B-spline Curve Fitting: Application to Cartographic Generalization of Maritime Lines

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Abstract

Generalization is the process of abstraction applied when the scale of a map is changed. It involves modifications of data in such a way that the data can be represented in a smaller space, while best preserving geometric as well as descriptive characteristics. A map is an abstracted model representing the geometric reality. The smaller the scale, the more schematic the representation. Line cartographic generalization deals with graphic representation of lines. Many algorithms are available for an automated line cartographic generalization. Instructions for using these algorithms are often complex and representations applied ill-adapted to some generalization processes. In this paper, we explain the advantages of using B-spline curves in a line generalization process. We focus on processing of line cartographic generalization operators in a maritime context.

Keywords: Line cartographic generalization, B-spline curve.

1 INTRODUCTION

We need to distinguish between the generalization issues that are brought about by graphic representation from those which arise from modelling at different levels of spatial and semantic resolution. Second generalization can be viewed as a series of transformations (in some graphic representation of spatial information), intended to improve data legibility and understanding, and performed with respect to the interpretation which defines the end-product. These two categories have motivated research mainly in two areas: model-oriented generalization, with focus on the first stage above-mentioned, and cartographic generalization, which deals with graphic representation. Our paper is relevant to cartographic generalization.

Cartographic generalization includes the whole processings encountered when the scale of the map is changed into a smaller scale. We should produce a legible map which is as close as possible from reality. The tools currently available for automated cartographic generalization resemble those of the manual generalization. A catalogue of cartographic generalization operators has been proposed [23], including selection/elimination, aggregation, structuring, compression (or filtering), smoothing, exaggeration, caricaturing, enlargement and displacement. One can essentially distinguish between two approaches for the implementation of the working tools in generalization. One is automatic while the other is interactive. The generalization automation has been studied for over twenty years. The difficulties of providing an automatic solution points out the complexity of the problem.

The second section of the paper deals with the representations used for data modelling. Subsection 2.1 is devoted to the representation by means of a list of points. Most generalization algorithms have been developed focusing on the manipulation of vectors. Representation by means of a list of points does not provide fair modelling of curves which may have complex and varying shapes. In addition, this representation is often ill-adapted to some generalization process. In subsection 2.2, we suggest a different representation based on B-spline curves.

The third section of the paper deals with the application of B-spline representation in processing of line cartographic generalization operators in a maritime context. In subsection 3.1, we focus our attention on data compression using a bisection method on the number of control points. Line smoothing and displacement operators are developed in subsection 3.2. The strategy is based on a mechanical approach. The curve displacement is obtained through the displacement of control points. Internal and external forces are applied at control points in order to produce the desired deformation. Lastly, we introduce a technique for curve aggregation (subsection 3.3).

2 GEOMETRIC DATA MODELLING

2.1 Representation by means of a list of points

Polygonal curves are often encountered for data modelling. They are appropriate to data compression as well as to simplicity and efficiency (CPU time) of their algorithms [25].

Data compression algorithms based on polygonal curves correspond to the first generalization algorithms. Cartographer were quickly aware that cartographic results were not sufficient using these algorithms. Research in automatic generalization turned to other algorithms permitting displacements. The goals were essentially smoothing and caricaturing.

Three trends can be emphasized for smoothing. We can cite smoothing methods based on averaging, convolution or neighbouring points. Averaging techniques [3, 19] smooth small details while preserving the general shape. Algorithms considering convolution, gaussian smoothing for example [2, 18], are more regular. They are used for smoothing details which have the same size. At the opposite, smoothing algorithms based on neighbouring points [6, 27] have little influence on lines which are defined with a high density of points.

Dutton's algorithm [8] corresponds to the Brophy inverse smoothing algorithm [3]. Increasing the angularity is not a common practice in generalization. Lowe's algorithm [18] is more interesting. Tests display its interest for smoothing by limiting deviations and for caricaturing [22]. Nevertheless, the choice of the parameters is difficult.

Generalization algorithms are usually based on a representation by means of a list of points. The result quality depends on the line morphology [4]. In practice, one of the solutions often encountered consists of combining a simplification and a smoothing process: for example, Douglas and Peucker's algorithm [7] is followed by a cubic spline computation. At the present time, one should have an empiric approach for determining a solution (choice of an algorithm and its parameter values). It is natural to notice the high cost of such a technique.

More generally, this representation is not sufficient:

- for the acceptance of some resulting displayed curves,
- as a general representation method.

As regards the acceptance of some resulting displayed curves, the drawbacks of the representation by means of a list of points are linked to the broken line effects of the approximating line (Figure 2). The smaller the scale, the more angular the approximating line. This kind of representation is ill-adapted for modelling smooth shapes such as roads (Figure 1), waterways or railways. One of the solutions consists of applying continuous functions (algebraic functions, wavelets, splines).

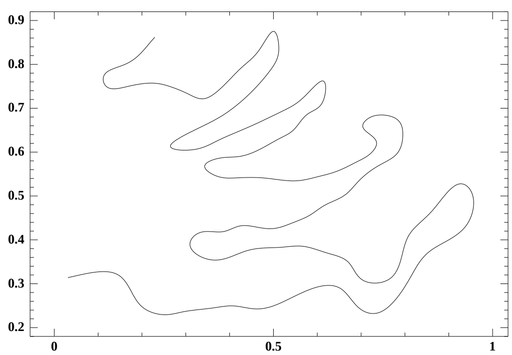

Figure 1: Initial polygonal mountain road.

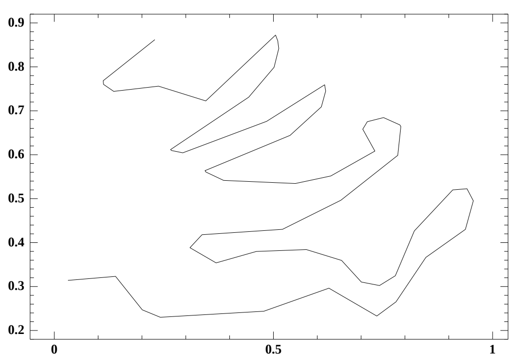

Figure 2: Jagged lines of the representation by means of a list of points.

As regards the representation method, it is limited to linear processing. For example, in order to locally modify a curvature, we should first identify the points which compose the curvature and modify them one by one afterwards. The information linked to a point is a strictly local information (each point represents a place where the line goes through), and includes no neighbourhood information [12]. Moving a point implies a discontinuous displacement along the curve. It would be useful to have a continuous displacement that is to say that shifting a point implies an automatic displacement of the neighbours. This need is important in order to satisfy the caricaturing and displacement operators (see subsection 3.2).

One should improve the generalization automation by developing other representations which lead to higher level processings. The need to introduce new representations in line cartographic generalization is detailed in Fritsch's thesis [12].

2.2 B-spline representation

B-spline curves seem suitable for the needs introduced in subsection 2.1. We assume that the reader is familiar with B-spline curves. If he is not, he can refer to [5, 9].

Our attempt is to include the fitting method in the line generalization process. Our goal is not to find a completely generic modelling but to find the best modelling for a type of lines. As B-spline curves are smooth curves, they are well-adapted for modelling smooth lines such as roads (Figure 1), railways or waterways (see also [1]). On the other hand, geographic features such as seaports should not be modelled with B-splines. The jagged line of a pier for example should remain in the generalized map (Figure 3). Polygonal algorithms ought to be applied in this case.

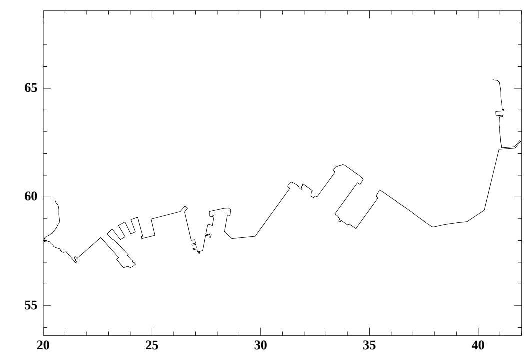

Figure 3: A type of lines adapted to polygonal algorithms.

We can essentially distinguish two approaches for the implementation of the working tools in automated generalization. One is an automatic process while the other is interactive [21]. The difficulties of providing an automatic solution have led some researchers to specialize in interactive techniques. In this case, low-level tasks are performed by the software, while high-level tasks are performed or controlled by cartographers. Through the interactive approach, B-spline representation makes it possible for a cartographer to modify a B-spline curve since additional points can easily be computed. Using local support of B-splines, a cartographer may introduce local displacements or shape modifications by first introducing additional points into the curve and by modifying them through control points (see subsection 3.2). This could be a more powerful tool (for solving line self-intersection problem for example) than the usual strategies based on a simple shifting of data points.

In addition, B-spline parameters are invariant with respect to affine transformations. As a result, B-splines are well-adapted to multiresolution problems [11, 15]. Fritsch explains in his thesis the advantage of wavelets in this context. He explains their drawbacks for solving generalization operators as well [12]. We can cite their lack of accuracy for spatial approximation.

Through the multiresolution approach, one can zoom in on a section of a curve (Figure 4) and still have a smooth representation of it using B-spline curves. As a matter of fact, one can compute additional points on the B-spline curve to improve the visual quality and the accuracy of the line (Figure 5). Such a property could be useful in embarked cartographic information systems. It is not possible for the polygonal representation to do the same: adding points in the line segments increases neither the visual quality nor the accuracy of the resulting displayed line (Figure 6).