LINE SIMPLIFICATION BASED ON GEOGRAPHIC-FEATURE CONSTRAINT

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Abstract: It is one of the most important aspects of line simplification in cartographic generalization. As a geographic object with geographic-feature properties, line simplification is not geometrical compression but structural generalization behavior which has to take into account geographic object properties in geometrical, semantic and topological aspects. This paper offers a new approach of line simplification based on geographic-feature constraint. The approach divides line into initial curves with Constrained Delaunay triangulation model according to geometrical morphology of line. It identifies basic curves and composite curves by the curve detection method, acquires the contiguity and hierarchical levels relationship by curve tracing method, and fully achieves structural method of line morphology. Neighboring geographic features in effective spatial neighborhood of line were gained and putted into sub-curves of line. The presented approach designs the rules of curve selection and the whole flow of line simplification. An application experiment shows that the algorithm is more excellent in the aspects of holding the morphology of line feature, geographic-feature consistency, and undergoes a high simplifying rate with a simple parameter, which fully proves its scientificalness and advantage.

Key words: line simplification, geographical feature constraint, structured, automated generalization

1. Introduction

Cartographic generalization is a core and difficult issue to crack in cartography, which has continuously drawn broad attention of numerous cartographers. From the range of derivation Cartographic database and “geographical surfing” on the network map to the production, management and expression of multi-scale spatial data in GIS, Cartographic generalization is in urgent need yet its exploration is far from living up to the expectation of researchers. Such a hard situation could be accounted for the following two aspects: one is the complexity of cartographic generalization and the other is that in previous studies, fewer have been emphasized upon the guiding function of geographic feature plays in cartographic generalization than upon the simplification of figure of geographic components[1].

Linear feature consists in the most important part in map content. In maps, there are many linear objects, like contour line, communication network and boundary line while rivers and lakes are areal targets. On the basis of internal uniformity, people are more concerned about external contour line so that line simplification is one of the chief concern in cartographic generalization. With decades of advancement, Many line simplification algorithms are reported in the literature[2-6], which include Douglas-Peucker algorithm, perpendicular distance algorithm, BLG(Binary Line Generalization tree) and Li-Openshaw algorithm. All these above-mentioned algorithms share the commonalities of conducting simplification from the perspective of geometrical characteristics and by deleting point coordinates on the curves while maintaining feature points, which is far from perfect in keeping the morphological character.A line, more than a point sequence, is an entity of geometric shape and thus its simplification is not a simple geometric operation of keeping or eliminating a vertex. Some scholars[7-10], basing upon the structural analysis, has proposed a method of simplifying lines, which is regarded a big forward step to the past, yet is still in the primary stage of analyzing and expressing line structures since geographic feature constraints have not been fully embodied in line simplification. Line simplification is expected to take the cognitive characteristics of curves into full account as well as geographic features of curve elements and analyzes the spatial knowledge contained in curve elements in reference to the spatial cognitive significance, which is a structured generalization behavior[11].The paper, grounding upon geographical feature constraints, puts forward a method of line simplification, which indicates in the process of line simplification, geographical features of line(spatial dimensionality, spatial distribution, spatial relations, types and grades) should be taken into consideration; subjective judgement and thinking mode as well as judging process should be transformed into knowledge that are computer-acceptable and can be modelized, and meanwhile, the nature of law in geographical features should be respectfully reflected in the result of simplification.

The present paper starts with the inner rules of curve morphology, summarizes and abstracts structural units and their inner relations of line morphology so as to realize the overall structurization of curve morphology, then obtaining the geographical constraints needed in the process of simplification by analyzing the geographical semantic features of line and the inner spatial relation of its neighboring geographical features. Thus, the process of line simplification, by referring to the structured knowledge of line morphology and satisfying the preconditions of geographical constraints, turns to be a process of generalization of small ones of curves with an aim to keep the overall structural features of lines intact and meanwhile simplifying low-level details of lines.

2. Acquisition of Geographical Features of Line

2.1 Structural Analysis of Line Morphology

In the world of nature, linear elements have a certain morphological characteristic and various parts of linear elements are no exception. For the convenience of studying line morphology, it’s necessary to structurally divide line morphology. Many methods of dividing the basic structure units of line morphology are available. Comparing to other structure units, curve is much more understandable and acceptable and thus, it’s feasible to divide line in accordance with curve units which is proved to be compliant to visual and cognitive rules[12].

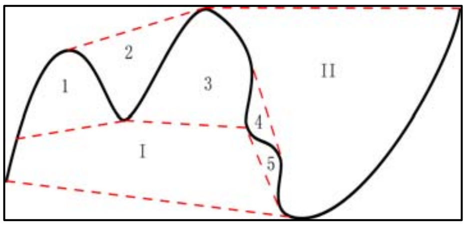


Figure1. Characters of curves

As a matter of fact, structural information of geographical features loaded upon linear objects also manifests themselves through curve features[12,13]: morphologically divide curves in the unit of curve and so curves are composed of a number of continuous curves. Parameters for describing single curve feature are length of base line, maximum vertical distance, area, perimeter of curve and shapes and so on. Curve in the world of nature contains complicated curves and hence comes our defined range: curve which does not include any other curves are called “basic curve”. Basic curve is the smallest morphological unit of curves and complex curve probably consists of a number of adjacent basic curves. Similarly, a number of continuous complex curves can make up a more complicated composite curves.

The cognitive process in understanding the objective world is always from coarse to fine, from simple to complex, from superficial to deep inside, the abstract description of which is hierarchy. As for curve elements, the curve is composed by a number of continuous composite curves, which is formed by continuous basic curves, which is eventually composed by consecutive vertexes. There is hierarchy among curves and curves, even inside the curves. The hierarchy between lines and curves is represented with the nesting relationship among the curves, which has great significance in the structured analysis before synthesizing the map.

Line is composed of consecutive vertexes, and the curves which form the line are also continuous. From one direction of the line (Figure 1, suppose the data acquisition direction of the curve is from left to right), concave and convex curves come forth by turns, that is, the adjacent curve of the convex curve must be concave one, and the concave one must be adjacent to convex one. The continuity of curve has a characteristic of hierarchy, that is, we should analyze the continuity of curves in the same hierarchical level. The relationship between the composite curve and the line has two basic situations: composite curves on the right of the line (Figure 1, composite curve Ⅰ), or on the left of the line; Similarly, the relationship between basic curves and composite curves also has two situations: the basic curves are inside the composite curve (Figure 1, the basic curve 1, 3), known as the convex sub-curve; basic curves are outside of the composite curve (Figure 1, basic curve 2), known as concave sub-curve. In Figure 1, the adjacent curve of curveⅠ is curveⅡ, curve 2 is adjacent to curve 1, 3, but if we say curveⅡ is adjacent to curve 3, obviously that is not correct. Because of the curve continuity, adjacent curves have a section of overlapped region, where the adjacent curves share the same small curves, which embodies that a small curve in overlapped region is a convex sub-curve of the composite curve on one side, but a concave sub-curve of the composite curve on the other side (Figure 1, Curve 4, 5).

Symmetry is another important characteristic of the line, V-shaped, U-shaped, semi-circular, open triangles are characterized by obvious symmetry. Symmetry is the cognitive representation of the overall characteristics of the curve morphology; basic curve has an apparent characteristic of symmetry, so does composite curve. In the process of line simplification, maintaining the symmetry feature of the curve is the first thing to consider.

2.2 Curve detection

At present, there are two basic kinds of methods on curve division, one method is based on inflection points of the line [12,13], the direction of the curve at the inflection point will be change from clockwise to counterclockwise or counterclockwise to clockwise along a direction, the part of line between two inflection points constitute a curve, but this method focuses only on the principle of continuity, neglecting symmetry and hierarchy in the overall structure, which is conflict with visual perception[14]; The other is based on the Delaunay triangulation model[9], which establishes the spatial relationship between the vertices, which has many advantages in the analysis of morphological characteristics of the line. Compared with the first category of methods, this method on curve division more accords with visual perception, but as a purely geometric method, there are some limitations in the detection and description of the structural characteristics of curve, in Figure 2, in the visual perception, edge BC is more appropriate than edge DC as a base line of curve. This paper presents an improved method based on the Delaunay triangulation model in curve detection.

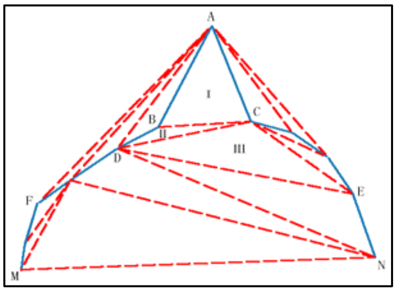


Figure 2. Illustration of basic conception

(1) Basic concepts

We will acquire a constraint Delaunay triangulation network after constraint Delaunay triangulation on line. Figure 2 illustrates the result of triangulation on a line. The solid line refers to the line, dashed lines are the new edges of triangles after triangulation. The relevant characteristics of subdivision triangle are as follows:

TypeⅠ triangle: only one non-constraint edge in the subdivision triangle (Figure 2, △ABC);

TypeⅡ triangle: only two non-constraint edges in the subdivision triangle (Figure 2, △BCD);

Type Ⅲ triangle: three edges are non-constraint edges in the subdivision triangle (Figure 2,

△CDE);

Skeleton feature point: the point of intersection of the two constraint edges in TypeⅠtriangle (Figure 2, point A, B and C), in the curve which base line MN points to, point A is the positive direction skeleton feature point, points B, C are the reverse direction skeleton feature points;

Partitioned boundary edge: there is only one adjacent triangle (Figure 2, edge AF).

Bifurcated edge: each edge of Type Ⅲ triangle corresponds to a curve, the corresponding curves of two edges is contained by the curve corresponding to another one, and these two edges is the bifurcated edges (Figure 2, edge CD and CE).

The orientation of storage of the vertexes determines the orientation of skeleton feature points and partitioned boundary edges. The direction of skeleton feature points is decided by the TypeⅠtriangle, and the direction of partitioned boundary edges refers to the left or the right of the line. If the curve corresponding to the partitioned boundary edge is an isolated curve, which is not a sub-curve of other curves, this partitioned boundary edge is then called the largest partitioned boundary edge (Figure 2, edge MN). The line is divided into some continuous composite curves by these edges, which are adjacent to each other, rather than hierarchical. Every skeleton feature point absolutely corresponds to a basic curve, whose direction determines the basic curve on the left or right of the line.

(2)Curve detection

There are two types of curve detection, basic curve detection and composite curve detection. The algorithm of line division was proposed in Literature [9] by utilizing bifurcated specialities of type Ⅲ triangle, which represents certian improvement comparing traditional mehods based on inflexion, but still falls short. Basic curve detection starts from skeleton feature points because a skeleton feature point inevitably corresponds to a basic curve after the data of line was triangulated by means of Delaunay triangulation network model. Fisrt of all, seach another non-constraint edge of its neigboring trianle from a non-constraint edge of the triangle which the feature point is located in, the work goes on from the non-constraint edge which is aquired in above way (as shown in figure 3). A basic curve detection is preliminarily accomplished untill a bifurcated edge or triangulation boundary edge, which corresponds to a basic curve, was encountered firstly.

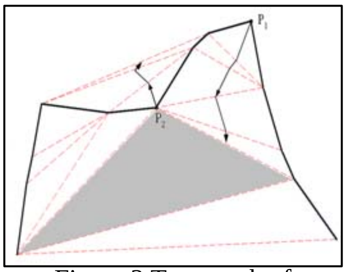


Figure 3.Trace path of basic curve

Composite curve detection starts from bifurcated edge of type triangle or partitioned boundary edge which corresponds to a series of continuous vertexes of line which make up of a curve. If the curve contains other curves, it is a composite one.

As a entirely geometrical technique, The curve detection method based on constraint Delaunay triangulation model needs to be revised on account of curves acquired by this method don’t accord with the Gestalt principle. The improvements are two cases: the first is elimination of pseudo basic curves, the second is rectification of base line of the curve.

As shown in figure 4, it is a river with cattle hornlike curves. Two basic curves acquired based on the above method of curve detection, named pseudo basic curves, whose base lines are AB and BC separately, like an integrated basic curve in vision. Literature[9] analyzes the cause of forming this type of curve and indicates that the two basic curves should be merged into a bigger basic curve in order to preserve morphological characteristic of the original line.

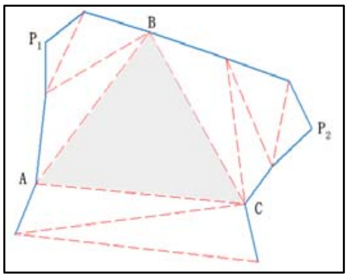


Figure 4.Merging pseudo basic curves

Skeleton feature points and end points of line are important points, and also points of inflection of variety of direction of neighboring curves. Curve detection should take into account bifurcated character of the type Ⅲ triangle in morphology as well as this kind of points. A line is preliminarily divided based on type Ⅲ triangle to acquire curves, whose base lines also need to be rectified. The processes of rectification are as follows: Trace edge along the direction from base line to skeleton feature points, judge whether end points of the edge are negative skeleton future points, if yes and the corresponding curves do not include the current curve, the corresponding end point of base line of the current curve is adjusted to the negative skeleton future point. As shown in figure 2, after preliminary curve division by bifurcated edges, skeleton future point A points to base line DC of the curve. Edge detection is implemented following the direction from base line DC to point A , and negative skeleton future point B which corresponds to the curve that don’t include the curve that point A points to is discovered, so the base line DC of the curve that point A corresponds to is modified to be line BC.

2.3 Structurization of line morphology

Structurization of line morphology is a series of operations of revealing morphological characteristics contained in the line, identifying and representing spatial structural relations among line curves, including hierarchical structure relations, neighboring relations, distributional characters, and etc so that the whole spatial relations of hierarchical and horizontal levels are established among the line and curves themselves.

Spatial structure relations among the curves are achieved based on the method of curve detection. Each partitioned boundary edge corresponds to a curve after the line has been triangulated. Curve detection starts from partitioned boundary edge, tracing path is illustrated in the figure 5. A type-Ⅱ triangle has the only tracing path, and type-Ⅲ triangle has two branching tracing paths which correspond to two neighboring triangles. Curve tracing including positive curve tracing and reversed curve tracing is implemented to acquire sub-curves and relations among the sub-curves. So-called positive curve tracing is a procedure of starting from the base line of the curve and searching convex sub-curves along the tracing path (as shown in figure 1, starting from the base line of curve ， positive curve tracing acquires convex sub-curves 1,3 and 5.) ; Reverse curve tracing is a procedure of starting from the biggest negative direction bifurcated edge which the curve includes and searching its concave sub-curves along the tracing path (as shown in figure 1, starting from the biggest negative direction bifurcated edge of the curve ， namely base lines of curves 2 and 4，reversed curve tracing acquires concave sub-curves 2 and 4)

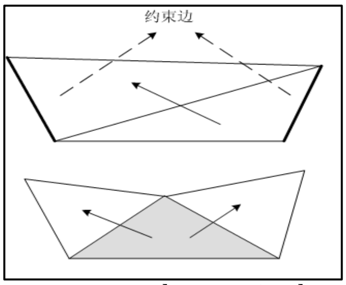


Figure5.Type and type triangle trace paths during identifying curves

The processes of curve tracing are as following:

(1) Along a direction of the line, positive curve tracing starts from every partitioned boundary edge in turn and enters regions of the curves.

(2)When encounter type Ⅲ triangle, judge which type of the bifurcated edges of the type Ⅲ triangle is in the process of tracing: (a) If it is a base line of basic curve, stop curve tracing in this direction of bifurcated edge and note this basic curve as a convex sub-curve of current curve; (b) if it is a base line of composite curve, note the composite curve as a convex sub-curve of current curve and continue curve tracing. Repeat step 2 until all convex sub-curves and relations among the sub-curves included in the big curves which partitioned boundary edge corresponds to are identified. Turn to step 3;

(3)Count up all the biggest negative direction bifurcated edges whose end points are included in the current curve that partitioned boundary edge corresponds to. To all these edges, Curve tracing is carried into execution to get all the concave sub-curves and relations among these concave sub-curves included in the curve which the biggest negative direction bifurcated edge corresponds to according as step 2 and step 3. Judge which one of all convex sub-curves of the current curve the concave curve belongs to and note it as its concave sub-curve. Thus, reversed curve tracing for the current curve is accomplished.

(4) Repeat step 1, 2, 3 and 4 until all the curves and relations between these curves in line are identified.

Acquire hierarchical relations between the curves through above steps, and then analyze the adjacent relations which are on the same hierarchical level. Line is divided into a series of continuous composite curves by the partitioned boundary edges. Adjacent composite curves have opposite directions. The middle composite curve has two adjacent curves on the both sides, whereas the composite curve situated at the end of the line only has one adjacent curve. The method for acquiring adjacent relations between sub-curves of the composite curve is similar to the above method. Two adjacent curves are linked with each other, but not containing. So far, all integrated spatial relations between the line and curves, and curves themselves are established in the above ways. The morphological structural characteristic of the line is expressed based on multi branched tree because it is very similar to that of tree structure. A root node represents a line, a child node represents every sub-curve in different levels, and an end node represents a basic curve. The curve is represented as a geographical entity with a useful abstraction which has great knowledge about morphological structural characteristic, natural attribute and spatial structural relationships, and finally encapsulated based on object-oriented model.

2.4 Acquisition of Knowledge in contextual circumstance of line

Geographic feature constraints are becoming an important issue in line simplification gradually. In the process of line simplification, the context of line should be taken into account in the first instance to ensure consistency of the geographic feature before and after line simplification. Geographic feature constraint contains point constraint, line constraint and area constraint basically. As area elements are always abstracted into points, the constraints of point and line in the geographical feature constraints are most outstanding. Line is a complex entity, whose effective spatial neighborhood covers itself (as shown in figure 6(A)) and the results of line simplification. There are some possibilities that neighboring geographical elements in the effective spatial neighborhood of line conflict with the results of line simplification. So it is necessary to study the spatial relationship between line and its adjacent geographical elements (point and line) in the effective spatial neighborhood of line, and determinate their influence area on line correctly so as to direct the process of line simplification. Line is composed of a series of curves which reflect line morphology characteristic, the relationship between line and its adjacent geographical elements in its effective spatial neighborhood can be translated into the relationship between curves and adjacent geographical elements, in this way, we can subdivide the influence which adjacent geographical elements exert on line and take morphology characteristic of line into account.

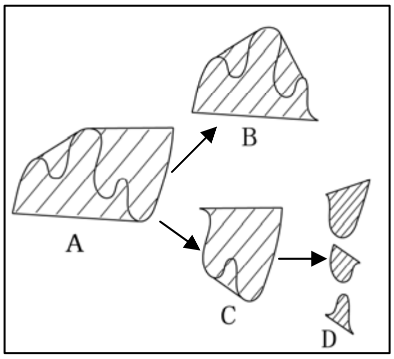


Figure 6. Dividing Effective Spatial Neighborhood of Line

According as the morphological structural characteristic of line, we disassemble the effective spatial neighborhood of line (as shown in figure 6), thereby every Sub-curve has an effective spatial neighborhood, the effective spatial neighborhood of parent-curve contains that of its sub-curve completely, then the union of effective spatial neighborhood of sub-curves must be equal or smaller than the effective spatial neighborhood of parent-curve (as shown in figure 6(C, D)). In the process of line simplification, the elimination of curve can be accomplished by jointing the base line of the curve. If there are some other geographical elements in the effective spatial neighborhood of the curve, the elimination of the curve may arouse geographic feature confliction (as shown in figure 7). Thus, we need judge whether there are other elements in the effective spatial neighborhood of curve and establish the spatial relationship between them before line simplification.

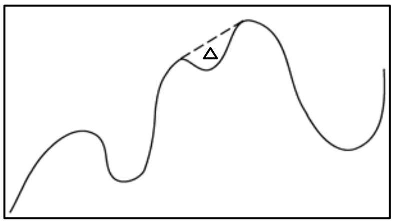


Figure 7. Geographic-Feature Conflict in Line Generalization

In cartography, as the positional significance and humanism significance of the spatial feature points are more important than positional precision of line, we must ensure that these kinds of points can not be moved in line simplification. There are three basic spatial relations between curve and spatial feature points in its effective spatial neighborhood: (Ⅰ) on the curve; (Ⅱ) inside of curve; (Ⅲ) out of curve (as shown in figure 8). The spatial relations between line and adjacent spatial feature points can be obtained as the following steps:

(1) Obtain all the spatial feature points in the effective spatial neighborhood by overlay analysis.

(2) Pick-up spatial feature points obtained by step 1 in turn, according to morphological structured tree of the line, make use of overlay analysis to judge which curve's effective spatial neighborhood the feature point is situated in. If the curve is a basic curve, judge whether the spatial feature point is situated on the curve, and note the information about situation of the spatial feature point in the curve; if the curve is a composite curve, turn to step 3;

(3) Pick-up the sub-curves of the curve (assumed curve C) to do overlay analysis in turn, if there is a sub-curve whose effective spatial neighborhood of sub-curve covers the feature point, and which is a basic curve, judge more whether the feature point is situated on the curve, and note the information about situation of the spatial feature point; if the sub-curve is a composite curve, analyze it more according as step 3; if all the effective spatial neighborhood of sub-curves of the curve C don't contained this feature point, which indicates that the feature point is out of the region of all the effective spatial neighborhood of sub-curves, judge whether the feature point is situated on the curve C, note the information about situation of the spatial feature point in the curve C.

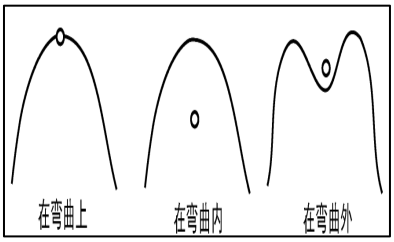


Figure 8.Type of Spatial Relationship between Spatial Feature Points and Curves

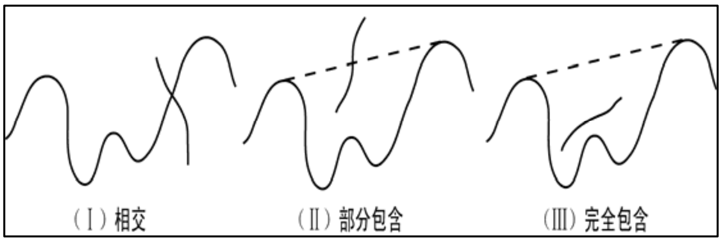


Figure 9.Type of Spatial Relationship between Spatial Feature Line and Line

To avoid the situation that the result of line simplification intersects adjacent linear elements, we must analyze the position of other linear elements situated in the effective spatial neighborhood and their affected region toward the line. We assume that the line to be simplified is *L*, its adjacent line is *M*, the spatial relationships between curve *L* and curve *M* have three basic types (as shown in figure 9): (Ⅰ) curve *L* intersect the curve *M*; (Ⅱ) the effective spatial neighborhood of curve *L* contains the curve *M* partially; (Ⅲ) the effective spatial neighborhood of curve *L* contains the curve *M* entirely. The specific methods are as follows:

(1) Acquire all adjacent linear elements in the effective spatial neighborhood of line by use of overlay analysis;

(2) Pick-up the every line (assumed line *M*) obtained by step 1. Firstly, we judge which type of the relationship between line L and line *M*, if it is type Ⅰ, we treat the point of intersection as a spatial feature point in the curve L directly; if it is type Ⅱor Ⅲ, we make a judgement of intersection between line *M* and the base lines of first-degree sub-curve of the line *L* in turn, if they intersect, note that the line *M* affects the curve that the base line corresponds to, and execute the step 3; If they don't intersect, judge furthermore whether the effective spatial neighborhood of the curve contains line *M* entirely, if yes, note that the line *M* affects the curve, and execute the step 3; otherwise, pick-up the next first-degree sub-curve;

(3) If the curve is a basic curve, the operation is accomplished; otherwise, pick up the sub-curves of the current curve and judge whether the baseline of the sub-curve intersects the line *M*, if they intersect, note that the line *M* affects the sub-curve, otherwise, judge furthermore whether the effective spatial neighborhood of the sub-curve contains the line *M* entirely, if it do, note that the line *M* affects the sub-curve, and then continue the step 3; if it don't, pick up the next sub-curve of the current curve, the iterative process may be continued until all the sub-curves are processed.

According to the above-mentioned method, the spatial relationship between line and its adjacent elements can be subdivided accurately into sub-curves of the line, thus, every curve contains not only morphological characteristic knowledge and spatial relationship knowledge between the curves, but also spatial relationship knowledge between the curve and neighboring elements.

3. Line Simplification Based on Geographic Feature Constraint

3.1 Rules of Curve Elimination

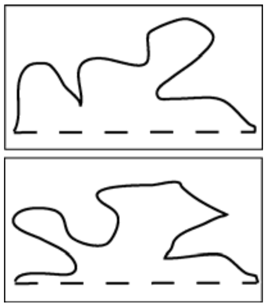


Figure 10.Two Curves with the Same Curvature

As a geometric entity, curve has some morphological characters. In order to be convenient for modeling and quantifying the concerned norms in line simplification, the morphological characters of the curve can be described by some parameters [15, 16] , the main parameters are: acre, the length of baseline, the maximum perpendicular distance, the length of arc, the compact degree, curvature ratio, symmetry degree, length of the skeleton line and so on, which play an significant role in describing morphological characters of line, and usually are references for judge whether the curve should be eliminated. However, the complexity of curve is far from describing them with these parameters. For example, as shown in figure 10, the morphological characters of the two lines are evidently different, but their curvature radios are equal; the curves with the same areas may have different morphological characteristic. Comparing with circular curve, the flat or narrow curves have pronounced visual perceptual effort, and are more easily selected. Therefore, the above-mentioned parameters are relatively rough, and have low maneuverability. The rules for the elimination of curve are proposed in this paper.

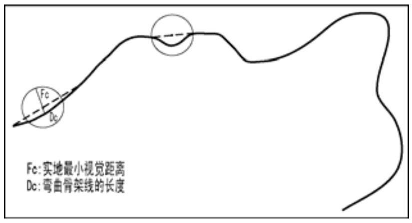


Figure 11. A Method of Acquiring the Threshold of Curve Selection Based on SVO

Rule 1: Base on the principles of human vision, the smallest diameter which the human can recognize is called the smallest visible object(SOV) [4], the practical distance in the target scale can be calculated by the formulation $F_c=S_t\times D\times(1 - S_s/S_t)$, while S_s is the denominator of source map scale, S_t is the denominator of target map scale, D is the diameter of SVO in the target scale map. In this paper, a method for calculating the threshold base on SVO is proposed (as shown in figure 11). The method is: Draw the circle with center at the middle point of baseline of the curve and radius equal to F_c, if the circle covers the curve completely or the length of curve framework is less than F_c, the curve will be deleted, otherwise it will be saved.

Rule 2: Ensure the geographical consistency before and after curve elimination; when judging whether or not delete the curve, we should analyze geographic feature knowledge contained in the curve, mainly includes attribute, the relationship between the curve and its adjacent geographical elements (as shown in figure 8, 9), and in view of the above, judge whether the results before and after the elimination of curve break geographical consistency.

Rule 3: When eliminating the curve, we should take condition of elimination of the adjacent curves into account so as to ensure that the amounts of the positional errors after eliminating curve are least.

3.2 Generalization of Curves

During the change of spatial scale, small curves which represent low-lever details of line are generally eliminated, whereas big curves which represent trends of line morphology are reserved. Generation of curves mainly contains two operations of elimination and exaggeration in the process of line simplification. Elimination is used to preserve mainly morphological features of line, and exaggeration is used to enhance some small but important curves.

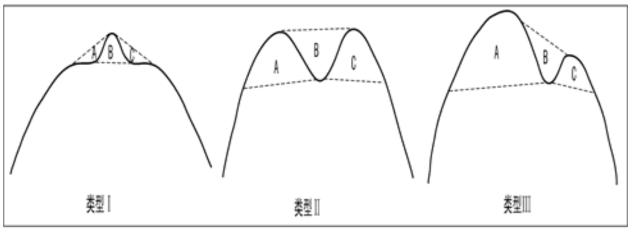


Figure12.Morphiological Type of Sub-curves in the Non-overlapping Region

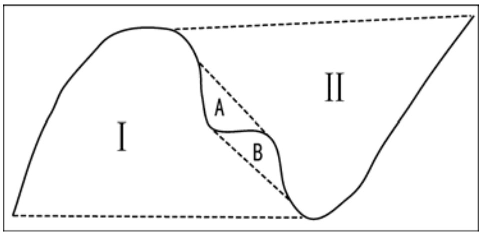


Figure 13.Subcurves in the Overlapping Region

Elimination of curves, by referring to some rules of generalization, is a process of replacing curve by base line of curve directly if curves fulfill qualification of elimination. Steps of judging whether curves can be deleted are as following:

① Firstly, Judge whether or not curves are satisfied rule 1. if satisfying it , turn to step ;

Judge consistencies of geographical features of curves by rule 2. If the consistencies of geographical features can be preserved after deleting curve, the curve can be eliminated; otherwise, it can’t be eliminated, turn to step ③;

Analyze the status of elimination of its neighboring curves according as rule 3. There are two cases: (a) the curve is a sub-curve of the alone complex curve (fig 12); (b) the curve lies in the overlapped region (Fig 13). The curve B is to be eliminated directly in normal condition toward the type Ⅰin figure 12, except that neighboring curves at its both sides satisfy rule 1 and 2, and positional errors produced by the elimination of them is smaller than that by curve B. In this condition, it needs to delete curve A and B instead of deleting curve B. To the type Ⅱ curves in figure 12 which were named as two-peak curves, the curve B is directly deleted, which corresponds to merging curve A and curve C. The type curves are the evolvement of type Ⅱcurves in figure 12, if the composite curve whose main sub-curve is curve A is reserved, curve A will be reserved. The standard for judging which one of curve B and C should be deleted is positional error. That is, the smaller curve should be deleted. This kind of curve, as shown in figure 13, is the sub-curve of the two composite curves. When judge the curve whether to be deleted, the location of the curve in the overlapped region and adjacent curves will be considered. On the premise of satisfying rule 1 and 2, we make it as a principle of optimality to producing the smallest positional error by deleting the curve by reference to the method in case (a).

3.3 Process of Line Simplification

Line is an element with composite geometry shape and consists of a series of units of different levels. Curve can be considered as the structure unit to divide line, and then get spatial feature and establish spatial relationship of different curves. The relationship and semantic feature of curve with may be used as the base to acquire the knowledge of geography feature. Thus all the sub-curves are units containing knowledge of geography feature, and simplification of line can be carried out by processing different levels of curves according to certain rules. Steps are as following:

①Take turns to get sub-curve of level 1 in a direction and judge if the curve can be deleted, use the base line of the curve to instead of it; if all curves of level 1 are processed, turn to step 2.

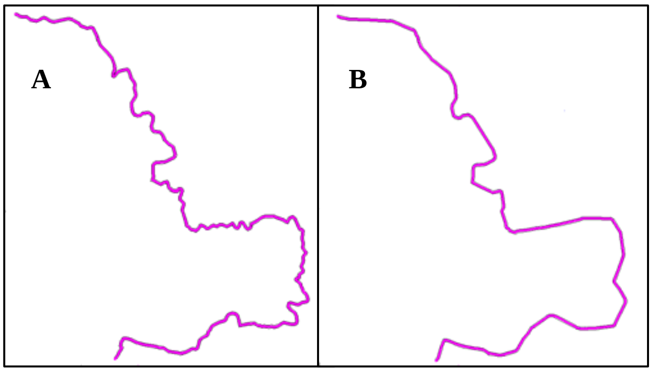
Getting curves of level 1 reserved in step 1 in turn along the same direction, take turns clockwise to judge if the sub-curve could be delete. If it does, the curve is replaced by its base line. After all the curves are treated, continue with sub-curves of the reserved curves by the above way. Processes iteratively until all the curves of lines are treated.

As the processing course is circulated, changing of curve will influence its neighbors, shape of curves must be re-divided structurally after all the curves are processed. Then structured spatial relationship is established, based on which knowledge of geography feature of each curve is acquired. Judge whether the curves could be deleted again by the steps above till all remain curves are fitted, then all the reserved curves are exaggerated to meet the demand of visualization.

4 Analysis on experiment

Figure 14 and Figure 15 are two instances used in the experiment, advantages of the algorithm in keeping of the overall shape of line and the rationality of geography feature.

Lines with many kinds of composite curves are shown in Figure14, and the curves are nested. Experiments are done by the algorithm and simplification result is shown in Fig.14 (B). By contrasting with the two figures it shows that the shape of line keeps well and most small curves are deleted and large curves are exaggerated.



（A）original line （B）the results based on the method proposed in this paper

Figure 14 The Advancement of This Approach on Preserving the Shape of Line

This approach is already used in a automatic map compilation system and a topographic map of 1 : 250000 with typical features (Figure 15 is the road network of a certain area) are experimented, which is consist of 70548 vertexes. The road network contains provincial highway, county road and country-road and there are some point community settlement places (circularity objects) around the roads. The approach is contrast with Douglas-Peucker algorithm by experiment, parameter D (diameter of SVO) is used in the algorithm, according to the scale of road, the formula $F_c=S_t\times D\times(1-S_s/S_t)$ is used to get the threshold F_c. Parameter in algorithm Douglas-Peucker is [H，W],which separately represents distance in vertical and horizontal. Target scale of the road is 1：500000.

Table 1. Different parameters lead to different simplifying results of two methods

Method and parameters / Amount of points	This method		Douglas-Peucker	
	0.5mm	0.8mm	[450m, 2000m]	[550m, 2000m]
total amount of points of original line	70548	70548	70548	70548
total amount of points after line simplification	14279	10371	25353	20615
Corresponding figure of the results		Figure16		figure18

Table 1 is the simplification results of the two algorithms under different parameters. It can be seen that degree of simplification become high as parameter D increasing; otherwise the degree is lower. In practice, the parameter is adjusted according to the map compilation rules of target scale.

Fig.18 is t he simplification result of Douglas-Peucker algorithm. Disagreement of topologic relations and self-intersect occurs (labeled by the circle), while shape feature of the roads are not well preserved. In the course of the proposed algorithm, settlement place of community and crosses of roads are existed as feature points with special nature attribute. When D is 0.8mm, 85.3% of roads are simplified (as shown in Figure 16). After simplification, lots of curves are deleted and shape of the road network keeps well, while topologic relationship between roads and cross, roads and point settlement place (Figure 17).

In simplification of each road, road is not divided into segments in cross and then simplify each segment to keep the position of cross. The algorithm simplifies roads as an entirety and cross of roads is used as a point object in spatial relationship analysis with roads. Roads that meet the cross should be maintained in simplification, which ensures that spatial position of cross topologic relationship keep still. Advantage of the operation is that it ensures the integrality of roads' shape in simplification (contrasted in Figure 16 and Figure 18).

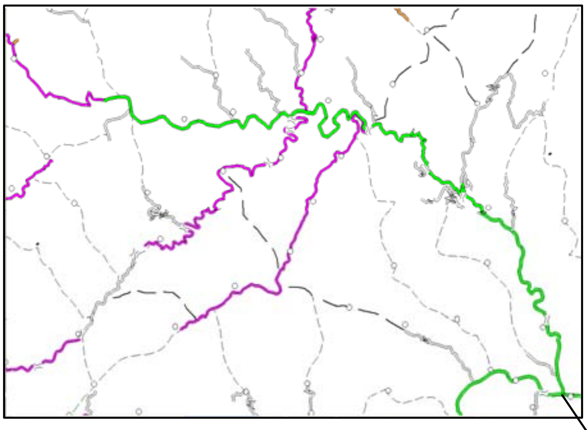


Figure15. Original Road Network Data of Scale 1:250000

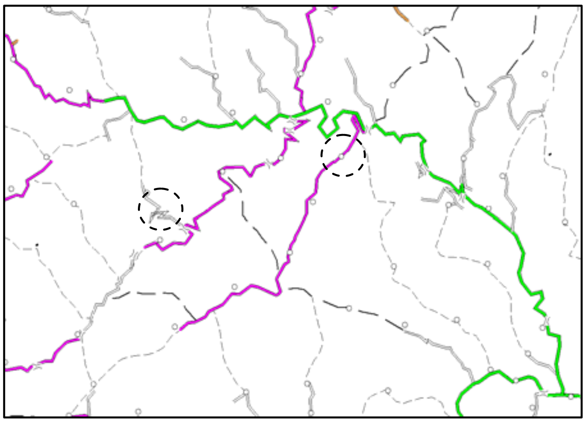


Figure18. Simplifying Result of Road Network Using Douglas-Peucker algorithm

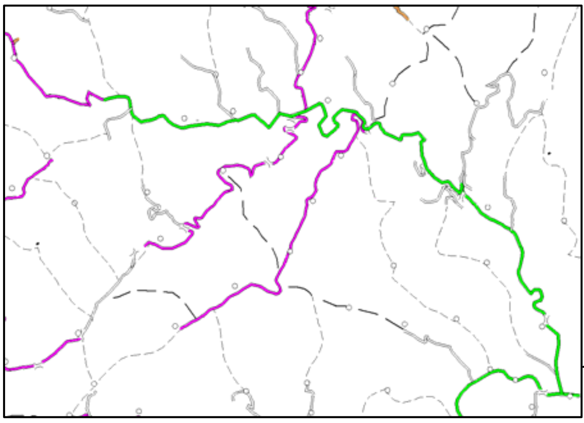


Figure16. Simplifying Result of Road Network Using This Approach

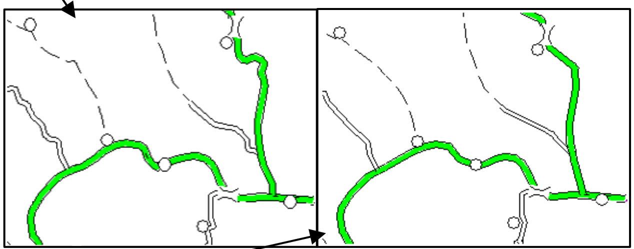


Figure17. The Advancement of This Approach on Preserving the Geographic-Feature of Road Network.

5. Conclusion

Line simplification is one of the most important algorithms in cartographic generalization. It is not just graphic generalization since not only do the results of line simplification must hold the shape or graphical figure of line, but preserve the consistency of geographical feature before-and-after line simplification. The paper presents a line simplification algorithm based on geographical feature constraint by acquiring the knowledge about morphological characteristics and other geographical feature which the line contains. The algorithm has been successfully tested on a case study on road data, which fully proves its scientific nature and advantage. The algorithm has following characters:

1. After analyzing structured characteristics of curve morphology, spatial relationships among the line and curves, and curves themselves are established. An overall structured method of curve shape is achieved and the relationships are represented by the multi branched tree structured model. Thus, the process of line simplification, by referring to some cartographic rules, turns to be a process of selection(elimination) of curves with the aim to conveniently keep the primary morphological characteristic of line and meanwhile simplify low-level details of line.

2. By referring to morphological characteristic of line, geographical features knowledge loaded on line is decomposed to all curves. Thus, each curve has a lot of knowledge of spatial relationship among the curves and geographical features which guide the process of curve selection and ensure consistency of geographical features(such as feature points, attribute and so on.) before and after line simplification.

3. In the design of curve selection, the algorithm takes curve morphological characteristic and geographical features as well as positional accuracy of curve into account. Therefore, simplifying result of line of the method presented in this paper is better than that of existing methods.

4. Complete structurization of line morphology implemented in this paper is convenient for further research on line simplification, so that parameters of the algorithm will be designed scientifically. Also, it is highly efficient in the process of line simplification that a lot of small curves were eliminated according to some rules, the amount of spatial data were considerably decreased, and holistic morphological characters of lines were preserved entirely.

6.Acknowledgement

The research presented in this paper is founded by the National Natural Science Foundation of China(40671162，40701157), the State Plan for High-Tech Research(2007AA12Z211) and the project of the institute of surveying and mapping(Y0809). The support is gratefully acknowledged.

References

[1]Qi Qingwen, Liu Yue . The theory and approaches of geographic feature oriented generalization in GIS environment[J].ACTA GEOGRAPHICA SINICA，1998，53(4):303-313．

[2] Douglas D H and Pecucker T K. Algorithms for the reduction of the number of points required to represent a digitized line or its caricature[J]. The Canadian Cartographer, 1973, 10(2):112-122.

[3] McMaster. Automated Line generalization[J]. Cartographical, 1987,24(2):74-111.

[4] Li Zhilin and S Openshaw. Algorithms for line generalization based on natural objective principles[J]. International journal of Geographic information systems,1992,6(5):373-389.

[5]Ying Shen, Li Lin．Consistent Line Simplification Based on Constraint Points[J]．Geomatics and Information Science of Wuhan University，2003，28(4)：488-491．

[6]Wu Hehai．Multi-way tree structure based on curve generalization method[J]．Geomatics and Information Science of Wuhan University，2004，29(6)：479-483．

[7] BRASSEL KE, WEIBEL R. A Review and Conceptual Framework of Automated Map Generalization[J]. International Journal of Geographical Information Systems, 1988,2(3):229-244.

[8] PLAZANET C, BIGOLINNM, RUASA. Experiment with Learning Techniques for Spatial Model Enrichment and Line Generalization[J]. Geoinformatica, 1998,2(4):315-333.

[9] Ai Tinghua, Guo Renzhong, Liu Yaolin. A Binary Tree Representation of Curve Hierarchical Structure in Depth[J].ACTA GEODAETICA et CARTOGRAPHICA SINICA, 30(4):343-348, 2001.

[10] Zhang Qingnian, Liao Ke. Line Generalization Based on Structure Analysis[J]. ACTA SCIENTIARUM NATURALIUM UNIVERSITATIS SUNYATSENI, 40(5): 118-121,2001.

[11] Wu H. Structured Approach to Implementing Automatic Cartographic Generalization[A]. Proceedings of the 18^{th} ICC. Stockholm: 18^{th} ICA,1997:349-356.

[12] Wang Z, MULLER J C. Line Generalization based on analysis of shape characteristics[J]. Cartography and Geographic Information Systems, 1998,25(1):3-15.

[13] PLAZANET C, AFFHOLDER J G, FRITH E. The Importance of Geometric Modeling in Linera Features Generalization[J]. Cartography and Geographic Information Systems, 1995,22(4):291-305.

[14] THOMSON R C, RICHARDSON D C. The ‘Good Continuation’ Principle of Perceptual Organization Applied to the Generalization of Road Networks[A], CD-Rom Proceedings of the 19^{th} ICC[C]. Ottawa: the 19^{th} ICA,1999,section 8.

[15]Wang Jiechen, Lv Guonian. Tiny concave-convex removing algorithm in vector curves generalization[J]. Bulletin of Surveying and Mapping, 2002, 1:17-19.

[16]Wang Qiao, Wu Hehai. Study on fractal description and automatic generalization of cartographic information[M]: Publishing company of Wuhan Technical University of Surveying and Mapping, 1998:74-76.