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Understanding Crowdsourced Map Layout Designs via Interpretable GNN-based Layout Representation Learning

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Abstract:

The recent development of AI, especially deep learning, has raised broad research interest in achieving machine understanding of maps for various map-centered tasks, e.g., map information retrieval and map generalization. For instance, Smith et al. (2025) developed an object detection algorithm to extract tree symbols from digitized maps of 1890s Leeds and Edinburgh, which aimed to understand current urban forests. Christophe et al. (2022) applied generative adversarial networks (GANs) to transfer map styles from simple styles to complex styles. Feng et al. (2019) investigated the use of deep convolutional neural networks (DCNNs) for building generalization and found that the residual U-net architecture achieved the most competitive performances. However, these models are often treated as "black boxs", which fail to generate interpretable training outcome, i.e., embeddings that models learnt from training samples.

In this paper, we address the "black box" issue based on our recent research efforts in developing learning algorithms for map layout understanding. In particular, we developed a GNN-based model to learn map layout representation from crowdsourced thematic map images on the internet, and used the model to perform map layout retrieval and classification. With such data-driven effort, we argue that 1) using representation learning as the objective of model development helps not only the task performance, but also resulting a more interpretable layout embeddings; 2) learning embeddings with deisgn monotonicity can be helpful to further pattern discovery and application.

As for the map layout retrieval task, we proposed a GNN-based model (Yang et al., 2025) for learning map layout representation without label supervision, which introduces the structural features and proposes a dual-graph network architecture to enhance the model representation of complex map layouts, e.g., alignment and overlap, at global and local scales. To ensure the model's generalization capability for ubiquitous maps, we employed a weakly supervised learning strategy. The model is trained with the combination of a triplet loss based on map layout similarity derived using heuristic rules and a mutual information loss to take full advantage of the dual-branch network architecture. To evaluate the effectiveness of MapLayNet, a map layout retrieval task is carried out using a map layout label dataset, ubiMap. MapLayNet has outperformed the baseline methods in similarity and stability by 2.5% and 4.2% respectively. In addition, MapLayNet has also shown better consistency against human evaluation than LayoutGMN. An ablation study has proved the effectiveness of the design in MapLayNet for structural enhancement. The analysis of embedding learned by MapLayNet has shown that the model can generate a concept hierarchy with compactness in lower-level layout patterns and partial-ordered concept relations in the higher-level layout abstraction.

As for the map layout classification task, we design an unsupervised GNN-based map layout representation learning method (Chen et al., 2025) that allows the model to gain a competitive layout understanding without heuristic rules in the training procedure. The proposed method leverages two key architecture designs including a graph data augmentation scheme tailored for map layout design and batch-wise layout distribution updates for unsupervised modeling training by explicitly optimizing intra-class and inter-class sample distances. To validate the feasibility of the model, we carried out a map layout classification experiment using the ubiMap dataset (Yang et al., 2023), four typical map layouts were manually labeled to establish a dedicated map layout experiment dataset. Along with other baseline models, we first pre-trained all models with unlabeled map images and then fine-tuned all models with a small set of map layouts for the layout classification task. The proposed model outperformed the baselines on the Macro F1 score by more than 9%. Further model analysis showed that the proposed model is more capable of understanding map layouts with irregular layout element sizes.

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Further improvement of learning layout embeddings is needed to develop a deployable embedding model. For instance, the use of heuristic rules to guide model training inevitably introduces some layout noise and more effective methods for generating layout samples for triplets are worth investigating. In addition, the use of vision foundation models (e.g., SAM) for building large-scale map image datasets with layout labels empowers research on the grounding theory on embedding space of map layout.

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