Modeling Structure and Patterns in Road Network Generalization

Qingnian Zhang[1,2]
[1]Department of RS and GIS, Sun Yat-Sen University
510275 Guangzhou, P R China
[2]GIS Centre, Lund University
SE-223 62 Lund, Sweden
Email: zhangstudio@sohu.com

Abstract: Roads are essential elements on topographical maps and in spatial data bases. In an effort to derive multiple representations of road information, quite a lot of research has been devoted to road network generalization in the past decades. A lot of methods to select, displace, and simplify road features have been proposed. However, they may distort road networks in generalized maps, for instance, losing the characteristic structures of road networks. This paper emphasizes the special value of density differences and regular patterns in road network generalization. Main patterns in road networks are identified and their properties are analyzed. Based on those properties, methods to model, identify and generalize network patterns are proposed. A case study on density differences shows that the explicit description of network structures favors for the maintenance of the overall characteristics of road network.

Key words: Structure, Pattern, Road network, Map generalization

1. Introduction

Roads are essential elements on topological maps, navigational maps, and other kinds of maps. Some applications involve in detailed road information, but others involve in fewer details. Map generalization is an effective approach to deriving a new version with fewer details from a detailed road map.

In the past decades, many methods have been proposed to generalize road networks. Among them, Graph Theory is widely used in road network generalization (Mackaness & Beard 1993; Mackaness 1995; Thomson & Richardson 1995; Jiang and Claramunt 2004; Jiang and Harrie 2004). A lot of concepts and parameters, for instance, connectivity, minimum cost spanning tree, shortest path spanning tree, were borrowed from Graph theory to facilitate structural analysis and road selection in road networks. Another approach based on perceptual grouping was adopted by Thomson and Richardson (1999). They developed a method to group road segments into "strokes" based on good continuation principle and to generalize road network by ordering and selecting strokes. From a functional point of view, Morisset and Ruas (1997) took use of agent system to simulate the amount of road use and proposed a method to select roads of high frequency usage by means of an agent-based simulation.

Those methods consist in an algorithm base for road network generalization. They can be used to create a generalized version of road network with certain properties. That is, good connectivity, long roads with good continuation, or roads with high frequency of usage.

However, some important properties can be still distorted. Most methods pay no attention to network pattern analysis, which result in the loss of these patterns in road networks.

Mackaness and Edwards (2002) argued that any given map can be viewed as a unique collection of patterns. (However, their definition of "pattern" is quite loose.) Every pattern has a lot of variant and invariant properties. Patterns can be categorized in a multidimensional "pattern space". They believe that the challenge in automated generalization is to present the information at a scale and theme that best conveys a particular set of patterns.

This paper concentrates on density differences and regular patterns in road network generalization. A focus of interest is to identify the properties of patterns, and maintain their main properties over large changes in scale. In order to meet these objectives, three aspects are explored. Main patterns in road networks were identified and their properties were analyzed in the next section. Section 3 explored the methods to model and generalize density differences and regular patterns in road networks. Section 4 presented a case study to maintain density differences in generalized road networks. Future work was discussed in Section 5. The paper was concluded in Section 6.

2. Road network patterns and their properties

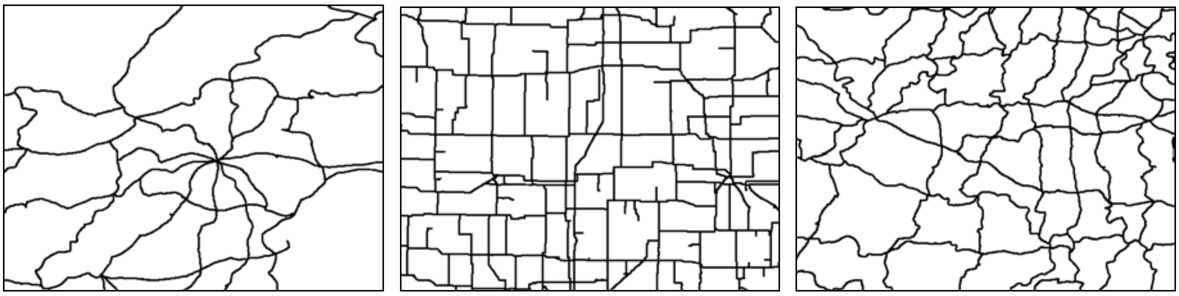
2.1 Patterns on maps

As Mackaness and Edwards (2002) pointed out, patterns are commonly defined as a property within an object, or between objects that is repeated with sufficient regularity. Such repeated properties may be shape, orientation, connectedness, density or distribution. For instance, dendritic drainage is characterized by the sharp angle that branches converging main streams; Land use patterns inside a city tend to display a circular layer structure, that is, commercial area in the city center, residential area in surrounding area, and agricultural area in the outer circle.

It is obvious that patterns can exist among the same kind of objects, or between different kinds of objects. While dendritic drainages and circular land use patterns are examples in the first case, the ribbon-like distribution of settlements along arterial roads or rivers is an example in the second case. The patterns between different object categories result from the interdependence of geographical phenomena.

2.2 Main patterns in road networks

Road networks consist of a large amount of roads which interwove each other. Many patterns may exist in road networks. Among them, star-like, grid-like and irregular patterns are often discernable in road networks, as presented in Figure 1. Star-like patterns display a radial structure where many roads converge at a point, or a set of dense points (Figure 1a). Grid-like patterns consist of two groups of roughly perpendicular roads, corresponding to Manhattan-style street networks (Figure 1b). As for irregular patterns, no regular shape and structure can be discerned (Figure 1c).



a) b) c)

Figure 1 Star-like (left), grid-like (middle) and irregular pattern (right) in road networks. Figure 1a shows the road network around Beijing, China, with a salient radial pattern where many roads converge at Beijing. Figure 1b presents the road network in North Iowa, USA, with two groups of roads intersecting perpendicularly. Figure 1c shows the road network in North China, with no regular patterns. Data source: http://sedac.ciesin.org/china/geomap/dcchnia/dcchina.htm (Figure 1a and Figure 1c), ftp://ftp.igsb.uiowa.edu/gis_library/IA_State/Infrastructure/Transportation/highway.zip (Figure 1b)

Further more, we would like to extend the pattern concept to include density differences in road networks, which is an important overall characteristic in some maps. For instance, there are always density differences between the central area and suburb in urban road maps, as presented in Figure 2.

Figure 2 Density differences in road networks. The city center (in the bottom left area on the map) is characterized by dense streets and roads, while the suburb is discernable with sparse roads. ©Lantmäteriverket 2004. From GSD-Property Map reference no. M2004/2828

2.3 Invariant and variant properties of patterns

In order to understand, model and evaluate patterns, the invariant and variant properties have to be identified. However, geographical phenomena tend to be different from place to place, and they are seldom repeated in different places with the same properties. That means the same kind of patterns may be different to some extent, with similar properties. Although this makes pattern modeling difficult, it is possible to identify the main properties of patterns.

Star-like (radial) patterns

- ♦ A hub-like junction with proportionately high degree, compared with average junctions in the network. For example, the hub junction in Beijing has a degree of 9 in Figure 1a.
- ♦ A set of roads cross the hub-like junction, or converge at it.

♦ (optional) A set of road segments consecutively connected and consisting in a ring around the hub-like junction. The ring can be repeated around the hub-like junction. That is, several rings nest each other around the hub-like junction.

Sometimes, the first property may appear in another manner, that is, a set of junctions in a small area instead of a single hub-like junction. In such cases, this set of junctions act as a complex junction. Its overall shape looks like a hub, which connects quite a lot of roads converging around it.

Obviously, when the first property is a complex junction, the second property changes accordingly. The roads converge at a set of junctions, rather than a single junction.

Grid-like (Manhattan-style) patterns

♦ A set of roughly parallel roads.
♦ Another set of roughly parallel roads, which intersect the first set of roads with roughly perpendicular angle.

These two set of roads may consist of segments with good or bad continuation. Although the continuation may be bad, the same orientation is discernable among the same set of roads, as those horizontal or vertical roads presented in Figure 1b.

Irregular patterns

♦ No components are repeated regularly.

Density differences

♦ There are obvious density differences in a road network.

3. Pattern modeling and generalization

3.1 Modeling Patterns as parameters

A primitive method to model patterns is parameter-based pattern description. Every kind of patterns has a set of properties, which can be described as a set of parameters, including shape, orientation, connectedness, density and distribution. In terms of these parameters, patterns with certain properties are identified, and evaluated in map generalization.

In most cases, we would like to use parameters describing the main properties of the patterns. For instance, grid-like patterns can be described using parallel orientation among the same set of roads and perpendicular intersection angle between two sets of roads.

However, it is also possible to use parameters indirectly indicating the main properties of the patterns. For example, computing density differences in road networks is not a trivial task. You have to partition the network into different parts in a reasonable way before you can extract the roads inside each part and calculate the density of each part. In such cases, an indirectly related parameter may be more convenient. We proposed a network density indicator, number of connections, to describe the density differences in road networks. This parameter records how many roads connect to this road. For two roads with the same length, the one in dense area will be connected to more roads than that one in sparse area, and thus the connection differences indicate the density differences to some extent. Refer Zhang (2004) for more details.

3.2 **Modeling Pattern as objects**

Since patterns consist of a set of objects, an approach to model patterns as a whole will be more powerful than the parameter-based approach which deals with their components separately. We can model patterns as objects, which is similar to modeling connectivity and arterial roads in road networks as MCST or SPST.

As pointed out in Section 2.3, star-like and grid-like patterns have their own components respectively. That means patterns can be modeled as complex objects as follows.

- ♦ Star-like patterns consist of three elements, i.e., a hub junction, a set of radial roads, and optional rings around the hub.
- ♦ Grid-like patterns consist of two sets of roads intersect perpendicularly.

3.3 **Identify and Generalize Patterns**

Based on component analysis, density differences and regular patterns can be detected and generalized.

♦ Star-like patterns

Star-like patterns are characterized by a hub-like junction. Therefore, it is a good start to detect such junctions in road networks. When such hub junctions are founded, radial roads crossing or touching it can be easily identified. Then the circular roads around the hub junction are further identified.

As pointed out in Section 2.3, the hub-like junction may be a set of dense junctions rather than a single junction. In such cases, a pre-process is necessary to collapse complex junctions according to the target scale. Clustering analysis can be used to detect and simplify complex junctions as suggested by Mackaness and Mackechine (1999).

Also worthy to be mentioned, the circular roads around the hub-like junction may be an incomplete ring. That is, the segments consisting in the ring may be connected to each other with bad continuation, or it is a broken ring with no consecutive segments along some parts of the ring (Figure 1a).

When generalize star-like patterns, the aim is to maintain the hub-like structure. The hub structure consists of the convergence junction and a set of roads. Generally speaking, the convergence junction will be retained at the target scale, but some of the roads crossing the hub have to be deleted owing to confliction. In most cases, the distances between every two neighboring roads centered at the hub junction are similar. It seems a reasonable way to delete one radial road every two neighboring radial roads, so as to maintain the similarity of the space between neighboring radial roads. Existing methods don not select roads in such a way, and they tend to destroy the hub-like structure. For instance, tests showed that length-based algorithm destroyed the radial network in Figure 1a. In order to select radial roads in such a way, the neighbor relationship between radial roads has to be computed and recorded, which can be dealt with in a pre-process.

As for the circular roads around the hub junction, they are selected or omitted according to conflict detection. If the ring is very small and close to the hub junction, it may conflict with the conjunction and has to be deleted. Otherwise, if nested rings are large and far enough from each other, they are retained in the target map. Rings are not the essential components of the star-like pattern, and their omission will not destroy the structure.

♦ Grid-like patterns

Grid-like networks consist of two sets of perpendicularly intersected roads. Therefore, a start to detect such patterns is to detect two sets of parallel roads respectively. Component roads in such patterns may not be connected to each other with good continuation (Figure 1b), and tests show that “stroke” is not effective at detecting such components. Therefore, it is more effective to detect such components using primitive segments rather than complex objects, “strokes”.

Generally speaking, the distances between every two neighboring parallel roads in the same group are similar. When generalize grid-like networks, the aim is to maintain the similar interval between neighboring roads in the same sets. Similar to radial network generalization, it seems reasonable to select one road every two neighboring parallel roads, so as to maintain the similarity of the interval between two neighboring parallel roads in the same group. Here, the neighboring roads refer to the last and next parallel roads in the same road group. For a horizontal road in Figure 1b, its neighbors refer to the horizontal roads immediately above and below it. Neighbors for vertical roads and roads with other orientation can be identified in a similar way. However, existing methods do not support road selection in such a way. For example, tests showed that length-based generalization algorithm failed to maintain the grid-like structure in Figure 1b. In order to select parallel roads in such a way, the neighbor relationship between parallel roads has to be computed and recorded.

4. A Case Study

We made a case study to generalize the density differences in road networks. A routine was implemented in Java environment to detect and generalize the density differences in road networks. However, algorithms to generalize star-like and grid-like patterns have not been implemented up to now. Generalization processing was controlled by two inputs, i.e., road ordering strategy and reduction ratio.

The map data used in this study came from the local municipality of Lund. The data is a comprehensive and detailed representation of road and street network in Lund, Sweden. Some roads are disconnected to each other owning to inaccurate representation of the reality. Roads are divided into highways, class one roads, class two roads, class three roads, class four (bad) roads and streets. However, this case study concentrated on road geometry, especially the density differences, so the road attributes were neglected.

In this study, road density was indicated by the number of connections. As expected, the algorithm based on this parameter tends to maintain the density differences among the network, which selects more roads in dense areas (city center) and fewer roads in sparse areas (suburb) than length-based algorithm does (Figure 3). Details of the algorithm is described in Zhang (2004).

Figure 3 Generalized road network with 25% (left) and 35% (right) reduction of length. ©Lantmäteriverket 2004. From GSD-Property Map reference no. M2004/2828

5. Future work

This paper discussed the importance to generalize the density differences and regular patterns in road networks. An algorithm to generalize the density differences has been implemented and tested. The next step is to implement an algorithm to detect and generalize the star-like and grid-like patterns. The regular patterns will be detected according to their main properties discussed in Section 2. Methods to generalize regular patterns will be based on neighbor relationship between converged radial roads, and parallel roads in the same group, as discussed in Section 3. That is, the algorithm will tend to select one radial or parallel road every two neighboring radial or parallel roads. However, when the changes in scale are not large, alternative method may be used. For instance, only component roads in dense parts are omitted.

6. Conclusions

Since roads are interwoven into complicated network, it is difficult to generalize road network. This paper emphasized the importance of density differences and regular patterns in automated road network generalization. Density differences, star-like and grid-like patterns among road networks are identified as important overall characteristics of road networks. The properties of patterns were outlined, and methods to model and generalize patterns are proposed accordingly. A case study on density differences shows that explicit description of network structures results in reasonable generalization results.

Acknowledgments

This research was supported by China National Science Foundation under grant No 40101024. This paper was written while the author was a guest researcher at the GIS Centre, Lund University, Sweden. I'd like to thank my colleagues at the centre for their cooperation.

References

Jiang B and Claramunt C, 2004, A Structural Approach to the Model Generalisation of an Urban Street Network. *GeoInformatic* 8(2): 157-171

Jiang B and Harrie L, 2004, Selection of Streets from a Network Using Self-Organizing Maps. *Transactions in GIS* 8(3): 335-350

Lamy S, Ruas A, Demazeu Y, etc, 1999, The Application of Agents in Automated Map Generalisation. In *Proceedings of the ICA 19th International Cartographic Conference* (Ottawa, 14-21 August 1999), pp.1225-1234

Mackaness W. A. and Beard M. K., 1993, Use of Graph Theory to Support Map Generalisation. *Cartography and Geographic Information Systems*, **20**, 210 – 221.

Mackaness W. A., 1995, Analysis of Urban Road Networks to Support Cartographic Generalization. *Cartography and Geographic Information Systems*, **22**, 306 – 316.

Mackaness W. A. and Mackechnie G. A., 1999, Automating the Detection and Simplification of Junctions in Road Networks. *GeoInformatica*, **3**, 185- 200.

Mackaness W and Edwards E, 2002, The Importance of Modelling Pattern and Structure in Automated Map Generalisation, Joint ISPRS/ICA workshop "Multi-Scale Representations of Spatial Data", Ottawa, Canada, 7-8 July 2002

Morisset B and Ruas A, 1997, Simulation and Agent Modelling for Road Selection in Generalisation. In *Proceedings of the ICA 18th International Cartographic Conference* (Stockholm, 23-27 June 1997), pp.1376-1380

Thomson R. C. and Richardson D. E. 1995, A Graph Theory Approach to Road Network Generalisation. In *Proceeding of the 17th International Cartographic Conference*, pp.1871–1880.

Thomson, R. C., and Richardson, D. E., 1999, The ‘Good Continuation’ Principle of Perceptual Organization Applied to the Generalization of Road Networks. *Proceedings of the ICA 19th International Cartographic Conference* (Ottawa, 14-21 August 1999), pp.1215–1223.

Thomson RC and Brooks R, 2002, Exploiting perceptual grouping for map analysis, understanding and generalization: The case of road and river networks. Graphics Recognition: Algorithms and Applications, Lecture Notes in Computer Science 2390/2002: 148-157

Zhang Q, 2004, Road network generalization based on connection analysis, SDH 2004.