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An efficient depression processing algorithm for hydrologic analysis

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Abstract

Depression filling and direction assignment over flat areas are critical issues in hydrologic analysis. This paper proposes an efficient approach for the treatment of depressions and flat areas, based on gridded digital elevation models. Being different from the traditional raster neighborhood process which is time consuming, a hybrid method of vector and raster manipulation is designed for depression filling, followed by a neighbor-grouping scan method to assign the flow direction over flat areas. The results from intensive experiments show that there is a linear relationship between time efficiency and data volume, and the extracted hydrologic structures of flat areas are also more reasonable than those proposed by the existing methods.

Keywords: Digital elevation models; Depression; Flat areas; Hydrologic structure; Hydrologic analysis

1. Introduction

Because it is a fundamental problem in digital terrain analysis, the extraction of hydrologic structures plays an important role in applications such as hydrologic analysis, mineral deposition, land erosion, pollution diffusion analysis, etc. (Wolock and McCabe, 1995; Chen, 1991; Freeman, 1991; Moore et al., 1994; Li et al., 2004). Ridges and valleys are the basic features in hydrologic structure information. The most popular application extracts them from gridded digital elevation models (DEMs) and almost all the methods are based on the flow routing model (O'Callaghan and Mark, 1984; Jenson and Domingue, 1988; Tarboton et al., 1991; Moore et al., 1994). In such a model, the main task is to derive three matrices from the original DEM: the depressionless elevation matrix, the flow direction matrix and the flow accumulation matrix.

Depressions and flat areas are common in gridded DEMs; most of them are the result of mistakes, whereas some represent real terrain features, e.g., quarries and grottoes. The majority are spurious features, which arise from interpolation errors during DEM generation, truncation of interpolated values, and the limited spatial resolution of the DEM grid (Martz and Garbrecht, 1993). Depressions and flat areas must be dealt with as a precondition of flow route tracing, but the process is time consuming. So far, a number of methods have been developed for handling the depressions and flat areas of DEMs. Band (1986) simply

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increases the elevation of these cells until a downslope flow path to an adjacent cell becomes available. O'Callaghan and Mark (1984) attempted to treat them by smoothing the data. Jenson and Domingue (1988) and Martz and de Jong (1988) presented a method for filling depressions by increasing the elevation of cells in it to the elevation of the lowest overflow point on the depression boundary. However, these methods are effective only for the simplest cell, they change the nature of the terrain, and they may produce new depressions. Martz and Garbrecht (1995, 1998) proposed algorithms that considered both higher and lower terrain effects in dealing with depressions and flat areas. Thus, they produce more realistic results in applications. However, they still consider each depression separately and thus recursive detecting and filling processes may be required. The inherent problems of the efficiency and accuracy of these approaches have hindered their application in the processing of large-scale DEMs. Aiming at solving these problems, a hybrid method for depression filling using both vector and raster processes is proposed in this paper.

A raster process does not record the relationship of two objects (such as the depression and flat area) directly and searches its adjacent objects only through four or eight neighbors. On the other hand, a vector process considers the vector characteristics of the objects and treats an object as a whole. The hybrid method will be discussed in detail in the next section. Section 3 deals with the direction of flow over flat areas, assigned by applying a neighbor grouping scan method. Intensive experimental analysis is illustrated in Section 4. Finally, a few concluding remarks are given in Section 5.

2. Hybrid method using vector and raster processes for depression filling

2.1. Detecting depressions

There are three kinds of depression in gridded DEMs: single-point depressions, stand-alone depressions and compound depressions. The compound depressions include all complex topographic situations, such as looping depressions (adjacent depressions flowing into each other), depressions within flat areas, and truncation of depressions and flat areas at the edge of the DEM. Compound depressions have been recognized as one of the chief obstacles in the extraction of hydrologic structures (Jenson and Domingue, 1988; Freeman, 1991; Tarboton et al., 1991; Moore et al., 1994).

In this paper, the lowest cells of each depression (a cell with an elevation lower than all of its eight neighbors) are marked out while calculating the initial flow direction matrix. Starting from these bottom cells, the procedures to detect and fill the depression are carried out by combining vector processes with traditional neighborhood raster processes. Compound depressions have more than one bottom cell and are usually caused by looping depressions.

The single-point depressions can be filled by simply raising the elevation of each bottom cell to the lowest value of its neighbors. After such a step, the steepest descent value of all cells is not less than zero. Since only the cells with a steepest descent value equal to zero can form a mutual-pointing phenomena (adjacent cells with the steepest descent directions point to each other), and mutual pointing can serve as evidence of the existence of a depression, these cells then can be used as clues for detecting depressions. Here, we adopt a stack-based seed-filling algorithm. A flag matrix (a flow accumulation matrix can be utilized for the present) is used to mark the detected depressions. The basic workflow includes the following steps (Fig. 1):

Step 1: An unmarked cell with a steepest descent value equal to zero (used as seed) is pushed into the stack, and its corresponding cell in the flag matrix is marked.

Step 2: If the stack is not empty, a cell at the stack top is taken as the current cell and removed from the stack. Then its corresponding cell in the flag matrix is marked.

Step 3: The cell's eight neighbors are scanned in sequence; if a neighbor's flow direction points to it and the corresponding flag cell of this neighbor is not yet marked, this neighbor is pushed into the stack.

Step 4: Steps (2) and (3) are executed until the stack is detected as being empty at the beginning of step (2).

Step 5: Return to step (1) and deal with another depression until no such seed points remain.

After undergoing such processing, all depressions can be detected. In order to explain our method more clearly, the definitions of some words concerning the vector characteristics of the depressions are now given.

The boundary cells of the depression, which are arranged in a clockwise sequence, compose its rim