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The effect of morphological smoothening by reconstruction on the extraction of peaks and pits from digital elevation models

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Abstract

In this paper, the effect of morphological smoothening by reconstruction on the extraction of peaks and pits from digital elevation models (DEMs) is studied. First, a mathematical morphological based algorithm to extract peaks and pits from DEMs is developed. Morphological smoothening by reconstruction is then implemented on the DEM of Great Basin using kernels of different sizes. The number of peaks and pits extracted from the resultant DEMs is computed using connected component labeling and the results are compared. This work is aimed at studying the capabilities of morphological smoothening by reconstruction in the modeling of objects and processes operating within an environment.

Keywords: Digital elevation models; Morphological smoothening by reconstruction; Kernel; Peaks and pits; DEM smoothening

1. Introduction

Geomorphometry is the science of measuring and depicting those parameters or attributes necessary to describe the precise nature and configuration of the earth topography, its geographic relationships to the land mass and the characteristics of geomorphologic processes. The recent advances in technology, including global positioning systems (GPS), ground and airborne laser terrain mapping, ground penetrating radar, and digital elevation models (DEMs) have provided a framework to numerically represent ground surface relief and patterns. In geomorphometry, it is possible to generate descriptive statistics of the shape of the surface or to assign a location in a landscape to an exhaustive set of features based on the local form of the land surface (Pike, 2000). The geomorphometric features of interest in this paper are peaks and pits.

The peaks of a terrain refer to the highest points of the mountains of the terrain while the pits of the terrain are the lowest points of the basins of the terrain. In DEMs, peaks are connected components that are completely surrounded by pixels of lower elevation while pits are connected components that are completely surrounded by pixels of higher elevation. The detection of peaks and pits is the first step in most techniques used to perform DEM characterization and to describe the general geomorphometry of a surface.

The objective of this paper is to study the effect of morphological smoothening by reconstruction on the extraction of peaks and pits from DEMs. In the Section 2, a brief introduction to mathematical morphology and morphological smoothening by reconstruction is provided. In Section 3, a mathematical morphological based algorithm to extract peaks and pits from DEMs is developed. In Section 4, the effect of morphological smoothening by reconstruction on the extraction of peaks and pits from DEMs is studied. In Section 5, the application of morphological smoothening by reconstruction to perform DEM smoothening is studied.

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Concluding remarks and perspectives for further research are presented in Section 6.

2. Morphological smoothening by reconstruction

Mathematical morphology deals with the extraction of image components that are useful in representation and description of region shape, such as boundaries, skeletons and convex hulls (Gonzalez and Woods, 1993). Mathematical morphology views a grayscale image as a topographic surface in 3D Euclidian space, with the grey level of a pixel standing for its elevation above the base plane. Hence, mathematical morphology is well suited to deal with processing of elevation data (Soille and Ansoult, 1990). The fundamental mathematical morphological operators are discussed in (Matheron, 1975; Serra, 1982; Soille, 2003). Morphological operators generally require two inputs; the input image A, which can be in binary or grayscale form, and the kernel B, which is used to determine the precise effect of the operator (Serra, 1982). The implementation and applications of morphological reconstruction is discussed in (Vincent, 1993) while the operation of ultimate erosion is explained in (Duchene and Lewis, 1996).

Dilation sets the pixel values within the kernel to the maximum value of the pixel neighbourhood. The dilation operation is expressed as

$$A \oplus B = \{a + b : a \in A, b \in B\} \tag{1}$$

Erosion sets the pixels values within the kernel to the minimum value of the kernel. Erosion is the dual operator of dilation

$$(A \ominus B) \subset (A^{c} \oplus B)^{c} \tag{2}$$

where A^{c} denotes the complement of A, and B is symmetric with respect to reflection about the origin.

An opening (Eq. (3)) is defined as an erosion followed by a dilation using the same kernel for both operations, while a closing (Eq. (4)) is defined as a dilation followed by an erosion using the same kernel for both operations:

$$A \circ B = (A \ominus B) \oplus B \tag{3}$$

$$A \bullet B = (A \oplus B) \ominus B \tag{4}$$

Grayscale opening is used to darken small bright areas and to reduce sharp peaks in images. Grayscale closing is used to brighten small dark areas and to fill valleys in images (Serra, 1982). Opening is used to remove local maxima while closing is used to remove local minima in an image. Morphological smoothening is implemented by performing grayscale opening followed by grayscale closing (Gonzalez and Woods, 1993). The biggest disadvantage of morphological smoothening is that the closing operation in the smoothening process can create larger local minima by filling narrow valleys while the opening operations can create large local maxima by enlarging valleys.

Morphological reconstruction allows for the isolation of certain features within an image based on the manipulation of a mask image X and a marker image Y. It is founded on the concept of geodesic transformations, where dilations or erosion of a marker image are performed until stability is achieved (represented by a mask image) (Vincent, 1993).

The geodesic dilation, δ^{G} used in the reconstruction process is performed through iteration of elementary geodesic dilations, $\delta_{(1)}$, until stability is achieved

$$\delta^{G}(Y) = \delta_{(1)}(Y) \circ \delta_{(1)}(Y) \circ \delta_{(1)}(Y) \cdots \text{ until stability} \tag{5}$$

The elementary dilation process is performed using a standard dilation of size one followed by an intersection:

$$\delta_{(1)}(Y) = Y \oplus B \cap X \tag{6}$$

The operation in Eq. (6) is used for elementary dilation in binary reconstruction. In grayscale reconstruction, the intersection in the equation is replaced with a pointwise minimum (Vincent, 1993).

Morphological reconstruction can be used to maintain the local maxima and minima removal effect of opening and closing while avoiding their valley filling and enlargement effect (Vincent, 1993). Morphological smoothening by reconstruction is implemented using the following process:

Step 1: *Performing opening on the original image*
This step removes the local maxima of the image of the DEM. However, it causes the formation of larger local maxima due to valley enlargment.

Step 2: *Performing morphological reconstruction on the opened image*
Morphological reconstruction is performed using the opened image as the marker and the original image as the mask. This step is performed to avoid the valley enlargement caused by the opening process.

Step 3: *Performing closing on the opened reconstructed image*
This step removes the local minima of the image. However, it causes the formation of larger local minima due to valley filling.

Step 4: *Performing morphological reconstruction on the closed image*
Morphological reconstruction is performed using the closed as the marker and the opened reconstructed image as the mask. This step is performed to avoid the valley filling effect caused by the closing process.

The operation to perform morphological smoothening by reconstruction is summarized in Fig. 1.

3. Peak and pit extraction

Grayscale erosion can be used to remove bright areas in grayscale images. It causes small peaks in the image to disappear. However, it also causes valley widening which results in larger peak. Morphological reconstruction can be used to maintain the peak removal effect of erosion