GNNs Getting ComFy: Community and Feature Similarity Guided Rewiring

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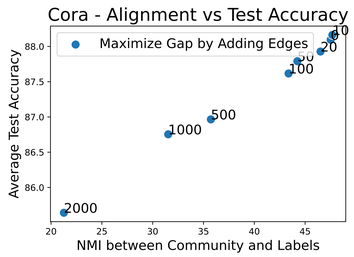
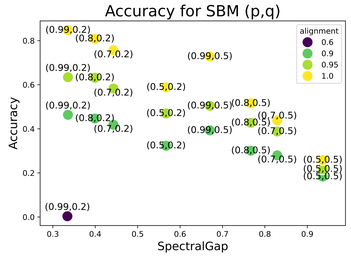
Background

GNNs fail to capture long-range interactions due to topological **bottlenecks** resulting in over-squashing. Graph **rewiring** (e.g. spectral gap max.) can help alleviate such bottlenecks.

Insight: It can also destroy community structure, which can be harmful when node labels **align** well with communities.



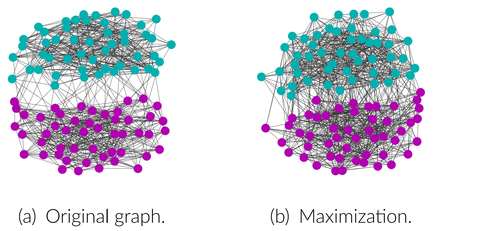


Research questions

- When is spectral gap **maximization/minimization** beneficial?
- How does the **graph-task alignment** influence performance?
- Can the **community structure** of the graph and the **node features** form better graph rewiring criteria?

Theory on (p, q)-SBMs

1. Spectral gap $\lambda_1 \sim -(p-q)/(p+q)$. Maximizing it means $\downarrow p$ and $\uparrow q$, which destroys communities.
2. If task labels = community membership labels (high alignment), destroying them is harmful.
3. If the alignment changes, this is not necessarily the case. But spectral gap rewiring cannot tackle this.

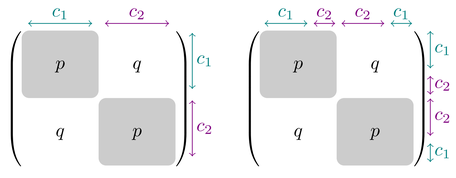


(a) Original graph. (b) Maximization. (c) Minimization.

(p, q)-SBM adjacency matrices for different alignments ψ.

In Fig. (d), the blocks match classes c_1 and c_2, so $\psi = 1$.

In Fig. (e), a third of each block is of opposite class, so $\psi = \frac{2}{3}$.



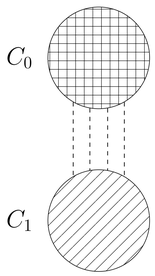
(d) $\psi = 1$. (e) $\psi = \frac{2}{3}$.

Rewiring methods

ComMa: Draws edges to ↑ or ↓ community strength.

FeaSt: Prioritizes edges that ↑ feature similarity.

ComFy: ↑ similarity proportionally to each community.



	ComMa		FeaSt		ComFy	
	LowerComMa	HigherComMa	Add	Del	Add	Del
$C_0 \times C_0$	If Del, draw and delete $\lfloor \frac{A}{A+C} \cdot k \rfloor$ edges	If Add, draw and add $\lfloor \frac{A}{A+C} \cdot k \rfloor$ edges	Add top k of $\text{sim}(u,v)$ for $(u,v) \in \bar{\mathcal{E}}$	Delete bottom k of $\text{sim}(u,v)$ for $(u,v) \in \mathcal{E}$	FeaSt Add $\left(\lfloor \frac{A}{A+B+C} \cdot k \rfloor\right)$	FeaSt Del $\left(\lfloor \frac{A}{A+B+C} \cdot k \rfloor\right)$
$C_0 \times C_1$	If Add, draw and add k edges	If Del, draw and delete k edges			FeaSt Add $\left(\lfloor \frac{B}{A+B+C} \cdot k \rfloor\right)$	FeaSt Del $\left(\lfloor \frac{B}{A+B+C} \cdot k \rfloor\right)$
$C_1 \times C_1$	If Del, draw and delete $\lfloor \frac{C}{A+C} \cdot k \rfloor$ edges	If Add, draw and add $\lfloor \frac{C}{A+C} \cdot k \rfloor$ edges			FeaSt Add $\left(\lfloor \frac{C}{A+B+C} \cdot k \rfloor\right)$	FeaSt Del $\left(\lfloor \frac{C}{A+B+C} \cdot k \rfloor\right)$

Experiments

Methods	Cora	Citeseer	Chameleon	Roman-Empire
GCN	86.12±0.36	77.83±0.35	39.33±0.59	70.30±0.73
GCN+SPAddMax	85.92±0.43	79.25±0.35	38.20±0.70	77.54±0.74
GCN+SPAddMin	84.10±0.39	78.77±0.40	39.33±0.55	79.18±0.06
GCN+SPDelMax	86.32±0.38	**81.84±0.38**	39.33±0.70	77.45±0.68
GCN+SPDelMin	85.92±0.37	79.01±0.34	39.89±0.59	79.09±0.05
GCN+FeaStAdd	87.73±0.39	78.54±0.34	43.26±0.62	**79.67±0.07**
GCN+FeaStDel	**90.74±0.39**	81.60±0.39	42.70±0.69	78.99±0.05
GCN+ComFyAdd	87.73±0.26	77.36±0.38	41.57±0.83	79.53±0.07
GCN+ComFyDel	88.13±0.27	78.07±0.35	**45.51±0.76**	79.17±0.07

SPAddMax & SPDelMax from Jamadandi et al., (NeurIPS, 2024)

Conclusions

We show that leveraging **node features** to rewire the graph can significantly boost GNN performance.

Moreover, spectral gap based rewiring and other topology-based methods are **insufficient** because they fail to account for the alignment between the graph and the task.