A Framework for Multicriteria Line Generalization to Support Scientific and Engineering Modeling

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Introduction

Existing line generalization (data reduction) algorithms aim to maximize only the geometric information contained in a cartographic line (Beard, 1991; Buttenfield, 1991, Cromley 1991; McMaster 1992). However engineering and scientific models require data reduction procedures to be sensitive to non-spatial parameters (hydrogeology, topography, mathematical limitations imposed by the model, sites of analysis and data collection) in addition to spatial parameters. This suggests the need for a robust framework to support the integration of map generalization techniques with non-cartographic applications. Spatial multicriteria decision-making has been defined as a process that combines and transforms spatial and aspatial data into a resultant decision.

Typical procedures utilize critical values for data and evaluation criteria for decision maker's preferences to aggregate multi-dimensional geographical data into 1-dimensional alternative decisions (Malczewiski, 1999). Previous work by Flewelling (1999) examined reducing sets of independent points, by focusing on the 0-dimensional elements of 1-dimenional entities the result is constrained by point order within the line. It becomes obvious in this context that any modern line generalization procedure, that aims to preserve spatial (specifically geometric) and aspatial content simultaneously, should consider incorporating optimization methods used in multicriteria decision-making. Our work in that direction has led us to explore methods of *multi-criteria line generalization* (MCLG) with the aim of supporting the Analytic Element Method (AEM) of groundwater modeling.

Attribute Classification

In the context of line generalization for groundwater modeling, the spatial-aspatial dichotomy does not provide enough differentiation when analyzing attribute data. A domain-centric classification into *cartographic* and *non-cartographic* classes is more suitable. Each of these classes can be further divided into subclasses containing data directly related to the "object of decision" (line) and data pertaining to the geographical or geophysical environment, in which the line is sited. This generates a preliminary 2x2 matrix for classifying all attribute data.

	Cartographic	Non-Cartographic
Line	I	II
Envn.	III	IV

Examples of the attributes from each class are as follows:

class I : length, sinuosity, angularity and bandwidth of line segments;

class II : flux, , transmissivity, velocity;

class III : topographic elevation;

class IV: location of wells, lithology and soil classification.

For purely cartographic line generalizations, only class I attributes are relevant. But in this new context of groundwater modeling, line generalization as a scheme for data reduction needs to consider the effect of the interplay of all the four classes. This classification of attributes prevents the decision maker from confounding the nature of the variables, when he has to consider each of them separately in his multi-criteria analysis. Class I variables are primarily an artifact of the spatial primitive (line) stored in the cartographic database and have traditionally been means of comparing the geometries of two lines. Class II attributes are properties of the real world feature (river) being represented in the database as line. These are practically irrelevant to the original shape of the line but are important aspatial criteria. Class III attributes do contribute to the shape indirectly by acting as environmental constraints on the flow of the river. Depending on the geographical region of analysis their importance can fluctuate widely. Finally Class IV variables are of major interest to the decision maker as they introduce his non-cartographic preference structure into the analysis. These attributes are a mix of hydrogeologic, economic, experimental set-up and policy constraints that normally no cartographer would ever consider during generalization of lines.

Framework for multicriteria analysis

In terms of the multicriteria vocabulary our *alternatives* comprise either sets of points or line segments. Alternatives could be defined by different methods of line simplification or in other ways. The four classes of attributes generate the various *evaluation criteria*. For this paper, we limit ourselves to 0 dimensional multicriteria analysis. This means that we do not consider the alternatives-criteria matrix at different locations in space but operate at one "point". This point represents the whole geographical space, condensed by aggregating the spatial distribution of each alternative into one 'composite score' per alternative, for the whole region under consideration.

In a GIS constraints can be used for eliminating all objects of decisions (lines/points) that are characterized by particular values or do not meet a particular threshold, during preliminary stages of line generalization. Traditional line simplification algorithms are based entirely on this concept actually, as they select or drop points on the cartographic line, depending on one geometric criterion. Our approach is therefore to modify those methods for multiple constraints defined for multiple criteria.

As explained by Malczewiski (1999) each alternative is evaluated with respect to the criteria considered relevant for that particular alternative. We adopt the common approach of assigning preferences to the criteria by determining numerical weights for each decision criterion. This is known as *criterion weighting*. The larger the weight, the more significant it is in determining the final outcome. For *n* criteria the set of weights is defined as $\mathbf{w} = \{w_1, w_2, w_3, \dots, w_j, \dots, w_n\}$, $w_j > 0$, and $\sum w_j = 1$. *Ranking, rating, pairwise comparison and trade-off analysis* methods of generating weights based on the judgments of the decision makers are available

Assuming that we employ only those attributes that possess linearity and additivity properties, we choose Simple Additive Weighing (SAW) as our decision rule to order all alternatives according to their performance with respect to the criteria and the weights assigned to them for different alternatives. This method essentially involves a multiplication of the criterion weight with its (scaled) value and the summing the product over all criteria (attributes) to generate a composite score for each alternative. When executed for each alternative SAW generates a ranking of all alternatives thus allowing us to choose the one that 'best' preserves the overall characteristics of the line in the AEM groundwater modeling context.

This is in essence is a synopsis of the framework we are using for multicriteria line generalization. As a concluding remark—the criteria that we have been referring to are all attributes. However in multicriteria analysis a criterion is a generic term for both attributes and objectives. We have consciously restricted ourselves to multi-attribute decision making (MADM) as it is more generic in its application to groundwater modeling. Multi-objective decision-making (MODM) on the other hand is more complex and context sensitive, requiring a better understanding of the specific goals and objectives of any simulation.

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