AN AUTOMATED CARTOGRAPHIC GENERALIZATION PROCESS: A PSEUDO-PHYSICAL MODEL

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ABSTRACT:

Automating the map generalization process has traditionally been a major focus of research in cartography and GIS environment, even though a usable holistic generalization method is still lacking. The model described in this paper examines the generalization process from a new standpoint that views the map as a stage in area warfare. A pseudo physical model was developed for automated generalization employing the electric field theory toward understanding and describing the action and behavior of active objects in the map generalization process. The paper focuses on the object properties analysis in order to determine the "power" of each object in any given map, and the interactions between these powers. These interactions produce "forces" that act on the objects and control their behavior according to cartographic constraints, in order to resolve spatial conflicts in an ideal manner.

1. INTRODUCTION

Cartographic generalization aims to simplify the representation of cartographic data to suit the scale and purpose of the map. Although automation of cartographic generalization has been an extensive field of research (Weibel & Jones 1998, Kilpelainen 2000, Harrie 2003, Steinger & Weibel 2005, Sester 2005), there remains a lack of a usable holistic generalization method. Successful implementation of a generalization process is supposed to produce a good map that satisfies cartographic requirements, rules and constraints. Recently several methods have been developed based on constraints and rules definition (Raus & Plazanet 1996, Sester 2000, Raus 2000, Harrie 2003). However, it is clear that more research is needed on defining and formulating the rules and constraints to be applied. The main issue of the generalization process is to determine where the conflicts are and how to resolve them without creating new conflicts. The objects in the map must not be treated in isolation, and the combined generalization should model the relationship between the objects and the way they affect each other. Several authors (Sajakoski & Kilpelanen 1999, Hehai 2001, Harrie 2003, Jones & Ware 2005, Sester 2005) have already suggested such holistic processes; however, no solution has been presented for the implementation of the complete generalization process in one continuous step.

The research described in this paper examines the behavior of the map objects and the interactions between them in order to better understand the generalization process. The suggested pseudo-physical model for automated generalization employs electric field theory to understand and describe the action and behavior of active objects in the map generalization process. Several parameters are defined in order to determine for each object in the map a "power" that expresses the "electric field" environment, and sets rules to control the mutual interaction forces between these powers toward a compromise between the constraints and to resolve the competition between the objects for space on the limited map area at a reduced scale. The parameters are dependent on object properties (area, type, stiffness, shape) on the one hand, and area properties (density, empty area surrounding an object, map target, map scale) on the other hand. Each object acts according to its power, computed as a function of its properties and these parameters. Interactions between map objects are expressed by the actions and the constructed forces aimed at retaining the cartographic constraints and affected by several parameters dependent on properties of surrounding objects. The pseudo-physical generalization model takes into consideration the surrounding objects and defines their properties, such as distance, type, density and topology. As a result, the surrounding objects affect and cause the "weak" objects to change their shape or place. The implementation of this new method requires: (i) determination of quantities and effect of each parameter; (ii) definition of rules and constraints of each force action; and finally (iii) translation of the results into one or more of the generalization operators - displacement, aggregation, selection, and enlargement.

2. THE PHYSICAL MODEL THEORY

In this study, the generalization process is controlled by the power of objects. These powers have been determined and thus affect and act according to the process rules. The forces that are "developed" in each object as a result of action of the powers are "translated" according to their value and direction to suit the generalization operator in respect to the process constraints.

An analogy to the interaction between a large numbers of objects can be found in electric field theory. In an electric field each "object" acts according to its power, affects its neighbors and is in turn affected by them. This study proposes to imitate the electric field theory, assuming that the map generalization process will be based on the mutual effect of the "powers" of the objects in the map.. A "power" is determined as a function of the object's properties, location, and the surrounding area and objects. Since the action of the power controls the object's behavior, it must be calculated carefully, taking into account all affecting elements, and the cartographic rules that must be maintained.

2.1 Cartographic Rules and Constraints

A successful generalization process must fulfill several requirements, defined as cartographic rules. A possible framework for automatic generalization would be to formulate these requirements as constraints and allow them to control the process (Beard, 1991). The major difference between rules and constraints is that the rules state what is to be done while constraints state what results should be obtained (Harrie, 2003). Since it is difficult to define the generalization process in the form of rules, several authors have proposed and used constraints in the generalization process (e.g. Brassel & Weibel 1988, Ruas & Plazanet 1996, Harrie 1999, Ruas 2000). This model will take into account several cartographic rules while maintaining the important constraints as follows:

- Preference of the map presentation area is given to the more important objects, according to their properties and the map target.
- The importance of the map object is a function of several parameters such as area, type, place, and their close surrounding area.
- Deletion of objects is permitted only if they are smaller than minimum area and belong to a minor type according to the map target.
- Cartographers prefer to move minor objects only, (e.g. moving roads is harder than moving buildings).
- In some cases objects may be reshaped to resolve spatial conflict.
- The process must maintain special topology relations such as parallelism or perpendicularity.

2.2 Object Properties

The objects in the map are treated according to their properties, their type, and what they represent. Cartographic map generalization at a given scale is a process of competition among the objects over the map area. The power of each object is a function of its properties, surrounding objects, map scale, and map type. This power controls the behavior of the object in the generalization process in accordance with the cartographic rules.

The aim of the suggested model is to apply an "automated generalization" process, where the powers are calculated and determined in order to highlight the different characteristics of each individual object. Area is a very important element in this process; since a larger object has a higher power value. Different objects have different characteristics under the cartographic rules (e.g., trees could be easier to move than buildings). According to the map type, each object has its relative importance value (e.g. in a tourist map hotels will be emphasized more than private houses). In a similar manner, high buildings should be "stronger" than low buildings, and the process prefers not to change their shape or location. Square buildings should be "stronger" than rectangular and rectangular stronger than elongated.

Analogous to electric field theory, the power contained in each object will be calculated as a function of the following object properties:

1. Area: calculated at the map scale (size of the plotted object or its plotted symbol).
2. Shape: calculated as a function of compactness(Guienko & Doytsher, 2003), solidity, and ratio between second order moments:

$$shape = \frac{solidity * compactness}{ratio} \tag{1}$$

$$ratio = \frac{\max(I_{xx}, I_{yy})}{\min(I_{xx}, I_{yy})}$$

3. Height: a normalized value, assigned to 2D objects such as roads, and single story houses. This value is increased for multistory buildings.
4. Type: an elastic value for each object describing its "material" according to cartographic rules and map content.
5. Importance in the map: normalized values according to map type.
6. Density: a value calculated by spatial analysis to describe the environment surrounding the object.

2.2.1 Density of the Area Surrounding the Object

The area surrounding an object affects its behavior as well. Objects can be located in a dense urban area, or "isolated" in a rural area. Objects with a higher density value resulting from more objects in the surrounding area should be "stronger" as it is practically impossible to change their shape or move them. The effect of the neighboring objects' areas and the free surrounding area were taken into consideration by calculating the density value of each object, based on "the ring analysis", the spatial analysis theory developed in this research (Joubran & Doytsher, 2005):

$$Density = \frac{\sum \frac{A_i W_i}{ring\_area_i \cdot \sum Wi}}{Free\_area} \tag{2}$$

Where:
A is the effect of the area of the objects contained in the surrounding ring

W is the weight of a given ring. The ring analysis method is based on giving a larger weight to rings nearer the object.

The neighboring objects and the free area around the specific object are detected by Delaunay triangulation (Joubran & Gabay, 2000).

2.3 Determination of the object power

Values of all these elements were chosen in proportion to the expected power, thus the power can be calculated as a function of the elements.

$$power = f(area, shape, hieght, elastic, importance, density) \quad (3)$$

In order to achieve generalization results similar to those of a skilled human cartographer, a neural network sub-model was set in order to determinate for each object its relative importance as a pseudo-physical power. The neural network sub-model was based on training datasets that have been clustered into several power levels taking into account the relevant parameters.

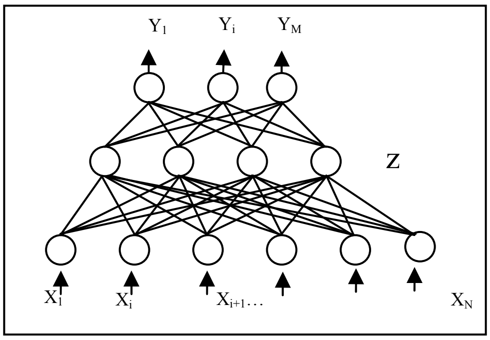

Figure 1 - Standard Neural Network Topology

A neural network is composed of neurons sorted by levels (Figure 1). The lowest level is the input of the network and the highest is the desired output. In this sub model case all inputs will be object properties. At each successive level, every neuron sums up all incoming neurons (with their assigned individual weights), effected by a special adaptive function (Equation 4). The highest level will produce the desired output. Output should be the object's relative importance as a power value level. Weights and adaptive functions will be determined according to a training data set where the power level of the objects has been set by a cartographer as a preparatory step for setting the neural network for the dataset being dealt with.

$$y_j = \sum w_{ji} z_i \qquad where \;\; z_i = f(\sum w_{ik} x_k \quad (4)$$

The developed sub-model is flexible enough to enable defining the objects' powers to be further modified according to each user's training dataset.

2.4 The Effective Shell of the Electric Field

The relative importance of each object in the map presentation area is a function of its properties, the map target and the affecting parameters of its surroundings. The object's importance is determined as an "electric charge" a value of power that protects from or affects the surrounding object and controls its behavior according to the generalization process. The interaction between powers of the involved objects is affected by the attraction and/or repulsion forces controlling its movements in relation to its neighboring objects. To enable these attraction or repulsion forces to affect the objects and change their shape or place, circumscribing "effective shells" are defined for the objects. As powers are computed according to the properties and the relative importance of the objects, each object is protected from the "stronger objects" and affects the "weaker objects" in its near vicinity. The effective shell is a circumscribing buffer around the object defined by the width of the tolerance distance. This buffer is defined and will act as the private surrounding area for the specific object.

Spatial conflict is detected when an object penetrates the other object's "effective shell", which will cause the forces between the involved objects to act in order to resolve the spatial conflict.

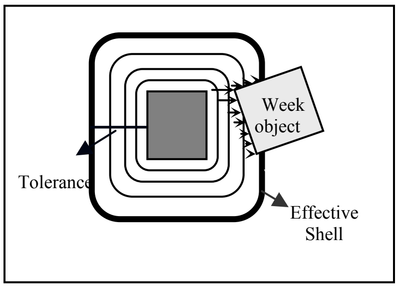

Figure 2 - Effective Shell

The effective shell contains several shells where the force of each affects as a function of its distance from the object. The scattered force acts on the weak object according to distance. The force acts only on that part of the object that lies within the effective shell and acts at each point on the weak object in a direction perpendicular to the shell. Its force value changes according to the distance of the shell from the object's edge (figure 2). The scattered force will act with equal force and moment on the appropriate point at the edge of a weak object within the effective shell of the strong object.

2.5 Forces between Map Objects

The interaction between the map objects within the effective shell is expressed as forces acting on the weaker object. In similar to an electric field, two types of constructed forces exist: attraction forces and repulsion forces. In contrast to the electric field, map objects of the same type will be attracted to each other and objects of different types will repel each other.

2.5.1 Repulsion Forces: Between objects of different types a repulsion force is constructed intended to move them away from each other to resolve this spatial conflict. The force between two objects is a direct function of the difference between the two powers. Thus, objects of the same type and power will not affect each other. However, an inverse function expresses the distance between the objects and their effect, with close objects producing a stronger effect (Equation 5).

$$Force\_repulsion_{a,b} = \frac{G*(P_a - P_b)}{R_{a,b}^{\;2}} \quad (5)$$

2.5.2 Attraction Forces: The attraction force between map objects of the same type is supposed to cluster these objects if they are too close, as a useful generalization operator for resolving spatial conflicts. The attraction force between two objects of the same type is a direct function of the sum of their powers. It is, however, an inverse function of the distance and the difference between their orientations, in consideration of the option of a clustering generalization operator caused by these attraction forces (Equation 6).

$$Force\_attraction_{ij} = \frac{(p_i + p_j)}{distance_{ij} \cdot \left|(\sin(2 \cdot rot_i) - \sin(2 \cdot rot_j))\right|} \quad (6)$$

$$rot_i = \left| round\left(\frac{min\_rot_i}{90}\right) \cdot 90 - min\_rot_i \right|$$

Where *rot* expresses the angular difference between the orientations of both circumstancing minimal rectangles of the two objects involved, it will be preferred to the clustered parallel objects.

2.6 Implementing Actions of Forces

The actions of forces on each object control and determine its behavior. An object between other objects acted upon by many forces from the surrounding objects is under higher risk of being deleted if the surrounding objects are significantly stronger. Alternatively, based on the type of object and its surrounding objects, the object will be clustered with them if they are all of the same type. A spatial conflict is resolved by displacing the weaker object in accordance with the value and the direction of the unified force affecting it.

2.6.1 Deletion of Minor Objects: Map objects of relatively minor importance according to their properties and the map target will be deleted in order to resolve spatial conflicts and enlarge the available representation area.

2.6.2 Clustering Map Objects: Attraction forces will detect close objects of the same type that should be clustered. Clustering is a useful generalization operator and is implemented in different ways. This suggested model will prefer moving clustered objects toward each other in order to enlarge their surrounding empty area. The weaker object will move toward the stronger object. Close edges will be detected and merged. In some cases the weak object might be slightly rotated in order to merge parallel edges (figure 3).

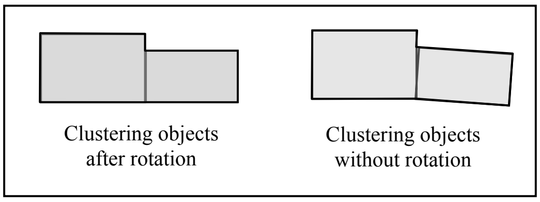

Figure 3 - Considering the option of rotating before clustering

Clustering of objects will be implemented in the second stage as another way of enlarging the representation map area. This process will start from the weakest object which will be clustered according to the strongest attraction force acting on it. Namely, it will be clustered with the strongest near neighbor of the same type. This process will be completed after a single pass over all map objects. The clustering will cause the clustered objects to change their power to become the same as the object that attracted it. The power of the clustered object might become stronger as its area increases.

2.6.3 Moving, Reshaping or Changing the Scale of Map Objects: Spatial conflicts are detected by repulsion forces between near objects, forces that intend to move them apart and resolve the conflict. The constructed forces will affect the weaker object and move it away from the stronger object (away means outside its effective shell). The weaker object will be moved only if the movement will keep him out of other effective shells, if it is already inside them or about to enter them by this movement. If no situation occurs that would take it out of all effective shells surrounding it, this weaker object will become distorted or change its scale in order to retain its shape (Figure 4).

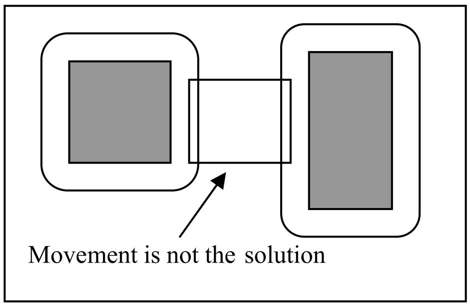

Figure 4 - Resolving spatial conflict

The method assures that no new conflicts are added during the adjustment process due to “alert shells”. Alert shells are defined around effective shells of involved objects, preventing any penetration of other objects into these “alert shells” while resolving current conflicts (figure 5).

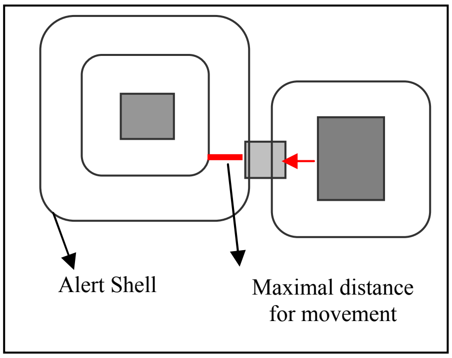

Figure 5 - The alert shell

The process is completed after passing over all objects on the map in a predefined sophisticated sequence, while repulsion forces are applied from the strongest to the weakest object. Each object is handled just once during the generalization process while taking into account all effects of its stronger surrounding objects. Movement, distortion or change of scale will not change the type of object power levels that ensure the need of just one passage over the map objects, and due to the alert shell guarantee that no new conflicts will be added during the process.

3. RESULTS

This chapter demonstrates the suggested method on a group of polygonal and polyline objects on a map of an area of buildings and roads in Haifa (Figure 6). Each building is described as a closed polygon composed of a known number of vertices, as well as regarding roads that are described as polylines. The numeric parameters for each object are calculated. A constrained Delaunay triangulation is applied by forcing building and road edges to become part of the triangle edges formed by the triangulation. The triangulation triangles detect free surrounding areas and neighbors for each object.

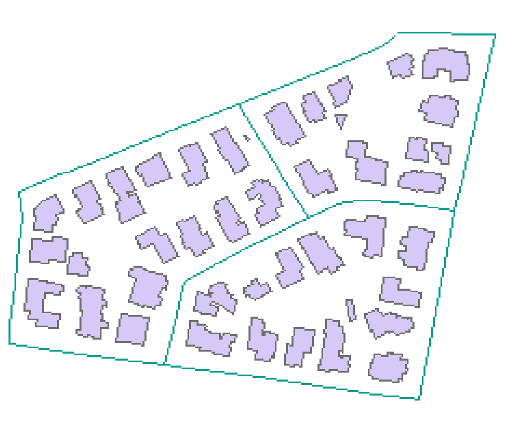

Figure 6 - Example of a group of buildings and roads

The spatial analysis uses the given properties of the objects and the layers, and calculates the effecting parameters. In this example roads are more important than the buildings and are described as solid shapes. Buildings are separated into several types with several kinds of attributes. A neural network is set to calculate the powers as a function of the relevant parameters relying on a training set of data with known powers that can be set by any user. The result of the power levels for the sample objects is demonstrated in Figure 7. Darker colors express stronger objects.

Figure 7 - Calculated powers of the map objects

The interaction between powers is expressed by forces that act on the objects involved in spatial conflicts. Translating the forces into generalization operators will resolve the conflicts. The deletion and clustering operators are carried out first, thus helping to resolve other conflicts by enlarging the empty spaces in the map (Figure 8).

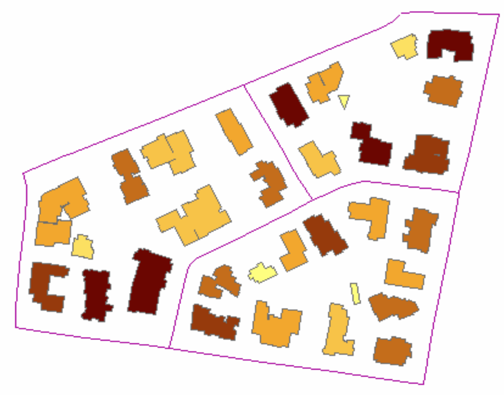

Figure 8 - Results of the deletion and clustering stages

The last stage of implementing the model implementation is resolving the spatial conflicts by movement, rotation or changing the scale or shape. Spatial conflicts are detected when an object penetrates the other object's effective shell, which causes action by forces between the involved objects in order to resolve the spatial conflict. Figure 9 demonstrates the results of the pseudo physical model by drawing the effective shell boundaries to show and insure good results by highlighting the absence of overlapping between the shells or the objects. Comparing the positions of objects before and after the last stage demonstrates the basics of the implemented theory. It shows that buildings are far from effective shells of the roads. Stronger objects affect the weaker objects and move them away from their effective shell boundaries. Weaker objects change their shape to stay away from the effective shells of their stronger neighbors.

Figure 9 – Final results of resolving conflicts

The model can be implemented for all map layers and provides satisfactory results by taking into account all layer properties and limitations and calculates the power levels for each object according to its layer and its private properties. The implemented solution translates the force actions by creating an ideal compromise between objects according to their power levels and limitations.

4. DISCUSSIONS AND FUTURE WORK

The method presented here for a new model of automated cartographic generalization, employs spatial data mining to understand the properties of objects and topology in order to determine their behavior in the generalization process. The algorithm examines the generalization process from a new standpoint that views the map as a stage in area warfare. Each object has its power and the forces control the object's final position. Electric theory helps compromise between the objects taking into account the relative importance according the objects' properties and the map target and scales. Neural networks were used to calculate the power levels for each object according to its properties, environment and to express its characteristics. Good results were achieved particularly at the stage of determining relative importance that is helpful in taking decisions for resolving spatial conflicts after investigating the properties of the object and its surrounding objects.

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