GEOG 176A: Introduction to Geographic Information Systems

Lecture 14: Terrain Analysis II

(chapter 7)

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Recall: Representation of terrain

- **Vector**
  - Point samples (regular and irregular)
  - Contours
- **Raster**
  - DEM → DTM → DSM
- **TIN**
- **Others**
  - Voxel
  - 3D point cloud
Recall: Vector - Point samples

- Regular point samples
- Irregular point samples
Recall: IDW interpolation

- **Inverse Distance weighting**
- Closer points have more influences on the target value:

\[
Z = \frac{\sum w_i z_i}{\sum w_i} \quad \text{where} \quad w_i = \frac{1}{(d_i)^p}
\]

- P is the power parameter which determines the influence of the distance towards weights:
  - p=0: every point has the **same weight** regardless of their distance towards the target location
  - p=large value: points that are **further away have less influence** on the target location
Kriging

- A statistically robust approach
  \[ Z = \sum w_i Z_i \]
- Weights \( w_i \) are determined in a statistical way with more complicated spatial dependence considered
Kriging

- \( w_i \) is calculated based on variogram
- **Variogram** measures **how attribute value change with regard to distance**
- Variogram is calculated based on the **variance of attribute change with regard to distance**
Comparison between IDW and Kriging
Vector - Contours

- A line with constant elevation
- Contours should not intersect with each other
- The interval between contour lines should be set appropriately
Raster - DEM /DTM/ DSM

- **Digital Elevation Model (DEM)**
  - Height above a given *sea level* with respect to a reference datum

- **Digital Terrain Model (DTM)**
  - Height of the *bare ground surface*

- **Digital Surface Model (DSM)**
  - *Highest thing* on the earth surface (e.g., buildings, tree canopy)

All these models are represented as *regular grid* in GIS.
DEM

- Two global scale DEM data sources:
  - SRTM
  - GDEM
DEM

- DEM is measured based on a datum (what if the datum changes?)
- Spatial resolutions
  - SRTM: inside the U.S. 30 meters; outside the U.S. 90 meters
  - GDEM: 30 meters for global coverage
- Vertical uncertainties
  - The elevation value within a cell may have a measurement uncertainty, e.g., 10 meters
  - For both SRTM and GDEM, they have a +/- 16 meters uncertainty (95% confidence level)
A vector data structure that partitions geographic space into contiguous, nonoverlapping triangles. The vertices of each triangle are sample data points with x-, y-, and z-values. These sample points are connected by lines to form Delaunay triangles. TINs are used to store and display surface models.
Voxels

Do not contain geographic coordinate; often used in game engines for terrain visualization, such as caves.
3D point cloud

- **LiDAR**: Light Detection And Ranging
- Illuminates a target area with a laser and then analyze the reflected light
3D point cloud

Can be either **airborne** or **terrestrial**
3D point cloud

Elevation models constructed from LiDAR
Terrain analysis

- Slope and aspect
- Hillshade
- Elevation profile
- Intervisibility and viewshed
- Curvature
- Flow accumulation
Slopes and aspects

- Calculating slopes and aspects based on 8 neighbors of DEM

→ first-order derivatives of DEM
Slopes and aspects

- **Slope**: maximum slope in neighborhood
- **Aspect**: direction (in azimuth) of the *maximum slope*

Slope as percent = \( \frac{\text{rise}}{\text{run}} \times 100 \)

\[= \frac{A}{B} \times 100\]

Slope as degrees = \( \Phi \)

\[= \tan^{-1}(A/B)\]
Slope and aspect

- Calculating slopes

\[
[dz/dx] = \frac{(c + 2f + i) - (a + 2d + g)}{(8 \times x\_cells)} = \frac{(50 + 60 + 10) - (50 + 60 + 8)}{(8 \times 5)} = \frac{120 - 118}{40} = 0.05
\]

\[
[dz/dy] = \frac{(g + 2h + i) - (a + 2b + c)}{(8 \times y\_cells)} = \frac{(8 + 20 + 10) - (50 + 90 + 50)}{(8 \times 5)} = \frac{38 - 190}{40} = -3.8
\]

\[
\text{rise}_\text{run} = \sqrt{(\frac{dz}{dx})^2 + (\frac{dz}{dy})^2} = \sqrt{(0.05)^2 + (-3.8)^2} = \sqrt{0.0025 + 14.44} = 3.80032
\]

\[
\text{slope\_degrees} = \text{ATAN} (\text{rise\_run}) \times 57.29578 = \text{ATAN} (3.80032) \times 57.29578 = 1.31349 \times 57.29578 = 75.255762
\]
Slope and aspect

- Slope example
Slope and aspect

- Calculating aspects

\[
\begin{align*}
\frac{dz}{dx} &= \frac{(c + 2f + 1) - (a + 2d + g)}{8} \\
&= \frac{(85 + 170 + 84) - (101 + 202 + 101)}{8} \\
&= -8.125 \\

\frac{dz}{dy} &= \frac{(g + 2h + i) - (a + 2b + c)}{8} \\
&= \frac{(101 + 182 + 84) - (101 + 184 + 85)}{8} \\
&= -0.375 \\

\text{aspect} &= 57.29578 \times \tan^{-1} \left( \frac{-0.375}{8.125} \right) \\
&= 2.64 \\

\text{cell} &= 90.0 - \text{aspect} \\
&= 90 - 2.64 \\
&= 92.64
\end{align*}
\]

Input elevation

Output aspect
Slope and aspect

- Aspects example
Hillshade

- **Shaded relief maps** depict the brightness of terrain reflections
- **Hillshade tool** creates a shaded relief raster from a surface by considering the illumination source azimuth and altitude
- **Azimuth**: the angular direction of the sun, measured from north in clockwise degrees from 0 to 360
- **Altitude**: is the angle of the sun above the horizon

\[
(1) \quad \text{Hillshade} = 255.0 \times ((\cos(\text{Zenith}_\text{rad}) \times \cos(\text{Slope}_\text{rad})) + \\
(\sin(\text{Zenith}_\text{rad}) \times \sin(\text{Slope}_\text{rad}) \times \cos(\text{Azimuth}_\text{rad} - \text{Aspect}_\text{rad})))
\]

Again, no need to remember!
Hillshade

- Hillshade example

Sun coming from 315 degree (azimuth) and at 45 degree in height (altitude)
Elevation profile

- Create an elevation profile along a line
Intervisibility and viewshed

- **Intervisibility**: visibility between two points
- **Viewshed**: given one or several observing points, find out which areas can be seen and which areas cannot
Intervisibility and viewshed

- How to determine visibility?
Curvature

- The curvatures of terrain → **second-order derivatives** of DEM

Profile curvature affects the acceleration or deceleration of flow across the surface
Curvature

- Examples

Plan curvature:
The rate of change in terms of aspects

Profile curvature:
The rate of change in terms of downhill slope
Flow accumulation

- Sum of upstream elements draining into the target cell
Flow accumulation

- Extract **ridges** from terrain
  - Flow accumulation → find the raster cells where **flow accumulation** = 0
  - Result is generally good in mountain areas