Methodological Documentation: DEM Generalization with Line Integral Convolution

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Introduction

Digital Elevation Model (DEM) generalization aims to reduce non-essential details while preserving key terrain features such as ridgelines, transitions between flat areas and slopes, and the overall shape of the terrain. The method described here relies on adaptive Gaussian blur and Line Integral Convolution (LIC) techniques.

The objective is to produce a simplified DEM that preserves essential structures and is visually coherent for applications such as shaded relief generation or contour mapping.

Methodology

The script implements a series of steps for DEM generalization, inspired by Jenny's method (2021) [1]:

1. **Preprocessing with adaptive Gaussian blur:** Reduces detail based on local curvature.
2. **Detection of flat and steep areas:** Identifies regions requiring distinct treatments.
3. **Modified Line Integral Convolution (LIC):** Combines different LIC methods for ridges and other areas.
4. **Weighting by maximal curvature:** Refines the model using curvature-based weighting factors.
5. **Multiple iterations:** Progressively improves generalization while limiting artifacts.

Main Steps

1. Preprocessing with Adaptive Gaussian Blur

An adaptive Gaussian blur is applied, modulated by local curvature. Areas with low curvature (gentle slopes) undergo stronger blurring, while areas with high curvature (ridges and valleys) are preserved.

- **Input:** Original DEM, local curvature.
- **Output:** Smoothed DEM retaining essential features.

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2. Detection of Flat and Steep Areas

A slope threshold is used to distinguish flat and steep areas. A binary grid is generated (0 = flat areas, 1 = steep areas), followed by cleaning to remove insignificant small flat regions.

- **Input:** Smoothed DEM.
- **Output:** Cleaned binary grid.

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3. Line Integral Convolution (LIC)

Two LIC variants are applied:

- **Standard LIC** (inspired by Roman Wolfgang Geisthövel's thesis [2]): Weighted by relative altitude.
- **Modified LIC:** Integration line length is modulated by a weight grid (calculated from flat/steep areas).

Each LIC method traces integration lines along local terrain gradients and applies Gaussian weights to smooth along these lines. Both methods are applied to the entire DEM, but the relative altitude grid is used to weight their combination. High altitudes give more weight to the standard LIC, while low altitudes favor the modulated LIC. This prevents the modulated LIC from degrading the sharpness of ridges.

- **Input:** DEM, binary grid, relative altitudes.
- **Output:** Smoothed DEM with preserved details.

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4. Weighting by Maximal Curvature

The maximal curvature is computed for each pixel. After applying Gaussian blur, these values are used as weights to combine the original DEM and the DEM generated from the LIC methods.

- **Input:** DEM generated by LIC, maximal curvatures.
- **Output:** Refined DEM.

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5. Multiple Iterations

The process is repeated several times for progressive generalization. In each iteration, the DEM is updated by combining the previous result and the current LIC result, weighted by maximal curvature.

Key Parameters

- **Block size and overlap:** Processing is performed block by block with overlap to efficiently handle large DEMs.
- **Integration length:** Controls the extent of smoothing along integration lines.
- **Number of iterations:** Determines the degree of generalization.

- **Weighting factor (k):** Influences the combination of the original DEM and LIC results.
- **Slope threshold:** Determines the distinction between flat and steep areas.
- **Minimum flat area size:** Removes small, insignificant flat areas.

Applications

- **Shaded relief generation:** Improves visual readability.
- **Topographic map creation:** Simplifies details while preserving key characteristics.

Differences from the Original Article

1. **LIC weighting by relative altitude:** This implementation uses relative altitude instead of absolute altitude (calculated for the current block) to dynamically adjust Gaussian weights. This avoids gridline artifacts when assembling blocks.
2. **Separate LIC procedures for ridges and other areas:** Distinct treatment optimizes the highlighting of specific topographic features.
3. **Cleaning of flat areas:** An additional step eliminates artifacts and insignificant small regions.

Expected Results

The process enhances the readability of major terrain structures while removing unwanted details. Ridges are emphasized, slopes are smoothed, and transitions between flat and steep areas are preserved.

References

[1] Bernhard Jenny (2021) *Terrain generalization with line integral convolution*, Cartography and Geographic Information Science, 48:1, 78-92, DOI: 10.1080/15230406.2020.1833762
[2] Roman Wolfgang Geisthövel (2017) *Automatic Swiss style rock depiction*, thesis submitted to attain the degree of doctor of sciences of ETH Zurich.