Preserving Changes After Cartographic Generalization: A Framework and Example of Line Simplification

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Abstract:

Given the increasing collection and availability of multi-temporal geodata (e.g., on ecological, epidemiological, or social topics), there is a growing need to visualize changes in geometry and content in a clear and interpretable way. Cartographic generalization must therefore be required not only to preserve important geometric and thematic features, but also their patterns of change. The problem is that this aspect has so far been addressed in only a very small number of scientific studies (exceptions include, for example, Schiewe 2024 or Cybulski 2022), let alone offered as a feature in GIS software.

Consequently, this paper has two objectives: First, it presents a framework that explicitly highlights the various options for preserving change properties following a cartographic generalization. Second, it focuses on a typical generalization operation—the simplification of lines—and demonstrates how algorithmic extensions of the Douglas-Peucker algorithm can follow the idea of this framework.

The following framework is based on the well-known, classic generalization operations involve modifying individual components of geo-objects (e.g., deleting vertices in lines to simplify them) or altering entire objects (e.g., by deleting them), which can also be performed in conjunction with other, adjacent objects (e.g., during displacement or merging). This concept can be used as the basis for temporal generalization: The well-known operations (simplification, deletion, etc.) are retained, but they are now applied not only at the level of individual objects or object components, but also to

- object components over time (e.g., simultaneous deletion of vertices for a line at multiple points of time),
- objects over time (e.g., deletion of entire objects at specific time points), as well as
- complete time frames (e.g., deletion of one or more frames containing all objects).

In principle, all known operations can be applied at these levels. By definition, however, frame-wise generalizations are not appropriate for simplification (which would correspond to a deletion over time), displacement (which would entail an undesirable change in chronological order), and degradation (since there is no "dimension" for frames). The goal of generalization is always to preserve certain significant characteristics of the changes (as well as the suppression of minor changes). These must be defined in advance for the specific application and formalized as criteria.

While in previous publications (e.g., Schiewe 2024) we have already addressed the preservation of significant changes in values following data classification (i.e., the generalization operation of aggregation), the framework presented above will now be applied to the simplification operation in order to demonstrate the need and the added value of necessary algorithmic extensions.

A very commonly used method for simplifying lines is the Douglas-Peucker (DP) algorithm (Douglas & Peucker 1973), which aims to delete selected vertices (i.e., object components) while still preserving the characteristic line shape. When applying the DP algorithm to a time series of lines, one should not rely on a single line (e.g., the one in the first frame) to determine the threshold value, because the curvature behavior within the following frames could be significantly different. Fig. 1 illustrates the selection of a threshold value that is too low, derived from the line at time t(1) (with the goal of eliminating 50% of the vertices in this line). The result is very few vertices being deleted in the subsequent lines t(2) and t(3). Conversely, a threshold that is too high would lead to excessive generalization for many lines.

In accordance with the aforementioned framework of multi-temporal generalization, we must consider not only the significant geometric changes within a single line, but also the changes between two lines separated by a certain time interval t(i) and t(i+j) over the whole time period of interest. In a first step, therefore, the vertices that are characteristic

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for temporal change are determined—i.e., those that exhibit particularly large changes in distance between the frames t(i) and t(i+j). These points are selected using a **change threshold** for corresponding points at t(i) and t(i+j). When selecting the threshold value for the change, for example, the change in position can be taken into account; it can also be based on application-specific requirements and the map scale.

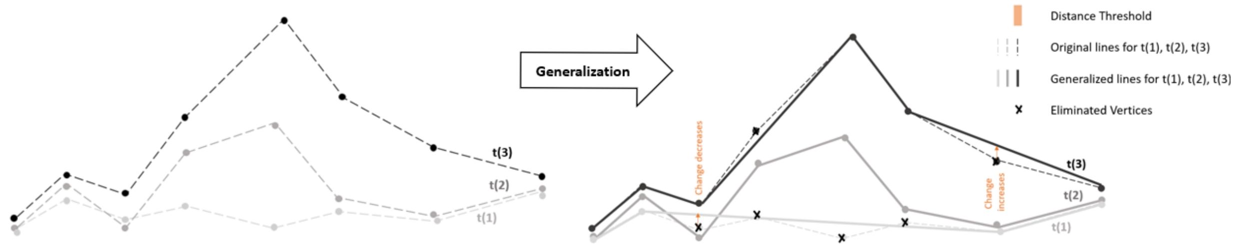

Figure 1. Application of a relatively small threshold value in the DP algorithm for a time series t(1) to t(3) – the figure (right) illustrates distorted changes over time resulting from the generalization

These selected vertices are treated as **constraint points** in the following. To date, such a constraint-based approach for DP has been used in mono-temporal datasets to preserve the dominant orientations of line segments or to avoid violating topological properties (Tienaah et al. 2015). This idea is now transferred to the preservation of changes in multi-temporal lines (Fig. 2): To this end, the original line is divided into segments at the aforementioned constraint points. The actual DP algorithm is then applied separately to these segments, and the results are recombined at the unchanged constraint points.

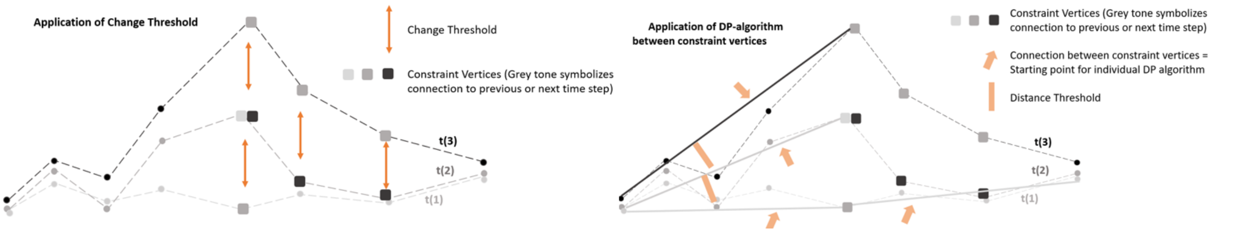

Figure 2. Application of a change threshold to determine constraint points (left), followed by starting the DP algorithm to segments between constraint vertices (right)

Depending on the application, it is not (only) the preservation of positional displacement over time that is of interest, but also the **preservation of certain line characteristics** such as line length, line shape, or the area of a closed line. If the desired condition (e. g. for preserving the relative line lengths) is not met after the first line simplification, there are two options: First, a line that has become too short due to generalization can be lengthened again by reinserting points, or the relatively too-long line can be shortened by further deleting intermediate points.

The presentation will also report of the implementation of these extensions to DP algorithm and first tests with real data that will proof the applicability, also addressing differences between animations and map series layouts.

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