A Method of Depression Filling with Consideration of Local Micro-relief Features

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Abstract—**Depression filling is one of the most basic and time-consuming operation steps in the process of hydrological analysis based on digital elevation model (DEM). With the improvement of spatial resolution of DEM data, quicker method of depression filling plays a key role in the calculation of distributed hydrological model. The paper described a quick depression-filling algorithm which means Micro-relief Flood algorithm (MFF algorithm). This method takes local micro-topographical features into full consideration. In this method, redundant points, depressions and flats will be processed optimally, to achieve further promotion of efficiency in depression filling. And then, 70 DEM data with different sizes are used to test the new algorithm. A comparative analysis was also conducted to investigate the accuracy and efficiency between our modified algorithm and the widely used W&L algorithm and M&V algorithm. Experimental results show that the MFF algorithm can not only fill the depression accurately, but also reduce the computation time by 40.13% than that of W&L algorithm, on average. This method provides a new approach to highly-efficient hydrological analysis.**

INTRODUCTION

In recent decades, Digital Elevation Models (DEMs) have been widely used in the automatic hydrologic analysis of surface topography [1-4]. Depression filling is one of the most basic and time-consuming operation steps in the process of hydrological analysis based on digital elevation model (DEMs). Depression by error and other causes are prevalent in DEM data, and would seriously interfere with the accuracy of the results of flow algorithm [5-7]. Depression filling enables each grid cell flow to the correct position through a certain path, so as to ensure accurate and continuous extraction of drainage network [8, 9]. Nevertheless, time-consuming has always been a problem in former depression filling algorithms. With the trend that high-resolution DEM data gradually become the main analysis data, more rapid and efficient depression filling algorithms are required.

Due to the undesirable results caused by depression, the common practice is to remove depression in the DEM at the very first step of hydrologic analysis [4]. Various algorithms of depression removal have been proposed to discover and fill the depressions. Filter in a window were firstly used to remove depressions [10]. It help to eliminate a great deal of depressions and bring about a great improvement in continuity of extracted stream network. However, it alter the original data too much and cause the distortion of DEM. To overcome the shortcoming above, three types of depression removal algorithms are proposed under the definition of the depression-filling problem [11]. Among those algorithms, the J&D Algorithm developed by Jenson and Domingue is the best known one, which was applied to ArcInfo [12]. This algorithm enable all the depression to be removed with a minimum modification of DEM. Besides, Moran and Vezina proposed the M&V algorithm, which reduce the iteration to make a progress in time cost [13]. Garbrecht optimize the algorithm with elevating flatland to eliminate parallel flow [14]. Soille and Gratin firstly applied the concept of Priority-Flood to depression filling and proposed a more efficient method [15]. As the best known one in methods of depression filling with Priority Flood, W&L algorithm was described by Wang and Liu, which identify and fill depressions with Least-Cost Search algorithm, LC-Search. This method process only once without iteration and further increase the speed of depression filling. In this method, the efficiency of LC-Search algorithm play a key role in the speed of depression filling. Hence, more efficient LC-Search algorithms are continue to be proposed to accelerate W&L algorithm [16-20]. Some researchers have also adopted the method of parallel computing to improve the speed of depression filling computing in large scale, but it still needs a serial algorithm as the ideological foundation [21]. These methods can solve the basic problem of depression removal, however, it ignores the impact of local micro-topographical features on depression filling efficiency and redundant computation exists in the algorithm.

This paper analyzed the regular pattern of water flowing in local micro-relief and proposed Micro-relief Flood Fill algorithm

In: Geomorphometry for Geosciences, Jasiewicz J., Zwoliński Zb., Mitasova H., Hengl T. (eds), 2015. Adam Mickiewicz University in Poznań - Institute of Geoecology and Geoinformation, International Society for Geomorphometry, Poznań

based on W&L algorithm. The generation and elimination of redundant computation in depression filling were discussed to try to release the potentiality of local micro-topographical features for improving efficiency of depression filling algorithm.

METHODS

Basic Idea

Wang and Liu proposed W&L algorithm based on Least-Cost Search algorithm. In this method, each of the cells in DEM data only be accessed once. Most of the cells, however, remain in priority queue and result in the priority queue operating slowly. Interestingly, a large number of cells in priority have nothing to do with the depression filling result. If these redundant computations were able to be avoid, the efficiency of depression filling will be promoted largely. This paper hold the view that the redundant computations mentioned above are primarily due to the ignorance of influence from local micro-topographical feature to depression filling. Therefore, two optimal strategies are proposed to speed up W&L algorithm.

Optimal strategies

1. Redundant Points Elimination

Redundant point is defined as the point involved in the calculation, but not related with the calculation result. The generation of redundant point is associated with the spatial distribution of elevation in local micro-relief. If the topographical feature is in accord with the following elevation distribution in 3 ×3 window, the central cell must be redundant point. All adjacent cells of the central cell are able to bypass the central one, along the direction of maximum gradient (Figure 1). Two general recognition method for redundant are concluded from next 8 circumstance ().

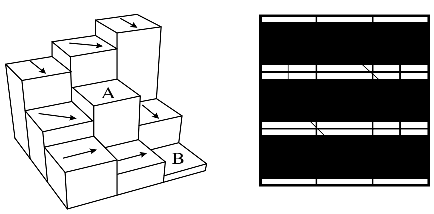

Figure 1.Flow direction in 3D and 2D

I. Diagonal position judgment method:

(1) Father point and pending point are in a diagonal position;

(2) Brother points is lower than pending point;

(3) Either one of the sub-points in orthogonal position is lower than pending point;

Then, the pending point must be a redundant point.

II. Orthogonal position judgment method:

(1) Father point and pending point are in an orthogonal position;

(2) Both of the brother points are lower than pending point;

Then, the pending point must be a redundant point.

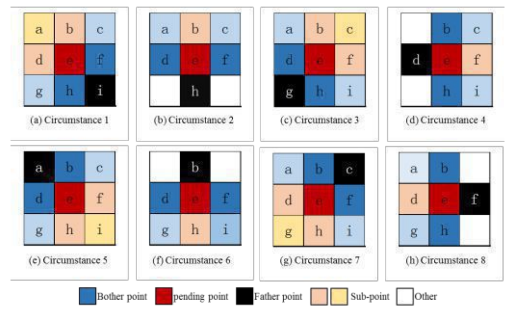

Figure 2.The judgment circumstances of redundant points

2. Faster Calculating for Flatland and Depression

The pending point is defined as flatland when its elevation is equal to one of its father point. Flatland has same priority level with its father due to their equal elevation. Thus, in this paper, the general queue as the fast calculating queue is used to calculate flatlands, for the reason that the time complexity of dequeuing operation in general queue are only O(1) much less than which in priority queue (O(logn)). Depression will be filled as flatland first, so it can also be treated as flatland. This strategy are able to calculate depression and flatland quickly and avoid them participating in the subsequent sorting calculation in priority queue (Figure 3).

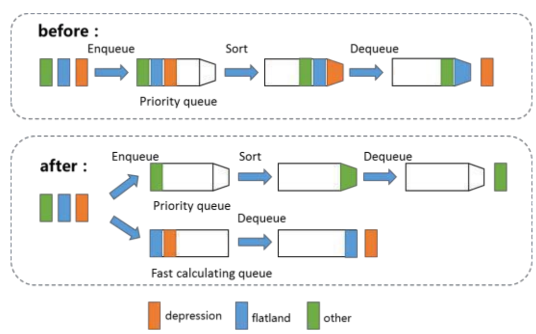

Figure 3.Fast calculating for flatland and depression

Algorithm

Micro-relief Flood Fill algorithm are proposed based on the above two optimal strategies and W&L algorithm. It is composed of next five steps. Step1. Initialization; Step2. Minimum spill elevation searching; Step3. Depression and flatland fast calculating; Step4. Redundant elimination; Step5. Repeat step2 to step4 until both of the fast calculating queue and priority queue are empty; Pseudo-code of MFF Algorithm is shown below (Figure 4).

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Algorithm  Micro-relief Flood Fill

Define DEM[] as the source data
Define Flag[] as the mark matrix which has the same dimensions as DEM
Define PriQueue as the priority queue
Define AdvQueue as the normal queue
Define IsRDPoint(cell, dir) as the function to check cell is a redundant point
Initialize Flag[] to FALSE
for all cell on the edge of DEM[] do
        PriQueue.Push(cell)
        Flag[cell] = TRUE
  while TRUE do
        if AdvQueue is not empty then
              cell = AdvQueue.Pop()
              for all neighbors n of cell do
                    dir = Current Direction      //Position between pending point
                    if Flag[n] is FALSE then       and father point
                          maxElevation = Max( DEM[n], DEM[cell] )
                          if DEM[n] <= maxElevation then
                                DEM[n] = maxElevation
                                AdvQueue.Push(n)
                          else if call IsRDPoint(n, dir) == FALSE then
                                PriQueue.Push(n)
        else if PriQueue is not empty then
              cell = PriQueue.Pop()
              for all neighbors n of cell do
                    dir = Current Direction
                    if Flag[n] is FALSE then
                          maxElevation = Max( DEM[n], DEM[cell] )
                          if DEM[n] <= maxElevation then
                                DEM[n] = maxElevation
                                AdvQueue.Push(n)
                          else if call IsRDPoint(n, dir) == FALSE then
                                PriQueue.Push(n)
        else
              break while
```

Figure 4.Pseudo-code of MFF Algorithm

RESULTS

70 DEM data with different sizes are used to test the new algorithm in comparison with W&L and M&V. All the algorithms in the test produce identical results. Hence, this paper will discuss the difference between the three algorithms only from the aspect of time cost. The testing result is shown in Figure 5 and Figure 6. The results shows that two optimal strategies proposed in this paper is proved effective. Scatter in Figure 5 shows a linear relationship between the speed-up rate of MFF vs. W&L and the proportion of cells be optimized.

Speed-up Rate = (MFF Runtime – W&L Runtime) / W&L Runtime

The linear regression equation is $y=1.067x+0.002(R^2=0.99)$, which means the optimal strategies have a good stability and cost performance. Figure 6 shows that difference of time cost between three algorithms increases with data size which means the cell count. The average runtime of MFF is 476s, the W&L being 820s and the M&V is 3536s when the data size goes to 5.29×10^8. It is clear that MFF has a greater advantage in dealing with large size data.

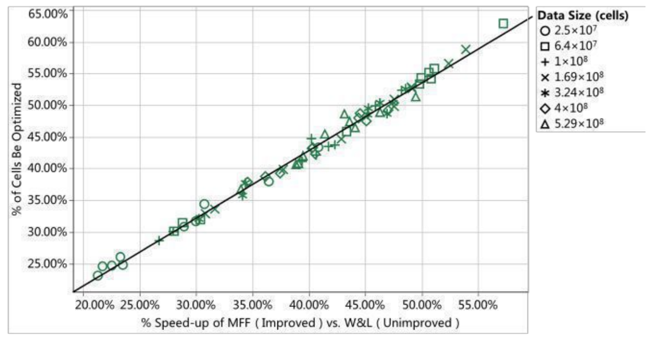

Figure 5.Scatter plot of proportion of cells be optimized and the speed-up rate of MFF vs. W&L.

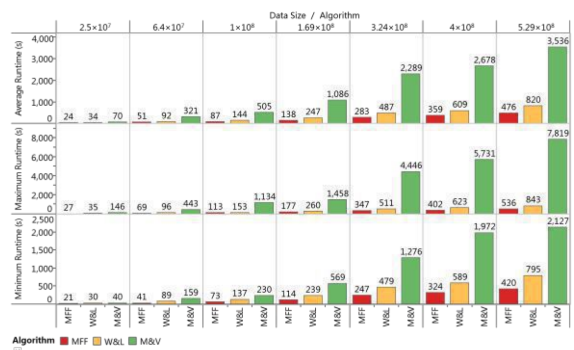

Figure 6.The comparison of runtime of MFF, W&L and M&V

CONCLUSIONS

This paper proposed Micro-relief Flood Fill algorithm to eliminate redundant computation during depression filling due to the fluctuation in local micro-relief. This method further reveals the influence of local micro-topographical feature on flow path in local micro-relief and make further efforts for releasing the potentiality of W&L algorithm.

By analyzing the regular pattern of water flowing in local micro-relief, this paper describe two optimal strategies to speed up depression filling. Testing results shows that MFF algorithm performed up to 57.21% faster than W&L algorithm at most and 40.13% on average.

ACKNOWLEDGMENT

The research is supported by National Natural Science Foundation of China (NO. 41171320, 41471316); Major Scientific Research Projects of Universities in Jiangsu Province (NO.13KJA170001); The authors express their great thanks to everyone who have helped in the writing of this article.

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