Methodological Documentation: Terrain Generalization with Line Integral Convolution

Introduction

The cartographic generalization of a Digital Elevation Model (DEM) consists of reducing irrelevant details while preserving important terrain features, such as ridge lines, abrupt transitions between flat areas and slopes, as well as the major landforms. The process detailed here is based on adaptive Gaussian blur techniques and Line Integral Convolution (LIC).

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

Method Used

The script implements a series of steps to generalize the DEM, inspired by the method of Jenny (2021) [1]:

1. **Preprocessing with adaptive Gaussian blur**: Reduces details based on local curvature.
2. **Detection of flat and steep areas**: Identifies regions requiring differentiated processing.
3. **Modified Line Integral Convolution (LIC)**: Adapts the standard LIC algorithm using factors based on curvature and the relative altitude of points along the integration line.
4. **Multiple iterations**: Progressively improves generalization while limiting artifacts.

Main Steps

1. Preprocessing with Adaptive Gaussian Blur

A Gaussian blur is applied, modulated by local curvature. Low-curvature areas (gentle slopes) undergo more blurring, while high-curvature areas (ridges and valleys) are preserved.

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

2. Detection of Flat and Steep Areas

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

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

3. Line Integral Convolution (LIC)

The standard LIC method (inspired by the technique described in the thesis of Roman Wolfgang Geisthövel [2]) is weighted by the relative altitude of points along the integration line. Another modification involves the integration length, which is modulated by a weight grid (calculated from the flat/steep area classification).

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

4. Weighting by Maximum Curvature

The maximum curvature is computed for each pixel. After applying a Gaussian blur, these values are used as weights to combine the original DEM with the DEM generated by the LIC-based method.

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

5. Multiple Iterations

The process is iterated multiple times for progressive generalization. At each iteration, the DEM is updated by combining the previous result with the current LIC result weighted by maximum curvature.

Key Parameters

- **Block size and overlap**: Processing is performed in blocks with overlap to efficiently handle large DEMs.
- **Integration length**: Controls the smoothing extent along the integration lines.
- **Number of iterations**: Affects the degree of generalization.
- **Weighting factor (k)**: Influences the combination between the original DEM and the LIC results.
- **Slope threshold**: Determines the distinction between flat and steep areas.
- **Minimum flat area size**: Removes small, insignificant flat areas.

Applications

- **Shaded relief production**: Enhances visual readability.
- **Topographic map creation**: Simplifies details while preserving essential features.

Expected Results

The process improves the readability of major terrain structures while removing unnecessary details. Ridges are accentuated, 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 at ETH Zurich.