Scale-aware polyline segmentation using hierarchical clustering and metric learning

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Abstract:

Linear features on maps exhibit a heterogeneous spatial distribution, making it challenging to achieve satisfactory performance in complex line generalization using a single algorithm or fixed parameter. The diversity of characteristics within individual linear objects necessitates adaptive processing tailored to the different sections. As a result, line segmentation becomes a critical pre-processing step that divides polylines into homogeneous sub-sections, providing a foundation for subsequent structure and process recognition.

Existing methods for polyline segmentation have primarily relied on the detection of characteristic points or supervised classification models (Balboa and López 2009, Samsonov and Yakimova 2017, Yang et al. 2022). However, these methods are often constrained by predefined parameters, rigid classification categories, and labor-intensive labeled datasets, which collectively limit their generalization capability. Additionally, these methods overlook the influence of scale effects, which play a significant role in the process of line generalization.

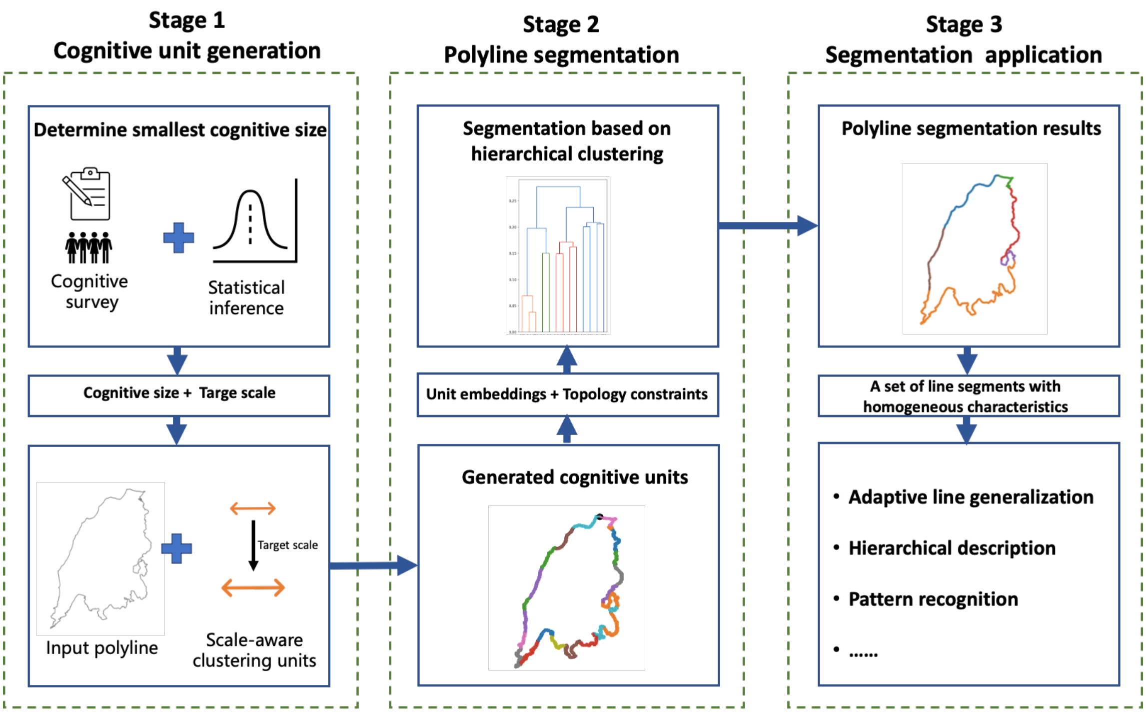

Figure 1. Pipeline of line segmentation using hierarchical clustering

To address these limitations and enhance the adaptability of polyline segmentation, this study proposes a novel scale-aware segmentation method based on hierarchical clustering (Figure 1). The process begins with determining the smallest cognitive size (SCS), a concept similar to the smallest visible size (SVS) rooted in the natural principle for objective generalization (Li and Openshaw 1993). Unlike the SVS, the SCS refers to the minimum size at which individuals can perceive visual semantics such as smoothness, meandering, zigzag patterns, or orthogonality. As illustrated in Figure 2, a complex polyline can be partitioned into a series of neighboring, overlapping, and scale-aware

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units based on the SCS. Each unit is represented by an embedding vector encoded by a metric-learning-based deep neural network (Li et al. 2023), which can measure the spatial similarity between different polyline units. The hierarchical clustering process groups similar units into separated clusters. The clustering process determines the number of clusters using a modified silhouette coefficient that considers the topological connections between the neighboring clusters. The proposed method produces segmentation outcomes that closely align with human cognitive patterns, highlighting its effectiveness and adaptability in addressing the challenges of polyline segmentation.

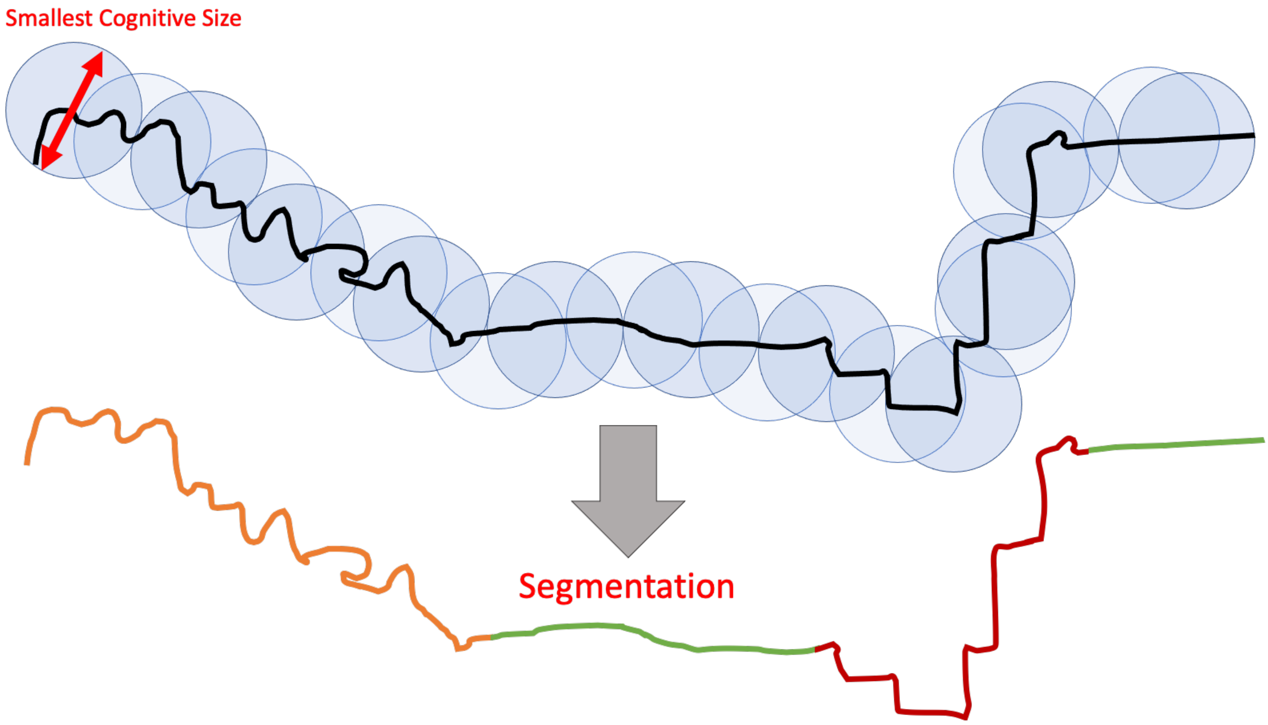

Figure 2. Segmentation example on a complex polyline

The proposed segmentation method effectively facilitates adaptive line generalization by enabling the recognition of structural patterns and hierarchical data structures across varying scales. Moreover, the scale-aware design ensures consistent and reliable performance across different scales. By minimizing human intervention and integrating scale-awareness, the method establishes a robust foundation for improving the efficiency and accuracy of line generalization.

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