DISTRIBUTION ANALYSIS AND AUTOMATIC GENERALIZATION OF URBAN BUILDING CLUSTER

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Abstract

This paper presents a model for building cluster distribution analysis based on Delaunay triangulation skeleton. Through selective organization, the skeleton connection within gap area between building polygons obtains a special geometrical construction which is similar to Voronoi diagram with properties of spatial partitioning equally. Each building polygon is considered as an inherent individual which can be regarded as growth region of building seed. Based on this model, several cluster structure variables can be computed for building distribution analysis, such as distribution density, topological neighbor, adjacent distance, adjacent direction. Considering the constraints of position accuracy, statistical characteristics in building cluster generalization, the paper gives a progressive algorithm of building cluster aggregation, including conflict detection (where), object (who) displacement, and geometrical combination operation (how). The context relationship of cluster structure is reflected through weighted distance computation, vector combination and other strategies. The algorithm has been realized in an active generalization system and some experiment illustrations are provided in the paper.

1. INTRODUCTION

Map generalization has to take into account spatial object properties in geometrical, semantic and topological aspects. The Objects with the same geometrical type, but different geographic meaning should be executed with different generalization model and algorithm. In recent years, the study of geo-oriented generalization is active, which aims at some special geographical categories (Pooten and Jones, 1999; Rasu, 1998; Bader and Weibel 1999). The research on urban building abstract is an example. As a polygon object with human culture characteristics, the building has different properties in spatial distribution, shape structure, Gestalt nature compared with natural features such as soil parcel, vegetable, lake. Disjoint cluster distribution and orthogonal shape properties require to be considered specially in building generalization.

Building cluster generalization includes multiple level analysis and operation. Grouping is the first decision-making which is based on conflict detection, distribution pattern recognition, Gestalt nature cognition. The following displacement involves how far and what direction identification. Thirdly, the geometrical combination and simplification has to maintain orthogonal geometric nature. Three level processes require special model to derive such descriptions variables as distribution density, distribution pattern, adjacency distance, adjacency direction etc. Independent building simplification is active in this field and achieves some methods and algorithms. From the point of readable view, Regnauld and Edwards (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, Regnauld (1996) develops a method to classify building group applying MST model in graph theory. Russo(1998) presents an algorithm of building displacement to resolve conflicts between building and street edge. These works are relative independent in the whole procedure of map generalization. This paper attempts to comb the first two issues of building generalization, concentrating on cluster structure displacement and aggregation and giving a model to support cluster analysis.

In building cluster generalization, it is difficult to satisfy all constraints. Group combination which exactly maintains position accuracy (no displacement) of each building may result in area increasing greatly, due to gap area between original buildings being included. The compromise strategy is to sacrifice each constraint partly, not respecting anyone condition completely. This strategy requires to handle three level operation interdependently. It also needs generalization model containing different functions to support both high level decision making and low level geometric operation, to answer such questions of where happens conflict, how to displace (direction and offset), how to aggregate. This paper will present some data model having this kind of properties to support building aggregation. Based on Delaunay triangulation skeleton, we will construct a geometrical construction which is similar to Voronoi diagram with properties of spatial partitioning equally. Each building polygon is surrounded by one partitioning polygon which can be regarded as the growth region of building seed. Based on this model, several cluster structure variables can be computed for building distribution analysis, such as distribution density, topological neighbor, adjacency distance, adjacency direction. This model makes use of the powerful function of Delaunay triangulation in spatial adjacency analysis.

Remained contents is organized as following: The constraints in building polygon generalization is discussed in section 2. Section 3 gives the model of partitioning geometrical construction and some variable computation based on this model. A progressive algorithm of building cluster aggregation is presented in section 4 with experiment illustrations, and then some future improvements are discussed in conclusion, section 5.

2. CONSTRAINTS OF BUILDING GENERALIZATION

Based on geometric, topological and semantic analysis, the constraints of building generalization involves position accuracy maintenance, short space distance avoidance, the whole area balance maintenance, Gestalt keep in distribution structure, and square shape retain. The main purpose in building generalization is to remove spatial conflict and during the procedure to respect above constraints as much as possible. From the point of readable view, when distance between buildings is shorter than cognition tolerance, we may think the spatial conflict generating. To resolve conflict, the candidate operations include deletion, displacement, aggregation. Deleting some buildings needs to consider semantic importance and
spatial characteristic, such as area size. Generally, through SQL conditional selection can delete some categories of building and remained building is equally of importance requiring other operation to solve conflicts. 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. Combination makes the conflict between original buildings disappear but increases the building size. Furthermore the conflict between new building and the old one exist, unless all buildings having conflict to each other are combined to one big block. Single operation does not work for building cluster generalization. The valid strategy is executing both displacement and aggregation. (The independent simplification is necessary, however we do not consider it here for building cluster.) Two or more buildings moving together and aggregating into one, the conflict between them does not exist, on the other hand, movement gives the contrary direction more room and the conflict between new just generated building and context neighbors may also be resolved.

Some of constraints are contradict to each other in building generalization. The compromising strategy to sacrifice each constraint partly, not respecting anyone completely. Spatial conflict removal is one of constraints and its solution has to consider maintenance of position accuracy, the whole area balance and Gestalt nature. The largest offset distance of displacement should be restricted within position accuracy. Generally displacement can not guarantee two neighbor buildings seamlessly sharing one common boundary, still with gap fragment. So the aggregation result has the trend to increase area. Following independent simplification needs to consider this fact, and to perform operation preferring area reduction.

The Gestalt nature is hard to maintain because of the difficulties of formally describing these cognition principles. We can psychologically feel some buildings with same size, same direction, same shape and other similar visual characteristics should be assigned to one group, but until now we can not find a model to represent spatial distribution pattern to identify the group. It depends on complex spatial relationship representation with the consideration of context environment, such as similarity relation map. For building cluster, when the difference of gap distance is distinct to each other, the grouping decision can be made on only distance computation. Otherwise there may be the case that all buildings within one street block has conflict distance to each other and needs to be classified as one group. In this situation, it is Gestalt nature rather than geometric distance that distinguish building group in cluster structure.

3. PARTITIONING GEOMETRICAL CONSTRUCTION BASED ON DELAUNAY TRIANGULATION SKELETON

Delaunay triangulation, which has the circumcircle principle and closest to equalateral 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. It can be applied to detect neighbor objects of one determine object and to analyze the conflict between them (Jones etc., 1995, Ware etc., 1997). In spatial pattern recognition, P enorm implements Delaunay triangulation model identifying islands lineal arrangement structure (Pen g 1995). For polygon categorical map generalization, Bader and Weibel propose an approach of polygon combination by dividing small polygon equally along skeleton and blending two parts into neighbor polygons respectively (Bader and Weibel, 1997). Poonten and Jones (1999) develop a method of customisable line generalization using Delaunay triangulation. [8] [2000] constructs a binary tree on the basis of Delaunay triangulation to represent curve bend hierarchical structure.

Building cluster distribution contains much information associated with adjacent relationship under context environment. Next we will use Delaunay triangulation constructing a special geometric construction to extract this kind of distribution structured information.

3.1 Constructing Interpolated and Constrained Delaunay Triangulation

When constructing Delaunay triangulation, all the building boundary must be forced to serve as edge of triangles, not intersecting with any triangles. This kind of triangulation is called constrained Delaunay triangulation (Jones, 1995). The triangles in Delaunay triangulation (not constrained) network have the properties of “as equilateral as possible” avoiding the appearance of very narrow triangles and very sharp angles. It is this nature that makes the Delaunay triangulation a powerful model in spatial adjacency analysis. However, for constrained triangulation, the constrained condition destroys this nature. In the case of building cluster, some of boundary segments may be long and leads to triangles also inheriting the long edge. The constrained triangulation will not correctly detect adjacent relationship between objects as illustrated in Figure 1 top. To resolve the contradict, we apply a method of point-interpolation on long boundary edges. This method divides the long edge into several short segments and makes them respectively act as different triangle edge in triangulation network. In Figure 1, for the top graphic copied from (Ware, 1997), the polygon boundary is not interpolated and object o0 cannot be identified having neighbor relation with object o1. After the polygon boundary is interpolated as shown in the bottom graphic, the triangulation may correctly detect neighbor relationship between object o1 and o0.

![Fig. 1. Directly constructing constrained Delaunay triangulation results in many very narrow triangles and can not find o0 is the neighbor of o1. After boundary being interpolated, the identification result is correct.](image)

A series of points add on building boundary edge in which interval distance between two points is longer than interpolation interval threshold w. Suppose the original building polygon boundary (P), then the interpolation points (Qw) is computed as following:

\[ X = \frac{x}{k+1} + k \frac{x}{P} \]

where, \( k = \frac{w}{P} \)

To prepare for the next application, we define a data structure for triangle storage with consideration of the relation between building polygon and triangles:

```c
typedef struct TRI-TYPE {
    int  belong_to[3];  /* Polygon IDs on which three triangle vertex points locate */
    int neighbor[3];  /* Three neighbor triangle IDs of the current triangle */
    POINT barycenter;  /* The barycenter point of triangle */
} ...
```

![Fig. 4. Based on building polygons, the geometric construct of skeleton (visualized as white lines).](image)

Fig. 4. Based on building polygons, the geometric construct of skeleton (visualized as white lines).
The barycenter contributes to decide whether triangle is within building or not through point-in-polygon judgement. Based on this data structure we can select triangle sub-set locating within building, outside building and connecting two or three buildings, outside building and only in one building's concave parts respectively.

3.2 Selecting and Classifying Interested Triangles

We use the following query statement to get interested triangle set (where t represents one triangle): Select { t | from All_Triangles where t.belong_to[0] == t.belong_to[1] == t.belong_to[2] } 

It removes two categories of triangle from the whole triangle set. One is those within building polygon, another outside building but locating in one building's concave region. The reason of latter removal is to avoid appearance of dangle skeleton branch in the next partitioning geometric construction creating. Figure 2 illustrates the selected triangles between buildings, shaded with light grey and marked with Rome number.

![Fig. 2. Interested triangles selection and their type assignment](image)

For selected 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. As shown in Figure 2, 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.

3.3 Creating Building Partitioning Polygon Based on Triangle Skeleton

Skeleton connection way for three types of triangle is described in figure 3, where P1, P2, P3 the midpoint of corresponding triangle edge, and O the triangle barycenter. Linking skeleton segment by means of next paths and through polygon topological organization, we obtain the special geometric construction as illustrated in Figure 4.

- Type I: A → P1 or P1 → A
- Type II: P1 → P2 or P2 → P1
- Type III: O → P1 or P1 → O1, l = 1, 2, 3

This geometric construction looks like Voronoi diagram (VD). But according to strict definition of VD (Shirai 1985), it is not Voronoi diagram. VD cell is convex polygon, while the partitioning polygon of this geometric construction may be concave. VD network is originally point cluster oriented. For polygon cluster, it is difficult to define VD, but just from the viewpoint of GIS application, considering properties of space partitioning equally, it is feasible to borrow Voronoi name and call this construction as polygon cluster's VD.

Rather than construction name calling, what we are interested in its properties as follows:

- Each partitioning polygon contains one building;
- Each node relates three skeleton edge;
- Each edge of partitioning polygon boundary faces to a left building and a right building, separating two buildings equally in space;

If the number of type I, type II, type III triangle is n1, n2, n3 respectively, then the node number is n1 + 3n2, and the edge number (n1 + 3n2)/2.

Property iii is except for the border area of building cluster. Property i and ii is problem for the case of concave building, for example of building A, B in Figure 4. As triangles locating in concave part have been removed in previous selection process, the skeleton is no long to separate space equally between concave building and its neighbor building. It means some of outside concave area is also regarded as belonging to building. But for such as building B in figure 4, not filling "formed mouth" is difficult to equal partitioning. It is same for the method of raster operation to get polygon cluster VD. This is the reason why we do not directly use skeleton based on all triangle outside building to get this kind of geometric construction.

The partitioning polygon can be thought of as the growth region of corresponding building, covering the whole area with neither gap nor overlapped region. We can understand it is the result of each building competing outward for growth range and this competition has considered context impact. In this sense, we can say each building has two representation in cluster coverage. Next we call building polygon OP (Object Polygon), and partitioning polygon GP (Growth Polygon). The relationship analysis of OP to each other can be transformed to that of GP instead.

To describe topological and geometric aspects, We define the following data structure for GP edge storage:

```c
typedef struct SKELETON_TYPE
{
    long LObject; // Left building
    long RObject; // Right building
    POINT *pt; // Coordinate string
    long pNum; // Coordinate point number
    double Width; // Weighted width between LR object
    double MinWidth; // Minimum width between LR point;
    long FromNode; // Related start node;
    long ToNode; // Related terminal node;
} SKELETON_Type;
```

3.4 Parameter Computation

Based on the relationship of GP to each other and the relationship between GP and OP, some useful geometric parameters can be computed.
3.4.1 Distribution density

For generalization application, the building distribution density supports operation decision from macro perspective. In partitioning model, the description of building distribution being dense or sparse depends on the rate of OP area to GP area. The denser, the smaller room one building gets during competing outward, and the more similar of GP size to OP size. So this area rate ranging from 0 to 1.0 is able to represent building distribution density. Figure 5 is an example of this kind of density representation. The region is shaded with gray scale proportional to the rate of OP area to GP area.

Fig. 5. An illustration of representation of building distribution density, the region shaded with grey scale proportional to the rate of OP area to GP area.

3.4.2 Adjacent Distance

In building cluster, the adjacent degree between two buildings can not simply be described as minimum distance, such as in Figure 6. 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). The context environment plays an important role.

Fig. 6. The minimum distance is same, but C is closer to A than B in visual cognition.

Based on partitioning model, applying differential idea we give the following method to compute distance between two buildings,

\[ \frac{W_{A}}{W_{B}} \leq \frac{|P_{A}P_{B}+||W_{W_{B}}||}{||W_{W_{A}}||} \]

Type I
Type II
Type III

Fig. 7. \( W_{W_{A}} \), skeleton width representation for 3 types of triangle

Fig 8. Neighbor C moving and rotating leads to the distance change between building A and B based on the weighted skeleton width computation.

A GP boundary edge relates two adjacent OPs and 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 by the length ratio of segment to the whole skeleton length. We use skeleton width representation, \( W_{W_{A}} \), expressed in Figure 7. The computation function is where \( l \) the whole skeleton length, \( k \) the number of involved triangle, \( \omega \) 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 Figure 8, building A and B keeps unchange and C moves and rotates, resulting in the distance between A and B decreases. In visual cognition, we can feel in the right A and B are closer than that in the left due to C position change. For Figure 6, this weighted distance computation will get the adjacent relation between A and C is closer than that of A and B. So this distance computation is consistent with visual cognition in some degree.

3.4.3 Adjacent Direction

An approximated direct line can be computed for one skeleton using Least Square Adjustment method, and the normal line direction can be regarded as the adjacent direction between two adjacent buildings. Adjacent direction will be used in next section for building displacement.

4. APPLICATION IN BUILDING CLUSTER GENERALIZATION

Building cluster generalization involves grouping, displacement, aggregation and simplification. The partitioning model is able to support the generalization in several aspects. From high level decision to low level operation, this section discusses the process on the basis of many experiments in detail.

4.1 Where Is There Conflict?

The weighted skeleton width acts as the condition of conflict recognition. We present two conflict concepts: conflict skeleton and conflict building. Those skeletons with weighted shorter than predefined tolerance are identified as conflict skeletons, and those building objects related to one or more conflict skeletons are defined as conflict building objects. Figure 9 gives an example of judgement of conflict skeleton and conflict building.

Fig. 9. Experiment illustrators of conflict skeletons, visualized as wide line, and building displacement direction, visualized as arrow line and dark dot.

According to GP connectivity, the conflict object can be assigned into classes. This class is depend on adjacent distance, and further grouping needs Gestalt analysis and other non-distance assessment.

4.2 How to Displace?

The judgement criteria is: a) no displacement in the same location direction the object; b) if the conflict building is adjacent directly, the width vector add overlap. We suppose that the conflict building is always surrounded by one building. In the application, when the threshold, we just consider enough overlap the overlapping width in Figure 9 expressed as dark arrow sys the dark dot represents.

For offset length and direction accuracy is a problem, the conflict building direction is the overlapping, the shortest displacement will not result in overlap displacement.

The purpose of this model is to maintain displacement, to gain a common solution for displacement and rotation scope, and to solve problem completely.

4.3 How to Aggregate?

Considering the aggregation meaning of nature, We use the filling on the object instead of finding MBR, and filling object shown in Figure 10.

According to practice, the filling object can be assigned to conflict building attribute class. This class is depend on adjacent distance, and further grouping needs Gestalt analysis and other non-distance assessment.
The judgement of conflict building object answers the question of who will displace. The further question is how far and what direction the conflict building moves.

If the conflict object has only one conflict skeleton, then the adjacent direction serves as moving direction. Otherwise, using vector and 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 directions, 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. Figure 9 expresses the movement direction of conflict object, the dark arrow symbol representing the displacement direction and the dark dot representing the building fixed.

For offset length of displacement, firstly we suppose the position accuracy is not less than half of conflict distance. It means conflict building moving face to face and meeting together in one 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 GP boundary. Select the shortest distance as displacement offset length. This process guarantees each building moving within its own GP range, not overlapping with other building's GP. It means the displacement will not result in new conflict. This point is very important in displacement generalization research (Mackness 1994).

The purpose of displacement in building cluster generalization is to maintain statistic area balance. But generally after displacement, it is not yet to get two buildings that 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.

4.3 How to Aggregate?

Considering the square characteristics of building shape, the aggregation of displaced buildings has to maintain orthogonal nature. We use the method of two vertical direction scanning and filling on the basis of raster data structure, including 6 steps: finding MBR, rasterizing, scanning and filling lines, scanning and filling column, vectorizing, rotating. The whole procedure is shown in Figure 10.

This method applies two vertical direction of MBR edge to scan and fit raster element using the suppose that the MBR edge direction can represent the main direction of building cluster. It guarantees that the gap area between neighbor buildings is filled in the shortest connection.
Concrete operation in building cluster generalization. How to use them 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 object which is connective. Aggregation of part of conflict object 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 can introduce MST method idea(Renauld 1997) to control the generalization procedure. It takes into account the distance difference not only in quality between conflict and non-conflict but also in quantity. The workflow is described briefly as follows.

Repeat the following steps until step i> finds no conflict :

i> Construct triangulation, compute GP and find conflict skeleton, conflict building object.
ii> Sort the conflict skeleton on weighted from short to long.
iii> Scan conflict skeleton to check the related left and right conflict OP. Two OPs can only remain current scanned skeleton as conflict. Remove other conflict skeletons.
iv> Resolve remained conflicts using the above aggregation method.

The above workflow guarantees each conflict removal happens exactly between two buildings. Figure 11 illustrates some procedures of building cluster generalization.

If the building distribution is random and the conflict s are few, the above workflow can get proper generalized result. The questions exist in next two aspects:

1. The early aggregated building will displace many times in geometric transformation and the position accuracy may be damaged.
2. Distribution pattern can not be maintained.

The workflow improvement depends on further grouping the conflict objects which have been identified by adjacent distance. The mini distance difference is not able to distinguish building group, requesting non-distance standard. The Gestalt nature in building size, orientation, shape, distribution structure is an important consideration fact.

Connecting center points within Voronoi diagram polygon gets dual geometric construction, Delaunay triangulation. Correspondingly, based on building partitioning model, connecting representative points of conflict building obtains some connective networks, as shown in Figure 12. The further works of this research in the future is to discover building distribution pattern based on network analysis and combined with other methods.

5. CONCLUSION

Based on Delaunay triangulation skeleton, this study constructs a building partitioning model which is similar to Voronoi diagram. The nature of equally separating space makes it a powerful tool to analyze polygon distribution cluster. When applied in building cluster generalization, it enables to solve conflict detection, displacement offset and direction computation. The improved distance computation between two buildings takes into account the context environment and conforms to visual cognition. The model and algorithm presented in the paper has been realized in an interactive map generalization system.

Independent building simplification gets some achievements. Building cluster generalization belongs to high level research facing challenges. The representation and automatic recognition of spatial distribution pattern is the first question to be resolved.

References


