Digital Elevation Models (DEM)

What is the difference between DEM, DSM and DTM?

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DEM

Digital Elevation Model

DTM

Digital Terrain Model

DSM

Digital Surface Model

DSM

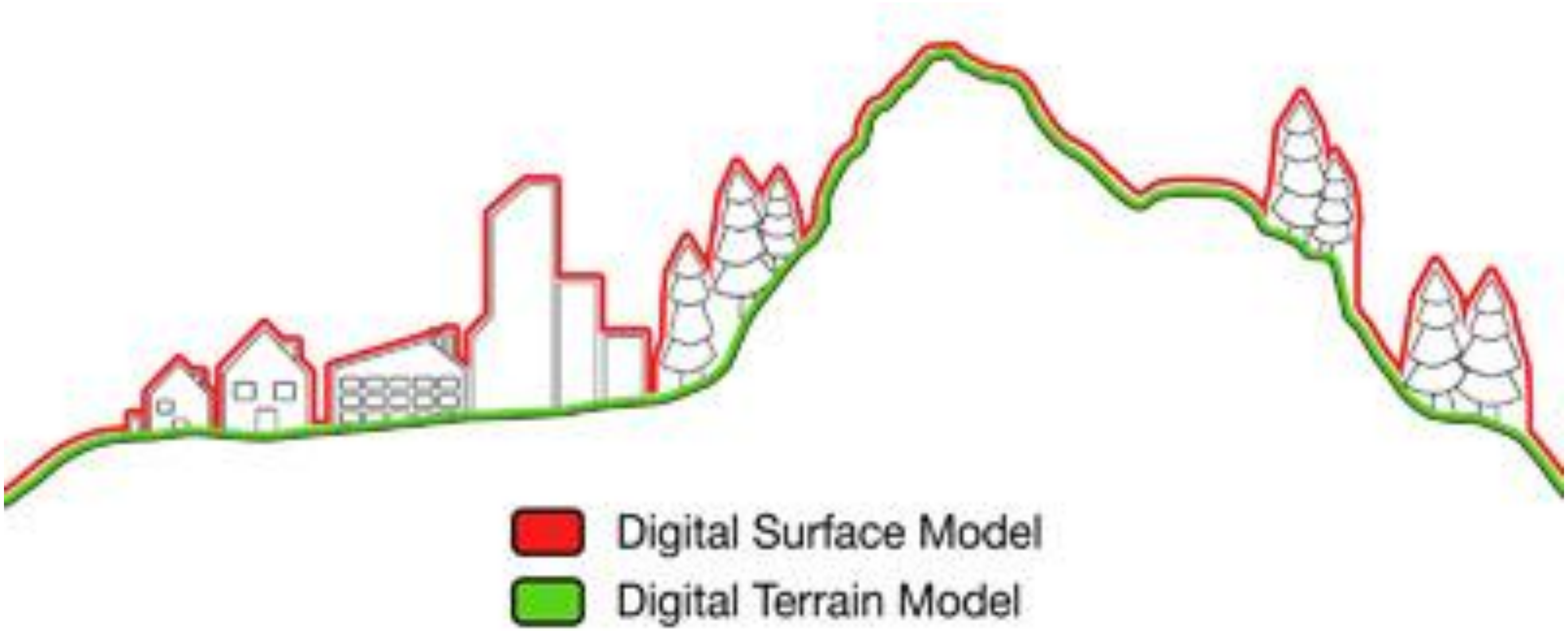
- Digital Surface Model (DSM) is a first-reflective-surface model that contains elevations of natural terrain features in addition to vegetation and cultural features such as buildings and roads.

DTM

- Digital Terrain Model (DTM) a bare-earth model that contains elevations of natural terrain features such as barren ridge tops and river valleys. Elevations of vegetation and cultural features, such as buildings and roads, are digitally removed.

- Orthorectified Radar Image (ORI) is a grayscale image of the earth's surface that looks very similar to a monochromatic aerial photograph. However, ORIs are able to accentuate features far more than it is possible with traditional aerial photography.

DTM VS. DSM



Digital Surface Model (DSM)

Digital Terrain Model (DTM)

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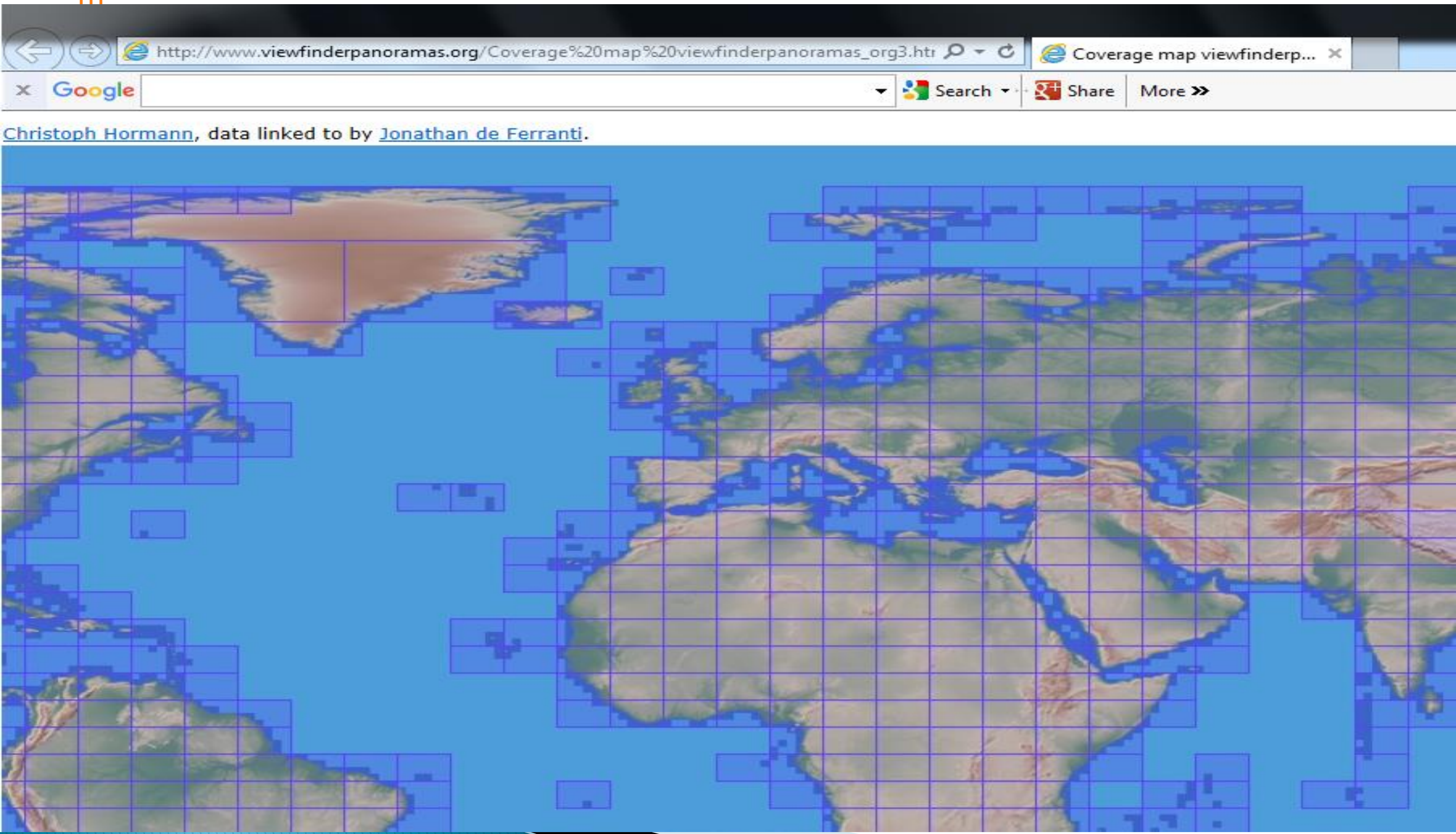
http://www.viewfinderpanoramas.org/Coverage%20map%20viewfinderpanoramas_org3.htm



Definition

- A digital terrain model (DTM) is defined as: a set of points with known planimetric position and known elevation which with the use of a mathematical model compose reliably a consistent ground surface.
- Points in a DTM may have either an irregular distribution over the ground surface and are called Triangulated Irregular Network (TIN), or, a regular grid distribution and are called GRID.
- A digital terrain model is a representation of earth's surface with its continuous and its discontinuous (brake lines) forms.

EXAMPLES OF SURFACE TYPES

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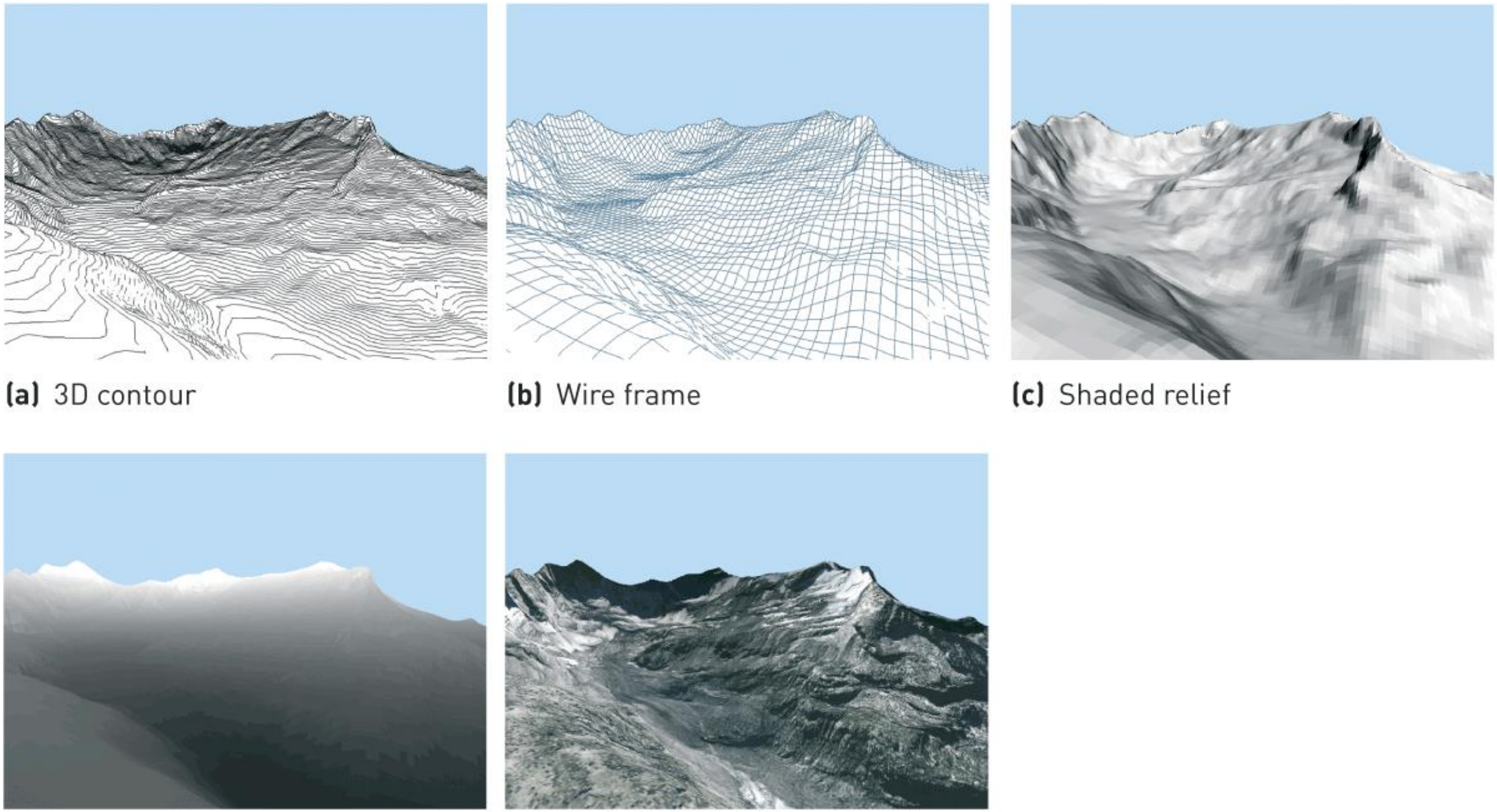


(a) 3D contour

(b) Wire frame

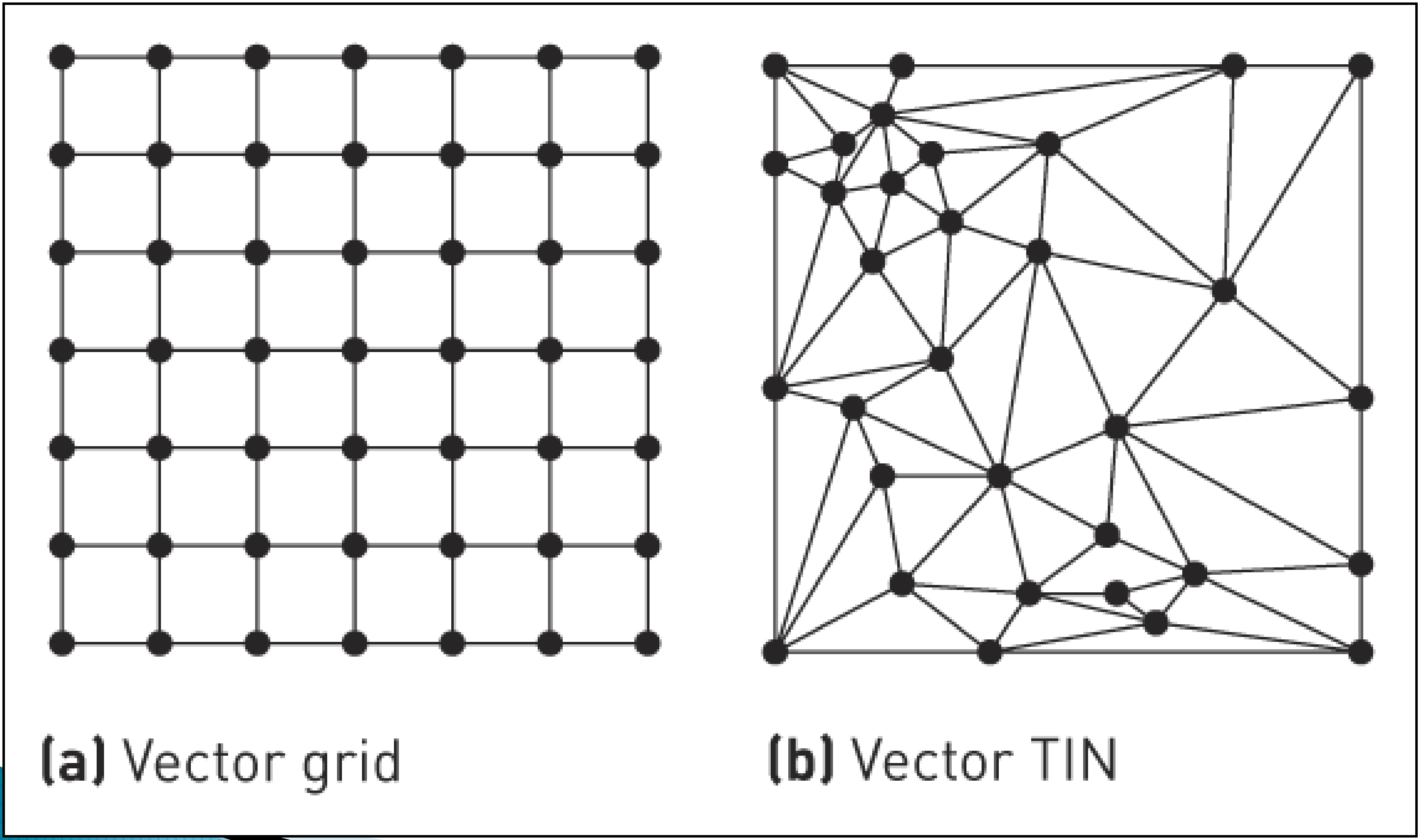
(c) Shaded relief

(d) 3D DEM

(e) Air photo drape

- DTM may be different as compared to the digital elevation model (DEM) which represents a continuous earth's surface without discontinuities or brake lines.
- However, terms DTM and DEM in this document will have the same significance.
- TINs cover the ground surface with high detail and are based on triangle shaped elements which result from three neighboring irregularly distributed elevation points which are selected based on specific criteria.
- GRID contains elevation points located at grid nodes ordered in rows and columns and they constitute a raster Form.

- GRID elevations are determined either directly (for example, from Photogrammetric measurements) or by interpolation from irregularly distributed elevation points (TIN, digitized contour lines from a scanned map, etc.).
- TINs store in electronic form all three coordinates (X, Y, Z), for each irregularly spacer elevation point while GRIDs store only the grid elevations because X, Y coordinates of grid nodes are determined indirectly and calculated according to their position in the grid mesh.


(a) Vector grid
(b) Vector TIN

DEMs and TINs

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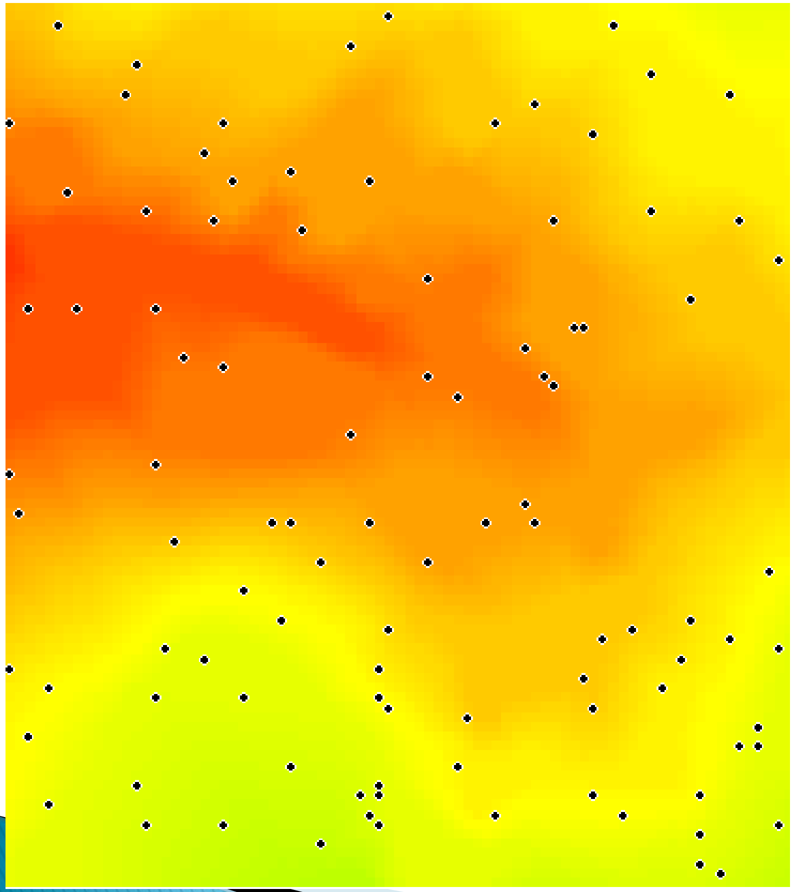
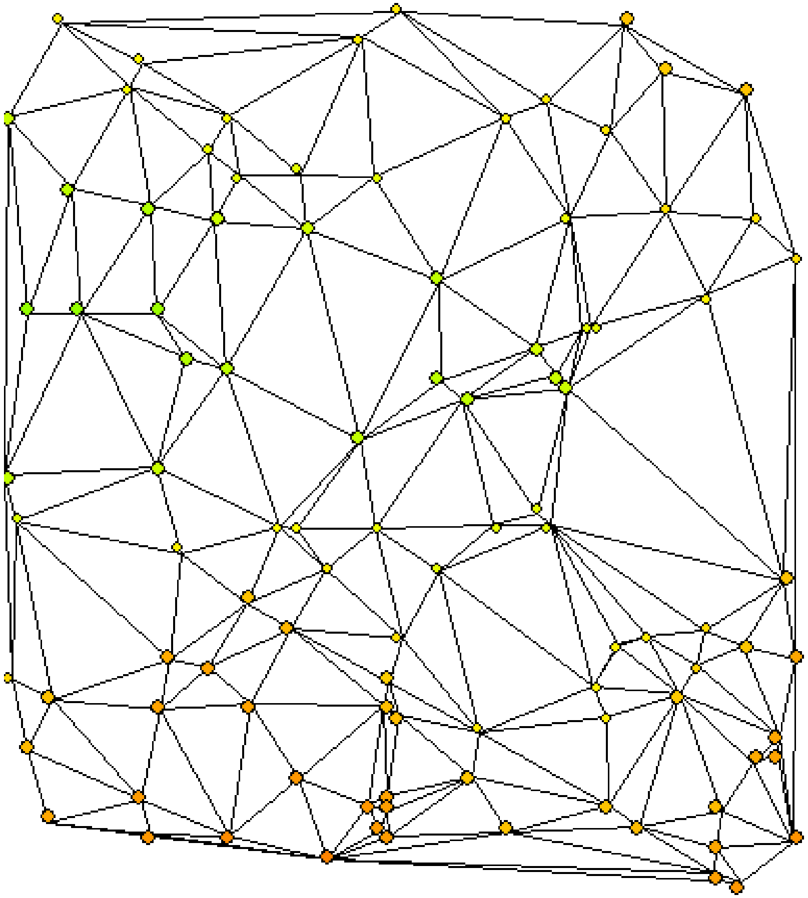
DEM with sample points



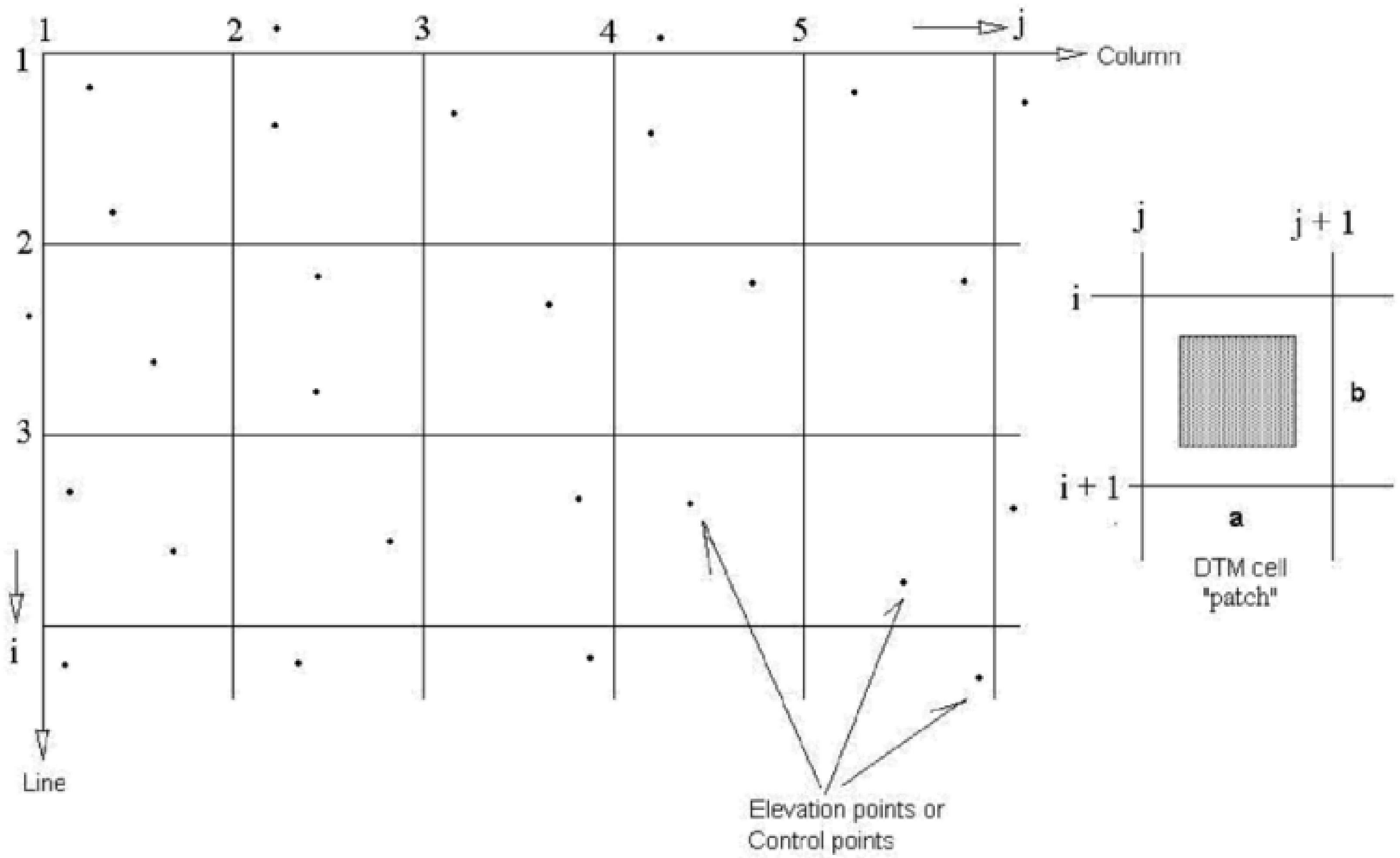
TIN based on same sample points



- Elevation points which are used to define a DTM are also called control points and their location must be selected so that to represent the ground surface which they express with precision according to map standards specifications.
- The same rules apply for the selection of a mathematical function which will be used to create a continuous surface as close as possible to the real ground surface.

- A mathematical function used to create a continuous ground surface, can be linear, bilinear, polynomial with more terms etc.
- This function is defined by a set of neighboring control points and it is in effect in a limited extent which does not exceed the limits of these control points.
- The minimum number of control points which are required for the definition of a linear function is three while for the definition of a bicubic spline function are required 16 points .

- The way a DTM is formed is defined as follows: The total ground surface is covered by individual cells or "patches" which are stitched together so that they cover all ground surface without leaving voids or making overlaps.
- Inside each "patch" is in effect a suitably adapted mathematical function or model.


1
2
3
4
5
j
Column
1
2
3
i
Line
Elevation points or
Control points
j
j + 1
i
i + 1
b
a
DTM cell
"patch"

- This mathematical function is the same for all DTM patches, but its numerical coefficient values are different from patch to patch.
- This mathematical function is not stored permanently in computer memory but its coefficients are computed instantly using surrounding GRID or TIN elevation points.
- These elevation points are known with their X, Y, Z coordinates and can be located not only inside the patch limits but also in the neighboring patches region.
- However, the function which is created is in effect only for a specific "patch".

- A basic characteristic of mathematical functions is the fact that they should give precisely the same elevation value when this is computed on the common boundary of two neighboring "patches".
- With other words, the elevation on the common boundary of two neighboring patches may be computed from two different functions one value from the "patch" on the left and another value from the "patch" on the right and therefore both of such values must be identical.

- Occasionally are imposed to these functions constraints to obtain a smooth transition from one patch to the other and this is obtained if first derivative of each function gives identical value on common border. More smoothing is obtained if higher order derivatives of both functions give identical values on common border.
- A digital terrain model can be directly created from topographic data collected on the ground.
- it can also be created from photogrammetric measurements on a stereo model, from GPS, from measurements using new technologies (LIDAR, IFSAR) as well as from digitization of contour lines from existing maps.
- Usually control points are found on irregular locations and distances on the ground and therefore creation of GRID takes place using interpolation methods where new points are determined in regular grid nodes.

- Such mathematical models (best fit surface models) may have the following forms:
- Z = A.X + B.Y + C : Function of a plane
- Z = A.X + B.Y + C.X.Y + D: bilinear function
- Z = $A.X^2$ + B.Y^2 + C.X.Y + D.X + E.Y + H: second degree polynomial
- Z = higher degree polynomial
- Where Z is the elevation X, Y are the planimetric coordinates A, B, C, are coefficients which define each mathematical function (model)

- Choice of a mathematical model among equations varies depending on the ground surface, specifications of precision and depending on the aim that serves the digital terrain model.
- Usually a single mathematical model is selected for a regular ground surface while in complicated areas differentiated models are used to express difficult regions (gaps, bluffs, etc.).
- Complicated functions tend to regularize the terrain surface and they are used in the generalization of data aiming at the simplification while in high precision topographic surfaces simpler functions are used as are linear (plane) and bilinear functions .

- In this case sampling of elevation points is performed on grid cell nodes using either direct measurements on the ground, photogrammetric measurements, digitization of contours from maps, or indirectly using interpolation methods.

Bilinear function

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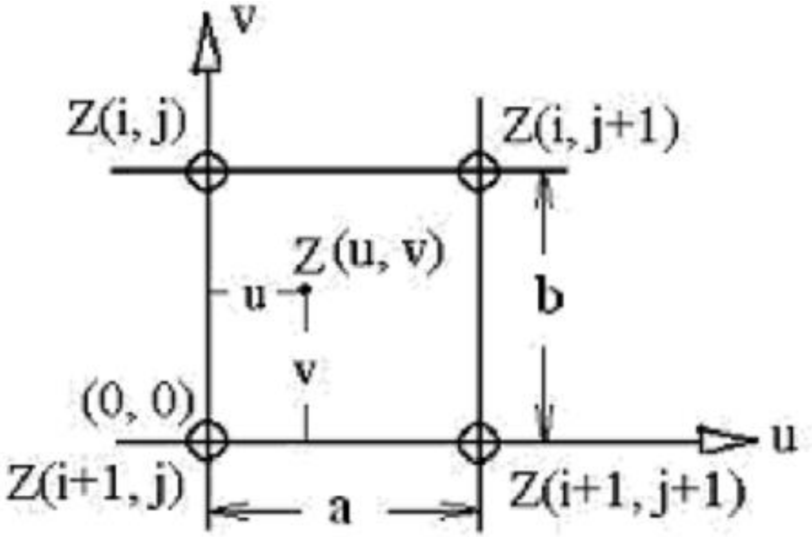
- Bilinear function is completely defined by elevations at the four nodes of the cell and is in effect only inside this cell.
- Let us assume a cell as shown in Figure below and Z(i, j), Z(i, j+1), Z(i+1, j), Z(i+1, j+1) are the elevations at corresponding four grid nodes that define this cell, then the elevation Z of point (u, v) found within the cell is given by the bilinear equation in the next slide.
- Notice that a local (within the cell) coordinate system (u, v) is established with origin the lower left cell node.



$$Z(u,v)=[1 \quad u].\begin{bmatrix} a_{00} & a_{01} \\ a_{10} & a_{11} \end{bmatrix}.\begin{bmatrix} 1 \\ v \end{bmatrix}$$

- Developing Last Equation we have:

$$Z(u, v) = a_{00} + a_{10}.u + a_{01}.v + a_{11}.u.v$$

Substituting u = v = 0 for node (i +1, j), then $a_{00} = Z_{(i+1,\,j)}$,

Substituting u = a, v = 0 for node (i +1, j+1), then $a_{00} + a_{10}.u = Z_{(i+1,\,j+1)}$ and a_{10} is computed

Substituting u = 0, v = b for node (i, j), then $a_{00} + a_{01}.v = Z_{(i,\,j)}$ and a_{01} is computed

Substituting u = a, v = b for the node (i, j+1), then a_{11} is computed and then we have:

$$Z(u,v)=\left(1-\frac{u}{a}-\frac{v}{b}+\frac{u.v}{a.b}\right).Z_{(i+1,j)}+\left(\frac{u}{a}-\frac{u.v}{a.b}\right).Z_{(i+1,j+1)}+\left(\frac{v}{b}-\frac{u.v}{a.b}\right).Z_{(i,j)}+\left(\frac{u.v}{a.b}\right).Z_{(i,j+1)}$$

Example:

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- Let us take a grid DTM with 6 rows and 5 columns, the coordinates of first node (I, 1) are Xo=500, Yo=1000, the dimensions the grid cell are: a = 50, b = 50, the elevations at the grid nodes (one row after the other) are: 28,35,67,45,12, 14,29,71,42,18, 16,37,82,53,23, 22,41,86,48,27, 26,39,93,57,35, 29,42,98,53,38

first node

	C1=500	C2=550	C3=600	C4=650	C5=700
R1=1000	28	35	67	45	12
R2=950	14	29	71	42	18
R3=900	16	37	82	53	23
R4=850	22	41	86	48	27
R5=800	26	39	93	57	35
R6=750	29	42	98	53	38

- The interpolation function is bilinear.
- It is wanted the elevation of point X=627.12, Y=823.64

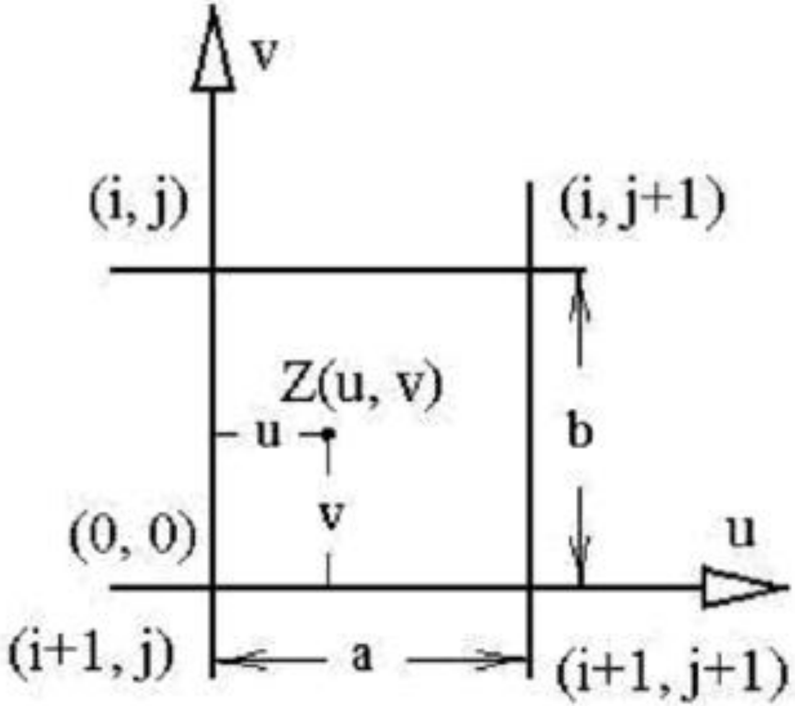
Solution :

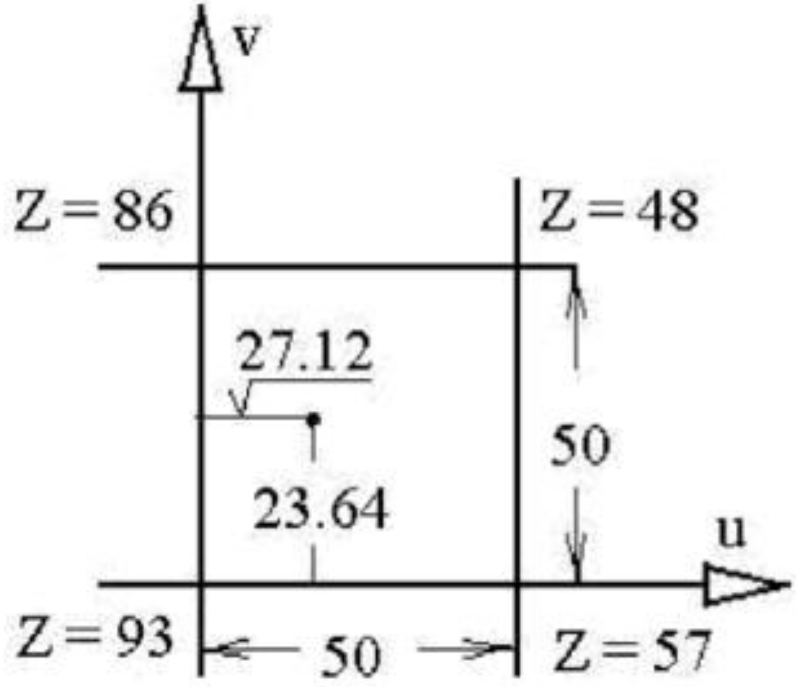
- Given data define the coordinates at grid cell nodes as follows:
- (500, 1000) (550,1000) (600,1000) (650,1000) (700,1000) (500, 950) (550, 950) (600, 950) (650, 950) (700, 950) (500, 900) (550, 900) (600, 900) (650, 900) (700, 900) (500, 850) (550, 850) (600, 850) (650, 850) (700, 850) (500, 800) (550, 800) (600, 800) (650, 800) (700, 800) (500, 750) (550, 750) (600, 750) (650, 750) (700, 750)
- Grid cell nodes which contain point with coordinates (X=627.12, Y=823.64) are computed as follows:

$$i = \text{int}\left(\frac{Y_0 - Y}{b}\right) + 1 = \text{int}\left(\frac{1000 - 823.64}{50}\right) + 1 = 4$$

$$j = \text{int}\left(\frac{X - X_0}{b}\right) + 1 = \text{int}\left(\frac{627.12 - 500}{50}\right) + 1 = 3$$

- Notice that: int(3.53) = 3 (Row)
- and int(2.54) = 2 (Col)
- Thus we have:
- Z(I,j) = 86, Z(I, j+i) = 48
- Z(i+1, j) = 93, Z(i+1, j+i) = 57


v
(i, j)
(i, j+1)
Z(u, v)
u
b
v
(0, 0)
u
(i+1, j)
a
(i+1, j+1)


v
Z = 86
Z = 48
27.12
50
23.64
u
Z = 93
50
Z = 57

- Local coordinates (u, v) of point are computed as follows:

$$u = X - \text{int}\left(\frac{X}{a}\right)a = 627.12 - \text{int}\left(\frac{627.12}{50}\right)50 = 27.12$$

$$v = Y - \text{int}\left(\frac{Y}{b}\right)b = 823.64 - \text{int}\left(\frac{823.64}{50}\right)50 = 23.64$$

- Applying relation to compute the elevation as follows:

Z =[1-27.12/50-23.64/50+(27.12x23.64)/(50x50)]x93 + [27.12/50-(27.12x23.64)/(50x50)]x57 + [23.64/50-(27.12x23.64)/(50x50)]x86 + [(27.12x23.64)/(50x50)]x48 =22.44+16.30+18.61+12.31 = 69.65

Example:

- Store the data of previous example in a text file which will occupy minimal storage space.
- Solution :
- The text data file is structured as follows: 6,5,500,1000,50,50
  28,35,67,45,12,14,29,71,42,18,16,37,82,53,23,22,41,86,48,27
  26,39,93,57,35,29,42,98,53,38
- First file line is a header and contains six values. The first two values give the number of rows and columns respectively.
- The two next values give the coordinates of North Western DTM node (XNw, YNw).
- And the last two values give cell dimensions (a, b).
- Following are all elevation values at grid cell nodes which are ordered row by row.

Uses of digital terrain models

There are many DTM applications and the most important are as follows:

(a) Computation of elevation analytically at any map point.

(b) Computation of slope analytically at any map point.

(c) Analytical computation of orientation of an earth's surface cell (aspect) at any map point.

(d) Analytical profile drawing in any direction which is usually useful in landscape works, road studies and construction works, etc.

(e) Analytical cross section drawings which is useful in terrain representation and helps in the computation of volumes of excavations from cuts and fills works.

(f) Analytical construction of contours lines.

(g) Analytical drawing of perspective view and visualization.

(g) Analytical drawing of shading on perspective view or topographic map of a region.

(i) Determination of characteristics of a watershed for water management and also determination and study of the following quantities:

1. speed and capacity of water from rainfall
2. water flow direction
3. water erosion,
4. water deposits
5. water floods. etc.

(j) Analytical determination of man interventions over landscape as are the excavations for road construction works, monitoring of development of solid waste dumps, complete re-establishment of landscape in man intervened areas.

DTM tasks

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Digital terrain modeling includes the following tasks

- DTM generation - sampling of original terrain data, formation of relations between and among the diverse observations (model construction)
- DTM manipulation - modification and refinement of DTM's, derivation of intermediate models
- DTM interpretation - DTM analysis, information extraction from DTM's
- DTM visualisation - graphical rendering of DTM's and derived information
- DTM application - development of appropriate application models for specific disciplines. DTM application forms the context for digital terrain modeling, with each particular discipline having functional requirements relative to the other terrain modeling tasks

DEM VS. TIN

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- DEMs:
  - Simple conceptual model
  - Data cheap to obtain, less complex
  - Easy to relate to other raster data, accept data direct from digital altitude matrices
  - Irregularly spaced set of points can be converted to regular spacing by interpolation (must be resampled if irregular data used)
  - may miss complex topographic features
  - may include redundant data in low relief areas
  - Linear features not well represented
- TINs:
  - accept randomly sampled data without resampling
  - accept linear features such as contours and breaklines (ridges and troughs)
  - accept point features (spot heights and peaks)
  - vary density of sample points according to terrain complexity

Quick comparison

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	TIN	GRID
Advantages	ability to describe the surface at different level of resolution	easy to store and manipulate
	efficiency in storing data	easy integration with raster databases
		smoother, more natural appearance of derived terrain features
Disadvantages	in many cases require visual inspection and manual control of the network	inability to use various grid sizes to reflect areas of different complexity of relief.