VISUALIZING SCHEMATIC MAPS THROUGH GENERALIZATION BASED ON ADAPTIVE REGULAR SQUARE GRID MODEL

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ABSTRACT:

Schematization is a quick visualization way to convey graphics information. In cartography, graphic schematization is one aspect of map generalization. This paper analyzes and summarizes the multiple criteria for schematic maps and quantifies these constraints functionally. Based on this, schematic map cartographic generalization framework based on the regular square grid is proposed. Furthermore, we research topological checking methods for schematic maps. Based on these constrains, an effective schematic map is schematized and visualized automatically in a test, while keeping the topological consistency of the network map between original and schematic map.

1. INTRODUCTION

In graphics and language, schematization is an important method to emphasize certain aspects and to deemphasize others. Different disciplines use schematization for different reasons. In cartography, graphic schematization is one aspect of map generalization (Klippel, 2005). The main advantage of schematic maps is that they provide a quick overview of the layout of the network, without showing unnecessary information like the precise shapes of the connections (Cabello, 2001).Schematic drawings of route directions are one of the most common forms of graphic communication.

Automated production of schematic maps has been discussed in several earlier papers. Neyer (1999) and Barkowsky (2000) describe a line simplification algorithm with the aim of generating schematic maps. But line simplification is only one characteristic of a schematic network. Equally important, schematic maps also involve the need of preserving the topological structure of the liner network and other aesthetic design characteristics. Elroi (1988a, 1988b, 1991) and Cabello et al. (2001) developed more specific approaches to automatize the schematization process. In the approach of Elroi, a grid is used to fit the line network in the schematic directions, but topological conflicts among line segments can still occur and no explanation is given about how to avoid them. In the approach of Cabello, the topological equivalence between the networks is preserved, but, if certain conditions cannot be met, no schematization is found at all.

Lately, the topic has reappeared in Agrawala (2001), Avelar (2000) and Mark Ware (2006) papers. They make use of some local operator, such that after applying it several times, the map converges to a schematic one. Different criteria based on different measures are used to decide in which order, and to which parts of the map the operator should be applied. Iterative approaches like these have prohibitive costs in time in interactive situations, and in these papers, no theoretical time bounds, nor are actual computation times given. Moreover, they both adopt the Douglas-Peucker (1973) simplification algorithm for graphic simplification which can generate self-intersection and change the topology.

Creating and visualizing schematic maps is quite complex work. Mapmakers use a variety of cartographic generalization techniques including distortion, simplification, and abstraction to improve the clarity of the map and to emphasize the most important information. To automatically generate schematic network maps and real-time visualize network maps clearly and concisely, we adopt new generalization methods including simplification and displacement based on adaptive square regular grid.

2. GENERATING SCHEMATIC MAPS

2.1 Graph model based on regular square grid

The model we use for the abstract representation of a schematic map is a graph. In this case, a graph, G (V, E), is a set of vertexes, V, with connections between pairs of vertexes represented by a set of edges, E. For drawing schematic maps, we use the vertexes to represent turning points on the network and edges to represent a road segment between two turning points. In some cases, there may be several edges connecting two vertexes. A graph model is used because of its programmatic flexibility which makes tasks such as finding neighboring vertexes or incident edges relatively easy.

The graph is embedded on a regular square grid, as shown in Figure 1. This means that vertexes can only be centered on grid intersections, but there is no requirement for edges to follow grid lines. The spacing between adjacent grids is denoted by g. The grid allows us to dramatically reduce the number of

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potential locations for nodes and also makes producing orthogonal maps easier as nodes are more likely to be in line with each other.

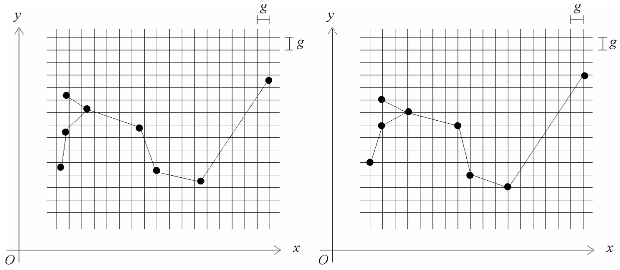


Figure 1 Regular Square Grid Model

We start with a geographic layout (or a close alternative using a sketch of the map). However, we need to make sure that vertexes are centered on grid intersections, so a way to displace the vertexes to the grid is needed. Calculating the nearest grid intersection to a vertex is simple but care must be taken to ensure that more than one vertex does not share the same grid intersection, mistake intersections and missing intersections do not be produced by checking duplicated vertexes and segments during the generalization. In the case of contention for a particular intersection, the node being displaced should be moved to the nearest grid intersection that is vacant.

Considering the representation of a geographic dataset as an imaging system with a CCD camera, what the observer can see are two-dimensional pixels, where each pixel corresponds to and represents statistically a region of the geographic data. Similar to the principle of a CCD camera, a grid is implemented by dividing the range of the target dataset to a two-dimensionally spread cells. The size of cells is the same with or proportional to the target resolution.

2.2 Multiple Criteria

Generating schematic maps, there are many aspects of the mapping situation which may need special attention. Besides characteristics of the network, cartographic aspects, such as the amount of simplification of lines, vertexes displacement, symbolization and the use of colours, are also important. All schematic maps shall have graphic simplicity, while retaining network information and presentation legibility.

Based on those aspects, we set up criteria for schematic maps by quantitive description, which including or Orientation Constraint, Distance Constraint, Length Constraint, Angular Constraint, Displacement Constraint.

① Orientation Constraint: In schematic map, based on the standard directions including horizontal, vertical or diagonal direction, all network edges only chose one of these directions which most close to their original directions. Supposing the standard orientation $RR = \underset{i\in\{0\sim7\}}{\forall}\left\{\alpha_i = i\times 45^\circ\right\}$ and original orientation is $\alpha(u,v) = \left|\tan^{-1}\left|\frac{y(u)-y(v)}{x(u)-x(v)}\right|\right| \quad \forall\{u,v\}\in V$, thus the Orientation Constrain is quantified by (1).

$$\min\left|\alpha_i - \alpha(u,v)\right| \;\; \Big| \;\; i\in\{0\sim7\}, \forall\{u,v\}\in V \qquad (1)$$

Where $\{x(u),\ y(u)\},\{x(v),\ y(v)\}$ is coordinates of two adjacent vertexes of an edge.

② Distance Constraint: When overlapping among network segments, we should separate these overlapping lines and the separating distance g which according to the environment is object resolution.

③ Length Constraint: The shortest line segment of network must more length than g and maintain the relative ordering of the line segments by length. Length Constrain is quantified by (2) and (3).

$$\min\left|L(e_i)'\right| \geq g \quad \forall\{i,j\}\in\{1\sim n\}, \forall\{e_i,e_j\}\in E \qquad (2)$$

and

$$\left|\frac{L(e_i)}{L(e_j)} - \frac{L(e_i)'}{L(e_j)'}\right| \leq \beta \;\; \forall\{i,j\}\in\{1\sim n\}, \forall\{e_i,e_j\}\in E \; (3)$$

Where $L(e_i)$ and $L(e_j)$ is the length of original network edge, $L(e_i)'$ and $L(e_j)'$ is the final length of these edges, g is the target resolution and β is the threshold assumed by the user.

④Angular Constraint: When meeting at one intersection and angular between each other is small; the direction of overlapped network segments shall be entitled by more detail standard orientation in $\left[\alpha_i{}', \alpha_{i+1}{}'\right]$ *or* $\left[\alpha_{i-1}{}', \alpha_i{}'\right]$. Angular Constrain is quantified by (4).

$$\begin{cases} \alpha(e)' = \left|\alpha_i{}' + \dfrac{\left|\alpha_{i+1}{}' - \alpha_i{}'\right|}{M}\right|, if \;\; \alpha_{i+1}{}' \notin OJ \\ \alpha(e)' = \left|\alpha_i{}' - \dfrac{\left|\alpha_i{}' - \alpha_{i-1}{}'\right|}{M}\right|, if \;\; \alpha_{i-1}{}' \notin OJ \end{cases} \quad i\in\{0\sim7\}, e\in E \; (4)$$

Where M is amount of these overlapped network edges, OJ is the collection of reoriented network edges, $\alpha(e)'$ is the adjusted orientation of network edges.

⑤Displacement Constraint: In all possible displacement results in which shortest displacement distance result will be selected. Displacement Constrain is quantified by (5).

$$\min\left|\sqrt{(y'(v_i)-y(v))^2 + (x'(v_i)-x(v))^2}\right| \;\; v\in V, i\in\{0\sim7\} \quad (5)$$

Where $\{x(v),\ y(v)\}$ are coordinates of original vertex, $\{x^{'}(v_i),\ y^{'}(v_i)\}$ is coordinates of displaced vertex.

2.3 Schematization Process

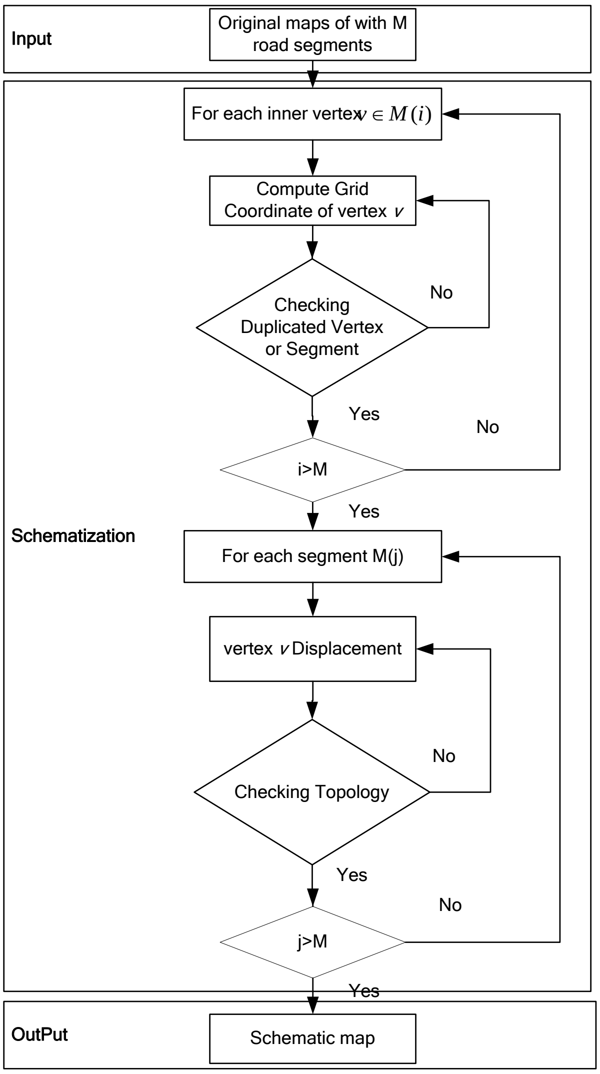


Figure2 Generating Schematic Maps Framework

Based on the regular square grid model, we propose a framework (see in Figure2) with the goal to produce a schematic network map which meets topological, geometric and semantic constraints.

As the first step, driven by the regular square grid, all network vertexes will be moved to the nearest corner of the grid (see in Figure 1) and the coordinates of these vertexes will be computed by formulation (7).

$$\begin{cases} x^{'}(v) = g \times \left[\dfrac{x(v)}{g} + 0.5 \right] \\ y^{'}(v) = g \times \left[\dfrac{y(v)}{g} + 0.5 \right] \end{cases} \tag{7}$$

Where $x(v), y(v)$ is the vertex coordinates before latticed. $x^{'}(v), y^{'}(v)$ is the vertex coordinates after latticed. g is the target resolution(usually actual distance represents by 1 pixie).[ ] is the integer of [z].

During the grid, we should check duplicated vertexes and segments and adopt generalization methods according to different cases. Duplicated vertexes and segments, which are those points which are originally different but locates at the same grid after being latticed, and those overlapping segments after being latticed. If the duplicated inner vertexes and segments are from the same feature and adjoining with each other (see in Figure3 (a), (b), (c)), the duplicated one should be deleted to keep the uniqueness of the simplified data. If they belong to the same feature but do not adjoin each other (see in Figure3 (d), (e)) or belong to different feature (see in Figure3 (f)), we should separating overlapping segments and duplicated vertexes.

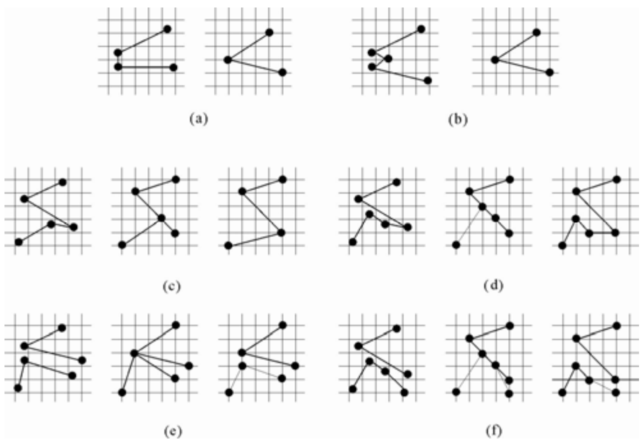


Figure3 Generating Schematic Maps Framework

Then, for the orientation constraint, vertex *q* will be displaced according to eight directions and make the schematic map more regular. The new location *q'* is chosen among the locations that fit *q* in one of the allowed schematic directions. In each line segment with *q*, e.g. $\overline{pq}$, we use the vertex *q* to compute the distance to the nearest schematic direction. In order to meet distance constraint, the nearest displacement distance determines the new location for *q* (see in Figure 4). All network segments orientation will be adjusted to the eight standard directions which is collection RR={0º,45º,90º,135º,180º,225º,270º,315º}.Where positive X axes representation 0º and 360 º, and orientation of network segments is the rotation angular calculated by counter-clockwise based on X axes.

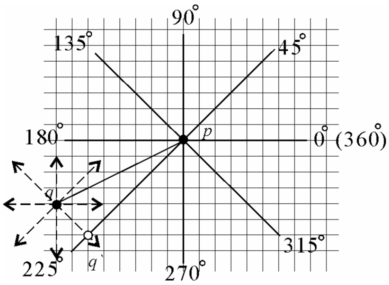


Figure 4 Displacement of Vertex

In order to satisfy the orientation constrain, the orientation and length of every adjusted network segment shall be calculated by using formulation (8) and (9).

$$\begin{cases} \alpha(e)' = \alpha_i, & if \ \min|\alpha_i - \alpha(e)| \\ \alpha(e)' = 0^\circ, & if \ \alpha_i = 360^\circ \end{cases} \quad i \in \{0 \sim 7\}, \forall \{e\} \in E \quad (8)$$

and

$$\begin{cases} L(e)' = \dfrac{L(e) \times r}{\min(L(e_i))} \times \left|\cos(\alpha(e)' - \alpha(e))\right|, & if \ \min(L(e_i)) < r \\ L(e)' = L(e) \times \left|\cos(\alpha(e)' - \alpha(e))\right|, & if \ \min(L(e_i)) \geq r \end{cases}$$

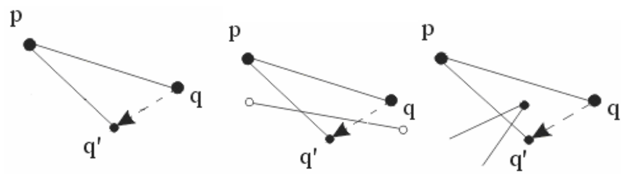
$$i \in \{1 \sim n\}, e \in E \quad (9)$$

We select intersection points of network segments, find the network segments collection adjacent to these points and get the adjusted orientation collection OJ. Firstly, judge whether there is overlapping network segments which have been adjusted, if have it is to say that there is orientation conflict at this intersection point, the method to solve the problem is adopting Angular Constrain. The orientations of overlapping network segments are reoriented during the collection of $\lfloor RR_{j-1}, RR_j \rfloor$ *or* $\lfloor RR_j, RR_{j+1} \rfloor$ and OR_2 —the length of these segments - are recalculated. Next, we grow all network segments that are shorter than a predefined minimum pixel length; $\min(OL)$ to be r pixels long by using formulation (6).

2.4 Topology Consistence Checking

During the course of shape simplification and point displacement, topology of network must be checked to and maintained. Before moving a point from its original position q to the new schematic location q' we perform a test to detect situations that can lead to a change in the map topology. For it we first create a triangle. The vertices of the triangle are q, q' and the other endpoint of the line segment being analyzed p (Avelar, 1997). We have to find out if there is any line segment of the map crossed by the boundary edge qq' of the triangle $\Delta(pqq')$ (Berg et al, 1997). We also have to check if the triangle $\Delta(pqq')$ contains inside it any point. If topology would change, point q' displacement must be recomputed. We distinguish the following three cases to check the topology.

If there is no point inside the triangle $\Delta(pqq')$ and no line segment crossing the edge qq' of $\Delta(pqq')$ the topology will be preserved, so the move of q to q' is allowed (see Figure 5(a)). If there is at least one line segment intersecting edge qq' of $\Delta(pqq')$ (see Figure 5(b)) or there is at least one point v inside the triangle $\Delta(pqq')$ (see Figure 5(c)), map topology will also change., map topology will change, then a new location for q' has to be recomputed and obtained.

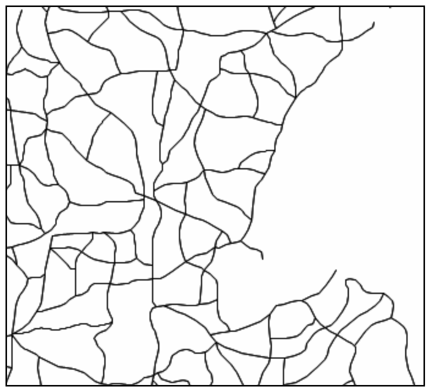


(a) (b) (c)

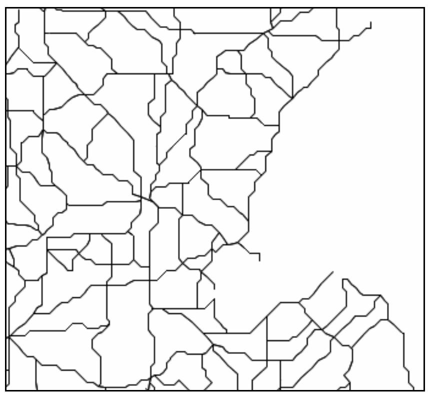
Figure 5 Topological Checking

3. RESULTS AND CONCLUSION

Based on the vector database of 1:4000000 road networks, we set square grid with 1000m x 1000m according to target resolution. Including 334 road segments, 506 intersections and 2286 vertexes, original road network map are latticed and schematized. Experiment results are shown in Figure 6.



(a) Original Road Network Map



(b) Schematic Road Network Map

Figure 6 Displacement of Vertex

Experiment results show that 156 interior vertexes of original road network (Figure 6(a)) are eliminated successfully while keeping the topology. Then, driven by square grid, original road networks are displaced and segments are oriented to horizontal, vertical or diagonal direction. Finally, a desired schematic road network (Figure 6(b)) is generated.

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