DSM / DTM Filtering

Theory and Application of Laser Scanning
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Overview

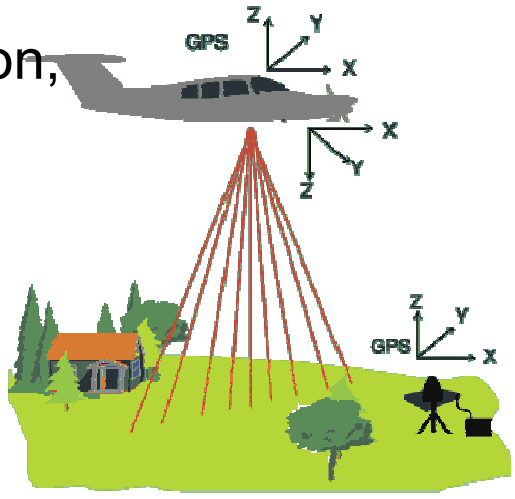
- Problem
  - DTM required
  - Observation by Laser Scanning
  - but: obstacles along the laser beam path
- Solution - Extract terrain information
  a number of different approaches can be identified
  - Block minimum filters
  - Morphological filters
  - Progressive densification
  - Surface based filtering
  - Segmentation based filters

Data Acquisition

- Sampling according to system parameters

➲ Points lie on different objects/surfaces

- Examples:
  terrain, vegetation, low vegetation,
  understorey, houses,
  (light) poles, … (what else?)
  multi path effects (long ranges)
- First/last detected echo

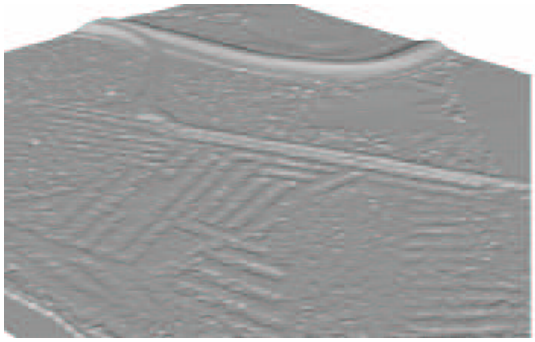
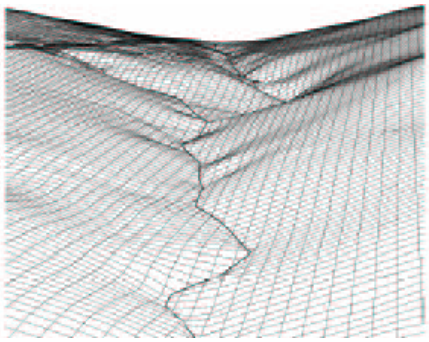
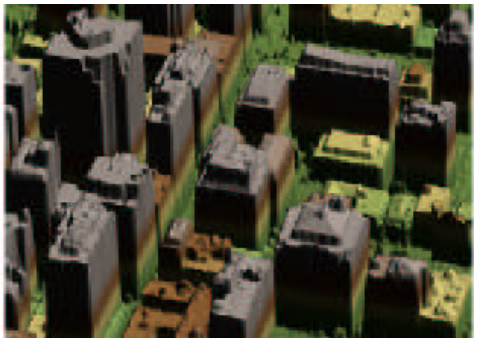
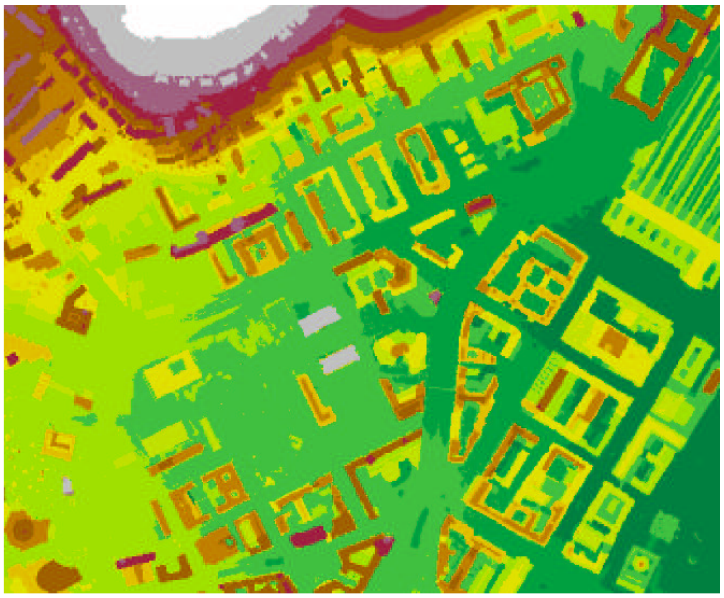
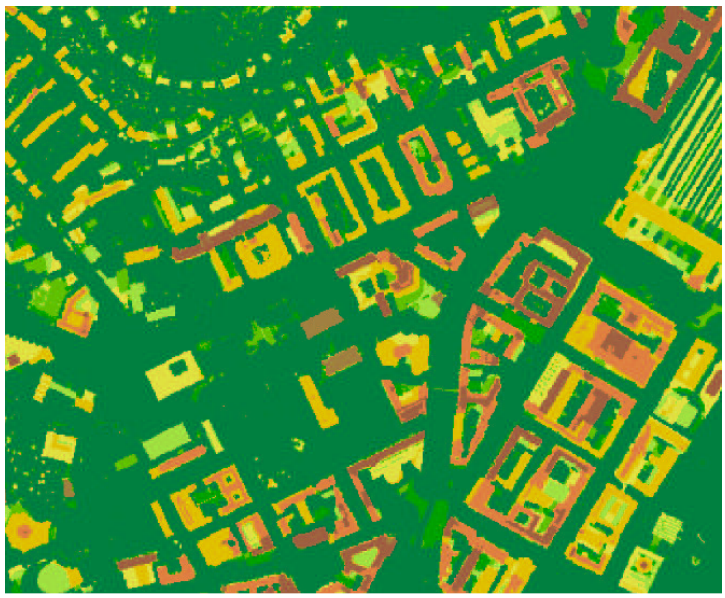


DEM / DTM / DSM / nDSM

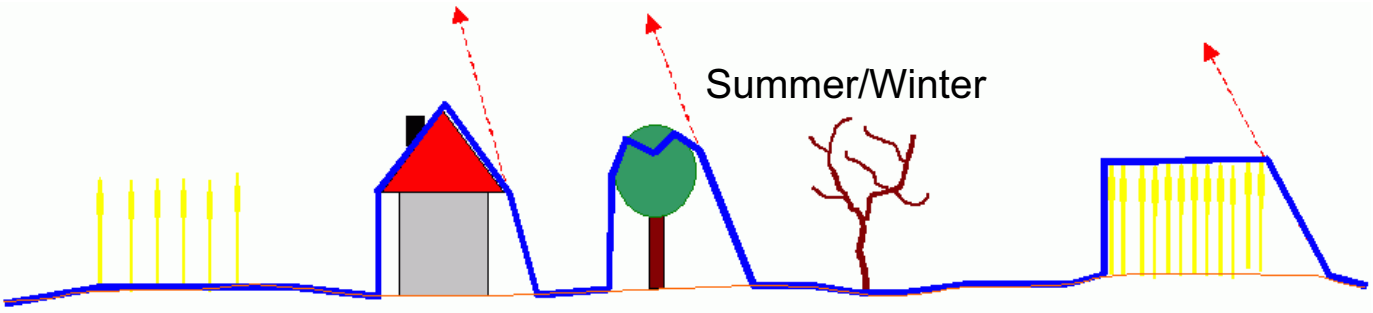
Digital models of topographic surfaces

- Digital Elevation Model
- Digital Terrain Model
  (=DEM, sometime + break lines, peak points, …)
- Digital Surface Model
- normalized Digital Surface Model
- Digital Canopy/Situation/… Model

DSM DEM nDSM DSM DTM

DSM from Laser Altimetry



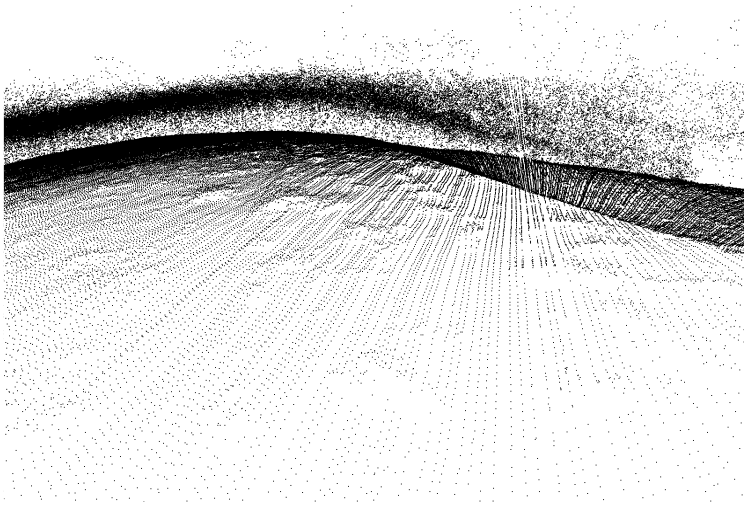
Useful for

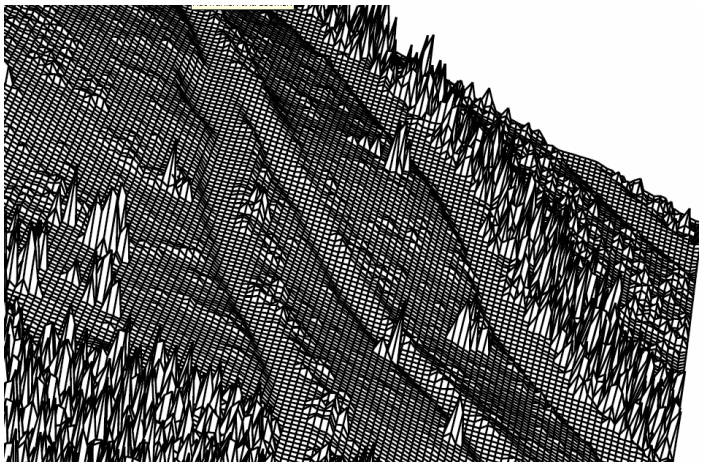
- Check completeness
- Check overlap (extent, errors, ...)
- visualization
- manual interpretation
  (e.g. measure distances)

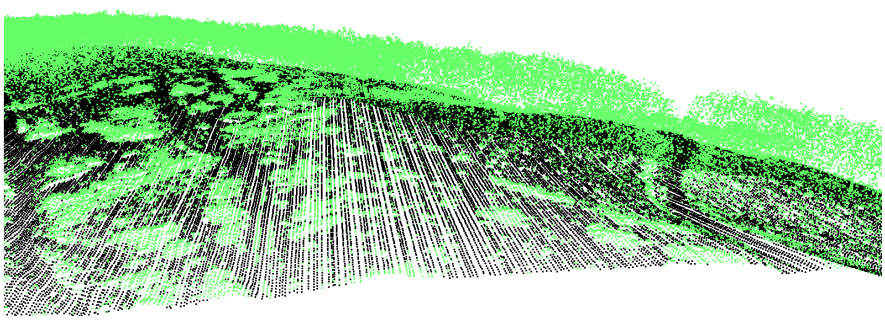
Problem definition

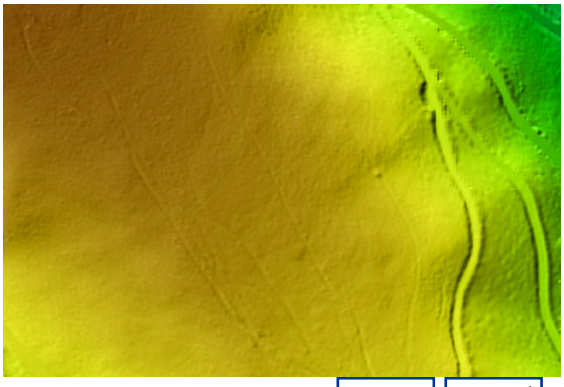
- Given:

- Required:









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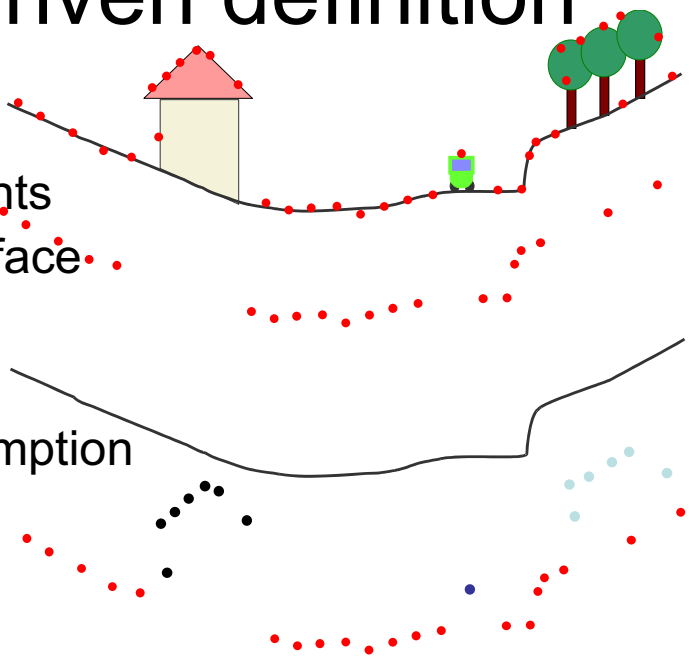
Filtering - result driven definition



- Filtering to extract ground points
- Filtering to extract ground surface
- Classification to label points

- Filtering requires terrain assumption
  e.g.:
  - No height jumps
  - Smooth surface
  - No points below terrain
  - … (what else?)

Filter algorithms overview

- Morphological filters
  Example: slope based filtering (Vosselman) + mathematical morphology
- Progressive densification
  Example: TIN densification (Axelsson)
- Surface based filters
  Example: robust interpolation (Kraus) + hierarchic extension
- Segmentation based filters

Block minimum filters

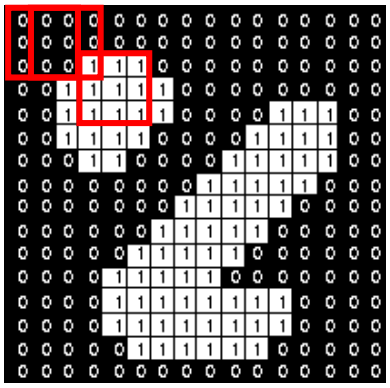
- Define regular mesh
  edge length =
- Take lowest point in each cell
- Compute DTM by interpolating set of these lowest points
- Problems:

Approach 1
Slope based filtering

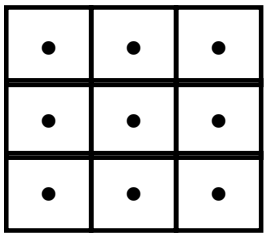
- Principles of mathematical morphology
  (Slides from Prof. Vosselman)
- Binary, rasterized data
  … continuous domain
- Slope based filtering
- Relation to mathematical morphology
- Derivation of filter kernel
- Example

Mathematical morphology

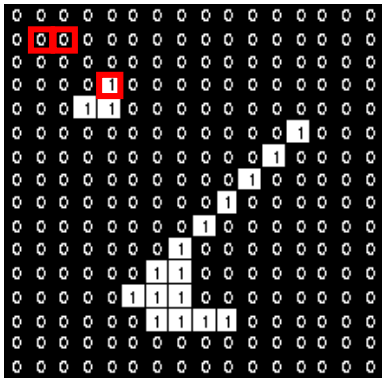
Original



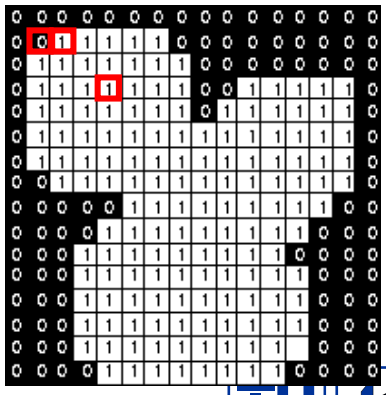
Kernel



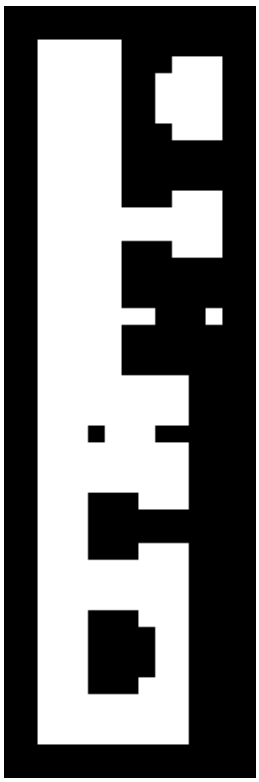
Erosion



Dilation



Morphological opening



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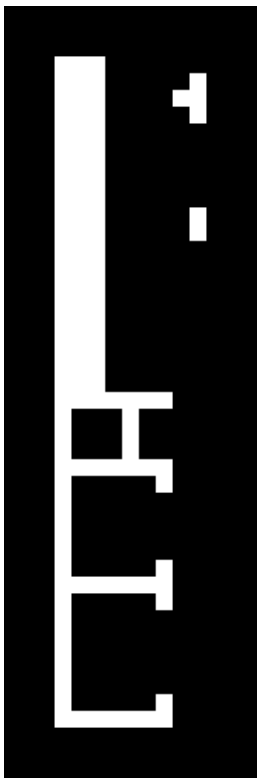
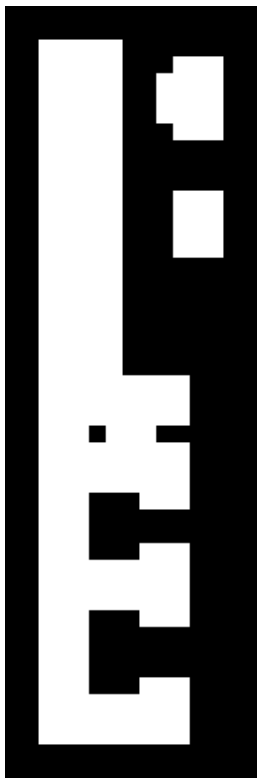
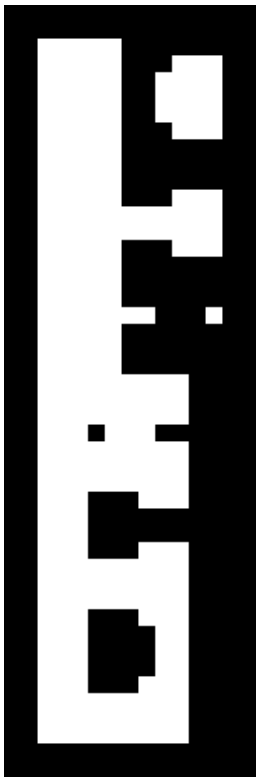


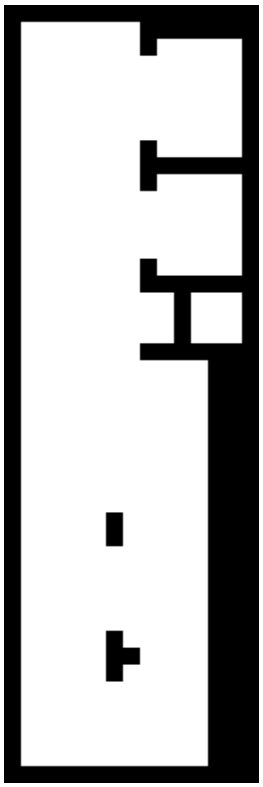


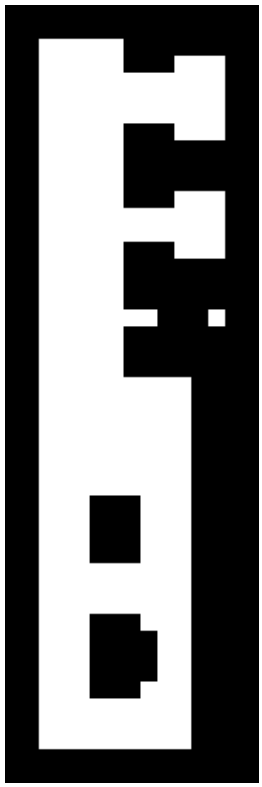
Erosion followed by dilation

Morphological closing



Original





Dilation followed by erosion

More formally

Erosion $$e(x,y) = \min_{\Delta x} \min_{\Delta y} h(x+\Delta x, y+\Delta y)$$

Dilation $$d(x,y) = \max_{\Delta x} \max_{\Delta y} h(x-\Delta x, y-\Delta y)$$

Δx, Δy - for all pixels inside structure element

Opening - Min/Max filter

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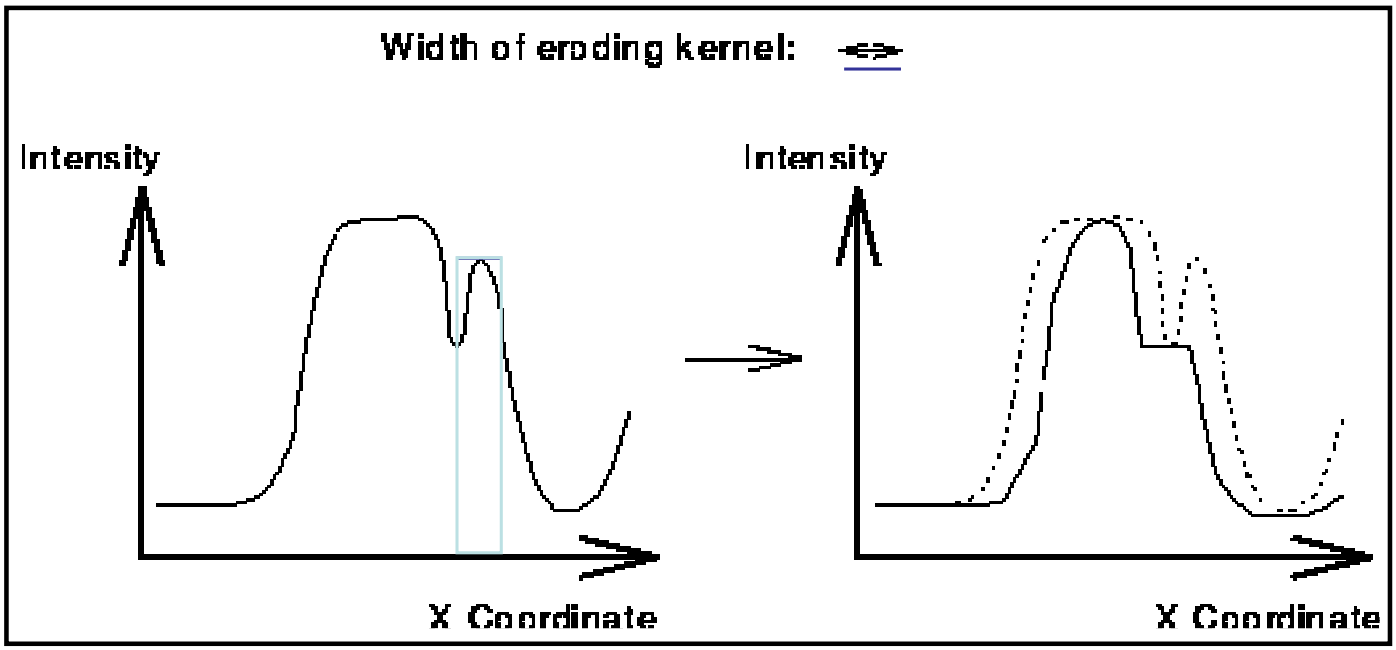
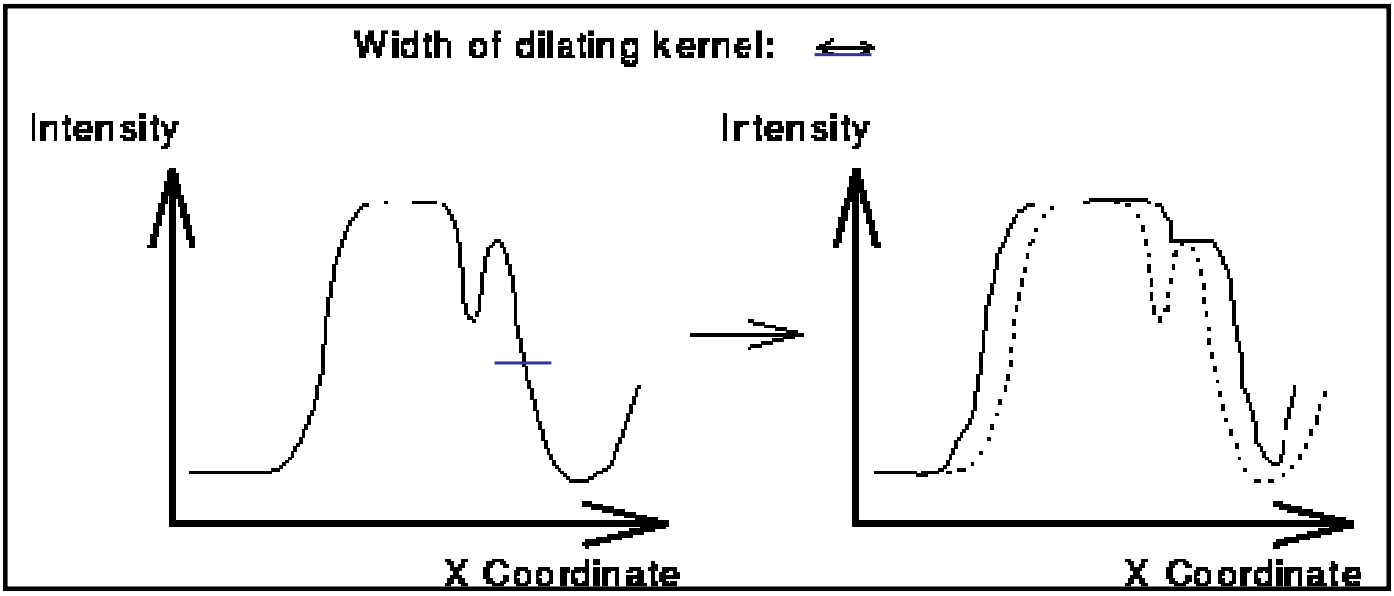
Grey scale erosion



Grey scale dilation



Grey scale mathematical morphology

Kernel function $k(\Delta x, \Delta y), \quad -\frac{K}{2} \le \Delta x, \Delta y \le \frac{K}{2}$

Erosion $e(x,y) = \min_{\Delta x} \min_{\Delta y} \left[h(x+\Delta x, y+\Delta y) - k(\Delta x, \Delta y) \right]$

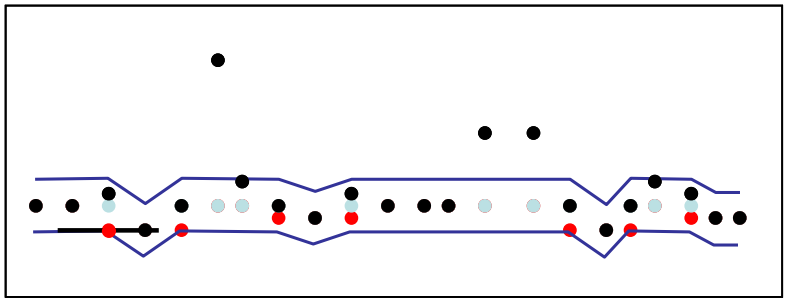
Dilation $d(x,y) = \max_{\Delta x} \max_{\Delta y} \left[h(x-\Delta x, y-\Delta y) + k(\Delta x, \Delta y) \right]$

Min/Max $k(\Delta x, \Delta y) = 0, \quad -\frac{K}{2} \le \Delta x, \Delta y \le \frac{K}{2}$

Filtering with mathematical morphology

Single opening (min/max)

- Selections
  - Window size
  - Height tolerance



Openings with multiple kernel sizes

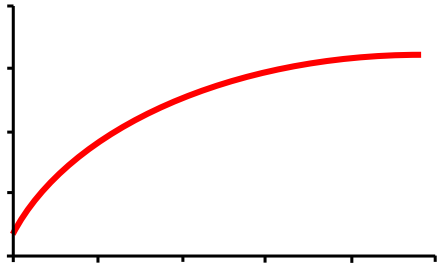
- Increasing height tolerance with increasing window size

Structure element

Slope based filtering

- Optimal filter depends on terrain type
- Reject large height jumps
- Take distance between points into account

Filter function: $\Delta h_{\max}(d)$



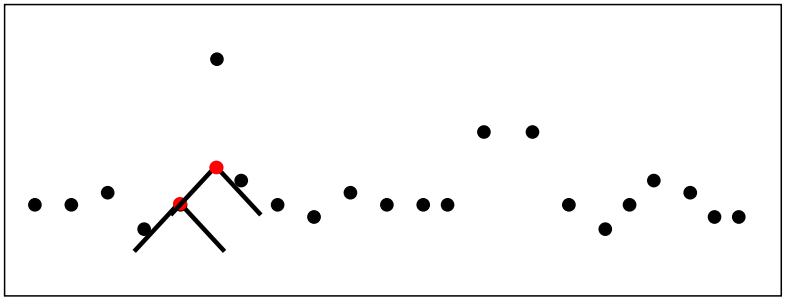
Let A be the set of all points. Define DEM* as

$$DEM = \{p_i \in A \mid \forall p_j \in A : \Delta h_{ij} \leq \Delta h_{\max}(d_{ij})\}$$

* DEM = ground point set

Erosion with a kernel function

Terrain properties encoded in structure element.



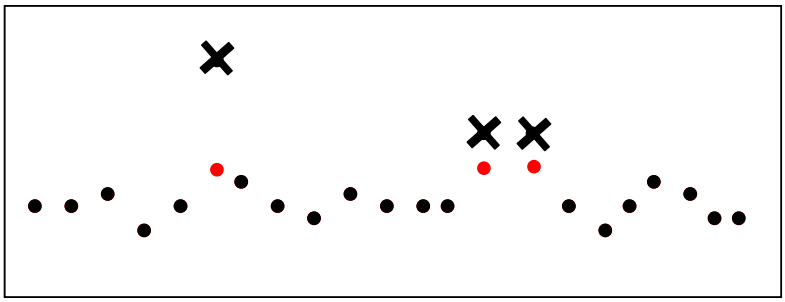
Example:

Maximum terrain slope

Structure element 

Erosion with a kernel function

Terrain properties encoded in structure element.



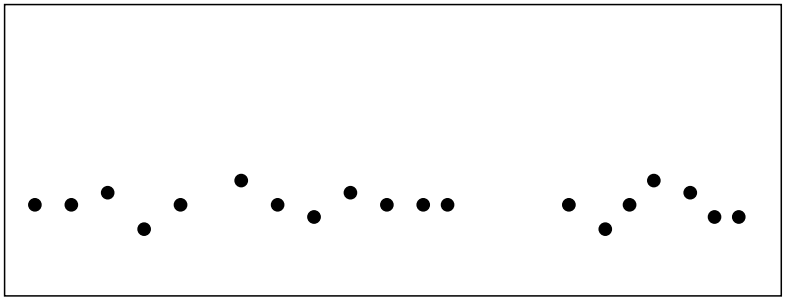
Example:

Maximum terrain slope

Structure element 

Erosion with a kernel function

Terrain properties encoded in structure element.



Height ≤ eroded height

Example:

Maximum terrain slope

Structure element 

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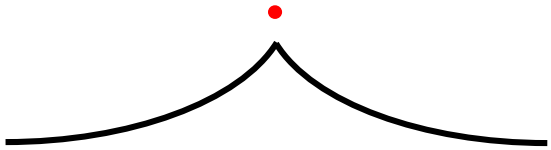
More formally

For images: $e(x,y) = \min_{\Delta x} \min_{\Delta y} \left[h(x+\Delta x, y+\Delta y) - k(\Delta x, \Delta y) \right]$

For sets: $e_{p_i} = \min_{p_j \in A} \left[h_{p_j} - k(\Delta x_{ij}, \Delta y_{ij}) \right]$

$$k(\Delta x, \Delta y) = -\Delta h_{\max}\left(\sqrt{\Delta x^2 + \Delta y^2}\right)$$



$$e_{p_i} = \min_{p_j \in A} \left[h_{p_j} + \Delta h_{\max}(d_{ij}) \right]$$

$$DEM = \left\{ p_i \in A \mid h_{p_i} \le e_{p_i} \right\}$$

Filter functions

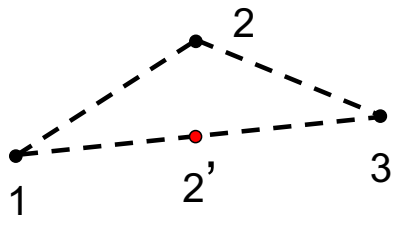
- Theoretical
  - Assume maximum slope, e.g. 30%
  - Assume standard deviation σ and a confidence interval, e.g. 95%.

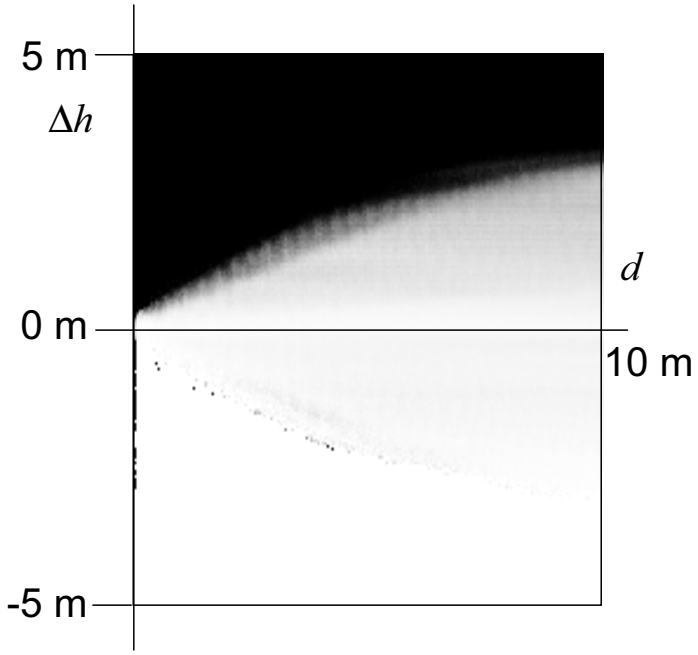
$$\Delta h_{\max}(d) = 0.3\, d + 1.65\sqrt{2}\sigma$$

- Preserving important terrain features
  - Training set with ground points only
  - For each distance interval d, determine max(Δh)

Filter functions (II)

- Minimising classification errors
  - Effect of type I error equals effect of type II error

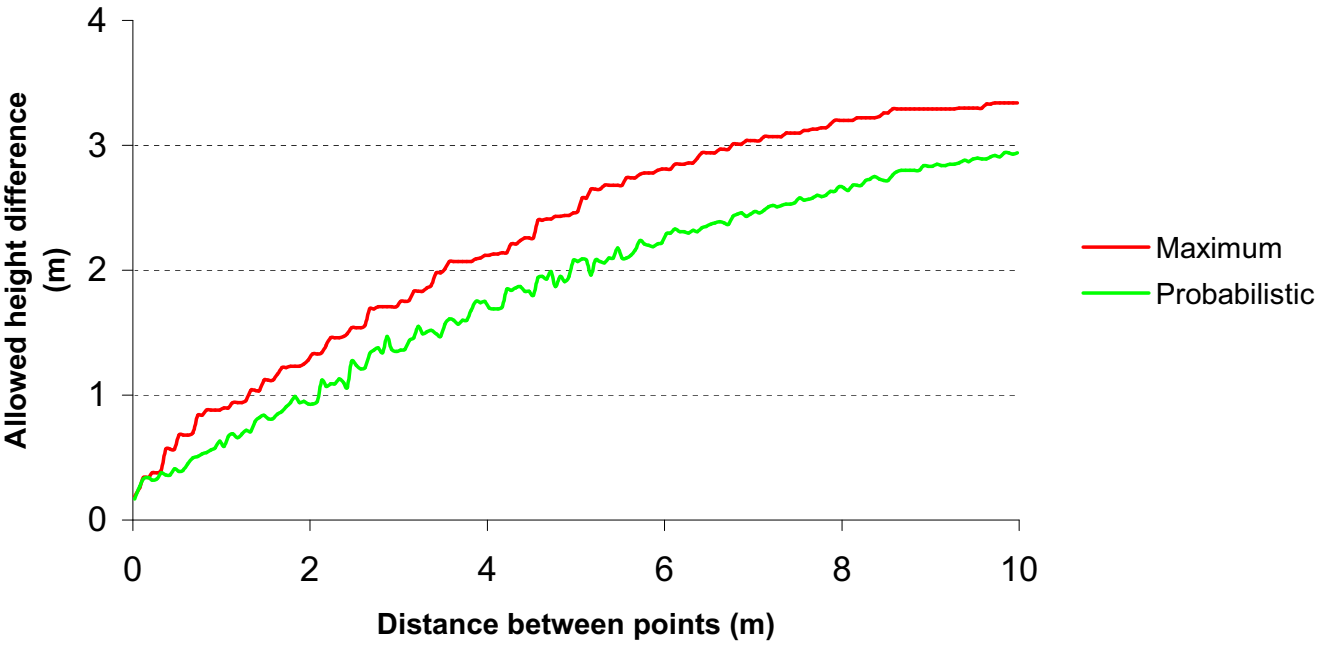




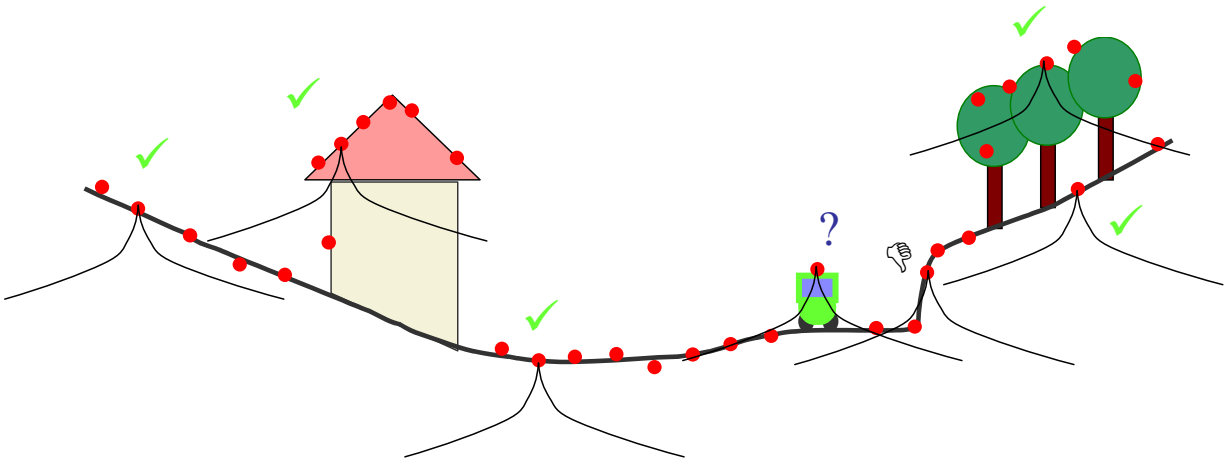
  - For each d, determine Δh for which

$$P(p_j \in DEM \mid \Delta h, d, p_j \in DEM) = 0.5$$

Filter functions (III)



morphological filtering



Example

Area: partly open, wooded, with a dike

Filter kerner: use training data set
maximum filter (i.e. no ground points lost)

Tested also with reduced resolution

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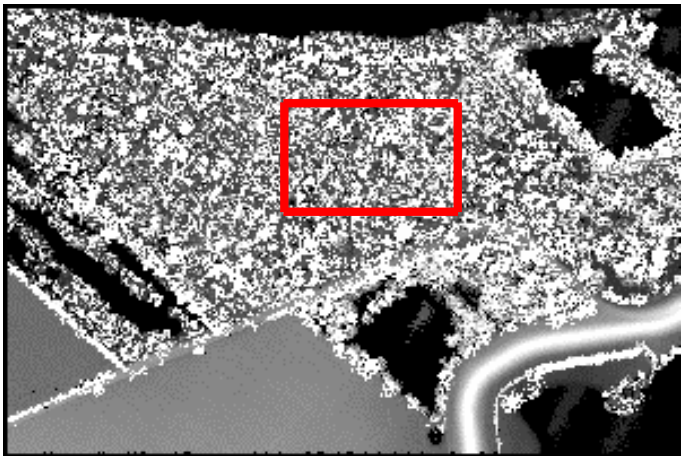
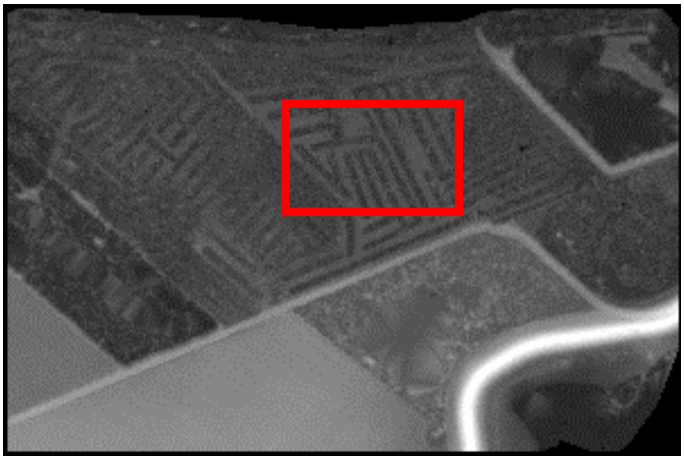
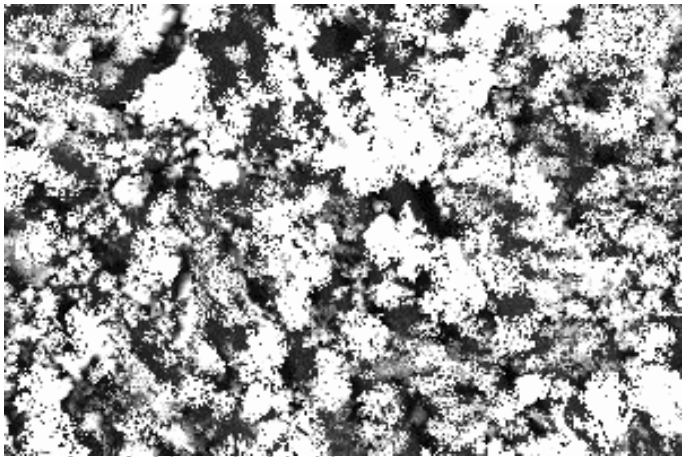
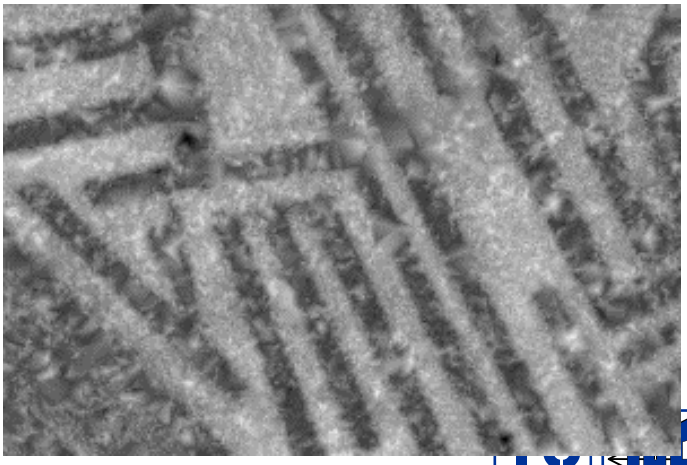
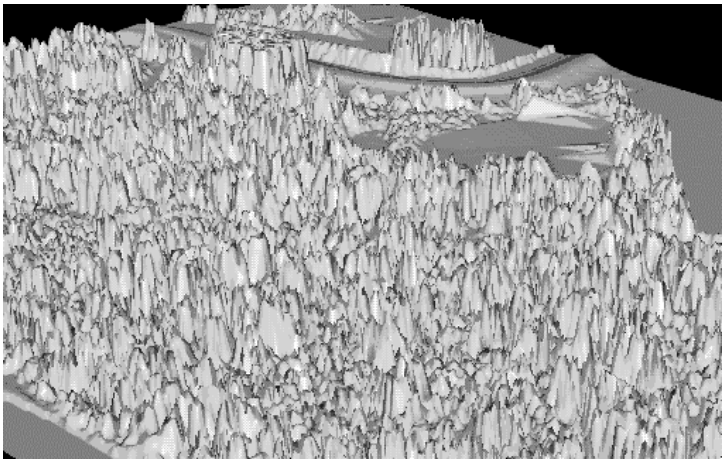
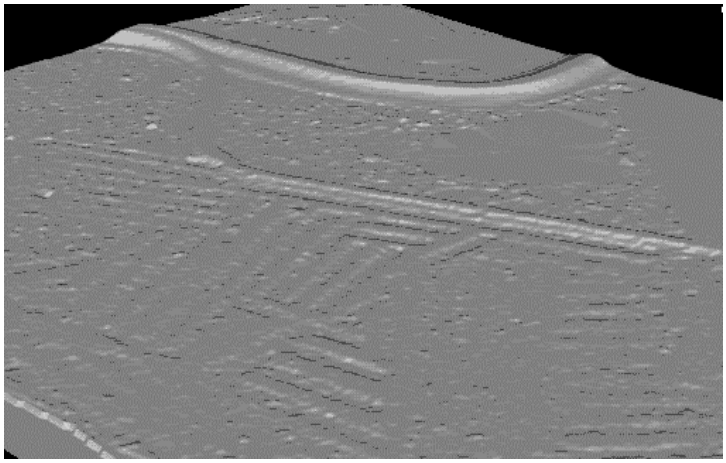


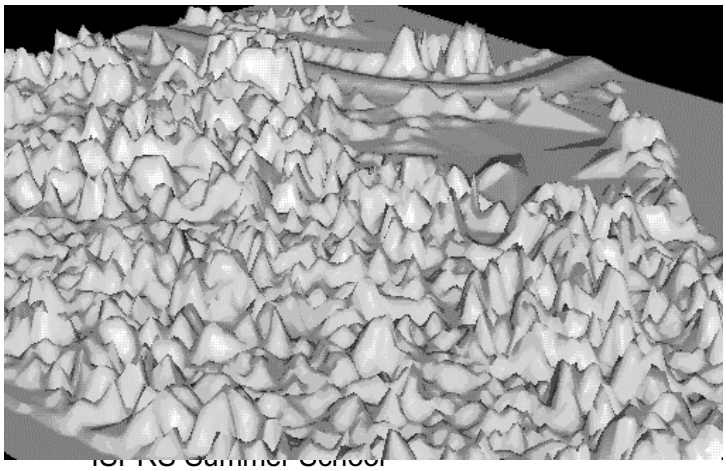


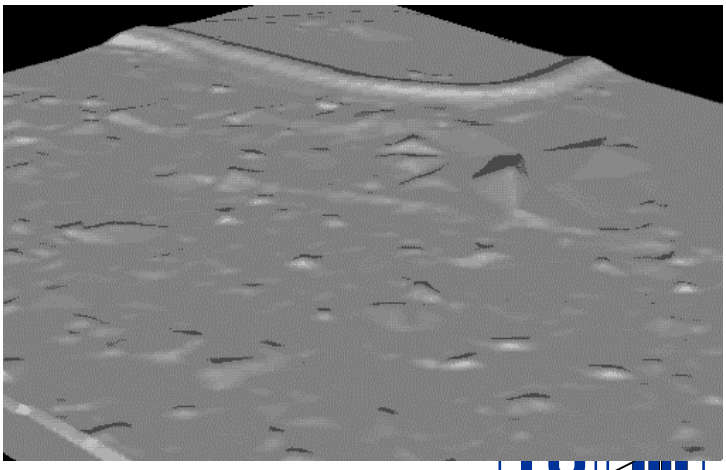










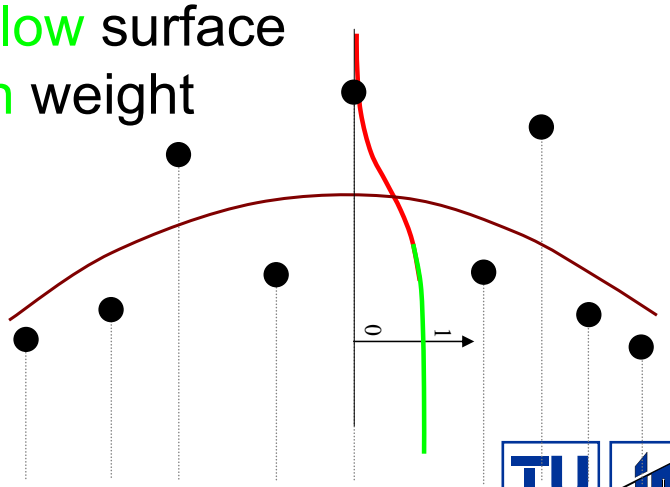


Approach 2
Robust interpolation

- Principle
- Mathematical description
- Hierarchic extension
- Example

Robust interpolation

- interpolation: surface $f(x,y)$ "through" points
  filtering of measurement errors
- robust: residuals (surface – laser point)
  weight function:
  points above/below surface
  ➲ small/high weight
- iterate
- General principle:
  weight function
  interpolation method



Mathematical formulation

$z(x,y) = \mathbf{c}^T\mathbf{C}^{-1}\mathbf{z}$

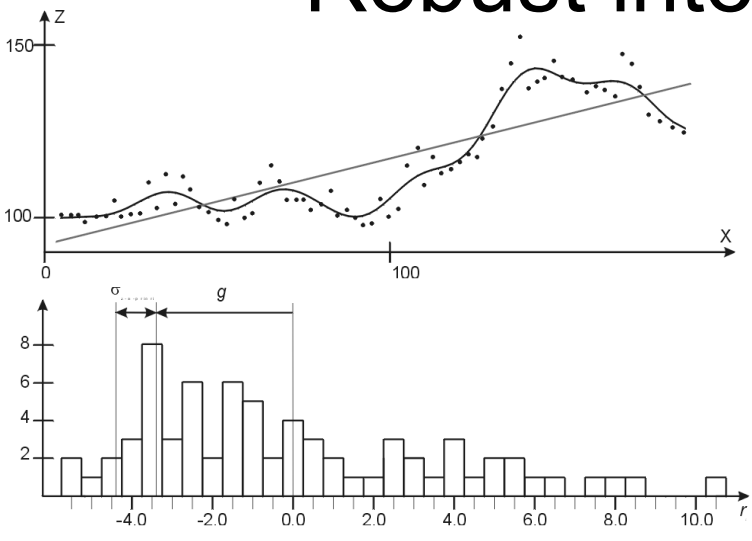
$\mathbf{c} = (C(p,p_1), \ldots C(p,p_n))^T, \quad \mathbf{z} = (z_1, \ldots z_n)^T$

$$\mathbf{C} = \begin{pmatrix} V_{zzp1} & C(p_1,p_2) & \cdots & C(p_1,p_n) \\ C(p_1,p_2) & V_{zzp2} & & C(p_2,p_n) \\ \vdots & & \ddots & \\ C(p_1,p_n) & C(p_2,p_n) & \cdots & V_{zzpn} \end{pmatrix}$$

$$V_{zzpi} = \sigma_z^2 / w_i + C(0)$$

$$w(r) = \begin{cases} r < g & : & 1 \\ g \le r \le g+h & : & \dfrac{1}{1+(a(r-g))^b} \\ r > g+h & : & 0 \end{cases}$$

Robust interpolation



Simple kriging (=lineare prediction)

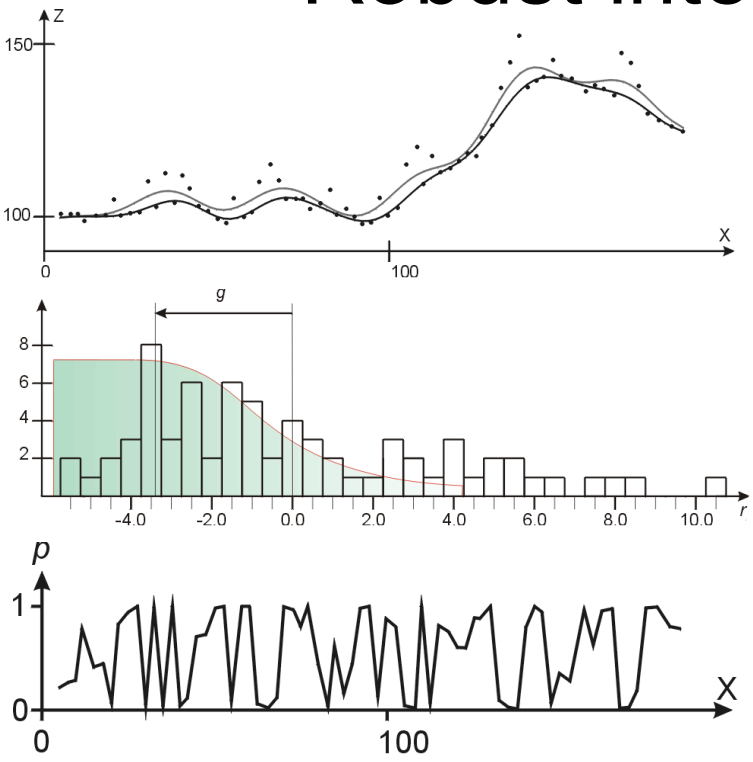
- random measurement errors

Histogram of residuals

Origin of the weight function

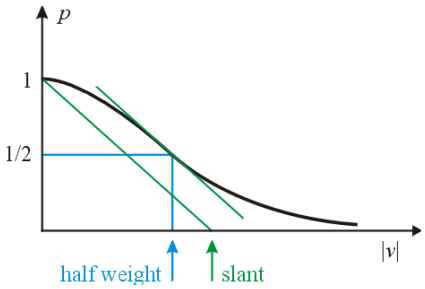
- statistical method
- penetration rate
- histogram analysis

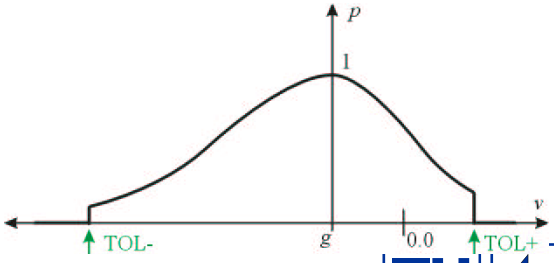
Robust interpolation



Weight funtion

- Half weight width
- Slant





Hierarchic filter strategy

- Robust interpolation requires good mixture of ground and off-terrain points
- Hierarchic approach guarantees mixture
- Hierarchic approach speeds up process

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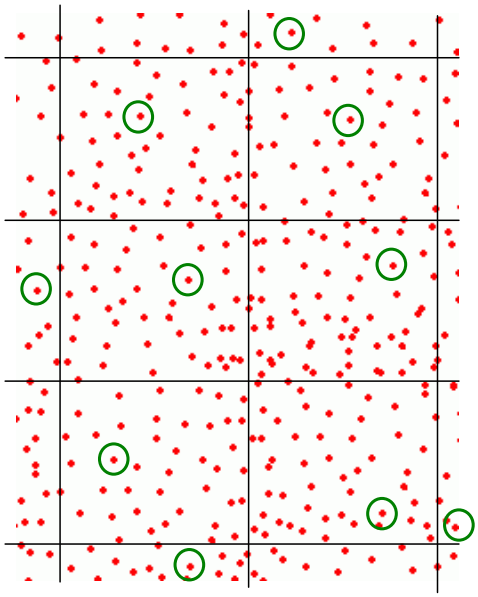
Hierarchic filter strategy I



- Compute data (point set) at different niveaus:

  Select

  – Lowest point or barycenter

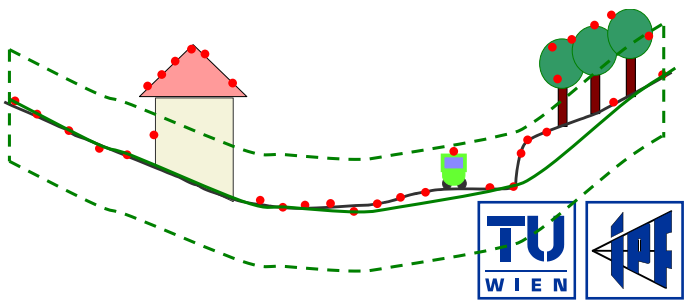
  for each cell (define edge length)

- Process (filter) different niveaus coarse to fine
  e.g.: 20m → 4m → original data

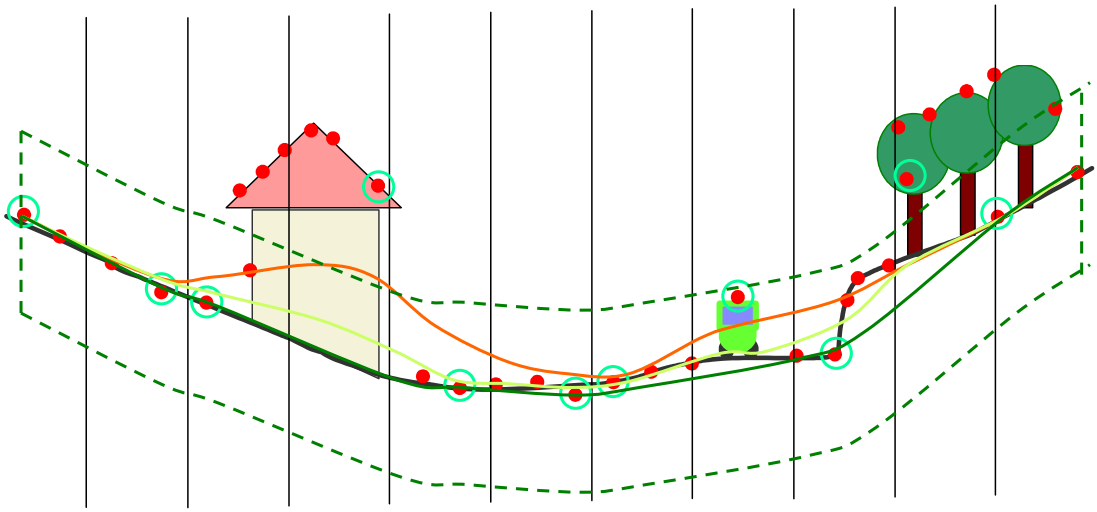
Hierarchic filter strategy II

Iteration

1. Robust interpolation for coarsest niveau
   → first DTM
2. Select points of next (finer) niveau within a tolerance band of DTM
3. Robust interpolation for selected points
4. Iterate from step 2

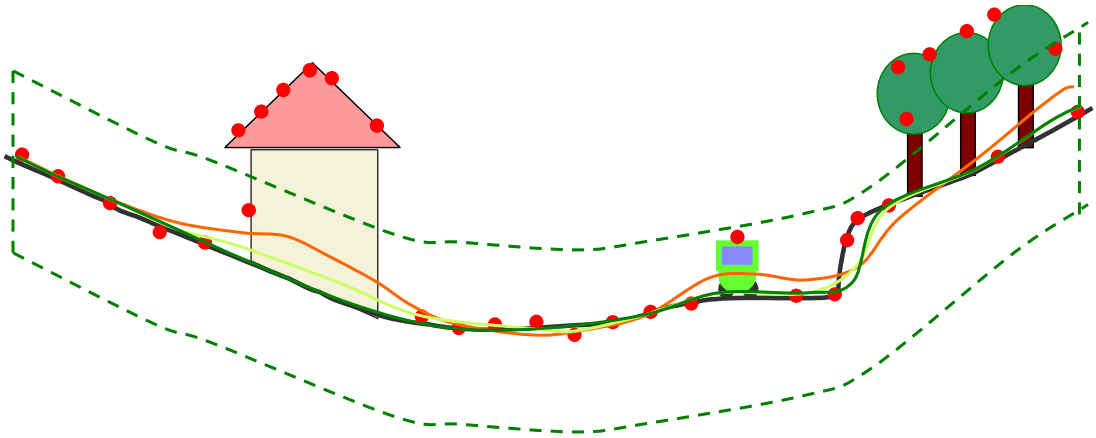


Hierarchic robust interpolation



Niveau 1

Hierarchic robust interpolation



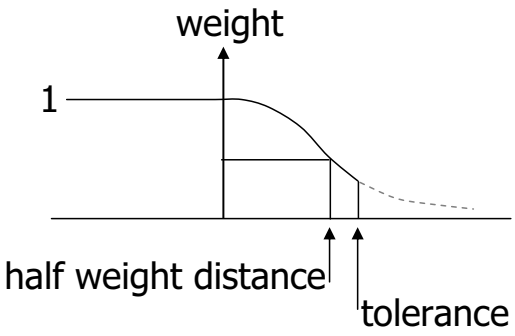
Niveau 2

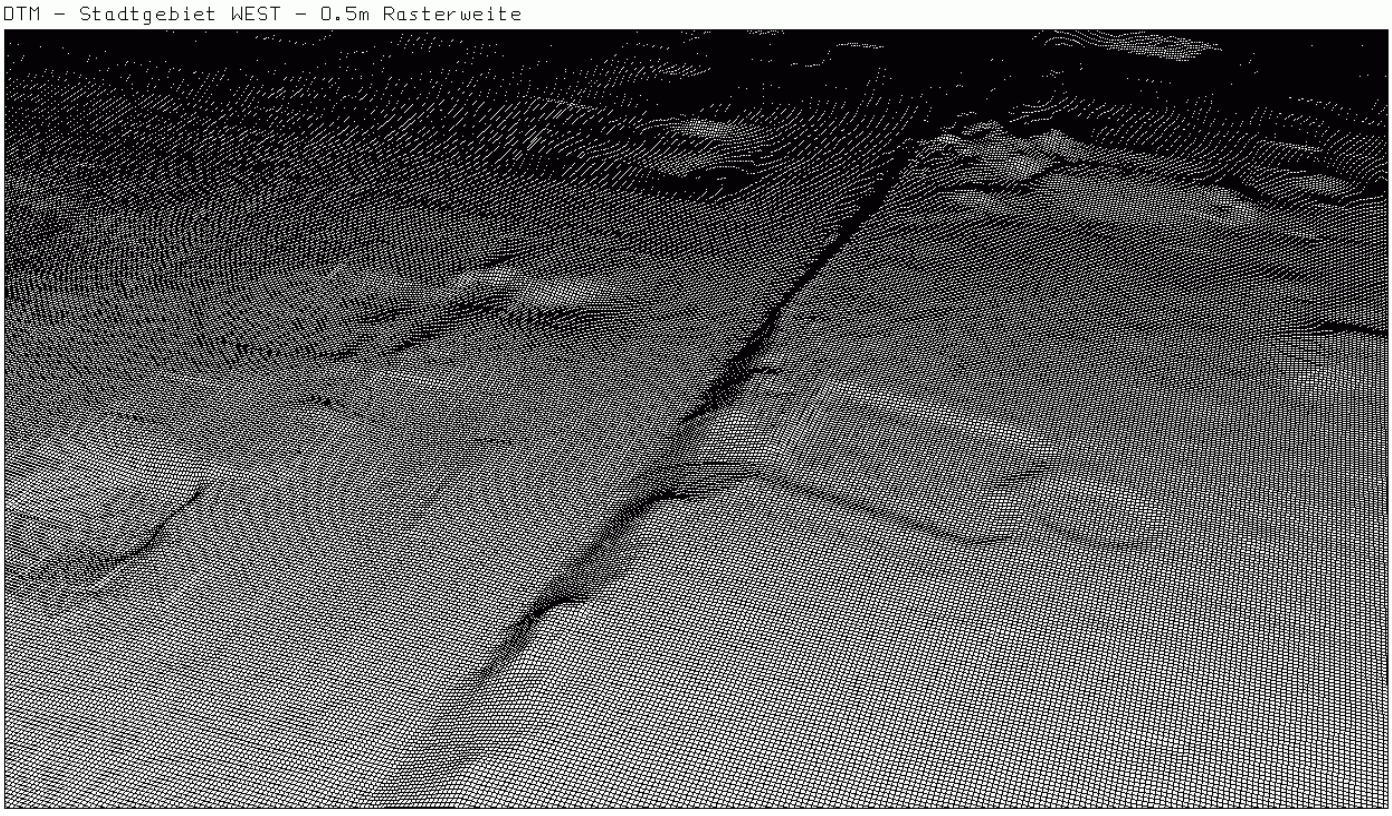
Example

5m level
- select mean point in 5m x 5m cell
- robust filtering
  - weight function half weight @75cm
  - weight function tolerance 1m
- select Points ⌖3m of DTM

2m level
- select lowest point in 2m x 2m cell
- robust filtering
  - weight function half weight @30cm
  - weight function tolerance 60cm
- select Points ±2m of DTM

original (0.5m level)
- robust filtering
  - weight function half weight @20cm
  - weight function tolerance 30cm





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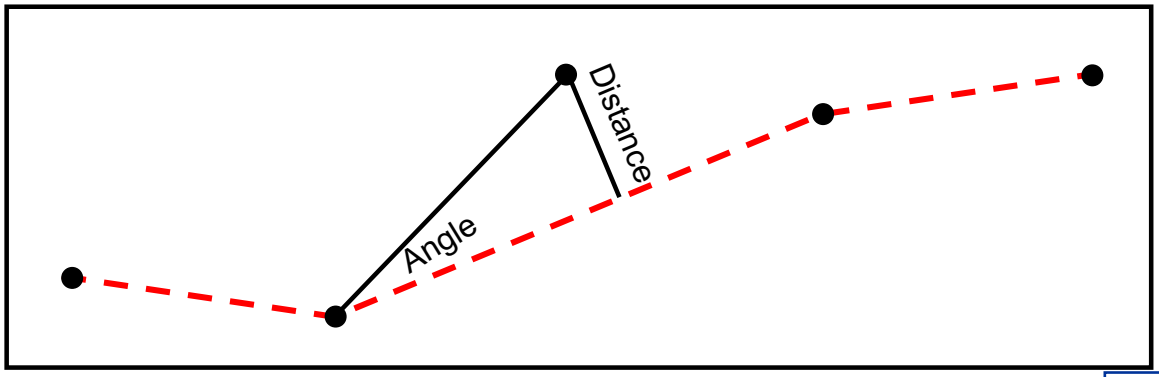
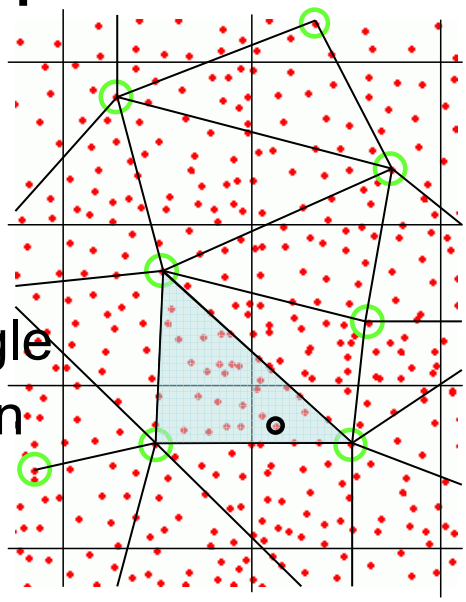
Approach 3
progressive TIN densification

- Select a few low points that are most likely terrain
- Build a TIN of the low points
- Add nearby points to TIN



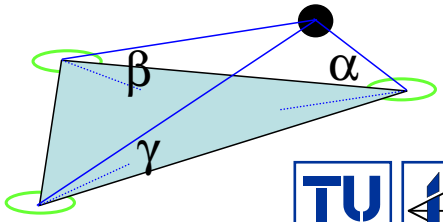
TIN densification

1. Select lowest points in big areas
2. Triangulate points
3. Test: single point ★ triangulation
   angle: (single point,vertex) to triangle
4. Add accepted points to triangulation
5. Iterate from step 3

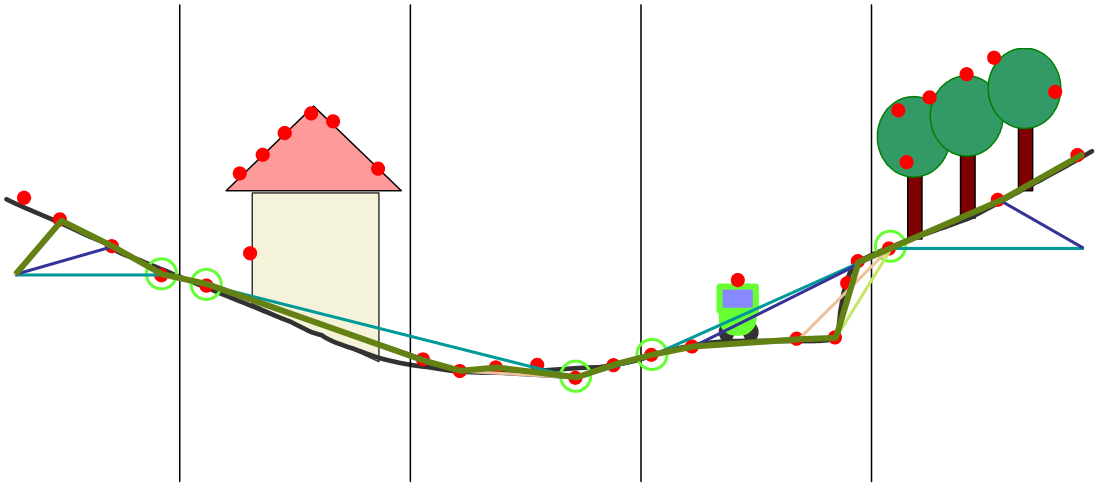


Variants:

- 1 point / more points per iteration
- criterion: angle, distance, ...

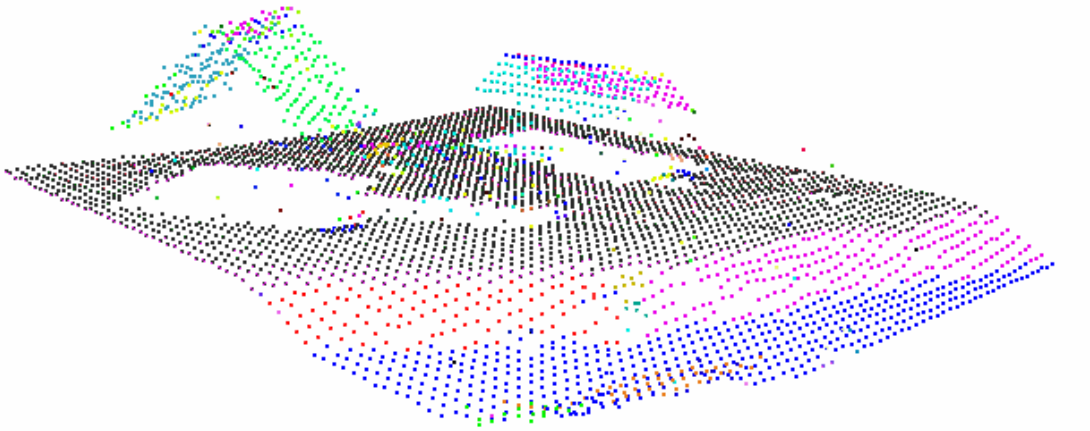


TIN densification



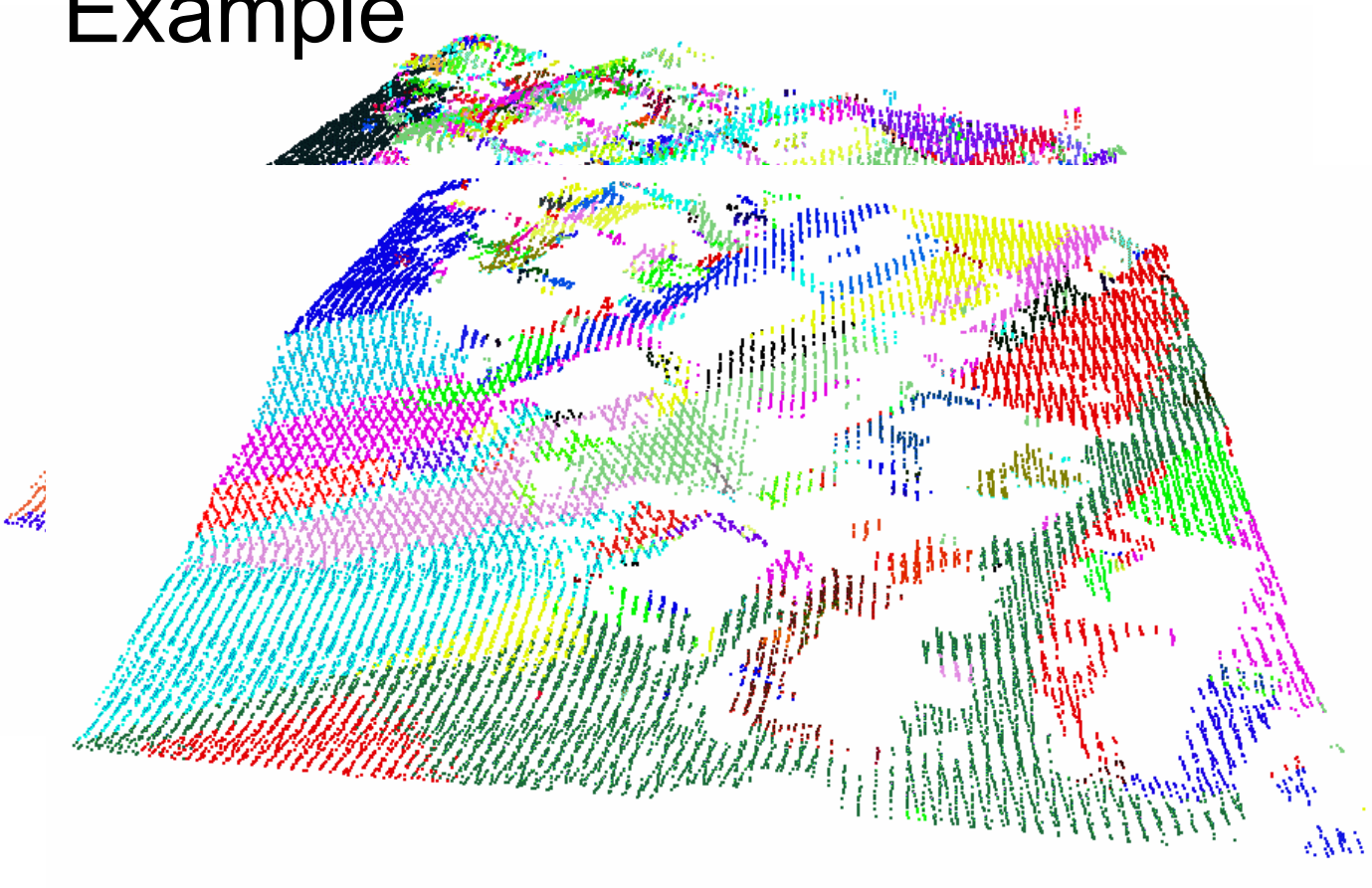
Segmentation based filtering

What is a segmentation ?



5 criteria:

Example



Comparison

- Concept of surface
- Reducing / adding information
- Experimental comparison

  Sithole et al., 2004. Experimental comparison of filter algorithms for bare—Earth extraction from airborne laser scanning point clouds. ISPRS Journal of Photogrammetry and Remote Sensing

Conclusions

- Filtering is operational
- Manual checking and improvement required for high quality
- Improvement options
  - FWF:
  - Other sensors:
- Commercial implementations:
  SCOP++: hierarchic robust interpolation
  Terra Modeler: progressive densification
- Overview on filters
  Kobler et al., 2007. Repetitive interpolation: A robust algorithm for DTM generation from Aerial Laser Scanner Data in forested terrain. Remote Sensing of Environment.