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Comparative Analysis of Structural Backbone Extraction Techniques

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Abstract. This study explores structural backbone extraction methods in diverse real-world networks, ranging from character to social networks. Eight techniques from the netbone package are analyzed using Jaccard and Overlap coefficients to measure similarities. The Kolmogorov–Smirnov statistic evaluates weight and degree distribution preservation. Results highlight correlations and hierarchical relationships among techniques, with Doubly Stochastic outperforming in mimicking original network distributions. The study’s comprehensive insights contribute to refining and advancing structural filtering techniques, fostering a deeper understanding of complex systems.

Keywords. *Complex Networks; Backbone Extraction; Filtering Techniques; Sparsification*

1 Introduction

Networks are indispensable tools for representing and comprehending intricate systems, providing diverse applications such as pinpointing pivotal nodes [9, 10, 12], revealing communities [3, 8], and delving into the dynamics of networks [2, 1]. Nevertheless, the computational challenges become daunting when confronted with large networks.

Researchers have introduced several techniques to tackle this issue, focusing on diminishing network size while maintaining its fundamental properties. Two primary approaches have emerged to attain this objective: structural and statistical methods. Structural methods strive to retain a set of topological features inherent in the network while downsizing its overall scale. In contrast, statistical methods eliminate noise by selectively filtering out nodes or links that might obscure the network’s underlying structure. Researchers have extensively compared statistical methods [14, 13], often against a few structural methods [7, 4]. However, there’s been limited focus on comparing only the structural backbone extraction methods [5, 6, 11].

We compared eight structural filtering techniques in the World Air Transportation network in a previous work. This study extends it across 39 real-world networks of different sizes and covering various fields. Our initial experiment compares the similarities among eight structural filtering techniques from the netbone package [15]. We use the Jaccard Coefficient and Overlap Coefficient to assess the similarity between the edge sets of technique pairs. Sub-

sequently, we examine the weight and degree distributions of the resulting backbones. The Kolmogorov–Smirnov (KS) statistic evaluates deviations from the original distributions within each network. Then, we rank the methods based on their KS statistic values, reflecting their alignment with the original network’s distributions.

2 Experimental Results

In Fig 1, the heatmaps of the Jaccard Score provide insights into significant correlations among specific pairs of techniques. Notably, there are strong correlations between Primary Linkage Analysis and Minimum Spanning Tree Filters (PLAM-MSP) and Ultrametric Backbone and Minimum Spanning Tree Filters (UMB-MSP). The H-Backbone and Doubly Stochastic Filters stand out due to their lack of correlation with other techniques, suggesting distinctive behavior.

Examining the heatmaps of the Overlap Coefficient, hierarchical relationships among backbones become apparent. For instance, the Minimum Spanning Tree is included in the Primary Linkage Analysis Backbone, the Minimum Spanning Tree Backbone is included in the Ultrametric Backbone, and the Ultrametric Backbone is included in the Metric Backbone. High percentages of overlap are observed in specific pairs, such as 90% and 97% of High Saliency Skeleton edges overlapping with Planar Maximally Filtered Graph and Metric Backbones, respectively. Additionally, 93% of Primary Linkage Analysis Backbones overlap with the Planar Maximally Filtered Graph Backbone. The H-Backbone shows, on average, 84% and 86% overlap with Planar Maximally Filtered Graph and Metric Backbones, respectively. Ultrametric Backbone edges overlap, on average, by 85% with the Planar Maximally Filtered Graph Backbone. High Saliency Skeleton edges overlap by, on average, 83% and 88% with Minimum Spanning Tree and Ultrametric Backbones, respectively. The Doubly Stochastic filter produces unique backbones with low overlap percentages with other methods.

The violin and box plots further illustrate the performance of backbone extraction methods. They highlight the superiority of Doubly Stochastic in extracting backbones that closely match the original network’s weight and degree distribution. Conversely, H-Backbones exhibit the furthest weight distribution, and Primary Linkage Analysis backbones display the furthest degree distribution. These findings contribute valuable insights into the comparative effectiveness of structural filtering techniques across diverse real-world networks.

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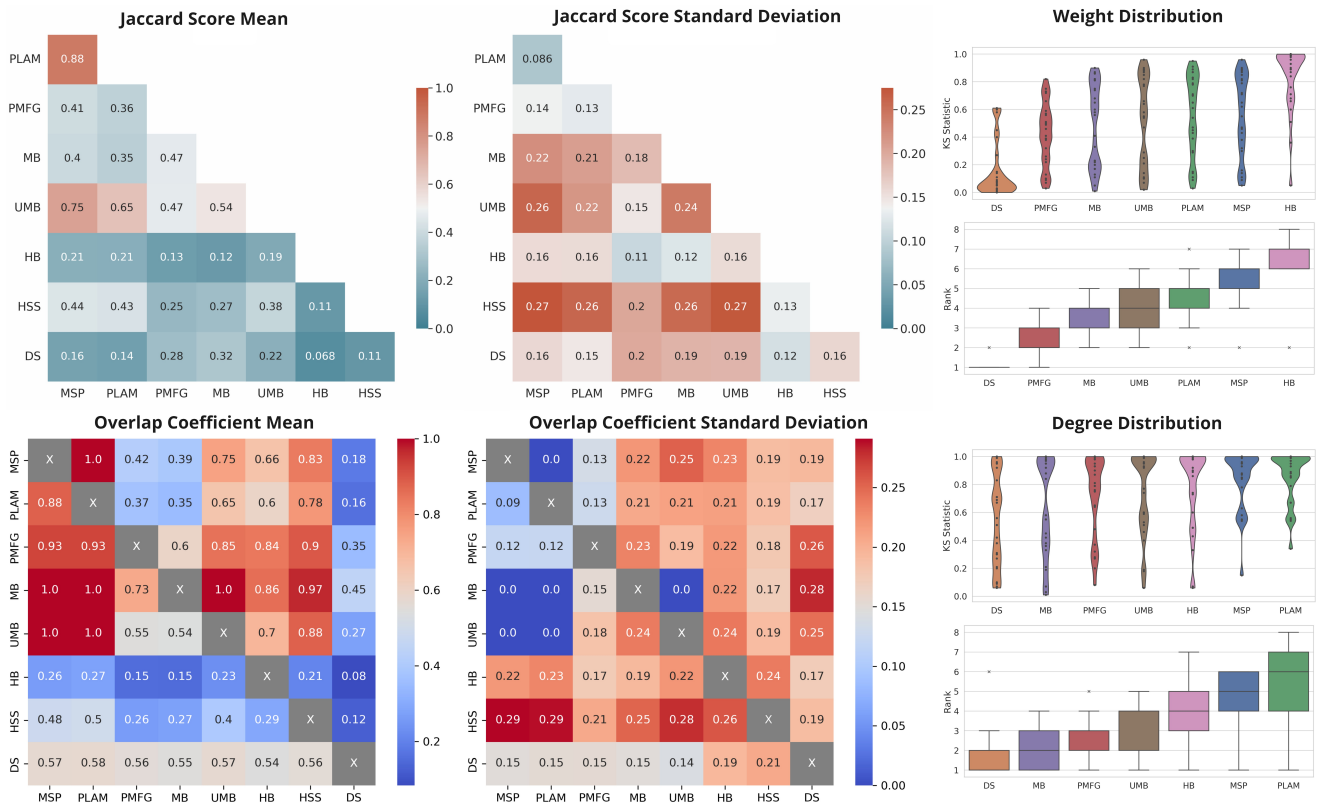


Figure 1: The top heatmaps display the mean and standard deviation of Jaccard Scores for each method pair, while the bottom heatmaps show the mean and standard deviation of Overlap Coefficient Scores. Additionally, the violin plot illustrates KS-static values between the backbone and original weight (degree) distribution across all networks. Boxplots depict method ranks based on the K-S statistic between each filtering technique’s weight (degree) distribution and the original network. Evaluated techniques include MSP (Minimum Spanning Tree), PLAM (Primary Linkage Analysis Method), PMFG (Planar Maximally Filtered Graph), HSS (High Saliency Skeleton), MB (Metric Backbone), UMB (Ultrametric Backbone), DS (Doubly Stochastic), and HB (H-Backbone).

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