Near Real Time Automated Generalization for Mobile Devices

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SUMMARY

In this paper a new pseudo-physical model for a real time cartographic generalization is introduced. The aim is to provide specific maps on the spot for mobile devices while responding to the needs of the different users with their different interests to viewing the geospatial information. The paper presents the developed method and algorithms, followed by graphical results of real data.

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1. INTRODUCTION

Cartographic Map Generalization is "the process of deriving from a detailed source spatial database a map or database the contents and complexity of which are reduced, while retaining the major semantic and structural characteristics of the source data appropriate to a required purpose" (Weibel and Jones 1998). Maps can be treated as graphical representations of spatial structure (i.e. they show the locations of features in a geographic space and the attributes to which they are linked). Mapping can be viewed as an abstraction process by which real world features are measured and then subjected to both simplification and reduction, and then stored on a medium. This leads to the important concepts of scale, classification, symbolization and generalization in cartography (Robinson et al., 1994).

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. More recently, the demand for automated map generalization, which has been longstanding in the context of conventional GIS, has been reinforced by the prevalence of geographical information access on the Internet, that make it more complicated. There are several types of public access map-based Web sites that allow a user to zoom in and zoom out of a particular region, but at present this is usually based on stepping between independent pre-processed generalized datasets which may differ markedly in their degree of generalization. It would be desirable to be able to change the level of detail on such systems in a smooth and progressive manner rather than the quantum-leap changes that often characterize the current approach. Hand-held computers and mobile phones with small screens can now support the display of small maps, but the size limitations of these devices make it all the more desirable that the level of generalization be adapted flexibly to meet the needs of individual users (Jones & Ware, 2005). Visualizing spatial information on small mobile displays is a big chance and challenge at the same time. In order to address the tradeoff between huge spatial data sets and small storage capacities and visualization screens, we propose to visualize only the information on the screen which adequately fits the current resolution (Sester & Brenner, 2005).

The substantial amount of geospatial data in the form of digital maps which is available on the World-Wide Web, together with the increasing number of mobile devices, motivates the development of modern techniques suitable to performing near real time applications on mobile devices. In this sense, geo-spatial applications are becoming a major goal to developing techniques and algorithms. One of these applications is the need to present spatial data in different resolutions and scales in real time. A customary approach in the last years to solving the varying map scale presentation was by applying a Multiple Representation/Resolution Database approach in order to prepare in advance digital maps at different scales, as generalizing the geospatial data is a time consuming process. Moreover, Multiple Representation/Resolution Database approach requires a complex updating process as all predefined maps in the different levels (scales) should be updated simultaneously.

The research described in this paper examines the behavior of the map features and the interactions between them in order to better understand the generalization process in order to be easily automated. The suggested pseudo-physical model for automated generalization employs electric field theory to understand and describe the action and behavior of active features in the map generalization process. Several parameters are defined in order to determine for each feature 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 features for space on the limited map area at a reduced scale. These powers will act as weights to the map features through the map generalization process, that can be changed according to the desired map, scale and the individual users" interest (Figure 1). The parameters are dependent on feature properties (area, type, stiffness, shape) on the one hand, and area properties (density, empty area surrounding an feature, map target, map scale) on the other hand. Each feature acts according to its power, computed as a function of its properties and these parameters. Interactions between map features 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 features. The pseudo-physical generalization model takes into consideration the surrounding features and defines their properties, such as type, density and topology. As a result, the surrounding features affect and cause the “weak” features 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 and reshaping.

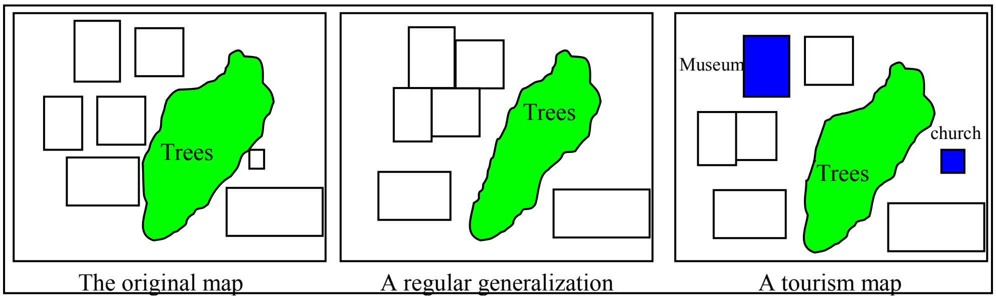

Figure 1 – different results according to the map target

2. THE PHYSICAL MODEL THEORY

This model treats the cartographic generalization process on the small screens as a physical dynamic action that is controlled by the powers of the map features. These powers have been determined and thus affect and act according to the process rules. The forces are "developed" between the map features as a result of the action of their powers and affect the weak features. The forces are “translated” according to their values and direction to fit the generalization operators in respect to the process constraints.

A similarity to the real time dynamic interaction between a large numbers of features through the digital cartographic presentation in several scales can be found in the electric field theory. In an electric field each “feature” acts according to its power, affects its neighbors and is in turn affected by them. This research 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 map features. A “power” is determined each time the process is executed according to the user interest as a function of the feature’s properties, location, and the surrounding area and features. Since the action of the power controls the features’ behavior, it must be calculated dynamically and carefully, taking into account all affecting elements, and the cartographic rules that must be maintained as well as fitting the map type and the individual user.

2.1 Cartographic Rules and Constraints

A successful generalization process must fulfill several requirements, defined as cartographic rules according to user's interest and the target of the map. A possible frame-work 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). The suggested model takes into account several cartographic rules while maintaining the important constraints as follows:

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

2.2 The Implementation of the Electric Field

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

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

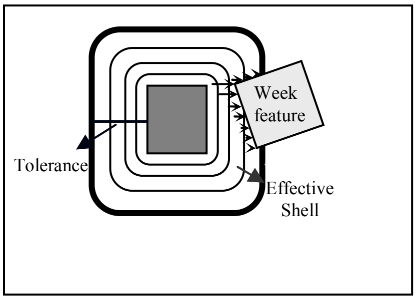

Figure 2 - Effective Shell

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

2.3 The Map Features' Powers

The powers are calculated and determined in order to highlight the different characteristics of each individual feature for presenting them in the desire view. The power for each feature will be calculated as a function of the cartographic and geometric parameters the affect the relative importance of the map features according to the desire scale and view target that set by the mobile device user. The major cartographic properties that were taken into account (Equation 1) are: area, height, the ability to move the feature or change its shape, density (calculated by hulls analysis (Joubran & Doytsher, 2008), and importance value according to the map type. The flexibility of the suggested model enables to use, in addition to the mentioned properties, more properties that might be part of future input data or required by the mobile users.

$$power = f(area, shape, hieght, elastic, importance, density) \qquad (1)$$

2.4 Neural Network Sub Model for Powers

In order to achieve generalization results that are similar to those achieved by a skilled human cartographer, a neural network sub-model was set aiming at determining for each feature 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. As mentioned earlier any type of other properties can be added, and will be involved correctly by the created neural network according to the training data. The flexibility of neural networks as well as the no necessity for further knowledge makes it a strong modeling tool.

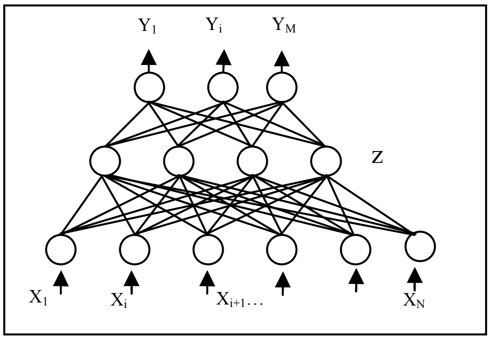

Figure 3 - Standard Neural Network Topology

A neural network is composed of neurons sorted by levels (Figure 3). 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 feature properties. At each successive level, every neuron sums up all incoming neurons (with their assigned individual weights), effected by a special adaptive function (Equation 2). The highest level will produce the desired output. Output should be the feature'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 features has been set by a cartographer as a preparatory step for setting the neural network for the dataset being dealt with. More information regarding neural network can be found in (Haykin, 1994)

$$y_j = \sum w_{ji} z_i \qquad where \;\; z_i = f(\sum w_{ik} x_k \tag{2}$$

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

2.5 Forces between Map Features

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

2.5.1 Repulsion Forces

Between features 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 features is a direct function of the difference between the two powers. Thus, features of the same type and power will not affect each other. However, an inverse function expresses the distance between the features and their effect, with close features producing a stronger effect (Equation 3).

$$Force\_repulsion_{a,b} = \frac{G*(P_a - P_b)}{R_{a,b}{}^2} \tag{3}$$

2.5.2 Attraction Forces

The attraction force between map features of the same type is supposed to cluster these features if they are too close, as a useful generalization operator for resolving spatial conflicts. The attraction force between two features 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 4).

$$\begin{aligned} Force\_attraction_{ij} &= \frac{(\mathrm{p_i} + \mathrm{p_j})}{\mathrm{distance_{ij}} \cdot \left|(\sin(2 \cdot rot_i) - \sin(2 \cdot rot_j))\right|} \\ rot_i &= \left| round\left(\frac{\min\_rot_i}{90}\right) \cdot 90 - \min\_rot_i \right| \end{aligned} \tag{4}$$

where *rot* expresses the angular difference between the orientations of the circumstancing minimal rectangles of the two involved features
As it is preferred to cluster parallel features, the weaker feature is rotated to be parallel to the stronger one as long as the rotation angel is smaller than a pre-defined criterion (see Figure 4).

2.6 Implementing Actions of Forces

The actions of forces on each feature control and determine its behavior. A feature can be in several situations as a result of the generalization process: it can be deleted if it is small and/or has minor importance; close features from the same type can be clustered; and, close features from different types can be shifted or distorted.

2.6.1 Deletion of Minor Importance Features

Map features 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 Features

Attraction forces will detect close features of the same type that should be clustered. Clustering is a useful generalization operator and is implemented in different ways. The suggested model proposes moving clustered features toward each other in order to enlarge their surrounding empty area. The weaker feature will move toward the stronger one. Close edges will be detected and merged. In some cases (when the rotation angel is smaller than a predefined value) the weaker feature is rotated till it is parallel to the stronger feature before they are clustered (Figure 4).

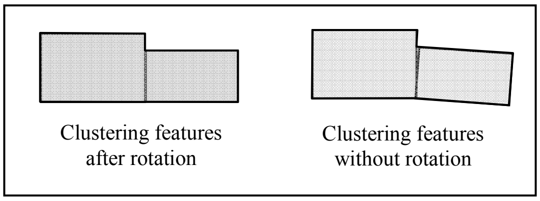

Figure 4 - Considering the option of rotating before clustering

Clustering of features is implemented in the second stage as another way to enlarging the free area on the map. This process starts from the weakest feature which, if it is needed, will be clustered with the strongest near neighbor of the same type. The process of checking the potential to clustering features is being applied by analyzing them feature by feature. This process is completed after a single pass over all map features. During the clustering process the powers of the clustered features are recalculated according to their new properties.

2.6.3 Moving, Reshaping or Changing the Scale of Map Features

Spatial conflicts are detected by repulsion forces between close features, forces that intend to move them apart and resolve the conflict. The constructed forces will affect the weaker feature and move it away from the stronger feature (away means outside its effective shell). The weaker feature will be shifted only if the movement will keep him out of other effective shells, while preventing to entering other features' effective shells. If there is no spatial location that would place the feature out of all effective shells surrounding it (Figure 5-a), the weaker feature can be distorted (Figure 5-c) or be reduced in size while retaining its shape (Figure 5-b).

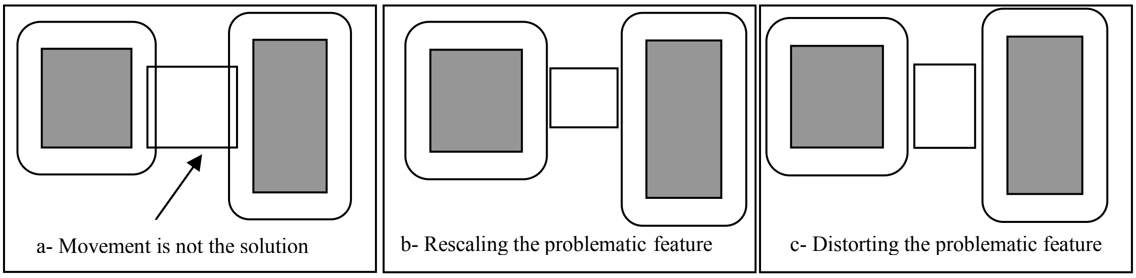

Figure 5 - Resolving spatial conflict

The method assures that no new conflicts are added during the adjustment process due to the “alert shells”. Alert shells are defined around effective shells of involved features; preventing any penetration of other features into these “alert shells” while resolving current conflicts (Figure 6).

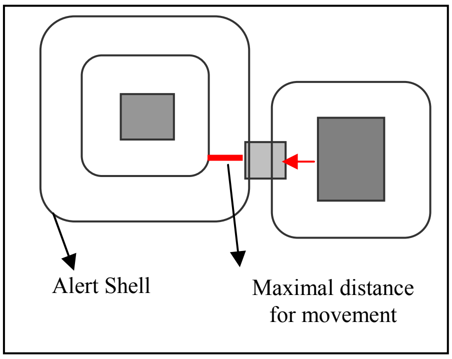

Figure 6 - The alert shell

The process is completed after passing over all features on the map in a predefined sophisticated sequence, while repulsion forces are applied from the strongest to the weakest feature. Each feature is handled just once during the generalization process while taking into account all effects of its stronger surrounding features. Movement, distortion or change of size will not change the type of feature power levels that ensure the convergence of the solution by only one passage over the map features. This is becoming possible due to the alert shell guarantee that prevents from new conflicts during the process.

The suggested model treats the map features during the generalization process according to their type, their properties, and the surrounding features. The process is controlled by the power levels of the involved features that are changed dynamically and in real time according to the desired scale and the user interest. These characteristics of the developed model enable a near real time automated cartographic generalization and thus to be applicable for mobile devices.

3. RESULTS

This chapter demonstrates the suggested method to imitating a usage of a mobile device. The presented example depicts a group of polygonal and polyline features of an urban neighborhood (the city of Holon) at several levels of zooming (Figure 7). The aim of the example is to set the right view in each desired screen. The numeric parameters for each feature were calculated and the importance values were set by the neural network sub model according to the chosen category. A constrained Delaunay triangulation was applied by forcing building and road edges to become part of the triangle edges formed by the triangulation. The triangulation triangles enabled to detect free surrounding areas and neighbors for each feature.

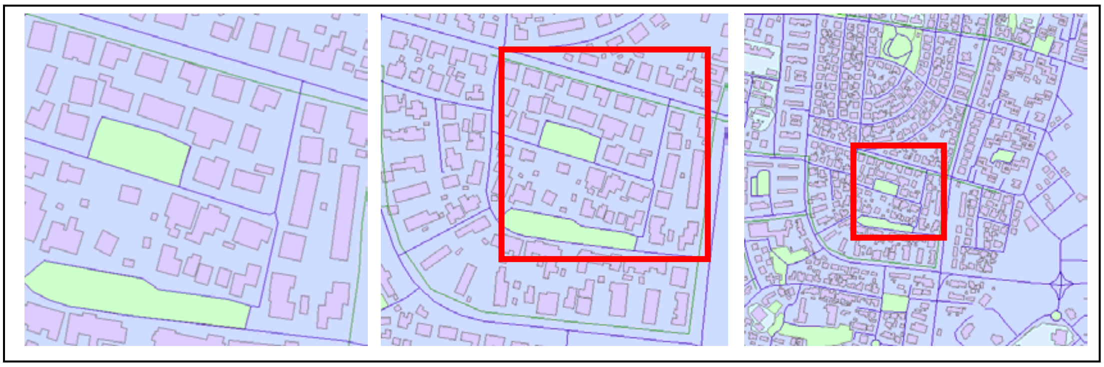

Figure 7 - Example of a group of buildings and roads

The spatial analysis was based on the given properties of the features and the layers to calculate the effecting parameters. In this example roads were set to be more important than the buildings and were described as solid shapes. Buildings were separated into several types with several kinds of attributes according to the chosen category by the user. A neural network was set to calculate the powers as a function of the relevant parameters relying on a training set of data with known powers that were set by the user. The result of the power levels for the features in the example are depicted in Figure 8. Darker colors express stronger features.

Figure 8 – the results of the determination of the powers of the simplified map features and deletion stage

The interaction between powers was expressed by forces that affected the features involved in the spatial conflicts. In order to resolve the conflicts, the forces were translated into generalization operators. The deletion and clustering operators were carried out first, thus helping to resolve other conflicts by enlarging the empty spaces in the map (Figure 8).

The last stage of the implementation was done by resolving the spatial conflicts that were detected when features penetrated other feature's effective shells. The penetration caused an action by the forces between the involved features, aiming at resolving the spatial conflict. Figure 9 demonstrates the results of the pseudo physical model by drawing the effective shell boundaries to show and ensure the satisfactory results by highlighting the absence of overlapping between the shells or the features. The fitting tolerances for the effective hulls were calculated (for each one of the three different scales). The spatial conflicts were solved by clustering, movement, rotation and changing the size or the shape of the features. A comparison between the positions of the features before and after the last stage demonstrates the basics of the implemented method. The comparison shows that buildings are far from effective shells of the roads; stronger features affect the weaker features and shift them away from their effective shell boundaries; and, weaker features change their shape to stay away from the effective shells of their stronger neighbors. The results are presented in Figure 10.

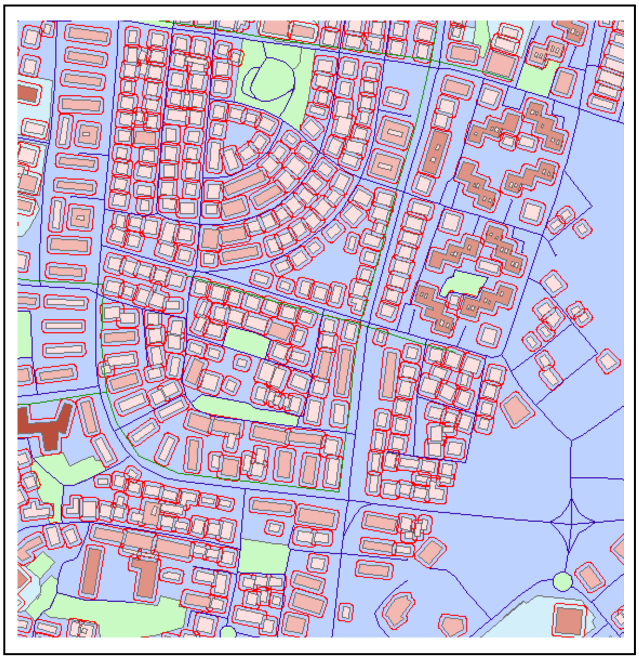

Figure 9 – The effective hulls surrounding the cartographic map features

Figure 10 depicts the final results in three levels (scales), and for each scale the three stages of the solution are given – scales are described in rows and stages in columns. Column "a" demonstrates the effective shells boundaries helping detecting spatial conflicts. Column "b" depicts the first stage of deletion and clustering. Column "c" depicts the final results including the effective shells that were added to insure that there are no spatial conflicts anymore.


a - Detecting spatial conflicts b - The stage of clustering c- Final stage of solving conflicts

Figure 10 – Final results of clustering and resolving conflicts

4. DISCUSSIONS AND FUTURE WORK

An appropriate method to carry out near real time automated cartographic generalization for mobile devices was presented. The method employs spatial data mining to understand the properties of the features and their topology in order to determine their behavior in the generalization process. The algorithms beyond the method examine the generalization process from a new standpoint that views the map as a stage in area "warfare". Imitating the Electric theory helps compromise between the features' warfare by taking into account the dynamic calculated relative importance according the features' properties, the map target and the scales – all this by using neural networks. Each feature has its power and the forces control the feature's final position in the desired view according to the users' purpose. Satisfied results were achieved particularly at the stage of determining relative importance. This is helpful in taking decisions for resolving spatial conflicts after analyzing the properties of each feature and its surrounding features. The power level for each feature is calculated dynamically according to its layer and its private properties. The implemented solution translates the force actions by creating an ideal compromise between features according to their power levels and limitations with respect to the area limitation and the view target and scale. The method can be implemented for all map layers and by taking into account all the layer's properties and their limitations is able to provide satisfactory results.

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BIOGRAPHICAL NOTES

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