Hydro

13-15 November 2012 Rotterdam | Taking care of the sea

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

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2. Grid modeling

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4. Grid versus TIN

5. Accuracy Aspects of TIN & grid models

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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, target: spike removal and/or update of models)
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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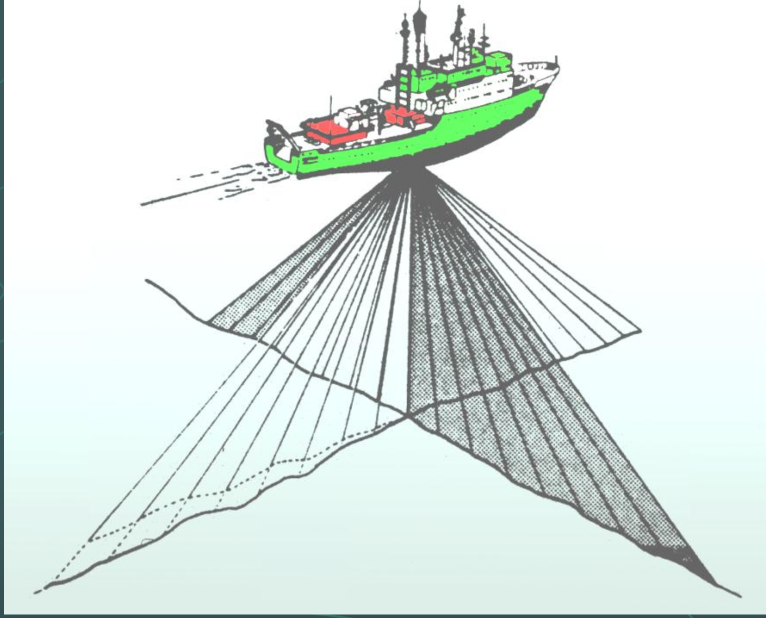
2. Grid modeling: Principle



- Multibeam =>
  - Equidistant coordinates in **international grid** system
    - Geodetic datum
    - Projection system (UTM,…)
    - Conventional reference plane (LAT, CD, GRS80 ellipsoid) with z from GNSS or tide gauges
  - Output = **equidistant** grid data (E, N axis) =>
    - **Store only Depth** values (typically 2 byte/point: 65536 depth values)
    - **Grid interval distance** is decisive parameter

2. Grid modeling: Filtering

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

$\Rightarrow$ 20.000 points/sec. or 72 million/hour or > 1 billion/day

For Quality Control: multiple points/cell needed

But for other applications (volumes, GIS, …): Less points needed => grid interval distance should be chosen carefully

2. Grid modeling: Filtering: How ?

- **Increase 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 ?)
  - Use model with variable grid intervals => complex

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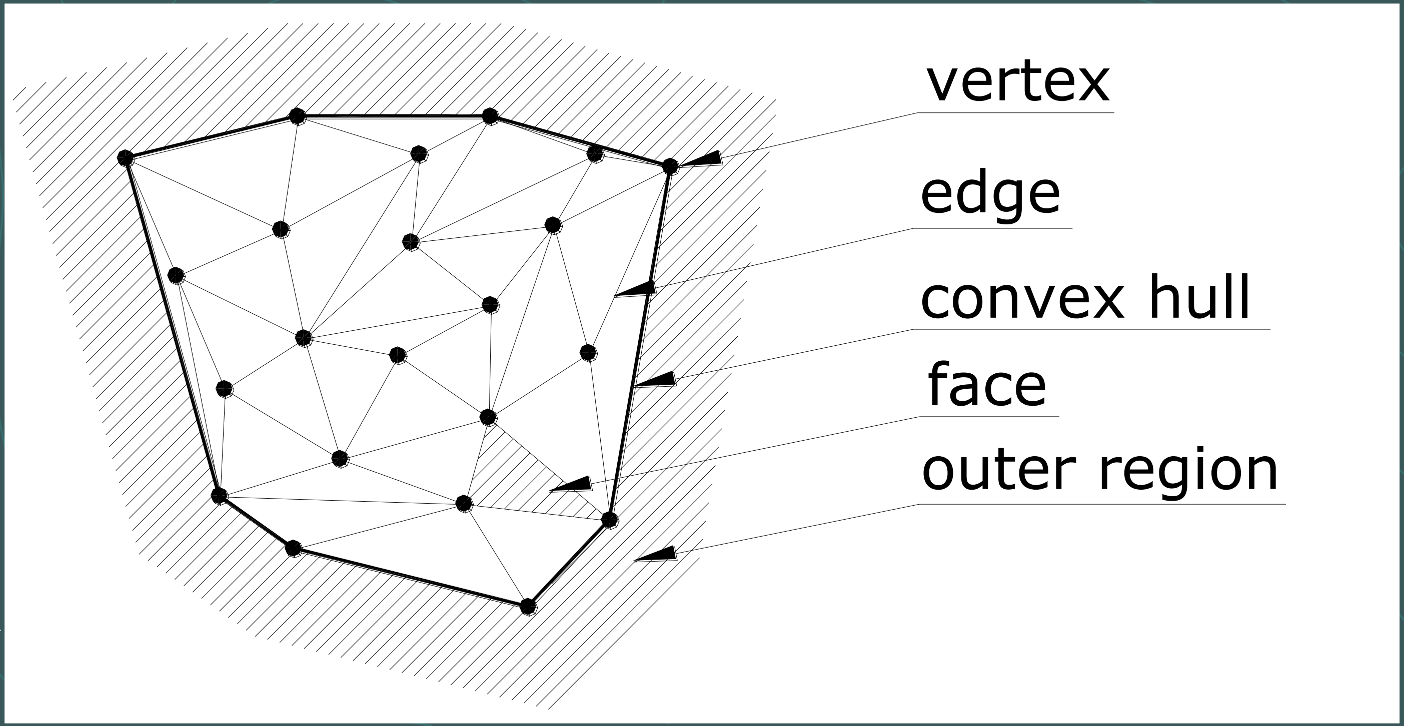
3. TIN based modeling: principle

- 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

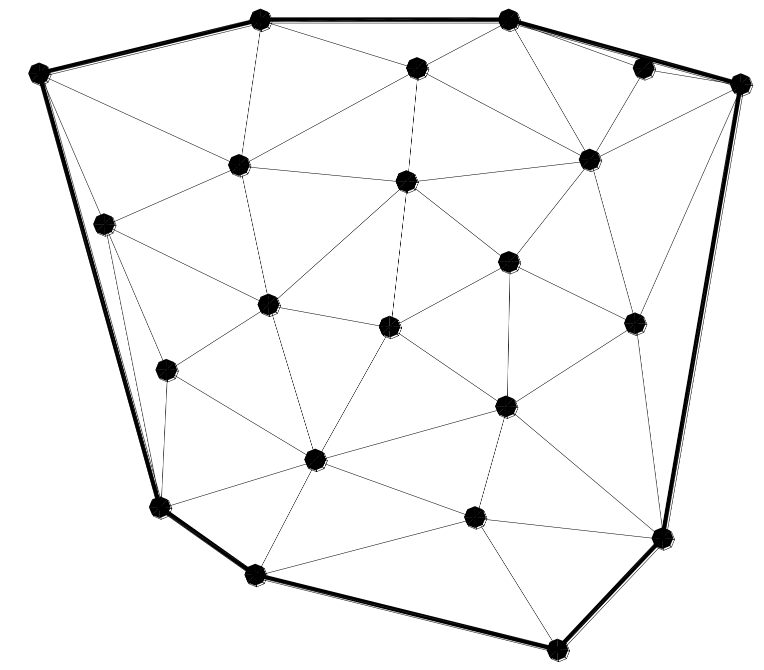
- no triangle sides are intersecting
- no triangles are superposed
- the union of all triangles fill up the hull of the triangulation



Why Delaunay triangulation ?

Advantages:

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

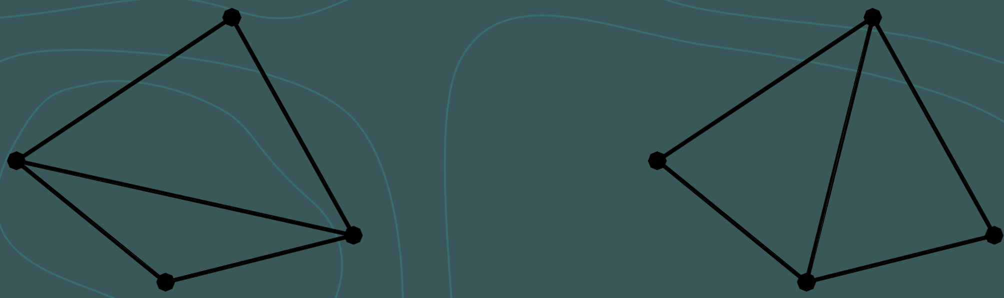


Delaunay triangulation

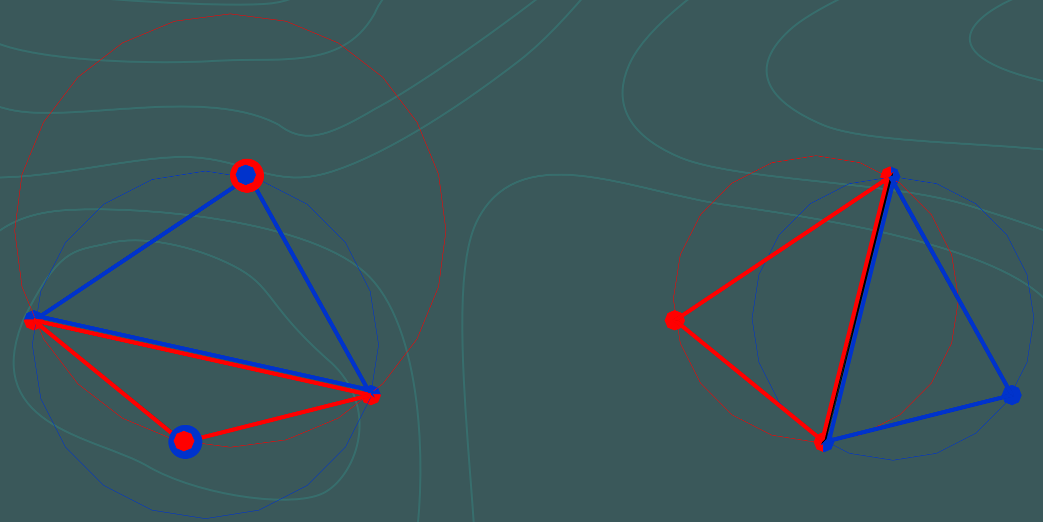
Drawbacks:

- 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.



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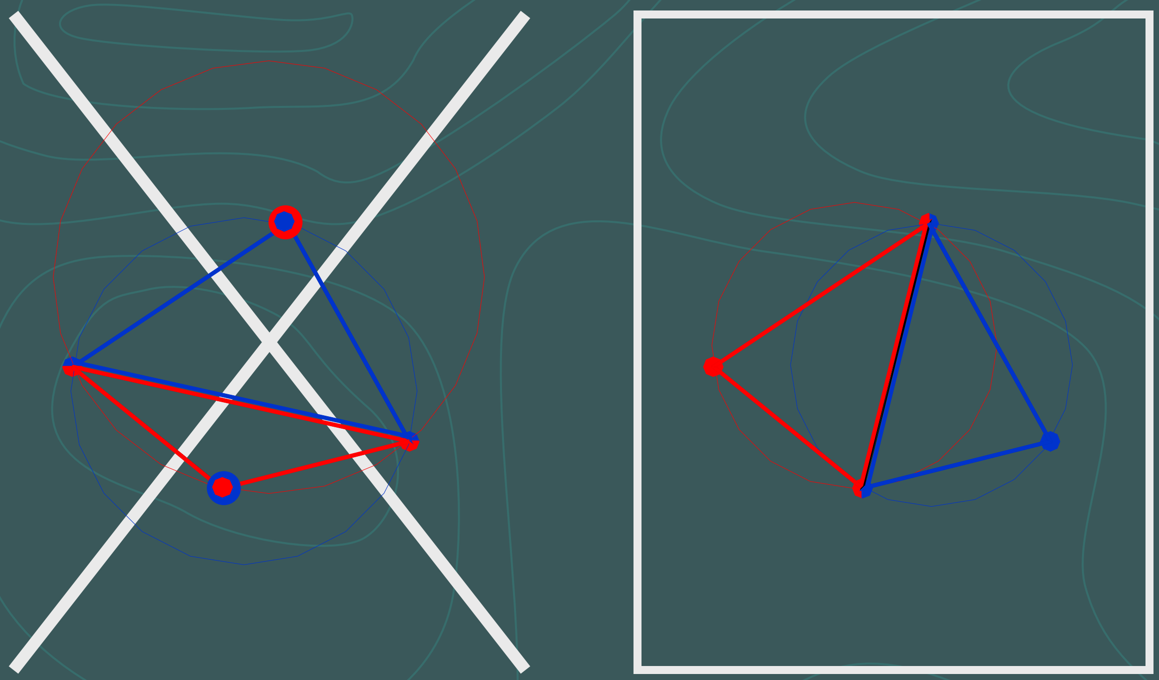

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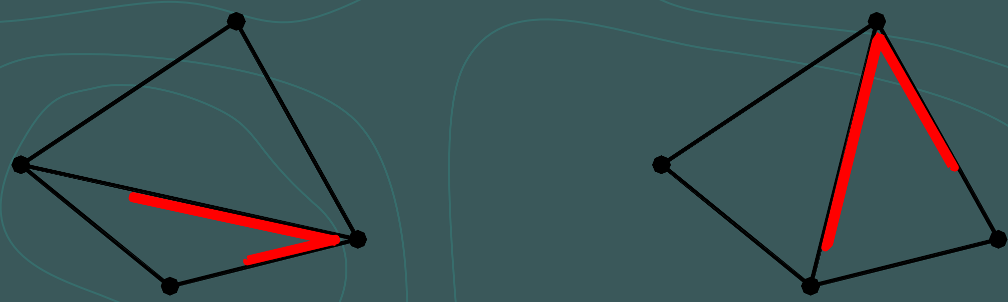
Circumscribing rule is equivalent tot the Min-max rule of Lawson



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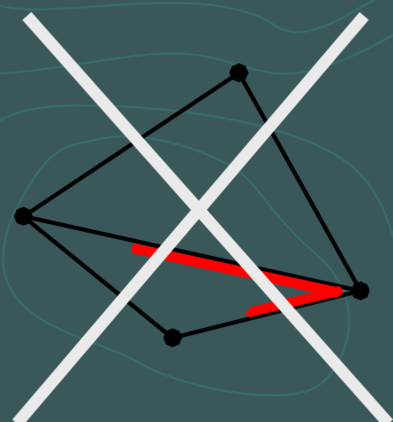
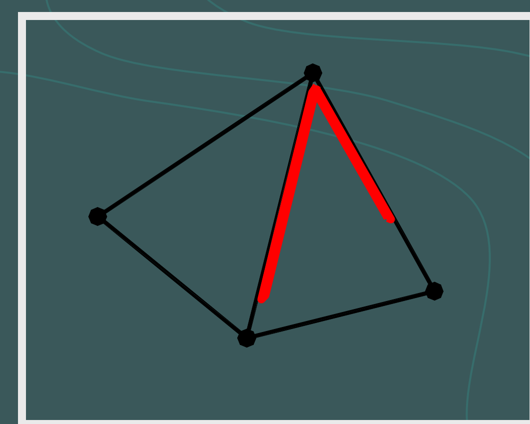


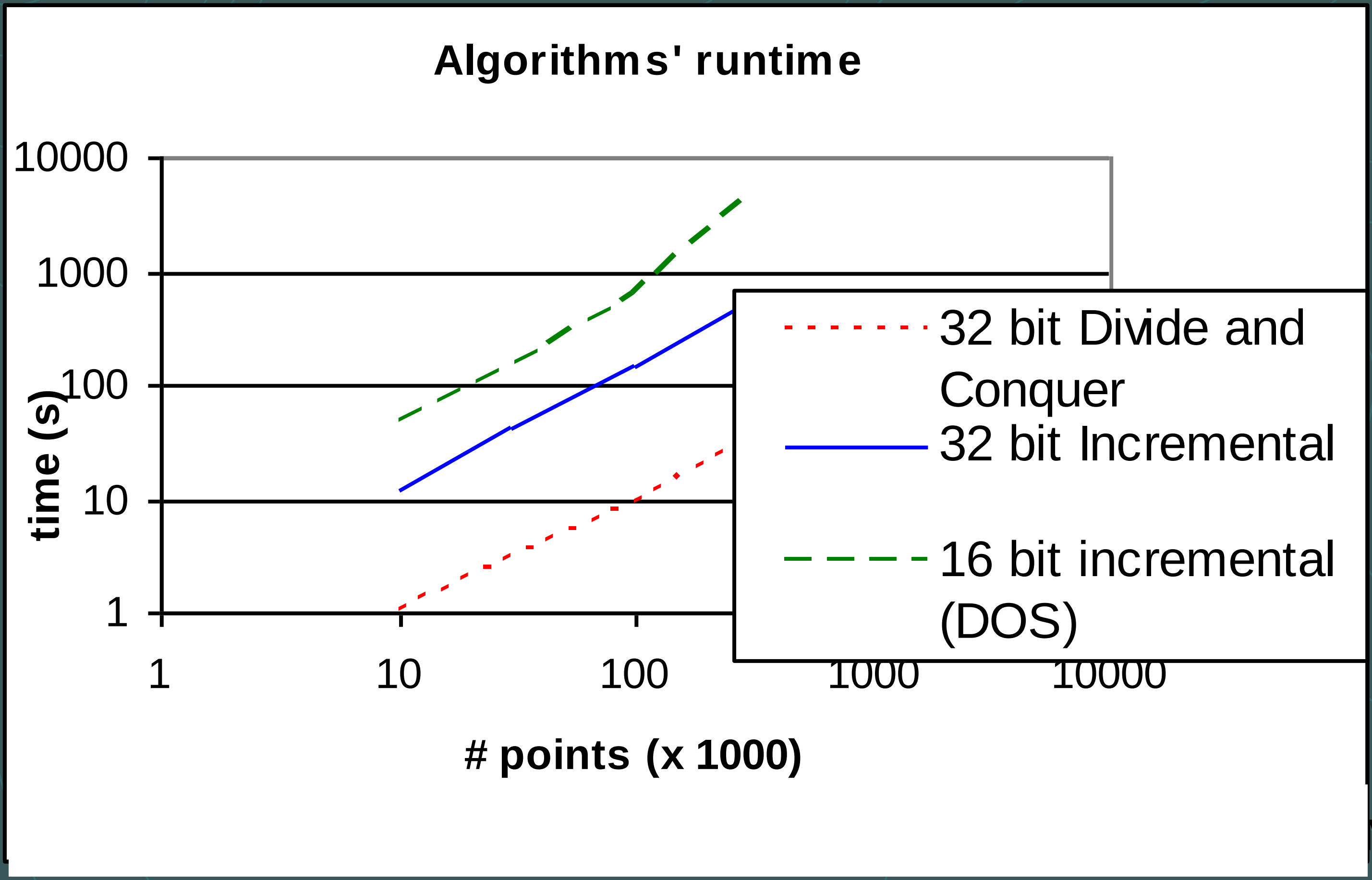


Local optimisation leads to global optimalisation

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 & grid models

- How to compute a volume in a TIN ?
- Standard deviation (σ)/variance of the computed volume
- Variance of a volume using interpolated points in a TIN

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- **How to compute a volume in a TIN ?**
- **Standard deviation (σ)/variance of the computed volume**
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$\frac{1}{3}\sum_i B_i - f_{ref}\,\mathrm{A}_{tot} = V$

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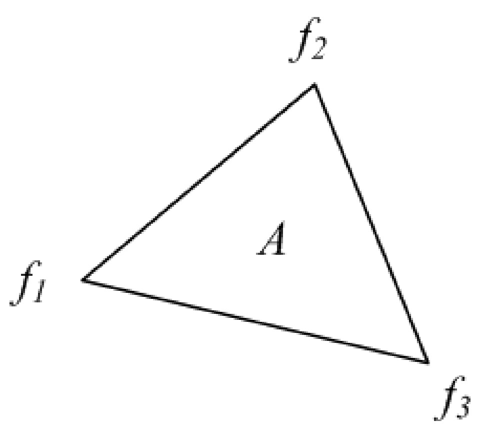
How to compute a volume in a TIN ?

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

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



$\frac{1}{3}\sum_i B_i - f_{ref}\,\mathrm{A}_{tot} = V$

How to compute a volume in a TIN ?

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

$$\frac{1}{3}\sum_i f_i\left(\sum_{f_i \in \mathrm{A}_j} \mathrm{A}_j\right) - f_{ref}\,\mathrm{A}_{tot} = V$$

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

$$B_i = \left(\sum_{f_i \in \mathrm{A}_j} \mathrm{A}_j\right)$$

Then we can write

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

5. Accuracy Aspects of TIN & grid models

- **How to compute a volume in a TIN ?**
- **Standard deviation (σ)/variance of the computed volume**
- **Variance of a volume using interpolated points in a TIN**

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

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

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

$$Var(V) = \frac{Var(f)}{9} \sum_i B_i^2$$

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

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

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

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.

5. Accuracy Aspects of TIN & grid models

- How to compute a volume in a TIN ?
- Standard deviation (σ)/variance of the computed volume
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Accuracy of a volume computation using a set of m points interpolated in a TIN

Assume:

- n original points => ca. 2n triangles in the TIN
- m points interpolated in this TIN

$$\mathrm{TIN} = \{f_i \in A : A \subset \mathbb{R}^3 : i = 0 \dots n\}$$

$$\mathrm{Subset} = \{\tilde{f}_i \in B : B \subset \mathbb{R}^3 : i = 0 \dots m\}$$

$\frac{1}{3}\sum_i B_i - f_{ref}\,A_{tot} = V$

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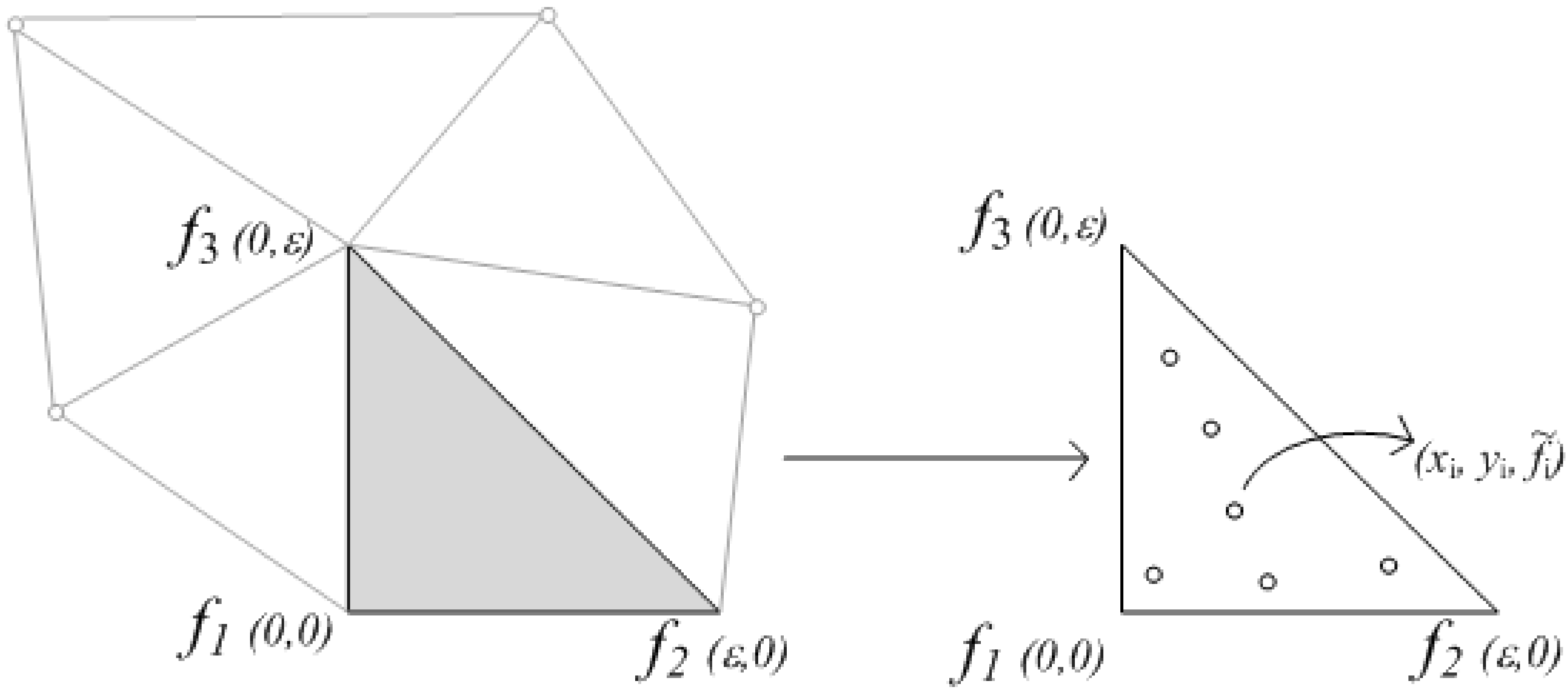

: Assumed structure of a triangle with m_Δ points, having elevation values $\tilde{f}_i$

$\frac{1}{3}\sum_i B_i - f_{ref}\,\mathrm{A}_{tot} = V$

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Accuracy of a volume computation using a set of m points interpolated in a TIN

Mathematical elaboration will be published in the NCG publications (http://www.ncg.knaw.nl/)

- Considering random interpolated points
- Knowing that the variance will be smaller for equidistant points
- The formula elaboration gives us the “worst case scenario” and leads to

$$\mathrm{Var}(V) = \sum_{\Delta} \frac{A_{\Delta}^2}{m_{\Delta}} \left(\frac{1}{4} \mathrm{Var}(f_{\Delta}) + \mathrm{Var}(f) \right)$$

$\frac{1}{3}\sum_i B_i - f_{ref}\,\mathrm{A}_{tot} = V$

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Accuracy of a volume computation using a set of m points interpolated in a TIN

$$\mathrm{Var}(V) = \sum_{\Delta} \frac{A_\Delta^2}{m_\Delta}\left(\frac{1}{4}\mathrm{Var}(f_\Delta) + \mathrm{Var}(f)\right)$$

The variance is a sum over all triangles, where within each triangle:

- m_Δ is the number of interpolated points,
- Var(f) is the a priori assumed stochastic measurement error,
- A_D is the planimetric surface,
- Var(f_Δ) the variance of the heights of the 3 vertices.

$\frac{1}{3}\sum_i B_i - f_{ref}\,A_{tot} = V$

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- Combining the variance of a TIN

$$\mathrm{Var}(V) = \mathrm{Var}(f)\frac{1}{n}A_{total}^2 \cdot \left[1 + \left(\frac{\sigma(B)}{\bar{B}}\right)^2\right]$$

- With the variance of the interpolated points

$$\mathrm{Var}(V) = \sum_{\Delta}\frac{A_{\Delta}^2}{m_{\Delta}}\left(\frac{1}{4}\mathrm{Var}(f_{\Delta}) + \mathrm{Var}(f)\right)$$

- Finally results in

$$\mathrm{Var}(V) = \sqrt{\mathrm{Var}(f)\frac{1}{n}A_{total}^2 \cdot \left[1 + \left(\frac{\sigma(B)}{\bar{B}}\right)^2\right] + \sum_{\Delta}\frac{A_{\Delta}^2}{m_{\Delta}}\left(\frac{1}{4}\mathrm{Var}(f_{\Delta}) + \mathrm{Var}(f)\right)}$$

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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
  - Prismatic vol. computation

$$\mathrm{Var}(V) = \mathrm{Var}(f)\frac{1}{n}A_{total}^2 \cdot \left[1 + \left(\frac{\sigma(B)}{\bar{B}}\right)^2\right]$$

  - Computation using interpolated points

$$\mathrm{Var}(V) = \sqrt{\mathrm{Var}(f)\frac{1}{n}A_{total}^2 \cdot \left[1 + \left(\frac{\sigma(B)}{\bar{B}}\right)^2\right] + \sum_{\Delta}\frac{A_{\Delta}^2}{m_{\Delta}}\left(\frac{1}{4}\mathrm{Var}(f_{\Delta}) + \mathrm{Var}(f)\right)}$$

Acknowledgments

The Institute for the Promotion of Innovation by Science and Technology in Flanders (IWT) funded project n° IWT990159 'Survey System for Dredging' (1999-2002) with

- Ghent University, Geography Department, as scientific partner.
- DEME, Survey Department as private partner.
- The present fundamental research fits in the larger, international Eureka project «Dredging Survey 2000 (EU203511)».

Thanks to **Gert Brouns** who carried out during 18 months research work concerning the editing of triangulation models.

Financial support from BOF/GOA 01GA0405, **funded by Ghent University,** for the research work of Denis Constales.

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Thank you for your attention !

Questions?

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