ACCURACY ASPECTS OF PROCESSING AND FILTERING OF MULTIBEAM DATA: GRID modeling VERSUS TIN BASED modeling

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FIG WORKING WEEK 2012
May 6–10 2012
Rome, Italy

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1. Introduction

2. Grid modeling

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4. Grid versus TIN

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6. Conclusions

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1. Introduction

Requirements for hydrographical Digital Terrain modeling processing:

1. "**Fast**" modeling (real-time and/or post-processing)
2. Allow "**Editing**" (manual and/or automatic)
3. Give the option of "**Intelligent**" filtering (reduction) of data
4. "**Accurate**" volume computation => "**accountability**"

=> **GRID and TIN (triangular irregular network) modeling**

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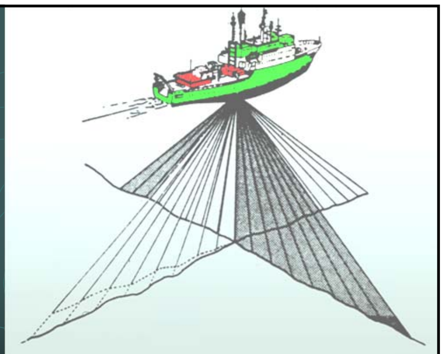
2. Grid modeling: Principle



- Multibeam =>
  - Equidistant coordinates in **international grid** system
    - UTM
    - Conventional reference plane (or GRS80 ellipsoid)
  - Output = **equidistant** grid data =>
    - **Store only Depth** values (typically 2 byte/point: 65536 depth values)
    - **Grid interval distance** is decisive parameter

2. Grid modeling: Filtering: Why ?

- Huge amount of points (e.g. Kongsberg EM3002)
  - 40 Hz
  - 500 pts./swap

  20.000 pts./sec. or 72 million pts./hour

+ interpolation by multibeam system software to equidistant grid

=> More or Less points depending on grid interval distance

2. Grid modeling: Filtering: How ?

- **Modify grid interval** distance

  e.g. 1 by 1 m => 5 by 5 m

  Reduction by 96 %

  Loss of resolution can cause loss of seabottom details

- Use of "**smarter**" algorithms
  - Depth is weighted average of all depths of initial cells
    - Weighting factor = inverse distance to power n (2 ?)
  - Minimum depth (control survey, not for volume computat.)
  - Use model with variable grid intervals => complex

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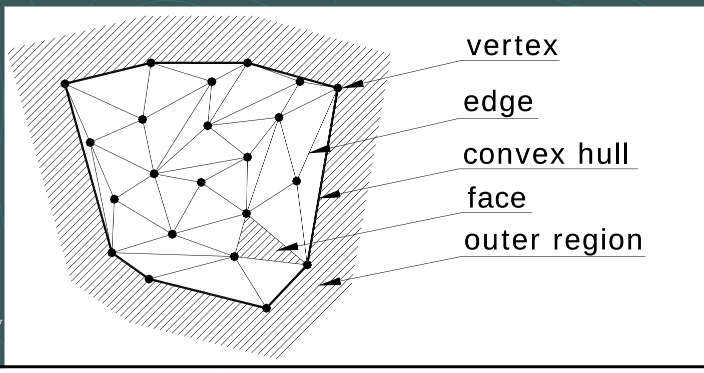
3. TIN based modeling: principle

- What is a triangulation ?
- Why Delaunay is the best triangulation ?
- Property of a Delaunay triangulation
- Different Algorithms

What is a triangulation (TIN) ?

= network of irregular triangles, created by connecting the points (vertices) of a dataset so that

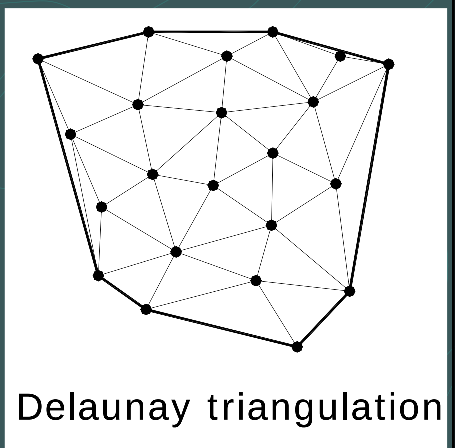
- no triangle sides are intersecting
- no triangles are superposed
- the union of all triangles fill up the hull of the triangulation



Why Delaunay triangulation ?

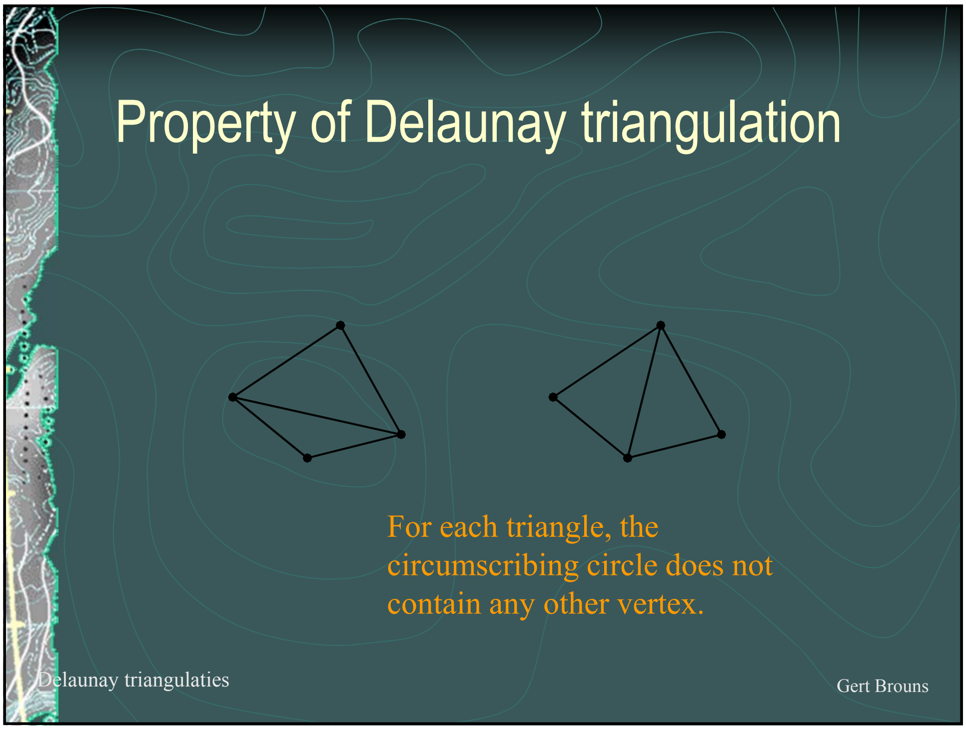
Advantages:

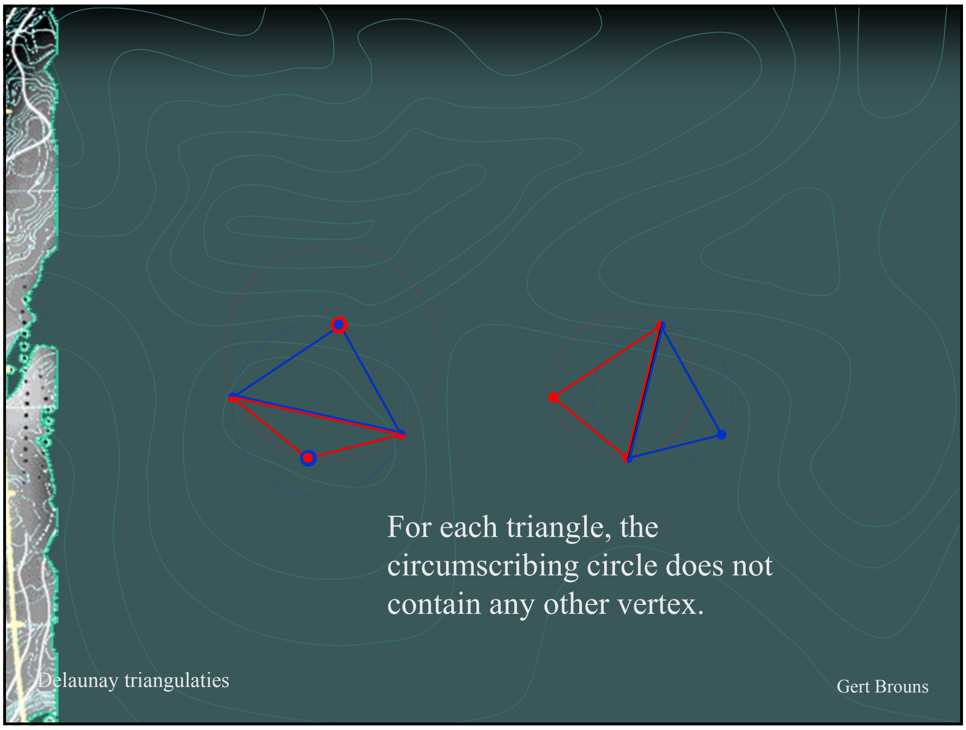
- Mathematically well defined
- Unique for a given dataset
- Data-sequence independent
- Independent control possible
- Variable density



Drawbacks:

- Complexity by storing points (E,N,H) and triangles (<> grid)


Property of Delaunay triangulation
For each triangle, the
circumscribing circle does not
contain any other vertex.
Delaunay triangulaties
Gert Brouns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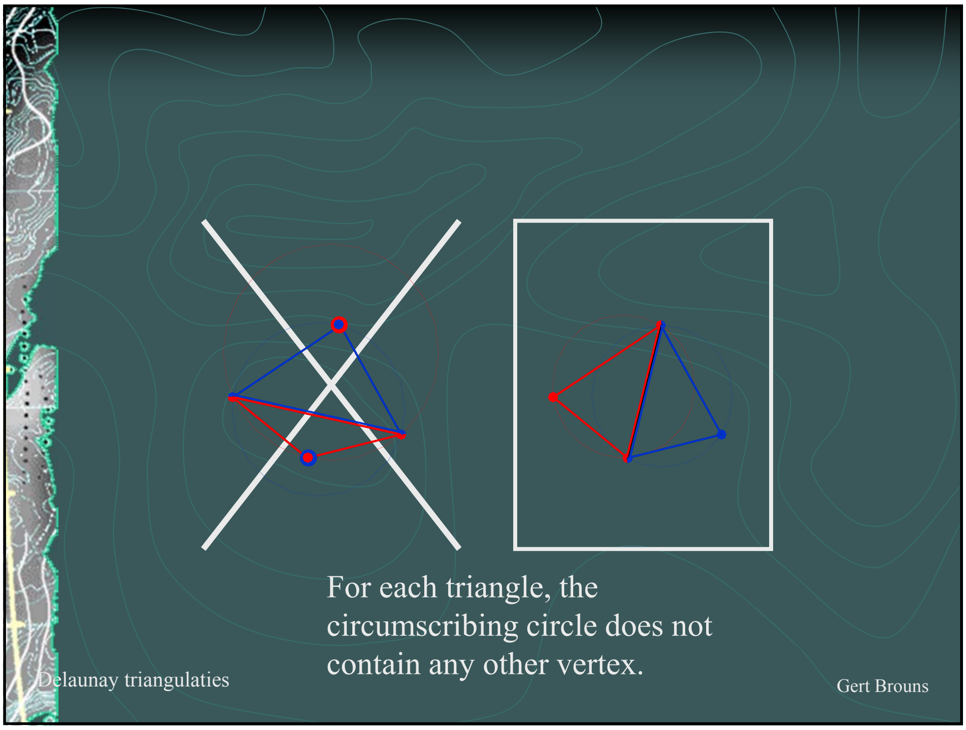
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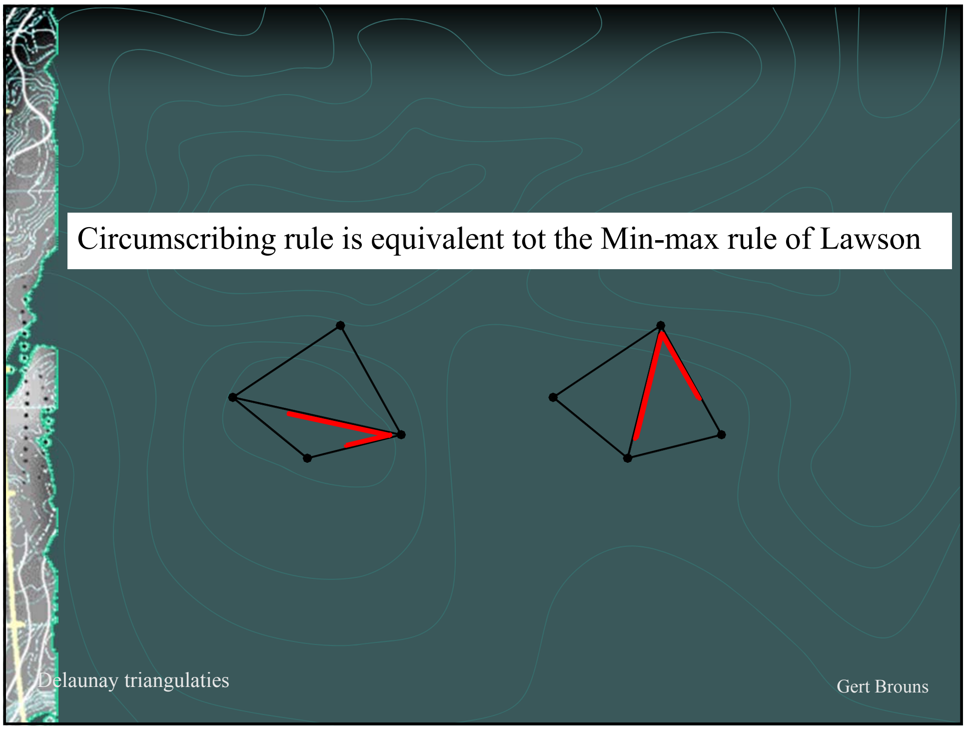
Circumscribing rule is equivalent tot the Min-max rule of Lawson
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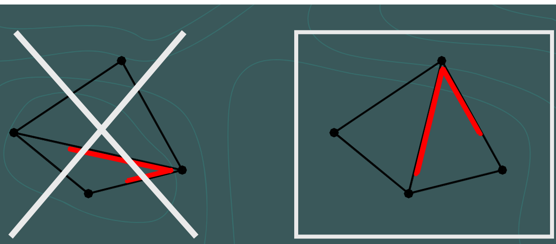
Circumscribing rule is equivalent tot the Min-max rule of Lawson

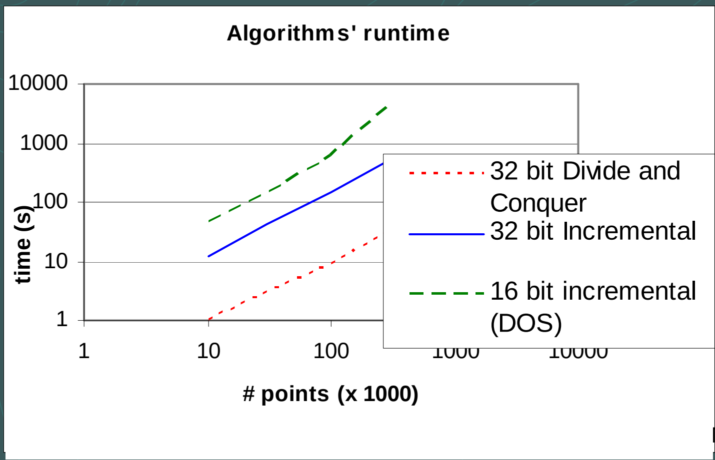


Local optimisation leads to global optimalisation

Delaunay-triangulation-algorithms

- Incremental
- Divide-and-conquer
- Sweepline
- Giftwrapping

Runtime comparison



3. TIN based modeling: Filtering

« Greedy insertion »

- Start situation = convex hull of triangulation
- Selective adding by using a rule (Min. Diff. in Depth or Vol.)

« Vertex decimation »

- Start situation = complete Delaunay triangulation
- Then selective elimination of points

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4. Grid modeling: Advantages

Grid model is more easy to implement (than TIN)

Higher processing speed

=> Higher visualisation speed

Algorithms can be raster based instead of vector based

Real-time modeling

Real-time editing

Higher software developing speed => lower cost

4. Grid modeling: Drawbacks

Accuracy ?

- **Loss** of the initial measured points
- Choice of **grid interval** distance is of capital importance
  Too small => huge amounts of redundant data
  Too big => loss of details
  - **Variable grid interval model** could solve this, but at the cost of complexity, computer memory and processing time !

4. TIN based modeling: Advantages and drawbacks

- **Original measured points** are kept
- **No interpolated** points
- **Adaptive** model
  - Locally higher point density => smaller triangles => more details
  - Locally lower point density => big triangles => saving computer memory
- **More complex** model
  - Higher computer memory requirements
  - Slower in processing
  - Algorithms difficult to implement

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5. Accuracy Aspects of TIN models

- How to compute a volume in a TIN ?
- Standard deviation (σ) of the computed volume
- Mathematical « best » and « worst » σ case
- Border Effects
- Example

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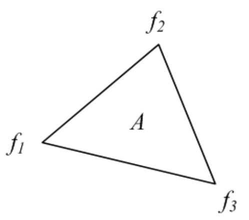
How to compute a volume in a TIN ?

With A_j as the planimetric surface of a triangle j, f_{ref} as the height of the horizontal reference plane and f_i as the elevation of the 3 vertices i of the triangle, the volume V_j generated by one triangle j is equal to

$$\left(\frac{1}{3}(f_1 + f_2 + f_3) - f_{ref}\right) A_j = V_j$$



How to compute a volume in a TIN ?

The total volume V is the sum of the volumes of all individual prisms, thus

$$\frac{1}{3}\sum_{i} f_i\Big(\sum_{f_i \in A_j} A_j\Big) - f_{ref}\, A_{tot} = V$$

If we call B_i the sum of the surfaces of all triangles with point i as vertex or

$$B_i = \Big(\sum_{f_i \in A_j} A_j\Big)$$

Then we can write

$$\frac{1}{3}\sum_{i=1}^{n} f_i B_i - f_{ref} A_{tot} = V$$

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Assuming that all f_i are independent, the variance of the volume can be found

$$\frac{1}{3}\sum_{i=1}^{n} f_i B_i - f_{ref} A_{tot} = V \quad \Rightarrow \quad Var(V) = \frac{1}{9} \sum_{i} Var(f_i)\, \mathrm{B}_i^2$$

The standard deviation and variance $Var(f_i)$ of the elevation of a point is usually assumed to be constant so that, with n the total number of points

$$Var(V) = \frac{Var(f)}{9} \sum_{i} \mathrm{B}_i^2$$

$$\sigma(V) = \frac{\sigma(f)}{9} \sum_{i=1}^{n} B_i^2$$

This form is useful in the case of a TIN model based on non-equidistant points.

$$\sigma(V) = \frac{1}{\sqrt{n}}.\sigma(f).A_{tot}.\sqrt{1+\left(\frac{\sigma\ (B)}{\overline{B}}\right)^2}$$

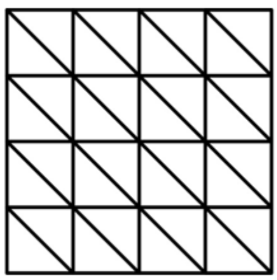
The latter form is applicable to TIN's of irregular spaced points but is also particularly suited in the case of a TIN model based on equidistant points.

TIN with regular spaced points

$$\sigma(V) = \frac{1}{\sqrt{n}}.\sigma(f).A_{tot}.\sqrt{1+\left(\frac{\sigma\ (B)}{\overline{B}}\right)^2}$$

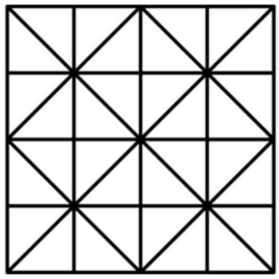
Assuming a TIN of regular spaced points, and without the consideration of border issues, a minimum of the standard deviation can be found for a layout where all rectangular cells of the TIN have an identical direction of the diagonal. In this case, every non-border point has 6 neighboring triangles and as all triangles have the same surface, $\sigma(B) = 0$, and it can be found that

$$\sigma(V) = \frac{1}{\sqrt{n}}.\sigma(f).A_{tot}$$



TIN with regular spaced points

In case the diagonals in the grid system are alternating, half the number of non-border points have 4 neighbors and the other half 8.



$$\sigma(V) = \frac{1}{\sqrt{n}}.\sigma(f).A_{tot}.\sqrt{1+\left(\frac{\sigma\ (B)}{\overline{B}}\right)^2}$$

Hence

$$\frac{\sigma\ (B)}{\overline{B}} = \frac{2}{6} = \frac{1}{3}$$

and

$$\sigma(V) = \frac{1}{\sqrt{n}}.\sigma(f).A_{tot}.\frac{\sqrt{10}}{3}$$

The difference in standard deviation of the volume between the optimal layout and the worse case layout is only a factor $\frac{\sqrt{10}}{3}$ or 5.4 % difference.

5. Accuracy Aspects of TIN models

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Mathematical « best » and « worst » σ case

$$\sigma(V) = \frac{1}{\sqrt{n}}.\sigma(f).A_{tot}.\sqrt{1+\left(\frac{\sigma\ (B)}{\overline{B}}\right)^2}$$

The mathematical "minimal variance" solution is obtained when all n surfaces B_i are equal,

$$Var_{\min}(V) = \frac{Var(f)}{n}.A_{tot}^2$$

$$\sigma_{\min}(V) = \frac{\sigma(f)}{\sqrt{n}}.A_{tot}$$

The mathematical theoretical "maximal variance" solution for the volume is when one surface A_j is maximal ($A_j = A_{tot}$) and all other A_k are neglectable and therefore set equal to zero. In this case there are 3 non-zero $B_i = A_j = A_{tot}$, and

$$\sum_i B_i^2 = 3A_{tot}^2$$

$$Var_{\max}(V) = \frac{Var(f)}{9}.3A_{tot}^2$$

$$\sigma_{\max}(V) = \frac{\sigma(f)}{\sqrt{3}}.A_{tot}$$

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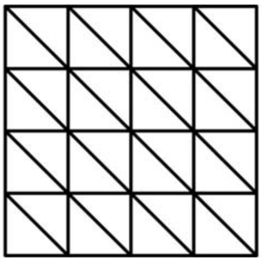
Border Effects

$$\sigma(V) = \frac{1}{\sqrt{n}}.\sigma(f).A_{tot}.\sqrt{1+\left(\frac{\sigma\ (B)}{\overline{B}}\right)^2}$$

Border effects



Assume a geometric layout with 6 neighbors and a total of n points, m (out of the n) points are border points, meaning that they are laying along the edges of the triangulated zone, within the area where the volume is computed, and where the ration m/n is called φ, with 0 <= φ <= 1.

Finally

$$\sqrt{1+\frac{\sigma(B)^2}{\left(\overline{B}\right)^2}} = \sqrt{1+\frac{9\varphi(1-\varphi)}{(6-3\varphi)^2}} \approx \sqrt{1+\frac{\varphi}{4}} \approx 1+\frac{\varphi}{8}$$

As 0 <= φ <= 1, the maximal border effect on the standard deviation of the volume is an augmentation of the standard deviation with 1/8 or 12.5 %.

Usually φ is close to 0 and the border effect on the standard deviation on the volume is neglectable.

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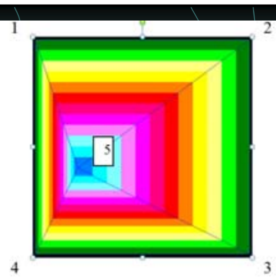


Figure 3: Elevation (contour) model of the exemplary points

The following small data set with 5 irregular spaced points given in (E, N, H) is considered:

E	N	H
0	0	0
5	0	0
0	5	0
5	5	0
1	2	6

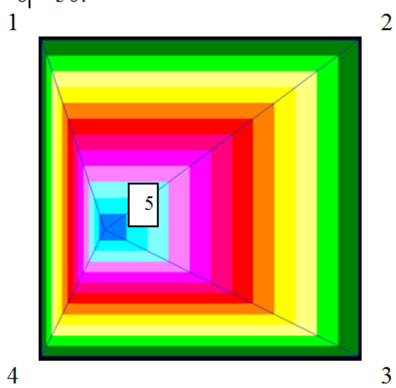
Table 1: coordinates of the example

A standard deviation of 0.5 for each of the height values is given.

Example: volume

E	N	H
0	0	0
5	0	0
0	5	0
5	5	0
1	2	6

The volume between a zero-level reference and this surface is easily computed as: 1/3 * planimetric surface * prism height. In this example, where the prism height is equal to 6, the prism volume = 1/3 * 5 * 5 * 6 = 50.



Example: σ(Vol)

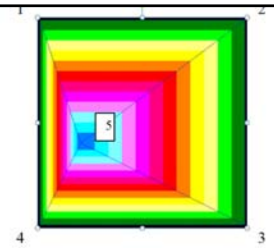


Figure 3: Elevation (contour) model of the exemplary points

The variance of the volume is Var(V) = $\frac{1}{9}\sum \mathrm{Var}(f_i)B_i^2$. *Var(fᵢ)* is computed as the square of the standard deviation of the heights or 0.5^2=0.25. The five different B_i for point 1, 2,…, 5 are

B_1 = 0.5*5*1+0.5*5*3	= 10
B_2 = 0.5*5*3+0.5*5*4	= 17.5
B_3 = 0.5*5*4+0.5*5*2	= 15
B_4 = 0.5*5*2+0.5*5*1	= 7.5
B_5 = 0.5*5*1+0.5*5*3+0.5*5*4+0.5*5*2	= 25

As a check, the sum of the B_i is always 3 times the total surface (75 = 25*3).
The sum of the B_i^2 is 100+306.25 +225 +56.25 +625 = 1312.5.
Hence the Var(V) is 0.25 * 1312.5 / 9 = 36.458.
The standard deviation for the volume of 50 is the root of 36.458 or approx. 6.038.
Thus, the volume between the zero-level and the prism surface is 50 +/- 6.038.

Example: alternatives

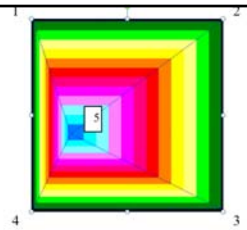


Figure 3: Elevation (contour) model of the exemplary points

If point 5 had been the central point with coordinates (2.5, 2.5, 6), the volume would have been the same. B_1, B_2, B_3 and B_4 would be all equal to 0.5*5*2.5+0.5*5*2.5=12.5, B_5 being equal to 25. Var(V) is then 0.25 * (4*12.5^2+25^2) / 9 = 34.722 and the standard deviation is now slightly reduced to 5.893 (instead of 6.038).

The theoretical "lower limit case" would yield σ_{min}(V) = sqrt(0.25*25^2 /5) = 5.590.

The theoretical "upper limit case" would yield σ_{max}(V) = sqrt(0.25*25^2 /3) = 7.217.

However, these two latter cases are purely hypothetical cases, both layouts being geometrically impossible.

Conclusion: σ spread (< 10%) is small: "Best case" is good approximation and easy to compute !

$$\sigma(V) = \frac{1}{\sqrt{n}}.\sigma(f).A_{tot}$$

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6. Conclusions

- Hydrographic impose specific requirements to the processing
- Multibeam or homogeneous data coverage => Grid modeling
    - Straightforward (easy implementation) => faster
    - Less flexible (fixed grid interval distance)
- Singlebeam or non-homogeneous data coverage => TIN
    - More complex (more difficult implementation) => slower
    - Flexible (variable triangle size)
- Accuracy of TIN Volume
    - Fast σ approximation
    - Accurate σ computation
    - Border effects are neglectable

$$\sigma(V) = \frac{1}{\sqrt{n}}.\sigma(f).A_{tot}$$

$$\sigma(V) = \frac{1}{\sqrt{n}}.\sigma(f).A_{tot}.\sqrt{1+\left(\frac{\sigma\ (B)}{\overline{B}}\right)^2}$$

Next meeting point:

HYDRO 2012, Rotterdam, 12-15 november 2012

Organised by the Hydrographic Society Benelux

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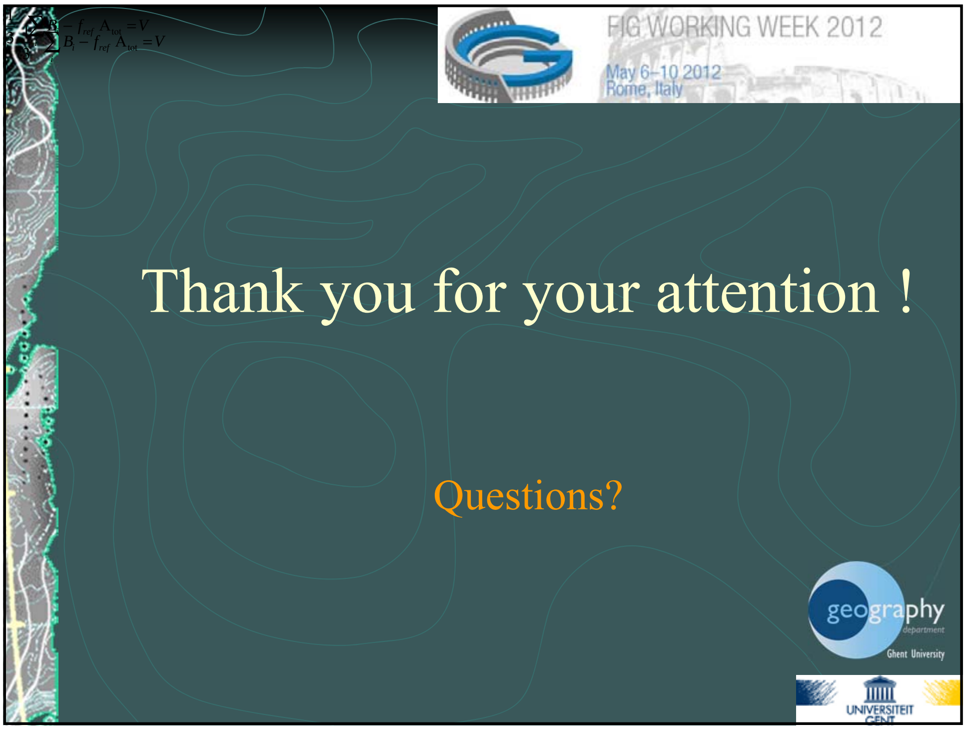
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