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The role of digital generalization in image segmentation

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Abstract. *The use of remote sensing imagery to obtain land cover and land use maps is a common task in GIS applications. Segmentation techniques identify closed regions in images, producing vector datasets composed by polygons. Since segmentation is a bottom-up technique, the resulting vector datasets are often too detailed. Thus, we need to use generalization techniques to reduce data storage and generate maps with different degrees of detail at different scales. This paper proposes new method for polygon generalization, useful for vector data sets drawn from remote sensing data.*

1. Introduction

This paper discusses the problem of generalizing land use and land cover maps obtained by the segmentation of remote sensing images. Image segmentation methods are important for remote sensing image analysis. Segmentation divides an image into continuous, disjoint and homogeneous regions. Segmentation algorithms have many advantages over pixel-based image classifiers. The resulting maps are usually much more visually consistent and more easily converted into a geographical information system. However, segmentation techniques tend to produce regions with excessive detail. These polygons (vectors) need to be simplified and generalized to help their use.

Generalization is a practice that originates in Cartography. It calls for selecting which objects will be present in a map, and simplifying shapes and structures, based on criteria of relative importance (Robinson et al. 1995). Automated map generalization is an active research area, focusing mainly on topographic map data (e.g. buildings, road networks etc.) produced by national mapping agencies Mackaness et al. (2007); Stoter et al. (2009); Oosterom (2009). In this paper, we consider generalization techniques that are suited for polygons obtained when a remote sensing image is segmented and then classified. Figures 1 shows an example of a remote sensing image.

Due the raster structure of remote sensing images, segmentation algorithms produce a set of jagged border polygons that are derived from the pixel structure. These polygons have high geometric complexity. The algorithms also make up small regions which are not compatible with the scale suitable to derive maps from a particular image resolution. Figures 2(a) and 2(b) respectively, illustrate these problems.

When we segment a set of images to cover a large geographic region, the result is a large vector mosaic with unnecessary detail. To solve this problem we need an automated digital generalization method. This work aims to review and suggest improvements on methods for polygon generalization, based on line simplification, when applied to remote sensing derived vector data sets.

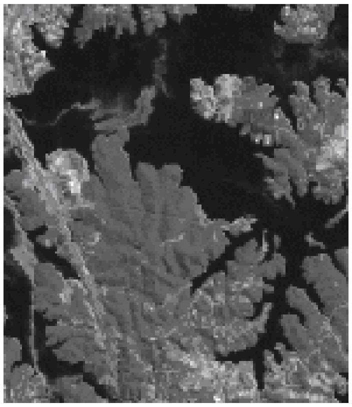
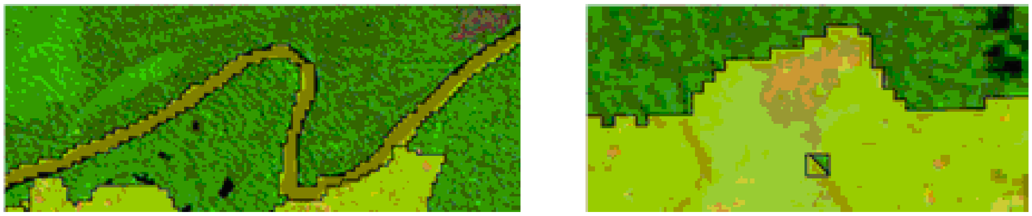


Figure 1. Example of a remote sensing image



(a) (b)

Figure 2. Examples of problems in image segmentation: (a) irrelevant features and (b) complex vectors

This works is organized as follows. In the section 2 we review some related work. In the section 3 we propose the enhancements. Section 4 shows an example of generalization of a remote sensing derived data and the result of some experiments. Finally, section 5 presents the conclusions of this work.

2. Related work

2.1. Generalization

In the context of digital cartography and GIS, map generalization involves two broadly distinct types of tasks: cartographic generalization and database generalization (Weibel and Jones 1998). Cartographic generalization aims to derive graphic products from a source database. Database generalization deals with the production of multi-level databases that contain diverse data sets at different scales. Database generalization methods do not consider artistic or intuitive components, neither deal with symbolization problems, but prioritize spatial accuracy and completeness. Jones and Ware (2005), considering the prevalence of geographical information access on the internet, recognizes two types of tasks associated to map generalization: semantic generalization and geometric generalization. Semantic generalization deals with the choice of information categories that should be represented, while geometric generalization is concerned with the simplification of shapes and structures that represent individual features.

Geometric generalization can be considered as a sub-process of the overall map generalization process and is done mainly through the application of generalization operators that represent single actions or atomic generalization functionalities. Typical generalization operators include simplification, exaggeration, aggregation, elimination, and displacement. They can be realized with different algorithms, and a reasonable set of tools have been implemented as part of GIS functionality (Foerster et al. 2008). A review about operators and their application to different types of features can be found in Choe and Kim (2007).

Cartographic constraints have been established as a concept to select the appropriate generalization operator or, to control the sequencing of them, in the automation of the generalization process. Constraints are factors, such as topology, proximity, size or shape, that are used to describe object characteristics and relationships required to produce the best result for a specific map scale and type (Neun et al. 2009). A constraint can be described by an appropriate measure that captures the property it expresses, for example, the area of a parcel is a measure for the size constraint (Steiniger and Weibel 2007).

Categorical data is a common data set used in GIS applications. Usually it refers to some spatially continuous phenomenon discretized into a manageable representation. For example, thematic maps of geological units or land use. One possible digital representation for categorical coverages is to use vector structures, more specifically a polygonal subdivision, where each polygon has an attribute value to represent a category or theme associated to that region. There is a lack of methods designed specifically for the generalization of categorical coverages in commercial GIS and cartographic systems, and usually line simplification is the method used. In order to obtain better results the special topological structure of categorical data should be considered (Galanda 2003).

Simplification is an operator used for linear or areal features to simplify unnecessarily detailed geometric data without fundamentally altering the basic shapes. It does not affect the non-spatial component of the data, and should preserve topological and spatial relationships between features. This operator can be implemented by different algorithms and there is no general theory that explains which algorithm is more convenient for the overall map, as well as for individual features. D'alge (2007) also addresses the process of generalization in the digital domain, especially considering categorical data. He performed a serie of generalization experiments for a dataset consisting of vegetation maps for the Brazilian Amazon using an adaptation of the model proposed by Mc Master and Shea (1992) and concludes that operators such as line simplification could be used to generate vegetation maps at different scales, although some further improvement should be done in the algorithms in order to solve potential topological problems.

2.2. Line simplification algorithms

One of the most cited algorithms for line simplification is the Douglas & Peucker algorithm (Douglas and Peucker 1973). The purpose of the algorithm is, given a curve composed of line segments, to find a similar curve with fewer points. It is a recursive algorithm. Initially it selects the first and last points of the curve and considers the line segment between these points and mark them as to be kept. It than finds the furthest point from the line segment. If the point is closer than a given tolerance (an input parameter of the algorithm) to the line segment then any points not currently marked to keep can be discarded. If the point is not closer to the line segment then that point must be kept. The algorithm recursively calls itself with the first point and the furthest point and then with the furthest point and the last point.

Another simplification method is the one based on the concept of effective area (Visvalingam and Whyatt 1993). Their method builds triangles from each three consecutive vertices of the curve and calculates its area. The central vertex of the triangle with the smallest area is eliminated and the algorithm recursively calls itself considering the remaining points. The recursion stops when a given condition is reached, for example, a given number of points are removed.

The methods cited above do not guarantee the maintenance of the original topology of a polygonal subdivision. This is due to the fact that they process each polygon independently, not considering its topological relationships with other geometries of the dataset. This might generate inconsistencies such as polygon self intersection, polygons overlapping or generation of areas not covered by any polygon. These inconsistencies can be fixed by a post processing step (Falls et al. 2005) (Muller 1990).

In this work, we agree that line simplification should be followed by a post-processing step to remove the inconsistencies in the generalized polygonal division. But we also propose enhancements that can be applied to different line simplification algorithms in order to reduce the number of further inconsistencies that might be generated.

3. Enhancements to line simplification algorithms

The focus of this work is on categorical data derived by automated segmentation and classification algorithms applied to remote sensing images, resulting in a contiguous collection of polygons that are topologically consistent, that is, there are no polygons in with self-intersections neither overlapping neighboring polygons in the collection. Each polygon of the collection follows a series of conditions that define their validity according to the geometry model proposed by the Open Geoespatial Consortium (Ryden 2005). However, the polygons usually have an unnecessarily high geometrical complexity and possibly very small artifacts, inconsistent with recommended cartographic scales for the vector products.

Considering the characteristics of the vector categorical coverages previously described, we propose two enhancements that can be applied to different line simplification algorithms in order to achieve better results. The first enhancement refers to the concept of anchor vertices. Anchor vertices are defined as the vertices that are part of three or more distinct segments. As an example, consider the Figure 3, which represents a small portion of a categorical coverage containing polygons *P1*, *P2* and *P3*. The vertices *v1*, *v2*, *v5* and *v6* are considered anchors, meaning that they should not be deleted or removed during the line simplification phase. In this example, vertices *v3* and *v4* can be removed during the simplification phase.

The second enhancement represents a way of propagating the simplification of a polygon to its neighbors: every time a vertex is removed from a polygon it is also removed from any other polygon that includes the same vertex. Figure 4 illustrates the propagation of the simplification. Figure 4(a) shows that vertex *V* is present in both Polygons *A* and *B*. Figure 4(b) shows a simplification step of polygon *A*, which removed the Vertex *V* from it. Figure 4(c) shows the propagation of the simplification, which propagated the remove of Vertex *V* to polygon *B*.

The generalization process can be summarized as follows:

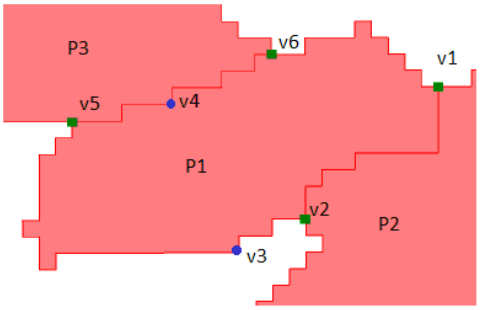
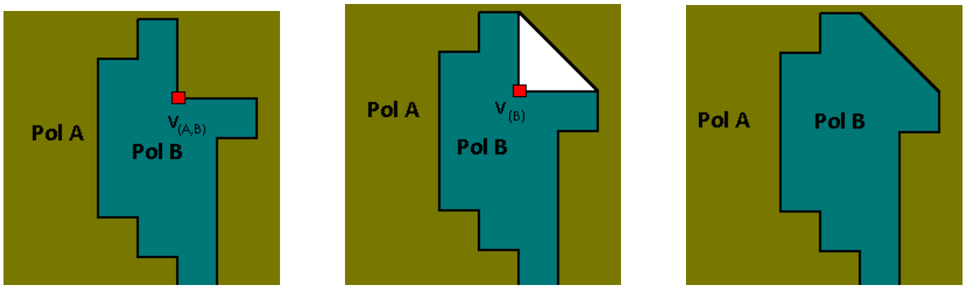


Figure 3. Anchor Vertices (*v1*, *v2*, *v5*, *v6*)



(a)

(b)

(c)

Figure 4. Propagation of the simplification: (a) Vertex *V* existing in polygons *A* and *B*; (b) *V* removed from polygon *A* and (c) *V* should be removed from polygon *B*

- Step 1: detect and label the anchor vertices;
- Step 2: apply the modified version of a line simplification algorithm on each polygon of the categorical coverage;
- Step 3: remove the inconsistencies that might have been generated during Step 2 (two types of consistencies are considered: polygons with self intersection lines and polygons overlapping).

4. Example of generalization of remote sensing derived data

This section illustrates the geometric simplification that can be performed using the proposed enhancements. The algorithms were implemented in C++ language and tested on real data. We used a Landsat-TM image of a region in São Paulo state, in Brazil as shown in Figure 5(a). Figures 5(b) and 5(c) show, respectively, the result of a segmentation and subsequent classification in 5 land cover classes. The segmentation and classification were performed using SPRING GIS (Camara et al. 1996). It should be noticed that it is not in the scope of this work to evaluate the quality of the segmentation and classification performed, since it depends on various factors, which do not affect the main motivation of this work.

Users of remote sensing imagery usually have to deal with the issue of choosing the most appropriate cartographic scale to generate products derived from a given image, or an image with a given spatial resolution, and there it not a definitive way to relate image spatial resolution to a maximum cartographic scale. Possible approaches are discussed in

(Boggione et al. 2009). During thematic mapping, object location accuracy requirements are usually milder than those for topographic maps. For example, LANDSAT-class images (30 m resolution) can be used for thematic mapping up to 1:60,000 scales, depending on the map theme. In this experiment the data original scale is set at 1:60,000, thus guiding the selection of the parameters used in the line simplification phase.

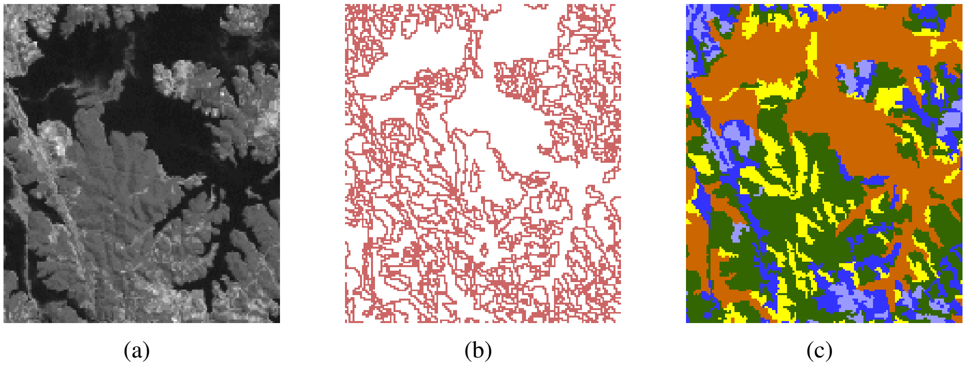

(a) (b) (c)

Figure 5. Example of a categorical map derived from a remote sensing image: (a) original image (b) segmented image and (c) classified image

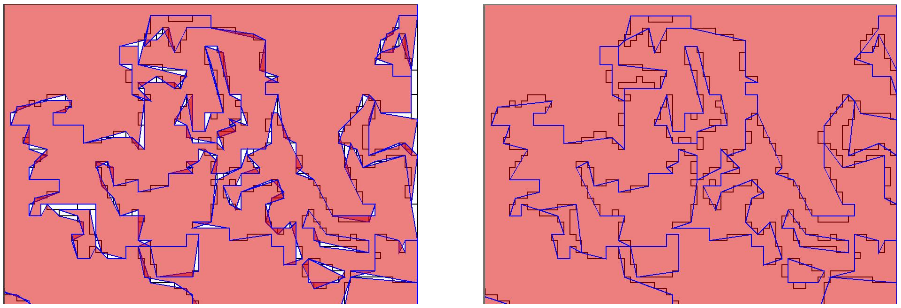
As described in section 3, two line simplification algorithms were modified in order to consider the list of anchor vertices: the Douglas & Peucker (DP) and the Effective Area (EA). The enhanced versions of the algorithms were applied to the categorical coverage shown in Figure 5(c). The dataset consisted of 1,464 polygons with 113,627 vertices.

Figure 6(a) shows the result of simplifying the categorical coverage using the DP algorithm without the anchor vertices and in Figure 6(b) with the anchor vertices (for legibility only a small part of the coverage is shown). The input polygons are the ones with a black border and the simplified ones are in red with blue border. The original DP algorithm removed 76,978 vertices (67.7% of the total), while DP plus anchor vertices removed 79,072 vertices (69.6% of the total). A possible explanation for the increasing number of removed vertices by the enhanced version is that the DP algorithm is dependent on the initial vertex of the segment that it uses to make the simplification. So, as the enhanced version also simplifies the adjacent polygons, the simplification power of the algorith might have been increased.

Figure 7(a) shows the use of the EA without the anchor vertices and Figure 7(b) with the anchor vertices. The input polygons are the ones with a black border and the simplified ones are in red with blue border. In this case, the original EA algorithm removed 63,286 vertices (55.7% of the total), while EA plus anchor vertices removed 62,008 vertices (54.6% of the total).

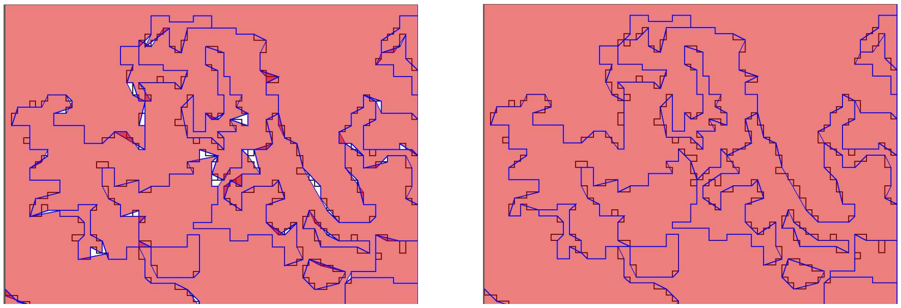
Although the reduction of vertices was similar using DP and EA algorithms, their original versions introduced topological inconsistencies such polygon overlapping and areas that are not covered by any polygon. The introduction of anchor vertices solved such inconsistencies.

This works deals only with pure geometrical generalization, based on line simplification algorithms applied to a polygonal division. A complete generalization process



(a) (b)

Figure 6. Simplification using the DP algorithm: (a) simplification without anchor vertices and (b) simplification with anchor vertices



(a) (b)

Figure 7. Simplification using the EA algorithm: (a) simplification without anchor vertices and (b) simplification with anchor vertices

would have also to consider the semantic structure of the categorical data. An indicative of how the simplification affected the semantic of the data can be the area of each class before and after the simplification. For the five classes in this categorical coverage, simplification using the enhanced versions of the algorithms produced a variation of less than 1%, comparing to the area calculated in the original raster categorical map.

5. Conclusions

Due the raster nature of remote sensing images, segmentation algorithms produce regions that are closely linked to the pixel structure, that is, a set of jagged border polygons. That implies in polygons with a unnecessarily high geometric complexity. Segmentation can also generate very small regions, associated with a single pixel for example, which are not necessarily compatible with appropriate scales of maps derived from a particular image resolution. Geometric generalization has to be considered as part of this process in order to overcome these problems.

In this type of data, an important constraint to be considered is the maintenance of topological consistency. In order to do that, we have introduced some important enhancements to line simplification algorithms. The first enhancement is the labeling of some vertices as anchors which should not be removed. The second enhancement is that every time a vertex if removed from a polygon it is also removed from any other polygon that include the same vertex. This last enhancement represents a way of propagating the simplification of a polygon to its neighbors. These two enhancements are the key factor to maintain the topological consistency after the simplification process.

We presented some experimental results showing the application of our method. Initially we intended to simplify the raw result from segmentation/classification to generate a vector categorical coverage consistent with the scale associated to the spatial resolution of the images, without unnecessary geometric complexity. A further development of this work is to apply the enhanced versions of the algorithms to generalize categorical coverages at smaller resolutions for different purposes, for example to facilitate its access on the internet.

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