A GENERALIZATION OF CONTOUR LINE BASED ON THE EXTRACTION AND ANALYSIS OF DRAINAGE SYSTEM

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ABSTRACT:

Unlike the simplification of independent line features, the generalization of terrain contour is to handle the "*line group*", which describes the geomorphologic characteristics, such as the terrain valley and ridge. In decision level, the real operation object in terrain generalization is not line segment itself but the drainage network contained in the contour representation. This paper presents a method to generalize contour based on the analysis of drainage structure. The first step is to extract the drainage system from the contour lines and build the associations between the valley branch and the bend group of contour lines. The second step is to analyse the properties of drainage tree structure to decide which branch to be removed, and then to perform the geometric elimination of bends. In this study the extraction of drainage system is directly from contour (other than from DTM data) based on Delaunay triangulation model. Three kinds of tree structure organization are investigated: the hierarchical binary tree representing bend inclusion relationship contained in each contour line, the planar structure tree describing valley topological relationship, the semantic hierarchical tree representing valley joint level from the point of view of hydrology.

1. INTRODUCTION

Map generalization is a process of "information abstraction" rather than the "data compression", although two purposes have associations to each other. Real generalization operation should be an intelligent action which considers object **geographical** characteristics not simple **geometrical** properties. Take the example of line simplification, the operation at the lowest level is the elimination or movement of coordinate points, but the decision is made on the level of geographical meaning. Recently the works in map generalization start to examine geo-feature. Some researches think the true generalization should investigate the geographical nature and so called geo-oriented generalization should move from critical points to sub-feature (Poorten and Jones,1999, Planzanet 1995). In this sense, the generalization is a task of structured analysis requiring to extract spatial knowledge (Wu,1997). In Brassel and Weibel's (1988) generalization model, structure recognition is regarded as the first step among five procedures. Plazanet etc.(1998) presents a learning method of feature simplification and from the expert system point of view she also stressed the importance of line structure knowledge. The *constraint* based generalization gets emphasis and this concept is also under the control of structure characteristics.

The contour simplification is a typical structure based generalization. As a special line representation, the contour contains a series of terrain characteristics such as valley distribution, ridge distribution, geomorphologic type and so on. Only when cartographers firstly assess the above properties correctly, could contour line simplification obtain satisfactory result. If the cartographer looks at each contour only as a single line with such geometric measures as distance, curvature, angularity, fractal dimension, the simplification result will deflect the terrain characteristics and terrain distribution. In some degree the real operation object in terrain generalization is not contour segment itself but the drainage network contained in the contour representation. After the judgment of small unimportant valley in the drainage system, the contour generalization is then to remove them through the elimination of bend group across series of adjacency contour lines. In this process, two key steps are required. One is to extract the drainage system from the contour lines and build the associations between the valley branch and the bend group of contour lines. Another is to analyse the structure of drainage system to decide which branch to be removed, and then to perform the geometric elimination of bends.

So the contour generalization includes two aspects at both geographic and geometric levels. The previous focuses on the decision of importance of terrain characteristics by the analysis of drainage structure, and the latter the simplification of line. In the literature of contour generalization, many works on the second question are conducted, but little on the first question. Weibel (1992,1987) systemically investigates the drainage analysis in the contour generalization from conceptual perspective, but the realization method is not available. Wu(1997) presents the idea of contour generalization based on the terrain structure analysis. For the second question, some special algorithms modified from general line simplification have been achieved aiming at contour. Li and Sui (2000) extended the algorithm based on the nature principle into the contour simplification avoiding the intersection between neighbor contours. Also an algorithm is presented for the derivation of a new contour from two original neighbor contours. Based on the shape analysis, Wang and Muller(1998) gave a method to simplify line through the bend detection and this algorithm is able to be used in contour simplification to remove the small bend corresponding to minor valley. The application of Berg's(1998) algorithm in contour simplification can well control the position error.

Alternatively, another indirect method based on DTM data can be used to generalize contour(Chen 1989; Weibel 1992, Li 1999). In these approaches, generalized contours are obtained from generalized terrain and digital surface models.

This study tries to generalize contour line combining the geographic analysis and geometric operation, developing a method to extract drainage system and through the removal of "bend group" across contour cluster to simplify contour. The rest paper is organized as follows. Section 2 presents a method to extract landform feature directly from contour line based on Delaunay triangulation model. The further organization of landform feature into drainage tree structure is given in section 3. Section 4 investigates the simplification of contour based on drainage system. Section 5 concludes with the future improvements.

2. EXTRACTING LANDFORM FEATURES FROM CONTOURS

2.1 Motivation of direct extracting landform features from contour

Terrain landform features include peak, pit, saddle, ridge and valley. The research on the extraction of them has been an interesting topic over years. In this field, the extraction of valley and ridge lines based on DTM data is active and achieves lots of algorithms (Band 1986, Yoile 1984, O'callaghan 1984, Qian 1990, Tribe 1992). However, the extraction of landform feature directly from contour is necessary. There are three reasons: (1) The contour representation is the main method of terrain model in the cartography history. Now there are many existing contour map sheets in hand. Usually the GIS users first get contour data and then need to construct DTM. (2) The construction of high quality DTM needs landform feature to support. How to get the landform feature? (or Who is first between DTM and landform feature?). Only from contour data. (3) For contour generalization, the landform feature extracted from DTM data is independent of contour line. When the decision is made to eliminate one valley branch, no proper contour segment is correspondent to remove.

Compared with the DTM based methods, the contour based approach extracting terrain features is very limited. Tang (1992) presented a skeleton extraction method which is based on flat triangle judgment using the Delaunay triangulation model. From the experiment result, the generated valley and ridge is broken, without the complete tree structure. Fei (1993) gave a method to detect valley bottom points based on the curvature judgment. The distribution sensitivity of vector point in one contour line leads to the judgment quite different from the manual identification of valley segmentation. In his study the further connection from valley bottom points to channel path is not available.

This paper will present a pure vector method to derive valley and ridge features from contour line. The Delaunay triangulation is still the support model, but its usage is quite different from Tang's method. Contour line is the representation of projected 3D terrain. The geometric features of each contour line in 2D plan implicitly delineate the terrain characteristics. The bend contained in contour line is such a key geometric feature. One bend can be seen as the projected fragment of valley channel at a determinate height level. One valley channel is represented as the group of series of bends in 2D plan. So the basic idea of directly extracting valley/ridge features from contour lines is first to segment each contour line into bends, and then to link the consecutive bends to form the channel.

2.2 Constructing the binary tree of contour bend inclusion

The key step in the extraction of landform feature is to segment the contour line into bends. Traditionally the definition of bend feature is based on inflection points. At an inflection point, the trace direction of vector point along the curve changes from leftward deviation to rightward deviation, or the opposite. The curve segment between two consecutive inflection points forms a bend. This definition is not suitable for the extraction of valley fragments from the whole contour line, because the bend is not in accordance with the principle of symmetry and hierarchy as the manual identification of one valley bend (Ai, Guo 2000). In the previous study (Ai and Guo,2000), a method is presented to detect the curve bend of one side based on Delaunay triangulation. The detected result is represented as a binary tree. For all the contour lines, adjust the line direction so that along the trace forward direction the left is higher and the right is lower, or the opposite. This adjustment guarantees that the bend selection from one side in the following process exactly corresponds to valley rather than the random appearance of valley or ridge. Construct the constrained Delaunay triangulation in the coverage of one contour. Just consider the triangles locating on one side of the contour line. According to the number of neighbor triangles, we can distinguish three types of triangles. Those triangles with three neighbors separate one big bend into two sub-bends. Here the bend is defined as the segment of contour line, which is cut by one triangle edge. Due to the sensitivity of triangle generation, the post process is required to remove additional bends which are against the manual cognition. For the detailed discussion, see Ai and Guo(2000). An example of bend segmentation is shown in figure 1 and figure 2. The binary tree of bend inclusion represents the hierarchical structure of valley fragments in one contour. The parent node of the binary tree corresponds to the lighter grey area representing the big valley fragment, and two child nodes corresponds to the darker grey area overlapping in the lighter area, representing two sub valley fragments. In this segmentation, the bend is approximately symmetric respecting the valley nature in the actual cognition.

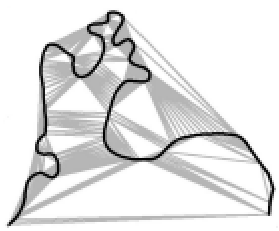


Figure 1. Delaunay triangulation construction in the coverage of one contour line.

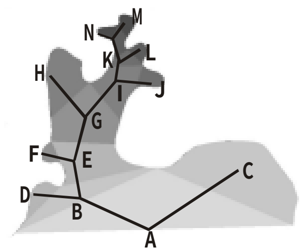
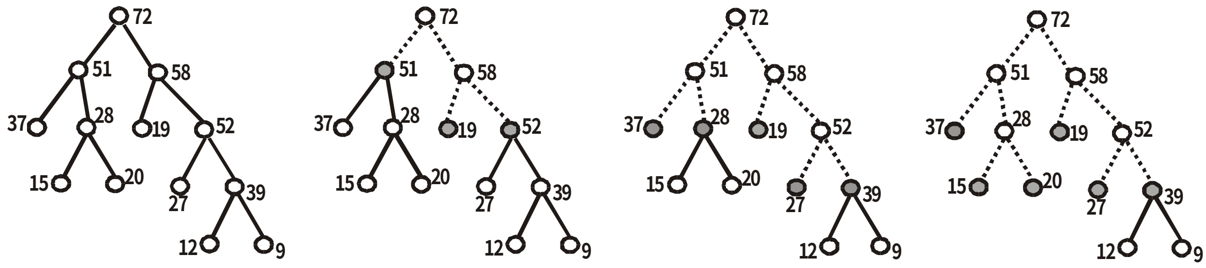


Figure 2. The binary tree representation of bend hierarchical inclusion

2.3 Selecting the valley fragments from the bend binary tree

According to the properties of self-similarity and fractal structure, the valley feature is able to be distinguished in an infinite way. So the valley extraction has to consider the resolution. For single contour, each node of the bend binary tree delineates the projection fragment of valley at some resolution. The hierarchical node depth in the binary tree describes the resolution of valley identification. Here we define the valley resolution the depth of the bend, which is represented as the length of the skeleton line from the mouth of current "node" to the farthest terminal in the bend area (see figure 6). The larger the bend depth is, the lower resolution of the valley detection is. Selecting large bend depth will miss the small valley channels.



Original binary tree Bend selection using depth tolerance 50, 35, 20 respectively

Figure 3. Binary tree separation and bend "node" selection based on bend depth resolution (the dashed line represents clipped link, the shaded circle represents selected bend. The number beside circle is the bend depth value)

Selecting proper "nodes" from the bend binary tree is based on the principle of "maximum-minimum". It means the selected node should meet the condition that its depth is the minimum among those with the depth greater than the threshold. From the root, when tracing point arrives at the node whose two child nodes have the depth shorter than the threshold, the current node will be selected (current "node" is the last one whose depth greater than the threshold). When arriving at the leaf node, the trace does not yet meet the node meeting the condition above. The leaf node is also selected. Figure 3 illustrates the process of selecting nodes based on different resolutions. In the above selection, the leaf node with small bend depth is also selected. The reason is that these nodes represent the valley source and along the flow direction the down stream will be greater than the threshold. In figure 4, for the threshold depth 30, we select bend *C, D, E*. But bend *A* , *B* is the beginning source of the valley channel and for the completeness they should also be selected, although their depth is shorter than the threshold. Figure 5 illustrates the extraction of valley fragment from the same contour using different bend depth threshold.

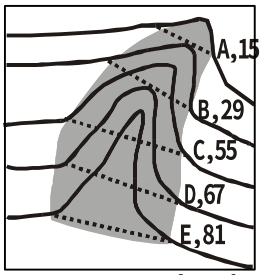


Figure 4. Bends with different depth compose a valley

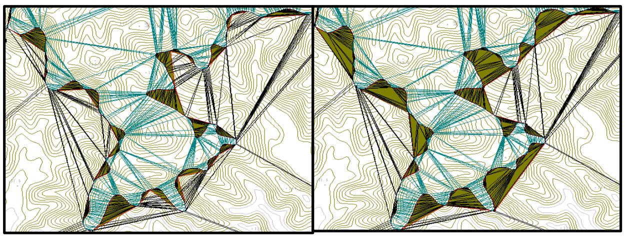


Figure 5. Two extractions of valley fragment from the same contour line applying different bend depth threshold value.

2.4 Detecting valley bottom points

Overlapping the selected valley fragments gets the distribution range of the valley channel. To get the topological relationship between valley channels, we need to detect the bottom points of the valley fragments and then to connect them to a tree structure. Consider the local triangle cluster within one bend and construct the skeletons of triangulation. From the open mouth of the bend to different terminals of skeleton branches, there exists one path respectively. Select the terminal point farthest away from the mouth acting as the valley bottom point. In figure 8, the terminal point *C* is the farthest away from point *O*, so *C* is the valley bottom point. An experiment of valley bottom point extraction is shown as red dot in figure 7. Some research(Wolf 1988, Fei 1993) considers the valley bottom point as the point with the local maximum curvature. The sensitivity of curvature resulted from the tremble of vector points will lead to wrong detection in this process. The identification of valley bottom points has to consider not only the local point distribution but also the context, the distribution of two sides of bend in the entire sense. The skeleton based method is from bend area to detect bottom point rather than local points distribution. In some degree, the context gets consideration.

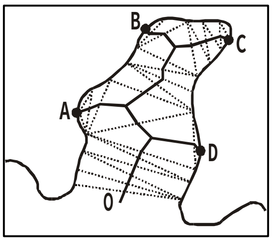


Figure 6. The branch end point *C* is regarded as valley vertex according to the longest skeleton branch principle.

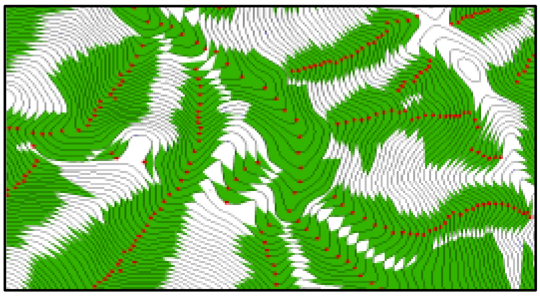


Figure 7. An experiment of valley bottom point detection

3. ORGANIZING DRAINAGE SYSTEM

The drainage system is a tree structure. The tree construction includes the connection from valley bottom points to channels, and the welding the channels into tree.

3.1 Linking bends to channel

According to the elevation descend, linking the consecutive bends to channel is a search process. In the DTM based method, we have the principles such as the steepest descend. Here in the

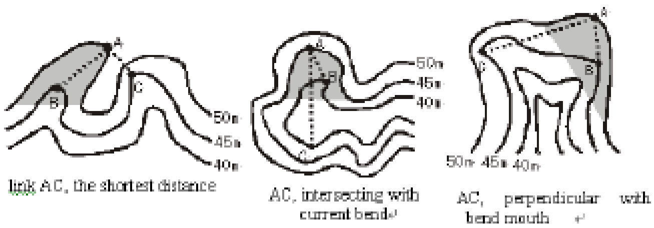


Figure 8, Cases of wrong link from high valley bottom point to low in valley line detection.(AC wrong, AB correct) vector operation, the linking has to consider the geometric principles: the shortest distance, the perpendicular direction (with the bend mouth), not intersection with bend segment, etc. But these principles should be integrated and adjusted the contradicts to each other. Three cases in figure 8 show that link *AC* satisfies one condition well but a wrong connection. Suppose the current bend *a* having valley bottom point *A*, the process of searching the next point *B* is described as follows:

> Initiate the set $\boldsymbol{b_0}$ all the valley bottom points. Execute the following step:
>
> I> From set $\boldsymbol{b_0}$, take the sub set $\boldsymbol{b_1}$ whose element has the elevation descend one interval height with respect to ***A***;
>
> II> From set $\boldsymbol{b_1}$, take the subset $\boldsymbol{b_2}$ whose element is closer to the point ***A*** . For the predefined distance threshold ***d*** **:** $b_2=\{B_i \mid B_i \in b_1 \ \& \ |AB_i|<d\}$
>
> III> From set $\boldsymbol{b_2}$, take the sub set $\boldsymbol{b_3}$ whose element locates within the enveloped polygon of bend ***a***. If $\boldsymbol{b_3}$ is not empty, select the point which is the closest to point ***A*** and this point is what we want ***B***. Otherwise turn to step .
>
> IV> From set $\boldsymbol{b_2}$, take the sub set $\boldsymbol{b_3'}$ whose element respects that the link between the element and point ***A*** intersects with the mouth edge of bend ***a*** and does not intersect with the segment of bend ***a***.
>
> V> From set $\boldsymbol{b_3'}$, select the point which is the closest to point ***A*** and this point is what we want, point ***B***.

In the process above, we have $B \in b'_3 \subset b_2 \subset b_1 \subset b_0$ or $B \in b_3 \subset b_2 \subset b_1 \subset b_0$. In the order of I,II,III,IV,V**,** conditions become stricter and stricter and the number of elements of set b_i reduces at an acceleration. Step I is a height comparison not involving geometric computation. Step II just needs a simple distance calculation. Step III needs the judgment of point-in-polygon, a time cost process of geometric computation. Step IV and step V involves the computation of curve intersection. In the latter steps, the computation just executes on the limited elements, requiring not much time. Based on the geometric judgment and computation of vector objects, this algorithm guarantees that the linked valley channel does not intersect to each other. In figure 9, the yellow line(not consider brown line) is the linking result from the valley bottom points to channels.

3.2 Organizing channel connection to drainage system

To link the channels to the drainage system, the geometric conditions is not strict like the above connection. We consider not only the slope descend direction but also the topologic connective relationship in the plan. The trend of the valley development allows the link could go across several contour lines. The most important constraint is that the link should not intersect with each other in the middle position. In the same way, the shortest distance and the steepest slop descend are the basic principles in the connection. In the figure 9, this link is symbolized as brown lines, just like welding the separate chains.

3.3 Identifying channel levels in drainage system.

The semantic hierarchical tree represents the channel levels in the drainage system and it can be derived from the planar structure tree. Select proper channels to form a complete valley and according to the hydrological significance judge the main branch vs. minor branch. The joint valley channels have to be reorganized. In the planar structure tree, the joint point relates to at least 3 channels, one as the downstream and the others as the upstream. Which upstream channel is selected together with the only downstream channel to form the complete main valley? The answer depends on the following conditions:

a) The continuous geometric connection (The connection approximating to 180^o has more preference.)
b) The long distance from current joint to the upstream source.
c) The smooth slope descend.
d) The high order of Horton code.

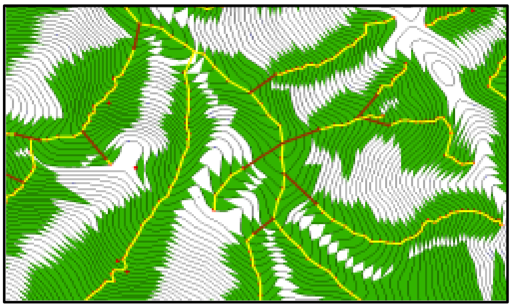
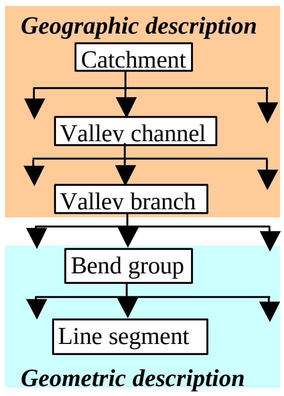


Figure 9. An experiment of valley channel search. The yellow line is the valley channel link and the brown line the welding between channels to form the tree structure.

The conditions above generally have high correlation to each other. But in some situations, the approximate 180^o connection may get a upstream channel from close source. Through the experiment comparisons, the condition b> is found to be better than the others. Figure 10 is an experiment based on condition b>. From the outlet which is the lowest, track the path to every upstream source. Select the one which is the longest as the main valley. Then from the remaining channels, select the second longest path as the 2nd order valley. Iterate the steps until no channel is remained. In the search process, if the local outlet of one valley *a* accesses to valley *b* , then allow *a* act as *b*'s child in the semantic hierarchical tree structure. Figure 10 is an experiment illustration, the final result of all process discussed above. The illustration includes three information contents: the topological relationship in the planar structure, the water basin distribution, the significance levels in the sense of hydrology. Figure 10 is the direct experiment result without any post process. Some broken or independent valley branches could be eliminated. Here from the purpose of contour generalization, we just consider the valley feature. Select the bend on the other side of each contour, the ridge feature can be extracted.

4. CONTOUR GENERALIZATION BY THE REMOVAL OF BEND GROUP

After the drainage tree is constructed, we can get the following hierarchical structure which bridges the geographic description and the geometric description of terrain contour. It is able to unify the high level decision and the low level operation in contour generalization. It means in the catchment network through geomorphologic analysis decides which valley branch is unimportant and to be removed. And then simplify the contour by the removal of series of segment which corresponds to the bend



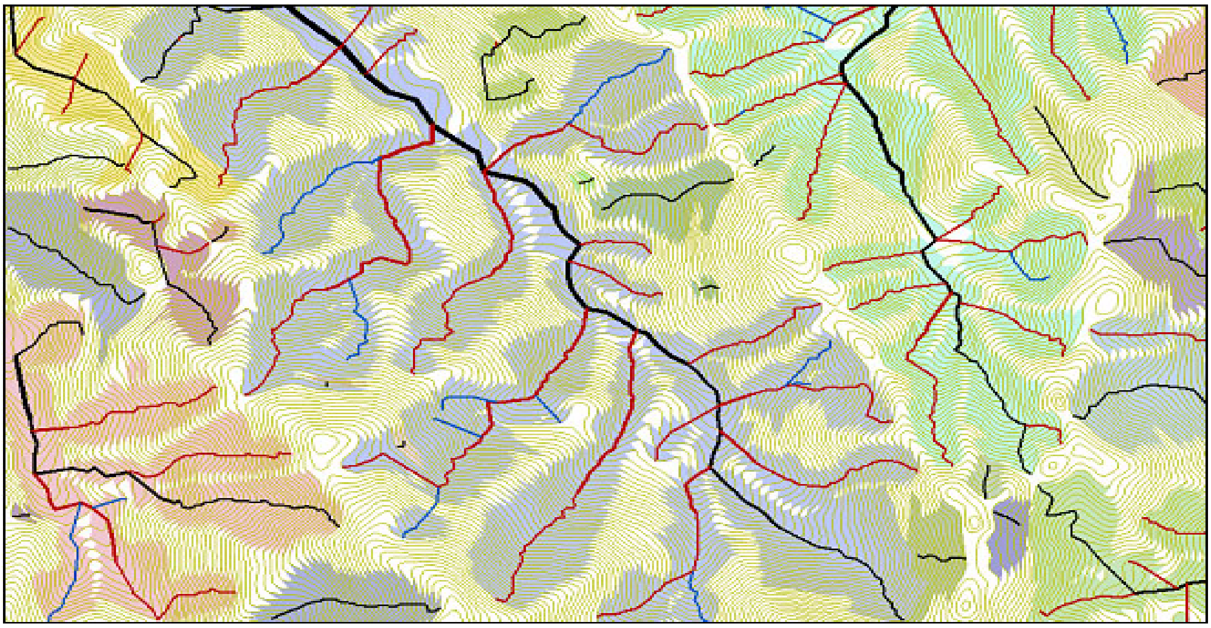


Figure 10. The visualization of semantic hierarchical tree of drainage system. Black channel is level 1, and red level 2, blue level 3, magenta level 4, etc. The width of channel visualization is related to the distance between current position and outlet representing the water flow direction. The random color region represents the different catchments.

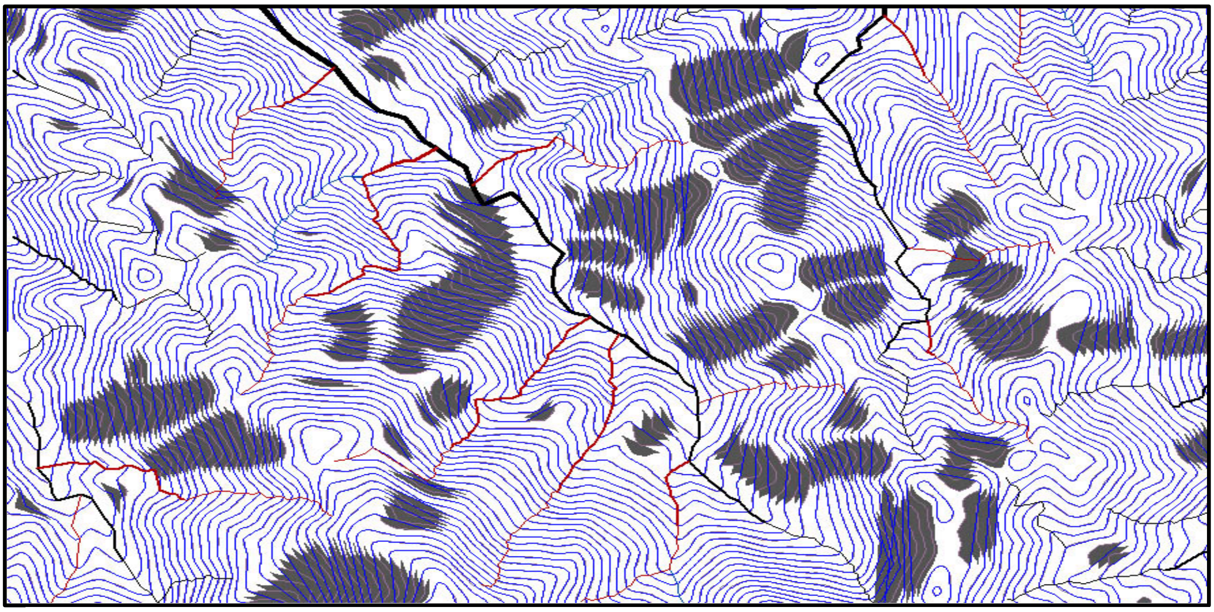


Figure 11. Contour generalization by the removal of bend group which corresponds to unimportant valley branch.

group representing insignificant valley. This strategy can exactly simulates the generalization process as the manual method does.

The decision of unimportant valley is a complex process(Weibel 1992). Two aspects requires to be considered: (1) The measure of the valley channel itself; (2) The relationship between context channels. The previous includes such as the valley depth, valley width, valley area and channel order level in the drainage tree (for instance, the Horton code). The latter includes the interval distance between neighbor channels, the distribution density of valley, the main geomorphologic pattern, and others. In this method, the above measures of valley are easy to compute based on bend representation.

For the limitation of paper page size, we just give a simple judgement to detect the unimportant valleys. There are two conditions: (1) the valley depth is less than the tolerance; (2) the valley locates at the lowest level of the catchment tree. Figure 11 illustrates the result of experiment. The shaded area represents the unimportant valley and the corresponding bend groups have been removed (reflected as the direct link of part segment). The other remained valley channels are still displayed across the contour line. From figure 10 to figure 11, the interval height changes. The contour selection has been conducted to remain one from every two neighbors.

This is a real simplification of terrain characteristics. But the graphics may be not ideal, sometimes ugly. Actually in manual generalization process, some intended adjustments are necessary to guarantee such as the neighbor contours distribute consistently. So the post process aiming at graphics is required. As the element in a bend group may not include exactly, instead with “mouth” overlapping, there produces a big question that generalized contours may locally intersect. When two neighor valleys are removed continually, the frequency of intersection is high.

5. CONCLUSION

Contour generalization is more difficult than that of independent line features. The object of decision and operation is not the same one. The analysis at geographic level is based on the drainage system which is hidden in contour representation requiring special algorithm to extract. But the simplification operation goes back to the contour itself. This study presents a method to generalize contour line combining the geographic and geometric handling. The main contribution exists in the extraction of drainage system from contour directly and the associations are built between the valley branches and the bend groups of contour lines. This structure is well to support the latter generalization of contour. The method has been realized in an interactive generalization system *DoMap* developed by author.

The extraction of drainage system in this study includes the segmentation of contour line into bends, the organization of the drainage system through two links and the identification of the channel levels according to the hydrological significance. In the organization of drainage system, the questions of which branches make up the valley channel and which one act as the main stream, have uncertainties. In the decision of terrain generalization based on drainage system, much knowledge is required to summarized.

To improve the method, the future works include:
1> Refining the bend detection with the consideration of the context of other bend distribution along the valley channel.
2> Improving the drainage organization according to not only the geometric measures but also the hydrological and geomorphologic characteristics.
3> Enhancing the decision analysis of contour generalization on the basis of drainage system, and investigating the integration with other graphic processing methods to get high quality generalized result.

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