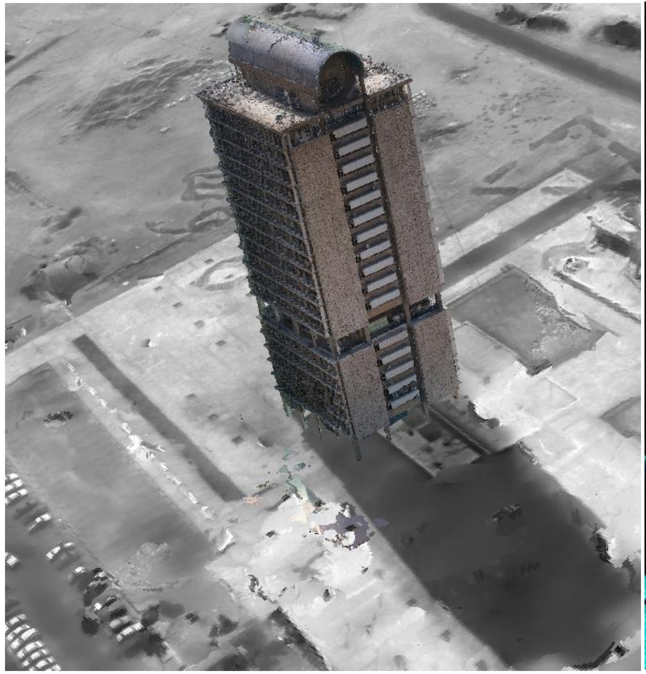
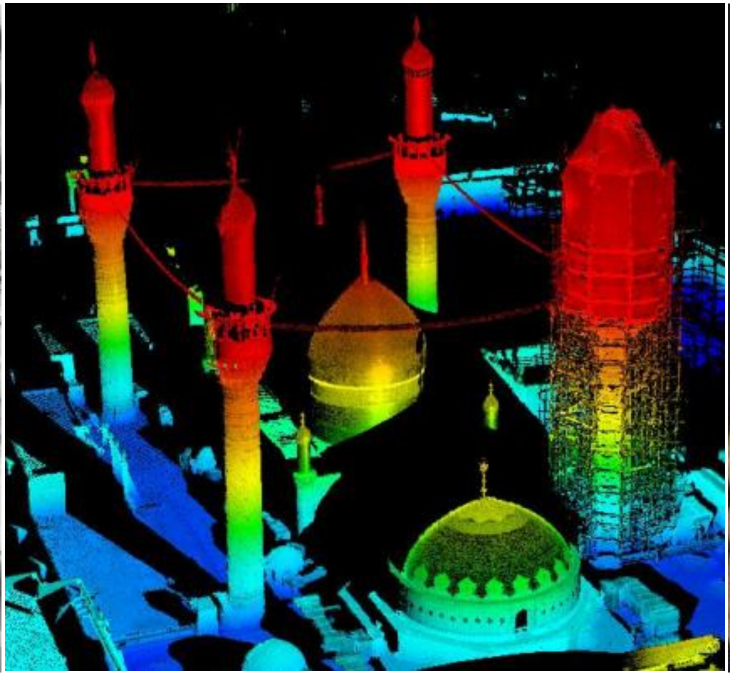
UNIVERSITY OF BAGHDAD

COLLEGE OF ENGINEERING

DEPARTMENT OF SURVEYING ENG.





PHOTOGRAMMETRY- DIGITAL SURFACE MODELLING

BSc - 4TH STAGE

2020-2021

LECTURE 8

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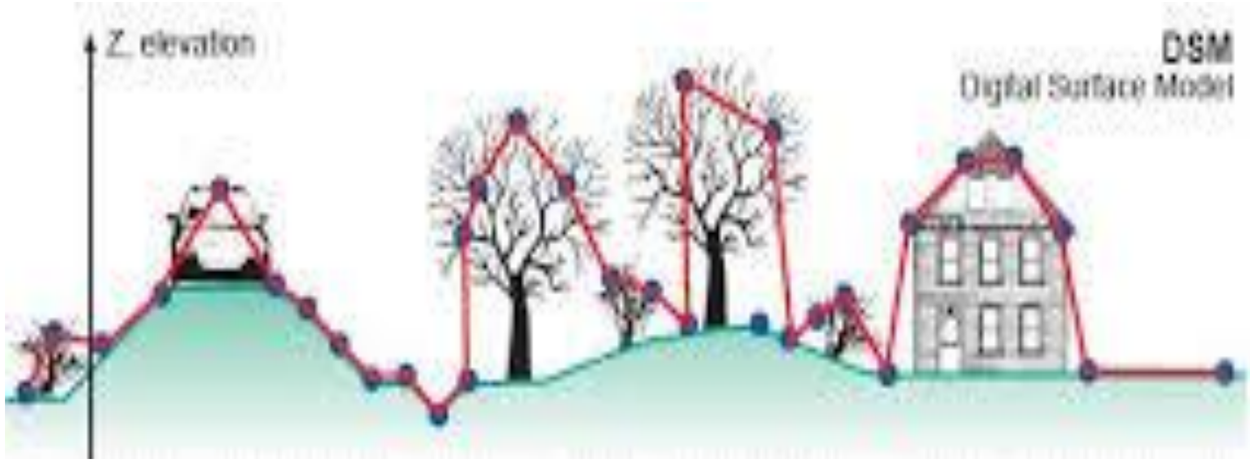
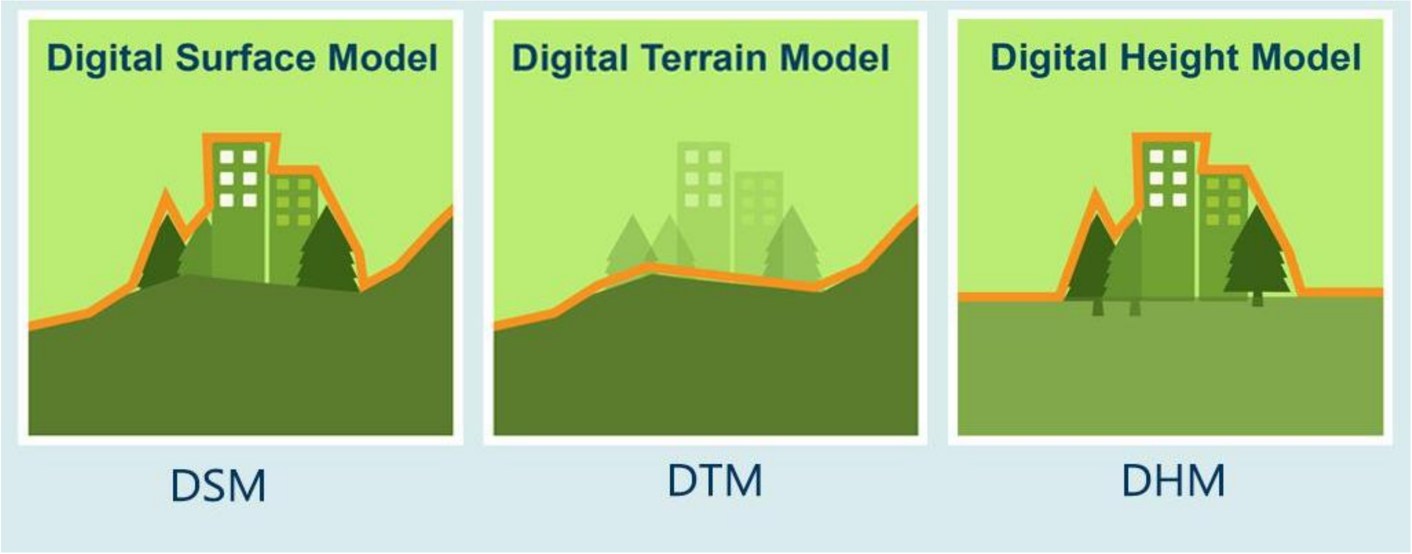
Digital Surface Model

- DSM is a statistical representation of a continuous reference surface based on a vast number of points with known (X,Y, Z) coordinates using automated procedures.
- The precision of DSM in simulating the true terrestrial parameters of elevation, slope and aspect improved significantly the quality of knowledge in numerous applications in earth, environmental and engineering sciences.



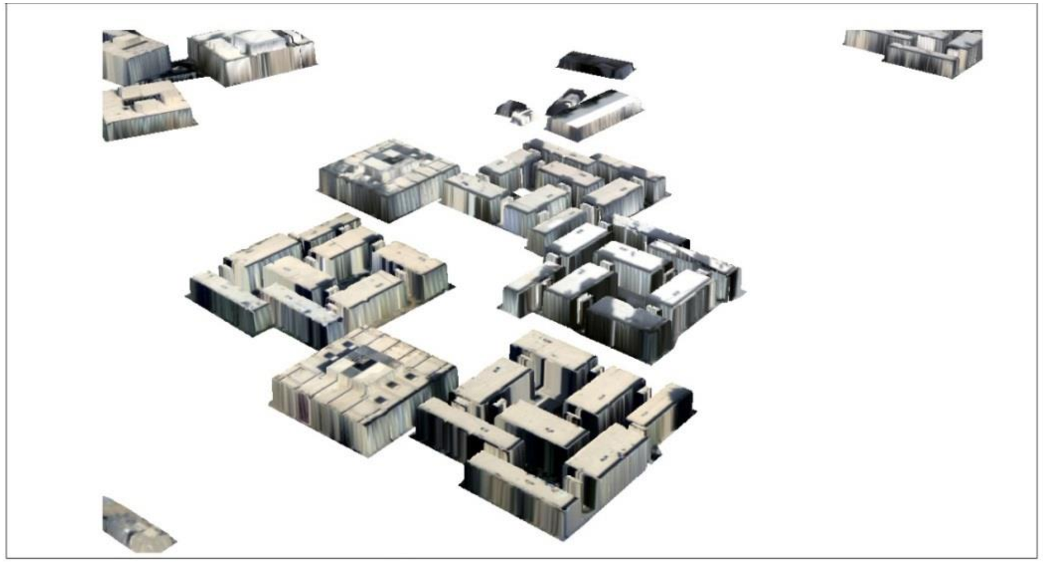
Terminology

- *Digital Terrain Model (DTM).*
- *Digital Elevation Model (DEM).*
- *Digital Height (Canopy) Model (DHM/DCM).*
- *Digital Ground Model (DGM).*
- *Digital Surface Model (DSM).*



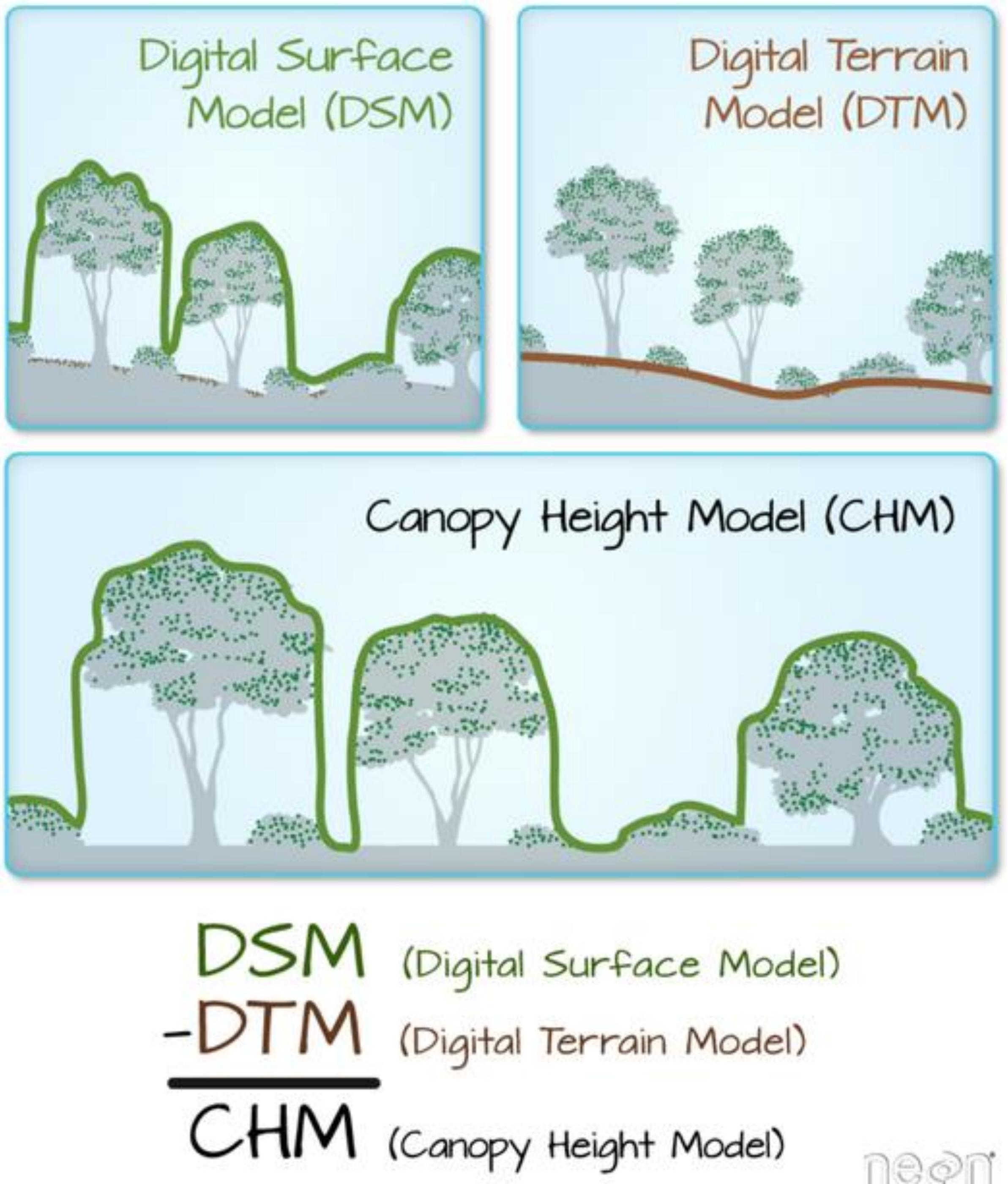
What is a DEM?

- A DEM provides a digital representation of a portion of the earth's surface terrain over a two dimensional surface (UNEP/GRID).
- A DEM is an ordered array of numbers that represents the spatial distribution of elevations above some arbitrary datum's in the landscape (Meijerink et al., 1994).
- A DEM is a digital file consisting of terrain elevations for ground positions at regularly spaced horizontal intervals (USGS definition).



DEM vs CHM!

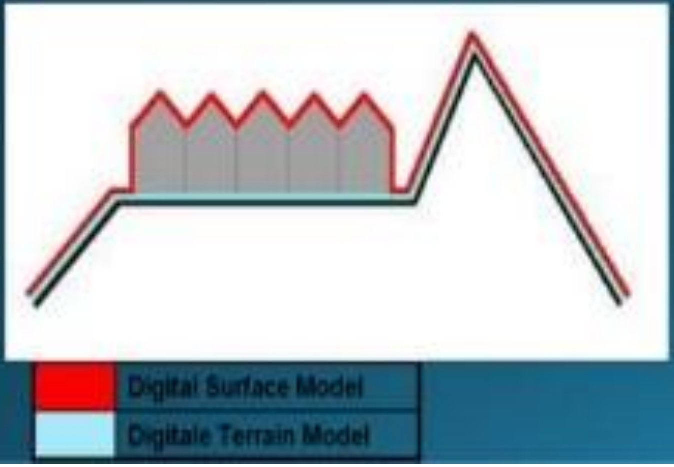
- DEM : defines digital heights of any type of features (including natural, artificial, etc.) above reference ground surface.
- CHM : defines digital heights of Canopies above reference ground surface!

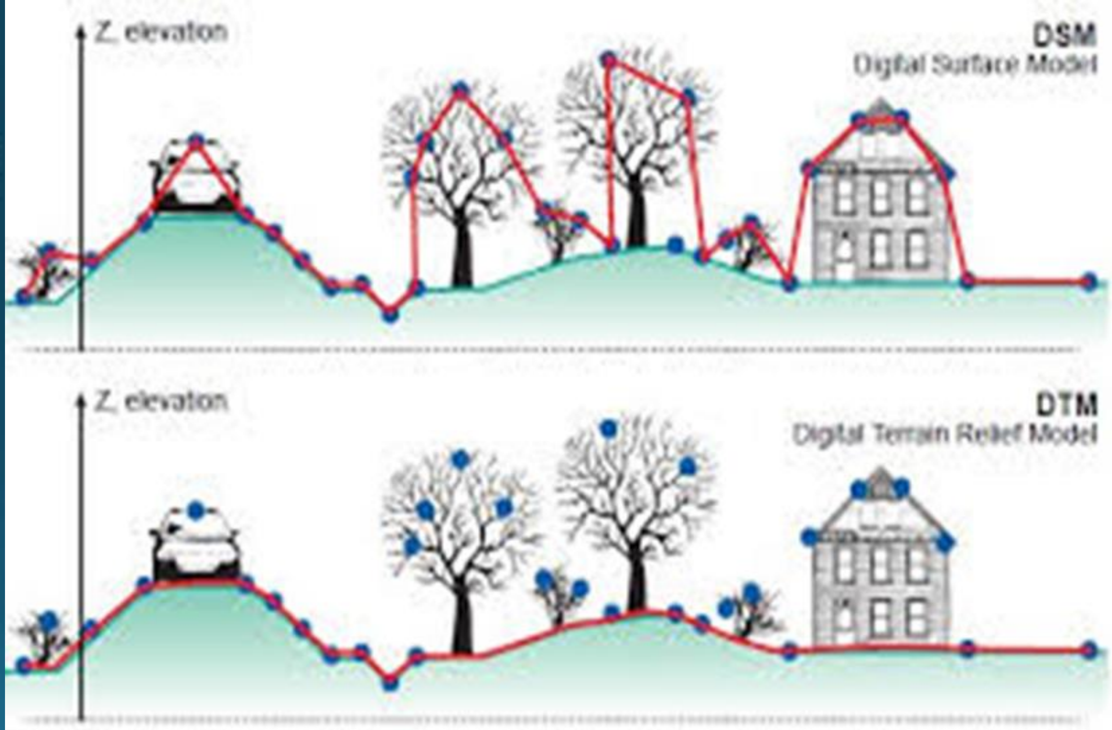


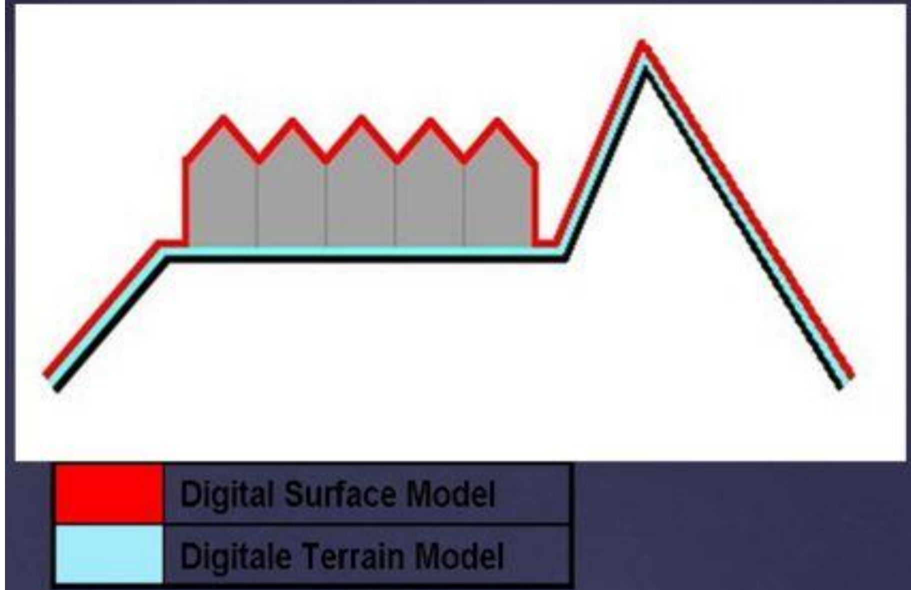
DTM vs DEM vs DSM

DSM = (earth) surface including objects on it

DTM = (earth) surface without any objects



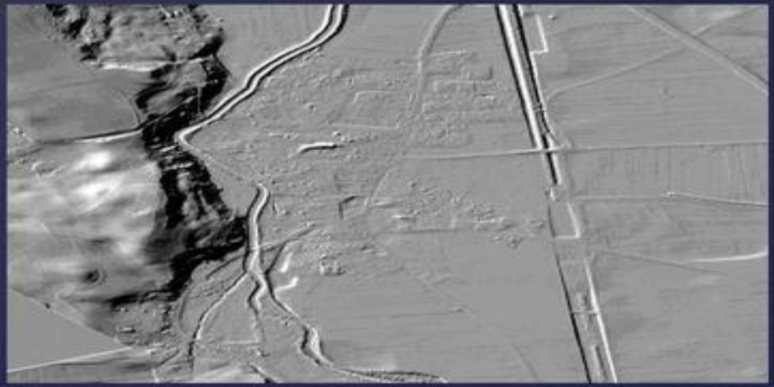




DEM, DTM and DSM…

A digital terrain model is a topographic model of the bare earth –terrain relief - that can be manipulated by computer programs.
Digital Surface Model measures the height values of the first surface on the ground. This includes terrain features, buildings, vegetation and power lines etc. DSM's therefore provide a topographic model of the earth's surface.

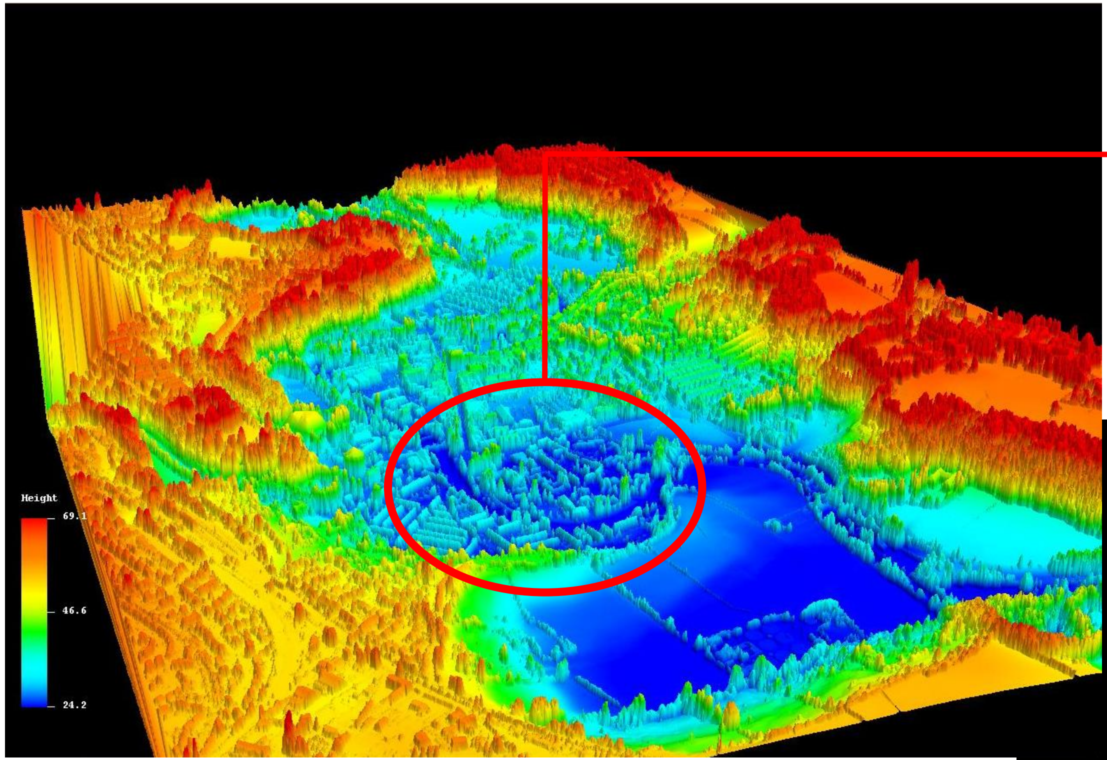
Digital Surface Model

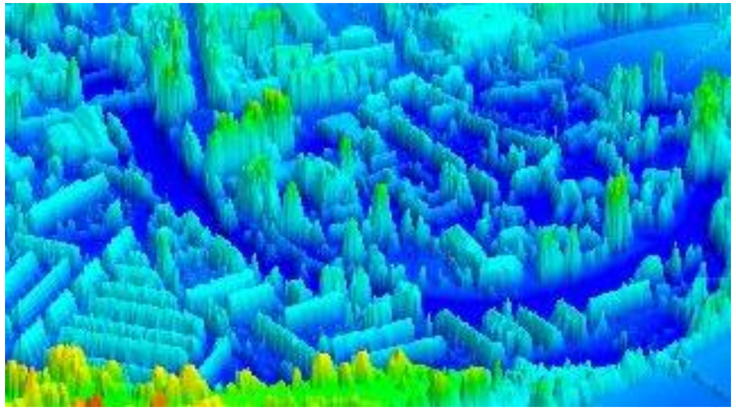


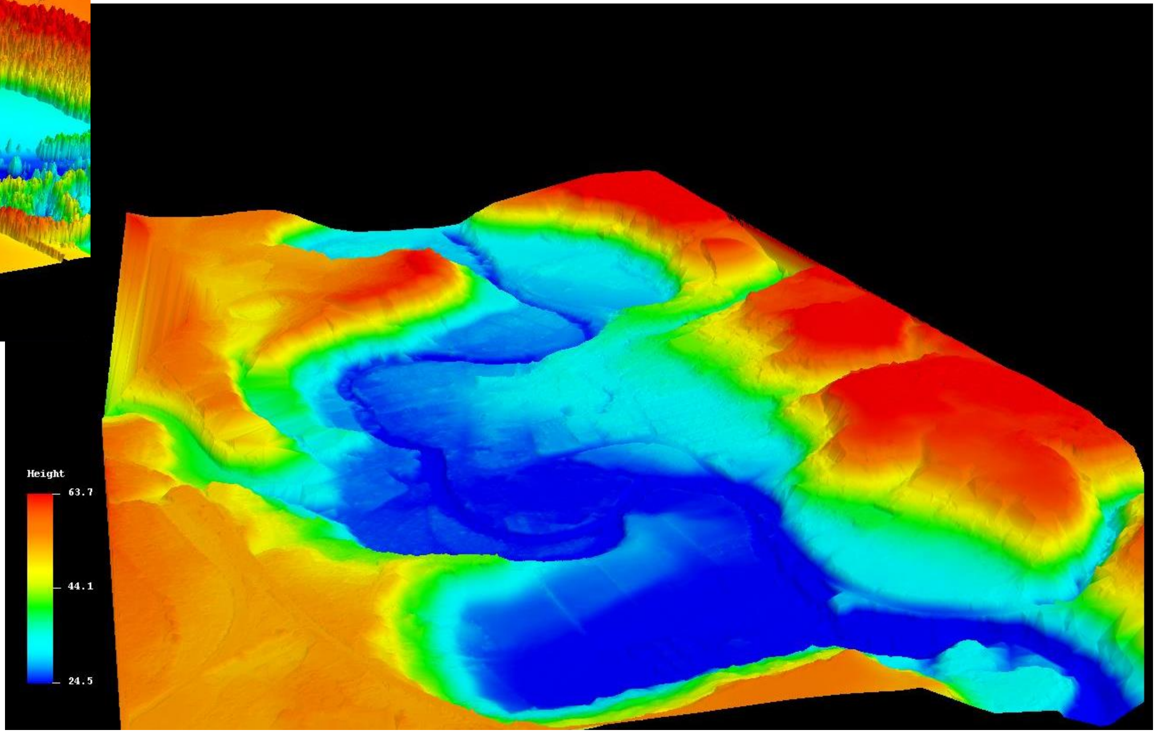
Digital Terrain Model

Digital hill-shade models generated from a Lidar scan.

DSM vs DTM



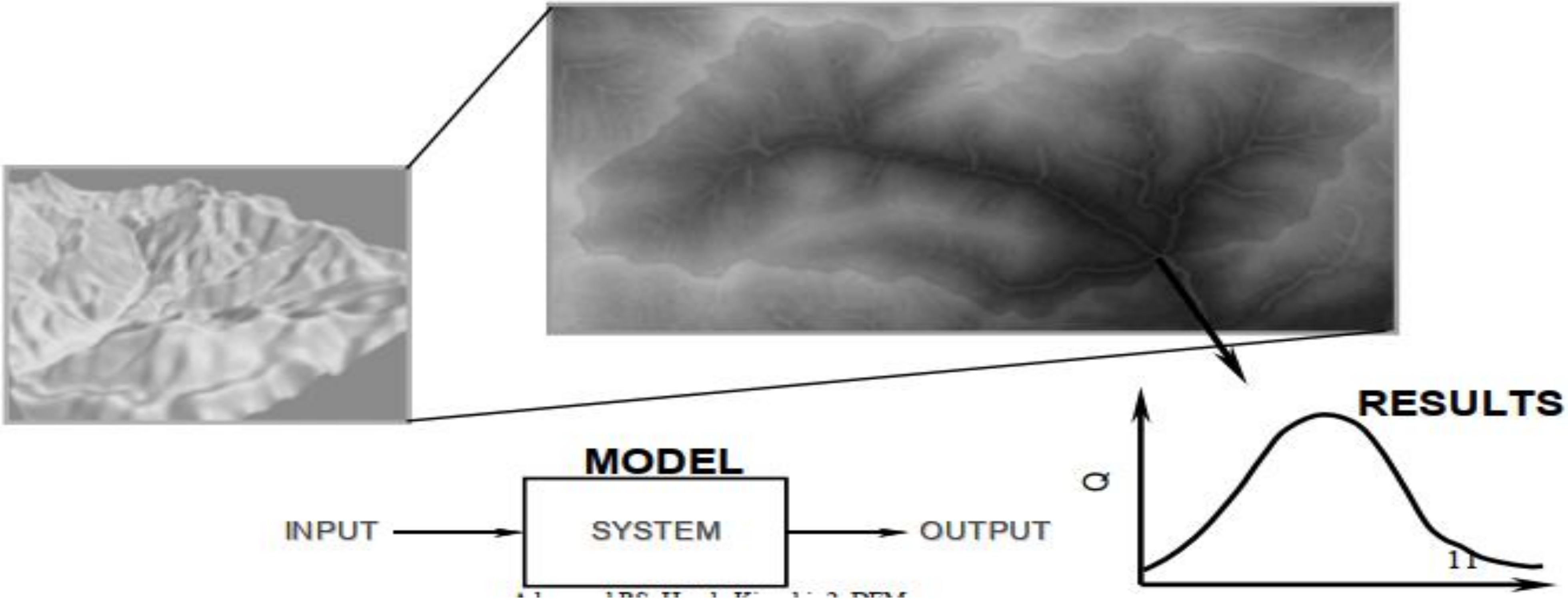





DigitalGlobe™

Why DEM is important?

DEM provides the basis in modeling and analysis of spatio-topographic information.



Structure of DEM

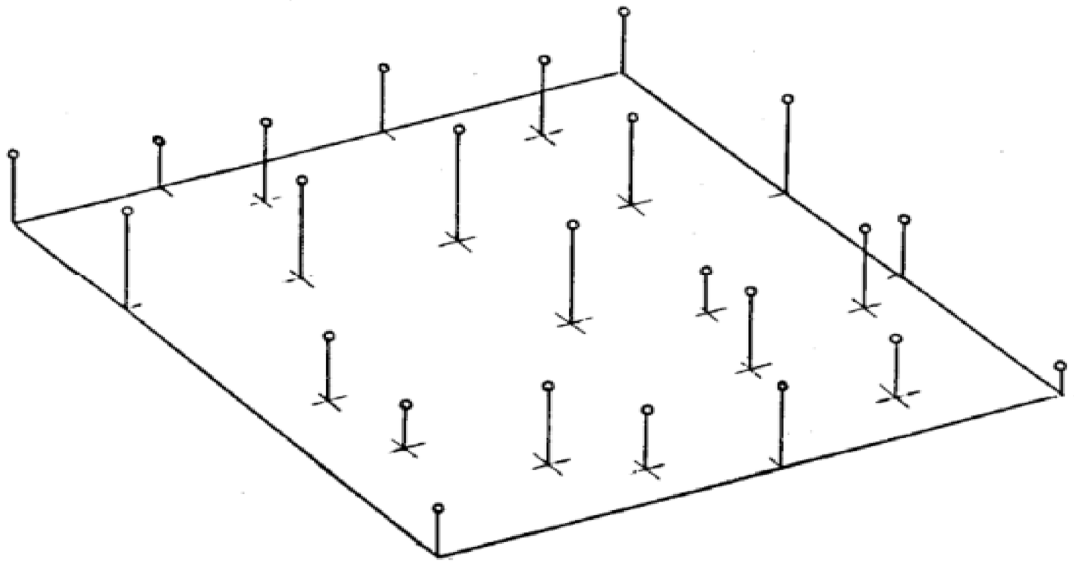
- Line model => describes the elevation of terrain by contours (stored as digital line graphs, DGLs), the x,y coordinate pairs along each contours of specified elevation

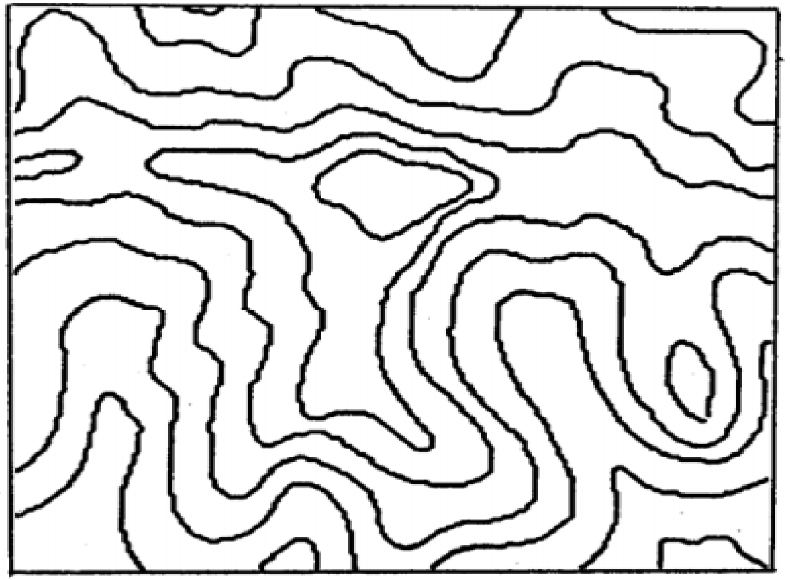
- GRID structure=>elevation data are stored in an array of grids. Data structure of a GRID shares much similarity with the file structure of computers: as two dimensional array (every point can be assign to a row and column). This similarity of storage structures, the topological relations between the data points are recorded implicitly. THIS streamlines information processing and algorithm development

- Triangulated Irregular Network (TIN)=>a network of interconnected triangles with irregularly spaced nodes or observation points with x,y coordinates and z values. Advantage over GRID is its ability to generate more information in areas of complex relief, and avoiding the problem of gathering a lot o redundant data from areas of simple relief

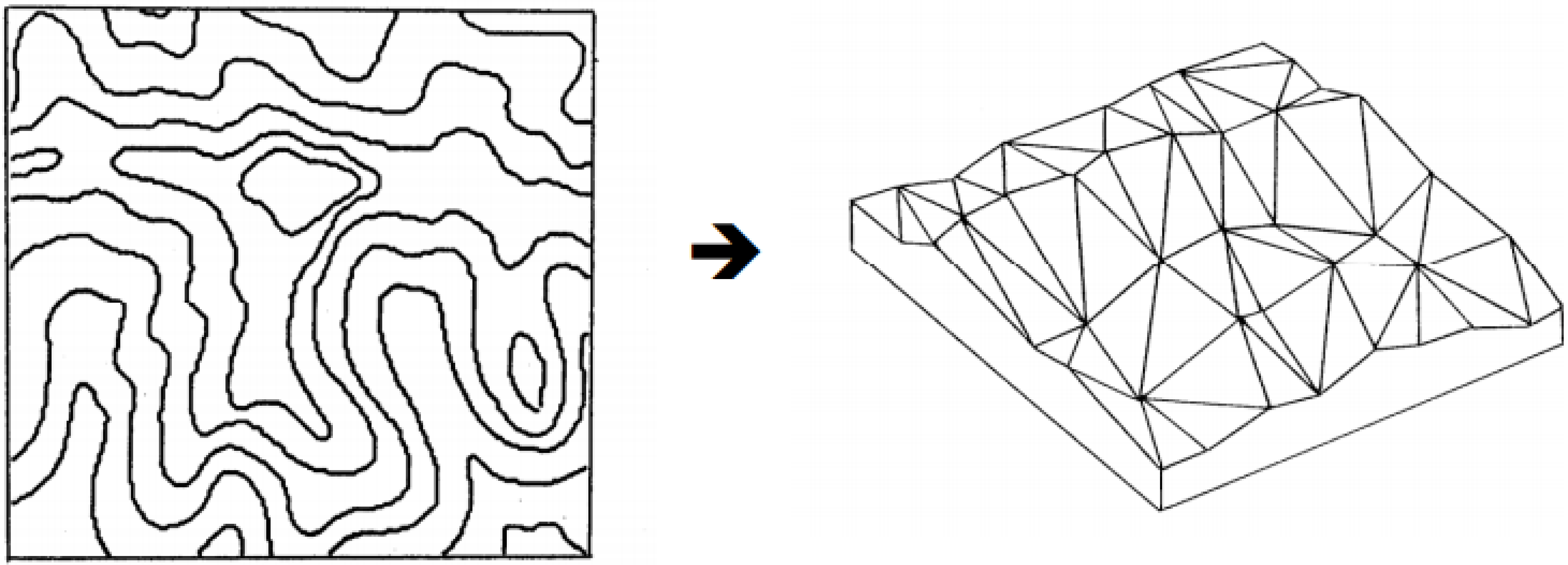
Data sources for DTM

1. Stereo aerial photos (photogrammetry)
2. Measured height values
3. Existing contour line maps

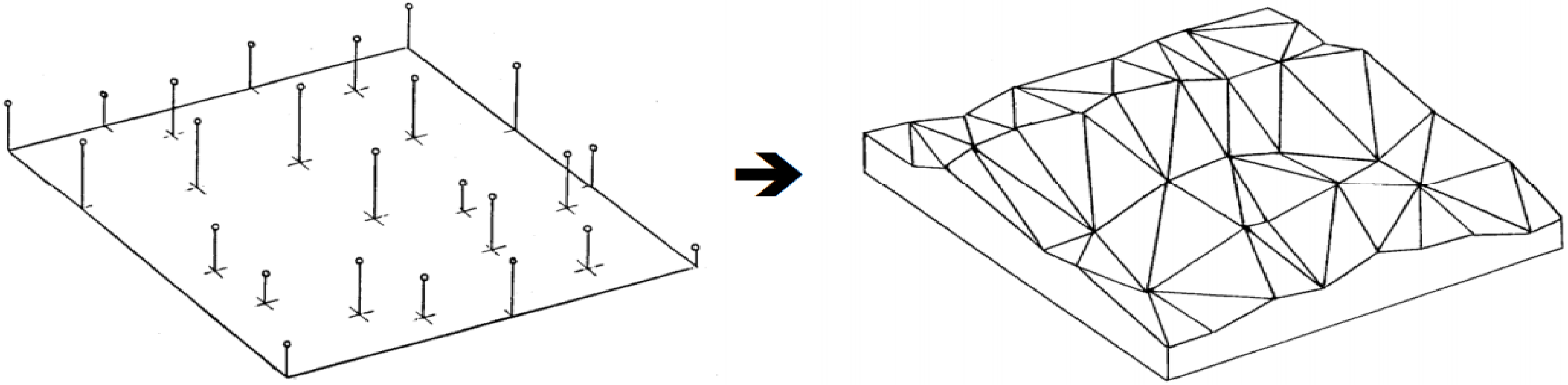




Generating TIN from contour line maps



Generating TIN from height values



a) Direct triangulation.

b) *S*patial interpolation and triangulation.

Spatial interpolation

Consider a terrain function $f(x, y)$.

Given: $f(x_1, y_1) = h_1, \ldots, f(x_m, y_m) = h_m$

Problem: estimating $f(x, y)$ in other points.

Solutions:

- Inverse distance weighted moving average
- Polynomial interpolation

Inverse distance weighted moving average

Given: height values $h_1, \ldots, h_m$ at points $P_1, \ldots, P_m$

Unknown: height value h of a given point P.

Estimation: $h = (h_1/d_1 + \ldots + h_m/d_m) \,/\, (1/d_1 + \ldots + 1/d_m)$

where d_i is the distance between P_i and P.

Properties:

- Good for ridges.
- Flat areas at peaks.
- Local maxima and minima may occur only at given points.

Polynomial interpolation

Given: $f(x_1, y_1) = h_1, \ldots, f(x_m, y_m) = h_m$

Task: approximate $f(x, y)$ with a polynomial $p(x, y)$ of degree r. For example, if $r = 2$:

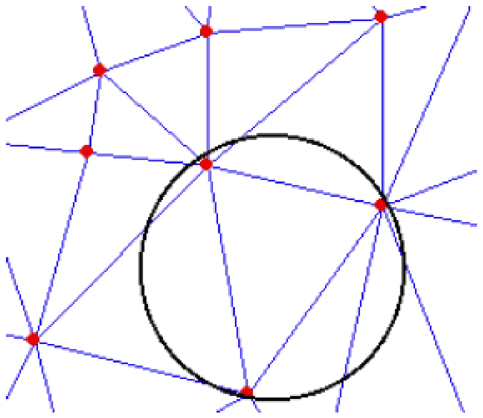
$p(x, y) = a_{00} + a_{10}x + a_{01}y + a_{20}x^2 + a_{11}xy + a_{02}y^2$

Solution: Coefficients $a_{i,j}$ are determined by least squares method: $E = \Sigma_i (p(x_i, y_i) - h_i)^2 \rightarrow \min.$

Properties:

- Local maxima or minima may occur ***not*** only at given points.
- Expensive procedure for contour lines (too many given points)
- Physical terrain features are not considered.

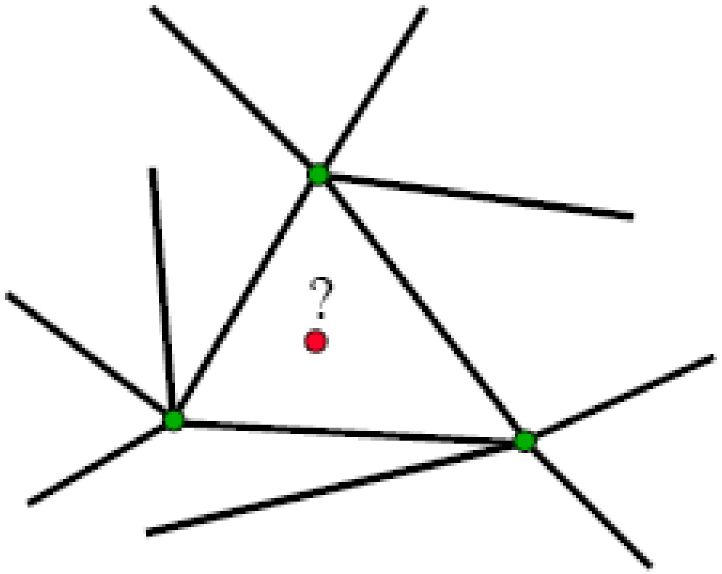
Standard Interpolation of TIN



- Three points form a triangle if the circle which passes through them contains no other point

Interpolation methods

- Linear Interpolation.
- 2nd Exact Fitted Surface Interpolation.
- Quantic Interpolation.



(Linear Interpolation)

$$Z(X,Y) = a_o + a_1 X + a_2 Y$$

$$l = \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \end{bmatrix} \mapsto A = \begin{bmatrix} 1 & X_1 & Y_1 \\ 1 & X_2 & Y_2 \\ 1 & X_3 & Y_3 \end{bmatrix} \mapsto x = \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix}$$

$$\begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \end{bmatrix} = \begin{bmatrix} 1 & X_1 & Y_1 \\ 1 & X_2 & Y_2 \\ 1 & X_3 & Y_3 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} \mapsto l_{3\times1} = A_{3\times3} \; x_{3\times1}$$

$$\hat{x}_{3\times1} = \left(A^T A\right)^{-1} A^T \, l \qquad or \qquad \hat{x}_{3\times1} = A^{-1} \, l$$

- Estimate the height at the interpolation point.

$$Z(X_P, Y_P) = \begin{bmatrix} 1 & X_P & Y_P \end{bmatrix} \bullet \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix}$$

Second Exact interpolation surface

$$Z(X,Y) = a_o + a_1X + a_2Y + a_3X^2 + a_4XY + a_5Y^2$$

$$l = \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \\ Z_5 \\ Z_6 \end{bmatrix} \mapsto A = \begin{bmatrix} 1 & X_1 & Y_1 & X_1^2 & X_1Y_1 & Y_1^2 \\ 1 & X_2 & Y_2 & X_2^2 & X_2Y_2 & Y_2^2 \\ 1 & X_3 & Y_3 & X_3^2 & X_3Y_3 & Y_3^2 \\ 1 & X_4 & Y_4 & X_4^2 & X_4Y_4 & Y_4^2 \\ 1 & X_5 & Y_5 & X_5^2 & X_5Y_5 & Y_5^2 \\ 1 & X_6 & Y_6 & X_6^2 & X_6Y_6 & Y_6^2 \end{bmatrix} \mapsto x = \begin{bmatrix} a_o \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix}$$

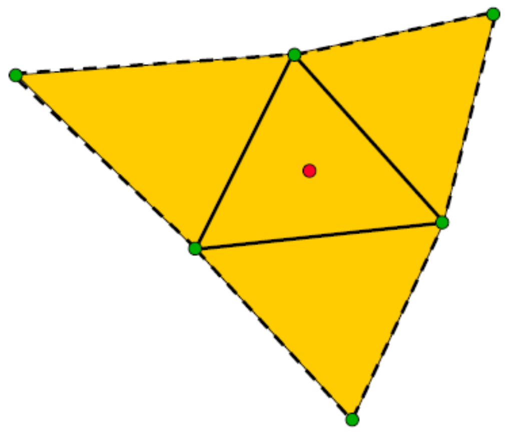
$$l_{6\times1} = A_{6\times6}\ x_{6\times1}$$

$$\hat{x}_{6\times1} = \left(A^T A\right)^{-1} A^T\, l \qquad or \qquad \hat{x}_{6\times1} = A^{-1}\, l$$

Second Exact interpolation surface

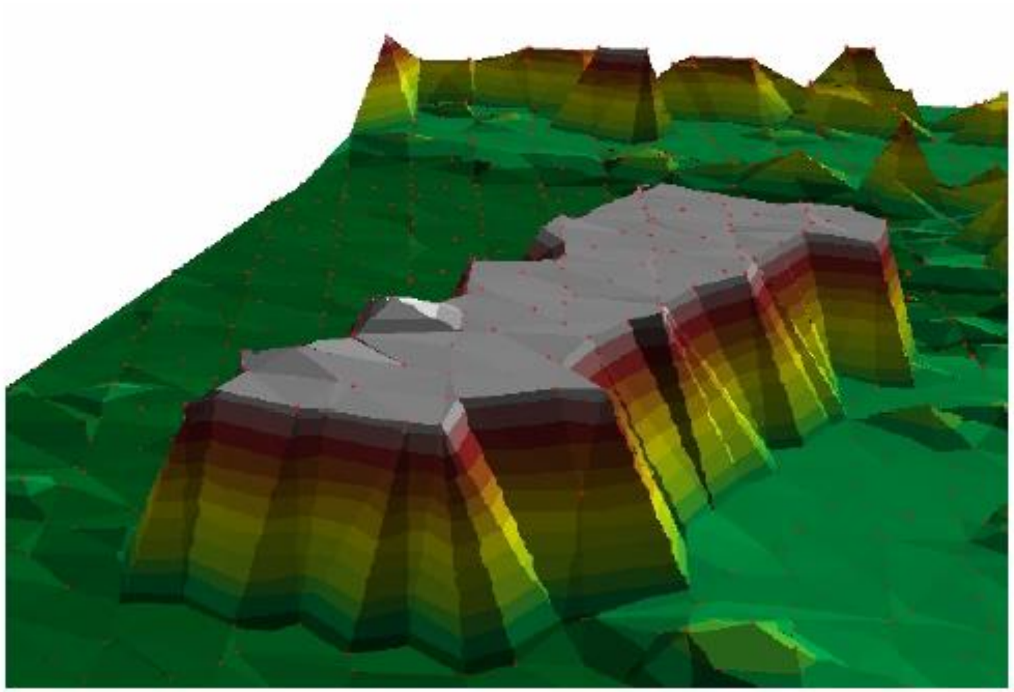
- Estimate the height at the interpolation point.

$$Z(X_P, Y_P) = \begin{bmatrix} 1 & X_P & Y_P & X_P^2 & X_P Y_P & Y_P^2 \end{bmatrix} \bullet \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix}$$



Quantic Spline Interpolation

$$Z(X,Y) = \sum_{i=0}^{5} \sum_{j=0}^{5-i} a_{ij} X^i Y^j$$



Standard Interpolation of Girding

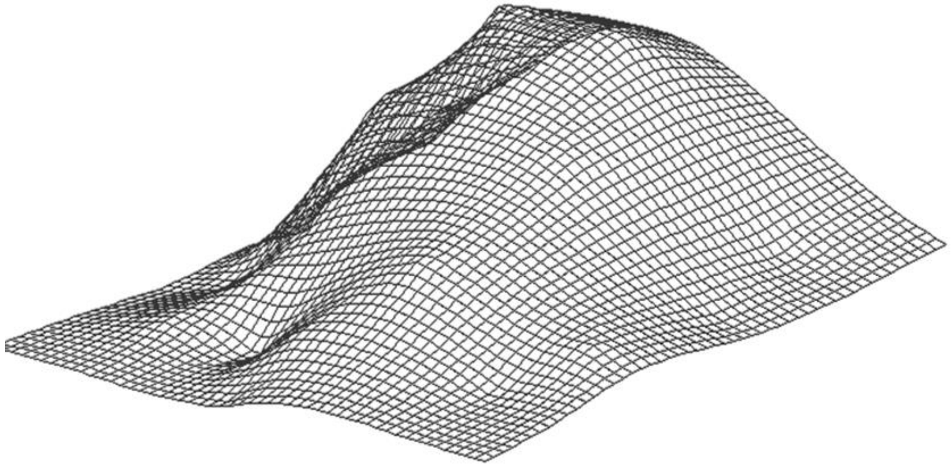
. Nearest Neighbor (NN).

. Bilinear Interpolation.

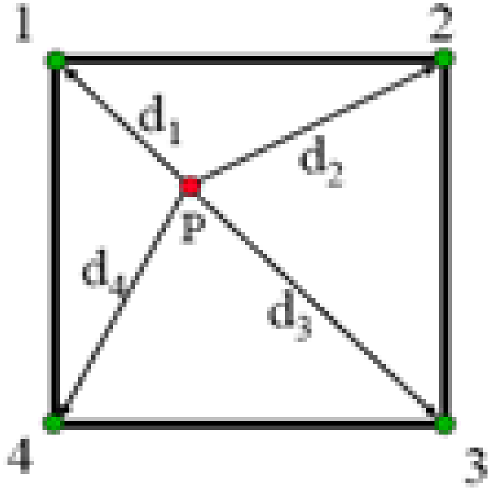
. Cubic Convolution Interpolation.

. Inverse Distance Weighting Interpolation.

. Linear Least Squares Interpolation.



Nearest Neighbor

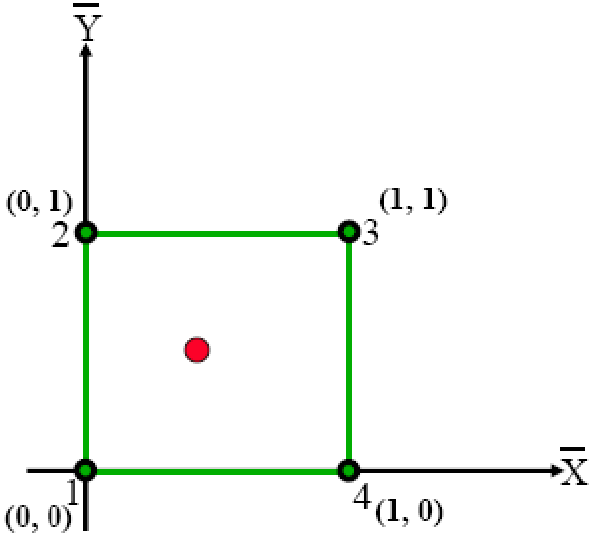


$$Z_P = Z@\min(d1,\ d_2,\ d_3,\ d_4) = Z_1$$

Bilinear Interpolation

$$Z(X,Y)=\sum_{i=0}^{1}\sum_{j=0}^{1}a_{ij}X^iY^j=a_{00}+a_{10}X+a_{01}Y+a_{11}XY=a_0+a_1X+a_2Y+a_3XY$$

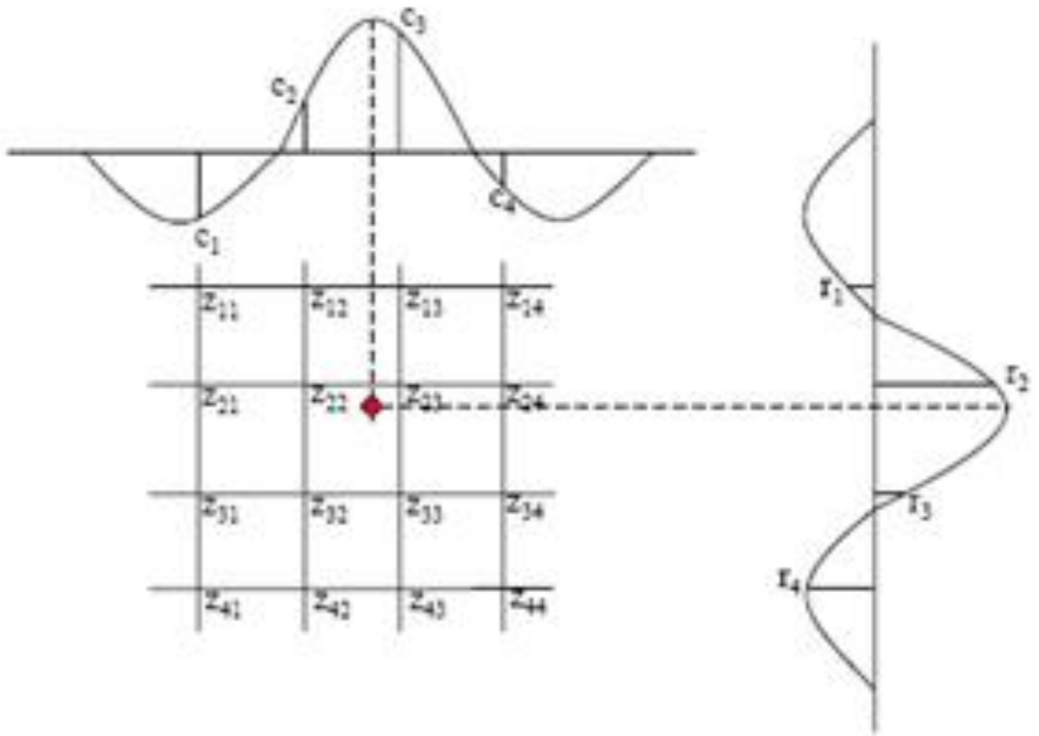
$$Z=a_0+a_1\,\overline{X}+a_2\,\overline{Y}+a_3\,\overline{X}\,\overline{Y}$$



- Sequential Estimation:
  - $1 \Rightarrow a_0$.
  - $2 \Rightarrow a_2$.
  - $4 \Rightarrow a_1$.
  - $3 \Rightarrow a_3$.

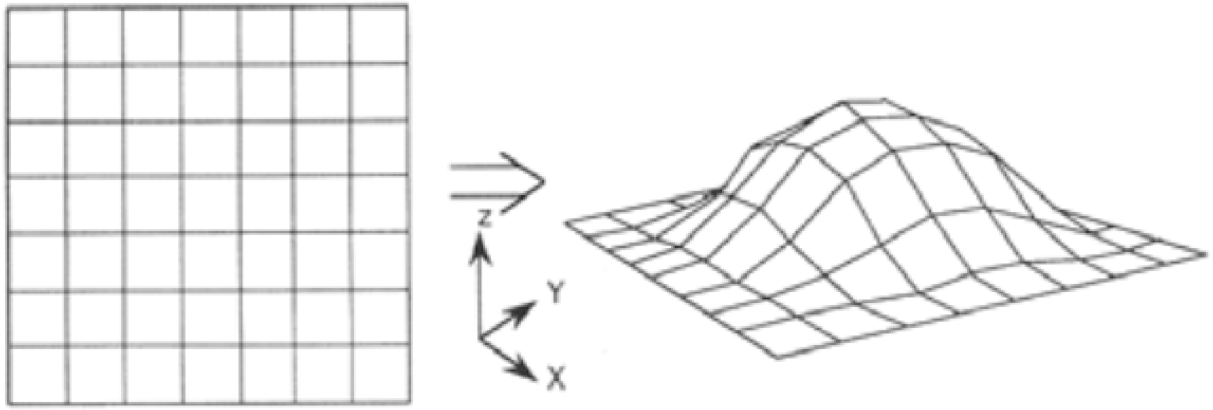
$$Z(\bar{X},\bar{Y})=Z_1+(Z_4-Z_1)\bar{X}+(Z_2-Z_1)\bar{Y}+(Z_1-Z_2+Z_3-Z_4)\bar{X}\,\bar{Y}$$

Cubic Convolution Interpolation

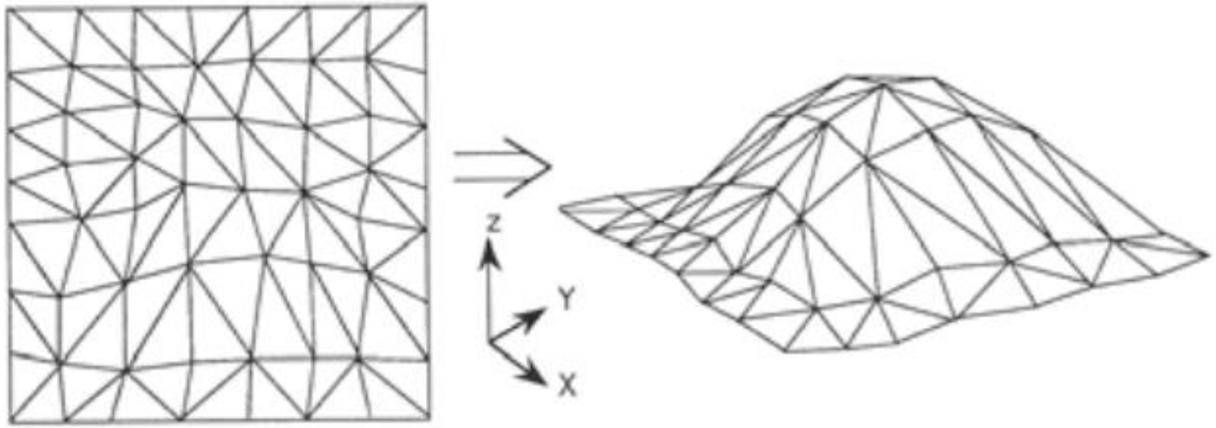


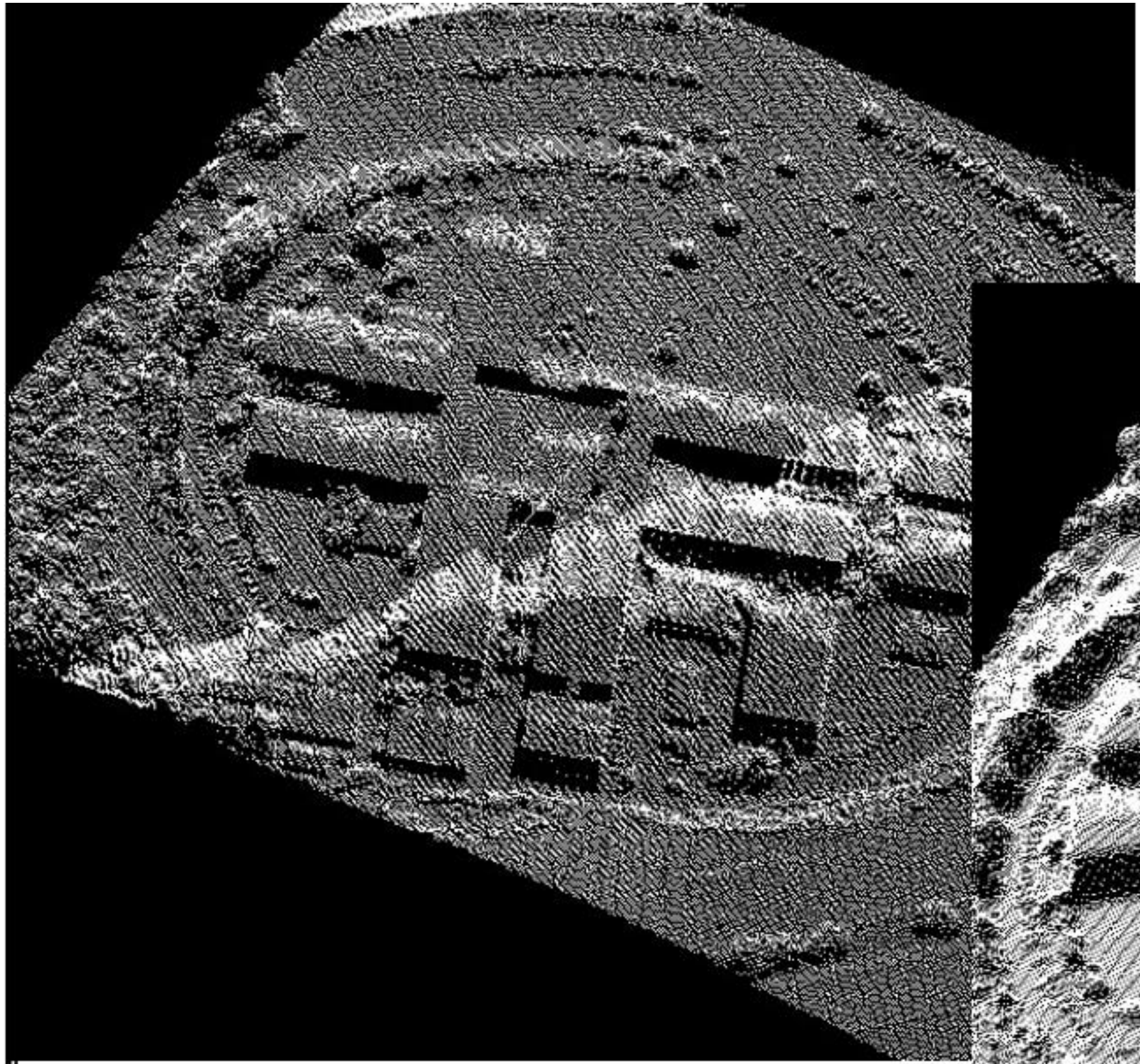
$$
\begin{aligned}
Z = \; & z_{11}\, r_1\, c_1 + z_{12}\, r_1\, c_2 + z_{13}\, r_1\, c_3 + z_{14}\, r_1\, c_4 + \\
& z_{21}\, r_2\, c_1 + z_{22}\, r_2\, c_2 + z_{23}\, r_2\, c_3 + z_{24}\, r_2\, c_4 + \\
& z_{31}\, r_3\, c_1 + z_{32}\, r_3\, c_2 + z_{33}\, r_3\, c_3 + z_{34}\, r_3\, c_4 + \\
& z_{41}\, r_4\, c_1 + z_{42}\, r_4\, c_2 + z_{43}\, r_4\, c_3 + z_{44}\, r_4\, c_4
\end{aligned}
$$

Grid DEM



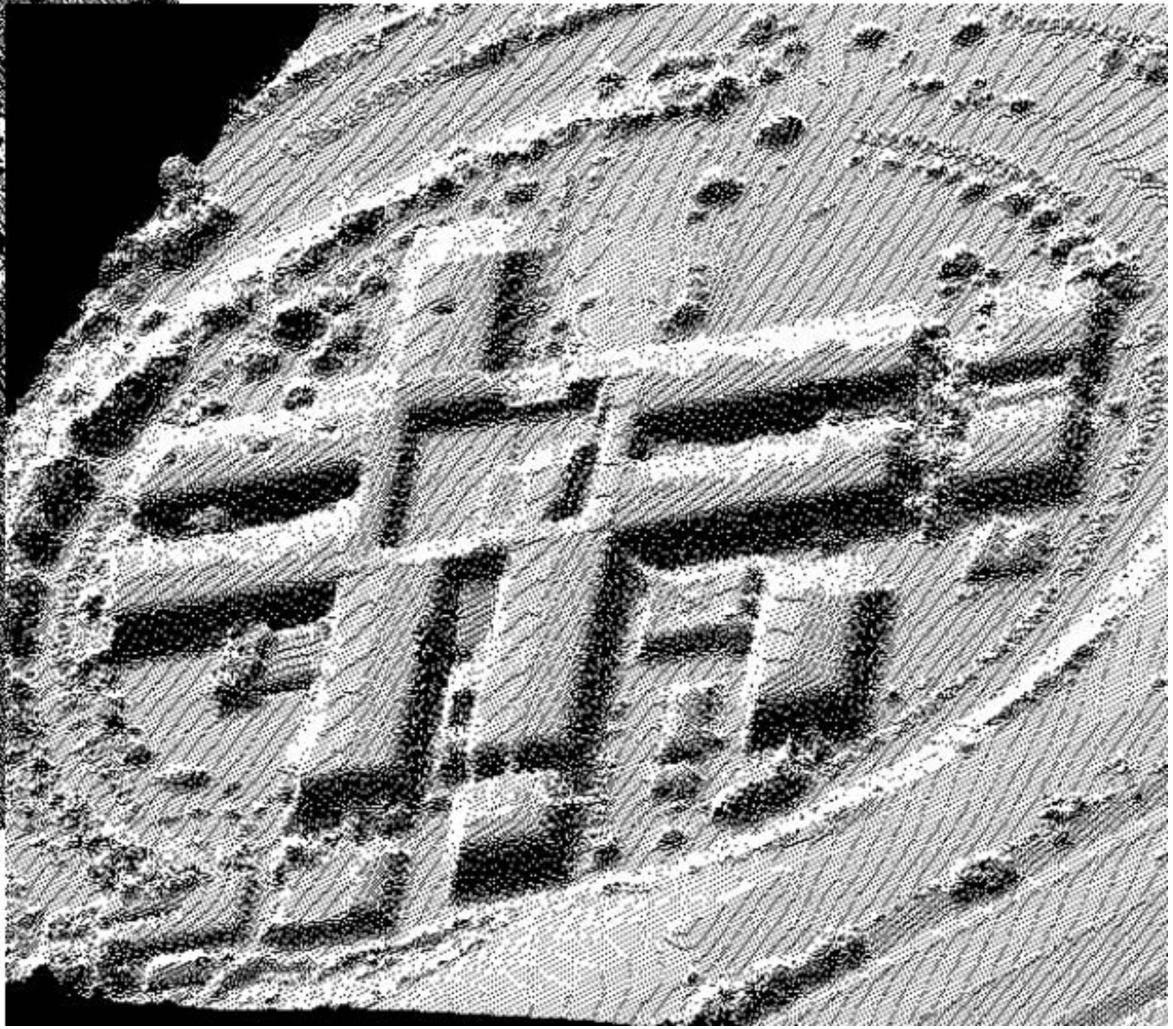
TIN DEM





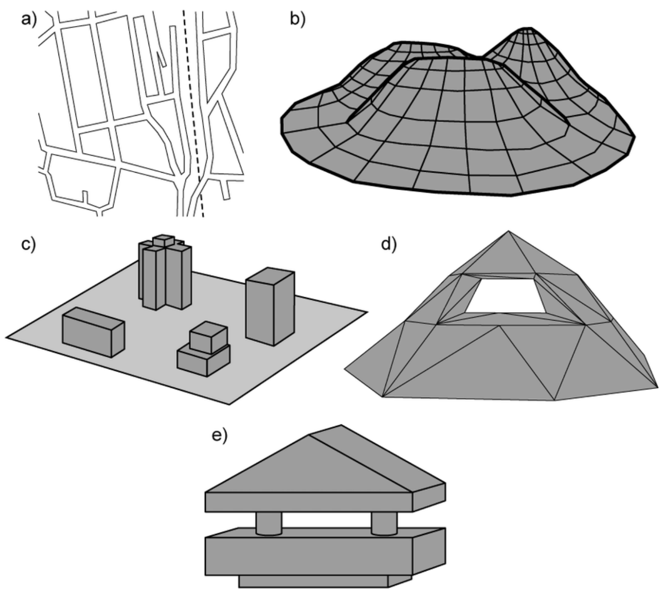
Raw Data

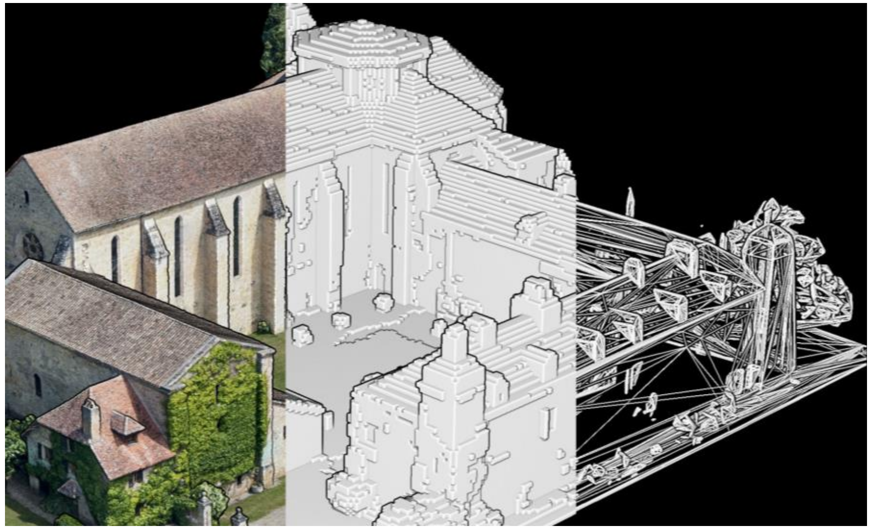
Interpolated data



3D vs 2.5D Modelling

- **2.5 dimensional modeling:** not suitable for caves, for instance.
  Model requirements:
  - good approximation of the real world
  - to determine h for any (x, y)





DEM uses

Extracting terrain parameters

Modeling water flow or mass movement

Creation of relief maps and models

Rendering of 3D visualizations

Rectification of aerial photography or satellite imagery

Reduction (terrain correction)

Terrain analyses in geomorphology and physical geography

DEM Applications

Civil Engineering: cut and fill in road design, site planning, volumetric calculations in dams and reservoirs etc.

Earth Sciences: for modeling, analysis and interpretation of terrain morphology e.g. drainage basin delineation, hydrological run-off modeling, geomorphological simulation and classification, geological mapping etc.

Planning and resource management: site location, support of image classification in RS, geometric and radiometric correction in RS images, erosion potential models, crop suitability studies, pollution dispersion modeling etc.

Military Applications: intervisibility analysis for battlefield management, 3-D display for weapons guidance systems and flight simulation, and radar line of sight analyses

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- University of Szeged, Hungary.
- DigitalGlobe www.digitalglobe.com