)*4/(1+2+1) - (50 + 60 + 8)*4/(1+2+1)) / (8 * 5)
        = (120 - 118) / 40
        = 0.05
```

The rate of change in the y direction for cell *e* is:

```
[dz/dy] = ((g + 2h + i)*4/wght3 - (a + 2b + c)*4/wght4) / (8 * y_cellsize)
        = ((8 + 20 + 10)*4/(1+2+1) - (50 + 90 + 50)*4/(1+2+1)) / (8 * 5)
        = (38 - 190 ) / 40
        = -3.8
```

Slope in GIS

From:

https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-slope-works.htm#:~:text=Available%20with%203D%20Analyst%20license,or%20percent%20(percent%20rise)

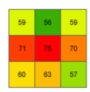
Taking the rate of change in the x and y direction, the slope for the center cell *e* is calculated using the following:

Surface scanning window

```
rise_run = √ ([dz/dx]² + [dz/dy]²)
         = √ ((0.05)² + (-3.8)²)
         = √ (0.0025 + 14.44)
         = 3.80032
```

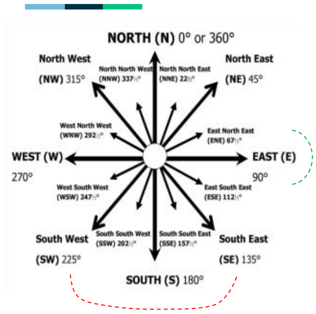
```
slope_degrees = ATAN (rise_run) * 57.29578
              = ATAN (3.80032) * 57.29578
              = 1.31349 * 57.29578
              = 75.25762
```

The integer slope value for cell *e* is 75 degrees.



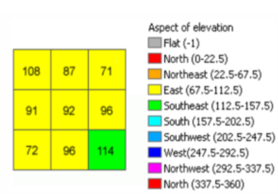
Slope example output

Aspect in GIS



East direction if the 8 main Cardinal Points are considered (67.5º – 112.5º)

South direction if only the 4 main Cardinal Points are considered (135º – 225º)



Aspect example output

https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-aspect-works.htm

Downloading public DEM

SRTM DEM spatial resolution 1arc-second≈30m: http://earthexplorer.usgs.gov/

How to download SRTM DEM 1arc-second: https://www.youtube.com/watch?v=0YPFegTcL4w

Documentation: https://www2.jpl.nasa.gov/srtm/

Remark: 1 arc-second ≈ 30 m near the Equator line (1° ≈ 111.321 km, 1° ≈ 85 km at parallel 40°)

Credits

The structure and content of the course, including most of the slides and exercises was developed by Professor Graça Abrantes (SIG 2021_2022) and Professor Rui Figueira (SIG 2023_2024)