

A Multi-resolution Model of Curve for Progressive Transmission over the Internet

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Abstract—Concerning the problems of high time complexity and topological inconsistency existed in vector map simplification, a multi-resolution model of curve for progressive transmission is proposed in this paper. By using pre-stored vertex deviation to simplify curve and using an optimized monotone chain intersection algorithm to maintain topological consistency, the model can quickly generate topologically consistent multi-resolution curve data. Finally, the model was used in the experiment of progressive transmission of river network and verified its effectiveness.

Keywords—*progressive transmission; multi-resolution; topological consistency*

I. INTRODUCTION

With the development of spatial information services, the transmission of spatial data over the network is increasingly frequent. However, the transmission time of massive spatial data is often long because of limited network bandwidth; this becomes a technical bottleneck that restricts the development of spatial information services. The progressive transmission of spatial data contains two steps: First, prior to transmission, the spatial data is decomposed into different resolution representations according to the volume of data to be transferred, network transmission speed and display equipment of the client; and then when received request from the client, the server sends the low resolution representation of spatial data quickly which represents the rough outline of the data and then the higher resolution one which represents a more accurate outline of the data. After received the low resolution representation of spatial data, the users can browse and analysis the data. When network is busy, the progressive transmission of spatial data can significantly reduce the time that users wait for data.

The progressive transmission system of vector data is shown in Fig.1. There have two technical difficulties: one is how to rapidly generate multi-resolution representation of vector data; the other is how to ensure topological consistency.

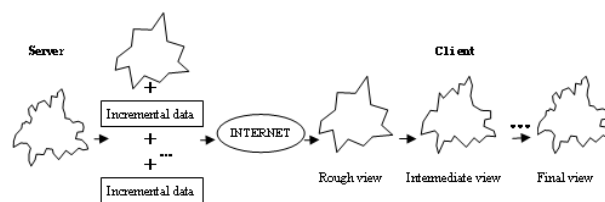


Figure.1. Progressive transmission of vector data over the internet

II. RELATED WORK

Bertolotto proposed a conceptual framework for progressive transmission of vector map in [1], due to the actual difficulties of automatic generalization the conceptual framework is still hard to achieve. The transformation from the original vector map to a low resolution one can be done by map simplification method, however, topological inconsistency often happens in the process of map simplification. Yang proposed a multi-resolution model of vector data for progressive transmission which can maintain topological consistency in [2,3], but the time complexity of the model is high. Line simplification algorithms proposed in [4,5] that can achieve high graphic precision often have a high time complexity. A linear BLG structure is proposed to speed up line simplification algorithm in [6]. Ai proposed changes accumulation model to transfer polygon data in [7], while the topology is not considered in the model. Several methods have been proposed to maintain topological consistency between spatial objects in map simplification in [8,9,10], but the time complexity of these methods is also high. Unreasonable intersection and self-intersection are main forms of topological inconsistency. The sweep-line algorithm proposed by Bentley in [11] is classical method to search intersections between segments. Park proposed monotone chain intersection algorithm which has better time efficiency than that of sweep-line algorithm in [12].

This paper proposes a multi-resolution model of curve for progressive transmission. By calculating and storing the vertex deviation, monotone chain and weight of curve in advance, the model can generate topologically consistent multi-resolution curve in shorter time. The time advantage is reflected in two places: First, by selecting vertexes according to their deviations stored in advance, time

complexity of simplifying line is reduced from $O(n^2)$ to $O(n)$; second, the time to handle topological inconsistency is shortened based on an optimized monotone chain intersection algorithm.

III. MULTI-RESOLUTION MODEL OF CURVE

Curve of this paper is defined as a series of line segments that are connected to each other without self-intersection. Vertex on the curve, curve L , simplified curve L' can be defined as following:

$$\begin{aligned} L &= \{ \overline{V_0V_1}, \overline{V_1V_2}, \dots, \overline{V_{n-1}V_n} \} \\ L' &= \{ \overline{V_0V_1}, \dots, \overline{V_{k-1}V_k}, \dots, \overline{V_{n-1}V_n} \} \\ L' &= L - \{V_k\} \\ V_k &= \{x, y\} \end{aligned} \quad (1)$$

The frame of multi-resolution model of curve is shown as Fig.2. For the time consuming works such as calculating vertex deviation, monotone chain and weight of curve are done in preprocessing stage, operations as selection, generalization and topological consistency maintaining can be finished rapidly in simplification stage.

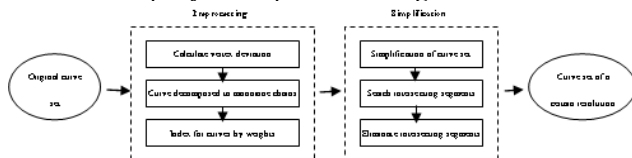


Figure.2 Frame of multi-scale model of curve

3.1 Computation of vertex deviation and monotone chain of curve

The execution result of Douglas-Peucker algorithm is BLG tree, vertexes which have larger deviation are located in the upper layer of BLG tree. The importance degree of vertex is reflected by the value of deviation. All vertexes' deviation can be computed in advance and be stored in a linear table structure in accordance with the order of vertexes. Because line simplification can be implemented by selecting vertexes according to their deviations, Time complexity of simplifying line is reduced from $O(n^2)$ to $O(n)$.

Constraint points which include endpoints of curve and vertexes that are shared by one more objects can be divided into two types: the first type of constraint points consists of endpoints of curve, the only adjacent or intersecting vertex of adjacent or intersecting objects, and endpoints of adjacent edge which are shared by adjacent objects; the second type of constraint points is vertexes on the adjacent edge except for endpoints. The method for maintaining topological consistency in this paper can be described as following: for the first type of constrain points, they must be prevented to be deleted by modifying their deviations to the largest deviation on the curve; for the second type of constrain points, because each vertex has

multiple deviations that are corresponding to adjacent objects, the max one of these deviations is adopted as its deviation; for other vertexes, after they are deleted, an optimized monotone chain intersection algorithm is used to search all intersecting segments. If minimum convex hull of each monotone chain is calculated, monotone chains can be divided into independent monotone chain whose convex hull does not overlap with all other convex hulls, and dependent monotone chain whose convex hull overlaps at least one convex hull. Monotone chain intersection algorithm can be optimized by excluding the independent monotone chains.

Two adjacent curves are shown in Fig.3. Thick, thin solid line stands for curve A, B respectively, and dash line stands for the boundary of convex hull of monotone chain. Curve A, B are decomposed into one independent monotone chain ($P_1P_2P_3P_4P_5P_6$) and two dependent monotone chains ($P_6P_7P_8P_9$ and $P_{10}P_{11}P_{12}P_{13}$). The endpoints' deviation of independent monotone chain should be modified to the largest deviation on the chain to ensure the type of independent monotone chain unchanged in the process of simplification.

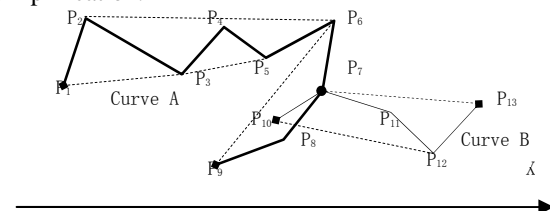


Figure.3. Curve is decomposed into monotone chains

Fig.4 describes the process of configuring vertex deviation and monotonic of curve A. The type of monotone chain is labeled on its left endpoint, number 1, -1, 0 stands for dependent monotone increasing chain, dependent monotone decreasing chain, and independent monotone chain respectively.

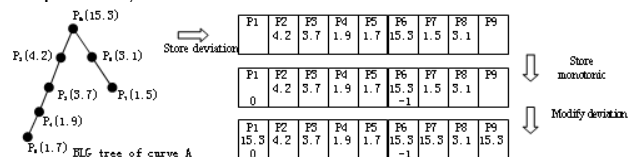


Figure.4. Configure deviation and monotonic of vertices

3.2 Index for curves according to their weights

When displaying curve set of certain resolution, curves that their sizes are less than current resolution or have less importance do not need to be displayed. The size and importance of curve is considered and quantified as weight. Selection of curves is based on their weights. As shown in Fig.5, the weight of curve is set to the value of long side of its minimum bounding rectangle, and then is adjusted according to its importance. The index aimed to fast select curves is built on adjusted weights.



Figure.5. Index for curves according to their weights

3.3 Generation of multi-resolution curve

Supposing current resolution for selection and generalization is R_1 , R_2 respectively, the method for current resolution representation of curve set can be described as:

- ① Select all curves that satisfy the condition: $W_i^* \geq R_1$.
- ② For each selected curve, select all vertexes whose deviations are larger than R_2 and pick up all dependent monotone chains simplified. The time complexity of this step is $O(n)$, where n is the number of vertexes.
- ③ Execute optimized monotone chain intersection algorithm to search intersecting segments based on dependent monotone chains.
- ④ Solve all intersecting segments found in previous step. First, add vertex that has max deviation on the segment and split it into two new segments, and then judge if there are intersections between all new segments. If it is, repeat above steps.
- ⑤ Output topologically consistent curve data of current resolution.

The time complexity of sweep-line algorithm is $O((n+k).Logn)$, where n is the number of vertexes in all curves, and k is the number of intersections. The time complexity of monotone chain intersection algorithm is $O((n+k).Logm)$, where m is the number of monotone chains. The time complexity of optimized monotone chain intersection algorithm is $O((q+k).Logp)$, where q is the number of vertexes in all dependent monotone chains, and p is the number of dependent monotone chains. It is obvious that q is smaller than n , and p is smaller than m and n , so the time performance of optimized monotone chain intersection algorithm is better.

IV. EXPERIMENT AND ANALYSIS

The progressive transmission system of river network is developed based on .NET platform. The model is adopted to generate multi-resolution river network on the server side. The client receives multi-resolution river network sent from the server and reconstructs them to a high-resolution river network automatically. Fig.6 is data view of the client. River network keeps its topological consistency and is getting more and more detailed as the data transmission continues.

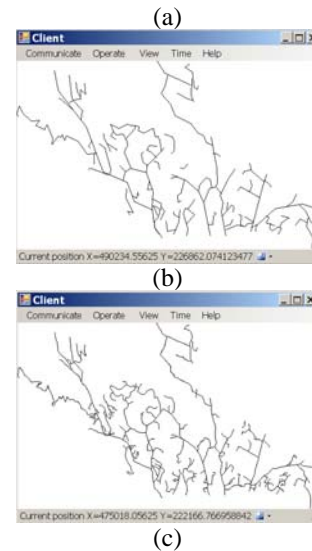


Figure.6. Data view of the client under progressive transmission mode

Time performance of the model is tested by counting the total generation time of a fixed resolution ($R_1=50m$, $R_2=5m$) river network when data volume changes. Experimental results are shown as Fig.7.

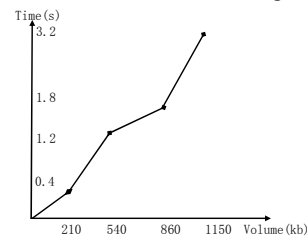


Figure.7. Relationship between the generation time of curve set and the data volume

As seen from Fig.7, when data volume increases, the total generation time varies approximate linearly. That is because curve generation process includes simplification and topology maintenance, and the time complexity of these two phases are respectively $O(n)$, $O((q+k).Logp)$. Where n is the number of vertexes and q is the number of vertexes on the dependent monotone chains, and p is the number of monotone chains, and k is the number of intersections.

V. CONCLUSIONS

Progressive transmission is an effective way to improve transmission efficiency of spatial data over the internet. The multi-resolution model of curve proposed in this paper supports the generation of topologically consistent curve data rapidly and has proved its effectiveness in experiment of progressive transmission of river network. Experimental results show that the total generation time for multi-resolution curve is nearly linear with increasing the amount of data changes. The model is suitable for progressive transmission of massive vector data.

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