Topological Consistent Generalization of OpenStreetMap

Padraig Corcoran[1], Peter Mooney[1], Adam Winstanley[1]

[1]National University of Ireland Maynooth,
Maynooth, Co. Kildare,
Ireland.
Tel. +353-1-708 3847
padraigc@cs.nuim.ie

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1. Introduction

Since its introduction in 2004, OpenStreetMap (OSM) has become an important source of geospatial information. The spatial data displayed by OSM represents the finest level of detail available. For web-based and mobile mapping applications it is often desirable to reduce the representation of such spatial data using generalization. There are two main reasons for this. Firstly, the spatial size and detail of OSM data is ever increasing and the bandwidth required to transmit this can be significant. Any device which attempts to obtain such data over a network will have finite bandwidth and this may prevent the map being transmitted in its original form. Secondly, many mobile devices used to display OSM data have limited screen resolution and processing power, and can only display a finite amount of detail. One class of generalization algorithm known as simplification methods, attempt to generalize polygon and line features by reducing the number of points or vertices used to represent them. Any simplification technique can be classified as a decomposition or reconstruction technique. Decomposition techniques produce a generalized result by iteratively removing points from the original polygon or line feature in question until a desired scale is reached. Reconstruction techniques produce a generalized result by initially representing the feature in its simplest form; subsequently, points are added in an iterative manner until a desired scale is achieved.

The intention of map generalization is to produce the best result possible subject to a set of objectives (Jones and Ware 2005). Topological objectives are primarily concerned with the need to ensure that the simplified representations of the selected features retain original relationships of containment and connectivity. The research presented in this work focuses on strategies for determining if a given simplification satisfies topological objectives; that is, it is topologically consistent. Any method for determining topological consistency may be summarised in terms of the following constraints:

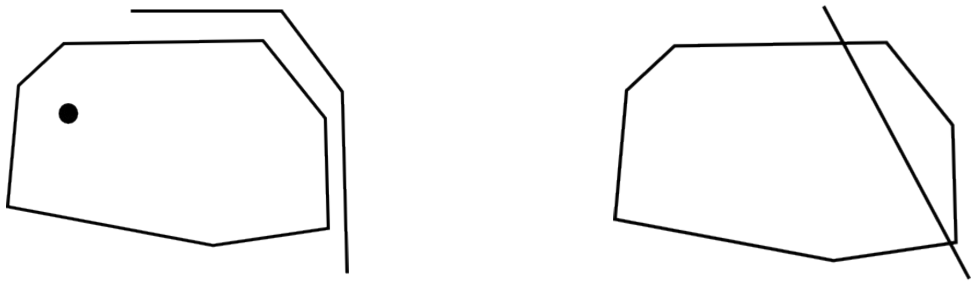
- Constraints on the types of topology for which the technique can determine consistency without returning a false-positive; that is, classifying a simplification as topologically correct when in fact it is not.
- Constraints on the types of topology for which the technique can determine consistency without returning a false-negative; that is classifying a simplification as topologically incorrect when it is in fact correct.
- Constraints on the types of simplification to which the technique can be applied.

If a technique has no such constraints it may be regarded as optimal. Developing a technique which is optimal is this sense is the research contribution made by this work. To achieve this goal we performed a geometrical analysis of strategies for determining the topological consistency of a vector map simplification. We propose that all topological relationships may be classified as planar or non-planar. A formal analysis of techniques for determining consistency in terms of such relationships was performed. For each technique we analysed any corresponding constraints which are imposed. This provides a unified understanding of the benefits and limitations of individual techniques and the relationships which exist between techniques. A new approach for determining non-planar topological consistency, which imposes the least possible constraints, is proposed. The effectiveness of this approach is demonstrated through the fusion with an existing simplification technique.

The layout of this paper is as follows. In the following section we introduce the concepts of planar and non-planar topological features. In section 3 we briefly review and summarize all existing techniques for determining planar and non-planar topological consistency. Through this analysis the authors developed a new strategy for determining topological consistency. In section 4 we present results and draw conclusions.

2. Planar and non-planar topological properties

All topological properties can be classified as those which represent a planar embedding of a graph and those which do not. Consider the simple map in Figure 1(a) which contains a polygon, line and point feature. No lines or edges in this map cross without forming a vertex; therefore we say that the topological relationships between all features are planar. Next consider the simple map in Figure 1(b) which contains a single polygon and line feature. Due to the fact that the line crosses the polygon without forming a vertex, we say the topological relationship between these features is non-planar.



(a) (b)

Figure 1. Planar relationships are displayed in (a). Non-planar topological relationships are shown in (b).

3. Maintaining topological consistency

We analysed three seminal methods for determining planar topological consistency in terms of the relationships for which they can determine consistency and constraints they impose. These are the works of De Berg et al. (1998), Saalfeld (1999) and da Silva and Wu (2006). Table 1 represents a summary the results of this analysis. For each technique we indicate if it can determine if a given simplification is topological inconsistency with respect to the three types of planar topological relationships. An asterisk indicates that the technique in question can determine the topological consistency without constraint and is therefore optimal. An x_i symbol indicates that the technique in question can determine the topological consistency but is subject to some form of constraint and therefore is not optimal. The final column defines what each constraint x_i represents. From this table the following conclusions can be drawn. The consistency of point features should be determined by the strategy of De Berg et al. (1998) while the consistency of line features should be determined by the strategy of da Silva and Wu (2006). This strategy imposes the least possible constraints.

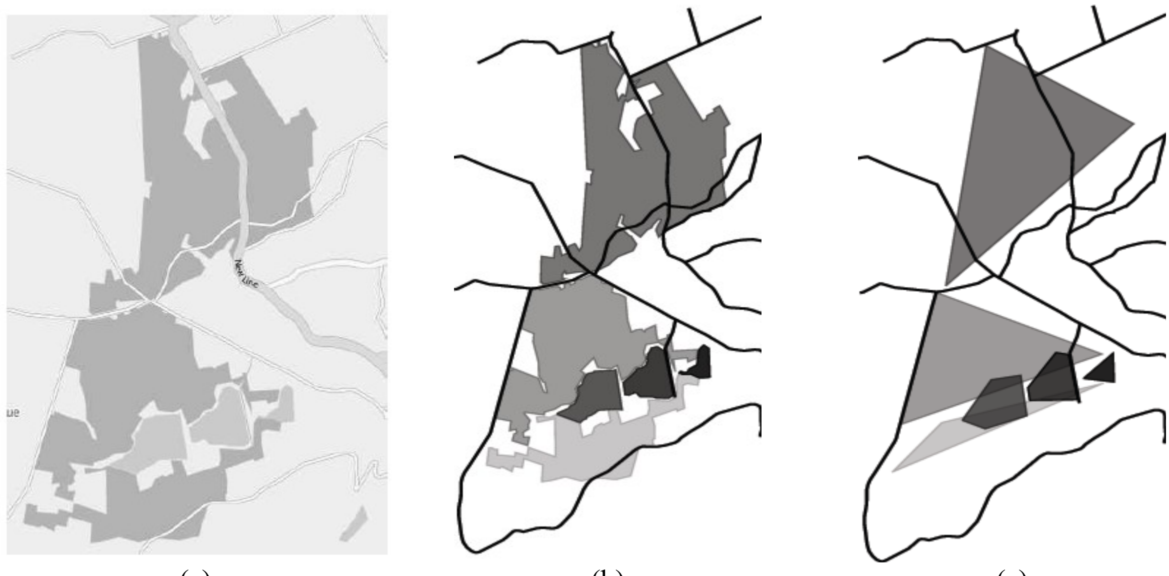
Most existing works proposed to maintain the non-planar topology line intersections by simply maintaining all line segments that contain intersections in the map. The drawback of this strategy is that it severely restricts the number of possible simplifications for which consistency can be determined. In this work we developed a technique which overcomes this limitation.

Table 1. The forms of planar topology for which each technique can determine consistency and any corresponding constraints.

	Point	Line	Non self-intersection	Constraints
de Berg	x_1		x_1	x_1 – Monotone chains
Saalfeld	*			
da Silva	x_2	*	*	x_2 – On point features

4. Results and Conclusions

In section 3 methodologies which can determine planar and non-planar topological consistency of a given simplification were presented. We propose to fuse these with an existing simplification technique which satisfies shape objectives. To satisfy shape objectives a contour evolution or simplification technique proposed by Latecki and Lakmper (1999) was used. Consider the sample map taken from OSM which is displayed in Figure 2(a) and plotted in Figure 2(b). The polygons in this map represent forests and lakes; the line features represent a road network. Each polygon in this map was simplified using the contour evolution technique with the corresponding result shown in Figure 2(c). Although the simplification satisfies shape objectives, it contains many topological inconsistencies. This includes the introduction of overlapping polygons and the removal of polygon line intersections.



(a) (b) (c)

Figure 2. The map in (a) is plotted in (b) and simplified in (c).

To demonstrate the effectiveness of proposed topological consistent simplification technique, the polygons in this data set were simplified by an increasing amount. These results are shown in Figure 3. The final simplification represents the convergence of the algorithm. From these results we can see that all planar topological relationships mentioned above were maintained throughout each simplification scale. It is also evident that each simplification satisfies shape objectives and represents a progressive intuitive shape evolution. The number of vertices used to represent each polygon at each simplification stage is given in Table 2. The final simplification in Figure 3(f) represents a 91% reduction in the number of vertices relative to the original map.

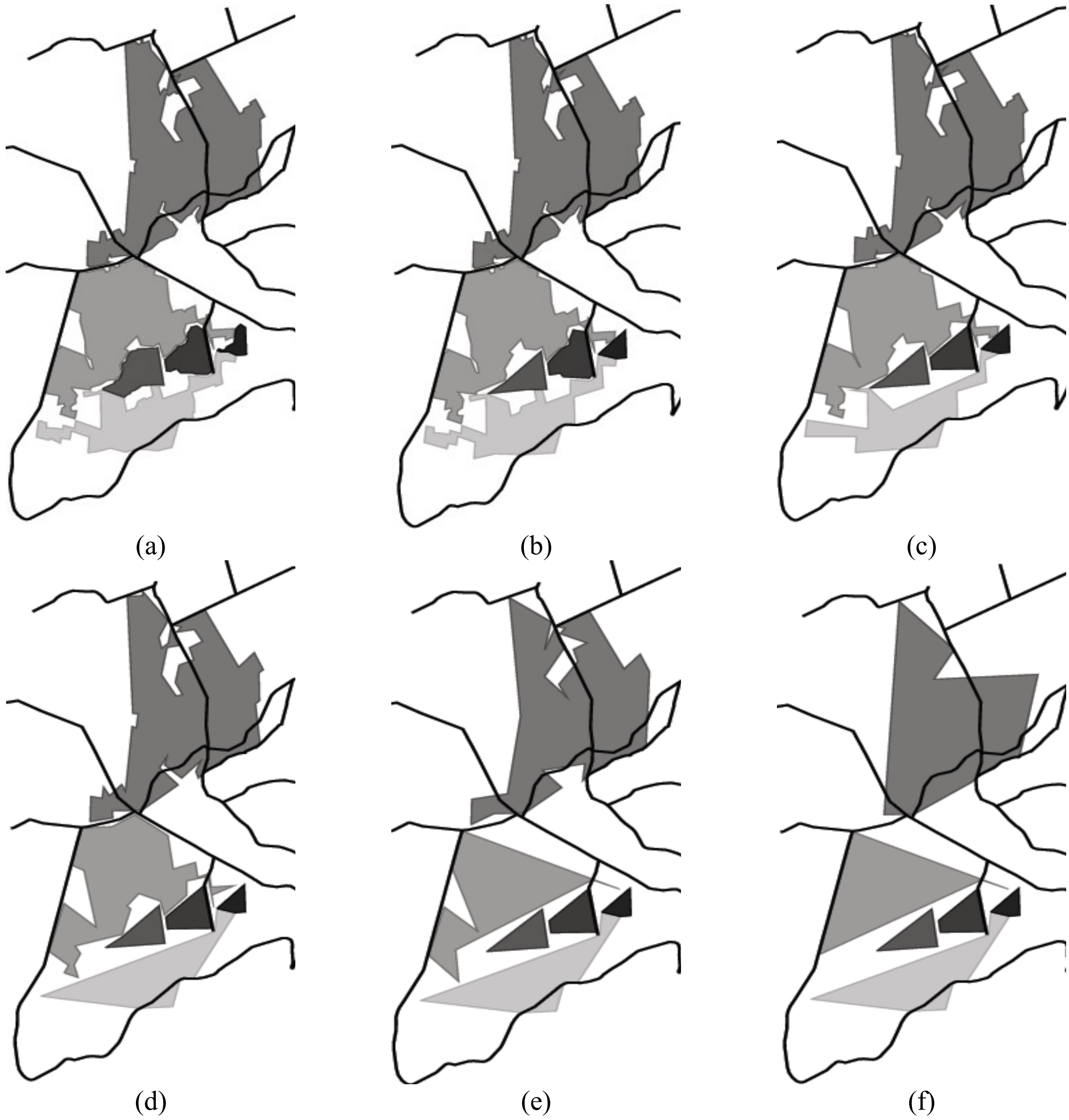


Figure 3. The set of polygon in (a) are simplified by an increasing amount in (b)-(f).

Table 2. The number of polygon vertices at each simplification stage in Figure 3.

	Poly. 1	Poly. 2	Poly. 3	Poly. 4	Poly. 5	Poly. 6	Total	% Red.
Fig. 3(a)	20	35	28	126	101	65	375	0
Fig. 3(b)	4	12	5	102	78	42	243	35
Fig. 3(c)	4	4	4	79	55	16	165	56
Fig. 3(d)	4	4	4	56	32	8	108	71
Fig. 3(e)	4	4	3	33	9	8	61	84
Fig. 3(f)	4	4	3	11	4	8	34	91

Due to space constraints, this paper only represents a very brief description of how our proposed generalized algorithm maintains planar and non-planar topological consistency. A more in-depth analysis will be presented in a later publication. Although this work has focused on the task of simplifying polygon features, the proposed methodology could also be applied in the context of simplifying line features. This will be the focus of future research.

6. Acknowledgements

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Biography

Padraig Corcoran completed a B.Sc. in Computer Science and Software Engineering and a Ph.D. in Computer Science in 2004 and 2008 respectively. He is currently working as a lecturer and researcher in the department of Computer Science at the National University of Ireland Maynooth.

Peter Mooney holds a BSc (1999) and PhD (2004) in Computer Science from the National University of Ireland Maynooth (NUIM). He is currently a Postdoctoral Research Fellow with the Department of Computer Science at NUIM and at the Irish Environmental Protection Agency (EPA).

Adam Winstanley gained MSc and PhD degrees in Computer Science in 1987 and 1991 respectively. Currently, he is Senior Lecturer and Head of Department of Computer Science and Senior Research Associate of the National Centre for Geocomputation at NUI Maynooth.