The Application of Mathematical Morphology and Pattern Recognition to Building Polygon Simplification

WANG Hui-lian, WU Fang, DENG Hong-yan, GE Lei, HUANG Qi
Institute of Surveying and Mapping
Information Engineering University
Zhengzhou 450052 China
E-mail: kookwang@263.net

Abstract
The simplification of the plan of inhabited area, especially simplifying the plan of urban inhabited area, is a difficult problem of automatic map generalization all along. There are many research results about this item in recent years; there is no perfect method which can make satisfactory generalization of the plan of inhabited area yet. The main reason of this status is that it is difficult to get and use the semantic and spatial information of the inhabited features. In this paper, we present an approach to simplifying building polygon—one aspect of the simplification, which is supported by a data model combining the raster and the vector model and adopt the methods of mathematical morphology and pattern recognition assisted by Neural Network. A system based on this method is carried out in the environment of Visual C++, the results of test proves that the method is in evidence on preserving the shape characters of urban blocks.

Key Word: Automatic map generalization, Building polygon simplification, Mathematical morphology, Syntactic pattern recognition, Freeman chain code, Neural network

Introduction
Generalization algorithms “must take into account the particular shape properties and semantics of the real-word features they aim to depict in a generalized version” (Weibel & Dutton 1998). There are many generalization algorithms now, but only a few of them consider the particular shape, spatial information and semantics of the features. The causation of this status is that it is difficult to acquire expert knowledge and get support from intelligent data structure.

The simplification of the plan of inhabited area includes street selection, district aggregation, inner structure generalization, polygon simplification and so on. If these operations are divided properly, the simplification could be carried out through a series of algorithms. This paper only concerns the simplification of building polygon in map generalization of large scale. Some research productions at this aspect as followed: applying pattern recognition and shape analysis in building polygon simplification (Zeshen Wang and Dan Lee 2000); designing strategies for building generalization (N.Regnauld, A.Edwardes and M. Barrault 1999); presenting some regulations for outline simplification of area feature and giving a progressive method based on spatial knowledge of polygon (Qinsheng Guo 1999); adopting combinatorial rectangle difference based on raster data in the simplification (Renzhong and Guo Tinghua Ai 2000).

On the basis of above researches, this paper designed a vector-raster union data structure, applied mathematical morphology and pattern recognition to building polygon simplification, and realized pattern recognition based on GA-BP neural network. This paper proposes to tackle the difficult issue of automatic map generalization from intellectualizing way.

1. The Principles and Process
Simplifying buildings means making a simpler representation of the original buildings by reducing details in their boundaries, while maintaining the essential shape and size of the buildings (Lee, 1999). So simplifying building polygons must observe the two chief principles: preserving the shape characteristic of the building polygons (cf. fig.1); Keeping the size of the building polygons (cf. fig.2). In addition, the simplification process will follow these rules:

- If a building polygon contains one side shorter than the threshold (it’s generally 0.3mm in the target map), it will be simplified.
- Since building polygons usually are orthogonal, simplification will preserve and enhance the character.
- According to different cases, a building polygon should be simplified by filling, cutting, enlarging, typifying and approaching etc.
- If a building polygon has been simplified to a rectangle, it can’t be simplified any more.

Referencing to the simplification process in the document [1], this paper take the following steps:

- Transforming a building polygon to a rectangle. If all detail of a building polygon could be ignored in the given threshold, it can be simplified in the maximum extent --- turn to a rectangle directly (cf. fig.3).
- Rectifying the angles of building polygon to right-angles. In large scale map, although most building polygons are orthogonal, data of building polygons is generally not strict orthogonal polygon because of the errors in digital data collection. So it’s necessary to adjust it (it’s a data correction virtually). It’s important to simplify by mathematical morphology and pattern recognition in the following steps (cf. fig.4).

- Applying mathematical morphology to the primary simplification of building polygons.
- Using pattern recognition to simplify the building polygons that should be simplified farther.
- Modifying the unacceptable parts of the simplified building polygons.
- Dealing with some complex building polygons in different ways.

2. The Realization of Building Polygon Simplification
To reduce the complexity of the algorithm and realize it easily by programming, author prefer to take more cursory simplifying in building polygon simplification (avoid to do too much shape analysis in simplification process). It has been showed in the process above: Transforming a building polygon to a rectangle firstly should avoid to simplifying a building polygon to a rectangle through complex simplification process, and the polygon can be directly transformed to a rectangle in fact: Applying mathematical morphology to building polygon simplification can’t keep the shape characteristic of the polygons very well, but it operates efficiently and easy to control. The methods and processes adopted by author is a middle course considering both effect and efficiency.

2.1 Vector-raster Uniform Data Model Considering The Simplification Scale

The scale is the most important factor in map generalization, because it decides the detail of a map. The minimum size of symbol graphics plays an important part in the building polygon simplification. In automatic map generalization, it’s useful to connect map data model with this two scales, so author designed vector-raster uniform data model which is related to the map scale.

Because the original data is vector data of building polygon, getting the raster data of building polygon must through rasterization. It takes two steps:
1) Using the classical Bresenham algorithm to rasterize the sides of building polygon.
2) Using the seed-filling algorithm to get the raster data of building polygon.
Step 2) is the necessary step before mathematical morphology operation. It’s very important to decide the size of grid. Considering the minimum size of geometric graphics and the demand of accuracy, and convenient for choosing the template of mathematical morphology, author set the width of grid 0.02mm (map size). The raster data model is as following:

```c
typedef struct tagResidentGridData
{
    double X, Y; // bottom-left coordinate of raster image (geographic coordinate)
    double m_dGridWidth; // width of a grid (dynamic)
    int m_iResidentGridRow; // rows (height of image)
    int m_iResidentGridColumn; // columns (width of image)
    BYTE* m_pResidentGridData; // habitation raster data (256 colors)
} GMS_ResidentGridData; // habitation raster data structure
```

To construct the grammar elements of syntactic pattern recognition easier and take the advantages of raster data better, tracing outline can be used to express the sides of building polygon as improved Freeman chain code. The Freeman chain code doesn’t record the tracing direction pixel by pixel; the direction and the tracing length along this direction are recorded when the tracing direction change. Redundant data are pressed and memory space is saved by using it; on the other hand, this chain code is the vectorization form of polygon boundary, so it’s convenient for pattern recognition. Data model of the freeman chain code is as following:

```c
typedef struct tagFreeman_CodeCell
{
    int m_iDirection; // tracing direction (0 is NW, 1 is N, 2 is NE, 3 is E, 4 is SE, 5 is S, 6 is SW, 7 is W)
    int m_iLength; // tracing length (number of pixels)
    int m_iPatternFlag; // pattern recognition flag (element type. value is 1~8)
} GMS_Freeman_CodeCell; // data structure of freeman chain code cell
```
typedef struct tagFreeman_ChainCode {
    BOOL m_bFinishedSimplification; // flag of accomplished simplification
    CPoint m_StartPoint; // start point coordinate (row and column)
    CArray< GMS_Freeman_CodeCell, GMS_Freeman_CodeCell > m_ChainCodeArray; // chain code data
} GMS_Freeman_ChainCode; // data structure of freeman chain code

The vector data model of building polygon is only the serial coordinates of the vertexes. The above raster data model contains the information needed in vectorization.

### 2.2 Simplification of Building Polygon Based on Mathematical Morphology

Mathematical morphology is a subject that is based upon strict mathematical theory, which is used in digital image processing and pattern recognition. Seven operations are often used in mathematical morphology: dilatation, erosion, opening, closing, hitting, thinning and thickening, these operations can be used in map generalization through proper combination. Excellence of these operations is easy to control and fast in operation.

For this characteristic, it’s more effective to simplify some typically simple polygon by mathematical morphology in building polygon simplification. Author uses hitting to recognize the structures of building polygon’s image (hitting is a type of pattern recognition) and then adopts the corresponding simplifying strategy. Mathematical morphology doesn’t do well in dealing with complex building polygon for the limitation of template structure, therefore only two simple structure of building polygon, convex and concave part whose sole width is shorter than the threshold, are simplified by mathematical morphology.

Filling up, cutting off, enlarging and preserving should be chosen appropriately to simplify small flexure of building polygon (cf. fig.5). If both the height and width is shorter than the threshold, filling up or cutting off it (flexure A in fig.5); if one in height and width is shorter than the threshold and the other is longer, enlarging the shorter one to the threshold (flexure B in fig.5); if both the height and width is longer than the threshold, preserving it. Raster data related to scale is better in using mathematical morphology to recognize the size of flexure, for the direct connection between the width of grid and the threshold, convex and concave part whose width (depth or height) is shorter than the threshold could be recognized as hitting template is properly chosen.

![Fig.5 Simplifying the Unattached Flexure Differently](image)

Because the grids are distributed vertically or horizontally, the sides of polygon should be mapped to the two directions after rasterization. Building polygon that is compatible to be simplified by mathematical morphology must have obvious orthogonal characteristic and it’s sides can be divided to two groups that is vertical with each other. So mathematical morphology could only be used in the simplification of building polygon with typical orthogonal characteristic in large scale map, but not suitable for most building polygons in small scale map. The process using mathematical morphology to simplify building polygon is as following:

- After rectangle transforming and right-angle adjusting, if the direction the least bounding box is not vertical or
horizontal, rotating the coordinates to make all sides of building polygon vertical or horizontal, and then rasterizing the polygon, getting the freeman chain code of polygon by tracing outline.

- Taking hitting operation to raster data using the 5*5 template in fig. 6, template 1, its 90 degrees rotated, 180 degrees rotated and 270 degrees rotated results could be used to recognize the narrow convex structure of the polygon that needed to be simplified; plate 2, its 90 degrees rotated, 180 degrees rotated and 270 degrees rotated results could be used to recognize the narrow concave structure of boundary that needed to be simplified.

- Taking more analysis of the Freeman chain code corresponding to the convex or concave part found, make sure that it's unattached convex or concave structure, get the height (depth) of structure and then operation such as filling up, cutting off, enlarging could be chosen. Boundary distortion operation aims at the Freeman chain code of raster data, only adjusting the tracing length of chain code cell, data processing is easy and effective compared with vector mode operation.

- Analyzing Freeman chain code of simplified raster data, vectorizing and making reversed coordinates rotating transformation if no short side needs to simplify; using pattern recognition to simplify it later if such short side exists.

In the building polygon simplification of fig.6, A, B, C, D, E could be recognized and processed properly, but part F can’t, this case and the more complex case with convex and concave part closed and consecutive need to be processed by pattern recognition later.

### 2.3 Pattern Recognition Simplification of Building Polygon Supported by Neural Network

Although building polygon in large scale map is complex, the detail feature and it’s simplification method is always of rules. For example, scalariform structure and wavy structure in fig.7 is very common, which can be simplified by the methods in fig.8. Because the Freeman chain code of polygon could be seem as a vector list whose head and tail linked, building polygon’s outline is easily to be represented to a cluster of elements or sub-patterns based on chromosome grammar. Then classifying them by syntactic translation and simplifying by different methods according to pattern.

![Fig.6 Building Polygon Simplification Based on Mathematic Morphology](image)

![Fig.7 The Different Patterns of Building polygon's outline](image)
Because rasterization image’s pixels are distributed vertically or horizontally through coordinates rotating, and clockwise tracing outline started from bottom-left of outline, structure of building polygon could be described by the eight structural elements in fig.9. Polygon c in fig.8 (A) could be described by the string abc’bc’b’c’d; polygon b in fig.8 (B) could be described to string abc’ba’bcd.

How to recognize different patterns from the strings describing outline is the core process in the operation of pattern recognition. One side an integrated grammar should be defined – terminative-symbol set \( \Sigma \) in chromosome grammar \( G(N, \Sigma, P, S) \) is known as \( \{a, a', b, b', c, c', d, d'\} \) and non-terminative-symbol set \( N \) and production set \( P \) should be confirmed; on the other hand, meaningful sentences with relevant pattern should be found from the strings describing outline. For example, in the string abc’b’a’bcd of polygon b in fig.8 (B), bc’ba’b is a sentence that represents a single retuse structure. Because of the variety of building polygon, there are many combinations with various sub-patterns, which make it difficult to confirm non-terminative-symbol set \( N \) (it could be considered to be sub-pattern set sometimes) and production set \( P \) (grammar rule set). Actually pattern recognition can’t simplify all kinds of outline, and it’s possible to enumerate all typical patterns and make corresponding grammar inference, it’s not hard to find sentence containing short side(elements \( a', b', c', d' \)) from the strings describing outline by using long side(elements a,b,c,d ) as sentence division.

From top to bottom or from bottom to top in grammar parsing is generally adopted to judge whether a sentence (pattern) is legal in Language L (\( G_i \)), and then distribute it to class \( i \) exclusively. Pattern recognition’s classification is actually a partition or mapping of the pattern feature space, and that neural network, especially multi-level neural network is based on pattern transformation, so it’s natural and effective in pattern recognition. Pattern recognition based on neural network does well in self-adapting, self-studying, self-organizing and fault-tolerance. As BP neural network with 3...
layers could separate multidimensional space randomly, to improve the whole optimization characteristic and convergence speed of network studying, author apply 3 layers mixed GA-BP neural network to assisting pattern recognition, in which neural network is used as syntax parsing. The process is as following:

- Enumerating all typical patterns as possible and taking grammar inference (detailed syntax ignored).
- Using top to bottom syntax parsing to get legal sentence of each typical pattern and transforming it properly as input of neural network, training neural network under guidance, storing weights matrix and corresponding pattern to pattern library after training. Storage is classified by the sentence length in pattern library.
- Transforming the Freeman chain code of building polygon to elements string.
- Finding out legal sentences from string and reading the weight matrix of neural network from corresponding pattern library according to the length of the sentence, constructing neural network (the sentence as input) until neural network get the output of legal pattern then pattern recognition is completed.

After accomplished pattern recognition, adopting reasonable simplification method according to different patterns and then building polygon simplification is finished. Some complex building polygon that can’t be simplified by pattern recognition could only be simplified in vector data mode.

### 2.4 Modifying simplified building polygon and simplifying complex building polygon

In some conditions, short side doesn’t exist in building polygon after simplification, but maybe conflicts with specifications of cartography sometimes. Too narrow case in fig.10 is undesirable, but it can’t be recognized by the above simplification and could only be recognized and removed by analysis in vector data. Strictly, it’s not the content of building polygon simplification, but it must be considered in simplification and conflicts like this should be avoided by all means.

![Fig.10 The Unresolved Conflicts after Simplification](image1)

![Fig.11 Some Status of Complicated Building Polygon](image2)

For some complex building polygons (cf. fig.11), methods similar to pattern recognition could be adopted to simplify the polygons. Some work has been done in this aspect, which need to be perfected.

### 3. Experiments and Conclusions

The algorithms of this paper has been put into practice in our developed automatic map generalization software, the results proves that the method is in evidence on preserving the shape characters of urban blocks (cf. Fig.12 and Fig.13).

The method presented in this paper does better in controlling the simplification degree by the data model relating simplification scale and keeping shape characteristic of polygon. What’s more, the automatic degree is high in simplifying complex building polygon and the result is more reasonable.

The neural network model stored in trained pattern library could recognize the corresponding structure pattern of building polygon at 80% or so. Comparing with pattern recognition based on syntax parsing, pattern recognition realized by programming is more transparent and have a better capability in fault-tolerance.
Although this paper shows that new progress has been made in building polygon simplification, integrating more intelligence with generalization algorithm and using the AI study fruits in automatic map generalization maybe is the only way for realizing the complete automation.

Reference


GUO Qing-sheng. The Method of Graphical Simplification of Area Feature Boundary as Right Angle. Wuhan Technical


