ENGRG 59910
Introduction to GIS

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Lecture 11: Terrain Analysis
Outline: Terrain Analysis

• Earth Surface Representation
  • Contour
  • TIN
  • Mass Points
  • Digital Elevation Models

• Slope and Aspect

• Hydrology Analysis
  • Flow direction
  • Flow accumulation
  • Watershed

• View sheds
The Big Picture: Raster Analysis Models

- **Suitability modeling**—most spatial models involve finding optimum locations, such as finding the best location to build a new school, a landfill, or a resettlement site.

- **Distance modeling**—what is the best path to build a highway between Gainesville and Jacksonville?

- **Hydrologic modeling**—In which direction will the water flow?

- **Surface modeling**—what is the pollution level for various locations in a county?
Representing Surfaces

• Surfaces involve a third elevation value (z) in addition to the x,y horizontal values

• Surfaces are complex to represent since there are an infinite number of potential points to model

• The basic data for terrain elevation are derived generally from one of three sources:
  • digitized contours
  • photogrammetric data capture (including aerial photography and digital satellite imagery);
  • surveying
Digital Representation of Terrain

A digital representation of terrain is known as:

- **Raster-based Digital Elevation Model (DEM) or Digital Terrain Model (DTM)**
  - Regular spaced set of elevation points (z-values)

- **Vector based Triangulated Irregular Networks (TIN)**
  - Irregular triangles with elevations at the three corners

- **Vector-based contour lines**
  - Lines joining points of equal elevation, at a specified interval

- **Massed points and breaklines**
  - *Massed points*: Any set of regular or irregularly spaced point elevations
  - *Breaklines*: point elevations along a line of significant change in slope (valley floor, ridge crest)
Digital representation to Terrain
Contour (isolines) Lines

Contour lines, or isolines connect points that have the same elevation

**Advantages**
- Familiar to many people
- Easy to obtain mental picture of surface
  - Close lines = steep slope
  - Uphill V = stream
  - Downhill V or bulge = ridge
  - Circle = hill top or basin

**Disadvantages**
- Poor for computer representation: no formal digital model
- Must convert to raster or TIN for analysis
- There is no information about how the terrain changes between lines
Triangulated Irregular Network

- A set of adjacent, non-overlapping triangles computed from irregularly spaced points, with x, y horizontal coordinates and z vertical elevations.

- The inclination of the terrain is assumed to be constant within each triangle.

- The coordinates of the vertices of each triangle are stored as well as its inclination and direction.

- Advantages
  - Can capture significant slope features (ridges, etc)
  - Efficient since require few triangles in flat areas
  - Easy for certain analyses: slope, aspect, volume

- Disadvantages
  - Analysis involving comparison with other layers difficult
Massed Points

- Clouds of points simply represent points where elevation data are known

- Can be as detailed as possible
  - Lots of points in high variable areas
  - Fewer points in homogeneous areas
Digital Elevation Models (DEM)

• Any digital representation of a topographic surface (broad concept)

• Most often a raster or regular grid of spot heights

• Digital Terrain Model or DTM may actually be a more generic term for any digital representation of a topographic surface, but it is not so widely used; DTM and DEM is interchangeable terms

• Digital Surface Model or DSM include above-ground features such as building and vegetation canopies.
Digital Elevation Model (DEM)

- Each cell stores the elevation value as an attribute
- Two approaches for determining the surface $z$ value of a location between sample points.
  - In a **lattice**, each mesh point represents a value on the surface only at the center of the grid cell. The $z$-value is approximated by interpolation between adjacent sample points; it does not imply an area of constant value.
  - A **surface grid** considers each sample as a square cell with a constant surface value.

**Advantages**
- Simple conceptual model
- Data cheap to obtain
- Easy to relate to other raster data
- Irregularly spaced set of points can be converted to regular spacing by interpolation

**Disadvantages**
- Does not conform to variability of the terrain
- Linear features not well represented
Digital Elevation Models (DEM)

• Simplest form of digital representation of topography and the most common

• A variety of DEMs are available, including coverage of much of the US from the US Geological Survey (USGS)
  • SRTM: Shuttle Radar Topography Mission
  • DLG: Digital Linear Graph
  • DRG: Digital Raster Graphic
  • DTED: Digital Terrain Elevation Data
  • ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer Sensor
Common USGS DEM Data Sources

• Shuttle Radar Topography Mission (SRTM) (30m US wide)
• 1/3" (10m), National Elevation Dataset (NED)
• 1" (30m) DEMs from 1:24,000 scale map
• 3" (100m) DEMs from 1:250,000 scale maps
• 30" (1km) DEM of the earth (GTOPO30)

http://edc.usgs.gov/geodata/
http://ned.usgs.gov
SRTM – Shuttle Radar Topography Mission

- 1 arc-second (30m) elevation data for the United States, 3 arc-second (100m) data for the globe
- Produced by radar measurements from a Shuttle mission, Feb 11-22, 2000
SRTM Data Coverage Map
San Andreas Fault, California

Salt Lake City, Utah

Mt Kilimanjaro, Tanzania

GTOPO30

Seamless Data Distribution

http://seamless.usgs.gov/
HydroSHEDS

Welcome to the HydroSHEDS website!

This is the official and only maintained website providing HydroSHEDS data. You currently can also find HydroSHEDS at the USGS mirror site (see Links above), but note that the USGS site is no longer updated.

Announcing HydroLAKES!

October 2016. We would like to announce a new product - HydroLAKES. Read more about HydroLAKES here and follow download links.

HydroSHEDS

Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales

HydroSHEDS is a mapping product that provides hydrographic information for regional and global-scale applications in a consistent format. It offers a suite of geo-referenced data sets (vector & raster) at various scales, including river networks, watershed boundaries, drainage directions, and flow accumulations. HydroSHEDS is based on high-resolution elevation data obtained during a Space Shuttle flight for NASA's Shuttle Radar Topography Mission (SRTM).

http://hydrosheds.org/
HydroBASINS

This section provides only a brief overview of the HydroBASINS product.

For more information on HydroBASINS please refer to the HydroBASINS Technical Documentation.

You can download HydroBASINS data here.

Background

HydroBASINS is a series of polygon layers that depict watershed boundaries and sub-basin delineations at a global scale product is to provide a seamless global coverage of consistently sized and hierarchically nested sub-basins at different size millions of square kilometers), supported by a coding scheme that allows for analysis of watershed topology such as up-connectivity.

Using the HydroSHEDS database at 15 arc-second resolution, watersheds were delineated in a consistent manner at different hierarchical sub-basin breakdown was created following the topological concept of the Pfafstetter coding system. These are termed HydroBASINS and represent a subset of the HydroSHEDS database.

http://hydrosheds.org/page/hydrobasins
HydroLAKES

HydroLAKES is a global database that provides the surface polygons of all lakes with a size of at least 10 ha. Additional attributes include shoreline length, average depth, volume and residence time. All lakes are linked to the HydroSHEDS database via their outlet points.

This database is currently under review and will be released soon (anticipated November 2016—stay tuned!)

http://www.hydrosheds.org/page/hydrolakes
Use of DEM

- Extracting terrain parameters
  - Slope, aspect, spot elevations
  - Source for contour lines
  - Modeling water flow or mass movement (Watersheds, drainage networks, stream channels)

- Creation of relief maps

- Rendering of 3D visualizations.

- Terrain analyses in geomorphology and physical geography
Terrain Analysis: Slope

- **Slope** refers to the inclination of the terrain

\[ \alpha \]

Calculated as percentage or degrees.

\[ \text{Slope}(\circ) = \tan^{-1}\left(\frac{\frac{y}{x}}\right) \quad \longleftrightarrow \quad \text{Slope}(\%) = \frac{y}{x} \times 100 \]

45 Degree  <-------->  100%

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Slope Direction

\[
\text{Degrees}
\]

\[
\text{Slope}(\circ) = \tan^{-1}\left(\frac{y}{x}\right)
\]

\[
\text{Percentage}
\]

\[
\text{Slope}(\%) = \frac{y}{x} \times 100
\]

But how to calculate it
Slope Calculation: 4 nearest cells

\[
Slope = \arctan \sqrt{\left(\frac{dz}{dx}\right)^2 + \left(\frac{dz}{dy}\right)^2}
\]

for \(Z_0\):

\[
dZ/dx = (49 - 40)/20 = 0.45\\
dZ/dy = (45 - 48)/20 = -0.15\\
slope = \arctan \left(\frac{(0.45)^2 + (-0.15)^2}{0.5}\right) = 25.3^\circ
\]
Slope Calculation: using 4 nearest cells

Do you remember **Kernel**? Set of constants; mathematical functions applied for every moving window location.
Slope Calculation: 3\textsuperscript{rd} order finite difference

3rd-order finite difference

<table>
<thead>
<tr>
<th>elevation values</th>
<th>( Z_1 )</th>
<th>( Z_2 )</th>
<th>( Z_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>45</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>44</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>48</td>
<td>52</td>
<td></td>
</tr>
</tbody>
</table>

\( C = 10 \)

kernal for \( dZ/dx \)

<table>
<thead>
<tr>
<th>( Z_1 )</th>
<th>( Z_2 )</th>
<th>( Z_3 )</th>
<th>( Z_4 )</th>
<th>( Z_5 )</th>
<th>( Z_6 )</th>
<th>( Z_7 )</th>
<th>( Z_8 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>0</td>
<td>-2</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

\[
dZ/dx = \frac{[(Z_3 - Z_1) + 2(Z_5 - Z_4) + (Z_8 - Z_6)]/8C}{[(Z_3 - Z_1) + 2(Z_5 - Z_4) + (Z_8 - Z_6)]/8C}
\]

dZ/dx = \[
\begin{align*}
\frac{(47 - 42) + 2(49 - 40) + (52 - 44)}{80} & = 0.39 \\
\frac{(47 - 52) + 2(45 - 48) + (42 - 44)}{80} & = -0.16
\end{align*}
\]

slope = \[\tan^{-1}\left(\frac{0.39^2 + (-0.16)^2}{0.5}\right) = 22.9^\circ\]
Terrain Analysis: Aspect

- **Aspect** has significant effects on vegetation on slopes.
  - In the northern hemisphere, south-facing slopes receive more sunlight and are drier than north-facing slopes.
Aspect

• Aspect: Direction that a surface faces

• Typically reported as an azimuth angle (measured in degrees from the north)

• Used to:
  • Determine Incident solar radiation
  • Visibility
Comparison of Shaded Relief Maps for 315° and 135° Sun Angles.

Sun Azimuth = 315°; Elevation = 45°

Sun Azimuth = 135°, Elev 45°

Alachua County, FL
Shaded Relief

Alachua County Shaded Relief
with 135° Sun Angle
Solar Radiation Analysis

• Incoming solar radiation (insolation)
  • Landscape scales
  • Topography
  • Elevation,
  • Orientation (slope and aspect),
  • Shadows cast by topographic features
Where should construct a Vineyard?
Hydrologic functions on DEMs

- Modeling the topographic form of a drainage basin
- Determining the drainage network and associated drainage divides
- Estimating slopes for understanding drainage patterns and processes
Understanding drainage systems
Basic Workflow of Hydrologic Analysis
River Network & SubwaterSheds
Flow Direction

- Useful for finding drainage networks and drainage divides

- Direction is determined by the elevation of surrounding cells
  - Direction of Steepest Descent
  - Water can flow only into one cell

- Water is assumed to flow into one other cell, unless there is a sink
  - GIS model assumes no sinks
A natural sink? Remove it

By default, this “sink” is removed, whether or not it is real.
Flow direction in a DEM

<table>
<thead>
<tr>
<th></th>
<th>340</th>
<th>335</th>
<th>330</th>
<th>340</th>
<th>345</th>
</tr>
</thead>
<tbody>
<tr>
<td>337</td>
<td>332</td>
<td>325</td>
<td>335</td>
<td>340</td>
<td></td>
</tr>
<tr>
<td>330</td>
<td>328</td>
<td>320</td>
<td>330</td>
<td>335</td>
<td></td>
</tr>
<tr>
<td>328</td>
<td>326</td>
<td>310</td>
<td>320</td>
<td>328</td>
<td></td>
</tr>
<tr>
<td>320</td>
<td>318</td>
<td>305</td>
<td>312</td>
<td>315</td>
<td></td>
</tr>
</tbody>
</table>

Flow directions for individual cells
Eight Direction Pour Point Model
Flow Direction Grid

![Flow Direction Grid diagram]

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Flow Direction Grid
Flow accumulation

- The number of cells, or area, which contribute to runoff of a given cell
- Accumulation, once it reaches a threshold appropriate to an region, forms a drainage channel
- Flow accumulation measures the area of a watershed that contributes runoff to a given cell
Flow accumulation as drainage network

Drainage network as defined by cells above threshold value for region.
Finding watersheds ...

- Begin at a source cell in a flow direction database, which is derived from a DEM (not from the DEM itself)

- Find all cells that flow into the source cell
  - Iteratively find all cells that flow into those cells
  - All of these cells comprises the watershed

- The resulting watershed is generalized, based on the cell size of the DEM
Watersheds ...

Once done manually ...

Contour lines (brown)
Drainage (blue)
Watershed boundary (red)
Hydrology Extension in ArcGIS

1. **Fill Sinks**
   - Input surface: dem
   - Fill limit: Fill_ALL
   - Output raster: C:\WorkSpace\hydro\Fill

2. **Flow Direction**
   - Input surface: Fill
   - Create drop: unchecked
   - Force flow at edge: unchecked
   - Output raster: C:\WorkSpace\hydro\Direction

3. **Flow Accumulation**
   - Direction raster: Direction
   - Weight raster: No Weight Raster
   - Output raster: C:\WorkSpace\hydro\Accumulation

4. **Watershed**
   - Direction raster: Direction
   - Accumulation raster: Accumulation
   - Minimum number of cells for a basin: 20000
   - Output raster: C:\WorkSpace\hydro\Watersheds

5. **Raster to Features**
   - Input raster: Watersheds
   - Field: Value
   - Output geometry type: Polygon
   - Generalize lines: checked
   - Output features: C:\WorkSpace\hydro\Watershed
Predictive Equations

• Runoff Availability Equation
  • Can be used to predict the amount of water that will become runoff given a specific rainfall event

  • For example, how much runoff can be expected if there is an inch of rain over a clay soil with dense vegetation

  • Based on soil characteristics and land cover

\[ Q = \frac{\sqrt{p - 0.2 \times (1000/CN - 10)}}{p + 0.8 \times (1000/CN - 10)} \]

Where:

- **Q** = total water available for runoff
- **p** = precipitation
- **CN** = curve number
Runoff Availability Equation

- Equation based on the CN number
  - CN number based on soil and land cover characteristics—both easily available in raster or vector format for GIS
  - CN values range from 0-100 (like a percentage)
    - Note: concrete has a CN value of nearly 100
### Some Common Curve Numbers

<table>
<thead>
<tr>
<th>Land Use Description on Input Screen</th>
<th>Description and Curve Numbers from TR-55</th>
<th>Curve Number for Hydrologic Soil Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cover Description</td>
<td>% Impervious Areas</td>
</tr>
<tr>
<td>Agricultural</td>
<td>Row Crops - Straight Rows + Crop Residue Cover - Good Condition (1)</td>
<td>64</td>
</tr>
<tr>
<td>Commercial</td>
<td>Urban Districts: Commercial and Business</td>
<td>85</td>
</tr>
<tr>
<td>Forest</td>
<td>Woods (2) - Good Condition</td>
<td>30</td>
</tr>
<tr>
<td>Grass/Pasture</td>
<td>Pasture, Grassland, or Range (3) - Good Condition</td>
<td>39</td>
</tr>
<tr>
<td>High Density Residential</td>
<td>Residential districts by average lot size: 1/8 acre or less</td>
<td>65</td>
</tr>
<tr>
<td>Industrial</td>
<td>Urban District Industrial</td>
<td>72</td>
</tr>
<tr>
<td>Low Density Residential</td>
<td>Residential districts by average lot size: 1/2 acre lot</td>
<td>25</td>
</tr>
<tr>
<td>Open Spaces</td>
<td>Open Space (lawns, parks, golf courses, cemeteries, etc.) (4) - Fair Condition (grass cover 50% to 70%)</td>
<td>49</td>
</tr>
<tr>
<td>Parking and Paved Spaces</td>
<td>Impervious areas: Paved parking lots, roads, driveways, etc. (excluding right-of-way)</td>
<td>100</td>
</tr>
<tr>
<td>Residential 1/8 acre</td>
<td>Residential districts by average lot size: 1/8 acre or less</td>
<td>65</td>
</tr>
<tr>
<td>Residential 1/4 acre</td>
<td>Residential districts by average lot size: 1/4 acre</td>
<td>33</td>
</tr>
<tr>
<td>Residential 1/3 acre</td>
<td>Residential districts by average lot size: 1/3 acre</td>
<td>30</td>
</tr>
<tr>
<td>Residential 1/2 acre</td>
<td>Residential districts by average lot size: 1/2 acre</td>
<td>25</td>
</tr>
<tr>
<td>Residential 1 acre</td>
<td>Residential districts by average lot size: 1 acre</td>
<td>20</td>
</tr>
<tr>
<td>Residential 2 acres</td>
<td>Residential districts by average lot size: 2 acre</td>
<td>12</td>
</tr>
<tr>
<td>Water/Wetlands</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Color Key**

- Basic Input Value
- Detailed Input Value
- Basic and Detailed Input Type Value
Visibility

What land is visible from the selected location?

• Forest lookout stations
• Wireless telephone base stations
• Microwave towers
• Highway advertisement pole
Viewsheds

- visible terrain
- hidden terrain

lines of sight

viewpoint
Viewsheds
An example
Shaded Relief

- **Shaded Relief** combines patterns of shadow with map information to give a 3D effect

- 3D views are also used to calculate the visibility of a particular area: Viewshed

- Can a cell phone receive a call in a particular place?
Shaded Maps
Tools in ArcGIS Spatial Analyst

- ArcScene provides you a 3D GIS analyst extension
- Arc GIS allows you to take a digital elevation model and derive:
  - Hillshade
  - Aspect
  - Slope
  - Contours