Digital terrain model generalization incorporating scale, semantic and cognitive constraints

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Introduction

Cartographic generalization is a well-known process accommodating spatial data compression, visualization and comprehension under various scales. In the last few years, there are several international attempts to construct tangible GIS systems, forming real 3D surfaces using a vast number of mechanical parts along a matrix formation (i.e., bars, pistons, vacuums). Usually, moving bars upon a structured grid push a stretching membrane resulting in a smooth visualization for a given surface. Most of these attempts suffer either in their cost, accuracy, resolution and/or speed.

Under this perspective, the main objective is to provide optimized visualizations of 3D digital terrain models with minimum loss of information. That is, to minimize the number of pixels in a raster dataset used to define a DTM, while reserving the surface information.

This neighborhood type of pixel relations adheres to the basics of Self Organizing Map (SOM) artificial neural networks, which are tested for the DTM generalization. Moreover, we develop variations of other widely used generalization algorithms including Douglas-Peucker line simplification and neighbor filters. Besides the quantitative evaluation of error vs information preservation in a DTM, cognitive and semantic inputs are incorporated in order to test the algorithms.

Methodology

The objective of the experiments is to evaluate whether a generalized surface created by using a subset of points, retain the important height information. Thus, we measure the reduction percentage (% points reduced from the initial dataset) vs the RMS Error of the heights between the new dataset (DTM) and the initial one.

We use various types of Algorithms, reduction scales and terrain types. More specifically:

Algorithms:

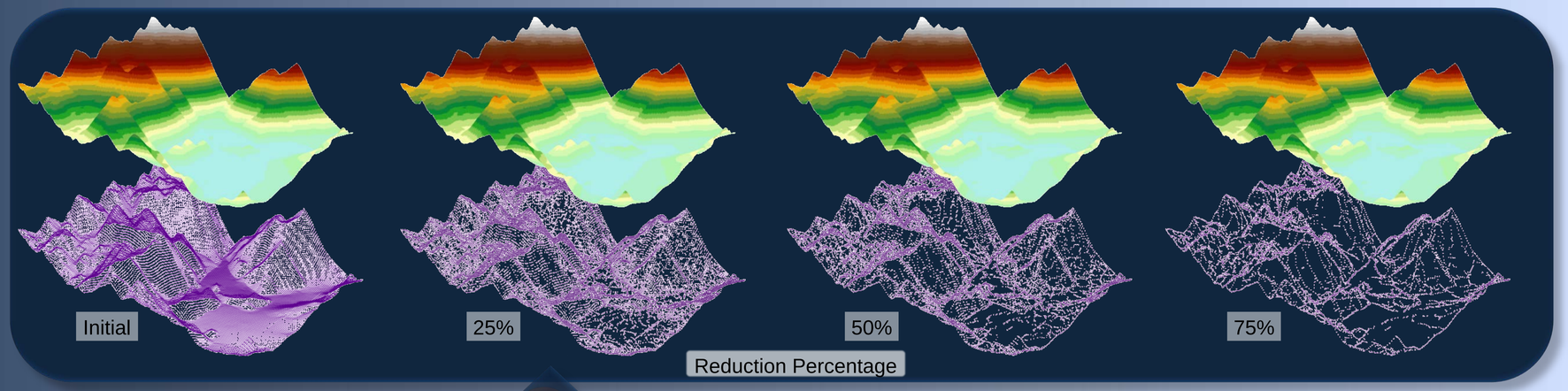
- Douglas-Peucker (D.P.)
  - Set a tolerance value depending on the target reduction,
  - Apply Douglas-Peucker to points that belong to each x plane,
  - Apply Douglas-Peucker to points that belong to each y plane,
  - Final generalization: join of final points resulting from x & y.
- Laplace
  - Apply 3-by-3 Laplace filter,
  - Keep the required percentage of points from the filtered image.
- Self Organizing Maps (SOM)
  - Set the training epochs and the initial centers in each axis,
  - Estimate final points through mapping of each of the output points to the closer initial point (application of Euclidean distance).

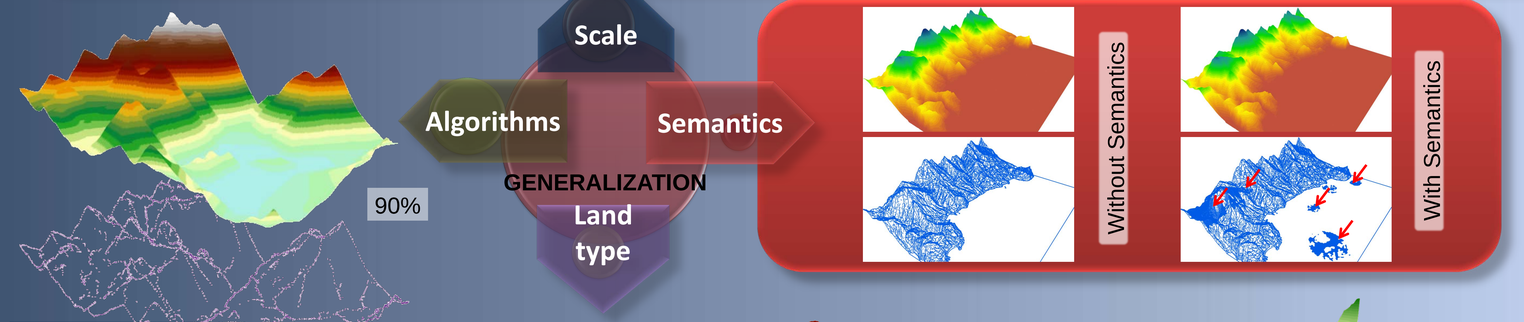
Scaling: Use of four reduction percentages, 25%, 50%, 75% and 90%.

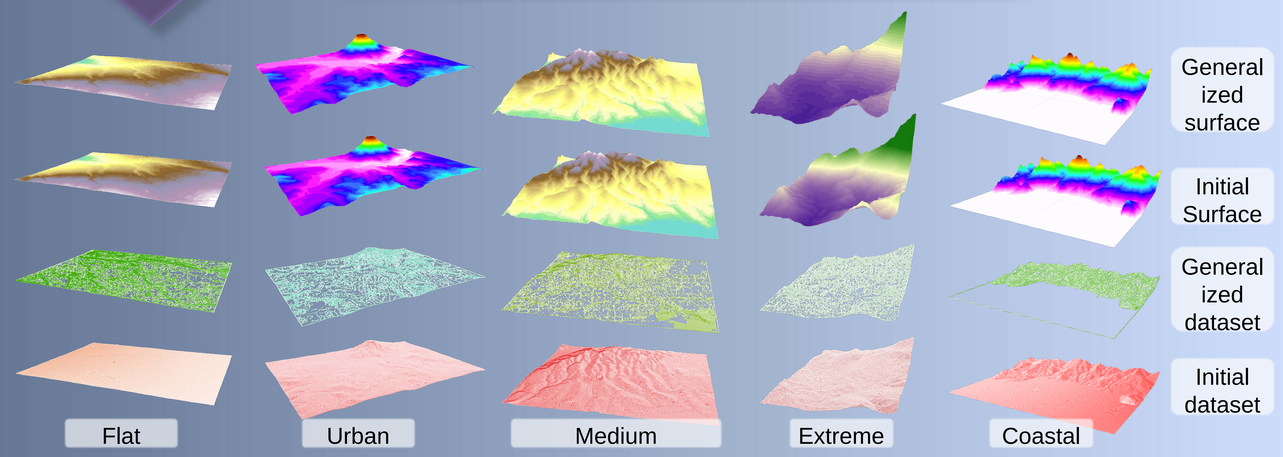
Land Types: Use of five types, namely, Urban, Flat, Coastal, Extreme and Medium Mountainous.

Semantics: Use of semantic map including mask areas not affected by generalization.

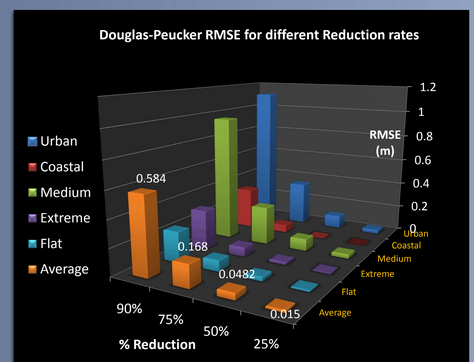
Cognitive: Get feedback from application "experts" to evaluate by observation, the similarity between DTMs and the importance of the information loss due to generalization.

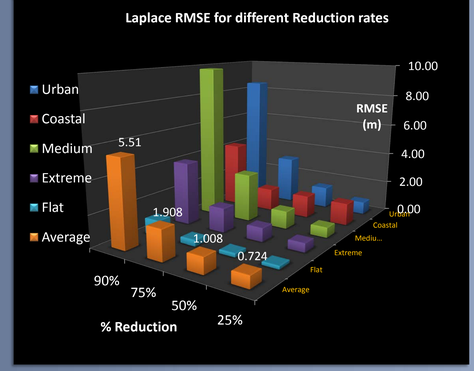






Reduction (%)	25%	50%	75%	90%
Landscape	D. P. / Laplace	D. P. / Laplace	D. P. / Laplace	D. P. / Laplace
Urban	0.03 / 0.80	0.1 / 1.37	0.34 / 3.08	1.11 / 8.49
Coastal	0 / 1.42	0.001 / 1.43	0.06 / 1.44	0.32 / 4.22
Medium	0.03 / 0.65	0.09 / 1.13	0.29 / 3.08	0.96 / 9.81
Extreme	0.005 / 0.55	0.02 / 0.87	0.07 / 1.56	0.3 / 4.03
Flat	0.01 / 0.20	0.03 / 0.24	0.08 / 0.38	0.23 / 1
Average	0.012 / 0.614	0.0442 / 1.008	0.168 / 1.908	0.584 / 5.51





Conclusions

- The error depends on the complexity of the terrain: generally, in a flat terrain the error is lower compared to mountainous terrain with reference to the same reduction level,
- Accordingly, high reduction rate (generalization) leads to increased error for all the algorithms and in all terrains,
- The Douglas Peucker algorithm outperforms the others, since it introduces a much lower error (approximately 0.1 fold) for a given reduction level,
- SOM algorithm was not applied in all landscape datasets, since it has a substantial computational cost that increases proportionally to the number of the training epochs and initial nodes, and thus makes the algorithm unusable to real time interaction systems,
- In extreme generalization percentages (75-90%) the RMSE is comparatively low (e.g. for 1000 meters height differences the error was lower than 1 meter), thus, generalization is highly effective and retains the important information,
- Cognitive analysis needs further investigation since the reduction didn't provide any apparent visual difference, as seen from the surface figures.

Acknowledgements

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