

Community Detection in Multi layer Networks

16CS60R58 Prishni Rateria
Under guidance of
Dr. Bivas Mitra

Outline:

- *Introduction*
 - Background
 - Motivation
 - Problem Statement
 - Contribution
- Related Work
- Multilayer Modularity
- Community Detection Algorithm
- Evaluation
- Summary and future work



Introduction

- Background

Community: Groups of nodes densely connected to each other than to the rest of the network.

Community Detection: partitioning the networks into groups of nodes.

Multi-Layer network:

- Comprises of multiple independent networks.
- Functionality of edges and nodes in different layer is different

- Community detection in homogeneous network has been studied extensively.

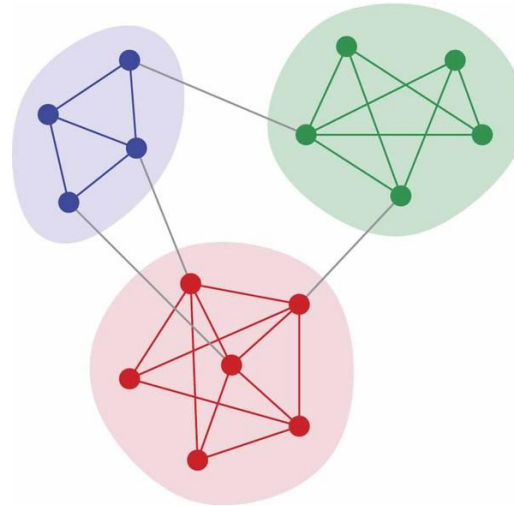


Figure1. Homogeneous network

- An entity in general is associated with multiple aspects of relationships,
- Multiple aspects of interactions can be modeled as a multi-layer graph

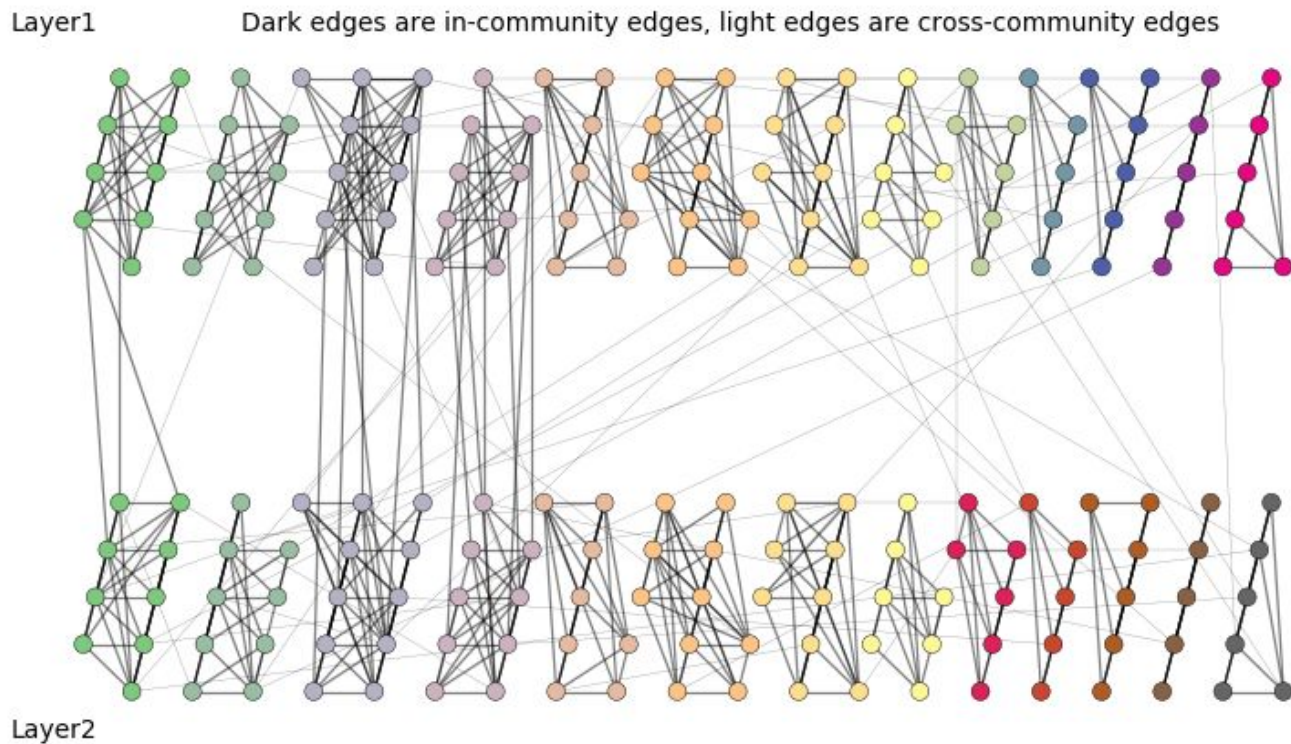


Figure2. Multi-layer network

An example of Multi-layer network.

- Layer 1 represents a friendship network, with nodes as people
- Layer 2 represents a location based social network, with nodes as locations and connected by proximity links



Motivation

- Can single layer community detection algorithm be used in multi-layer network?



Motivation

- Can single layer community detection algorithm be used in multi-layer network?

NO

Motivation

- Can single layer community detection algorithm be used in multi-layer network?

NO

- Because,
 - Links in multi-layer networks have different meaning.
 - Nodes may represent different entities

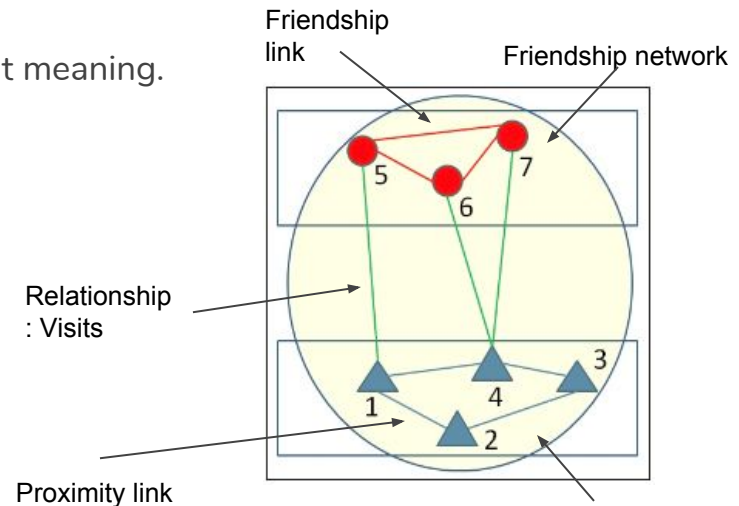


Figure4. Cross layer edges in multilayer networks have a different meaning

Location based network

Cont.

- Single layer community detection algorithm fails for networks having low density of coupling links

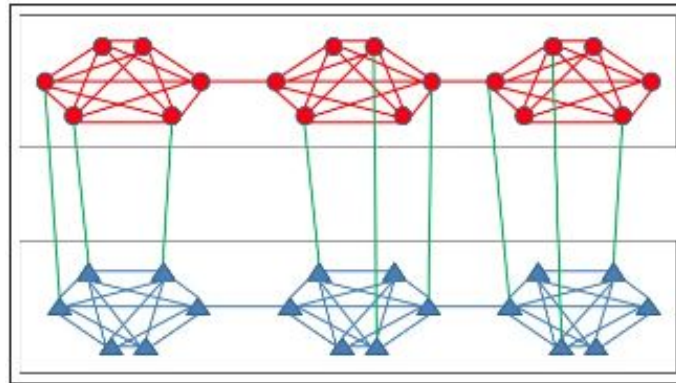


Figure5. Network with low density of coupling edges

cont.

- With single layer community detection algorithm,

Total communities detected = 6

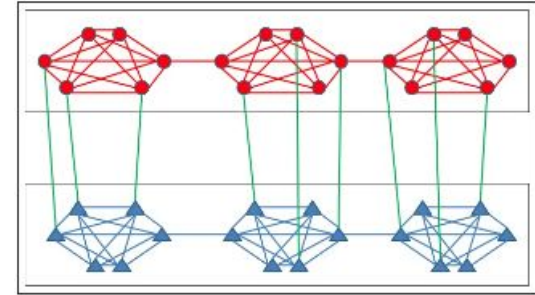


Figure6. Communities detected by single-layer community detection algorithm

- Desired number of communities = 3

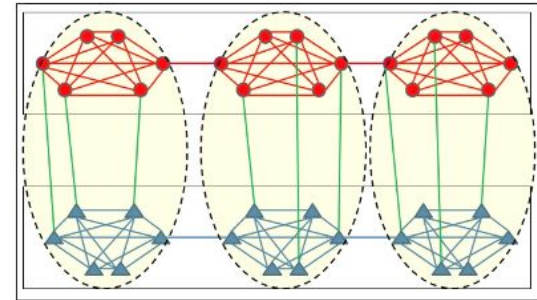


Figure7. Desired community structure

Problem Statement

Detecting communities in a multi-layer network comprising:

- Single type of nodes
- Multiple type of nodes

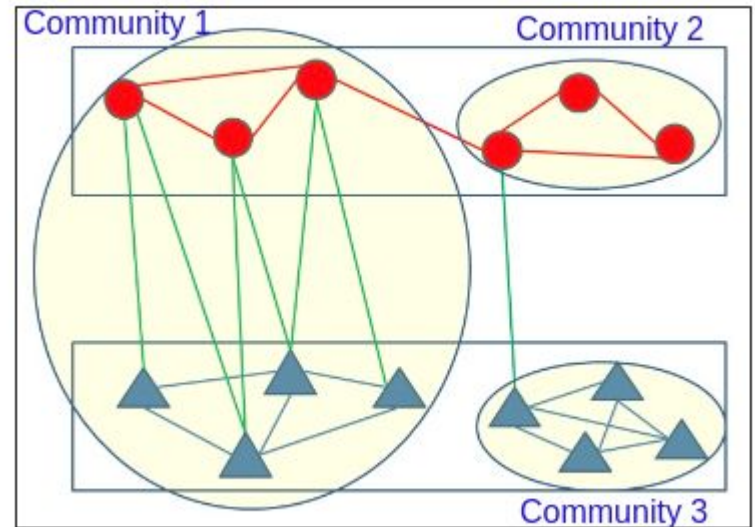


Figure8. Multi-layer community structure

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Related Work

- There has been several work done on this problem , but most of them suffer from several limitations
 - Example:
 - Forced to detect communities comprising only multiple types of Nodes.
 - Desired number of communities are required to be fixed apriori.
- Discovering community structure in multi layer network(DSAA) :
 - We found this work closest to the problem addressed
 - Proposes a new multi-layer modularity metric,
 - Uses a single layer community detection algorithm which work on the principle of maximizing the modularity of network partition.

P. J. Mucha et al. "Community structure in time-dependent, multiscale, and multiplex networks," science, 2010.

Y.-R. Lin et al. Metafac: community discovery via relational hypergraph factorization. SIGKDD, 2009.

X. Liu et al. A framework for community detection in heterogeneous multi-relational networks. Advances in Complex Systems, 2014.

J. Song et al. "A modularity based method reveals mixed modules from chemical-gene heterogeneous network," PLoS ONE, 2015

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MultiLayer Modularity:

For a multi layer community

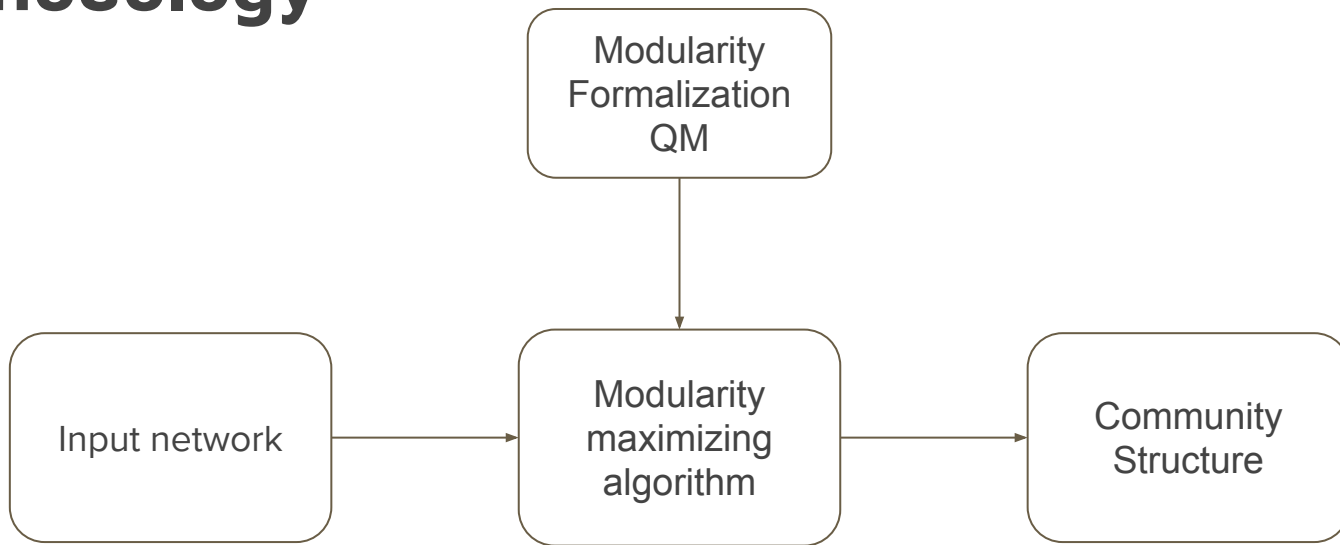
$$Q_M^C = \forall i, j \in C \left[\frac{1}{3} \left\{ \frac{1}{2|E_1|} \sum_{i,j \in V_1} (A_{ij} - \frac{h_i * h_j}{2|E_1|}) + \right. \right. \\ \left. \left. \frac{1}{2|E_1| + 2|E_2| + |E_{12}|} \sum_{i \in V_1, j \in V_2} (A_{ij} - \frac{c'_i * c'_j}{2|E_1| + 2|E_2| + |E_{12}|}) \right. \right. \\ \left. \left. + \frac{1}{2|E_2|} \sum_{i,j \in V_2} (A_{ij} - \frac{h_i * h_j}{2|E_2|}) \right\} \right]$$

For a single layer community

$$Q_M^C = \forall i, j \in C \left[\frac{1}{3} \left\{ \frac{1}{2|E_1|} \sum_{i,j \in V_1} (A_{ij} - \frac{h_i * h_j}{2|E_1|}) \right\} \right]$$



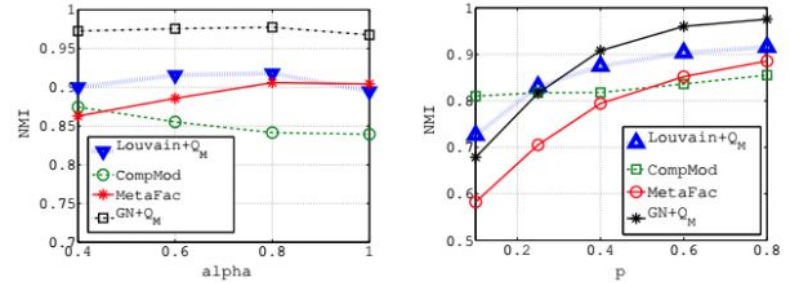
Methodology



Results of DSAA

Figure 9 shows: The method proposed in DSAA works better than other state-of-art algorithms.

But it also has some limitations.



(a) Varying α values for $p = 0.8$, $\mu = 0.4$ and $d = 0.04$

(b) Varying p values for $\mu = 0.4$, $\alpha = 0.6$ and $d = 0.04$

Figure9. NMI of obtained and ground truth communities for various α and P values



Limitations of DSAA

- The method uses Louvain algorithm for community detection.
- However, Louvain is a single layer community detection algorithm.



Louvain Algorithm

1. Assign a different community to each node
 2. For each node i
 - ▶ For each neighbor j of i , consider removing i from its community and placing it to j 's community
 - ▶ Greedily chose to place i into community of neighbor that leads to highest modularity gain
 3. Repeat until no improvement can be done
- No positive gain,
i stays in its original community

Louvain Algorithm:

- Initially every node is in its own community
- We merge nodes which are densely connected and form one single node representing that community.
- Recursively apply the same steps

Observation: The algorithm modifies the network structure

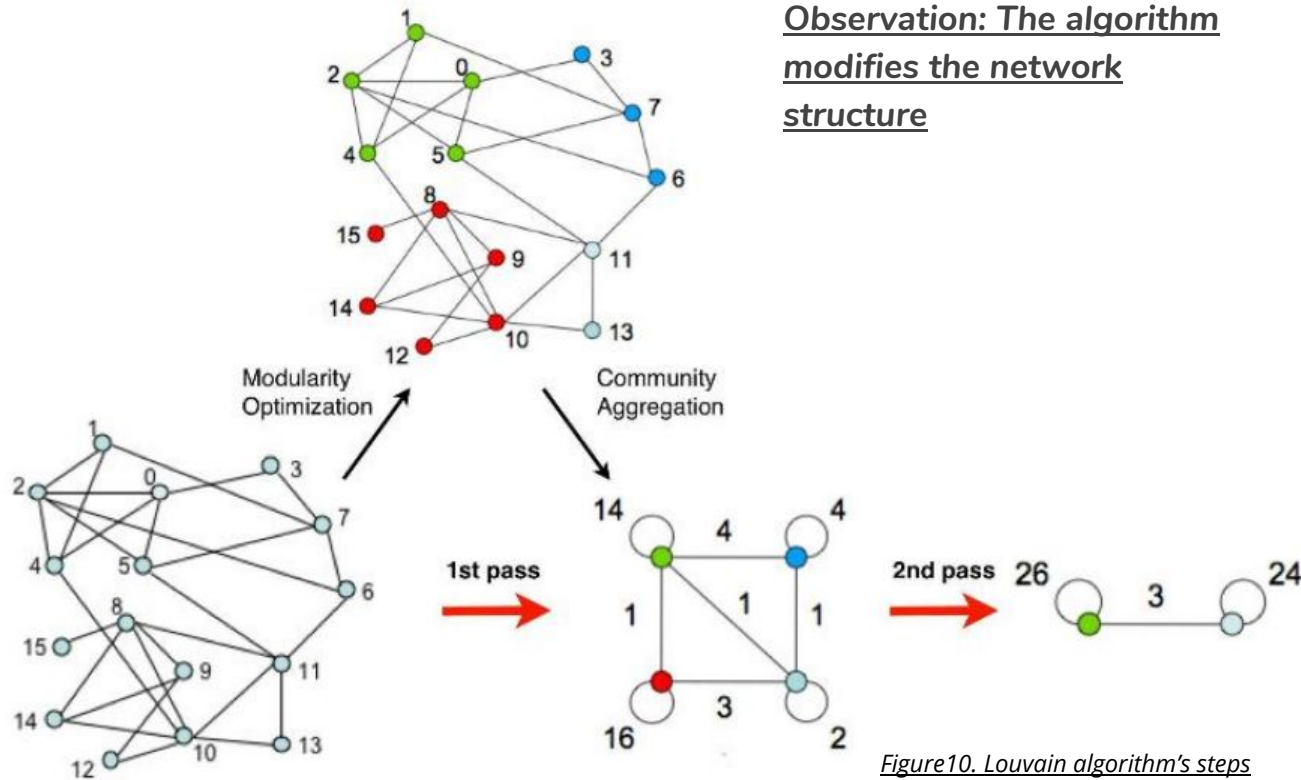


Figure10. Louvain algorithm's steps



Limitations of DSAA

- The method uses Louvain algorithm for community detection.
- However, Louvain is a single layer community detection algorithm.

Louvain algorithm merges nodes and modifies the network structure, So, if we apply it on multi-layer network:

1. We would lose the layer information after first the merge.
2. The network no more remains multi-layered.

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Algorithm: MixMod

The multi-layer network structure is preserved

While merging nodes and constructing new network.

- If the community has multiple types of node, we form multiple nodes for each type.
- Keep the information of them being in one community

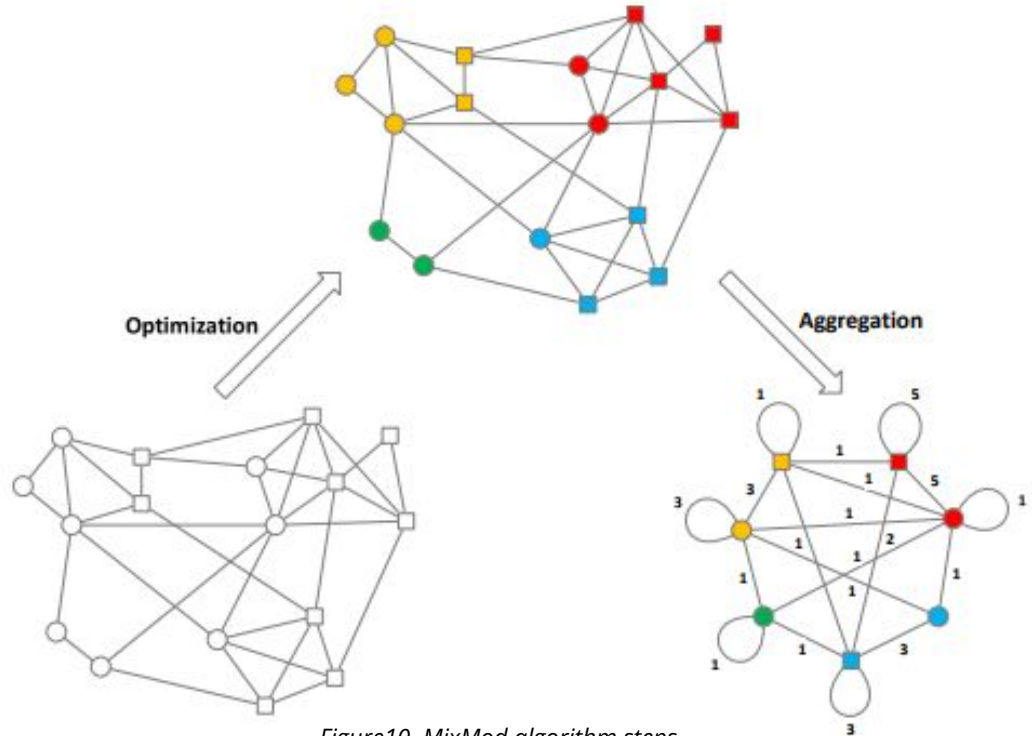
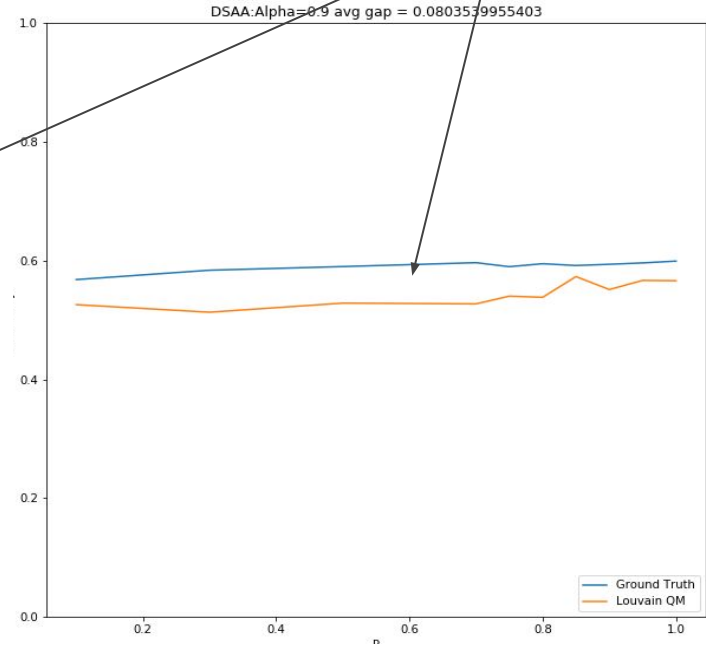
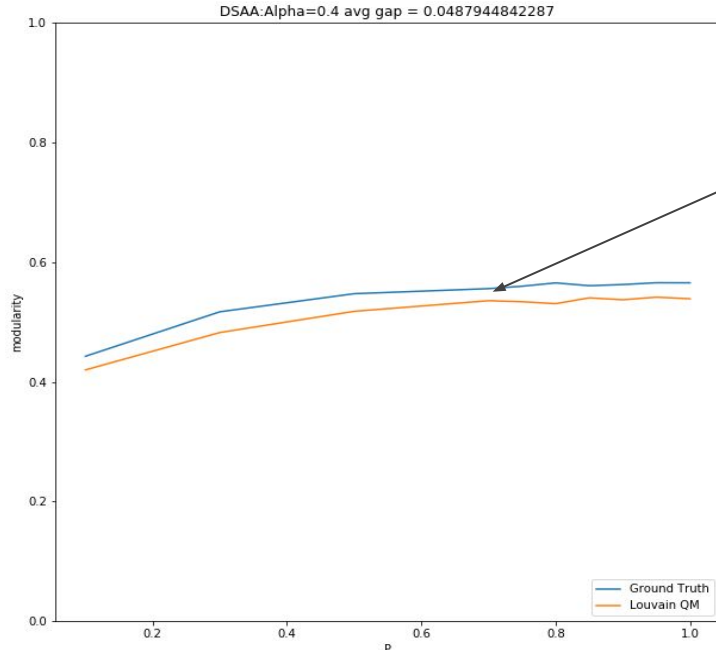


Figure10. MixMod algorithm steps

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Evaluation: (DSAA alpha plot)



Gap between the modularity of detected community and ground truth community

Figure11. Modularity plot using Louvain QM algorithm for two different values of alpha (0.4,0.9) and varying P

Evaluation: (DSAA p plot)

Gap between the modularity of detected community and ground truth community

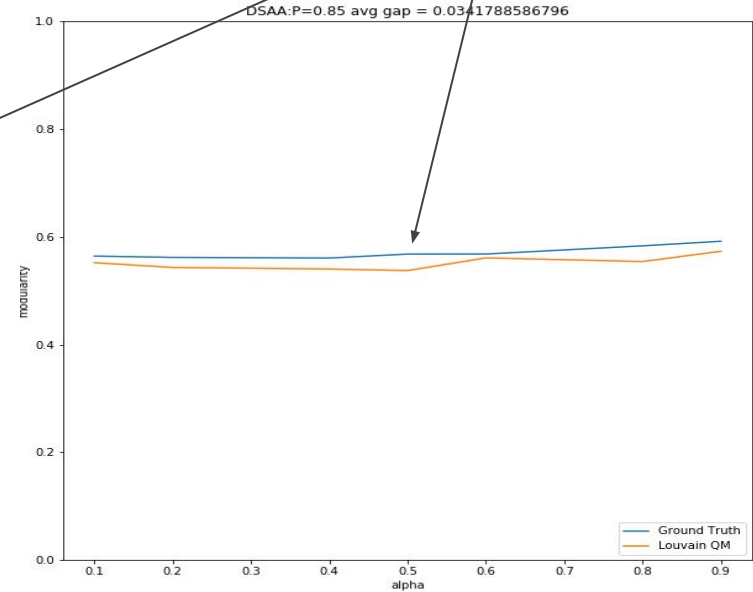
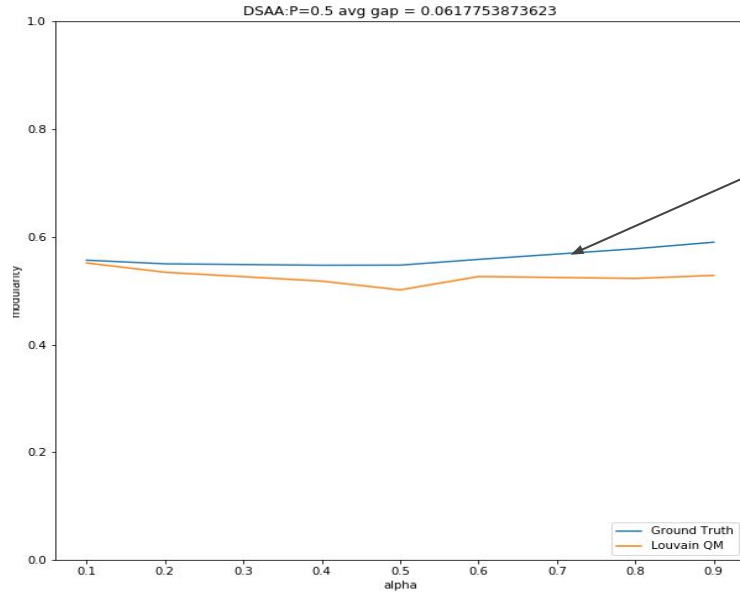
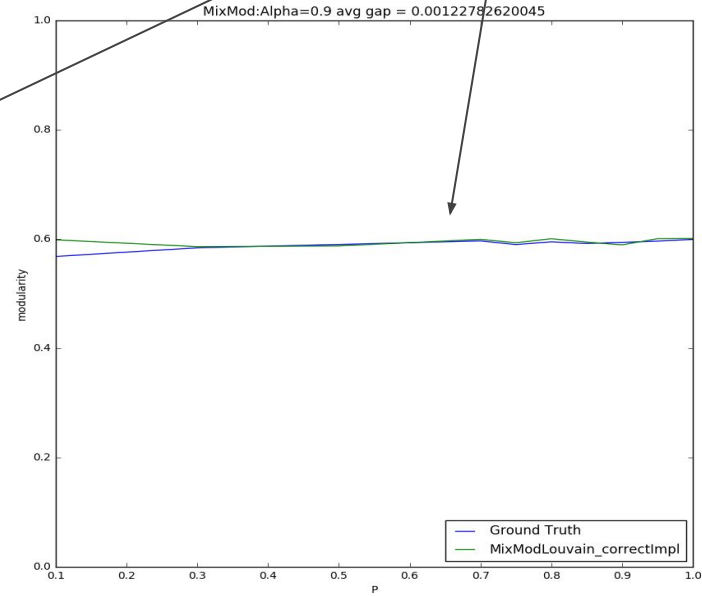
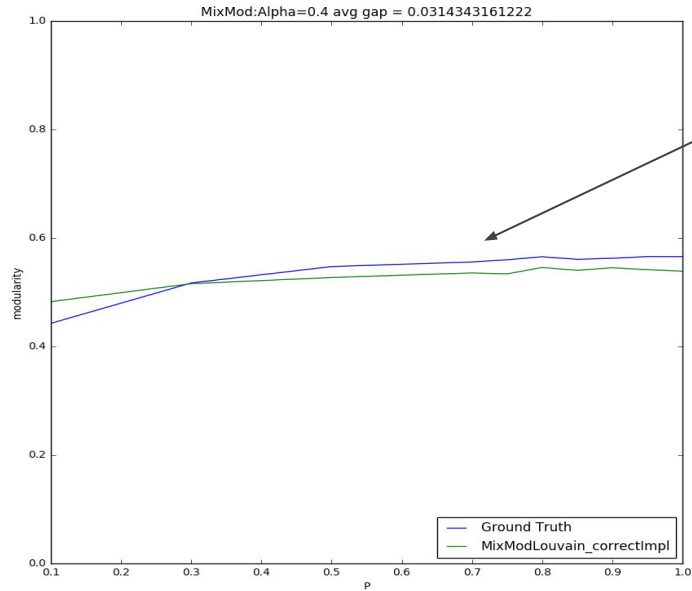


Figure12. Modularity plot using Louvain QM algorithm for two different values of p (0.5, 0.85) and varying α

Evaluation: (Mixmod alpha plot)



Gap reduced between the modularity values

Figure13. Modularity plot using MixMod algorithm for two different values of alpha (0.4,0.9) and varying P

Evaluation: (Mixmod p plot)

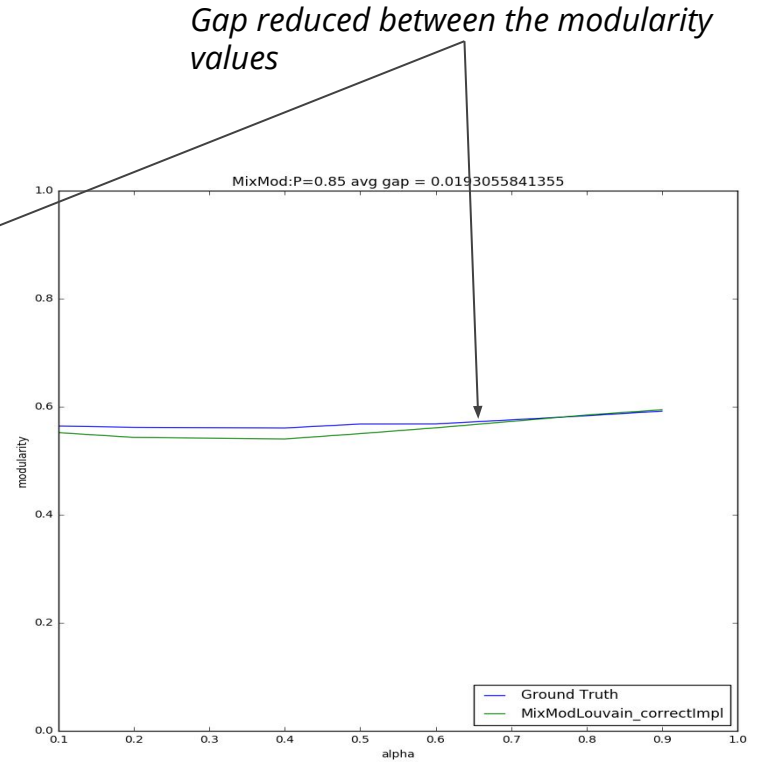
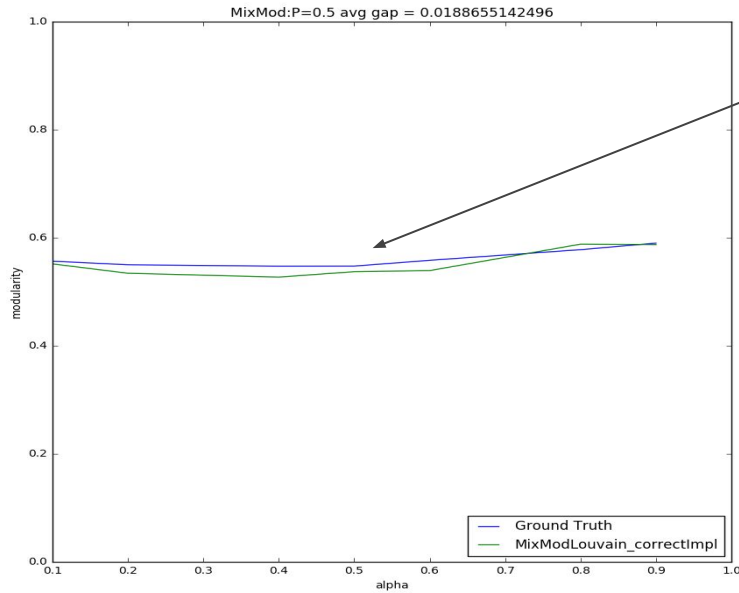


Figure14. Modularity plot using MixMod algorithm for two different values of p (0.5,0.85) and varying alpha



Further Analysis

The plot also shows that

1. Algorithm performs well for high values of α , means when maximum communities in the ground truth are multi-layer.
2. Performs poorly for $\alpha = 0.4$ and performs well for $\alpha = 0.9$

The multi-layer modularity measure QM described is kind of biased towards detecting multi-layer communities. So, it has a scope of improvement

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Summary and Future work:

- The MixMod algorithm when plugged with QM performs better than Louvain
- The Modularity index QM has some bias towards detecting multi-layer communities.

Future Work:

- Improvising the modularity index to overcome the bias

Questions?



Thank You

