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Community-Aware Node Ranking in Complex Networks

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1 Abstract

Centrality measures are widely used to rank influential nodes in complex networks. However, traditional ranking schemes often concentrate top-ranked nodes within the same region, limiting their effectiveness in network-wide influence. To address this limitation, we propose a community-aware ranking scheme that distributes influential nodes across different communities, ensuring broader coverage. We evaluate the proposed scheme using the Susceptible-Infected-Recovered (SIR) model on both synthetic and real-world networks across six centrality measures. Our results demonstrate that the community-aware ranking consistently achieves a larger outbreak size compared to the classical descending order scheme, making it more effective for applications such as viral marketing, misinformation control, and vaccination strategies. This approach is adaptable to various network types and centrality measures, offering a robust tool for enhancing diffusion processes.

2 Introduction

Centrality measures play a crucial role in identifying and ranking the most influential nodes within a network. These measures are used across diverse domains, from urban planning in land transportation networks to the identification of critical proteins in biological networks. In Internet infrastructure, centrality helps prevent system failures by identifying critical servers, while in terrorist networks, it aids in pinpointing key individuals. Social networks utilize centrality measures for effective viral marketing, combating the spread of fake news, and optimizing information dissemination [1]. Despite the wide applicability of centrality measures, their conventional ranking approach, which orders nodes in descending importance, has significant limitations.

A major drawback of the classical descending order ranking scheme is its tendency to concentrate influential nodes within the same region of a network. As a result, the impact of these nodes becomes localized, leaving other parts of the network under-influenced. In real-world scenarios—such as preventing the spread of misinformation or maximizing the reach of a viral marketing campaign—this localized influence can be counterproductive, as it neglects the broader network structure. Consequently, the need arises for a ranking method that ensures the influential nodes are more evenly distributed across the network, maximizing their collective impact.

To overcome this limitation, we introduce a community-aware ranking scheme [2]. Instead of focusing solely on the highest-ranking nodes in a network, our approach

selects influential nodes from different communities, ensuring a more widespread distribution of influence. By iterating across communities, starting from the largest to the smallest, this method prevents the oversaturation of influence in any particular region.

Note that this work differs from the development of community-aware centrality measures [3–19] in that our proposed community-aware ranking scheme is not tied to any single centrality measure. Instead, it operates independently of the specific centrality definition and can be applied to any centrality measure and on all types of networks (i.e., directed/undirected and weighted/unweighted). The scheme adjusts node rankings by incorporating the network’s community structure, ensuring a more distributed and effective influence across the network.

We evaluate our proposed community-aware ranking scheme using the Susceptible-Infected-Recovered (SIR) diffusion model on various synthetic (generated by the LFR algorithm) and real-world networks (including social, biological, infrastructural, and collaboration networks). We explore its effectiveness across six different centrality measures, including both local (Degree, Maximum Neighborhood Component), path-based (Betweenness, Closeness), and iterative (Katz, PageRank) methods.

3 Results

To assess the effectiveness of the proposed community-aware ranking scheme, we compared it against the traditional descending order ranking scheme using the Susceptible-Infected-Recovered (SIR) diffusion model. For the sake of brevity, we show the results of the measures —Degree centrality and Closeness centrality— in the EU Airlines and AstroPh networks. The key metric for comparison is the outbreak size, measured by the number of nodes in the recovered state, which indicates the spread of influence within the network.

As shown at the top of Figure 1, we observe a positive relative difference in the outbreak size (ΔR) when using the community-aware ranking scheme, compared to the descending order ranking scheme. For both Degree and Closeness centrality in the EU Airlines and AstroPh networks, the community-aware scheme consistently yields higher outbreak sizes, regardless of the fraction of initially infected nodes. This demonstrates that distributing influential nodes across different communities significantly enhances the diffusion process, allowing influence to spread more uniformly throughout the network.

At the bottom of Figure 1, the visualization of the EU Airlines and AstroPh networks highlights the spatial distribution of the top 15% most influential nodes selected by both ranking schemes. In the classical descending order scheme, these nodes tend to cluster in the network’s core, limiting their reach to peripheral communities. In contrast, the community-aware ranking distributes the top nodes across the entire network, covering distinct regions and maximizing the spread of influence. This spatial distribution is crucial, as it prevents the diffusion process from becoming confined to specific zones, which would otherwise result in a more localized and less effective spread.

The results from both networks demonstrate the advantage of the community-aware ranking approach, which ensures that influential nodes are selected from across the entire network, enabling a higher overall diffusion impact. Similar results were observed

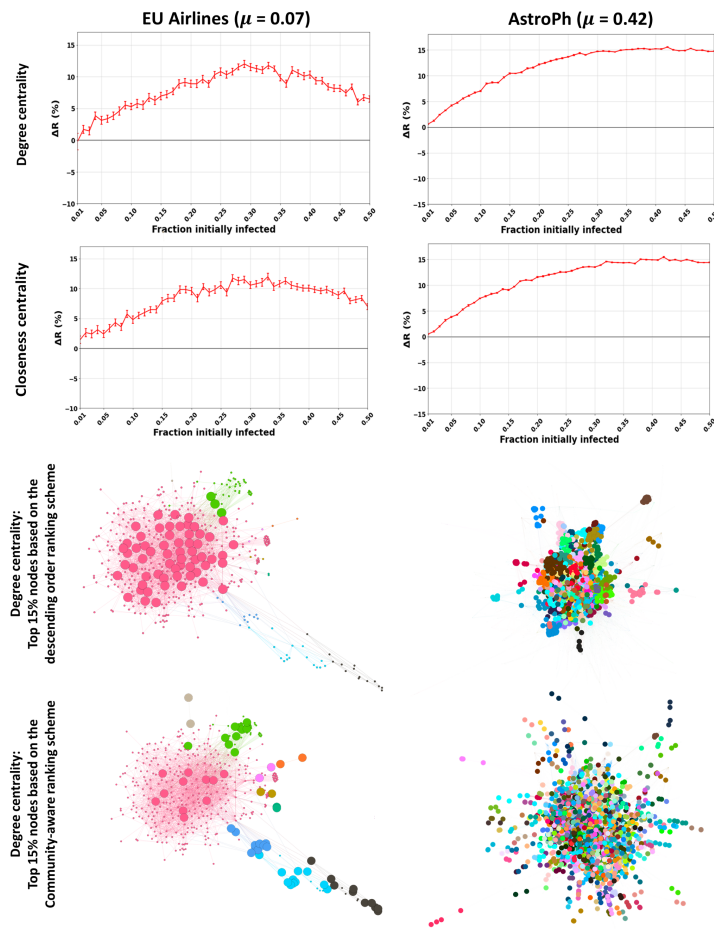


Fig. 1. The top two rows illustrate the relative outbreak size (ΔR) as a function of the fraction of initially infected nodes. The red curve indicates the relative performance difference of the community-aware ranking scheme compared to the descending order ranking scheme of the Degree centrality and Closeness centrality. The bottom two rows illustrate the top 15% of nodes selected based on the Degree of centrality using the descending order and community-aware ranking schemes in the EU Airlines and AstroPh networks.

with other centrality measures (Betweenness, Katz, PageRank) and network types, further validating the robustness of this approach.

In summary, the community-aware ranking scheme not only outperforms the classical descending order scheme in terms of outbreak size but also ensures a more efficient and balanced distribution of influence across the network. This makes it a powerful tool for real-world applications where maximizing network-wide diffusion is critical.

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