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Searching for Influential Nodes in Modular Networks

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1 Introduction

Ranking nodes according to their importance is a fundamental issue in the research on complex networks. While many centrality measures have been proposed over the years based on local or global topological properties of the networks, few studies have considered the influence of the community structure. Despite the fact that many real-world networks exhibit a modular organization, this property is almost always ignored in the design of the ranking strategies. In a modular network, we can distinguish two types of influences for a node [1]: A local influence on the nodes belonging to its own community through the intra-community links, and a global influence on the nodes of the others communities through the inter-community links. Therefore, centrality measures should not be represented by a simple scalar value but rather by a two-dimensional vector. Its first component measures the local influence of the node, while the second component measures its global influence. Based on this assumption, we propose to extend all the classical centrality measures to modular networks [2]. We need to consider two cases corresponding to the nature of the communities (with overlapping nodes or not). Thus, in the following, "Modular Centrality" stands for centrality in modular networks with non-overlapping communities, while "Overlapping Modular Centrality" refers to centrality in modular networks with overlapping communities. We conducted a series of experiments in order to test the relevancy of the Modular centrality and the Overlapping Modular centrality as compared to their classical counterpart. Considering the most influential centrality measures (Degree, Betweenness, Eigenvector, Closeness), the local and global components have been evaluated separately. Additionally, a straightforward combination of both components (modulus of the two-dimensional vector) has been tested. Experiments have been conducted on synthetic networks with controlled community structure, and on real-world networks in an epidemic spreading scenario using the SIR model. Results show that the spreaders identified by the proposed approach are more influential than those targeted by the standard centrality measures.

2 Proposed approach

The global component of the vector is defined in the same way for both type of community structure (overlapping and non-overlapping). It is computed on the global network obtained by removing all the intra-community links from the original network. Remaining isolated nodes are also removed. The local component computation depends on the type of the network. In networks with non-overlapping community structure, it is computed on the local graph obtained by removing all the inter-community links from the original network. In networks with overlapping communities, the local component of a node is computed according to its nature. For a non-overlapping node, as previously, only members of its community are considered. For an overlapping node, all the communities that the node belongs to are merged in a single community.

Due to the lack of space, we only present the algorithm used to compute the Modular centrality.

Step 1. Choose a standard centrality measure β.
Step 2. Remove all the inter-community edges from the original network G to obtain the set of communities $\mathscr{C}$ forming the local network G_l.
Step 3. Compute the local measure β_L for each node in its own community.
Step 4. Remove all the intra-community edges from the original network to reveal the set of connected components $\mathscr{S}$ formed by the inter-community links.
Step 5. Form the global network G_g based on the union of all the connected component. Isolated nodes are removed from this network and their global centrality value is set to 0.
Step 6. Compute the global measure β_G of the nodes linking the communities based on each component of the global network.
Step 7. Add β_L and β_G to the Modular centrality vector B_M.

3 Results

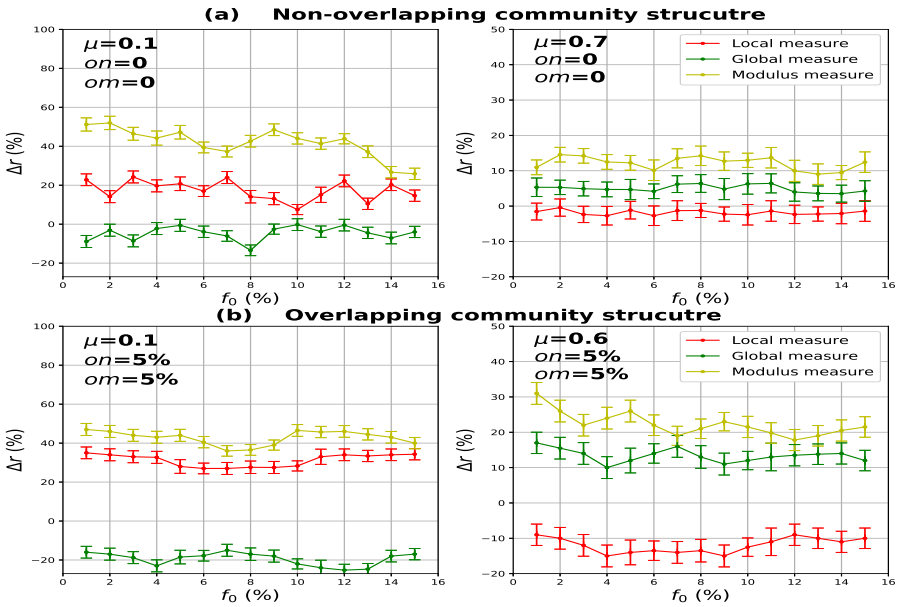

Fig. 1: Relative difference of the outbreak size Δr as a function of the portion of the initial spreaders f_0. Where $\Delta r = (R_c - R_s/R_s)$, R_c and R_s are the final number of recovered nodes for the centrality measure under test and the standard Degree centrality. Each value is the average of 100 SIR simulations per method and fraction of initially infected nodes. Positive value of Δr means that the centrality under test is more efficient than the standard centrality. Synthetic networks generated with the LFR algorithm are used with various community structure strength μ. (a) is for networks with non-overlapping community structure. (b) is for networks with overlapping community structure, where the number of overlapping nodes *on* is fixed to 5% of the size of the network, and the community membership parameter *om* is equal to 5% of the total number of communities.

We report the results of the Degree centrality in Figure 1. The Δr values between the various measures (Local component, Global component, and the modulus of either the Modular Degree centrality or the Overlapping Modular Degree centrality) and the classical Degree centrality have been computed while varying both the fraction of initial spreaders and the mixing proportion parameter μ. For low values of μ, the communities are well separated (few inter-community links), while high values of μ indicates a weak community structure. Results for networks with strong community structure are illustrated in the left panel of Figure 1. We notice that in both type of networks, Δr is always positive for the local component , while it is always negative for the global component. Indeed, in networks with strong community structure the local influence predominates. The same type of results are shown in the right panel of Figure 1 for networks with weak community structure strength. This time, one can notice that Δr is always positive for the global component, while it is negative for the local component. Indeed, in this situation, the global influence takes over the local influence. Furthermore, we notice that the measure that combines both components is always the most efficient in any case.

To summarize, in order to evaluate efficiently the centrality of nodes in networks with community structure (overlapping communities and non-overlapping communities), we cannot rely on the traditional centrality measures that do not take into account this topological property. It is necessary to consider and combine properly the two types of influence (local, global) occurring in such networks.

References

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