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Simplification and aggregation of vector building footprints using deep learning models

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Abstract:

Map generalization is one of the most fundamental tasks in cartography. As an important step of spatial data handling and map production, map generalization aims to abstract the spatial information derived from original geographic data, to facilitate the spatial representation at a reduced scale, while preserving the main spatial relationships and characteristics. The generalized outcome is a visually engaging and comprehensible presentation of complex geographic data. This process not only simplifies data volume, but also promotes the discovery of spatial knowledge by harnessing the complexity of scale to unlock deeper insights and understanding. In practical terms, map generalization enhances the utility of maps across various application domains such as vehicle navigation, urban planning, and environmental protection. Consequently, this process ensures that maps align more closely with user requirements, thus, contributing to their efficacy.

However, automatic map generalization remains a challenge in the fields of cartography, despite years of development. Due to the complexity of spatial distribution and cognitive perception of buildings and roads, the generalization of these elements is a significant difficulty within automatic map generalization. The complexity and challenges of map generalization are largely due to its high dependency on human cognitive activities, which are subjective, flexible, and often based on fuzzy judgment standards. Therefore, not all problems in map generalization can be modeled or algorithmically solved, making deep learning a promising strategic solution for map generalization.

Research in map generalization, particularly concerning buildings, has attracted significant attention. This process involves applying different operators, such as selection, simplification, aggregation, and displacement. Simplification and aggregation stand out as the most fundamental techniques among them. The simplification process refers to reducing the complexity of building outlines by decreasing the number of vertices that make up the building outlines, it aims to reduce map details. The aggregation process involves combining adjacent or proximate buildings into larger units or groups. This not only helps reduce the number of elements on the map but also conveys spatial relationships and patterns at a higher level of abstraction.

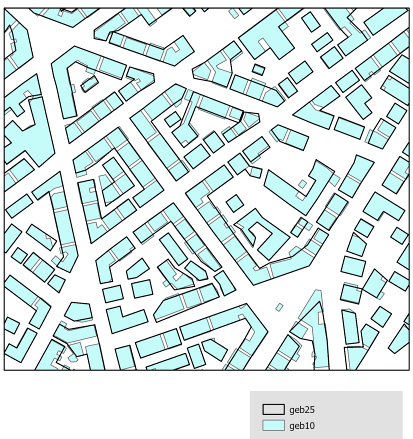

Figure 1. Dataset used for learning the simplification and aggregation operators: blue for buildings at map scale 1:10,000 and polygons with black borders indicating the buildings at map scale 1:25,000 after map generalization.

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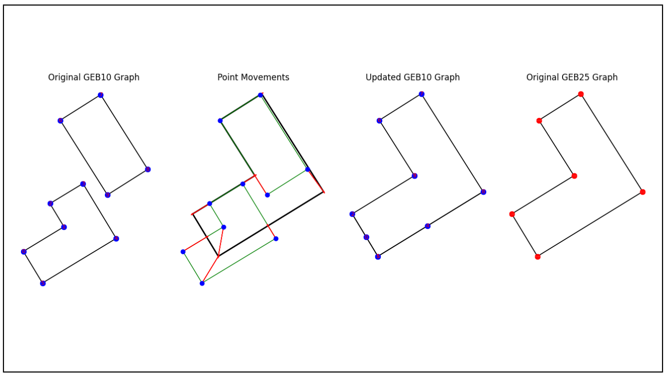

Figure 2. The process of training data preparation: (1) original buildings at map scale 1:10,000; (2) vertex movement illustrated in red with adjacency updates; (3) aggregated building at target map scale; (4) buildings after removing redundant vertices.

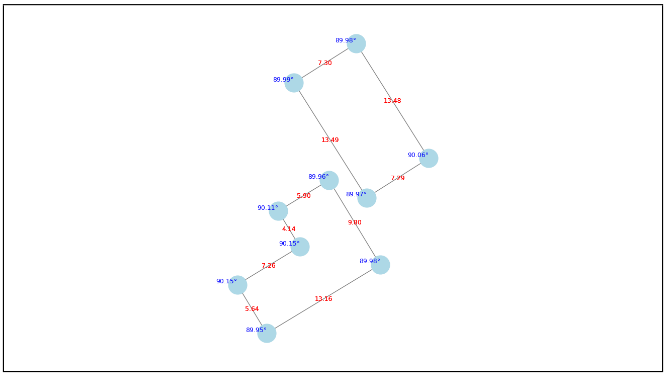

Figure 3. Vertex features at map scale 1:10,000, including polygon interior angles and edge lengths.

In previous studies on deep learning-based map generalization of buildings, researchers explored both raster-based and vector-based solutions. Raster-based solutions require rasterization of vector data, which are less than ideal, but allow for multiple generalization operators to be realized simultaneously, e.g., Feng et al. (2019) and Sester et al. (2018). Until now, vector-based approaches could only address the simplification operator, without considering adjacent or neighboring geographical entities, e.g., Zhou et al. (2023) and Yan et al. (2019). In this research, our objective is to develop a vector-based approach for map generalization that encompasses not just the simplification but also the aggregation of building footprints.

To account for neighboring buildings, all vertices from the buildings to be aggregated undergo Delaunay triangulation. Graph structures are employed to train a graph-based model, predicting the movement of individual vertices and the new connections between neighboring vertices. Therefore, training dataset is prepared based on the data used in (Feng et al., 2019) as illustrated in Figure 1 at map scale 1:10,000 and 1:25,000. In further, the process of training dataset preparation is presented in Figure 2, where the vertices are firstly moved and then the vertices connections are rebuilt by predicting a new adjacency matrix. Furthermore, features at individual vertices are calculated as shown in Figure 3, including features such as polygon interior angles and edge lengths. In this work, we aim to further test different graph-based neural network architectures, including Graph Convolutional Networks (GCNs) and Graph Attention Networks (GATs), for the map generalization task.

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