A Method for Generating Contour Tree Based on Voronoi Interior Adjacency

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ABSTRACT A contour tree is a good graphical tool for representing the spatial relations of contour lines and has many applications in map generalization, map annotation, terrain analysis, etc. A new method for generating contour trees by introducing a Voronoi-based interior adjacency concept is proposed in this paper. The immediate interior adjacency set is employed to identify all of the children contours of each contour without contour elevations. It has advantages over existing methods such as the geometric method and the region growing-based method.

KEYWORDS spatial relations of contour lines; contour tree; Voronoi interior adjacency set

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Introduction

Topographic contour lines play an important role in the process of humans analyzing landform. Particularly, the spatial relations of contours are usually analyzed and interpreted by humans to recognize topographic features. In order to model and represent the relationships between contour lines, in 1963 Boyell and Reston proposed a contour tree generated by mapping contour lines as edges and interstitial spaces as nodes [1,2].

There has been a great deal of previous work representing the contour map as a tree structure. The identification of the enclosure relation is a crucial issue, and two different kinds of methods have been developed: the geometric method and the region growing-based method. However, there are some deficiencies in both of the methods. After careful analysis, the authors found that the one to many immediate enclosure relations between contours can be described by Voronoi interior adjacency. Based on this, a new method for generating contour tree is developed.

1 Previous work on generating contour tree

The contour tree is contained by two kinds of elements, i.e. node and edge. For a given contour map, the identification number (ID) of each contour is known. Therefore, the nodes of contour tree are known. The key issue to be addressed is to justify whether there is an edge between each pair of contours. Since the two contour nodes linked by an edge hold immediate enclosure relation, identification of this relation is a crucial issue for generating contour tree.

Based on the way of identifying enclosure relation, existing methods can be divided into two kinds. In the first kind, enclosure relations of contours are directly identified by point in-polygon method. This method is called geometric
method. In another kind, enclosure relations of contours are indirectly identified by virtue of adjacent relations. This method is called region growing-based method.

1.1 Geometric method

The basic idea of this method is to sort contour lines into $n$ levels according to their elevation and to check the enclosure relation for each pair of contour lines between two successive levels via point-in-polygon processing. The point-in-polygon algorithm or MBR (minimum bounding rectangle) algorithm is used to determine whether two contours hold enclosure relation. This processing will be performed for any contour line pair between two successive levels.

One of the limitations of the geometric method is that it is necessary to elevate the contour lines to sort them into different levels in the tree. But the elevations may be unknown or false in some cases. Another problem comes from the low computational efficiency, as point-in-polygon processing should be executed for each pair of contour lines between two successive levels.

1.2 Region growing-based method

In geometric method, the enclosure relations of contours are directly identified. By contrast, some researchers employ other method to indirectly identify those relations. Roubal and Poiker pointed out that the adjacent relations of contours can be used to identify enclosure relations of contours. Here, their method is called region growing-based method. The basic idea of this method is to check whether or not the regions growing from two adjacent neighboring contour lines share a common boundary with a relatively significant length, as many enclosed/enclosing contour lines are adjacent neighbors.

The major disadvantage of the region growing-based method comes from the fact that the spatial adjacency does not equal the enclosure relation, which may lead to incorrect results. Moreover, the efficiency of identifying enclosure relations is low in the indirect way.

2 A Voronoi interior adjacency-based method

To improve the existing methods, a new method employing Voronoi interior adjacency to identify enclosure relations of contours is illustrated in this section.

2.1 Voronoi interior adjacency set

It is well known that topographic contours are disjoint line objects. This disjoint relation can be regarded as a kind of adjacent relation. It is this adjacent relation that is used in region growing method. The relations of disjointed contours can be described by Voronoi diagram of contours. Voronoi diagram is a good tool to describe the relations among disjoint spatial objects. It is the tessellation of the whole space occupied by spatial objects, which is based on the nearest principle. The adjacent relations of contours can be defined on basis of Voronoi diagram. Fig. 1 shows a contour map and the Voronoi diagram of contours. It can be seen that the Voronoi region of one contour, $L_i$, is a ring and is represented by $L_i^v$. This Voronoi region is composed of two parts: one belongs to the exterior of the regions enclosed by the contour, called the exterior Voronoi region and denoted by $L_i^{e}$; the other belongs to the interior, called the interior region and denoted by $L_i^o$. The Voronoi region of contour $L_i$ can therefore be described as follows

$$L_i^v = L_i^{o} + L_i^{e}$$

where $L_i^{o} \subset L_i$, $L_i^{e} \subset L_i$.

The number of the Voronoi regions between two contours indicates the adjacent degree of these contours. Therefore, the Voronoi distance between contours can be defined as follows.

Let $L$ be a set of topographic contours $L_1$, $L_2$, ..., $L_n$, $L_i, L_j \in L$ (i $\neq$ j, i, j = 1, ..., n), $V(L)$ be the Voronoi diagram of these contours. The least number of the Voronoi regions between two contours $L_i$ and $L_j$ is called the Voronoi distance of the two contours, denoted as $\text{vd} (L_i, L_j)$, $\text{vd} (L_i, L_j) \geq 0$. 
The value of Voronoi distance is only decided by the number of Voronoi regions between two contours, and has no relation to the size of those Voronoi regions. The value indicates the adjacent degree of contours.

On the basis of the definition of Voronoi region, the Voronoi-based k-order neighbors of a contour line $L_i$ can be described as:

$$N_k(L_i) = \{L_j \mid vd(L_i, L_j) = k, k > 0\} \quad (2)$$

Apparently, the k-order neighbors of a contour $L_i$ may be divided into three types, i.e. contours enclosed by $L_i$, contours enclosing $L_i$, and contours that hold disjoint or parallel relation with $L_i$. Since the crucial issue for generating contour tree is identifying immediate enclosure relation among contours, those contours that are enclosed by $L_i$ is the research objects. The set of those contours is defined as the interior adjacency set of $L_i$ ($IAS_i$):

$$IAS_i(L_i) = \{L_j \mid vd(L_i, L_j) = k, L_j \subseteq L_i, k = 1, 2, \ldots\} \quad (3)$$

In particular, we can express the immediate interior adjacency set ($IAS_i$) of a given contour line $L_i$ as:

$$IAS_i(L_i) = \{L_j \mid vd(L_i, L_j) = 1, L_j \subseteq L_i\} \quad (4)$$

2.2 Using $IAS_i$ to identify enclosure relations of contours

For a given contour $L_i$, the contours belonging to the $IAS_i$ of $L_i$ hold 1-order enclosure, i.e. immediate enclosure relation with $L_i$. Therefore, immediate interior adjacency set can be used to indirectly identify immediate enclosure relations of contours.

In the previous methods for generating contour tree, immediate enclosure relations of contours are identified in the way of one to one. In the geometric method, each time only one pair of contours is identified whether they hold enclosure relation. In the region-growing based method, the identifying direction is from inside contours to outside contours. The immediate enclosure relations of contours are also identified in the way of one to one. By contrast, identifying $IAS_i$ is searching all the neighboring contours of a given contour in the surrounding area of this contour by means of Voronoi interior adjacency, in which immediate enclosure relations of contours are identified in the way of one to many'.

Here, one issue should be addressed. The $IAS_i$ of a given contour $L_i$ is a subset of the set of all children contours of $L_i$. All the children contours of a given contour can be described as follows.

$$children(L_i) = IAS_i(L_i) + \bigcup_{k=2}^n \{L_m \mid L_m \cap L_i^+ \neq \emptyset, L_m \in IAS_i(L_i), L_m \in IAS_{k-1}(L_i)\} \quad (5)$$

2.3 Generating contour tree by means of $IAS_i$

From above analysis, it can be known that the $IAS_i$ can be used for indirectly identifying the immediate enclosure relations of contours, and further to identify the children contours of a given contour. However, two problems should be solved in the process.

Firstly, when searching $IAS_i$ of a contour $L_i$, those contours that contain $L_i$ and those contours that hold disjoint or parallel relation with $L_i$ must be excluded. To meet this need, one can search the $IAS_i$ of each contour on topographic map from the most outside contour to the inside of the map.

The second problem is how to find the children contours of a given contour $L_i$ that are k-order ($k > 1$) adjacent with $L_i$. In fact, according the sequence character of k-order adjacency [11], each contour that is k-order interior adjacent with $L_i$
is immediate adjacent with at least two contours belonging to the IAS_{k-1} (L_{i}). Therefore, one can continually search the contours that are 1-order adjacent with at least two contours identified as children contours, until no more contours meeting the condition can be found. Although the children contours that are Voronoi-based k-order (k>1) adjacent with a given contour must be identified during the process of identifying the children contours, it is fortunate that those contours only occur in places where the density of contours is relatively high. In most places of contour map, all the children contours of a given contour belong to the IAS_{i} of this contour.

Thus far, a new strategy for generating contour trees has been drawn out. That is, taking the farthest contour line on the map as the root and starting from this contour, all the children contours of each contour are gradually detected by means of Voronoi-based 1-order adjacency and are stored as nodes located on different levels of the tree, until all the contours on the map are stored as nodes. The final structure created is just the contour tree. Before generating a contour tree, contours should be ensured to be closing lines, which ensures the correctness of the identification of adjacent relations [3].

The immediate interior adjacency set-based method include three steps:

1) Generating a Voronoi diagram of contours;
2) Identifying adjacent relations based on a Voronoi diagram;
3) Taking the most outside contour line on the map as the root and starting from this contour, all the children contours of each contour are gradually detected and stored as nodes of contour tree.

To verify the proposed method, real contour data are used to generate corresponding tree structure. The contour map shown in Fig. 2(a) is at the scale of 1 : 50 000 and 5 km × 5 km in size. The contour interval is 20 m. Fig. 2(b) shows the corresponding contour tree by using the immediate interior adjacency set-based method. By comparing the two figures, it can be seen that the tree structure describes the spatial relations of the contours correctly.

3 Conclusions

A contour tree is a good graphical tool for representing the spatial relations of contour lines. One of the premises for mining useful information from large contour database is generating contour tree correctly and efficiently. To overcome the defects of existing methods, an immediate interior adjacency set-based method is proposed, in which the relation between Voronoi interior adjacency and enclosure relations of contours is taken into account, and Voronoi 1-order interior adjacency is used to identify the one to many enclosure relation between a given contour and its children contours.

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proved.

The last is when using SOM-PCA algorithm the problem of zero-cross has been solved very well. There is only one zero-cross at the point of 400 nm while there are about 9 zero-crosses in Fig. 3 when using PCA directly. On the other hand when too many zero-crosses appeared, near half of the spectra distribution is under zero; and it is the handicap for applying the multispectral space to practice. The principal spectra components spanning the modified multispectral space are all distributed above the zero axis, so it is easy to turn it into reality.

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