Lecture 4: Digital Elevation Models

GEOG413/613
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Digital Terrain Modeling

- Terms: DEM, DTM, DTEM, DSM, DHM...not synonyms. The concepts they illustrate are different

- Digital Terrain Modeling
  - Concepts and techniques of acquiring and using digital elevation data
  - The most used terms in the field are
    - Digital Elevation Model, DEM
    - Digital Surface Model, DSM
    - Digital Terrain Model, DTM
Digital Terrain Modeling

- Digital Elevation Model
  - The term is widely used in North America
  - Measurement of height from a reference surface like mean sea level or a geodetic datum
  - Mostly used for elevation data alone

- Digital Surface Model
  - Includes heights of natural features like vegetation and anthropogenic features (e.g., buildings)

Digital Terrain Modeling

- Digital Terrain Model
  - Digital Terrain Model: Coined in 1958 by Miller and Laflamme
  - Measurement of height from a reference surface like mean sea level or a geodetic datum
  - Tends to include topographic information (such as terrain features, land forms) and non-topographic information (such as social economic data)
  - Tends to have a wider meaning than DEM
Digital Surface Models

Digital Terrain Models

PG LiDAR DEM (2009) – ‘bare earth’ – high precision (sub-metre) and accuracy
Digital Elevation Models

- **DEM**
  - An array of uniformly spaced elevation data
  - A data file containing an array of elevation values
- **DTM**
  - A computer representation of terrain stored as a set of 3D coordinates (x,y,z)

Digital Terrain Modeling

- Digital Terrain Modeling as a process
  - Terrain data sampling
  - Terrain data processing and analysis
    - Manipulations, algorithms to output useful information, & further use in a GIS
  - Terrain visualization
    - Effecting display for problem solving and decision making
- Digital terrain modeling applications
  - Practical use in different fields of science
Digital Terrain Modeling

- DTM Storage Structure
  - Line: Elevation of terrain by contours. \( x,y \) coordinate pairs along each contour for a specified elevation
  - GRID: elevation data stored as arrays ASCII characters or binary numbers. A matrix of elevation values

Source: Li, Zhu and Gold, 2005
Digital Terrain Modeling

- DTM Storage Structure
  - Triangulated Irregular Network (TIN) model: A vector-based structure for storing terrain information. Each point has x,y,z. All points are connected by edges; edges form non-overlapping triangles. Also referred to as irregular triangular mesh
  - Advantage over GRID: can generate more information in areas of complex relief; can avoid the problem of gathering unnecessary data from areas of simple relief

Teknomo, Kardi. Introduction to GIS. Oldref: http://people.revoledu.com/kardi
Break lines

**Soft breaklines** are used to ensure that known z-values along a linear feature are maintained in a TIN, e.g., ridge, valley bottom.

**Hard breaklines** define interruptions in surface smoothness. They are the most common type of a breakline. Hard breaklines are typically used to define streams, roads, shorelines, dams.

Digital Terrain Modeling

- **TIN vs. Grid**
  - TINs are more useful for:
    - highly variable surfaces with irregularly distributed sample data
    - representing the influence of streams, roads, lakes (breaklines)
    - examining localized areas (large-scale maps)
    - they take longer to build and require more disk space
  - Grids are more useful for:
    - evenly distributed sample data
    - examining large study areas
    - load fairly quickly and require less disk space
    - simpler data structure, *simpler* for transfer/storage
      (= demise of use of TINs with the internet era)
Digital Terrain Modeling

- Methods of acquiring Digital Terrain Data
  - Existing Contour Map
  - Surface Sensing
  - Photogrammetry
  - Ground Survey

Acquiring Digital Terrain Data

- Existing Contour Maps
  - Manual Digitization, scanning
  - Label the contour lines
  - Create TIN: by triangulation
  - Create GRID: by interpolation
    - Accuracy is low
    - Useful for small scale maps (wide area coverage)
Acquiring Digital Terrain Data

- **Surface Sensing**
  - Imagery is acquired by recording radiation reflected back using a variety of sensors
    - Visible – Infrared
    - Synthetic aperture radar (SAR)
    - Hyperspectral
    - High Accuracy

- **Photogrammetry**
  - Stereo plotting machines
  - Software algorithms
  - Using the relation between stereo parallax and object elevation in the scene for orthogonal and central projection imagery
  - High Accuracy

- **Ground Survey**
  - Total stations, laser scanners
  - Very High Accuracy
Building Surface Models

- Satellite or aerial digital images can directly lead to the generation of a DEM as a continuous surface.
- Otherwise point interpolation is essential:
  - no interpolation algorithm can be defined as best
  - Factors include:
    - ground morphology or terrain characteristics
    - the application and required accuracy of the DEM
    - the DEM structure that the interpolation software can manage

Two interpolation methods can produce different results.

Source: Mario A. Gomarasca 2009
Building Surface Models

- Interpolation Methods
  - among the most popular are:
    - Inverse Distance Weighting
    - Nearest Neighbour
    - Splining
    - Kriging

DEM creation by interpolation

- Inverse distance weighted – simple and quick
- Nearest neighbour – honours raw values
- Spline – minimizes curvature -> smooth surface
- Kriging – uses spatial correlation of points
DEM creation by interpolation

Inverse Distance weighted - simple  Nearest neighbour – honours raw values

**Spline**
- minimizes curvature -> smooth surface

**Kriging**
- uses spatial correlation of points (employing semi-variogram of distance v difference)

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**DEM Caution**

- They are models, not reality
- They always include errors (subject to scale and data collection process)
- Display, analyse – reproject to coordinate system
- Reproject DEMs with caution
  - if raster and vector data have different projections, reproject vector to match raster, not vice versa
  - Raster reprojection involves resampling every pixel and may introduce artefacts
  - If DEM download offers geographic or UTM, pick UTM
- Generate and examine hillshade for errors / quality
DEM**: Sources of error and variability

- **Resolution – pixel size**
  - The accuracy of a DTM depends on the accuracy of its source data and on the resolution.
  - Two DTMs produced from the same data will contain different information if their resolution and sampling strategies are different.

- **Data processing and interpolation**
  - A TIN produced from a grid DTM will contain uncertainties related to the original DTM structure and its inherent errors.
  - Analysis and calculations based on existing DTMs may also introduce errors due to point interpolation or fitting surfaces.
DEMss: Sources of error and variability

- Missing data – clouds, steep slopes
- Change – landslides, glacier ablation, forest clearance

Hillshading to highlight possible errors

... after acquiring or generating DEM
Vector reprojection – simple reallocation of x, y coordinate for vertices in new coordinates

ArcGIS also has a ‘majority’ method

Raster reprojection – not so simple: Every pixel has to be reassigned / resampled

Resampling

After the transformation, a resampling of the pixel values is performed
- nearest neighbour
- bilinear interpolation
- cubic convolution

ArcGIS also has a ‘majority’ method

pixel arrangement 1 = input (distorted)
pixel arrangement 2 = output (corrected)
This can cause striping and artifacts.

Avoid reprojecting rasters if you can!

- Reproject vectors first e.g. topo to raster
Modeling the Earth: Geoid, Ellipsoid, Datum

- **Geoid** – The surface representing the earth's gravity field, which approximates mean sea level. It is perpendicular to the direction of gravity pull. Since the mass of the Earth is not uniform at all points, the magnitude of gravity varies, and the shape of the geoid is irregular.

- **Ellipsoid (Spheroid)** – Measure location (latitude and longitude) of points of interest. Many different ellipsoids have been defined for the world.

- **Datum** - Built on top of the selected spheroid, and can incorporate local variations in elevation.

Geodesic measurements
Some widely available DEMs

- **NTDB**: geobase.ca - all Canada  **1950-2010**  50m
  - Interpolated from map contours (**except BC**)
  - Downloaded by 1:50,000 map sheet E / W

- **BC TRIM**: Raster from air photos  **(1979-89)**  25m
  - Interpolated from mass points and breaklines
  - Redistributed for NTDB-BC

- **Shuttle Radar Topographic Mission (SRTM)**  **2000**  90m / 30m

- **ASTER Global DEM (GDEM)**  **2000-08**  30m

Common uses of DEMs

- Extracting terrain parameters
- Modelling water flow
- Mass movement studies (e.g. landslides)
- Rendering of 3D visualizations
- Ortho-rectification of satellite imagery
- Terrain analyses in geomorphology
References


- Mario A. Gomarasca (2009) Basics of Geomatics, New York Springer