

A DISPLACEMENT METHOD BASED ON FIELD ANALYSIS

Tinghua AI¹, Peter van Oosterom²

¹Laboratory of Digital Mapping and Land Information Application Engineering Wuhan University, P. R. China
aith@wuhan.cngb.com

²Section GIS Technology, Department of Geodesy Faculty of Civil Engineering and Geosciences
Delft University of Technology, the Netherlands
oosterom@geo.tudelft.nl

Commission II, WG II/6

KEY WORDS: map generalization, displacement, field analysis, Delaunay triangulation, building cluster

ABSTRACT:

As an important operator in polygon cluster generalization, the displacement has two contributions. One is to resolve the proximity conflicts to guarantee the legibility constraint. Another is to act as the prior operator of other generalization operator, such as aggregation. This paper presents a field based method to deal with the displacement of polygon cluster in both aspects above. On the basis of the skeleton of Delaunay triangulation, a displacement field is built in which the propagation force is taken into account. Taking the building cluster as the example, the study offers the computation of displacement direction and offset distance for the building displacement which is driven by the street widening. The vector operation is performed based on the grade and other field concepts.

1. INTRODUCTION

Due to the impacts of context, the generalization of cluster object is much more complex than that of single object. The constraints aiming at the whole cluster system and at every element object have to be considered simultaneously in such as position retaining, structure pattern maintenance, statistic principles preservation, etc. Usually the constraints from different viewpoints are contradict to each other and no solution could be found to satisfy all constraints. In recent years, the research of cluster object abstraction is active in the community of map generalization and the interests focus on the displacement of cluster object.

In GIS domain, the spatial data model includes object oriented and field oriented. From the latter viewpoint, the space is regarded as the field with associations between different spatial objects. We can image that the associations are resulted from some forces, just like the gravity force in the gravity field or electromagnetic force in the electromagnetic field. The change of force balance will lead to the position readjustment of involved objects. The map abstraction can be thought of as the "force balance change" during the process of the removal, exaggeration, and aggregation of part of objects. So the post-process is required to maintain the balance. Ruas (1998) called this kind of post-operation reactive displacement. From the point of legibility view, the displacement to handle too close proximity is called active displacement. In both cases, the displacement acts as an independent operation. However the displacement can also be served as prior sub-operation of such as aggregation.

In the area of displacement study the field idea is popular. Ruas (1998) viewed the displacement as a set of localized distortions in a continuous field composed of a set of objects whose internal geometry is fixed. Hojholt (2000) presented a displacement approach using the finite element method in mechanic structure subject. The finite element method contains the idea in which the force acts on the field. Based on the

neighbor analysis, Mackness(1994) developed a method to detect conflicts and to displace the objects with the offset decreasing from the conflict center. The key question of the implementation of field theory in the displacement exists in the field modeling and the force action modeling. Based on the different understandings, we can build different field model and use different field concept. This study presents a displacement field model based on the geometric construction similar to the Voronoi diagram. Through the analysis of adjacent degree in neighbor relationship, the force action is propagated in the field with the magnitude decreasing, which is not settled in the finite element method.

The rest of paper is structured as below. In section 2 the research motivation is given which is to process two kinds of displacement in building cluster generalization. Section 3 presents the method of displacement field construction. The displacement as the proximity resolving and the prior operation of aggregation is discussed in section 4 and section 5 respectively. Finally section 6 concludes with the future works.

2. THE MOTIVATION---BUILDING CLUSTER GENERALIZATION

Multi-scale representation and map generalization has to take into account spatial object properties in geometrical, semantic and topological aspects. The Objects with the same geometric type, but different geographic meaning should be executed with different generalization strategies and algorithms. Recently the study of geo-oriented generalization is active, which aims at some special geographical categories. The research on urban building abstraction and multi-scale representation is an example. As the polygon object with human culture characteristics, the building has different properties in spatial distribution, shape structure and Gestalt nature compared with natural features such as soil parcel, vegetable, lake etc. Building generalization involves the simplification of independent building, the aggregation, displacement of building cluster.

From the point of legibility view, Regnaud and Edwardes (1999) discuss three operations for building simplification: detail removal, squaring, local enlargement. Lee(1999) presents some ideas on single building simplification focusing on shape maintenance. Based on divide-and-conquer idea, Guo and Ai(2000) give an algorithm to simplify building polygon through separating a building into multiple hierarchical organization of rectangle elements. For building cluster aggregation, Regnaud (1996) develops a method to detect building pattern group applying MST model in graph theory.

Building cluster generalization can be classified into three levels of decision and operation. Grouping is the first decision-making which is based on conflict detection, distribution pattern recognition and Gestalt nature cognition. The second level is the operator decision. And the third is the execution of geometric operation. This study focuses on the second and the third steps and concentrates on the displacement operation.

The constraints of building generalization involves the maintenance of position accuracy, avoidance of short space distance, maintenance of the whole building area balance, preservation of Gestalt nature, and retaining of orthogonal shape. Due to the contradiction between different generalization constraints, it is difficult to find a solution satisfying all of them. One proper method is to remove spatial conflicts and during the procedure to respect the other constraints above as much as possible. The compromise strategy requires to sacrifice each constraint partly, not respecting anyone completely.

From the point of legibility view, when the distance between buildings is shorter than cognition tolerance, we think the spatial conflict generating. To resolve conflict, the candidate operators could be deletion, displacement and aggregation. Deleting part of buildings leaves space for the remaining neighbor buildings and the conflicts between original buildings may be resolved. Displacement is valid just within relative large space. When scale changes largely, in limited space one displacement may result in new conflicts and it's very hard to find an appropriate position for each building polygon. Directly aggregation makes the conflict between original buildings disappear but increases the building size. Furthermore the conflicts between new combined results still exist, unless all buildings having conflicts to each other are combined to one big block. To avoid the case that the space between conflict buildings becomes the building area in the aggregation, we can execute both displacement and aggregation. It means the displacement acts as the prior operation before aggregation to guarantee the balance of building area. Moving two or more buildings together and then aggregating them into one leads to the conflicts between them disappear. On the other hand, movement gives the opposite direction more room and the conflict between new just generated building and context neighbors may also be resolved. This strategy guarantees the balance of the whole building area in some degree, but destroys the position accuracy of moving buildings. The largest offset distance of displacement should be restricted within position accuracy. Generally, the prior movement can not guarantee two neighbor buildings seamlessly sharing one common boundary, still with gap room. So the aggregation result still has the trend to increase area. Considering this fact, the followed independent simplification can be controlled to prefer to the operation reducing the building area.

So the displacement has two contributions in building cluster generalization. One is to resolve the proximity conflicts to

guarantee the legibility constraint. Another is to act as the prior operator of other generalization operator, such as aggregation. The previous can be either active or reactive displacement in Ruas(1998)'s classification. For the previous displacement, the studying object is the whole building cluster with the associations to each other. For the latter, the studying object is the building objects within local group which will be combined. Both cases can be put in the study of field. This paper will construct such a field model to process two kinds of displacement respectively.

3. CONSTRUCTING DISPLACEMENT FIELD

We suppose the force action exists in the whole building cluster, the displacement field. The force can be either repulsive or attractive. In the displacement field to resolve proximity conflicts, we suppose the repulsive force drives the adjacent buildings to move along the propagation direction. In the displacement field to support post aggregation, we suppose the attractive force drives close buildings together. The force association depends on the distance between one building and its neighbors. To model this kind of displacement field, we build a geometric construction similar to Voronoi diagram on the basis of Delaunay triangulation skeleton.

Delaunay triangulation, which has the circumcircle principle and closest to equilateral properties (Preparata and Shamos, 1985) plays an important role in spatial adjacent relationship analysis and results in series of achievements related to spatial neighbor assessment (Jones etc., 1995, Ware etc., 1997, Ai etc. 2000, Ai and Oosterom 2002). Building cluster distribution contains much information associated with adjacent relationship under context environment.

3.1 Constructing the Partitioning Model Similar to Voronoi Diagram

For the building cluster within one street block, we construct the constrained Delaunay triangulation and just consider the triangles connecting different building object. Those locating within building polygon or locating in the concave area of building polygon are removed. The reason of latter removal is to avoid appearance of dangle skeleton branch in the next partitioning geometric construction creating. For remaining triangle set, we assign them into three types according to the number of neighbors. Those having one neighbor, two neighbors and three neighbors are respectively classified as type I, type II and type III. Figure 1 illustrates the selected triangles between buildings, shaded with light green and marked with Roman number. Type I triangle appears on the exit of building cluster, type III triangle on the region of three buildings meeting together, and type II distributing around the gap area between two buildings.

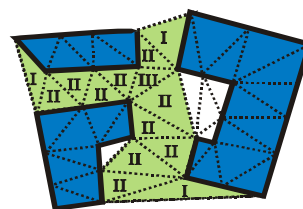


Figure 1. Selecting specific triangles and assigning type

Skeleton connection way for three types of triangle is described in figure 2, where P_1 , P_2 , P_3 is the midpoint of corresponding

triangle edge, and O is the triangle weight center. Link skeleton segments by means of next paths:

- Type I: $A \rightarrow P_1$ or $P_1 \rightarrow A$;
- Type II: $P_1 \rightarrow P_2$ or $P_2 \rightarrow P_1$;
- Type III: $O \rightarrow P_i$ or $P_i \rightarrow O$, $i=1,2,3$

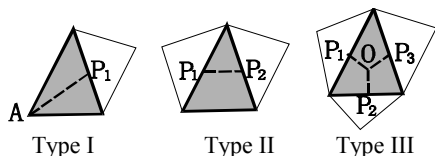


Figure 2. Skeleton connection ways for three types of triangle

Through polygon topological organization based on linking the skeleton edges, we obtain the special geometric construction as illustrated in Figure 4.

This partitioning model has the following properties:

- i>. Each partitioning polygon contains one building;
- ii>. Each node relates to three skeleton edges;
- iii>. Each edge of partitioning polygon boundary faces to a left building and a right one, separating two buildings equally in space;
- iv>. If the number of type I, type II, type III triangle is n_1, n_2, n_3 respectively, then the number of edge is $(n_1 + 3n_3)/2$;

Property i, ii, iii is valid except for the border area of polygonal cluster. Adding an outside closed boundary through clip handling can guarantee the border object also within one partitioning polygon. As triangles locating in the concave part have been removed in the previous selection process, which implies some of outside concave area is also regarded as belonging to object polygon, for such as object polygon B in figure 3, filling the “U” formed mouth based on equal partitioning is necessary because the left/right region of skeleton edge is the same polygon. It is similar for the method of raster operation to get the polygonal cluster Voronoi diagram. This is the reason why we do not directly use skeleton based on all triangles outside object polygon to get this kind of geometric construction.

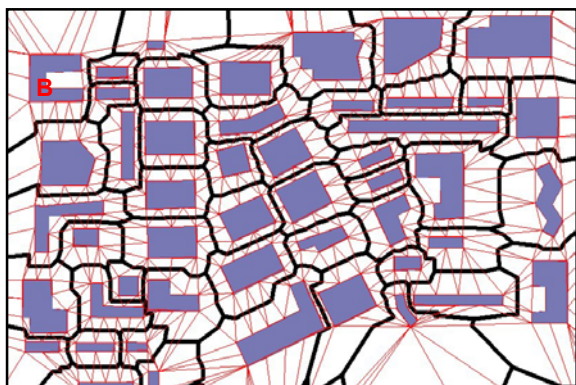


Figure 3. Based on the triangles between building polygons, the skeleton connection gets a special geometric construction similar to Voronoi diagram (visualized as wide dark line)

This geometric construction looks like Voronoi diagram(VD). But according to the strict definition of VD (Preparata and Shamos 1985), it is not Voronoi diagram. Originally the

Voronoi diagram is point cluster oriented and has geometric properties that partitioning cell polygons are convex and the connection of neighbor center point gets its dual, Delaunay triangulation. For line and polygonal cluster, it is difficult to give a strict definition of Voronoi diagram in computation geometry and usually depends on the construction method. The usual method is based on raster data expansion (Li and Chen 1999) to construct the Voronoi diagram of line cluster and polygonal cluster. But obviously the partitioning polygons do not satisfy the above two principles. For the purpose of application rather than the strict theory of computation geometry, we can think it as a Voronoi diagram if it equally partitions the space between cluster elements.

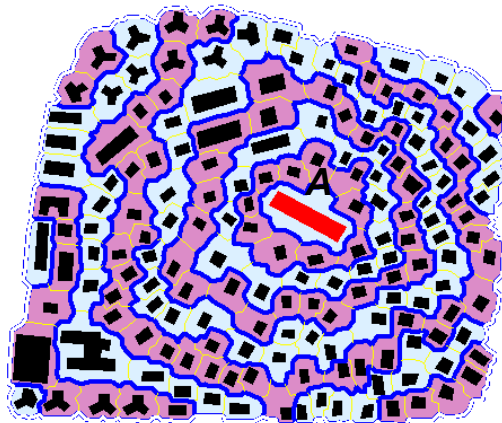


Figure 4. The iso-distance-relationship contour with respect to the center object A

The partitioning polygon can be thought of as the growth region of corresponding object polygon, covering the whole area with neither gaps nor overlapped regions. We can understand it as the result of each object competing outwards for growth range and this competition has to consider context impacts. The neighborhood relationship between original object polygon is now mapped as the topological touch relationship between partitioning polygons in this partitioning model. Based on the relation of partitioning polygons, see figure 3, we can find any object polygon’s geometric neighbor candidates. Some are far away to each other but the triangle connection makes them possible neighbors, and if the distance between them is less than tolerance then they are real neighbors.

3.2 Constructing Displacement Field

In map generalization, the displacement of geographic objects has to take into account the propagation influence in the context. One object receives the driven force moving itself and also pushes the force to its neighbors with magnitude reduction. This process is similar to the phenomena of magnetic or electronic field in physics subject. To model the displacement field, we need to decide the force source and the propagation behavior. For every building object, we need to find the fore propagation direction and its associated neighbors receiving the propagation force.

In field analysis, we can use isoline to represent the model. The objects locating in the same loop between two adjacent isolines receive the identical force action in magnitude. Along the normal direction, when the object moves across one isoline, the force will reduce/increase one grade. We use this idea to build

iso-distance-relationship model to represent the displacement field

For the simple purpose, in the partitioning model above we call the building polygon OP which is surrounded by one partitioning polygon, and partitioning polygon PP. With the reference OP, each other OP has certain distance relationship to it depending on the context rather than just metric distance. From the reference OP to the current OP, the path needs to go across a number of PPs. We define the minimum number across PPs as the concept *adjacent degree*. If two PPs share a common boundary, the corresponding OPs are called immediate neighbor and having adjacent degree 1. The topological relationship between PPs is able to be mapped to represent the distance relationship between OPs. This representation is based on the assumption that the space is isotropic.

We define the reference OPs the fore source in the displacement field. The force source could be one OP or set of OPs. For the case of street widening, the buildings within one street block will be displaced in different ways and the force source can be thought from the street boundary. The immediate adjacent OPs with the street boundary can be defined as the references. For the situation that one building is too close to its neighbors, the

center building can be assigned to the force source to push away its neighbors.

Based on the partitioning model above, we present the following algorithm to compute the adjacent degree of every OPs in the building cluster. The referenced object is with respect to the street boundary, say b . Assign the immediate related buildings of boundary b to set A :

- 1> Let OPs in set A *adjacent degree* 0, and initiate other OPs *adjacent degree* -1;
- 2> Initiate A belonging to active object set, Initiate variable *degree_count* 0;
- 3> Repeat next steps until active object set NULL;
 - 3.1> Find all adjacent objects of active object set based on PP boundary extending search;
 - 3.2> Ignore those adjacent objects with *adjacent degree* greater than -1;
 - 3.3> *degree_count* adds 1 and assign the value to each valid adjacent object;
 - 3.4> Empty active object set and let valid adjacent objects belong to active object set;

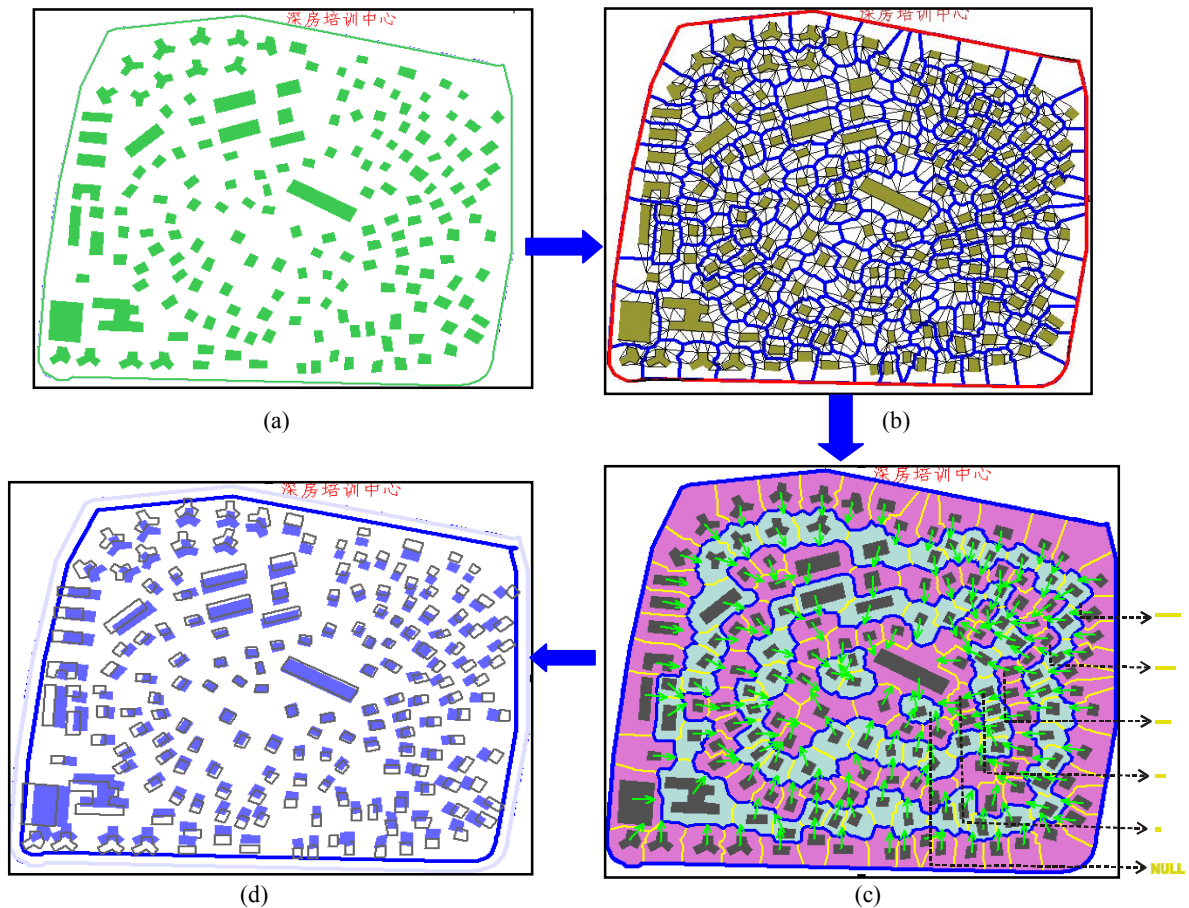


Figure 5. The field construction and the displacement result

- (a). Original building cluster and street boundary.
- (b). Based on Delaunay triangulation and skeletons, construct the partitioning model similar to Voronoi diagram.
- (c). The construction of displacement field in which the force propagation direction and magnitude is computed and visualized in the graphic.
- (d). The displacement result driven by boundary compress. The nearer to the boundary, the longer offset the building has moved. The core buildings have no movement.

Next we remove the PP boundary arcs which face the two side OPs having the same *adjacent degree*, represented as yellow line in figure 5 c. Connecting the rest PP boundary arcs form the closed contour line which separates OPs with *adjacent degree n* from those with *adjacent degree n+1*. The objects within the loop between two neighbor contour lines have the same *adjacent degree* with respect to boundary *b*. So we call this kind of contour line the iso-distance-relationship contour, just like the altitude contour of terrain representation. The lower adjacent degree exists between two OPs, the closer relationship is to each other. Obviously this contour is different from the iso-distance contour which is represented as progressive circle buffers with the same center and increasing radius. The iso-distance-relationship model considers the context environment and spatial distribution. An OP far away in metric distance, possibly has very low *adjacent degree* and close distance relationship with the reference boundary *b*. In this case the boundary acts the force source to drive the displacement, and the force propagation passes across the contour. Figure 5 illustrates the whole process of the displacement filed construction with respect to the street boundary. Figure 4 describes another example which is referenced with a determinate OP, building A in the cluster center.

4. DISPLACEMENT AS THE PROXIMITY CONFLICT RESOLVING

The street widening results in the spatial conflicts between the boundary and the involved buildings. Under the action of the street block boundary compressing, the buildings receive different forces to move its position. Based on the displacement field of iso-distance-relationship representation, we give the method to compute the displacement direction and offset distance.

The force is propagated from the outer street boundary to the inner buildings. The force action on one OP is decided by the boundary properties of the corresponding PPs. Except the center buildings, each OP faces some OPs with low adjacent degree and on the other side faces OPs with high adjacent degree. We call the previous the active boundary and the latter the reactive boundary. For the same PP boundary, it may be reactive with respect to one OP, but active to its neighbor. The fore is propagated from the active boundaries and the action result is to push the neighbor OPs through the reactive

boundaries. In this process the yellow boundaries in the figure does not participate in the force propagation. It implies the movement of an OP within one loop does not change the distance relationship with respect to the street boundary. But the local conflicts between OPs within the same loop may generate in this situation.

Through vector add operation, we compute the movement direction of each building driven by the propagation force from the active boundaries. Usually the boundary edge is a curve. We construct an approximated direct line using the least squares method and let the normal direction as the vector direction. In figure 5 c, the green arrow symbols represents the added vector direction of all vectors resulted from active boundaries.

For the computation of offset distance, we define a decay function about the adjacent degree, say $f(x) = c - kx$. It implies the higher adjacent degree leads to the shorter offset distance. This function is the simplest one, the lineal type. The function form can also be other decay ones according to the decay speed along the change of adjacent degree. This function corresponds to the concept grade in the field. The OPs within the same contour loop have the same grade and move the same offset. The core objects which are the farthest away from the street boundary could be controlled without offset keeping original position. Figure 5 d is the displacement result based on the computation of displacement direction and offset in figure 5 c. Figure 6 gives a real application example based on the above displacement method.

One question is that too densely distributed buildings may overlap after displacement. The improvement is to consider the local force produced from the close objects to each other. It means the displacement driven is not only from the street boundary compression but also the very close buildings. When too close, the buildings generate the local repulsive force and the new vector is added to the vector operation. But when objects distribute very densely, the final combined vector approximates to zero, and the overlap does not yet avoid. In this case, the only displacement generalization could not resolve the question and the aggregation, deletion is required. The next section will discuss the integrated operation of displacement and aggregation.

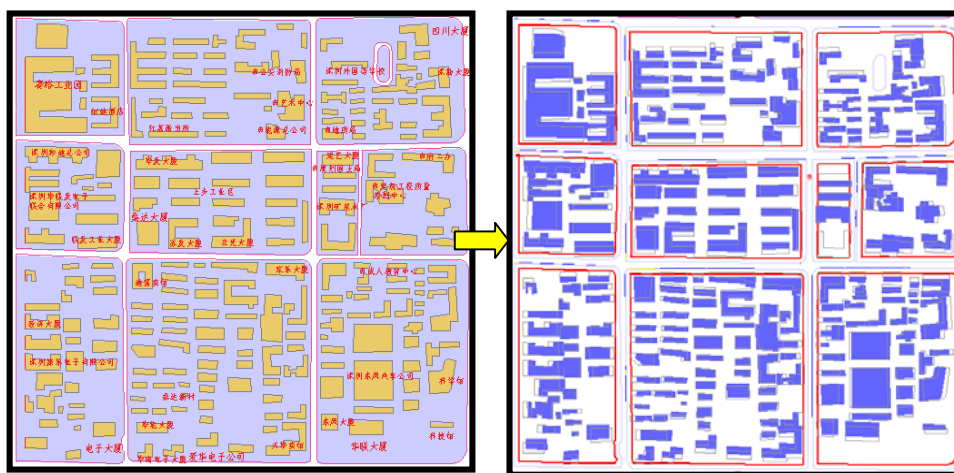


Figure 6. Real application in the displacement of street buildings during the street widening.

5. DISPLACEMENT AS THE PRIOR OPERATOR OF AGGREGATION

According to the discussion in section 2, the integration of displacement and aggregation is able to solve the conflicts and simultaneously keep the area balance of all buildings. We still use the cluster partitioning model, but concentrate on the local region where conflicts result from too close proximity. In this case, we just consider the immediate neighbor buildings not involving force propagation. The displacement force behaves as attractive one.

5.1 Where Is There Conflicts?

The distance between two neighbor buildings is usually used to detect the conflicts. But how to compute the distance between objects when considering their geometric shape? What it means for A to be near B depends not only on their absolute positions (and the metric distance between them), but also on their relative sizes and shapes, the position of other objects, the frame of reference (Hernandez and Clementini, 1995). Based on differential idea we offer the following method to compute the weighted distance between two buildings. A PP boundary goes across a set of triangles which divide the skeleton into segments. For each short segment, compute this local distance between OPs according to triangle type and then integrate the local distance weighted with the rate of local segment length to the whole skeleton length. For three types of triangle, the local skeleton width representation, W_1W_2 is expressed in Figure 7.

The computation function is $\bar{w} = \sum_{i=0}^k \frac{\|P_i P_{i+1}\|}{l} \|W_{i1} W_{i2}\|$, where

l the whole skeleton length, k the number of involved triangle. \hat{w} is also called skeleton width. This weighted distance computation based on skeleton takes into account the building shape structure, spatial distribution and other building's influence. In the recognition of building group, as the judgment parameter, the weighted distance is better than minimum distance.

Allow the weighted skeleton width as the condition of conflict detection. In the partitioning model, those skeletons with weighted width shorter than predefined cognition tolerance are identified as conflict skeletons, and those building objects related to one or more conflict skeletons are defined as conflict building objects. Figure 8 gives an example judging conflict skeletons which is represented as wide red line. According to PP connectivity, the conflict objects can be assigned into groups.

5.2 How to Displace?

The judgment of conflict buildings answers the question of who will be displaced. The further question is how far and what direction the conflict building moves.

If the conflict building has only one conflict skeleton, then the normal direction of the approximated direct line of the conflict skeleton serves as the displacement direction. Otherwise, using vector add operation computes the integrated moving direction. We suppose each conflict building is attracted by its neighbor conflict building and the attraction force is equal. When one building is attracted by neighbors from two opposite direction, or surrounded by conflict buildings (it means all skeleton related to one building are conflicted), it will keep unchanged. In actual application, when the added vector length is shorter than a threshold, we can think no one direction attraction is strong enough over other directions and also regard the object as

fixed. In figure 8, for conflict objects the dark arrow symbol represents the displacement direction and the dark dot represents the building fixed.

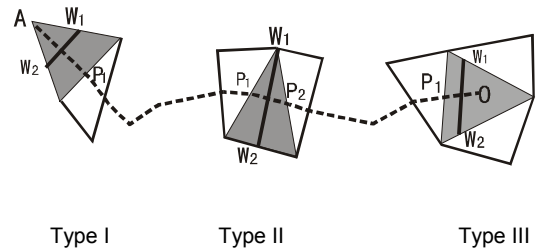


Figure 7. W_1W_2 , skeleton width representation for 3 types of triangle

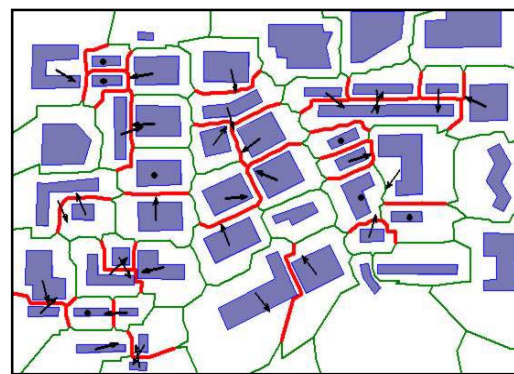


Figure 8. Experiment illustrations of conflict skeletons, visualized as wide line, and building displacement direction, visualized as arrow line and dark dot

For offset length of displacement, firstly we suppose the position accuracy is not less than half of conflict distance. It means the conflict building moving face to face and meeting together in some position is not against position accuracy. Parallel with the displacement direction, draw an extended line from each vertex of conflict OP and compute the distance between start vertex and intersection point of extended line and PP boundary. Select the shortest distance as displacement offset length. This process guarantees each building moving within its own PP range, not overlapping with other building's PP. It means the displacement will not result in new conflict.

The purpose of displacement in building cluster generalization is to statistically maintain area balance. But usually after displacement, it is not yet to arrive that two buildings exactly share a common seamless boundary, still existing gap area. An improvement is to execute rotation, but rotation angle and rotation scope is complex to decide and yet can not resolve problem completely.

5.3 Progressive Generalization Workflow

How to integrate displacement and aggregation in a complete generalization process depends on workflow control. Considering the fact that conflict in building cluster is related to each other, we can not simply aggregate all the conflict buildings which is connective to each other. Aggregation of part of conflict objects and displacement may resolve the conflict between different part groups. Especially when scale changes largely, the predefinition of large conflict distance may

lead to all building locating within one street block are conflict. Obviously it is not proper to combine all building into a big one. The whole control workflow of building cluster generalization should be a progressive procedure to remove conflict step by step.

If the distribution frequency of skeleton width covers a broad range and the width value is able to be obviously distinguished, we introduce MST method idea(Regnauld 1997) to control the generalization procedure. It takes into account the distance difference in quantity. The workflow is described briefly as follows.

- Repeat the following steps until step i> finds no conflict :
- i> Construct triangulation and based on the partitioning model find conflict skeletons, conflict buildings.
 - ii> Sort the conflict skeletons on weighted width from short to long.
 - iii> Scan the sorted conflict skeleton to check the related left and right conflict OPs. Two OPs can only remain current scanned skeleton as conflict. Remove other conflict skeletons.
 - iv> Aggregate two buildings between the current conflict skeleton.

The above workflow guarantees each conflict removal happens exactly between two buildings. Figure 9 illustrates the progressive procedure of building cluster generalization. If the building distribution is random and the conflicts are few, the workflow above can get proper generalized result. But questions exist in next two aspects: 1>The early aggregated building will displace many times in the following processes and the position

accuracy may be damaged. 2> Distribution pattern can not be maintained completely.

6. CONCLUSION

Based on the Delaunay triangulation skeleton, this study constructs the partitioning model which is similar to Voronoi diagram. The property of equally separating space makes it a powerful tool to analyze the distribution of polygon cluster. A displacement field is constructed in which the displacement propagation and decay can be realized. Aiming at the resolving of proximity conflict and the prior operator of aggregation, this study presents two displacement methods respectively. But for an automatic generalization, two methods have to be combined. The selection of generalization operators and inter-execution of them is the complex decision-making in the macro level.

Independent building simplification gets some achievements. Building cluster generalization belongs to high level research still facing many problems. The representation and automatic recognition of spatial distribution pattern is the first question to be resolved in the future research. When the distance between building is generally the same, the judgment of building cluster mainly depends on non-distance fact. The Gestalt nature in building size, orientation, shape, and distribution structure will be an important consideration fact. How to involve the Gestalt principles in the pattern recognition of building cluster is our next research in the future.

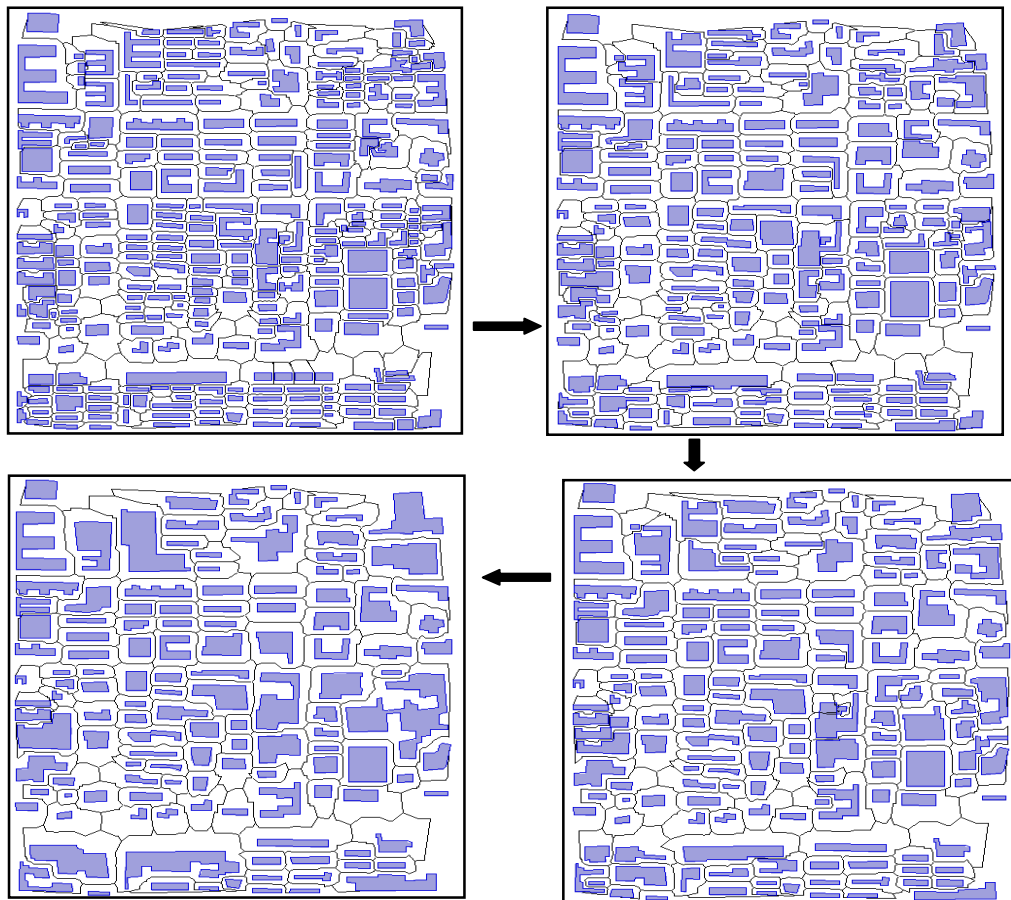


Figure 9. The progressive generalization of densely distributed building cluster

ACKNOWLEDGMENT

Tinghua's research is supported by National Science Foundation, China under the grant No. 40101023.

REFERENCES

- AI T, and Oosterom, P. Van, 2001. A Map Generalization Model Based on Algebra Mapping Transformation. In: Aref W G(eds) *Proceedings of the 9th ACM-GIS*. Atlanta,GA, pp 21-27.
- AI T, Guo R, LIU Y, 2000. A Binary Tree Representation of Bend Hierarchical Structure Based on Gestalt Principles. In: Forer P, Yeh A G O, He J(eds) *Proceedings of the 9th International Symposium on Spatial Data Handling*, Beijing, pp. 2a30-2a43.
- GUO, R. and AI T., 2000. Simplification and Aggregation of Building Polygons in Automatic Map Generalization. *Journal of Wuhan Technical University of Surveying and Mapping*, 25(1),pp.25-30 (in Chinese).
- Harrie, L. E., 1999. The Constraint Method for Solving Spatial Conflicts in Cartographic Generalization. *Cartography and GIS*, 26(1),pp.55-69.
- Hernandez, D. and Clementini, E., 1995. Qualitative Distance. *Proceedings of COSIT'95*, Semmering, Austria,pp.45-57.
- Hojholt, P., 2000. Solving Space Conflicts in Map Generalization: Using a Finite Element Method. *Cartography and GIS*, 27(1),pp. 65-73.
- Jones, C. B., Bundy, G. L. and J. M. Ware, 1995. Map Generalization with a Triangulated Data Structure. *Cartography and GIS*, 22(4),pp. 317-331.
- Li C, CHEN J and LI Z., 1999. A Raster-based Algorithm for Computing Voronoi Diagrams of Spatial Objects Using Dynamic Distance Transformation. *International Journal of Geographic Information Sciences*, 13(3),pp.209-225
- LI Z. and Su, B., 1997. Some Basic Mathematical Methods for Feature Displacement in Digital Map Generalization. *Proceedings of the 18th ICC*, Stockholm, Sweden, Vol. 2, pp.452-459.
- Mackaness, W. A., 1994. An Algorithm for Conflict Identification and Feature Displacement in Automated Map Generalization. *Cartography and Geographic Information Systems*, vol. 21, no. 4, pp. 219-232.
- Peng, W. and J. C. Muller. 1996. A Dynamic Decision Tree Structure Supporting Urban Road Network Automated Generation. *The Cartographic Journal*, 33(1), pp.5-10.
- Preparata, F. P. and M. I. Shamos, 1985. *Computational Geometry An Introduction*, Springers-Verlag.
- Regnauld, N., 1996. Recognition of Building Cluster for Generalization. *Proceedings of the 7th International Symposium on Spatial Data Handling*, pp. 185-198.
- Regnauld, N., Edwardes, A. and Barrault, M., 1999. Strategies in Building Generalisation: Modelling the Sequence, Constraining the Choice. *Workshop of map generalization*, 19th ICC, Ottawa.
- Ruas, A., 1998. A Method for Building Displacement in Automated Map Generalisation. *International Journal of Geo-graphic Information Science*, v. 12, pp. 789-803.
- Ware, J. M. and C. B. Jones, 1997. A Spatial Model for Detecting (and Resolving) Conflict Caused by Scale Reduction". In: M.J. Kraak and M. Molenaar (eds.), *Advance in GIS Research II (7th Int. Symposium on Spatial Data Handling)*, London: Taylor & Francis, pp.547-558.