DTM: definition

- Why DTM (Digital Terrain Modeling)?:

- Q: (1) Digital?
- (2) Terrain?
- (3) Modeling?
- (4) limited to the Earth?

DTM: definition

- Why DTM (Digital Terrain Modeling)?: representation of terrain surface
  (e.g.) various representation methods - see Fig.1.4 (Li et al, 2005)

- DTM: is simply a statistical representation of the continuous surface of the ground by a large number of selected points with known X, Y, Z coordinates in an arbitrary coordinate field (Miller and LaFlamme, 1958)

- Similarity? DEM(Digital Elevation Model) / DHM(Digital Height Model) / DGM(Digital Ground Model) / DTED(Digital Terrain Elevation Data):
  (1) Differences: Ground/ Height/ Elevation/ Terrain (p.7, Li et al, 2005)

  - Ground: the solid surface of the earth, a solid base or foundation, a surface of the earth, bottom of the sea etc.
  - Height: measurement from base to top, elevation above the ground or recognized level especially that of the sea, distance upwards, etc.
  - Elevation: height above a given level especially that of the sea, height above the horizon etc.
  - Terrain: tract of country considered with regarded to its natural features etc, an extent of ground region territory

DTM:

- (2) Differences: DEM/DHM/DGM/DTM/DTED (p.2, El-Sheimy et al, 2005)

- -DEM: measurement of height above a datum and the absolute altitude or elevation of the points in the model, creation of a regular array of elevations, normally squares or a hexagon pattern over the terrain
- -DHM: synonymous to DEM
- -DGM: emphasis on a digital model of the solid surface of the Earth. Any point on the ground surface can be generated by an inherent interpolation function. Earth surface no longer considered discrete.
- -DTM: involves both height and elevations and other GIS features such as rivers and ridge lines. Also includes derived data such as slope, aspect, and visibility. (= planimetric + terrain relief data)
- -DTED: used by U.S. DMA (Defense Mapping Agency). Grid-based data
- * DEM includes roof of buildings and tops of trees (e.g. satellite imagery)
- **LIDAR (LIght Detection And Ranging) can produce DEMs or DTMs.

DTM: possible information to be contained

- (1) Landforms: elevation, slope, slope form, relief etc.
- (2) Terrain features: hydrographic features (river, lakes, coat lines), transportation networks (roads, railways, paths), settlements, boundaries, etc.
- (3) Natural resources and environments: soil, vegetation, geology, climate etc.
- (4) Socioeconomic data: population distribution in an area, industry and agriculture and capital income, etc.
- (p.8, Li et al, 2005)

DTM: procedures

- Real World to model
- (1) Planning & Design of DTM project: contracting with market producer
- (2) DTM Generation: sampling, data capture, verification of raw data
- (3) DTM Manipulation: reconstruction, modification, refinement, editing, filtering, merging, joining, converting format (e.g. TIN to grid)
- (4) DTM Surface: validation, QC(Quality Control)
- (5) DTM Interpretation: DTM is a function of value as extractive knowledge, attributes, information
- (6) DTM Visualization: required for better perceptual understanding (interactive or static)
- (7) DTM Application & DTM product: e.g. soil erosion analysis
- (8) Shipment to User

- (p.10, Li et al, 2005 & p.5, El-Sheimy et al, 2005)

DTM: data models

- Types of models: Conceptual, Physical, Mathematical:

- Requirement as good data model:

- (1) accurately represent the surface
- (2) be suitable for efficient data collections
- (3) minimize data storage requirements
- (4) maximize data handling efficiency
- (5) be suitable for surface anaylsis

- Methods for DTM:
- (1) Contours
- (2) Grids
- (3) TIN (Triangular Irregular Network)

DTM: comparison of data models

- Grid data structure vs TIN data structure (p.12-13, El-Sheimy, 2005)

- Grid data sturcutre: easy processing but inefficient sampling (e.g. missing the highest or lowest points), no flexibility with various grid sizes

- TIN data structure: flexible resolution but requires manual control

- Comparison for Smoothing, Geomorphology, Point density, Robustness, Applicability & data structures (see Table 1.1, p.15 & Table 3.4, p.88, El-Sheimy, 2005)

DTM: Global data models (p.16-18, El-Sheimy, 2005)

- (1) GLOBE
- -Global Land One-km Base Elevation
- -international effort by CEOS (Committee on Earth Observation Satelites) and IGBP-DIS (International Geosphere-Biosphere Programme's Data and Information System)
- -absolute vertical accuracy: 10 to 500 m at 90% linear error
- -from 11 sources: satelite imagery, aerial photography, satelite altimetry, cadastral survey data, hardcopy topographic maps
- -horizontal coordinate system: WGS84 (World Geodetic System 84)
- -vertical unit: elevation in meters above mean sea level (-407m to 8752 m on land, no data on ocean area with virtual value of -500)

DTM: Global data models (p.16-18, El-Sheimy, 2005)

- (2) DTED
- -Digital Terrain Elevation Database
- -U.S. product by NIMA (National Imagery Mapping Agency)
- -horizontal grid spacing of 30 arc-seconds (approx. 1km) (Level 0 available to public)
- -horizontal accuracy of 23m, vertical accuracy of 18m (Level 2)
- -horizontal with WGS84, vertical with MㄴI by EGM(Earth Gravitational Model) 1996

- (3) GTOPO30
- -global DEM with horizontal grid spacing of 30 arc-seconds (approx. 1km)
- -USGS EROS Data Center over 3-year period
- -derived from several vector, raster sources of topographic information (e.g. USGS DEM, Peru Map, Antarctic Digital Database)
- -accuracy varies depending on the data source

DTM: Global data models (p.16-18, El-Sheimy, 2005)

- (4) SRTM
- -Shuttle Radar Topography Mission
- -joint project between NASA (National Aeronautics and Space Administration) and NGA (National Geospatial-Intelligence Agency)
- -acquired using radar interferometry with manned space-born vehicle
- -all weather, all the time acquisition with min. influence of clouds
- -targeted to all lands between 60˚ north and 56˚ south latitude
- -some data: 16m abs. vertical accuracy, 10m relative height accuracy, 20m absolute horizontal circular accuracy

DTM: data acquisition methods

- (1) Traditional surveying
- (2) GPS surveying
- (3) Aerial Photogrammetry: *Greek words photos + gramma + metron*
- (4) Space photogrammetry: satelite image
- (5) InSAR, IFSAR (Interferometric Synthetic Aperture Radar):
- -works with interferometric phase information
- (6) Radargrammetry, Satelite Stereo SAR, RADARSAT:
- -works with intensity information from two SAR images
- (7) LIDAR

- Comparison of unit cost and accuracy (Fig. 2.29 p.64, El-Sheimy et al, 2005, Table 3.6 p.62, Li et al, 2005)

- Reading assignments:
- -p.19-29 (El-Sheimy et al, 2005), p.40-55 (Li et al, 2005)
- *Other ref: ASPRS Workshop (2006) – separate file

DTM: various modeling methods

- Examples of popular GIS S/W: -Similarity? GRASS vs ESRI DTM Grid Data Format (see Table 3.1 & 3.2, p.72-73, El-Sheimy et al. 2005)

- Classification of surface modeling (by basic geometric unit used)
- (1) point-based modeling: too many data points for flat surface
- (2) triangle-based modeling: accommodates complex morphology
- (3) grid-based modeling: simple but just averaging the morphology
- (4) a hybrid approach combining any two of the above three items

- Classification of surface modeling (by type of source data used)
- (1) direct construction from measured data
- (2) indirect construction from derived data

DTM: Discrete vs Continuous

- Discrete vs Continuous:
- -Simple but complex: Polynomial function (more terms for more complex surface), Table 4.1 & Fig.4.1 (p.66-67, Li et al, 2005)

- Semi-Continuous: by smoothing discrete surface
- -interpolation (e.g. Kriging, see the example, Chap.5 or p.147-158, El-Sheimy et al, 2005)
- -moving average (e.g. Fig.4.23, p.125, El-Sheimy et al, 2005)

DTM: TIN

- Principles of TIN:
- (1) Batch (or static) approach: all the data to form an overall network
- (2) Dynamic process: allows the addition or removel of points during the triangulation process (*dynamic does not mean the movement of points)

- TIN can be generated from Raster data or Vector data, using Static mode or Dynamic mode (by gradually adding new points, i.e. incremental triangulation).

- Any combination of TIN is possible (Fig. 5.2, p.88, Li et al, 2005), BUT !
- -fully representative of each area of triangle?
- -efficient & consistent to create? (not just randomly?)

DTM: For better TIN

- Several principles for better TIN (p.89-90, Li et al, 2005)
- (1) Empty circumcircle principle: no other points are contained by the circumcircle of a Delaunay triangle (Fig.5.3, p.89, Li et al, 2005)
- (2) Local equiangularity principle (Fig.5.4, p.89, Li et al, 2005)
- -MAX-MIN principle with LOP (Local Optimization Procedure) (see Tsai, 1993)
- -If for every convex quadrilateral formed by two adjacent triangles, the swapping of diagonals will not cause a decrease in the minimum of the six interior angles concerned and at the same time will not cause an increase in the maximum angle (minimum angle is maximized and the maximum angle is minimized)

DTM: For better TIN

- Several principles for better TIN

- (3) Minimum sum-distance principle: the new point selected to construct a new triangle is the one that has the sum of its distances to the end two points of the triangle baseline as the smallest value (Yeoli, 1977)

- (4) Minimum circumscribing circle radius principle: the new point that is selected should form a triangle in which its circumscribing circle radius is the smallest value (Elfick, 1979)

- (5) Minimum distance from the center of the circumscribing circle to the base line (McLain, 1976)

DTM: Vector-based Static Delaunay Triangulation

- Selection of starting point: any point will give same result
- -geometric center of the data points
- -a line segment on the imaginary boundary (see Fig.5.5, 5.6 p.91, Li et al, 2005)
- -a line segment on the boundary convex hull (e.g. Gift Wrapping algorithm, see Fig. 5.7, p.92, Li et al, 2005)

- Example of Process of Delaunay triangulation (Fig.5.9, p.93, Li et al, 2005)
- (1) Starting point as the point with min. Y coordinate
- (2) Choose the one nearest the starting point along the convex hull clockwise as the second vertex of the first triangle
- (3) Choose the third vertex point depending on the criteria
- (4) Move forward clockwise and gradually toward the center

- *For imaginary boundary: Choose the lower-left corner and proceed the triangulation shell by shell (Fig.5.10, p.94, Li et al, 2005)

DTM: Vector-based Dynamic Delaunay Triangulation

- Problem of Static process: inefficient process for searching for points if the amount of data is large

- Dynamic triangulation by gradual adding of new points into the network (i.e. incremental triangulation)

- e.g. Bowyer-Watson algorithm (Fig.5.11 & 5.12, p.95, Li et al, 2005)
- -most practical algorithm
- -start with coarse triangles
- -add new point within triangle to build more triangles
- -check a need for swapping the edge with the alternative diagonal by applying the empty circumcircle principle into the three edges of the old triangle
- -swap or leave and then proceed with another coarse triangle

- *Removal of point from triangulation: for alternative design (Fig.5.16, p.99, Li et al , 2005)

DTM: Constrained Delaunay Triangulation

- Problem with F-S (Feature-Specific) lines such as ridge lines, course lines, break lines (see Fig.5.17(c), p.100, Li et al, 2005 and definitions on p.23 & Fig.27 & 2.8, p.24, Li et al, 2005)

- Ridge lines: the lines connecting pairs of points such that the points on them are local maxima

- Course lines: the lines connecting pairs of points such that the points on them are local minima

- Passes: crossing points of ridge lines and course lines

- Break lines: where the slope change is very sudden

- Solution: Point densification on feature lines (Fig.5.18, p.100 and Fig.5.20, p.102, Li et al, 2005)

DTM: Triangulation from contour data

- (1) treat contour lines as random points: BUT Problem (p.103, Li et al, 2005)
- -an edge of triangle crossing another contour (Fig.5.21a)
- -three vertices of a triangle taken from the same contour line (Fig.5.21b)

- (2) treat all contour lines as constraint lines: BUT problem of heavier computation

- *Solution: Use skeleton lines instead of contours
- -Add more points to derive skeleton lines (Fig. 5,22 – 5.25, p.103-105, Li et al, 2005)
- -Estimate the height for skeleton points using eqn. (see Eqn.5.6, p.105, Li et al, 2005) (see the calculated heights (e.g. 22.41 etc) on the skeleton between contour 20 and contour 30 Fig.5.27a, p.107, Li et al, 2005)
- *Self-study: estimation of heights on skeleton (Fig.5.26 using Eqn.5.6, Li et al, 2005)

DTM: Triangulation from Voronoi diagrams

- Simple process with vector-based algorithm for generation of Voronoi diagram:
- -Two points that share a common Voronoi boundary are joined to form a triangle edge (Fig. 5.29, p.109, Li et al, 2005)

- More complex process with raster-based algorithm for generation of Voronoi diagram:
- -Distance calculation will reveal the Voronoi diagram
- -Problem: Euclidean distance is not always in interger
- -Solution: Use raster distance (e.g. city block distance or chessboard distance) instead of vector distance (Fig.5.32 & 5.33, p.112, Li et al, 2005)

- Example of Voronoi diagram: Fig. 5.36, p.114, Li et al, 2005

DTM: Contouring from DTM

- 4 contouring methods (main Principle: contouring by interpolation)
- (1) vector-based contouring from a grid-based DTM
- (2) vector-based contouring from a triangulation-based DTM
- (3) raster-based contouring from a grid-based DTM
- (4) raster-based contouring from a triangulation-based DTM

- Case (1):
- Ambiguity of contour line direction: Fig.11.6 p.237, Li et al, 2005
- → solution: (1) add a central point, whose height is the average of the heights of the four nodes (2) arbitrarily set a priority criterion

- Case (2):
- Problems of only two possible exits for a triangle (Fig.11.13)
- → solution: contour threading (exit edge of the current triangle is the entrance edge of the adjacent triangle, Fig.11.14, p.242, Li et al, 2005)

DTM: application

- Calculation of surface area: surface in 3D from triangle or from grid
- (Eqn. 13.1 & Eqn.13.3, p.268, Li et al, 2005)
- -TIN: use Eqn. 13.1
- -Grid: divide the grid as two triangles and then use Eqn.13.1

- Calculation of projection area: is equal to the computation of horizontal area (with z=0)
- -TIN: use Eqn. 13.4 (Fig.13.1, p.268, Li et al, 2005)
- -Grid: only count the number of cells

- Calculation of volume: projection area x height (which one?)
- -Example: Eqn. 13.9 & Eqn. 13.10 (using average) (p.270, Li et al, 2005)
- -Question: (1) Any error? (2) Any improvement method reducing error?
- -Application: calculation of volume for cutoff or fill-up for design

DTM: application

- (1) Slope & Aspect: Slope is a vector consisting of gradient and aspect BUT has been used as the same meaning of gradient (i.e. slope = gradient)
- - Slope can be defined in any direction: e.g. Slope $_{E\text{-}W}$
- - BUT sometimes slope means max slope in a certain point (without fixed direction) (Eqn 7.7, p.191, El-Sheimy et al, 2005, Eqn13.18, p.272, Li et al, 2005) and Aspect means the one from the surface with max slope (Eqn 13.19, p.272, Li et al, 2005) (see the references by Dunn & Hickey, 1998)

- - Variety of algorithms for calculation of slope and aspect
- (e.g.) Table 13.1, p.273, Li et al, 2005, see also the example p.192-193, Li et al, 2005 (Question: Which one can we choose?)

- - Illustration of slope and aspect as map with LEGEND
- (No general rule for the interval of slope or aspect, see Figs. 7.13 & 7.14, p.195-196, El-Sheimy et al, 2005, and Figs. 13.6, p.273, Li et al, 2005)

DTM: application

- (2) Plan and Profile curvatures: Table 13.2 & Fig.13.7, p.274, Li et al, 2005
- (application): Finding the good place for collection of water, i.e. dam, Finding the worst place for diffusion of pollutant by surface water
- (Question): How can you interpret the meanings (see Fig.13.8, p.275, Li et al, 2005)

- (3) Rate of change in slope and aspect:
- -Eight values can be calculated (see Fig.13.5)
- -Max magnitude among eight values is the rate of slope changes at the specific point
- -Second derivative as the plan and profile curvature

- (Homework 1: Make a short report based on the paper AND references by Corripio, 2003, IJGIS, vol.17, no.1, p.1-23) assigned to ???

DTM: application

- (4) Roughness: the ratio of the surface area S and its projection onto the horizontal plane A
- - Roughness $_A$ = S/A (1 means horizontal plane)
- - Roughness $_Z$ (to consider two average heights) (Eqn.13.31, p.276, Li et al, 2005)

- (5) Visibility analysis
- - Point-to-Point Visibility (Line of Sight): Eqn.13.34, Fig.13.17, P.282-283, Li et al, 2005
- - Point-to-Area Visibility (Viewshed): see the references, p.284, Li et al, 2005
- (Homework 2: Make a short report based on the paper AND references by Llobera, 2003, IJGIS, vol.17, no.1, p.25-48) assigned to ???

- (6) Hydrological modeling: e.g. ArcHydro