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Optimizing the balance between area and orientation distortions for variable-scale maps

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ABSTRACT

Applying a variable scale transformation to maps leads to area distortions of the maps, i.e. enlarging interesting areas on maps to larger scales and shrinking other areas. Such area distortions improve the clarity of the interesting areas. However, it may result in the over-distortion of line orientations so as to reduce map recognition. This article developed an optimization method to correct orientation distortions for variable-scale maps generated by any existing variable scale transformations, while preserving the map clarity as much as possible. The proposed method is tested with the variable-scale resultant maps of two real-life datasets and evaluated by statistical analysis and perceptual tests. The experimental results indicate that the proposed method is able to effectively reduce the orientation distortions so as to improve map recognition, while map clarity has been sufficiently achieved.
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1. Introduction

Maps are often represented on portable electronic devices (e.g. tablet PCs and mobile phones) to provide location-based services, e.g. personal navigation. However, it is difficult to ensure the clarity when representing larger maps on these devices because of their small displays. This problem has been focused on by many researchers. In recent research work there are two common approaches to improve map visualization for small displays. In the first approach, the map size is reduced to fit small displays while a uniform map scale is preserved. Visual clutter arising from uniform downscaling may be reduced by some techniques, e.g. zooming, based on: a multi-scale geo-database (showing detailed views on other display windows) (Karnick et al., 2010); generalization operations (Li, 2006); and personalization (Wilson et al., 2010). The second approach replaces the principle of uniform scale used on maps by a variable scale transformation. Such a transformation allows for a better exploitation of the limited map space (Wang and Hu, 1993; Reichenbacher, 2004; Zipf and Richter, 2002; Ti and Li, 2014), so that the detailed information of a map can be more clearly displayed to meet the user's requirements.

In variable-scale maps, the geometric accuracy of map features is not a focus, and distortions in different map areas are applied to help users focus on the important or interesting map features. However, such area distortions will result in orientation distortions, i.e. the difference between the original orientations and its deformed orientations. As shown in Fig. 1, it is not easy to match the enlarged area in the variable scale map (see Fig. 1(b)) with the map's original shape (see Fig. 1(a)), so map users need more time to recognize the map. Furthermore, significant orientation distortions will result in a reduction of the effectiveness of map recognition and readability (Barkowsky and Freksa, 1997; Lin et al., 2014). According to the set of properties in the hierarchy (Barkowsky and Freksa, 1997) for map recognition (see Fig. 2), the orientation is the second most important aspect, next only to the connectedness (topology).

Currently many techniques on variable scale transformation have been developed for different specific goals, as will be discussed in more detail in Section 2. However, few of these techniques have considered the reduction of orientation distortions. Considering the importance of line orientation for map recognition, this study aims to develop a versatile method for the reduction of orientation distortions, which can be used with any of the existing techniques.

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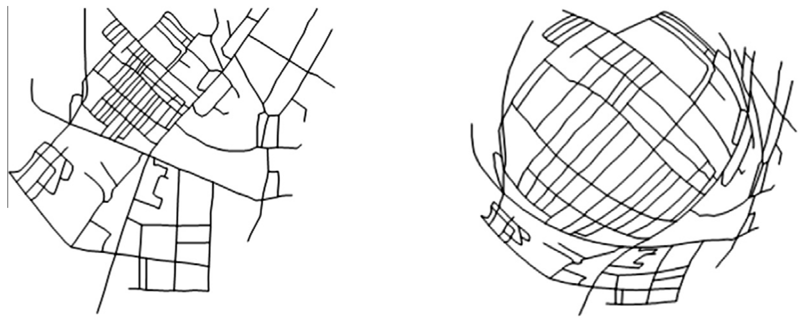

(a) Original shape

(b) Deformed result by a focal projection with the method of (Kadmon and Shlomi 1978)

Fig. 1. A real-life dataset and its deformed result.

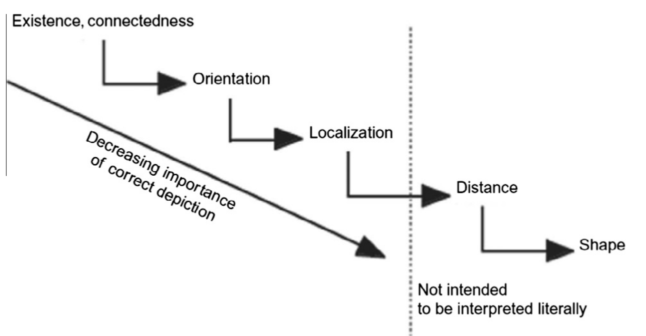

Fig. 2. Hierarchy of constraints for cognitive purpose (Barkowsky and Freksa, 1997).

The remainder of the article is organized as follows: Section 2 reviews current methods on variable scale transformation and discusses how to reduce orientation distortions of variable scale maps; Section 3 develops an optimization method for balancing the areas and orientation distortion and describes the implementation; Section 4 reports an experimental evaluation. Finally, in Section 5 some conclusions are made.

2. Problem of the orientation distortion with variable-scale maps

Currently many variable scale transformation methods have been developed. A common approach is the fish-eye projection to improve the clarity of preferred areas on a map by locally enlarging these areas, e.g. the polyfocal projection by Kadmon and Shlomi (1978) and the methods of Harrie et al. (2002), Wang et al. (2008) and Li (2009). There are also other methods to improve the clarity of the whole map by making the spatial density more even (Merrick and Gudmundsson, 2006; Bak et al., 2009; Van Oosterom and Meijers, 2014; Li and Ti, 2015). Several optimization methods (Agrawala and Stolte, 2001; Kopf et al., 2010) for the generation of route maps considered the reduction of orientation distortions for the path, from one location to another, as a constraint in their optimization models. Several optimization methods (Haunert and Sering, 2011; Van Dijk et al., 2013; Van Dijk and Haunert, 2014) have considered the reduction of the geometric distortion in the generation of focus maps. The optimization method by Wang and Chi (2011) generated focus + context metro maps by minimizing the sum of the differences between the original and the corresponding octilinear edge directions. Ti et al. (2015) applied a variable scale transformation in the schematization of network maps in order to improve the clarity of resultant maps for the representation on small displays.

As mentioned before, this study aims to reduce the orientation distortion for a given resultant map generated by current variable scale transformation methods. Orientation distortions may bring two problems for map recognition. The first problem is for individual lines. Although it is not necessary to preserve the exact geometric shape of roads in their variable-scale representations (Tversky and Lee, 1999), the over-distortion of orientations may reduce road recognition for users. The second problem is the over-distortion of the whole map, which increases the users' difficulty in mentally matching the map with the physical world (Kopf et al., 2010).

However, in variable scale maps the cartographic principle of geometric correctness must be violated (Barkowsky and Freksa, 1997). Hence it is impossible to completely eliminate the orientation distortions while preserving the map clarity that was improved by area distortions. Hence optimizing the balance of the orientation and area distortions, i.e. minimizing orientation distortions while preserving map clarity as much as possible, is adopted in this study. The preservation of clarity on variable-scale maps cannot be achieved by keeping the scales of different areas on the map as similar as possible, because it is difficult to determine these scale values for different areas on the variable-scale maps, especially for inhomogeneous smooth scale variations.

A map is represented as a plane geometric graph $G = (V, E)$ whose edge set E contains an element for each line segment of a map object (i.e. a polygon or polyline) and whose vertex set V contains the endpoints of those line segments. For variable-scale resultant maps, current methods (e.g. Kadmon and Shlomi, 1978; Van Dijk and Haunert, 2014) generally lengthen edges in enlarged areas and shorten them in other regions. Hence, balancing area and orientation distortions is achieved in this study by minimizing orientation distortions while preserving the lengths of edges as far as possible. As balancing area and orientation distortion is an ill-posed problem and has no unique solution, an optimization method is developed in this study.

3. Formulation of balancing areas and orientation distortions as a convex quadratic optimization problem

In this section, an optimization-based method using convex quadratic programming (CQP) is developed to balance the area and orientation distortions.

An optimization problem is an abstraction of the problem of making the best possible choice of a vector x from a set of candidate choices (Boyd and Vandenberghe, 2004) and is often used to

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