An efficient map generalization heuristic based on the Visvalingam-Whyatt algorithm

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ABSTRACT

We present *Grid-Gen2*, an efficient heuristic for map simplification that deals with a variation of the generalization problem where the idea is to simplify the polylines of a map without changing the topological relationships between these polylines or between the lines and control points. *Grid-Gen2* is a strategy based on the Visvalingam-Whyatt algorithm to create simplified geometries with shapes similar to the original map. The simplification process is accelerated using a uniform grid. *Grid-Gen2* can process a map with more than 3 million polyline points and 10 million control points in 24 seconds in a Lenovo T430s laptop.

1. INTRODUCTION

One important problem in computational geometry is the curve generalization (or simplification) problem, where the objective is to reduce the amount of information needed to represent a curve while keeping it "similar" to the original geometry. The most well-known algorithms to solve this problem are Douglas-Peucker [1, 3] and Visvalingam-Whyatt [5].

While methods such as Douglas-Peucker try to simplify lines while keeping them as "similar" to the original input as possible, the direct application of these algorithms to simplify polylines in a map may create undesirable features. For example, if Douglas-Peucker is applied to a county dataset, the counties' boundaries may be simplified in a way that a point representing a city will be in the wrong county. Also, simplifying a polyline may make it cross another line in the map.

In this work we will deal with the following variation of the geometry generalization problem: given a set of polylines and a set of control points, simplify these polylines by removing some of their points (except the endpoints) such that the topological relations between pairs of polylines and between the polylines and the control points do not change. In a previous paper [4], we proposed *Grid-Gen*, which uses a uniform grid to efficiently generalize maps. This paper presents *Grid-Gen2* that is an extension of our previous method *Grid-Gen* where we included a new heuristic based on the Visvalingam-Whyatt [5] algorithm to generate maps with better quality than the maps generated by *Grid-Gen*.

2. THE GRID-GEN HEURISTIC

Given a set of control points C and an input map M composed of a set P of polylines, our heuristic simplifies M by iteractively processing each polyline independently. When a polyline is processed, *Grid-Gen* [4] iterates through all its interior points v_i (that is, the points excluding the endpoints) and removes v_i if this deletion would not change the topological relations between the map's elements. This process is repeated until the number of points in the simplified map reaches a target value defined by the user or until the map cannot be further simplified without changing its topology.

To determine if the deletion of a polyline point v_i would change the map topology, *Grid-Gen* verifies if there is any control point or polyline point inside the triangle t whose vertices are v_i and its two adjacent points (i.e., v_{i-1} and v_{i+1}).

Figure 1 presents an example of the possible topological changes that may happen during the deletion of points. Notice that there is a control point x inside the triangle (in red) formed by polyline point a and its two adjacent points. If a polyline is simplified by removing a, then the topological relation between the curve and x will change. Point b also cannot be removed since polyline point y is inside the red triangle containing b as vertex and, thus, the deletion of b would change the topological relation between b's polyline and y's polyline (in fact, the two polylines would cross if b was removed). Therefore, neither a nor b could be removed from the current map.

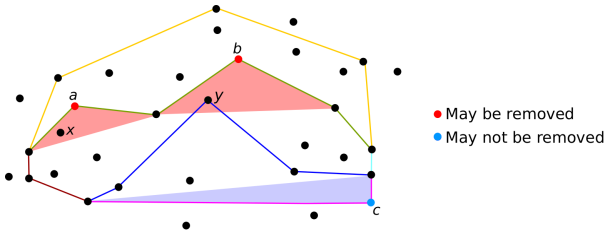
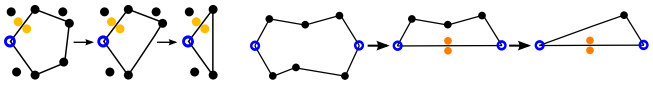


Figure 1: Determining if the deletion of some points would change the map topology.



(a) (b)

Figure 2: Use of dummy control points (in orange) to avoid invalid simplifications.

There are two special cases that *Grid-Gen* needs to deal in order to avoid creating a simplified map with invalid topology. First, if one polyline p has coincident endpoints and the polygon (or *island*) defined by this polyline does not have any control point or other polylines in its interior, then *Grid-Gen* may remove all interior points from p (creating an invalid polygon). Second, if two polylines p_1 and p_2 have the same endpoints and the polygon formed by them does not contain any control point or polyline in its interior, then *Grid-Gen* may remove all interior points of p_1 and p_2, creating two coincident line segments.

To solve these two problems, *Grid-Gen* preprocess the input adding *dummy* control points that ensure that the heuristic would never simplify the polylines to an invalid state. If a polyline p has coincident endpoints, two dummy control points are added at an infinitesimal distance around one of the line segments that forms p. See an example in Figure 2 (a). This ensures that one of these control points will be always in the interior of the polygon defined by p and, therefore, the heuristic will never remove all interior points of p.

If an input polyline p has only two points *Grid-Gen*, also adds two *dummy* control points in an infinitesimal distance around p. Furthermore, if during the simplification all the internal points of a polyline are removed, the dummy points are also added around the resulting polyline. This ensures that no simplification would create a polyline coincident to p. Figure 2 (b) presents an example where all interior points of a polyline p are removed and, then, two *dummy* points are added to the map.

Since the bottleneck of *Grid-Gen* is to detect if a polyline or control point lies inside a triangle, a uniform grid [2] is used to accelerate this process. More specifically, the idea is to create a $N \times M$ grid (where N and M are parameters defined by the user), superimposed over the map being simplified. Each cell

c of the grid contains a list of all points (polyline and control points) inside it. Given a triangle t, only the points in the cells that intersect t need to be checked in order to verify if there is any point in t. If a polyline is simplified, the point removed from the polyline is also removed from the uniform grid.

3. THE PROPOSED EXTENSION

As explained in section 2, *Grid-Gen* iteratively process the input map removing from the polylines the interior points whose deletion would not cause a change in the map topology. This strategy can efficiently create simplified maps with no topological inconsistency, but it does not try to keep the simplified map similar to the original geometry.

We propose *Grid-Gen2*, an extension of *Grid-Gen* that ranks the interior polyline points based on their "importance" to the map shape and try to perform the simplification by removing the least important points first. More specifically, the points are ranked using the same strategy as Visvalingam-Whyatt [5] algorithm and, then, a simplification process similar to *Grid-Gen* is performed in the map, processing the points in an order based on their rank. Thus, while the point ranking strategy tries to generate simplified maps similar to the original input data, the topological inconsistency detection strategy derived from *Grid-Gen* ensures that no topological error is introduced in the output map.

Given a polyline point p_i, the rank of p_i is defined based on the area (called *effective area*) of the triangle defined by p_i and its two adjacent points from its polyline. As shown by Visvalingam-Whyatt [5], points with higher effective areas are usually "more important" than points with smaller areas and, thus, the latter should have a higher priority when choosing which point to remove during the simplification process.

For efficiency purposes, *Grid-Gen2* initially preprocess the input data computing the *effective area* of the polyline points. These points are kept in a priority queue with priority based on the point's *effective areas*. When a point p_i is deleted from the map, this may change only the *effective area* of its two adjacent points p_{i-1} and p_{i+1} (in p's polyline) and, thus, these two areas are recomputed and the new values are used to update the priority of p_{i-1} and p_{i+1} in the queue.

4. EXPERIMENTAL EVALUATION

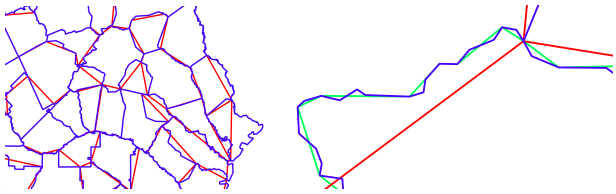
Grid-Gen2 was tested on a laptop with the following configuration: i7-3520M 3.6 GHz processor, 8GB of RAM memory, Samsung 840 EVO SSD (500 GiB) and Linux Mint Mate 16 operating system. The tests were performed on the same datasets previously used by Magalhães et al. [4]. However, due to the lack of space in this paper, we will not present the results from datasets 1 and 2 (the smallest datasets).

We compared the processing time of *Grid-Gen2* against the processing time of *Grid-Gen*. Both methods were configured to simplify the maps by removing 50% of their points. The uniform grid size was chosen based on the configuration that leaded to the fastest performance in Magalhães et al. paper [4]. Table 1 presents the processing time (in milliseconds) for each step of the simplification process (the time for computing the *effective area* and for initializing the priority queue is included in the the simplification step of *Grid-Gen2*). Since the time for data I/O and the uniform grid initialization step are the same for both methods (since these steps use the same implementation in the two algorithms), only the simplification time is presented separately.

Observe that, in the worst case, the simplification step of *Grid-Gen2* was 8 times slower than the same step in *Grid-Gen*. However, even though the tests were performed in a machine with a fast SSD drive, in all scenarios both algorithms spent most of their processing time performing I/O. Indeed, if we consider the total running time of the algorithms, *Grid-Gen2* was less than 2 times slower than *Grid-Gen* in the worst test.

Dataset	3	4	5	6	7
# input points	8531	3×10^4	3×10^4	3×10^5	4×10^6
Input reading	10	22	29	257	37092
Un. grid init.	0	1	1	24	1472
Simp. (*Grid-Gen2*)	2	15	13	435	23759
Simp. (*Grid-Gen*)	1	4	3	54	3481
Output writing	6	21	21	170	1817

Table 1: Processing-time (in milliseconds).



(a) (b)

Figure 3: (a) Region of a simplified map. The polylines in blue, red and green represent, respectively, the original map and the maps simplified by *Grid-Gen* and *Grid-Gen2*; (b) Zoomed region from the map.

Figure 3(a) presents an example of a region from dataset 3. In this Figure, the original dataset and the simplified map obtained by the two methods are overlayed, with the original map (in blue) in the top layer. It is easy to see that *Grid-Gen2* maintained the map shape better than *Grid-Gen*. Indeed, it is difficult to see in this figure regions where the green polylines, that represents the map simplified by *Grid-Gen2*, are visible. Figure 3(b) displays a zoomed region from the map in Figure 3(a) where it is possible to observe the difference between the three maps. Notice that *Grid-Gen2*'s output keeps the similarity with the original map better than *Grid-Gen*.

5. CONCLUSIONS AND FUTURE WORKS

We presented *Grid-Gen2*, a heuristic that uses techniques based on the Visvalingam-Whyatt [5] algorithm to perform map simplification generating maps that not only are topologically correct but also preserves the shapes of the original map better than *Grid-Gen*, our previous heuristic. Even though *Grid-Gen2* uses a simplification strategy much more sophisticated than *Grid-Gen*, it is only two times slower (considering the total processing time).

Future work includes evaluating *Grid-Gen* and *Grid-Gen2* by comparing their performance and the quality of their solutions with other methods. Furthermore, another extension is determining an efficient strategy to automatically determine an adequate uniform grid size for each input map.

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6. REFERENCES

[1] D. H. Douglas and T. K. Peucker. Algorithms for the reduction of the number of points required to represent a digitized line or its caricature. *Cartographica 1973.*

[2] W. R. Franklin, D. Sun, M.-C. Zhou, and P. Y. Wu. Uniform grids: A technique for intersection detection on serial and parallel machines. In *Proc. Auto Carto 9.*

[3] U. Ramer. An iterative procedure for the polygonal approximation of plane curves. *Comp. Graphics and Image Proc. 1972.*

[4] S. V. G. de Magalhães, W. R. Franklin, W. Li, and M. V. A. Andrade. Fast map generalization heuristic with a uniform grid. In *ACM SIGSPATIAL 2014.*

[5] M. Visvalingam and J. Whyatt. Line generalisation by repeated elimination of points. *The Cartographic J. 1993.*