Geomorphometry 2025 Perugia

DEM Generalization Tool

Using Grid-Based Quadric Error Metric

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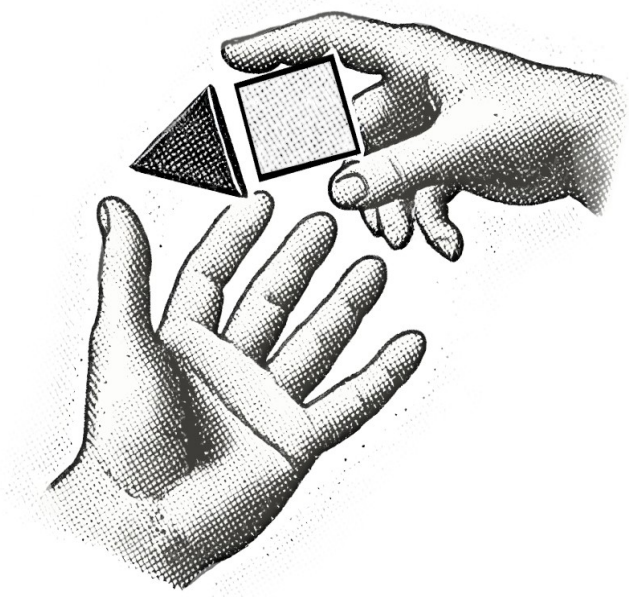
Motivation

- Need for generalized model
  - Working with highly detailed and accurate (LiDAR) DEMs
  - Smoothing has become a very common procedure
- Need for high level of generalization
  - Some applications require a high level of generalization, e.g., surface segmentation
  - Creating a highly generalized model that retains essential land surface features is difficult

Rethinking TIN and Grid

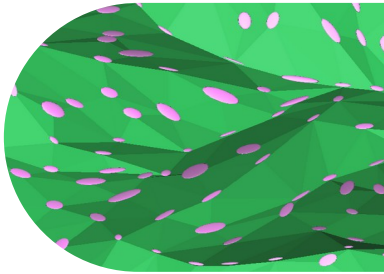
- Polygonal (TIN-based) simplification is beneficial
  - Can represent major geomorphic structures bounded by distinct edges
  - Some algorithms produce near-optimal triangles for surface representation
  - However, a grid structure is needed for calculations
- Grid version of polygonal algorithm?

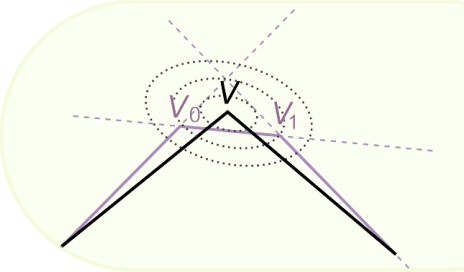


Original Algorithm – TIN

Original Quadric Error Metric (QEM) Simplification

- Uses triangle planes from the surrounding area to encode surface shape → Q matrix
- Collapses edges to vertices ($V_0\,V_1 \rightarrow V$) to simplify the model while combining Q matrices $Q_0 + Q_1 = Q$
- Uses an error metric to order edge collapses and calculate the optimal vertex position





Grid constraints

- Replace the edge collapse procedure with an alternative method to combine Q matrices
- Determine the optimal position while keeping x, y fixed

Modified Algorithm – Grid

- Initial calculation of Q matrix
  - Derived from 8 triangles with 8 nodes around a grid node
  - 4×4 symmetric matrix (10 coefficients)

$$Q = \begin{bmatrix} a & b & c & d \\ b & e & f & g \\ c & f & h & i \\ d & g & i & j \end{bmatrix}$$

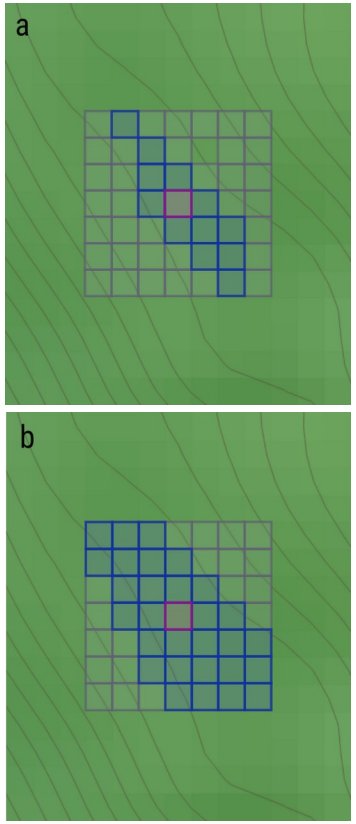
- Combining Q matrices
  - Performing focal operation
  - Neighborhood averaging → new Q matrix
- Calculating the new elevation
  - Optimizes the error quadratic function based on Q
  - Finds z with the minimum error for fixed x and y

Generalization step 🔁

$$z = -\frac{cx + fy + i}{h}$$

Modified Algorithm – Grid

- QEM error evaluation
  - Crucial for maintaining significant land surface features
  - Allows restricting neighborhood nodes based on error values
  - Using only nodes with a similar surface shape helps retain edges—places with significant changes
  - Threshold error value for restricting the neighborhood affects the amount of edge preservation



Threshold Implementation

- Relative threshold value
  - Error values depend on resolution, surface shape, roughness, and other factors – the absolute error is not a suitable metric
  - Based on all values from the last step, determined by selecting a chosen percentile
  - Repeated with an increasing percentile, up to 100%
  - Mimics the original approach with edge collapse ordering
- Tuning parameter
  - *Sharpness* parameter (0–9)
  - Setting the starting percentile: 1 − (0.1 × sharpness)

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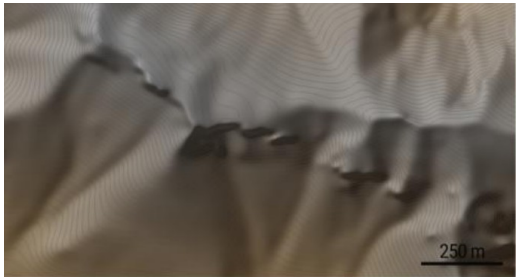

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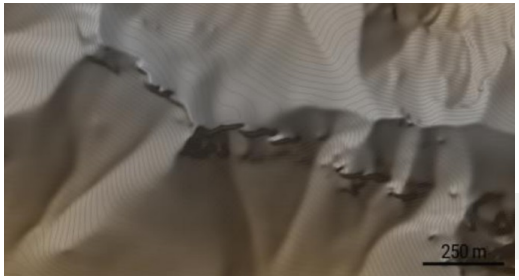


Implementation

QEM Generalization

- Command-line tool
- Rust programming language
- Parallelized calculations

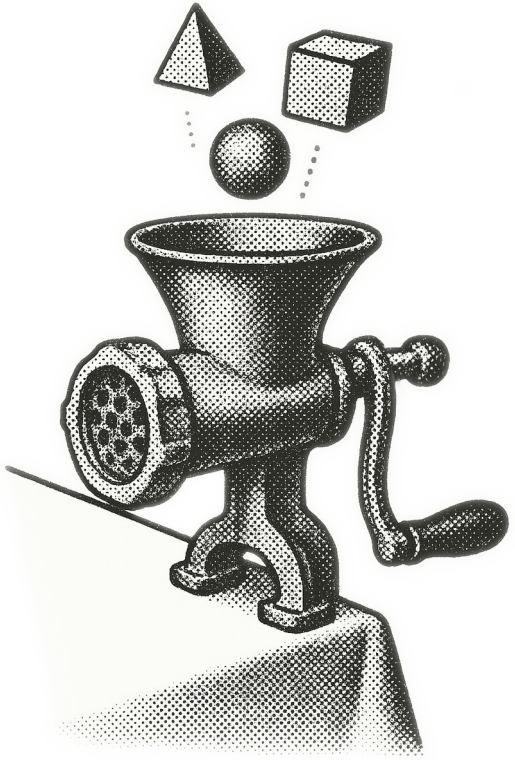
```
$ qem_generalization --input-file dem.tif --output-file generalize_20_s_5.tif --iterations 20 --sharpness 5
```

- Github repository

🔗 `https://github.com/xiceph/physical-geomorphometry-tools/tree/main/generalization`

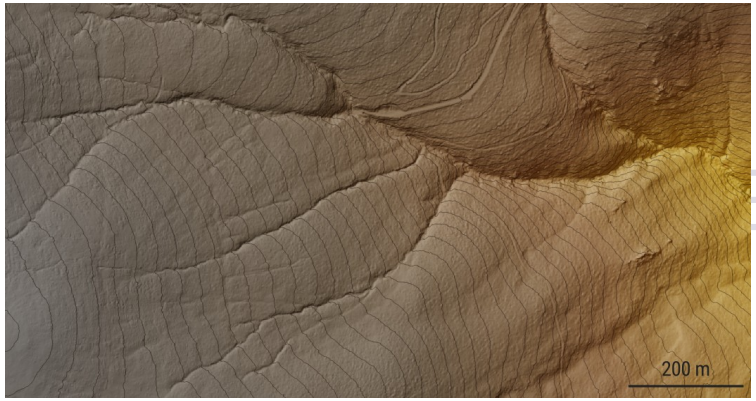
Inputs

- DEM Grid (GeoTIFF)
- Iterations
  - Basic parameter for generalization level
  - Higher → greater level of generalization
- Sharpness
  - Higher → improves edge retention
  - Needs more iteration to generalize
- Resolution Reduction
- Jobs (number of threads to use)



Output

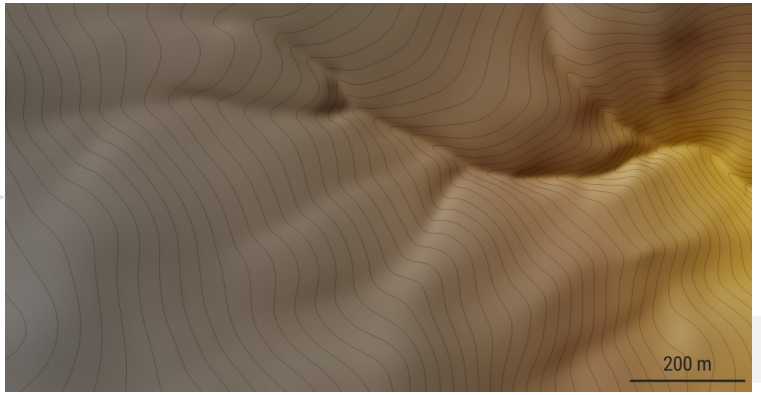
- Generalized models



20 iterations

100 iterations

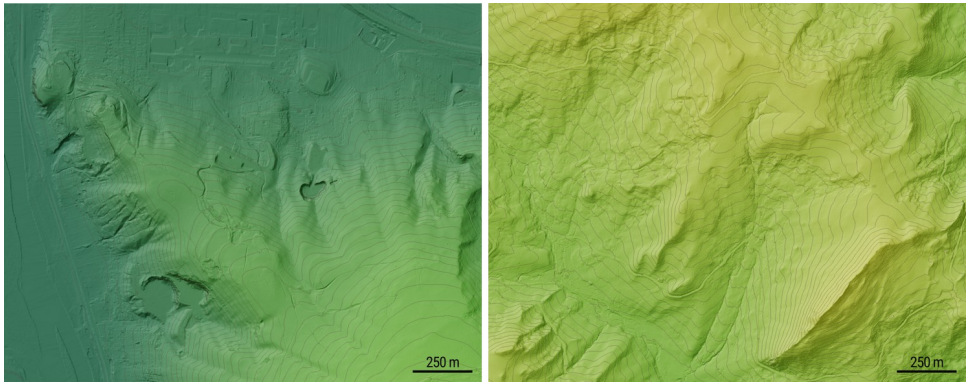
500 iterations

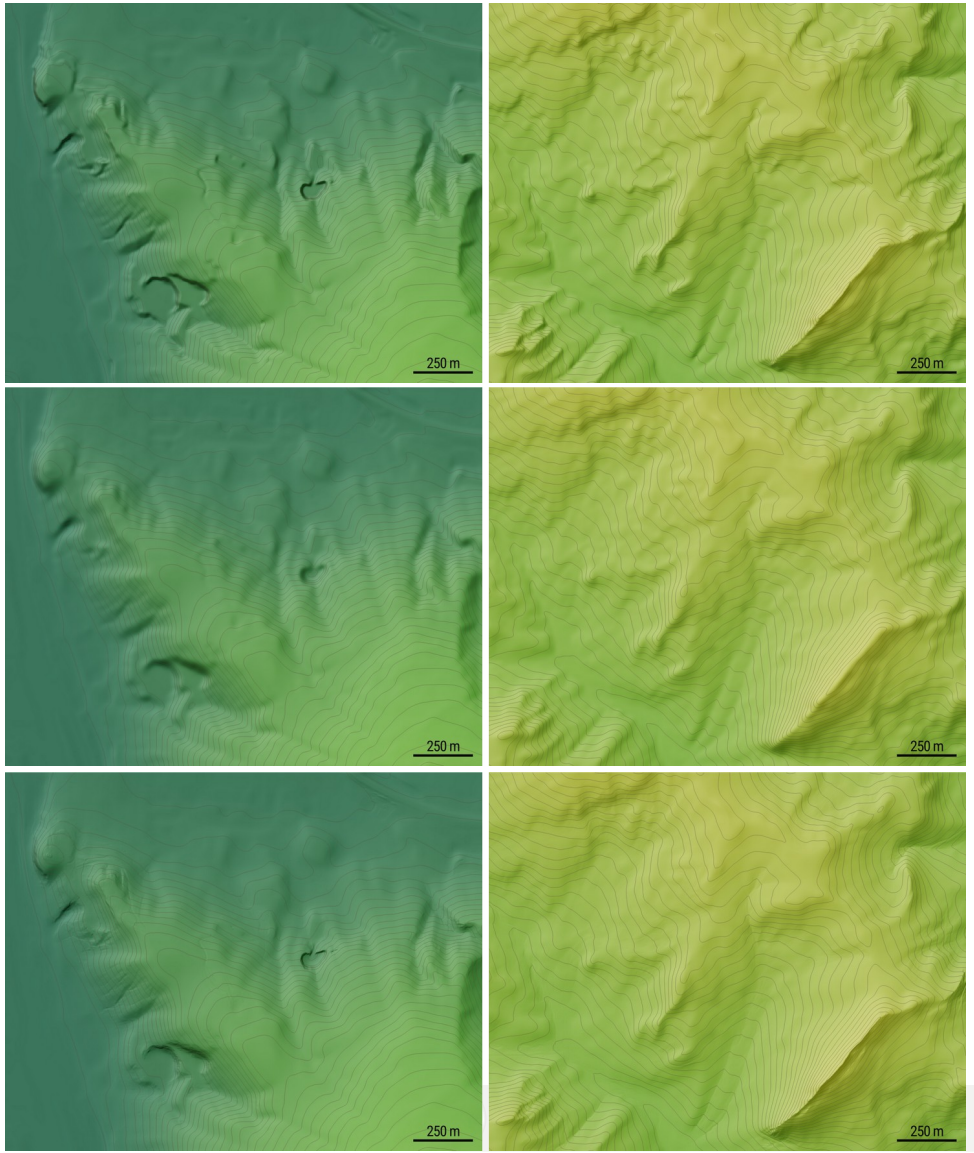


- Sharpness = 5
- Without resolution reduction

Comparison

- Comparing 3 algorithms
  - QEM Generalization
  - Gaussian Filter
  - Feature Preserving Smoothing
  - Share common properties
  - Equal level of generalization

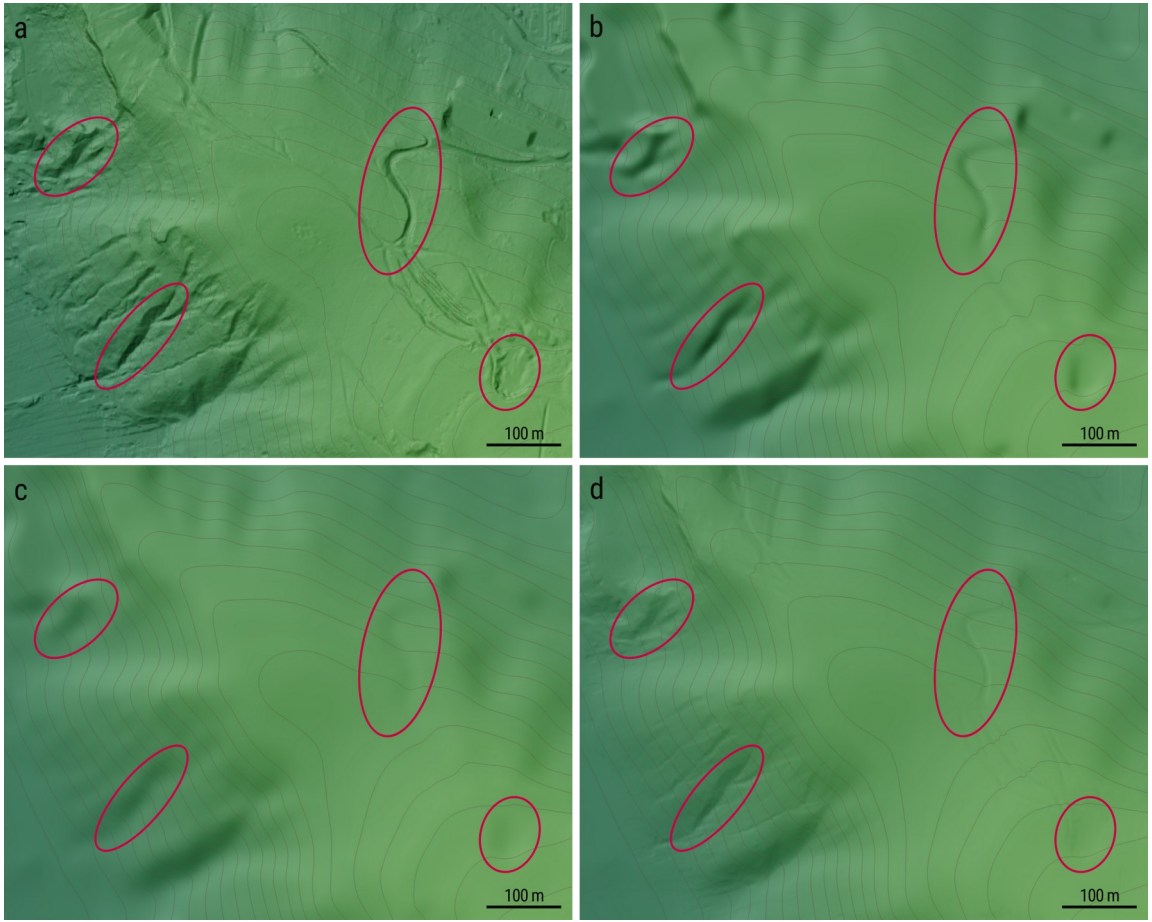




Comparison

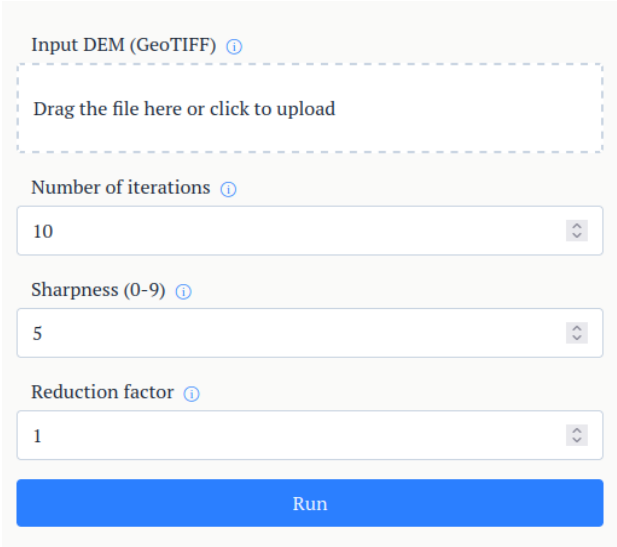
- Depth of forms
  - Visible differences

- a – Input DEM
- b – QEM Generalization
- c – Gaussian Filter
- d – Feature Preserving Smoothing



Web Service

- We offer web computational service
  - No need to install
  - File size and pixels count restriction
  - Currently in test mode 🆕



🔗 `https://geomorphometry.fns.uniba.sk/calc-service/generalization`

Further Reference

- The referenced paper provides deeper theoretical insights

Feciskanin, R., Minár, J. (2025). *Advancing raster DEM generalization with a quadric error metric approach*. Computers and Geosciences, 202, 105963. https://doi.org/10.1016/j.cageo.2025.105963.

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