

ISA

Geographic Information Systems 2025/2026

Lesson 17 - Digital Terrain Modelling

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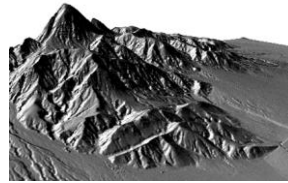
Digital Terrain Modelling

- 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
 - ...



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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:

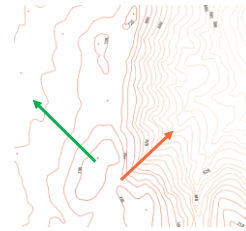
1. modelling a geographic phenomena with continuous distribution
2. high volume of data
3. high volume of data processing

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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

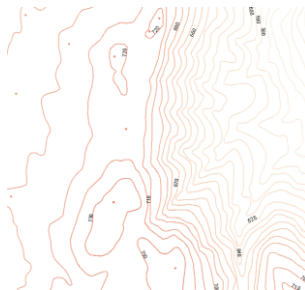


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Contours and spot elevations in GIS

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



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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)



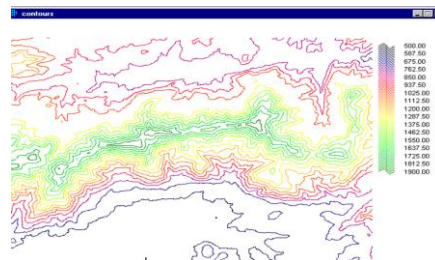
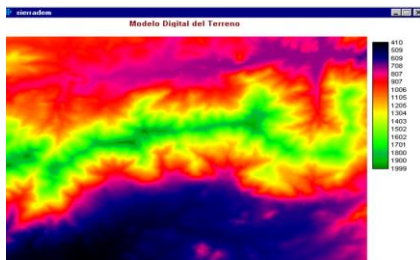
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DEM vs. Contours

Continuous fields
DEM (raster data)

vs.

Discrete objects
Contours (vector data)



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Techniques contributing to DEM creation

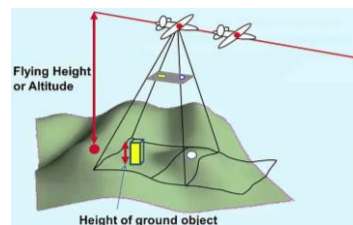
- Topographic maps (contours, spot elevations, waterlines, ...)
- Theodolite or total station



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Techniques contributing to DEM creation

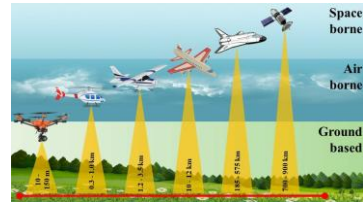
- Topographic maps (contours, spot elevations, waterlines, ...)
- Theodolite or total station
- GPS
- Stereo photogrammetry from aerial surveys



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Techniques contributing to DEM creation

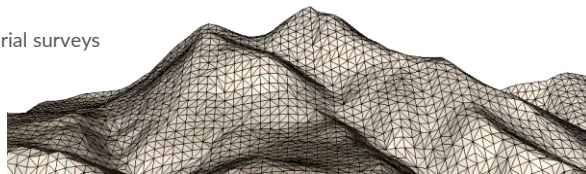
- Topographic maps (contours, spot elevations, waterlines, ...)
- Theodolite or total station
- GPS
- Stereo photogrammetry from aerial surveys
- Remote sensing



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Techniques contributing to DEM creation

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



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Techniques contributing to DEM creation

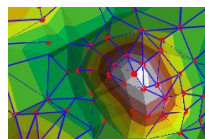
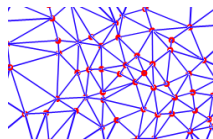
- Topographic maps (contours, spot elevations, waterlines, ...)
- Theodolite or total station
- GPS
- Stereo photogrammetry from aerial surveys
- Remote sensing
- **TIN**

Geographic data are only as good as
the sampling scheme used to create them

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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



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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

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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

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DEM creation using QGIS

Use the menu Processing / Toolbox / Interpolation / TIN interpolation

The screenshot shows the QGIS TIN Interpolation dialog box on the left and the resulting DEM output map on the right. The dialog box has several sections: Parameters, Vector data sets input, Polygon RegionBoundary, and Spatial resolution of the output raster data set. The Vector data sets input section shows a table with columns for Name, Path, and Type. The Polygon RegionBoundary section shows a list of layers. The Spatial resolution of the output raster data set section shows a table with columns for Rows, Columns, and Pixel size. The resulting DEM output map is a heatmap showing elevation values, with a color scale on the right ranging from 0 to 100.

QGIS TIN Interpolation Dialog Box:

- Parameters:**
 - Input (vector):
 - Interpolation method: ☒ Use Z coordinates for interpolation
- Vector data sets input:**

Name	Path	Type
Pondings	Z:\COORD	Points
ControlLines	CTDA	Structure Lines
Streams	Z:\COORD	Break Lines
Contours	Z:\COORD	Break Lines
- Polygon RegionBoundary:**
 - Layer:
 - Input (vector, union, union, union):
- Spatial resolution of the output raster data set:**

Rows	Columns	Pixel size
1000	1000	10,000000
- Interpolation:**
 - Interpolation method:
 - Interpolation:
 - Interpolation:
 - Interpolation:

DEM output:

The DEM output is a heatmap showing elevation values, with a color scale on the right ranging from 0 to 100.

The screenshot shows the QGIS Processing Toolbox with the 'TIN to Raster' tool selected. The tool parameters are configured as follows:

- Input TIN:** `input.tin`
- Coordinate System:** `ETRS 1989 Portugal UTM6`
- Input Feature Class:** `main.Streams`
- Height Field:** `geom2`
- Type:** `Hard Line`
- Tag Field:** `-none-`
- Input Features:** `main.RidgeLines`
- Height Field:** `geom2`
- Type:** `Hard Line`
- Tag Field:** `-none-`
- Input Features:** `main.ContourLines`
- Height Field:** `elevation`
- Type:** `Soft Line`
- Tag Field:** `-none-`
- Input Features:** `main.PointHeights`
- Height Field:** `geom2`
- Type:** `Mass Points`
- Tag Field:** `-none-`
- Input Features:** `main.RegionBoundary`
- Height Field:** `-none-`
- Type:** `Soft Clip`
- Tag Field:** `-none-`

The tool is set to **Constrained Delaunay** and **Run** is selected. The output is a raster map of a coastal area, showing the result of the TIN to Raster conversion.

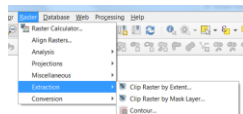
DEM accuracy

- 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
 - ...

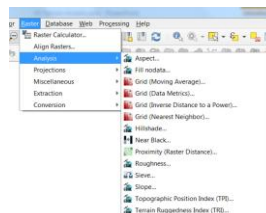
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Derived data from DEM/TIN (QGIS)

- Contour

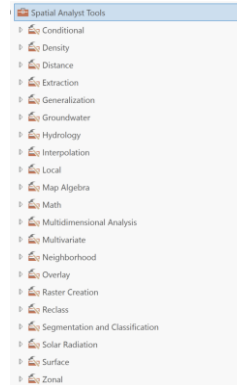
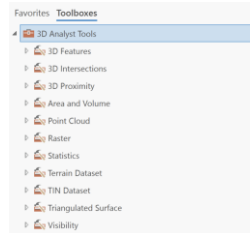


- Slope (either % or degrees)
- Aspect
- Visualization:
 - Hillshade
 - Ruggedness Index



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Derived data from DEM/TIN



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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\(percentage%20rise\)](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(percentage%20rise))

Planar slope calculation example

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



Slope example input



Surface scanning window

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

$$\begin{aligned}
 [dz/dx] &= ((c + 2f + i) * 4 / \text{wght1}) - ((a + 2d + g) * 4 / \text{wght2}) / (8 * \text{x_cellsize}) \\
 &= ((30 + 60 + 10) * 4 / (1+2+1)) - ((50 + 60 + 8) * 4 / (1+2+1)) / (8 * 5) \\
 &= (120 - 118) / 40 \\
 &= 0.05
 \end{aligned}$$

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

$$\begin{aligned}
 [dz/dy] &= ((g + 2h + i) * 4 / \text{wght3}) - ((a + 2b + c) * 4 / \text{wght4}) / (8 * \text{y_cellsize}) \\
 &= ((8 + 20 + 10) * 4 / (1+2+1)) - ((50 + 90 + 50) * 4 / (1+2+1)) / (8 * 5) \\
 &= (38 - 190) / 40 \\
 &= -3.8
 \end{aligned}$$

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

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

$$\begin{aligned} \text{rise_run} &= \sqrt{[(dz/dx)^2 + (dz/dy)^2]} \\ &= \sqrt{[(0.05)^2 + (-3.8)^2]} \\ &= \sqrt{0.0025 + 14.44} \\ &= 3.80032 \end{aligned}$$

$$\begin{aligned} \text{slope_degrees} &= \text{ATAN}(\text{rise_run}) * 57.29578 \\ &= \text{ATAN}(3.80032) * 57.29578 \\ &= 1.31349 * 57.29578 \\ &= 75.25762 \end{aligned}$$

The integer slope value for cell e is 75 degrees.



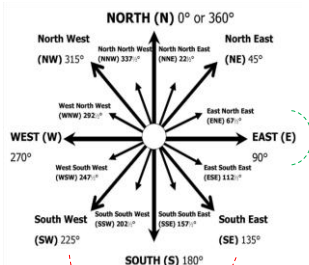
Slope example output

a	b	c
d	e	f
g	h	i

Surface scanning window

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Aspect in GIS



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

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

108	87	71
91	92	96
72	96	114

Aspect example output

Aspect of elevation

- Flat (-1)
- North (0-22.5)
- Northeast (22.5-67.5)
- East (67.5-112.5)
- Southeast (112.5-157.5)
- South (157.5-202.5)
- Southwest (202.5-247.5)
- West (247.5-292.5)
- Northwest (292.5-337.5)
- North (337.5-360)

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

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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 $\approx$ 30 m near the Equator line ($1^\circ \approx 111.321$ km, $1^\circ \approx 85$ km at parallel 40°)

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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)

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