NEURAL INFORMATION PROCESSING SYSTEMS

Graph Few-Shot Learning via Adaptive Spectrum Experts and Cross-Set Distribution Calibration

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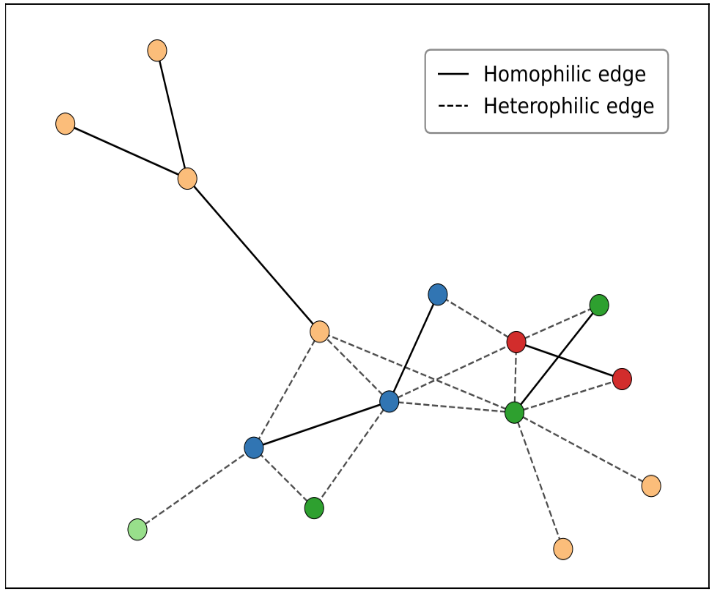
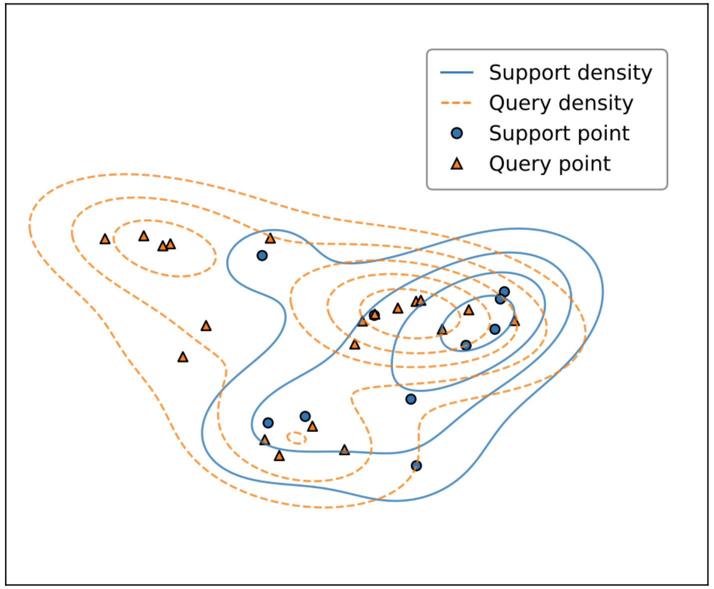
Introduction

- Graph Few-Shot Learning (GFSL) aims to rapidly adapt to novel classes with only a few labeled nodes.
- However, existing GFSL methods still struggle in real-world scenarios due to **two key challenges**:

  (1) Local structural heterogeneity: different nodes exhibit diverse homophily/heterophily patterns.

  (2) Distribution shift: support and query sets often follow mismatched distributions.
- These limitations lead to **suboptimal node embeddings** and **unreliable decision boundaries.**





Heterogeneous local structures and distribution shift motivate our design.

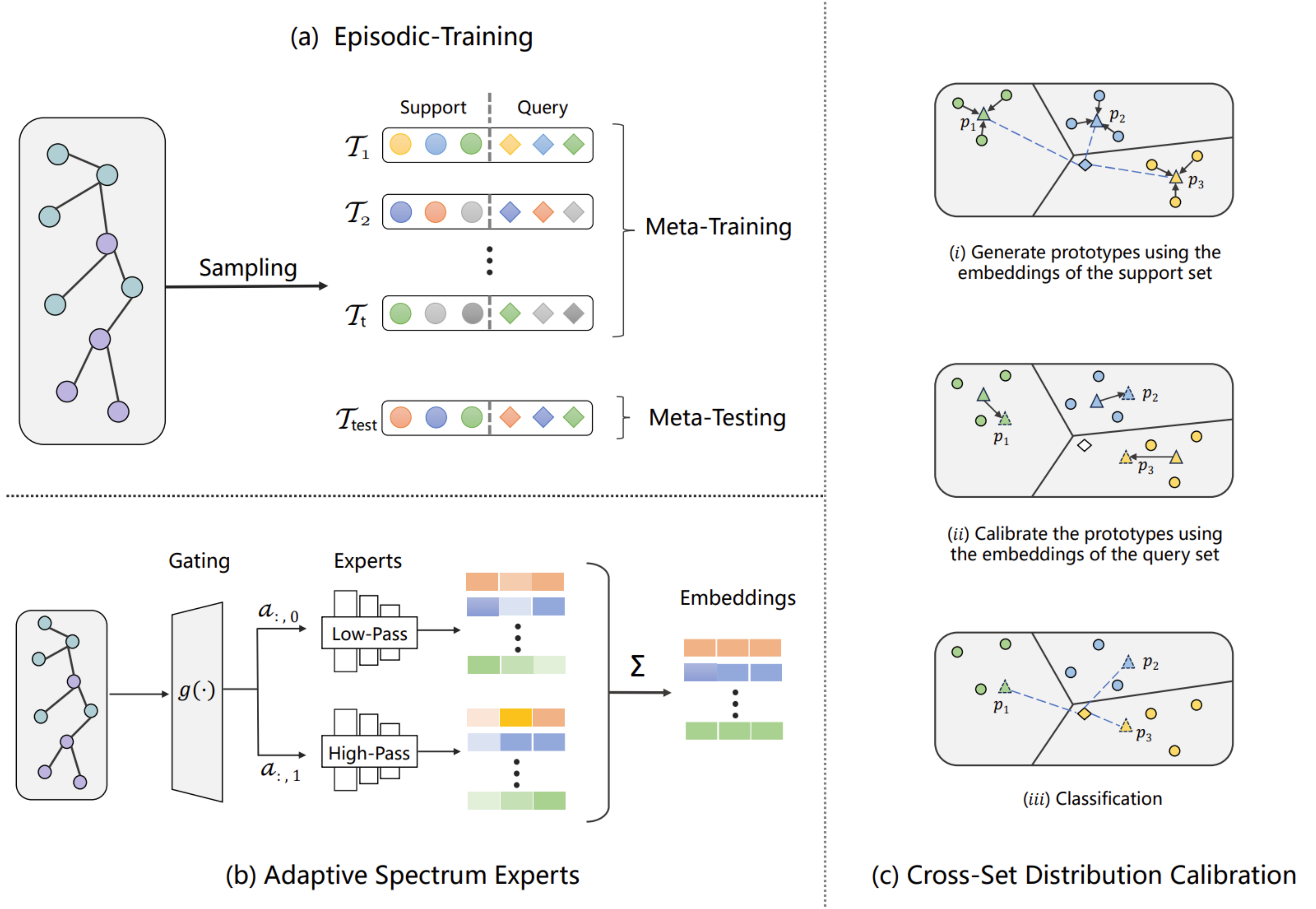
Our contribution:

- We propose a novel framework, GRACE, which integrates **adaptive spectrum experts** and **cross-set distribution calibration** to address the challenges of graph FSL.

- We provide theoretical analysis showing that GRACE offers **improved generalization** guarantees by adapting to local structural heterogeneity and mitigating distribution shift.

- We conduct extensive experiments on multiple benchmark datasets, demonstrating that GRACE consistently outperforms existing **state-of-the-art** methods.

Framework



(a) Episodic-Training
Support
Query
$\mathcal{T}_1$
$\mathcal{T}_2$
$\mathcal{T}_t$
$\mathcal{T}_{test}$
Sampling
Meta-Training
Meta-Testing
Gating
Experts
$g(\cdot)$
$a_{:,0}$
$a_{:,1}$
Low-Pass
High-Pass
Σ
Embeddings
(b) Adaptive Spectrum Experts
p_1
p_2
p_3
(i) Generate prototypes using the embeddings of the support set
(ii) Calibrate the prototypes using the embeddings of the query set
(iii) Classification
(c) Cross-Set Distribution Calibration

Methods

➢ Methods (I): Adaptive Spectrum Experts

- **1. The Low-Pass Expert:** Uses a Graph Convolutional Network (GCN) , which acts as a low-pass filter to smooth features, ideal for homophilic regions.

$$H^{(l+1)} = \sigma(\tilde{D}^{-\frac{1}{2}}\tilde{A}\tilde{D}^{-\frac{1}{2}}H^{(l)}W^{(l)})$$

- **2. The High-Pass Expert:** Designed to capture heterophilic structures by amplifying feature differences. It computes the difference F between original features (X') and smoothed features (H_{low})

$$H_{high} = softmax(\frac{F_Q F_K^\top}{\sqrt{d'}})F_V$$

- **3. Gating Module:** Adaptively assigns weights (α) to combine the expert outputs (H_{low}, H_{hign}) into the final node embedding Z.

$$Z = \alpha_{:,0}H_{low} + \alpha_{:,1}H_{high}$$

Methods

➢ Methods (II): Cross-Set Distribution Calibration

- **Problem:** Standard Prototypical Networks can fail due to the distribution discrepancy between support (S) and query (Q) sets.
- **Step 1: Compute Initial Prototypes:** Calculate class prototypes P from the support set embeddings Z^s.

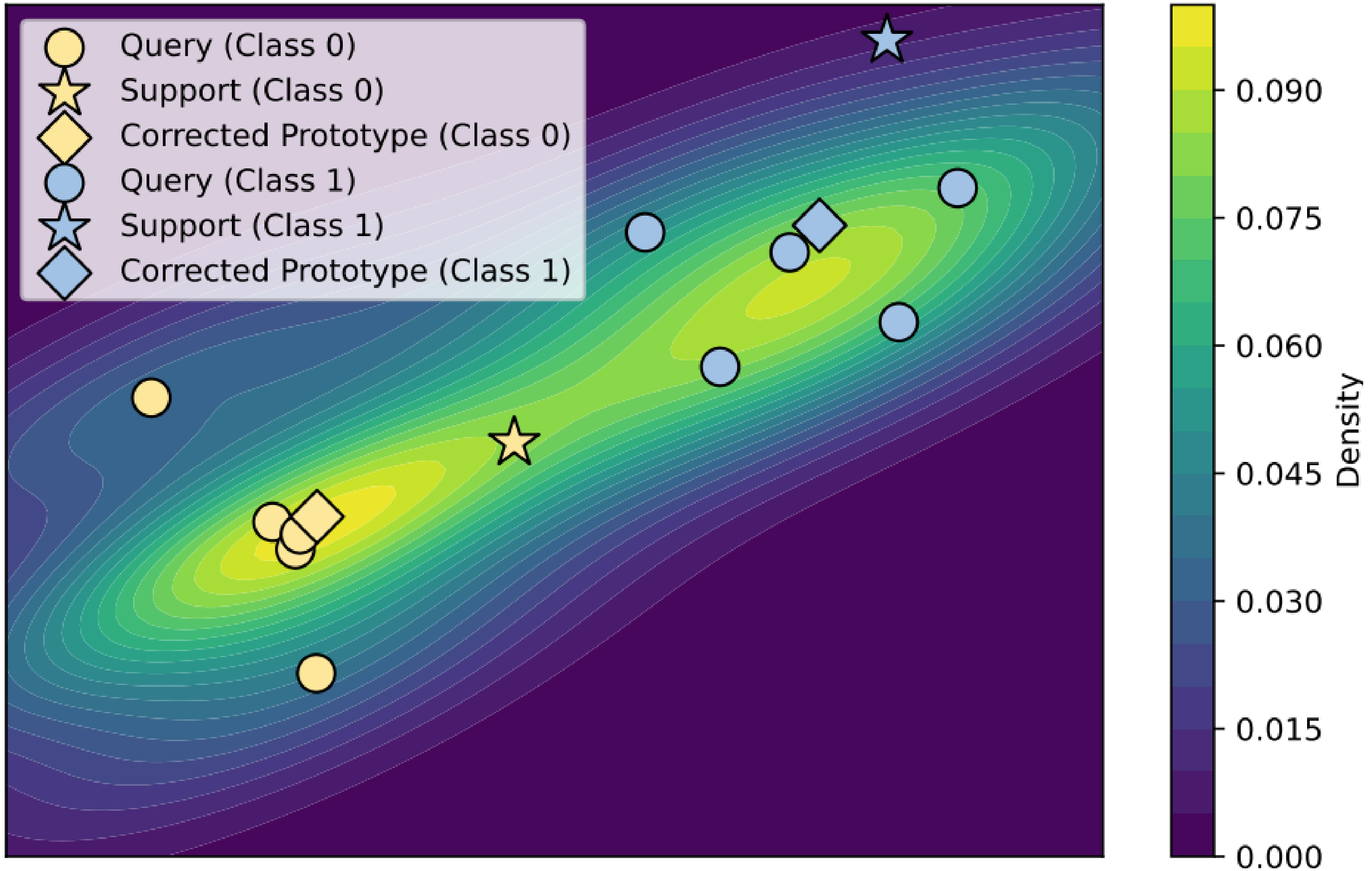
$$P_k = \frac{1}{K}\mathbb{I}[Y_{t,i} = k]Z^s_{t,i}$$

- **Step 2: Calibrate Prototypes:** Refine the prototypes using samples in high-density regions of the query distribution, inspired by Kernel Density Estimation (KDE).
- **Step 3: Obtain Calibrated Prototypes:** A correction vector ΔP is computed, and the final calibrated prototype $\hat{P}$ is obtained.

$$\hat{P} = P + \hat{\beta}\Delta P$$

Methods

➢ Methods (II): Cross-Set Distribution Calibration



Experiments

Datasets

Dataset	#Nodes	#Edges	#Features	#Labels
Cora	2,708	5,278	1,433	7
CiteSeer	3,327	4,552	3,703	6
Amazon-Computer	13,381	245,778	767	10
Coauthor-CS	18,333	81,894	6,805	15
DBLP	40,672	144,135	7,202	137
CoraFull	19,793	65,311	8,710	70
ogbn-arxiv	169,343	1,166,243	128	40

Model Performance

Model	Cora			CiteSeer			Amazon-Computer		
	2 way 1 shot	2 way 3 shot	2 way 5 shot	2 way 1 shot	2 way 3 shot	2 way 5 shot	2 way 1 shot	2 way 3 shot	2 way 5 shot
DeepWalk	32.95±2.70	36.70±2.99	41.51±2.70	39.56±2.79	39.72±3.42	43.22±3.19	46.49±2.35	49.29±2.46	51.24±2.72
node2vec	31.17±3.16	35.66±2.79	40.69±2.90	40.12±3.15	42.39±2.79	47.20±2.92	49.25±2.56	51.46±2.25	53.49±2.69
GCN	55.46±2.16	69.96±2.52	67.95±2.36	51.95±2.45	53.79±2.39	55.76±2.56	60.16±2.20	63.46±2.16	67.39±2.46
SGC	56.75±2.31	70.15±1.99	70.67±2.11	53.72±2.55	55.12±2.59	57.25±2.79	61.29±2.45	65.39±2.06	69.35±2.12
ProtoNet	50.39±2.52	52.67±2.28	57.92±2.34	49.15±2.29	52.19±2.96	53.75±2.49	57.15±2.55	60.49±2.09	65.12±2.69
MAML	52.40±2.29	55.07±2.36	57.39±2.23	49.15±2.25	52.75±2.75	54.36±2.39	53.72±2.25	59.20±2.55	61.20±2.59
Meta-GNN	58.82±2.56	70.40±2.64	72.51±1.91	55.45±2.15	59.71±2.79	61.32±3.22	62.36±2.70	67.49±2.11	70.15±2.16
GPN	60.12±2.12	74.05±1.96	76.39±2.33	57.36±2.20	64.22±2.92	65.59±2.49	65.56±2.60	72.19±2.30	76.19±2.21
G-Meta	59.72±3.15	74.39±2.69	80.05±1.98	54.39±2.19	57.59±2.42	62.49±2.30	64.56±3.10	69.49±2.42	73.50±2.92
TENT	55.39±2.16	58.25±2.23	66.75±2.19	60.03±3.11	65.20±3.19	67.59±2.95	80.75±2.95	85.32±2.10	89.22±2.16
Meta-GPS	62.19±2.12	80.29±2.15	83.79±2.10	58.95±2.12	69.95±2.02	72.56±2.06	82.12±2.55	87.10±2.65	90.16±2.05
X-FNC	61.47±2.99	78.19±3.25	82.70±3.19	58.79±2.56	67.96±3.10	70.29±3.05	81.50±2.29	86.39±2.29	90.25±2.26
TEG	62.52±2.95	80.65±1.53	84.50±2.01	59.70±2.69	73.79±1.59	76.79±2.12	86.49±2.10	89.02±2.57	92.40±2.05
COSMIC	63.16±2.47	65.37±2.49	69.10±2.30	60.95±2.75	70.22±2.56	75.10±2.30	85.49±2.46	88.26±2.02	91.59±2.59
TLP	60.19±2.25	71.10±1.66	85.15±2.19	61.12±2.10	71.10±2.17	75.55±2.03	83.35±2.07	89.49±2.06	92.09±2.12
Meta-BP	66.42±4.12	76.32±4.30	83.12±4.16	60.15±2.45	72.19±3.19	76.11±3.29	86.10±4.10	89.22±4.29	92.39±4.45
GRACE	**66.48±2.88**	**82.40±2.03**	**86.19±1.80**	**63.90±2.84**	**75.67±2.44**	**79.64±1.79**	**90.23±0.90**	**92.46±0.55**	**94.66±0.50**

Model Performance

Model	Coauthor-CS				DBLP			
	2 way 3 shot	2 way 5 shot	5 way 3 shot	5 way 5 shot	5 way 3 shot	5 way 5 shot	10 way 3 shot	10 way 5 shot
DeepWalk	59.52±2.72	63.12±3.12	33.76±3.21	40.15±2.96	49.12±2.25	59.12±2.32	37.11±2.19	49.16±2.39
node2vec	56.16±4.19	60.22±4.06	30.35±3.93	39.16±3.79	45.65±2.79	55.92±2.36	35.72±2.52	46.19±2.75
GCN	73.52±1.97	77.20±3.01	52.19±2.31	56.35±2.99	64.12±2.15	67.26±2.39	42.16±2.39	56.12±2.10
SGC	75.49±2.15	79.63±2.01	56.39±2.26	59.25±2.16	66.32±2.25	70.19±2.36	40.19±2.26	55.16±2.56
ProtoNet	71.18±3.82	75.51±3.19	47.71±3.92	51.66±2.51	59.95±2.56	62.95±2.72	32.35±1.62	52.95±1.90
MAML	62.32±4.60	65.20±4.20	36.99±4.32	42.12±2.43	55.05±2.30	60.67±2.41	29.59±2.90	40.22±2.61
Meta-GNN	85.76±2.74	87.86±4.79	75.87±3.88	68.59±2.59	73.41±3.20	77.95±3.12	65.22±2.79	69.12±2.51
GPN	85.60±2.15	88.70±2.21	75.88±2.75	81.79±3.18	75.39±3.41	79.90±2.62	67.20±2.40	71.12±1.87
G-Meta	92.14±3.90	93.90±3.18	75.72±3.59	74.18±3.29	76.49±3.29	80.12±2.46	68.95±2.70	72.19±2.11
TENT	89.35±4.49	90.90±4.24	78.38±5.21	78.56±4.42	78.22±2.10	81.30±2.02	69.52±2.16	73.20±1.95
Meta-GPS	90.16±2.72	92.39±1.66	81.39±2.35	83.66±1.79	79.12±1.92	81.66±2.16	70.16±2.20	73.59±1.26
X-FNC	90.95±4.29	92.03±4.14	82.93±2.02	84.36±3.49	77.45±2.39	80.69±2.52	69.72±2.39	72.95±1.76
TEG	92.36±1.59	93.02±1.24	80.78±1.40	84.70±1.42	79.26±2.49	82.19±2.40	72.49±2.12	73.99±2.55
COSMIC	89.35±4.49	93.32±1.93	78.38±5.21	85.47±1.42	78.34±2.06	81.81±2.05	66.53±1.54	70.09±1.53
TLP	90.35±4.49	90.90±4.24	82.30±2.05	78.56±4.42	77.49±3.22	81.95±2.39	71.49±2.35	73.16±2.30
Meta-BP	91.19±2.21	92.32±2.11	81.35±2.02	82.12±2.15	78.22±2.10	81.13±2.55	71.30±2.12	73.15±2.39
GRACE	**95.50±1.30**	**96.20±0.97**	**86.03±1.05**	**86.82±1.01**	**81.72±2.05**	**85.30±1.90**	**74.22±1.56**	**76.70±1.46**

Model Performance

Model	CoraFull				ogbn-arxiv			
	5 way 3 shot	5 way 5 shot	10 way 3 shot	10 way 5 shot	5 way 3 shot	5 way 5 shot	10 way 3 shot	10 way 5 shot
DeepWalk	23.62±3.99	25.93±3.45	15.32±4.12	17.03±3.73	24.12±3.16	26.16±2.95	20.19±2.35	23.76±3.02
node2vec	23.75±2.93	25.42±3.61	13.90±3.32	15.21±2.64	25.29±2.96	27.39±2.56	22.99±3.15	25.95±3.12
GCN	34.65±2.76	39.83±2.49	29.23±3.25	34.14±2.15	32.26±2.11	36.29±2.39	30.21±1.95	33.96±1.59
SGC	39.56±3.52	44.53±2.92	35.12±2.71	39.53±3.32	35.19±2.76	39.76±2.95	31.99±2.12	35.22±2.52
ProtoNet	33.67±2.51	36.53±3.76	24.90±2.03	27.24±2.67	39.99±3.28	47.31±1.71	32.79±2.22	37.19±1.92
MAML	37.12±3.16	47.51±3.09	26.61±2.19	31.60±2.91	28.35±1.49	29.09±1.62	30.19±2.97	36.19±2.29
Meta-GNN	52.23±2.41	59.12±2.36	47.21±3.06	53.32±3.15	40.14±1.94	45.52±1.71	35.19±1.72	39.02±1.99
GPN	53.24±2.33	60.31±2.19	50.93±2.30	56.21±2.09	42.81±2.34	50.50±2.13	37.36±1.99	42.16±2.19
G-Meta	57.52±3.91	62.43±3.11	53.92±2.91	58.10±3.02	40.48±1.70	47.16±1.73	35.49±2.12	40.95±2.70
TENT	64.80±4.10	69.24±4.49	51.73±4.34	56.00±3.53	50.26±1.73	61.38±1.72	42.19±1.16	46.29±1.29
Meta-GPS	65.19±2.35	69.25±2.52	61.23±3.11	64.22±2.66	52.16±2.01	62.55±1.95	42.96±2.02	46.86±2.10
X-FNC	69.32±3.10	71.26±4.19	49.63±4.45	53.00±3.93	52.36±2.75	63.19±2.22	41.92±2.72	46.10±2.16
TEG	72.14±1.06	76.20±1.39	61.03±1.13	65.56±1.03	57.35±1.14	62.07±1.72	47.41±0.63	51.11±0.73
COSMIC	73.03±1.78	77.24±1.52	65.79±1.36	70.06±1.93	52.98±2.19	65.42±1.69	43.19±2.72	47.59±2.19
TLP	66.32±2.10	71.36±4.49	51.73±4.34	56.00±3.53	41.96±2.29	52.99±2.05	39.42±2.15	42.62±2.09
Meta-BP	72.90±1.90	74.36±2.19	62.35±2.27	67.26±2.59	55.12±4.12	65.39±4.55	46.25±4.52	50.12±3.39
GRACE	**78.22±1.38**	**81.60±1.28**	**70.91±1.08**	**74.54±0.98**	**62.31±1.94**	**68.34±1.73**	**50.18±1.01**	**55.07±0.91**

Ablation Study

Model	Cora	CiteSeer	Amazon-Computer	Coauthor-CS	DBLP	CoraFull	ogbn-arxiv
	2 way 1 shot	2 way 1 shot	2 way 1 shot	5 way 3 shot	5 way 5 shot	5 way 3 shot	5 way 3 shot
w/o high	64.01±2.67	62.26±2.60	82.89±2.13	79.05±1.23	79.35±2.00	76.73±1.45	59.32±1.90
w/o low	63.94±2.79	59.64±2.75	90.08±0.79	80.31±1.14	85.05±1.83	77.23±1.49	61.98±1.92
w/o cal	65.66±2.80	58.61±2.58	89.58±1.02	85.97±1.13	83.52±1.89	77.18±1.45	61.84±1.96
w/o both	60.12±2.12	55.36±2.20	65.56±2.60	75.88±2.75	79.90±2.62	53.24±2.33	42.81±2.34
Ours	**66.48±2.88**	**63.90±2.84**	**90.23±0.90**	**86.03±1.05**	**85.30±1.90**	**78.22±1.38**	**62.31±1.94**

Thanks for your attention!