



强化学习优化的图神经网络

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and Brain Computing



彭浩，北京航空航天大学，网络空间安全学院、北京市大数据科学与脑机智能高精尖创新中心，讲师，博士生导师
近五年发表IEEE TPAMI、TKDE、TPDS、TC、TNNLS、ACM TOIS、TKDD、TIST、WWW、SIGIR、AAAI、IJCAI、CIKM等顶级论文60余篇，授权发明专利20余项，主持国家自然科学基金、国家重点研发、北京市自然基金、河北省重点研发等项目课题10余项；任Springer Nature出版集团旗下International Journal of Machine Learning and Cybernetics期刊（SCI检索，IF: 4.012，JCR Q1期刊）副主编（Associate Editor）。

主要研究方向：网络数据挖掘、深度学习、强化学习、异常检测；

科研获奖：ESI高被引论文2篇（TKDE2019、TITS2019），国际顶级学术会议最具影响力论文6篇（WWW2018、CIKM2019、SIGIR2020、CIKM2020、Web Conference 2021），学术会议最佳论文提名2篇（ICDM2021、KBCOM2018），2018年中国电子学会技术发明一等奖、2020年中国人工智能学会优秀博士学位论文奖。



研究工作

CARE-GNN : 基于强化多关系图神经网络的欺骗检测器

RIOGNN : 递归强化邻域选择的多关系图神经网络

RTGNN : 强化聚合的多视图张量图神经网络

1

2

3

4

5

FinEvent : 多智能体强化增量跨语言社会事件检测

SUGAR : 基于强化汇聚和自监督互信息机制的子图神经网络

研究工作1：CARE-GNN框架

- 改进
- 使用强化学习选择过滤阈值
- 根据过滤阈值聚合不同关系

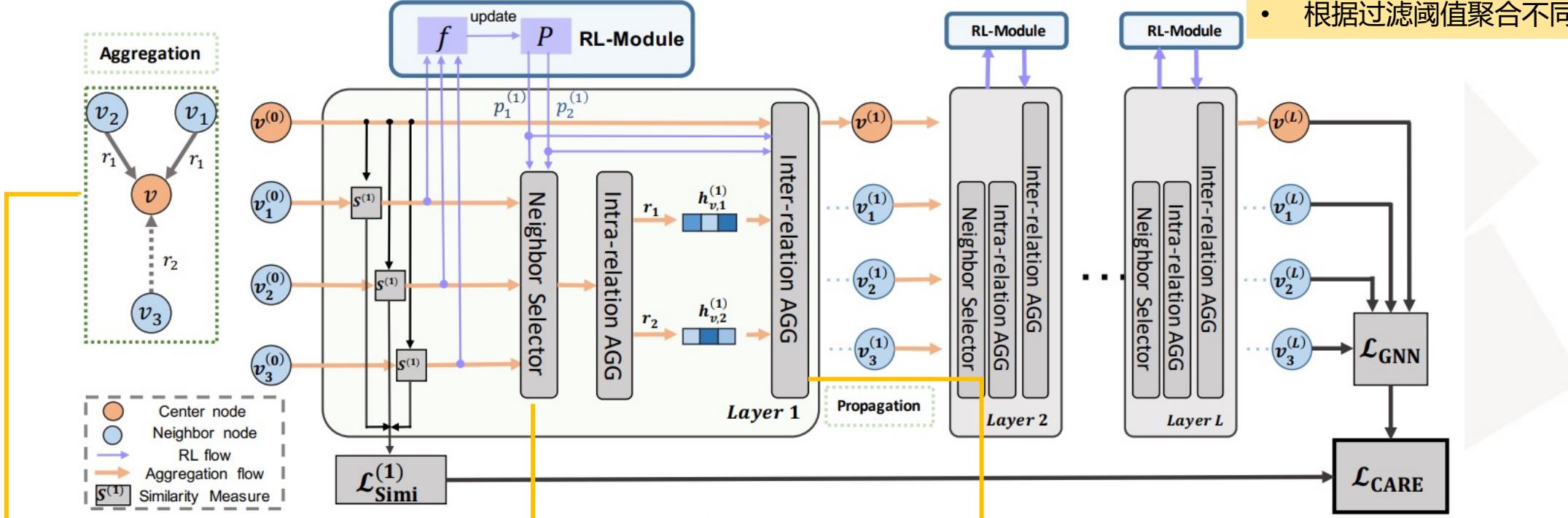


Figure 2: The aggregation process of proposed CARE-GNN at the training phase.

- MLP单层节点标签预测
- 交叉熵定义损失函数
- 快速筛选相似邻居

- 强化学习指导的邻居选择器
- 自动选择过滤阈值而非视为超参数
- Top-p采样保留最相关的邻居

- 强化学习指导的过滤阈值作为权重
- 聚合来自不同关系的信息
- 综合考虑中心嵌入与邻居嵌入

实验结果

- 数据集特点**
- 巨量真实节点
 - 复杂异构关系
 - 多种实体行为
 - 较低欺诈比例

Table 2: Dataset and graph statistics.

	#Nodes (Fraud%)	Relation	#Edges	Avg. Feature Similarity	Avg. Label Similarity
Yelp	45,954 (14.5%)	R-U-R	49,315	0.83	0.90
		R-T-R	573,616	0.79	0.05
		R-S-R	3,402,743	0.77	0.05
		ALL	3,846,979	0.77	0.07
Amazon	11,944 (9.5%)	U-P-U	175,608	0.61	0.19
		U-S-U	3,566,479	0.64	0.04
		U-V-U	1,036,737	0.71	0.03
		ALL	4,398,392	0.65	0.05

包含对酒店和餐馆的良性实体评论与垃圾评论

包含对乐器的良性实体评论与垃圾评论

Table 3: Fraud detection performance (%) on two datasets under different percentage of training data.

	Metric	Train%	GCN	GAT	RGCN	Graph-SAGE	Genie-Path	Player-2Vec	Semi-GNN	Graph-Consis	CARE-Att	CARE-Weight	CARE-Mean	CARE-GNN
Yelp	AUC	5%	54.98	56.23	50.21	53.82	56.33	51.03	53.73	61.58	66.08	71.10	69.83	71.26
		10%	50.94	55.45	55.12	54.20	56.29	50.15	51.68	62.07	70.21	71.02	71.85	73.31
		20%	53.15	57.69	55.05	56.12	57.32	51.56	51.55	62.31	73.26	74.32	73.32	74.45
		40%	52.47	56.24	53.38	54.00	55.91	53.65	51.58	62.07	74.98	74.42	74.77	75.70
	Recall	5%	53.12	54.68	50.38	54.25	52.33	50.00	52.28	62.60	63.52	66.64	68.09	67.53
		10%	51.10	52.34	51.75	52.23	54.35	50.00	52.57	62.08	67.38	68.35	68.92	67.77
		20%	53.87	53.20	50.92	52.69	54.84	50.00	52.16	62.35	68.34	69.07	69.48	68.60
		40%	50.81	54.52	50.43	52.86	50.94	50.00	50.59	62.08	71.13	70.22	69.25	71.92
Amazon	AUC	5%	74.44	73.89	75.12	70.71	71.56	76.86	70.25	85.46	89.49	89.36	89.35	89.54
		10%	75.25	74.55	74.13	73.97	72.23	75.73	76.21	85.29	89.58	89.37	89.43	89.44
		20%	75.13	72.10	75.58	73.97	71.89	74.55	73.98	85.50	89.58	89.68	89.34	89.45
		40%	74.34	75.16	74.68	75.27	72.65	56.94	70.35	85.50	89.70	89.69	89.52	89.73
	Recall	5%	65.54	63.22	64.23	69.09	65.56	50.00	63.29	85.49	88.22	88.31	88.02	88.34
		10%	67.81	65.84	67.22	69.36	66.63	50.00	63.32	85.38	87.87	88.36	88.12	88.29
		20%	66.15	67.13	65.08	70.30	65.08	50.00	61.28	85.59	88.40	88.60	88.00	88.27
		40%	67.45	65.51	67.68	70.16	65.41	50.00	62.89	85.53	88.41	88.45	88.22	88.48

半监督学习快速训练模型

动态调整阈值强泛化能力

强化学习有效性解释

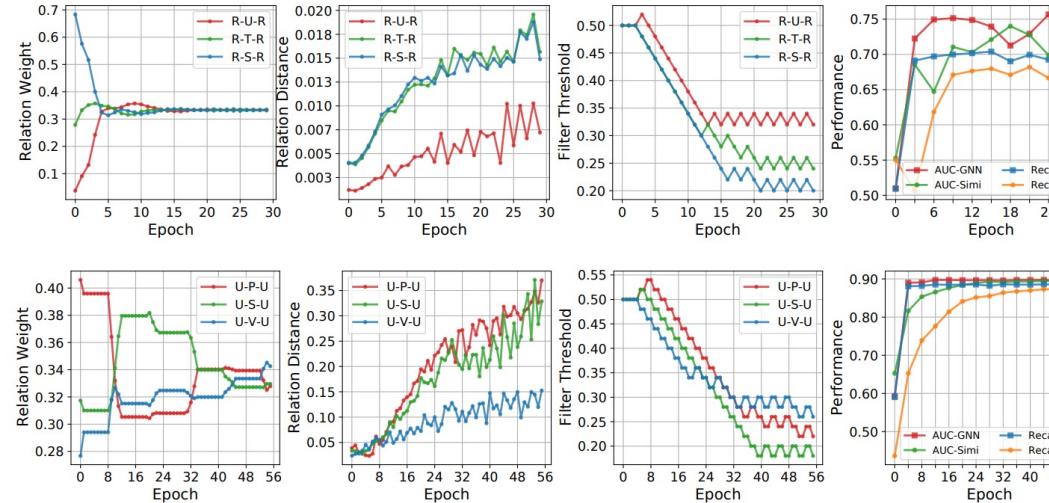


Figure 3: The training process and testing performance of CARE-Weight on Yelp (upper) and Amazon (lower) dataset.

邻居选择的必要性

不同关系的区分度

滤波阈值的稳定性

模型综合表现对比

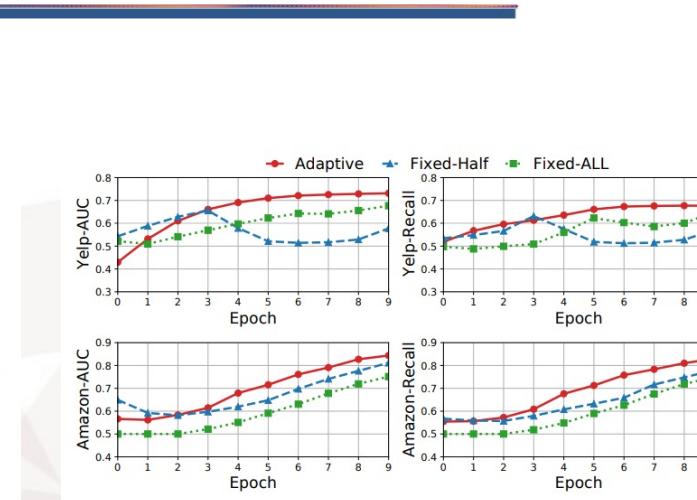


Figure 4: The testing AUC and Recall for CARE-GNN with different neighbor filtering methods during training.

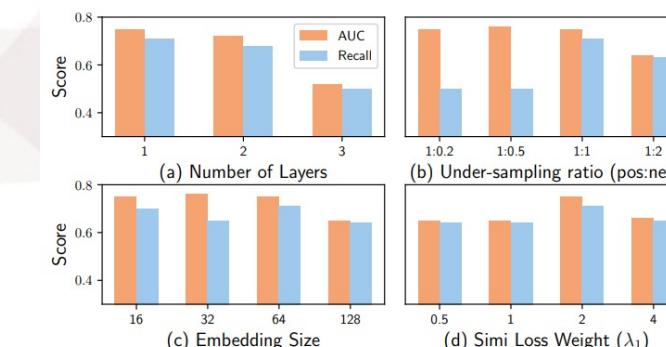


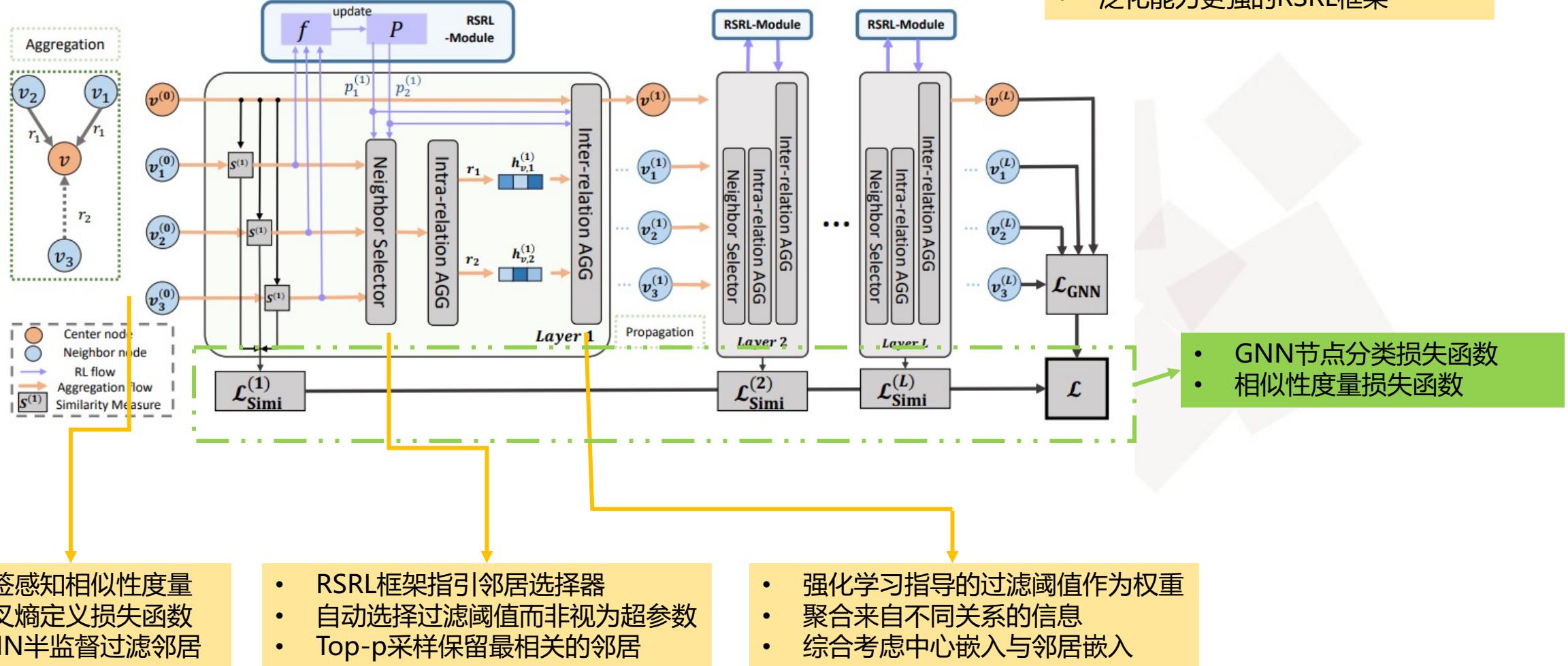
Figure 5: Parameter Sensitivity. For each parameter configuration, only the best results among 30 epochs are recorded.

自适应滤波优越性

参数灵敏度分析

- 训练层数
- 欠采样比例
- 嵌入规模
- 相似损失权重

研究工作2：RIOGNN框架



相似性感知自适应邻居选择器

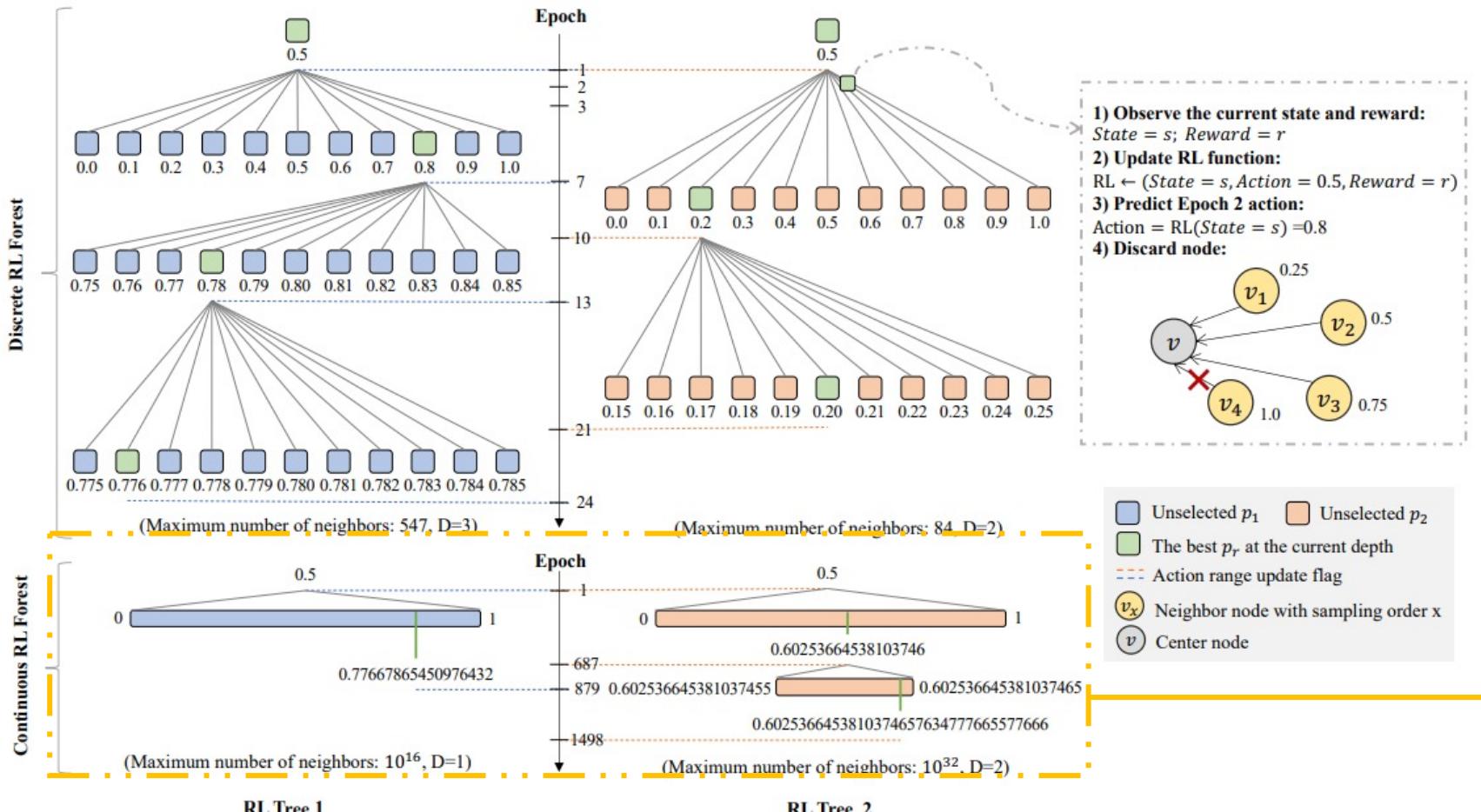


Fig. 4. One layer Reinforcement Learning Forest.

Hao Peng, et. al. 2021. Reinforced Neighborhood Selection Guided Multi-Relational Graph Neural Networks. TOIS 2021.

RSRL框架要点

- 递归选择更高精度阈值
- 连续动作空间离散化
- 标签感知距离度量作为状态
- 节点相似度视为奖励
- 连续三次相同动作终止迭代

对比实验

准确性分析

Models	Yelp								Amazon							
	AUC				Recall				AUC				Recall			
	5%	10%	20%	40%	5%	10%	20%	40%	5%	10%	20%	40%	5%	10%	20%	40%
GCN	54.98	50.94	53.15	52.47	53.12	51.10	53.87	50.81	74.44	75.25	75.13	74.34	65.54	67.81	66.15	67.45
GAT	56.23	55.45	57.69	56.24	54.68	52.34	53.20	54.52	73.89	74.55	72.10	72.16	63.22	65.84	67.13	65.51
GraphSAGE	53.82	54.20	56.12	54.00	54.25	52.23	52.69	52.86	70.71	73.97	73.97	75.27	69.09	69.36	70.30	70.16
RGCN	50.21	55.12	55.05	53.38	50.38	51.75	50.92	50.43	75.12	74.13	75.58	74.68	64.23	67.22	65.08	67.68
GeniePath	56.33	56.29	57.32	55.91	52.33	54.35	54.84	50.94	71.56	72.23	71.89	72.65	65.56	66.63	65.08	65.41
Player2Vec	51.03	50.15	51.56	53.65	50.00	50.00	50.00	50.00	76.86	75.73	74.55	56.94	50.00	50.00	50.00	50.00
SemiGNN	53.73	51.68	51.55	51.58	52.28	52.57	52.16	50.59	70.25	76.21	73.98	70.35	63.29	63.32	61.28	62.89
GraphCensis	61.58	62.07	62.31	62.07	62.60	62.08	62.35	62.08	85.46	85.29	85.50	85.50	85.49	85.38	85.59	85.53
GAS	54.43	52.58	52.51	52.60	53.40	53.26	53.37	51.61	71.40	77.49	74.51	71.03	64.31	64.57	62.08	63.74
FdGars	61.77	62.15	62.81	62.66	62.83	62.16	62.73	62.40	85.58	85.41	85.88	85.81	85.83	85.73	85.84	85.93
GraphNAS ^H	52.93	54.69	56.73	54.46	52.40	54.15	55.69	56.16	71.01	72.48	73.52	76.05	69.17	69.48	70.35	70.16
GraphNAS	53.26	55.31	57.15	55.59	53.69	55.47	56.04	57.00	72.41	73.04	73.58	76.25	70.36	70.53	71.73	71.88
Policy-GNN ^H	54.04	55.73	59.30	60.60	53.08	55.35	58.75	59.99	72.20	73.30	74.11	77.20	70.10	71.20	73.08	74.44
Policy-GNN	55.75	56.29	60.01	61.52	54.15	56.16	58.95	60.33	73.69	74.06	75.29	78.85	71.34	72.46	74.55	76.70
CARE-GNN	71.26	73.31	74.45	75.70	67.53	67.77	68.60	71.92	89.54	89.44	89.45	89.73	88.34	88.29	88.27	88.48
RioGNN	81.97	83.72	82.31	83.54	75.33	75.78	75.51	76.19	95.44	95.41	95.63	96.19	90.17	89.48	89.51	89.82

Table 4. Fraud Detection results (%) compared to the baselines.

对比实验

- 多层GNN效果更优
- 多深度结构的快速准确收敛
- 过滤阈值作为关系间权重的优越性

Table 5. Fraud Detection classification results (%) compared to RioGNN variants.

Models	Yelp		Amazon	
	AUC	Recall	AUC	Recall
RioGNN <i>2l</i>	76.01	63.15	91.28	72.46
BIO-GNN	78.67	71.21	95.47	88.35
ROO-GNN	83.59	75.56	95.58	89.22
RIO-Att	78.65	71.69	93.97	83.78
RIO-Weight	80.40	72.83	96.25	89.61
RIO-Mean	77.84	71.43	94.57	89.47
RioGNN	83.54	75.55	96.19	88.66

RSRL框架要点

- 递归选择更高精度阈值
- 连续动作空间离散化
- 标签感知距离度量作为状态
- 节点相似度视为奖励
- 连续三次相同动作终止迭代

Table 6. Fraud detection clustering results (%) compared to RioGNN variants.

Dataset	Metric	RioGNN <i>2l</i>	BIO-GNN	ROO-GNN	RIO-Att	RIO-Weight	RIO-Mean	RioGNN
Yelp	NMI	3.18	9.36	12.39	9.80	12.05	8.39	12.22
	ARI	6.12	11.84	16.61	11.88	15.88	8.80	16.45
Amazon	NMI	58.87	59.83	57.81	55.76	58.76	58.72	61.26
	ARI	76.53	77.38	76.09	76.54	76.73	76.51	78.40

- RIOGNN在密集数据集上的显著优势

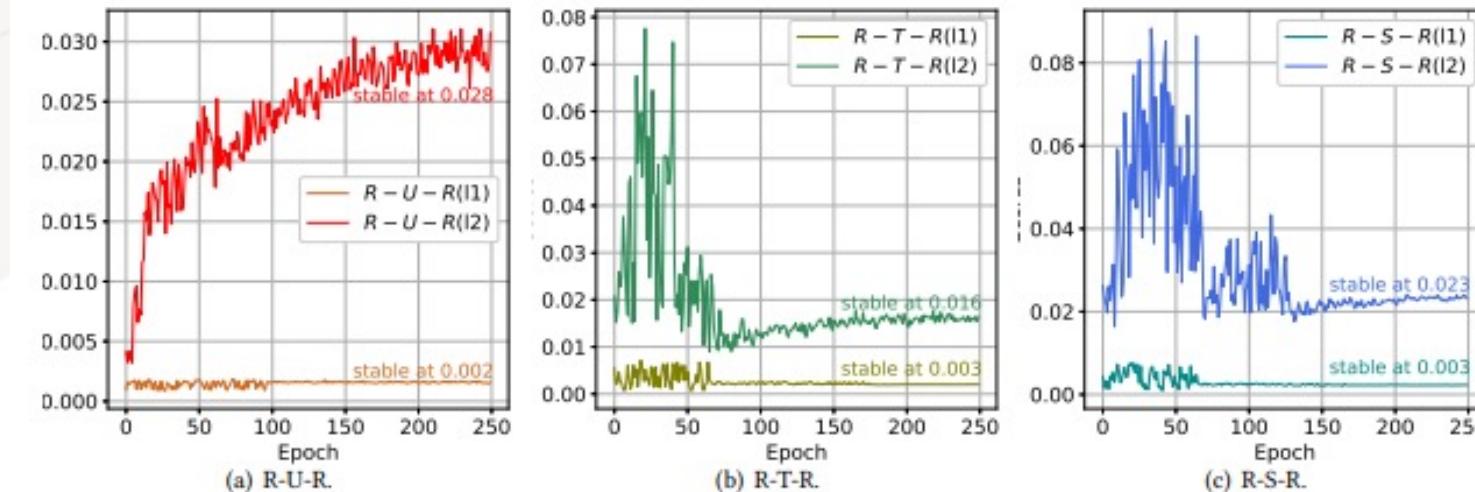


Fig. 7. Scores of Multi-Layer RioGNN on Yelp.

实验的解释性

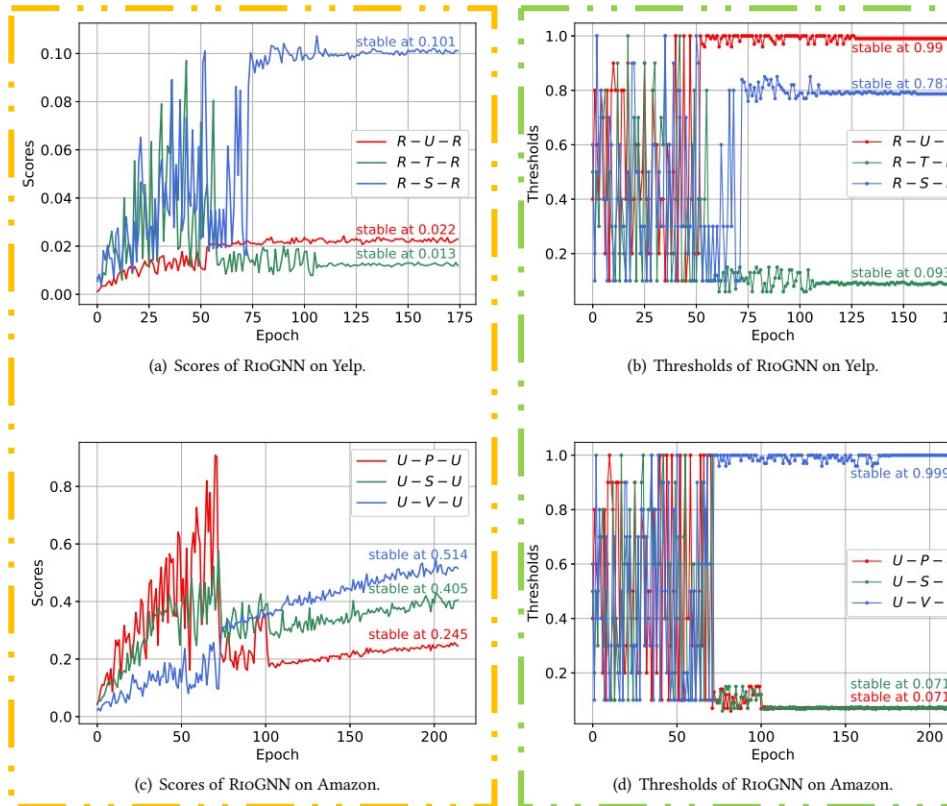


Fig. 5. The training scores and thresholds of RioGNN on Yelp and Amazon.

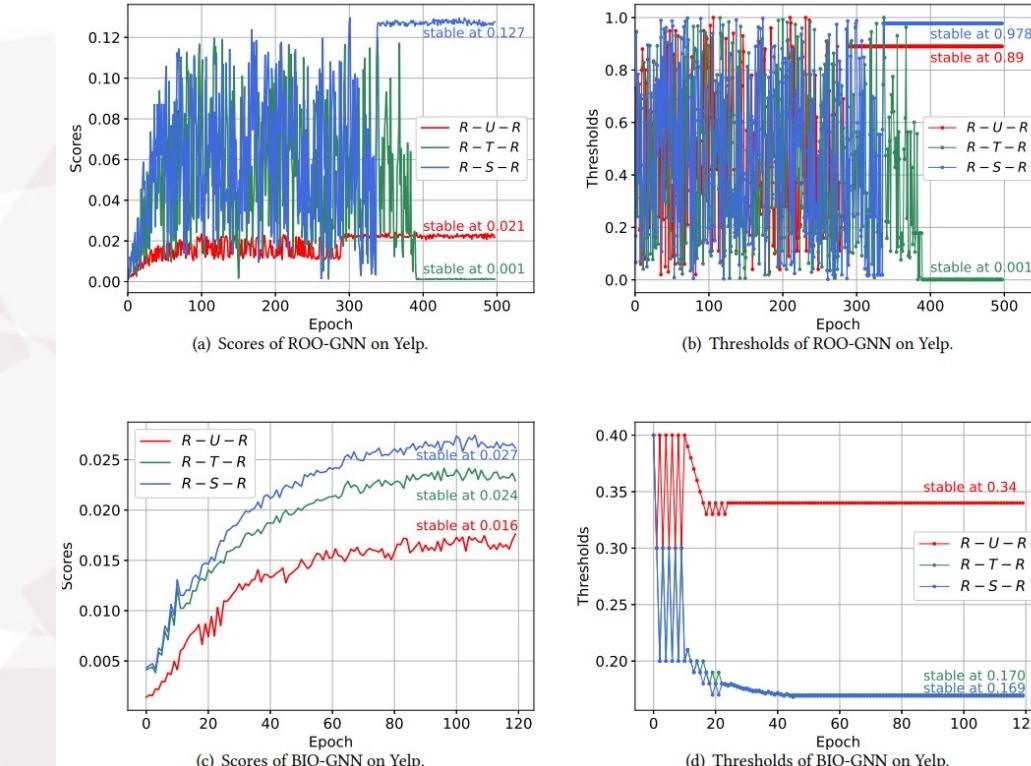


Fig. 6. The training scores and thresholds of RioGNN variants on Yelp.

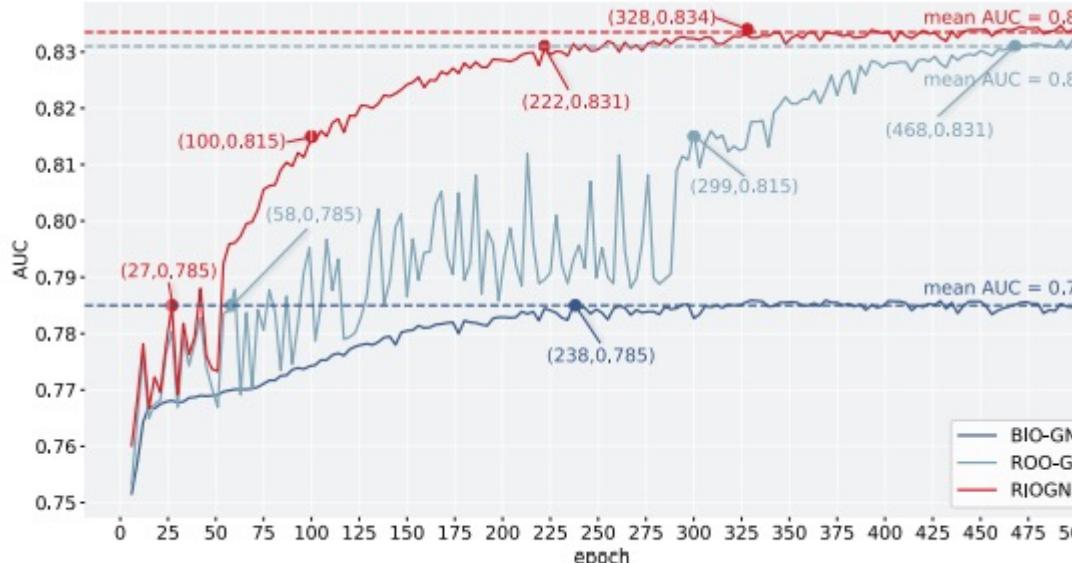
奖励对照

不同关系的重要性对照

RIOGNN变体对照（消融实验）

实验记录分析

递归框架影响分析



(a) AUC of Rio-GNN, BIO-GNN and ROO-GNN on Yelp.

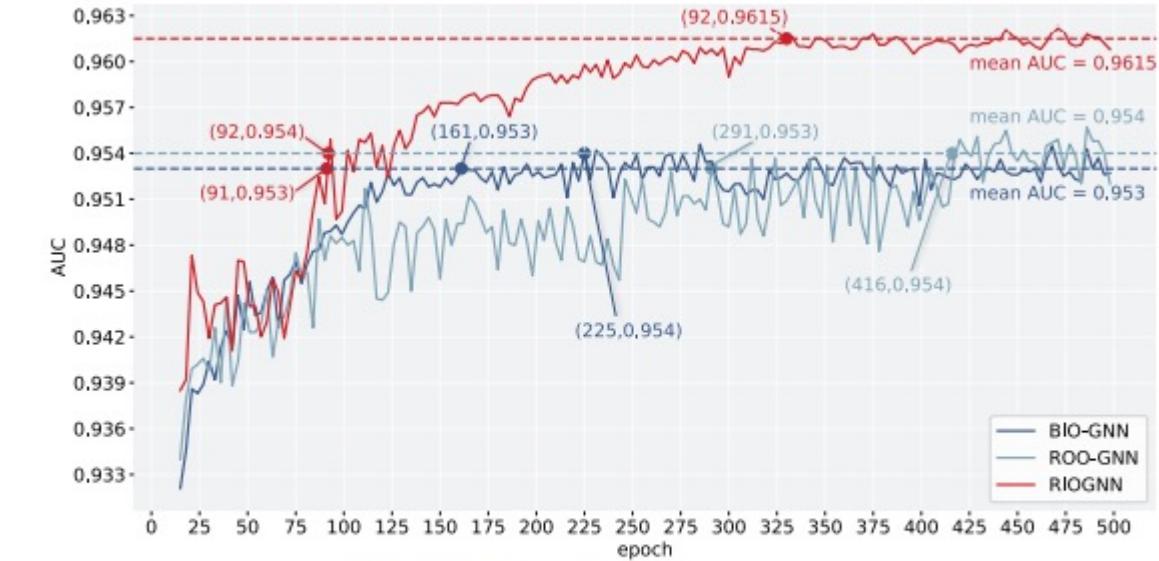
(b) AUC of RioGNN and RioGNN *No Recursion* on Amazon.

Table 10. Results (%) compared to different RL algorithms and strengthening strategies.

Methods		Yelp	Amazon	MIMIC-III
Continuous Discrete	AC [50]	83.54	96.19	81.36
	DQN [69]	84.08	95.13	80.96
	PPO [86]	80.52	94.99	80.98
	AC [50]	81.31	94.72	80.98
	DDPG [55]	83.80	95.39	81.17
	SAC [31]	80.42	94.76	80.87
	TD3 [23]	84.18	95.11	81.51

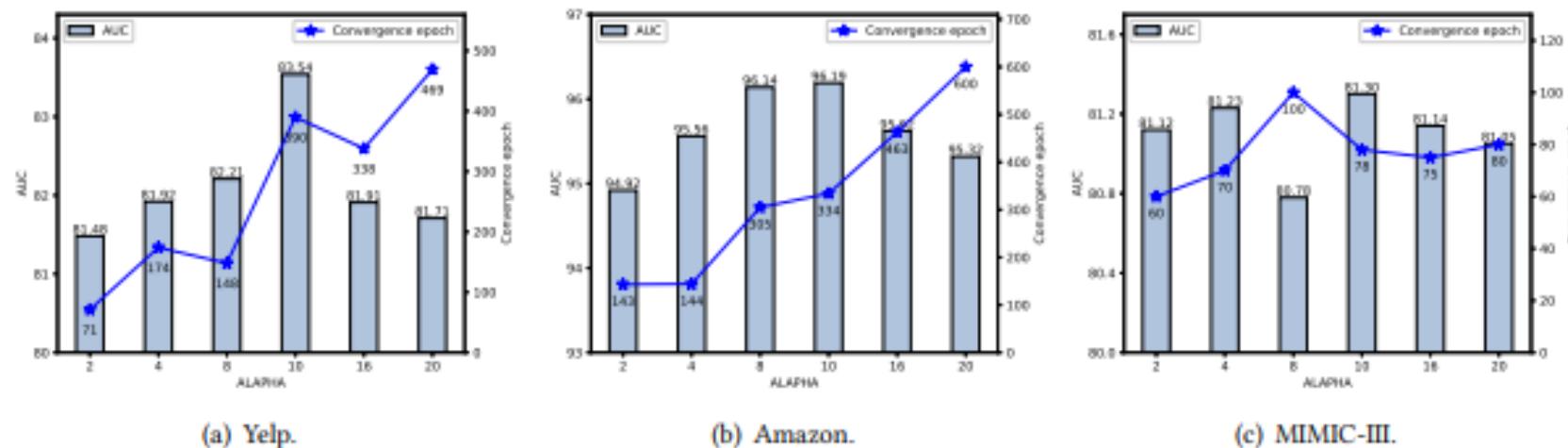


Fig. 11. Depth and Width for Different Task Scenarios.

研究工作3: 增强的异构图事件表示与检测模型 (FinEvent)

Raw Messages

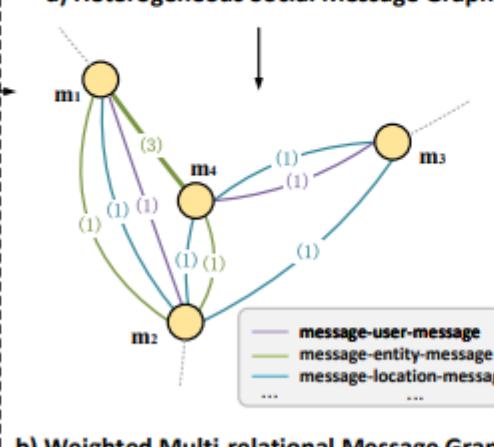
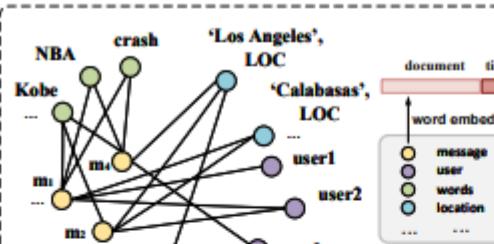
m1
@user1 Jan 27th, 2020
NBA legend Kobe Bryant was one of five people killed in a helicopter crash in Calabasas, California, ...@user2

m2
@user2 Jan 27th, 2020
Kobe Bryant avait 41 ans. Une femme, 4 filles, dont une de seulement 7 mois. Il avait pris sa retraite en 2018. ...

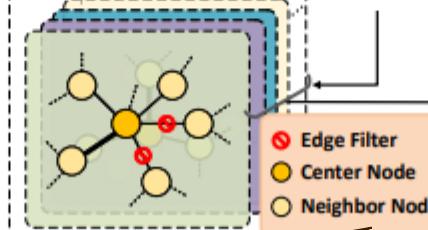
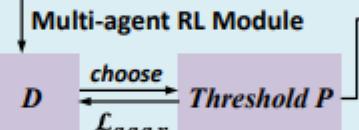
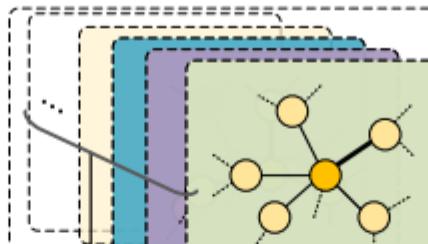
m3
@user3 Jan 27th, 2020
The Los Angeles County Sheriff Department's Recruitment Unit is hosting its Inaugural Women's Symposium. ...

m4
@user3 Jan 28th, 2020
BREAKING: Kobe Bryant, the Los Angeles Lakers superstar and future NBA Hall of Famer, died on Sunday in a helicopter crash. He was 41.

I. Preprocessing

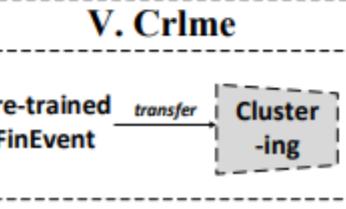
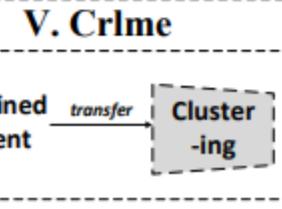
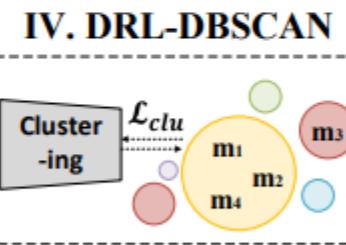
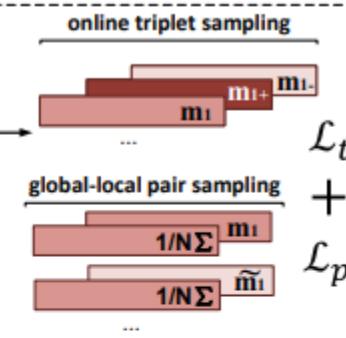


II. MarGNN

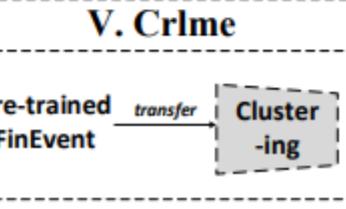
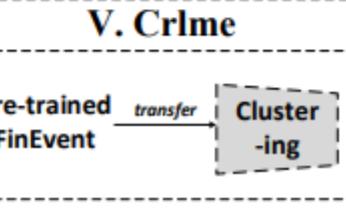
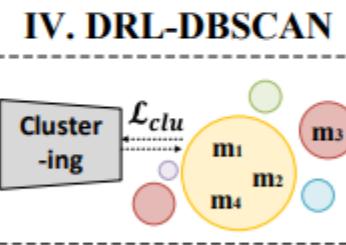
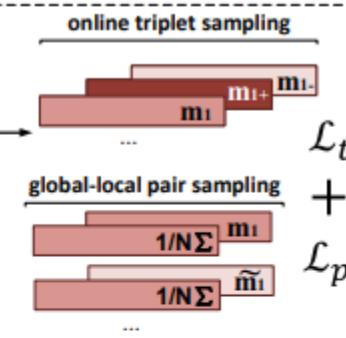


Guide

III. BasCL



IV. DRL-DBSCAN



带权多关系消息
图模型

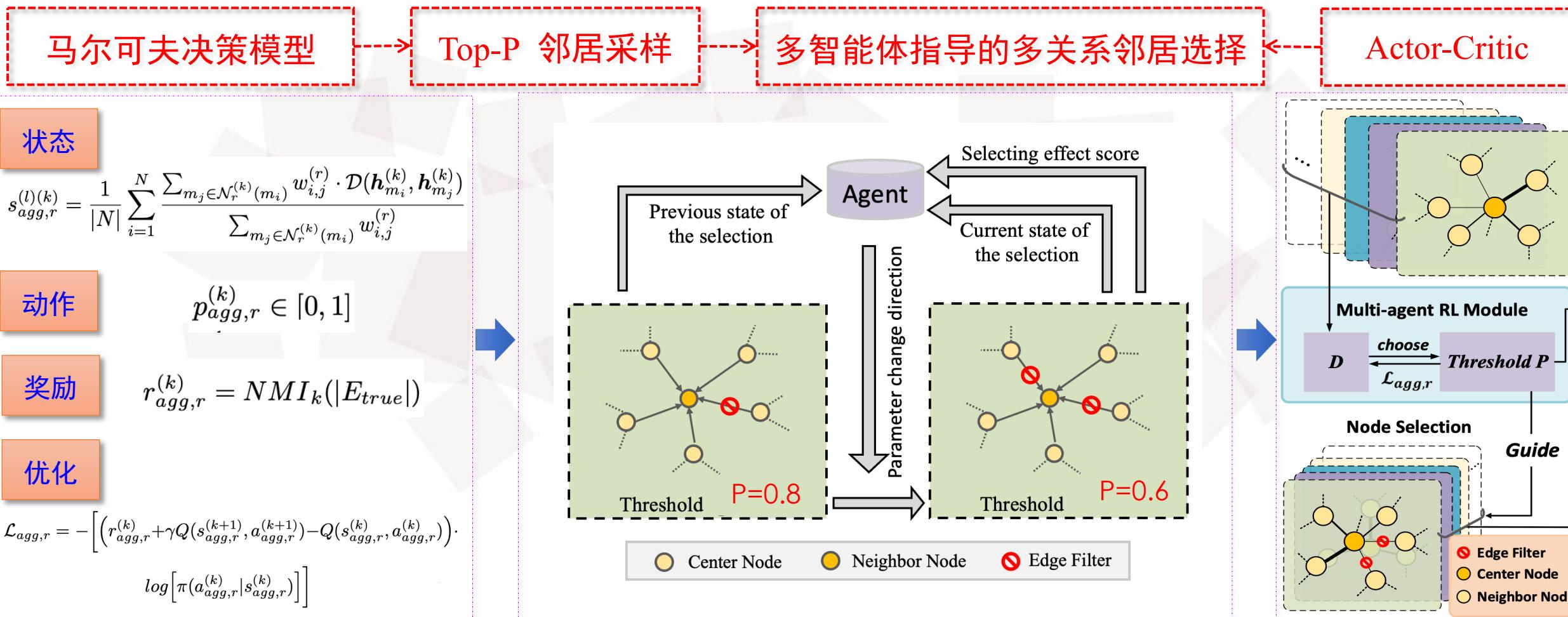
多智能体强化图神
经网络信息聚合

关系内及关系
间信息聚合

深度强化密度
聚类模型

多智能体强化加权多关系图神经网络框架

强化的邻居选择

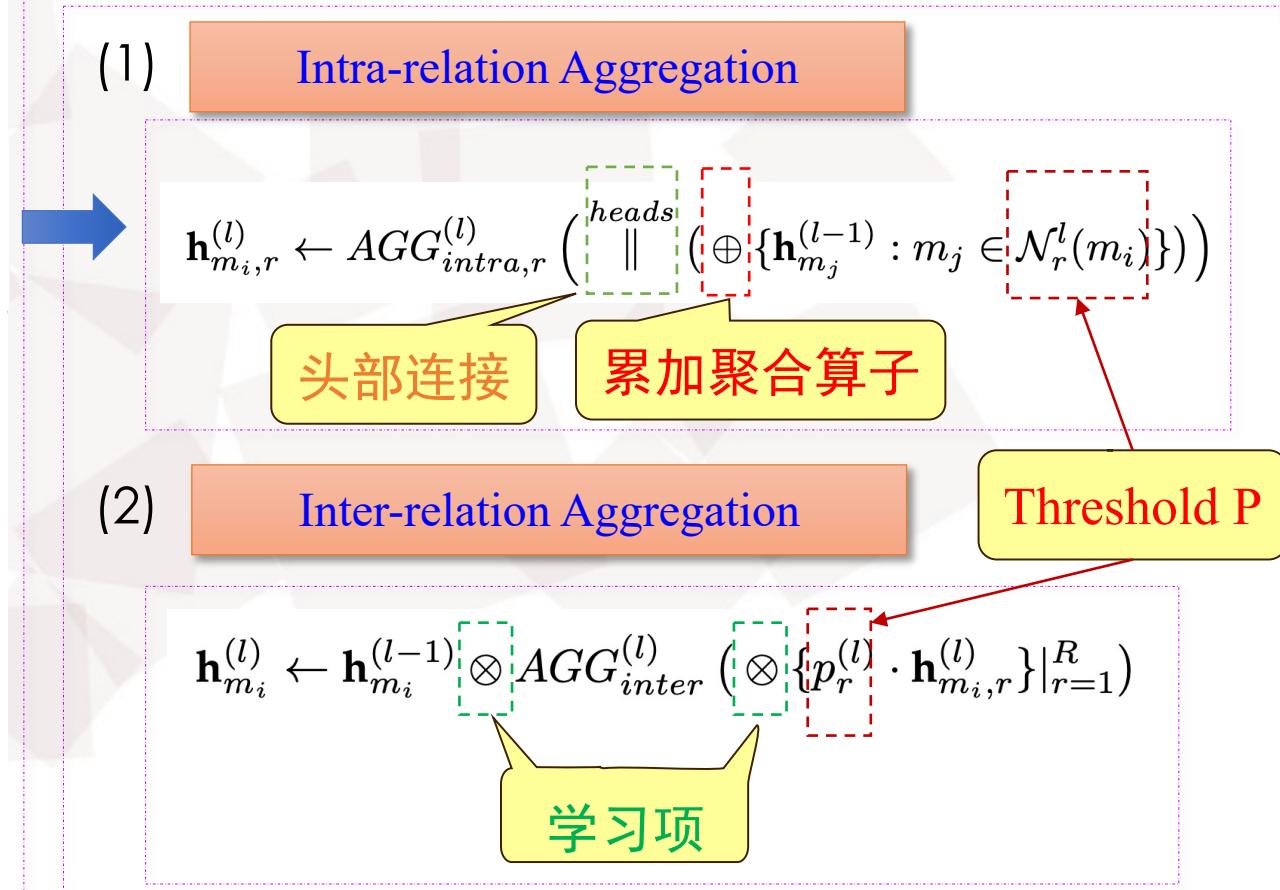
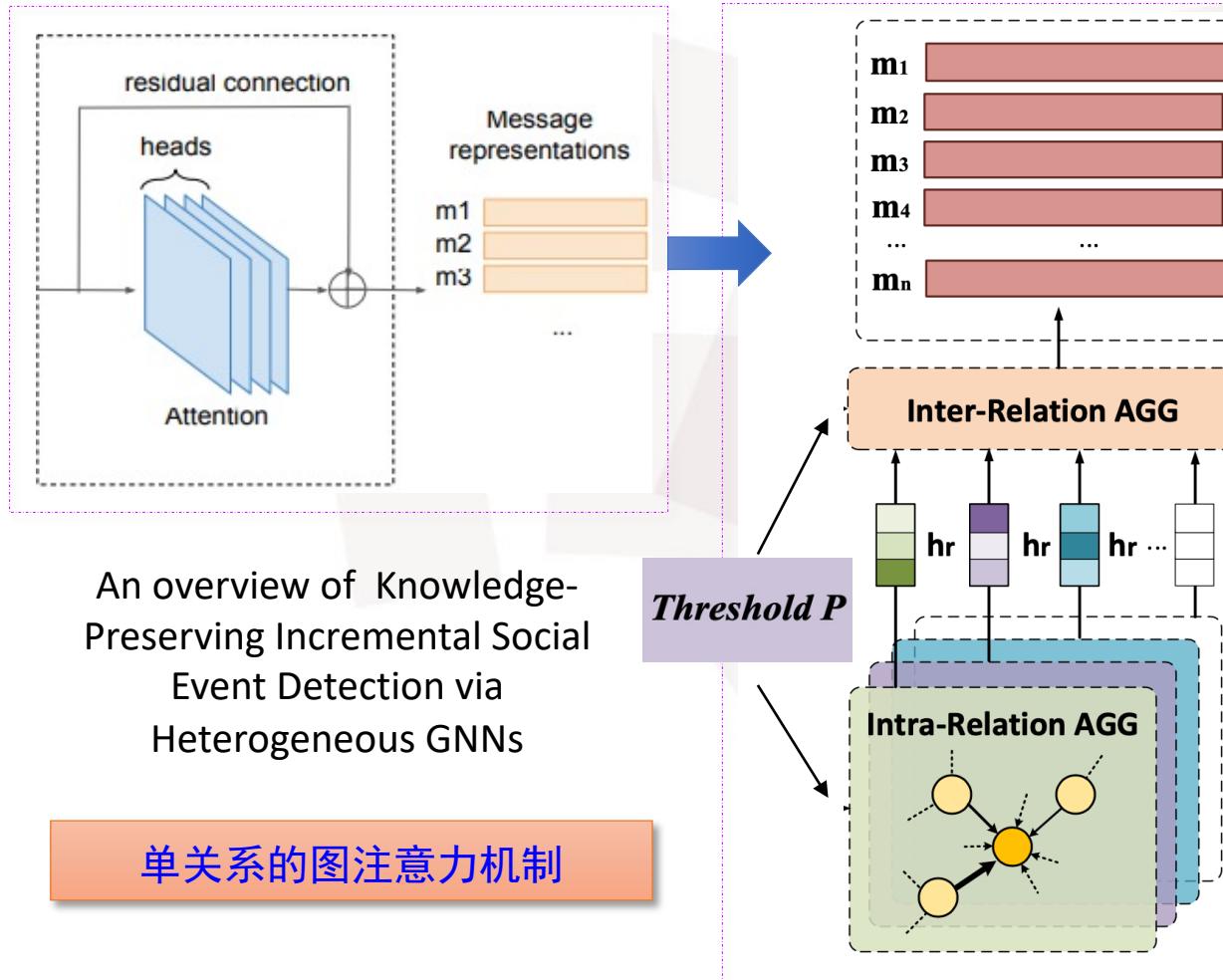


协作学习在不同关系之间找到平衡

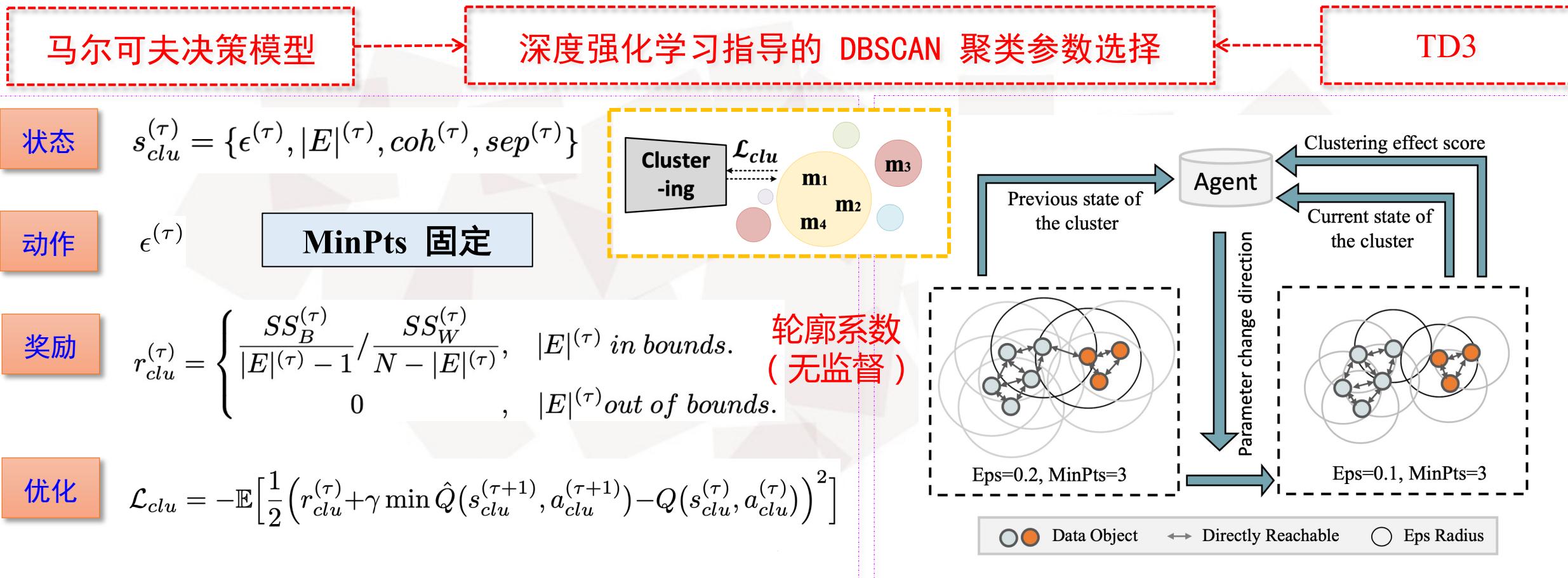
缓解不同关系中杂质信息对聚合的影响

多智能体强化加权多关系图神经网络框架

关系感知的加权邻居聚合



深度强化学习优化的DBSCAN模型



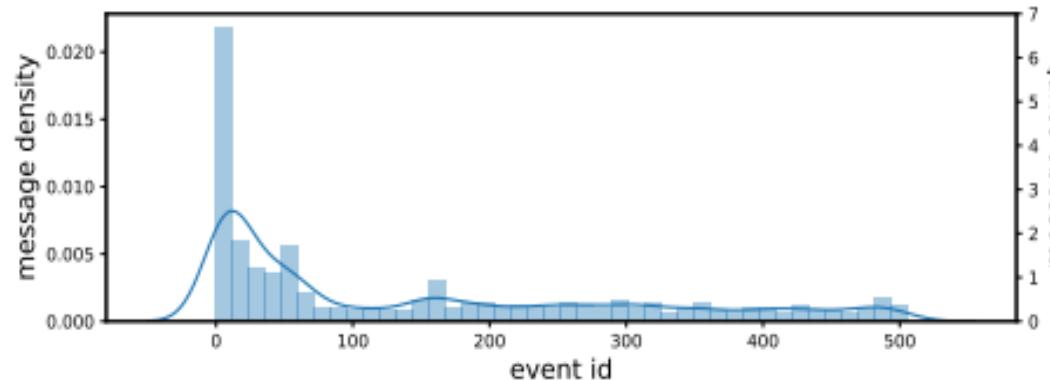
流式场景自适应的聚类参数选择

无需依赖样本的真实标签和事件类的数量

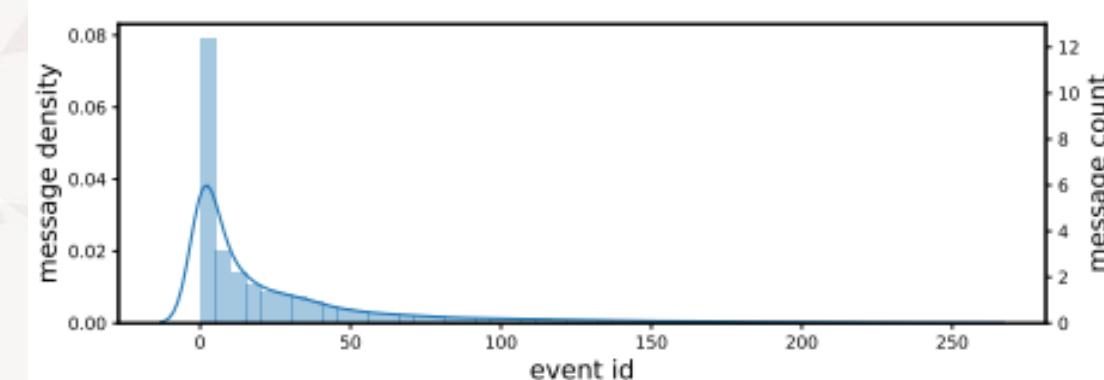
实验分析: 数据统计分析及静态事件检测实验结果

挑战1: 长尾分布

挑战2: 语言模态



(a) English Twitter Dataset statistics.



(b) French Twitter Dataset statistics.

TABLE 2: Offline evaluation results on the Twitter dataset. The best results are marked in **bold**.

Metrics	Word2vec	LDA	WMD	BERT	BiLSTM	PP-GCN	EventX	KPGNN _t	KPGNN	FinEvent _k	FinEvent _d
NMI	.44±.00	.29±.00	.65±.00	.64±.00	.63±.00	.68±.02	.72±.00	.69±.01	.70±.01	.79±.01	.80±.01 ↑ .08
AMI	.13±.00	.04±.00	.50±.00	.44±.00	.41±.00	.50±.02	.19±.00	.51±.00	.52±.01	.62±.01	.69±.01 ↑ .19
ARI	.02±.00	.01±.00	.06±.00	.07±.00	.17±.00	.20±.01	.05±.00	.21±.01	.22±.01	.24±.01	.48±.01 ↑ .28

实验分析：总体增量评估

NMI 提升 8%- 136%

TABLE 3: Incremental evaluation NMIs. The best results are marked in **bold** and second-best in *italic*.

Blocks	Word2vec	LDA	WMD	BERT	BiLSTM	PP-GCN	EventX	KPGNN _t	KPGNN	FinEvent _k	FinEvent _d
<i>M</i> ₁	.19±.00	.11±.00	.32±.00	.36±.00	.24±.00	.23±.00	.36±.00	.38±.01	.39±.00	.38±.01	.84±.01 ↑ .49
<i>M</i> ₂	.50±.00	.27±.01	.71±.00	.78±.00	.50±.00	.57±.02	.68±.00	.78±.01	.79±.01	.81±.00	.84±.01 ↑ .06
<i>M</i> ₃	.39±.00	.28±.00	.67±.00	.75±.00	.39±.00	.55±.01	.63±.00	.77±.00	.76±.00	.83±.00	.89±.01 ↑ .14
<i>M</i> ₄	.34±.00	.25±.00	.50±.00	.60±.00	.40±.00	.46±.01	.63±.00	.68±.01	.67±.00	.71±.01	.71±.01 ↑ .08
<i>M</i> ₅	.41±.00	.26±.00	.61±.00	.72±.00	.41±.00	.48±.01	.59±.00	.73±.01	.73±.01	.76±.00	.83±.01 ↑ .11
<i>M</i> ₆	.53±.00	.32±.00	.61±.00	.78±.00	.50±.00	.57±.01	.70±.00	.81±.00	.82±.01	.84±.00	.83±.01 ↑ .06
<i>M</i> ₇	.25±.00	.18±.01	.46±.00	.54±.00	.33±.00	.37±.00	.51±.00	.54±.01	.55±.01	.56±.00	.73±.01 ↑ .02
<i>M</i> ₈	.46±.00	.37±.01	.67±.00	.79±.00	.49±.00	.55±.02	.71±.00	.79±.01	.80±.00	.87±.01	.87±.01 ↑ .08
<i>M</i> ₉	.35±.00	.34±.00	.55±.00	.70±.00	.43±.00	.51±.02	.67±.00	.74±.01	.74±.02	.78±.02	.79±.01 ↑ .09
<i>M</i> ₁₀	.51±.00	.44±.01	.61±.00	.74±.00	.50±.00	.55±.02	.68±.00	.79±.01	.80±.01	.81±.01	.82±.01 ↑ .08
<i>M</i> ₁₁	.37±.00	.33±.01	.50±.00	.68±.00	.49±.00	.50±.01	.65±.00	.73±.00	.74±.01	.76±.00	.75±.01 ↑ .08
<i>M</i> ₁₂	.30±.00	.22±.01	.60±.00	.59±.00	.39±.00	.45±.01	.61±.00	.69±.01	.68±.01	.76±.01	.67±.01 ↑ .15
<i>M</i> ₁₃	.37±.00	.27±.00	.54±.00	.63±.00	.46±.00	.47±.01	.58±.00	.68±.01	.69±.01	.67±.00	.79±.01 ↑ .18
<i>M</i> ₁₄	.36±.00	.21±.00	.66±.00	.64±.00	.44±.00	.44±.01	.57±.00	.68±.01	.69±.00	.74±.00	.82±.01 ↑ .16
<i>M</i> ₁₅	.27±.00	.21±.00	.51±.00	.54±.00	.40±.00	.39±.01	.49±.00	.57±.01	.58±.00	.64±.00	.69±.01 ↑ .15
<i>M</i> ₁₆	.49±.00	.35±.01	.60±.00	.75±.00	.53±.00	.55±.01	.62±.00	.78±.01	.79±.01	.80±.00	.90±.01 ↑ .15
<i>M</i> ₁₇	.33±.00	.19±.00	.55±.00	.63±.00	.45±.00	.48±.00	.58±.00	.69±.01	.70±.01	.73±.00	.83±.01 ↑ .20
<i>M</i> ₁₈	.29±.00	.18±.00	.63±.00	.57±.00	.44±.00	.47±.01	.59±.00	.68±.01	.68±.02	.72±.01	.74±.01 ↑ .11
<i>M</i> ₁₉	.37±.00	.29±.01	.54±.00	.66±.00	.44±.00	.51±.02	.60±.00	.73±.00	.73±.01	.76±.02	.66±.01 ↑ .10
<i>M</i> ₂₀	.38±.00	.35±.00	.58±.00	.68±.00	.48±.00	.51±.01	.67±.00	.73±.00	.72±.02	.73±.00	.80±.01 ↑ .12
<i>M</i> ₂₁	.31±.00	.19±.00	.58±.00	.59±.00	.41±.00	.41±.02	.53±.00	.59±.01	.60±.00	.65±.01	.74±.01 ↑ .15

实验分析：总体增量评估

AMI 提升 11%- 147%

TABLE 4: Incremental evaluation AMIs. The best results are marked in **bold** and second-best in *italic*.

Blocks	Word2vec	LDA	WMD	BERT	BiLSTM	PP-GCN	EventX	KPGNN _t	KPGNN	FinEvent _k	FinEvent _d
<i>M</i> ₁	.08±.00	.08±.00	.30±.00	.34±.00	.12±.00	.21±.00	.06±.00	.36±.01	.37±.00	.36±.01	.84±.00 ↑ .50
<i>M</i> ₂	.41±.00	.20±.01	.69±.00	.76±.00	.41±.00	.55±.02	.29±.02	.77±.01	.78±.01	.77±.00	.84±.00 ↑ .08
<i>M</i> ₃	.31±.00	.22±.01	.63±.00	.73±.00	.31±.00	.52±.01	.18±.01	.75±.00	.74±.00	.82±.01	.89±.00 ↑ .16
<i>M</i> ₄	.24±.00	.17±.00	.45±.00	.55±.00	.30±.00	.42±.01	.19±.01	.65±.01	.64±.01	.67±.02	.69±.00 ↑ .14
<i>M</i> ₅	.33±.00	.21±.00	.57±.00	.71±.00	.33±.00	.46±.01	.14±.00	.71±.01	.71±.01	.74±.00	.82±.00 ↑ .11
<i>M</i> ₆	.40±.00	.20±.00	.57±.00	.74±.00	.36±.00	.52±.02	.27±.00	.78±.00	.79±.01	.81±.00	.82±.00 ↑ .08
<i>M</i> ₇	.13±.00	.12±.01	.46±.00	.50±.00	.20±.00	.34±.00	.13±.00	.50±.01	.51±.01	.53±.00	.72±.00 ↑ .22
<i>M</i> ₈	.33±.00	.24±.01	.63±.00	.75±.00	.35±.00	.49±.02	.21±.00	.75±.01	.76±.01	.84±.01	.87±.00 ↑ .12
<i>M</i> ₉	.24±.00	.24±.00	.46±.00	.66±.00	.32±.00	.46±.02	.19±.00	.70±.01	.71±.02	.75±.00	.78±.00 ↑ .12
<i>M</i> ₁₀	.39±.00	.36±.01	.57±.00	.70±.00	.39±.00	.51±.02	.24±.00	.76±.01	.78±.01	.78±.00	.81±.00 ↑ .11
<i>M</i> ₁₁	.26±.00	.25±.01	.42±.00	.65±.00	.37±.00	.46±.01	.24±.00	.70±.00	.71±.01	.73±.00	.74±.00 ↑ .09
<i>M</i> ₁₂	.23±.00	.16±.01	.58±.00	.56±.00	.32±.00	.42±.01	.16±.00	.66±.01	.66±.01	.75±.01	.67±.00 ↑ .17
<i>M</i> ₁₃	.23±.00	.19±.00	.50±.00	.59±.00	.31±.00	.43±.01	.16±.00	.65±.01	.67±.01	.64±.00	.79±.00 ↑ .20
<i>M</i> ₁₄	.26±.00	.15±.00	.64±.00	.61±.00	.34±.00	.41±.01	.14±.00	.65±.01	.65±.00	.72±.00	.82±.00 ↑ .18
<i>M</i> ₁₅	.15±.00	.13±.00	.47±.00	.50±.00	.26±.00	.35±.01	.07±.00	.53±.01	.54±.00	.61±.00	.67±.00 ↑ .17
<i>M</i> ₁₆	.36±.00	.27±.01	.59±.00	.72±.00	.41±.00	.52±.01	.19±.00	.75±.01	.77±.01	.75±.01	.90±.00 ↑ .20
<i>M</i> ₁₇	.24±.00	.13±.00	.57±.00	.60±.00	.35±.00	.45±.00	.18±.00	.67±.01	.68±.01	.71±.02	.82±.00 ↑ .22
<i>M</i> ₁₈	.21±.00	.12±.00	.60±.00	.53±.00	.35±.00	.45±.01	.16±.00	.66±.01	.66±.02	.70±.00	.74±.00 ↑ .14
<i>M</i> ₁₉	.28±.00	.22±.01	.49±.00	.63±.00	.35±.00	.48±.02	.16±.00	.70±.00	.71±.01	.75±.01	.66±.00 ↑ .12
<i>M</i> ₂₀	.24±.00	.23±.00	.55±.00	.62±.00	.34±.00	.45±.02	.18±.00	.68±.00	.68±.02	.68±.00	.78±.00 ↑ .16
<i>M</i> ₂₁	.21±.00	.13±.00	.52±.00	.57±.00	.31±.00	.38±.02	.10±.00	.57±.01	.57±.00	.63±.01	.64±.00 ↑ .07

实验分析：总体增量评估

ARI 提升 24%- 170%

TABLE 5: Incremental evaluation ARIs. The best results are marked in **bold** and second-best in *italic*.

Blocks	Word2vec	LDA	WMD	BERT	BiLSTM	PP-GCN	EventX	KPGNN _t	KPGNN	FinEvent _k	FinEvent _d
<i>M</i> ₁	.01±.00	.01±.00	.04±.00	.03±.00	.03±.00	.05±.00	.01±.00	.06±.01	.07±.01	.05±.00	.90±.00 ↑ .85
<i>M</i> ₂	.49±.00	.08±.00	.48±.00	.64±.00	.49±.00	.67±.03	.45±.02	.76±.01	.76±.02	.67±.01	.90±.00 ↑ .23
<i>M</i> ₃	.16±.00	.02±.01	.28±.00	.43±.00	.17±.00	.47±.01	.09±.01	.60±.02	.58±.01	.58±.00	.89±.00 ↑ .42
<i>M</i> ₄	.07±.00	.07±.00	.11±.00	.19±.00	.11±.00	.24±.01	.07±.01	.30±.01	.29±.01	.27±.02	.27±.00 ↑ .06
<i>M</i> ₅	.17±.00	.06±.00	.26±.00	.44±.00	.19±.00	.34±.00	.04±.00	.48±.01	.47±.03	.43±.01	.63±.00 ↑ .19
<i>M</i> ₆	.25±.00	.07±.01	.16±.00	.44±.00	.18±.00	.55±.03	.14±.00	.67±.05	.72±.03	.65±.00	.74±.00 ↑ .19
<i>M</i> ₇	.02±.00	.01±.00	.08±.00	.07±.00	.08±.00	.11±.02	.02±.00	.11±.01	.12±.00	.09±.01	.45±.00 ↑ .34
<i>M</i> ₈	.17±.00	.03±.00	.22±.00	.50±.00	.08±.00	.43±.04	.09±.00	.59±.02	.60±.01	.65±.02	.72±.00 ↑ .22
<i>M</i> ₉	.08±.00	.03±.01	.12±.00	.33±.00	.27±.00	.31±.02	.07±.00	.45±.02	.46±.02	.43±.00	.68±.00 ↑ .35
<i>M</i> ₁₀	.23±.00	.09±.02	.20±.00	.44±.00	.22±.00	.50±.07	.13±.00	.64±.01	.70±.06	.62±.02	.74±.00 ↑ .24
<i>M</i> ₁₁	.09±.00	.03±.01	.12±.00	.27±.00	.17±.00	.38±.02	.16±.00	.48±.01	.49±.03	.42±.01	.60±.00 ↑ .22
<i>M</i> ₁₂	.09±.00	.02±.01	.27±.00	.31±.00	.13±.00	.34±.03	.07±.00	.50±.03	.48±.01	.44±.00	.26±.00 ↑ .16
<i>M</i> ₁₃	.06±.00	.01±.00	.13±.00	.14±.00	.13±.00	.19±.01	.04±.00	.28±.01	.29±.03	.21±.02	.75±.00 ↑ .56
<i>M</i> ₁₄	.10±.00	.02±.00	.33±.00	.30±.00	.16±.00	.29±.01	.10±.00	.43±.02	.42±.02	.43±.01	.81±.00 ↑ .48
<i>M</i> ₁₅	.09±.00	.01±.00	.16±.00	.10±.00	.14±.00	.15±.00	.01±.00	.16±.02	.17±.00	.16±.00	.46±.00 ↑ .31
<i>M</i> ₁₆	.10±.00	.11±.01	.32±.00	.41±.00	.10±.00	.51±.03	.08±.00	.62±.03	.66±.05	.56±.01	.88±.00 ↑ .37
<i>M</i> ₁₇	.06±.00	.02±.00	.26±.00	.24±.00	.17±.00	.35±.03	.12±.00	.41±.03	.43±.05	.36±.01	.81±.00 ↑ .46
<i>M</i> ₁₈	.21±.00	.02±.00	.35±.00	.24±.00	.19±.00	.39±.03	.08±.00	.46±.02	.47±.04	.44±.01	.52±.00 ↑ .13
<i>M</i> ₁₉	.28±.00	.03±.00	.12±.00	.32±.00	.16±.00	.41±.02	.07±.00	.50±.01	.51±.03	.44±.00	.35±.00 ↑ .10
<i>M</i> ₂₀	.24±.00	.02±.01	.19±.00	.33±.00	.20±.00	.41±.01	.11±.00	.51±.01	.51±.04	.43±.02	.71±.00 ↑ .30
<i>M</i> ₂₁	.21±.00	.01±.01	.19±.00	.18±.00	.16±.00	.20±.03	.01±.00	.23±.02	.20±.01	.23±.00	.48±.00 ↑ .27

实验分析：聚类可视化

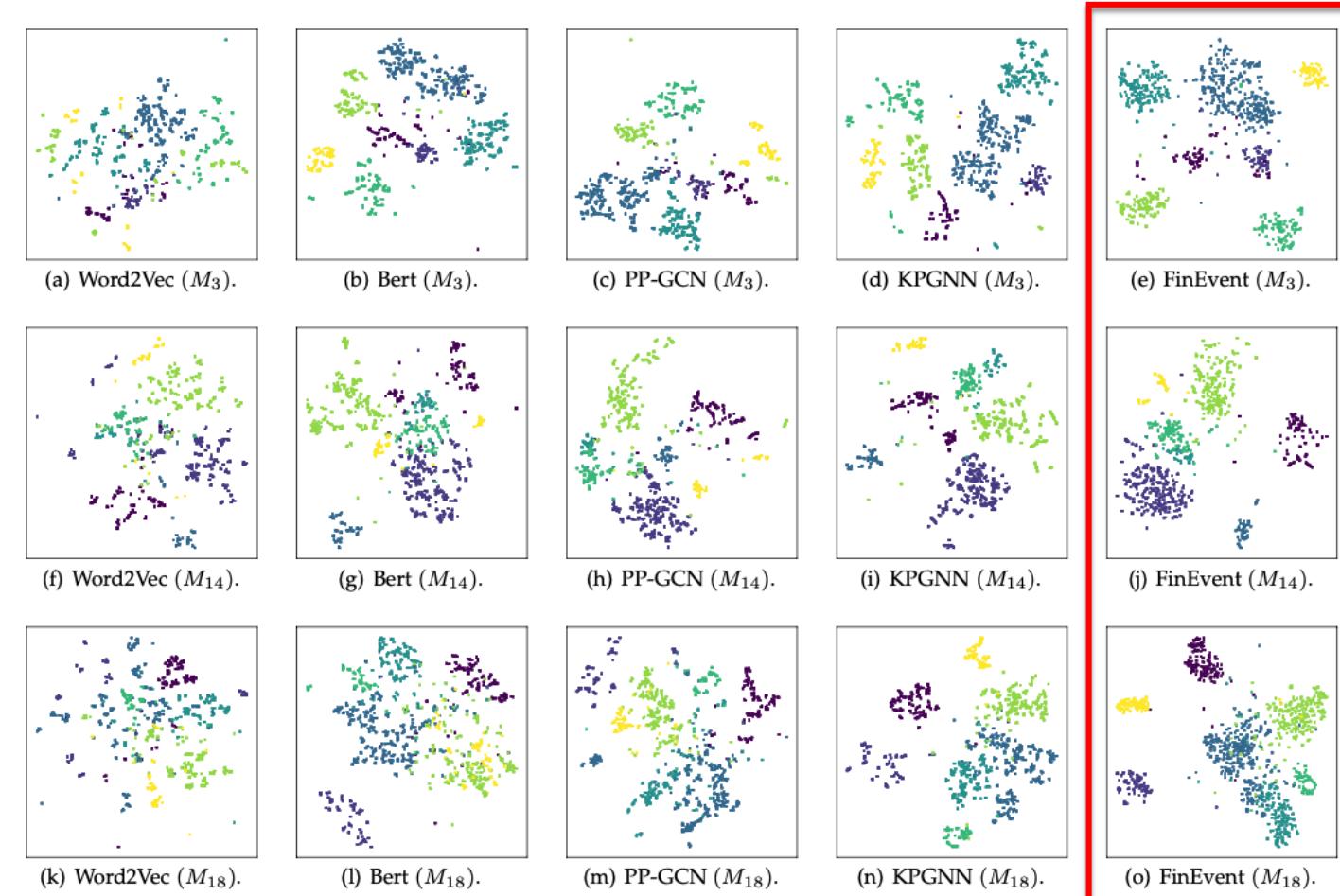


Fig. 4: Cluster visualization of message representations in the detection stage.

实验分析：消融对比实验

TABLE 6: Ablation study for neighbor sampler strategy, Intra-relation Aggregation AGG_{intra} and Inter-relation Aggregation AGG_{inter} . The best results are marked in **bold** and second-best in *italic*.

	Neighbor Sampling Strategy			Cluster Type	Intra-relation Aggregator		Threshold	Inter-relation Aggregator			Avg. Metrics		
	Random	Constant	Reinforced		Shared-GNN	RNN		Cat.	Sum	MLP	NMI	AMI	ARI
1	-	-	✓	DBSCAN	-	-	✓	✓	-	-	0.788	0.777	0.645
2	-	-	✓	K-Means	-	-	✓	✓	-	-	0.727	0.702	0.443
3	-	✓	-	K-Means	-	-	-	-	-	-	0.698	0.671	0.448
4	-	top 50%	-	K-Means	-	-	-	✓	-	-	0.719	0.699	0.441
5	-	bottom 50%	-	K-Means	-	-	-	✓	-	-	0.698	0.670	0.427
6	✓	-	-	K-Means	-	-	-	✓	-	-	0.718	0.694	0.437
7	-	✓	-	K-Means	-	-	-	✓	-	-	0.722	0.696	0.442
8	-	-	✓	K-Means	✓	-	✓	✓	-	-	0.700	0.673	0.416
9	-	-	-	K-Means	-	✓	-	-	-	-	0.449	0.324	0.168
10	-	-	✓	K-Means	-	-	-	✓	-	-	0.723	0.697	0.438
11	-	-	✓	K-Means	-	-	✓	-	✓	-	0.702	0.674	0.425
12	-	-	✓	K-Means	-	-	-	-	✓	-	0.700	0.672	0.422
13	-	-	✓	K-Means	-	-	✓	✓	-	✓	0.653	0.620	0.383
14	-	-	✓	K-Means	-	-	-	✓	-	✓	0.645	0.610	0.368

实验分析：多智能体强化学习进程分析——邻居采样

稳定收敛：动态纳什均衡

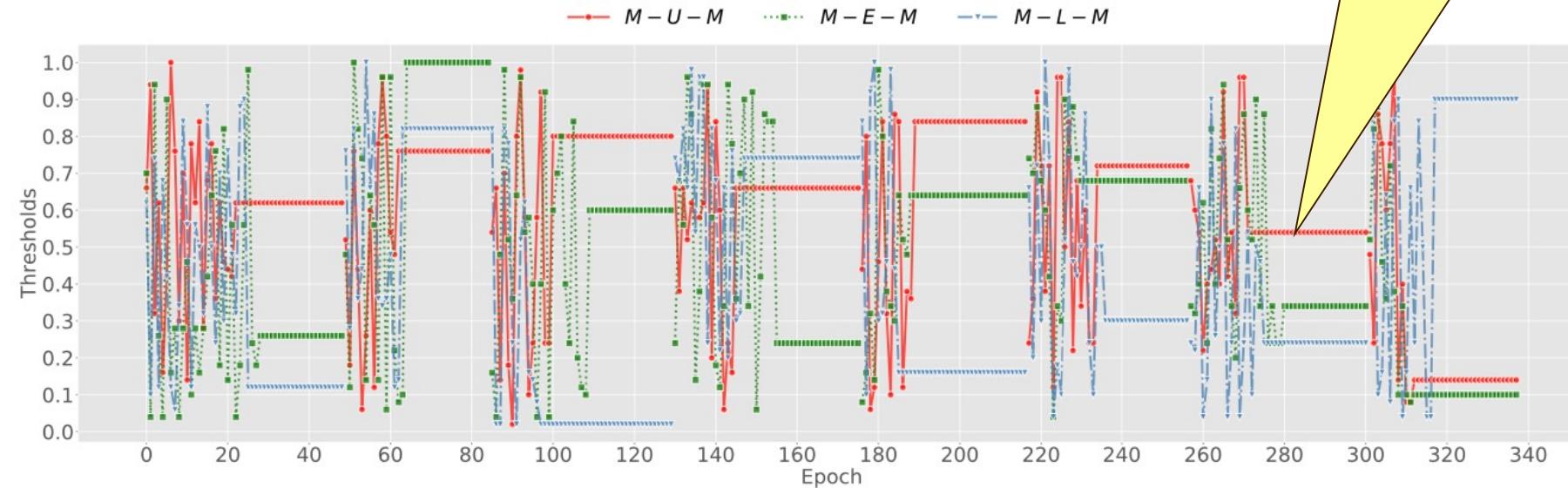
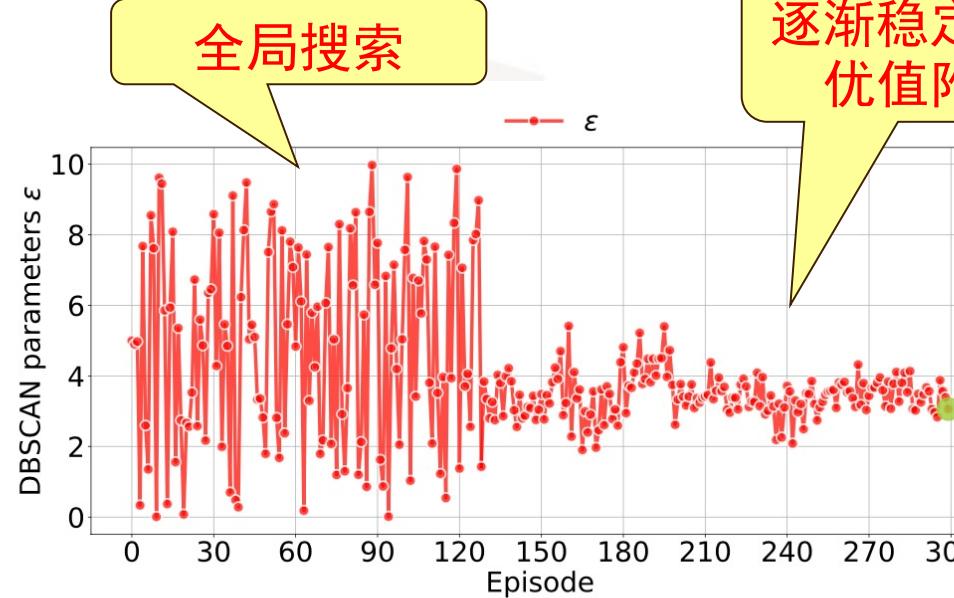


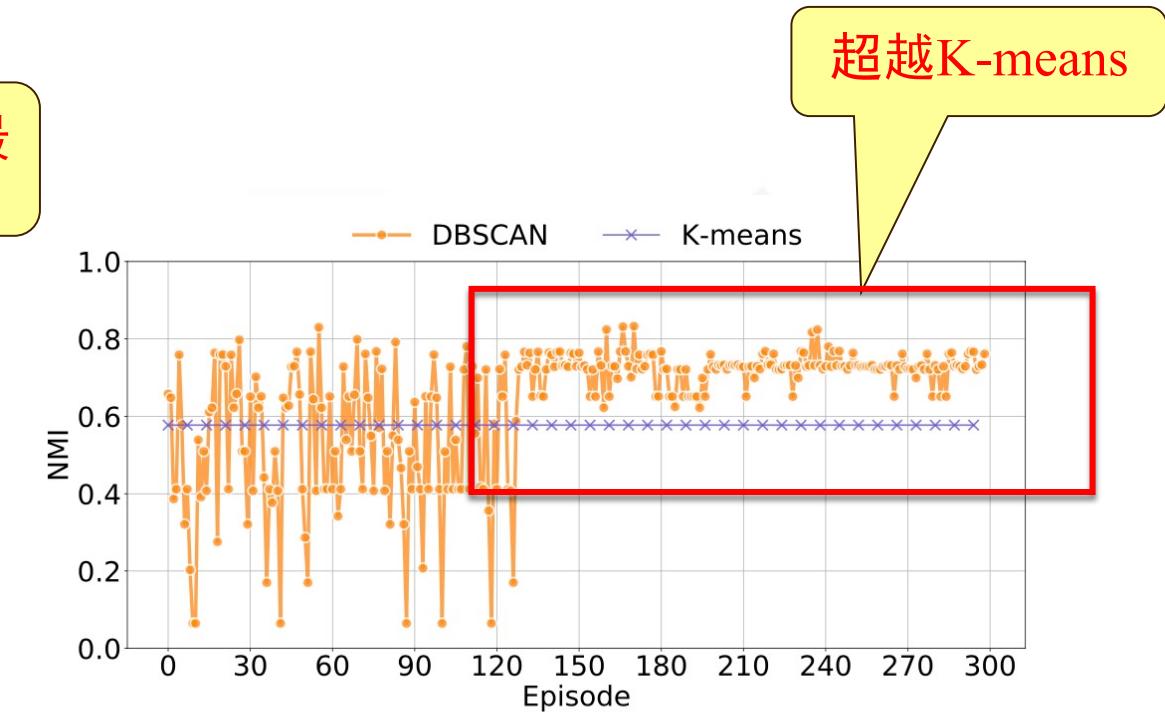
Fig. 5: Multi-agent reinforcement learning process in the online maintenance stage. We summarize the epochs of all time periods. Note that each process from fluctuation to stability is a pre-training or maintenance stage. The figure contains a total of one pre-training process and seven maintenance processes.

包含 1 个预训练阶段(从 epoch 0 到 epoch 50)和 7 个维护阶段(从 epoch 50 到 epoch 340)

实验分析：深度强化学习进程分析——聚类



(a) DBSCAN parameters.



(b) NMI scores.

Fig. 6: Deep reinforcement learning process in the online detection stage. We show the DRL-DBSCAN parameter adjustment and NMI change process of block M_7 as an example of DRL-DBSCAN, where the green marked points represents the final convergence parameter.

实验分析：增量检测中的强化学习及跨语言实验分析

TABLE 7: Preserving thresholds in the detection stage.

Blocks	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
$M-U-M$	—	.88	.24	.98	.24	.50	.40	.40	.12	.06	.96
$M-E-M$	—	.82	.56	.22	.20	.88	.90	.74	.20	.28	.50
$M-L-M$	—	.96	.08	.80	.54	.42	.78	.80	.56	.70	.86

Blocks	M_{11}	M_{12}	M_{13}	M_{14}	M_{15}	M_{16}	M_{17}	M_{18}	M_{19}	M_{20}	M_{21}
$M-U-M$	.22	.94	.22	.14	.10	.46	.44	.24	.10	.32	.38
$M-E-M$	.66	.72	.24	.60	.76	.82	.90	.90	.20	.10	.34
$M-L-M$	.74	.64	.20	.98	.54	.18	.50	.46	.24	.16	.92

TABLE 8: DBSCAN parameters in the detection stage.

Blocks	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
ϵ	—	3.87	3.29	2.57	3.25	3.24	3.70	2.35	2.95	3.39	3.57

Blocks	M_{11}	M_{12}	M_{13}	M_{14}	M_{15}	M_{16}	M_{17}	M_{18}	M_{19}	M_{20}	M_{21}
ϵ	3.19	3.28	3.76	3.93	2.00	3.37	3.54	3.23	4.00	2.23	3.18

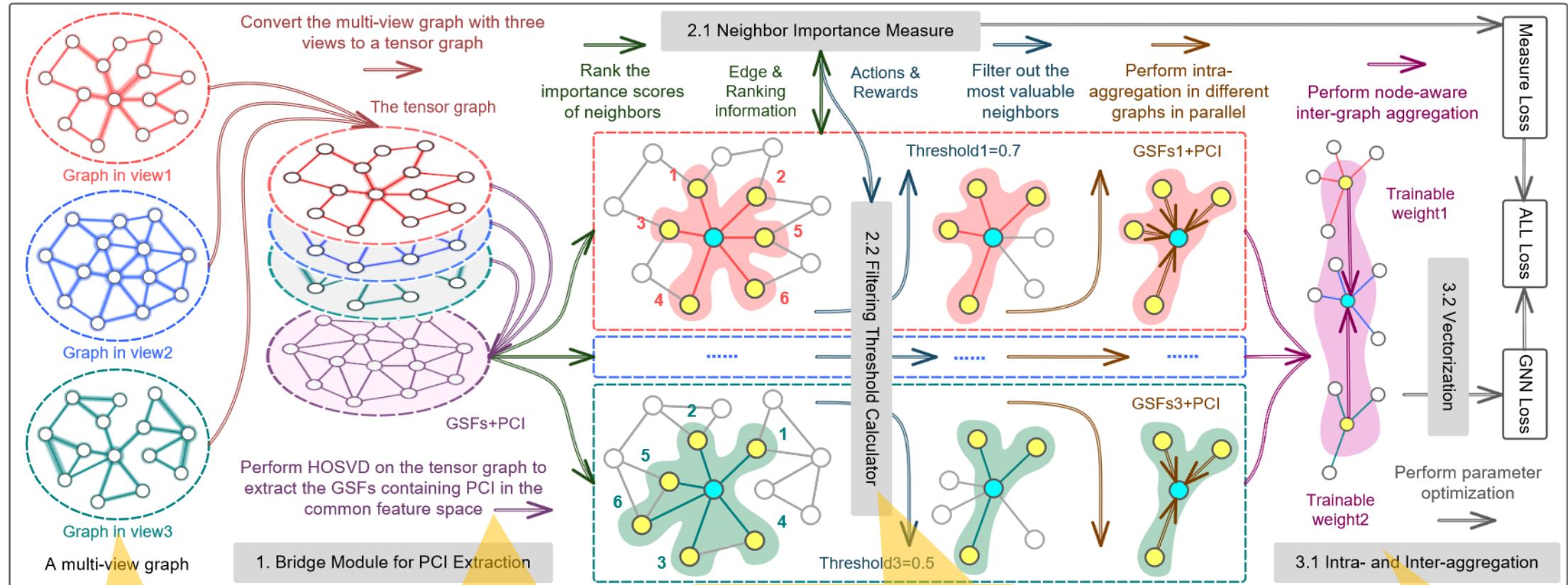
TABLE 9: Cross-lingual transferring evaluation on French dataset. The best results are marked in bold.

Blocks	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7
FinEvent_r	—	.575	.620	.577	.512	.556	.488	.584
FinEvent_{cr}	—	.576	.578	.580	.534	.633	.656	.615
FinEvent_g	—	.592	.574	.591	.474	.568	.511	.580
FinEvent_{cg}	—	.578	.575	.604	.542	.641	.659	.600

语义映射+法语有标注+重训练
语义映射+法语无标注+参数利用
谷歌翻译+法语有标注+重训练
谷歌翻译+法语无标注+参数利用

Blocks	M_8	M_9	M_{10}	M_{11}	M_{12}	M_{13}	M_{14}	M_{15}
FinEvent_r	.640	.484	.627	.529	.545	.472	.519	.586
FinEvent_{cr}	.612	.523	.597	.610	.616	.569	.622	.630
FinEvent_g	.625	.484	.623	.546	.548	.474	.530	.591
FinEvent_{cg}	.598	.512	.599	.584	.610	.563	.640	.626

研究工作4: 强化聚合的多视图张量图神经网络 (RTGNN)



多视图图表示
· 转化为张量图

PCI抽取桥接模块
· HOSVD算法
· 抽取潜在关联信息和图结构信息

强化学习引导的邻居过滤器
· 邻居重要性评价
· 过滤阈值计算

图内特征聚合

图间特征聚合

强化学习模块引导的邻居过滤器

邻居重要性度量

FNN节点标签
预测器图中的边
权信息二维范式节
点距离

$$IMP_j^{(l)}(k, k') = |\mathbf{A}_{i,j}(k, k')| \otimes (1 - DIST_j^{(l)}(k, k')),$$

$$DIST_j^{(l)}(k, k') = NORM \left(\left\| \sigma \left(FNN_j^{(l)} \left(\mathbf{F}_{i,j}^{(l)}(k) \right) \right) - \sigma \left(FNN_j^{(l)} \left(\mathbf{F}_{i,j}^{(l)}(k') \right) \right) \right\|_2 \right),$$

$$\mathcal{L}_{edge}^{(l)} = - \sum_{g_{train}} \sum_{j=1}^V \sum_{k=1}^{|N|} \mathbf{X}(k) \log \left(\sigma \left(FNN_j^{(l)} \left(\mathbf{F}_{i,j}^{(l)}(k) \right) \right) \right).$$

FNN与图神经网络
协同优化计算所有邻居节点
的重要性并排序

强化学习

动作

奖励

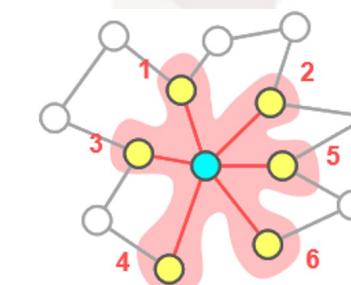
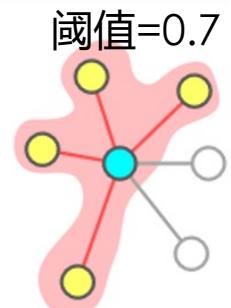
终止
条件动作描述如何计算阈值更新， ϵ -greedy 算法优化策略

相邻迭代轮船间，邻居的平均重要性差异决定奖励

$$AVG_j^{(l)[p]} = \frac{\sum_{\mathbf{A}_{i,j}^{(l*)[p]}(k, k') > 0} IMP_j^{(l)}(k, k')}{\sum_{n_k \in N} T_j^{(l)[p]} |N(k)|},$$

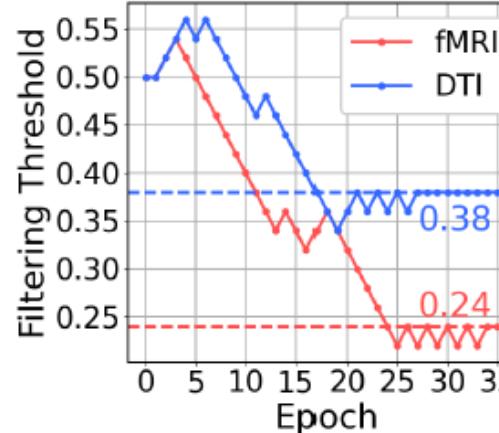
$$REW_j^{(l)[p]} = \begin{cases} -1, & AVG_j^{(l)[p]} \leq AVG_j^{(l)[p-1]} \\ +1, & AVG_j^{(l)[p]} > AVG_j^{(l)[p-1]} \end{cases}.$$

$$\left| \sum_{p=10}^P REW_j^{(l)[p]} \right| \leq 1.$$

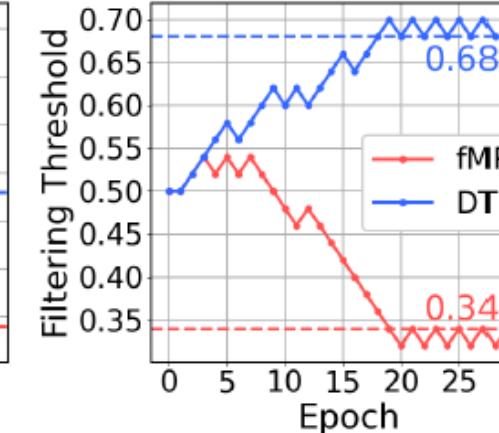
过滤器阈值
计算器

强化学习引导模块在GNN中的表现

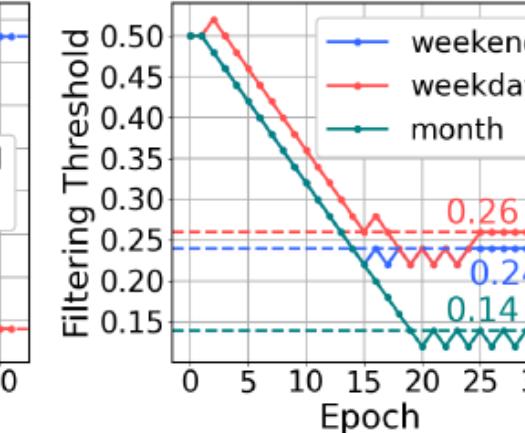
邻居过滤器参数变化



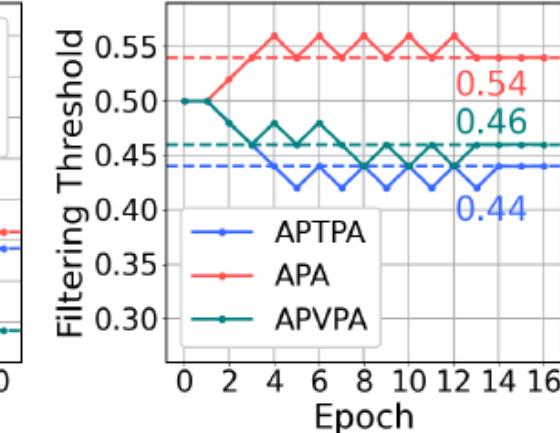
(a) HIV



(b) BP

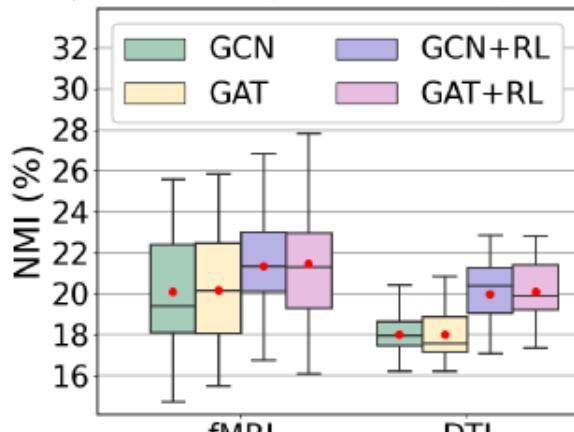


(c) BikeDC

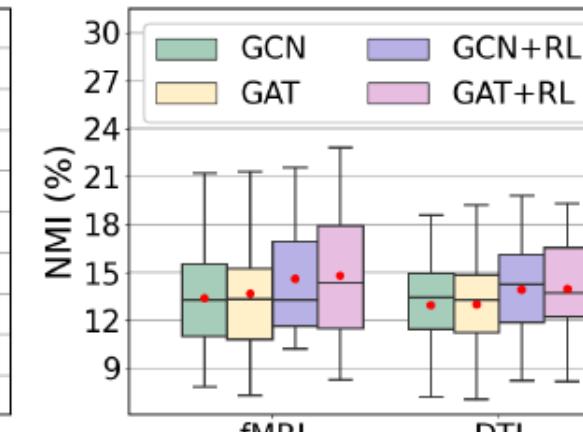


(d) DBLP

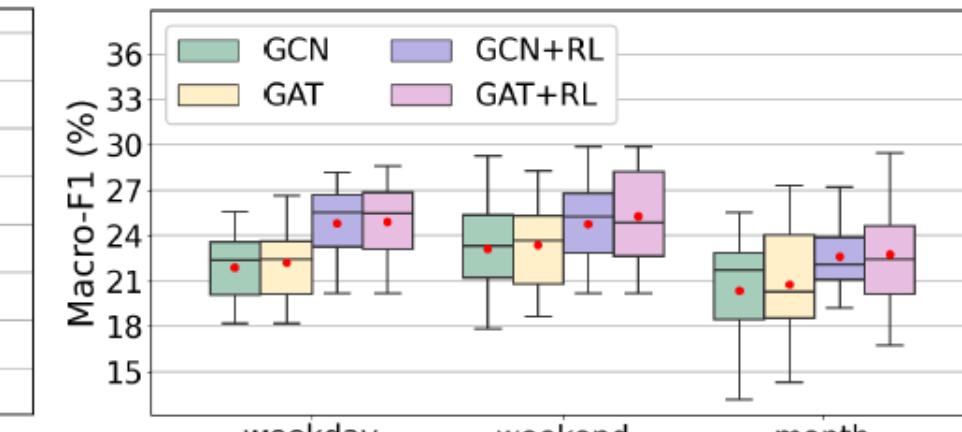
强化学习引导GNN与原生GNN



(a) HIV



(b) BP

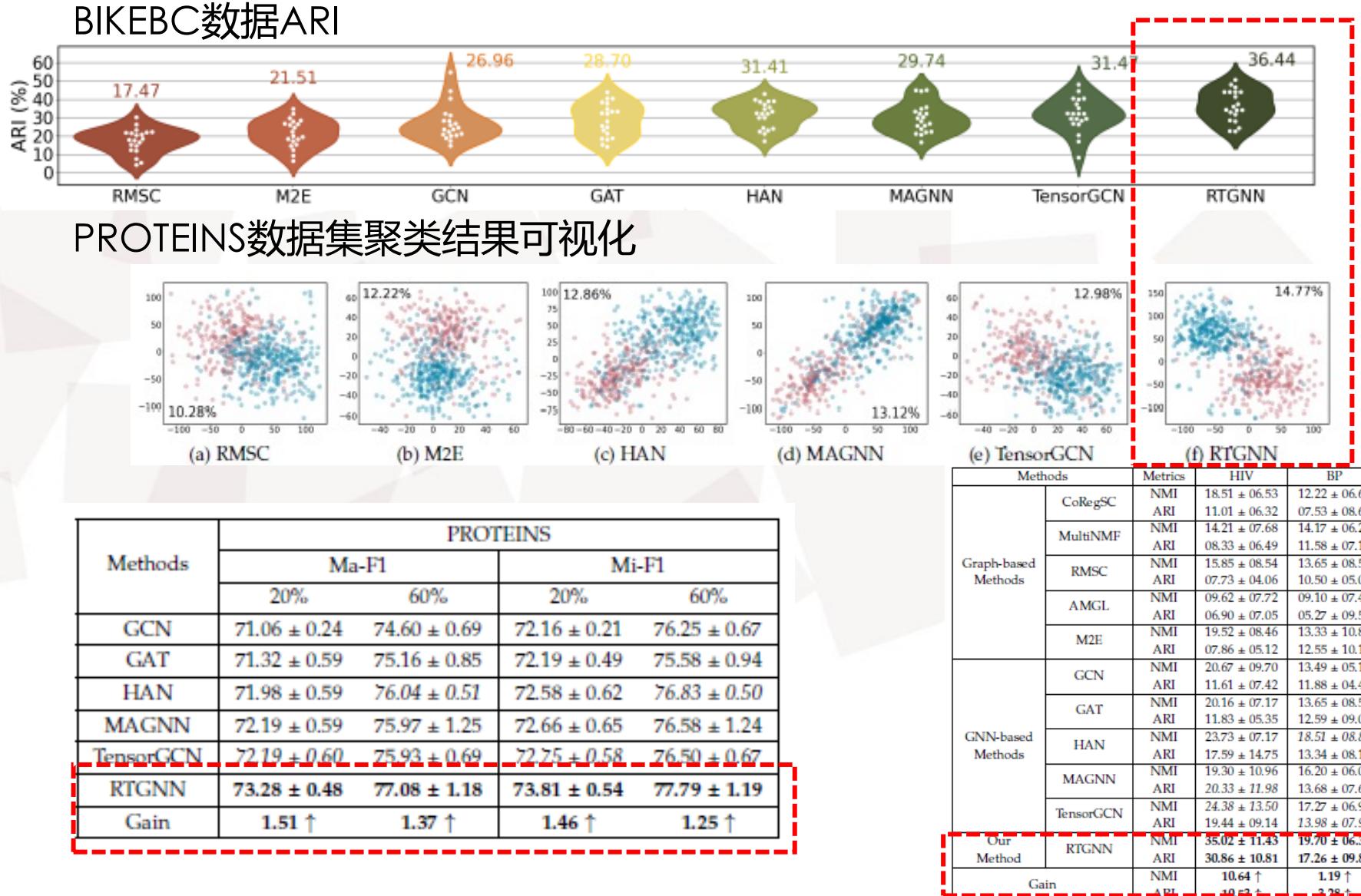


(c) BikeDC

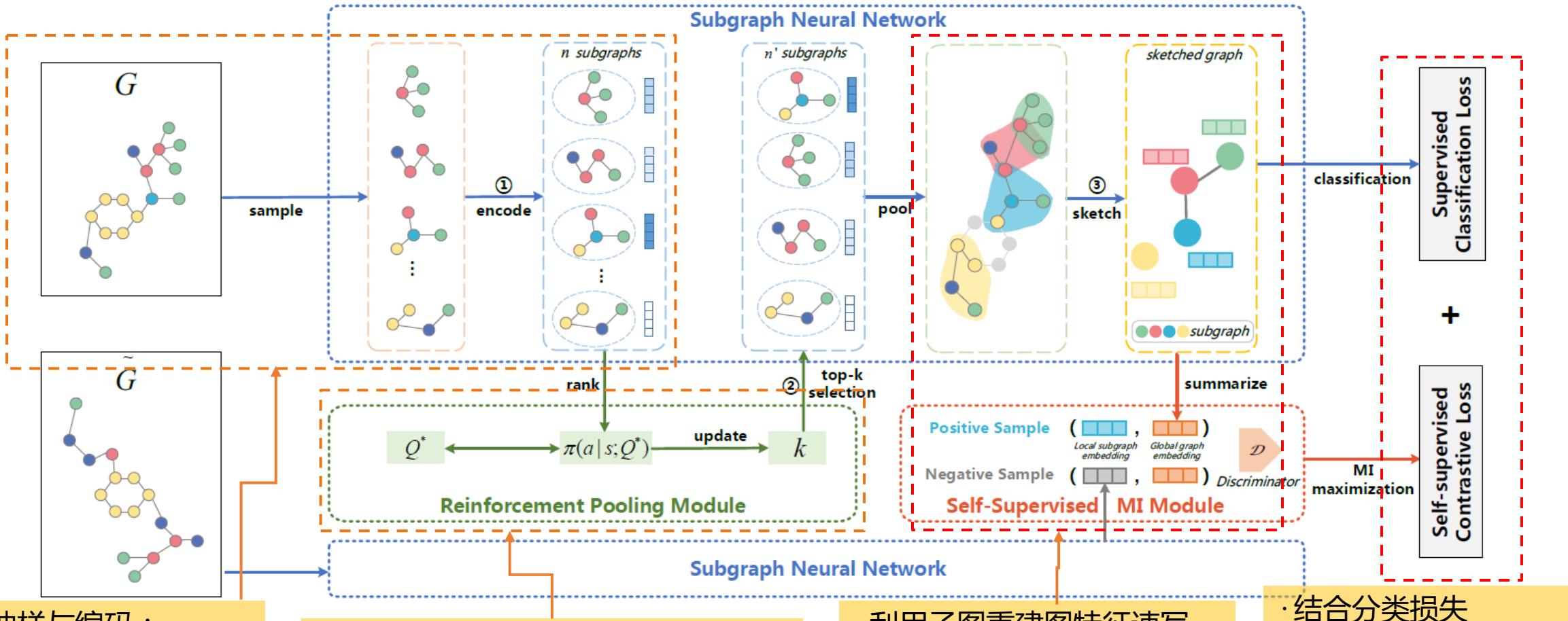
分类任务表现

Methods	Train%	HIV		BP		BikeDC		DBLP		
		Ma-F1	Mi-F1	Ma-F1	Mi-F1	Ma-F1	Mi-F1	Ma-F1	Mi-F1	
Graph-based Methods	CoRegSC	20%	49.34 ± 03.17	50.51 ± 04.72	46.31 ± 08.02	54.00 ± 02.63	20.47 ± 04.67	35.29 ± 03.72	80.63 ± 00.28	81.61 ± 00.93
		60%	59.19 ± 07.16	60.14 ± 09.56	54.13 ± 07.24	57.82 ± 04.36	29.05 ± 03.75	43.52 ± 05.99	82.90 ± 00.15	83.88 ± 00.33
	MultiNMF	20%	48.85 ± 06.94	49.19 ± 03.81	53.84 ± 09.24	58.22 ± 05.60	22.24 ± 02.75	37.35 ± 02.29	78.43 ± 00.43	79.20 ± 00.70
		60%	53.36 ± 08.89	54.71 ± 04.19	55.10 ± 07.58	58.69 ± 06.22	26.21 ± 02.77	42.35 ± 04.40	82.02 ± 00.20	82.57 ± 00.19
	RMSC	20%	51.24 ± 06.93	51.69 ± 06.47	43.95 ± 08.19	53.33 ± 03.29	20.38 ± 03.58	34.11 ± 02.99	83.46 ± 00.51	83.82 ± 00.18
		60%	62.50 ± 09.54	63.12 ± 06.07	53.96 ± 06.98	57.39 ± 03.79	30.57 ± 06.14	45.88 ± 08.64	84.89 ± 00.27	85.03 ± 00.32
	AMGL	20%	48.26 ± 08.68	49.48 ± 03.06	33.82 ± 10.68	51.11 ± 04.24	19.21 ± 05.97	35.58 ± 05.17	80.52 ± 00.21	81.38 ± 00.91
		60%	56.60 ± 09.54	58.76 ± 08.47	34.28 ± 09.31	52.17 ± 05.49	25.84 ± 04.85	43.52 ± 06.55	84.50 ± 00.37	85.11 ± 00.13
	M2E	20%	53.98 ± 03.03	56.25 ± 05.13	51.47 ± 07.45	55.55 ± 03.71	22.85 ± 05.22	38.23 ± 04.36	83.45 ± 00.12	83.82 ± 00.18
		60%	63.75 ± 03.75	65.00 ± 05.00	54.70 ± 06.98	56.95 ± 05.97	30.21 ± 03.75	45.88 ± 06.85	85.74 ± 00.05	86.41 ± 00.09
GNN-based Methods	GCN	20%	55.60 ± 03.03	56.56 ± 03.93	50.54 ± 08.94	55.77 ± 03.50	22.75 ± 03.28	39.11 ± 03.49	89.12 ± 00.17	89.94 ± 00.16
		60%	65.73 ± 04.85	67.50 ± 04.67	57.24 ± 07.12	59.56 ± 05.84	30.73 ± 03.57	48.23 ± 04.40	90.17 ± 00.05	90.40 ± 00.12
	GAT	20%	55.98 ± 04.73	56.25 ± 02.82	50.58 ± 06.98	55.55 ± 02.81	23.83 ± 04.33	39.70 ± 03.54	91.06 ± 00.03	91.19 ± 00.07
		60%	65.69 ± 04.19	68.75 ± 04.14	57.57 ± 05.88	60.00 ± 05.07	31.98 ± 04.73	48.23 ± 06.33	91.94 ± 00.18	92.35 ± 00.09
	HAN	20%	58.90 ± 05.04	60.00 ± 03.64	56.18 ± 06.31	59.33 ± 04.97	25.40 ± 02.26	40.00 ± 03.52	91.92 ± 00.08	92.42 ± 00.07
		60%	69.55 ± 04.23	70.62 ± 04.88	60.29 ± 02.50	62.60 ± 03.47	33.07 ± 05.16	50.00 ± 03.94	92.10 ± 00.04	93.56 ± 00.12
	MAGNN	20%	56.66 ± 04.75	58.43 ± 03.14	54.01 ± 05.91	57.11 ± 02.63	24.04 ± 03.53	37.05 ± 04.20	93.30 ± 00.27	93.82 ± 00.32
		60%	69.84 ± 04.59	71.25 ± 05.00	59.74 ± 06.62	62.17 ± 05.16	32.10 ± 06.47	49.41 ± 06.55	94.35 ± 00.06	94.58 ± 00.41
	TensorGCN	20%	59.02 ± 04.38	60.31 ± 02.81	53.07 ± 07.54	56.88 ± 04.68	25.30 ± 02.68	40.29 ± 03.73	92.40 ± 00.24	93.08 ± 00.11
		60%	70.98 ± 04.36	72.50 ± 05.00	60.29 ± 08.42	61.73 ± 08.43	33.99 ± 08.56	50.58 ± 09.18	93.30 ± 00.13	93.99 ± 00.09
Our Methods	RTGNN	20%	64.48 ± 05.97	66.87 ± 05.44	57.13 ± 09.55	59.77 ± 05.74	31.84 ± 06.01	44.41 ± 03.82	94.13 ± 00.07	94.58 ± 00.06
	-mean	60%	72.23 ± 08.59	73.75 ± 08.29	63.86 ± 05.51	64.34 ± 05.43	45.35 ± 09.68	54.11 ± 10.12	95.19 ± 00.41	95.48 ± 00.36
	RTGNN	20%	65.26 ± 07.05	67.18 ± 05.45	58.09 ± 03.15	60.44 ± 02.39	33.48 ± 03.98	45.58 ± 01.97	94.30 ± 00.12	94.76 ± 00.30
	-att	60%	73.07 ± 06.88	74.37 ± 05.89	65.67 ± 05.50	66.08 ± 05.43	46.27 ± 08.05	55.88 ± 05.42	95.21 ± 00.16	95.56 ± 00.05
	RTGNN	20%	65.74 ± 05.75	67.50 ± 06.43	60.70 ± 04.62	61.11 ± 04.44	35.22 ± 07.25	45.88 ± 03.76	94.50 ± 00.13	94.91 ± 00.15
		60%	75.14 ± 08.18	76.25 ± 08.29	66.12 ± 06.00	66.52 ± 06.16	48.25 ± 05.10	57.05 ± 04.59	95.42 ± 00.26	95.62 ± 00.44
	Gain	20%	$6.72 \uparrow$	$7.19 \uparrow$	$4.52 \uparrow$	$1.78 \uparrow$	$9.82 \uparrow$	$5.59 \uparrow$	$1.20 \uparrow$	$1.09 \uparrow$
		60%	$4.16 \uparrow$	$3.75 \uparrow$	$5.83 \uparrow$	$3.92 \uparrow$	$14.26 \uparrow$	$6.47 \uparrow$	$1.07 \uparrow$	$1.04 \uparrow$

聚类任务表现



研究工作5:基于强化汇聚和自监督互信息机制的子图神经网络 (SUGAR)



子图抽样与编码：

- BFS提取子图
- 基于GNN的子图编码器

· Top-k采样：选择有显著模式的子图
 · 强化学习模块优化自适应池化率 k

· 利用子图重建图特征速写
 · 子图间注意力机制
 · 由自监督的互信息模块引导

· 结合分类损失
 和自监督损失综合优化

$$\mathcal{L} = \mathcal{L}_{Classify} + \beta \sum_{G \in \mathcal{G}} \mathcal{L}_{MI} + \lambda \|\Theta\|^2,$$

强化汇聚模块

马尔可夫决策模型

Top-k采样先验知识问题

强化汇聚模块

ϵ -greedy

状态

阶段e由子图的idx值决定

$$s_e = idx_e$$

动作

为k加减一个固定值

$$\Delta k \in [0, 1]$$

奖励

$$reward(s_e, a_e) = \begin{cases} +1, & \text{if } acc_e > acc_{e-1}, \\ 0, & \text{if } acc_e = acc_{e-1}, \\ -1, & \text{if } acc_e < acc_{e-1}. \end{cases}$$

优化

值迭代

$$Q^*(s_e, a_e) = reward(s_e, a_e) + \gamma \arg \max_{a'} Q^*(s_{e+1}, a')$$

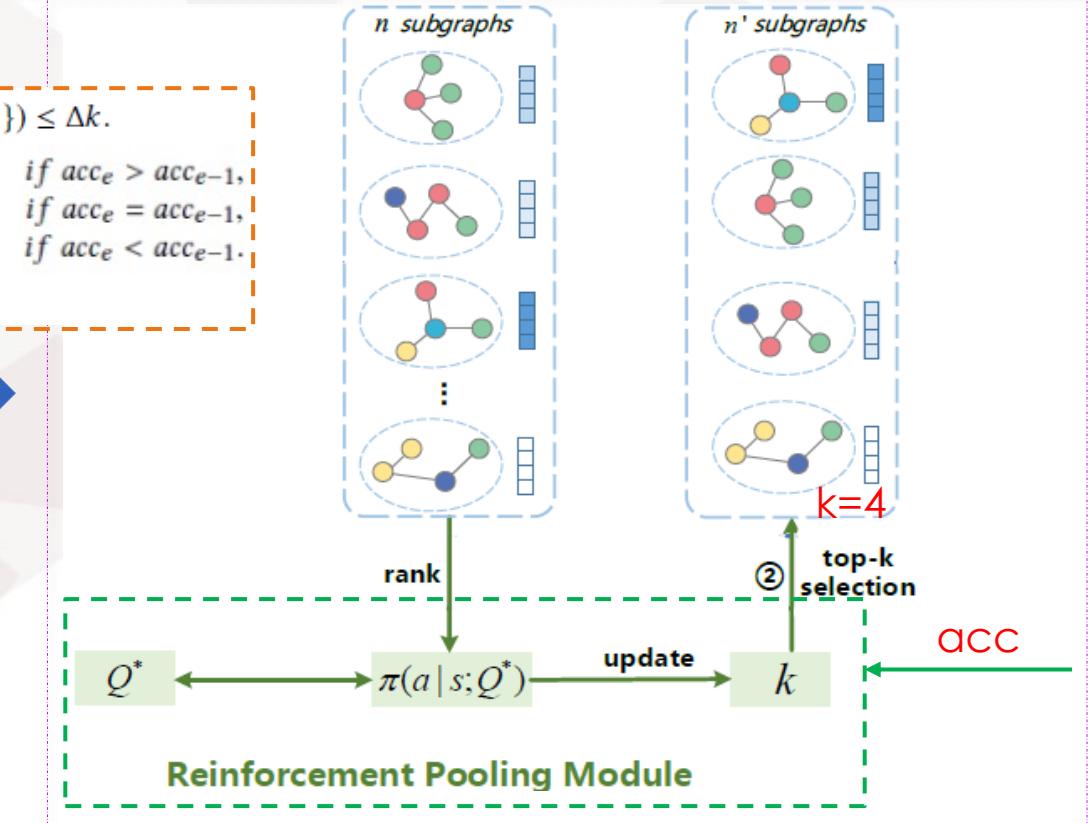
$$\pi(a_e | s_e; Q^*) = \begin{cases} \text{random action,} & \text{w.p. } \epsilon \\ \arg \max_{a_e} Q^*(s_e, a), & \text{otherwise} \end{cases}$$

第e步策略

while $Range(\{k_{e-10}, \dots, k_e\}) \leq \Delta k$.

$$\begin{aligned} reward(s_e, a_e) &\leftarrow \begin{cases} +1, & \text{if } acc_e > acc_{e-1}, \\ 0, & \text{if } acc_e = acc_{e-1}, \\ -1, & \text{if } acc_e < acc_{e-1}. \end{cases} \\ a_e &\leftarrow \pi(a_e | s_e; Q^*) \\ k &\leftarrow a_e \cdot \Delta k; \end{aligned}$$

强化汇聚模块



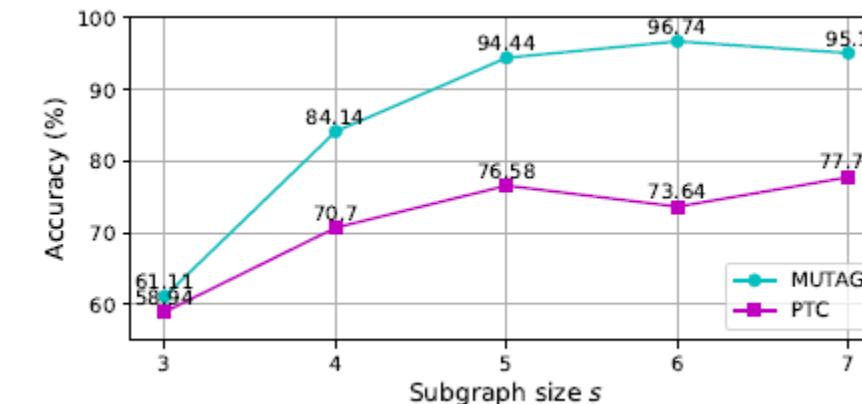
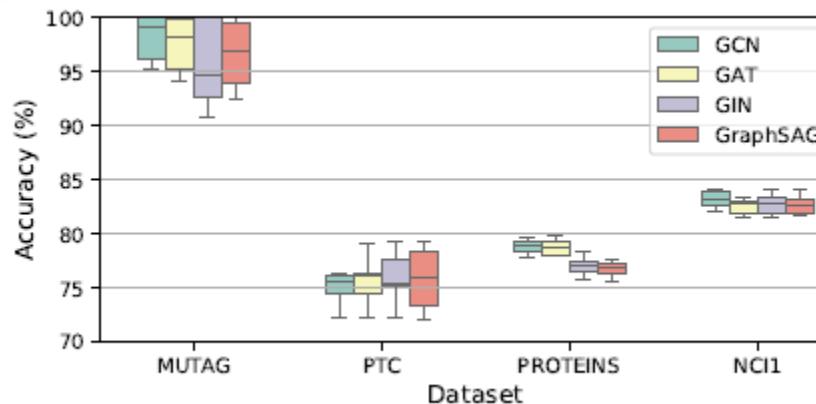
自适应选择参数

Qingyun sun, etc., SUGAR Subgraph Neural Network with Reinforcement Pooling and Self-Supervised Mutual Information Mechanism. WWW 2021;

实验

分类任务表现

Method	Dataset						Avg. Rank
	MUTAG	PTC	PROTEINS	D&D	NCI1	NCI109	
WL [40]	82.05±0.36 (13)	-	-	79.78±0.36 (5)	82.19±0.18 (6)	82.46±0.24 (3)	6.75
GK [41]	83.50±0.60 (12)	59.65±0.31 (9)	-	74.62±0.12 (13)	-	-	11.33
DGK [57]	87.44±2.72 (9)	60.08±2.55 (8)	75.68±0.54 (12)	-	80.31±0.46 (9)	80.32±0.33 (7)	9.00
PATCHY-SAN [32]	92.63±4.21 (3)	62.29±5.68 (7)	75.89±2.76 (11)	77.12±2.41 (10)	78.59±1.89 (10)	-	8.20
ECC [42]	89.44 (6)	-	-	73.65 (14)	83.80 (2)	81.87 (4)	6.50
GIN [55]	89.40±5.60 (7)	64.60±7.00 (5)	76.20±2.80 (10)	-	82.70±1.70 (5)	-	6.75
GCAPS-CNN [50]	-	66.01±5.91 (4)	76.40±4.17 (7)	77.62±4.99 (9)	82.72±2.38 (4)	81.12±1.28 (6)	6.00
CapsGNN [54]	86.67±6.88 (10)	-	76.28±3.63 (8)	75.38±4.17 (12)	78.35±1.55 (11)	-	10.25
AWE [20]	87.87±9.76 (8)	-	-	71.51±4.02 (15)	-	-	11.50
S2S-N2N-PP [45]	89.86±1.10 (5)	64.54±1.10 (6)	76.61±0.50 (4)	-	83.72±0.40 (3)	83.64±0.30 (2)	4.00
NEST [58]	91.85±1.57 (4)	67.42±1.83 (3)	76.54±0.26 (6)	78.11±0.36 (8)	81.59±0.46 (8)	81.72±0.41 (5)	5.67
MA-GCNN [35]	93.89±5.24 (2)	71.76±6.33 (2)	79.35±1.74 (2)	81.48±1.03 (3)	81.77±2.36 (7)	-	3.20
SortPool [63]	85.83±1.66 (11)	58.59±2.47 (10)	75.54±0.94 (13)	79.37±0.94 (6)	74.44±0.47 (13)	-	10.60
DiffPool [61]	-	-	76.25 (9)	80.64 (4)	-	-	6.50
gPool [15]	-	-	77.68 (3)	82.43 (2)	-	-	2.50
EigenPool [29]	-	-	76.60 (5)	78.60 (7)	77.00 (12)	74.90 (8)	8.00
SAGPool [23]	-	-	71.86±0.97 (14)	76.45±0.97 (11)	67.45±1.11 (14)	74.06±0.78 (9)	12.00
SUGAR (Ours)	96.74±4.55(1)	77.53±2.82(1)	81.34±0.93(1)	84.03±1.33(1)	84.39±1.63(1)	84.82±0.81(1)	1.00

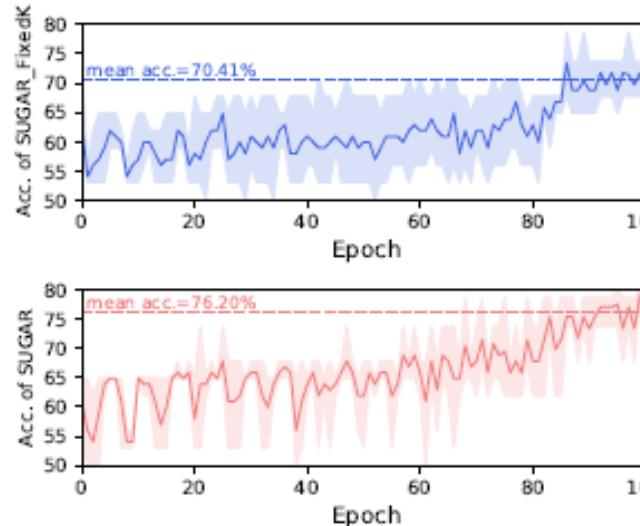


SUGER在不同node-encoder和子图大小下的任务表现

实验

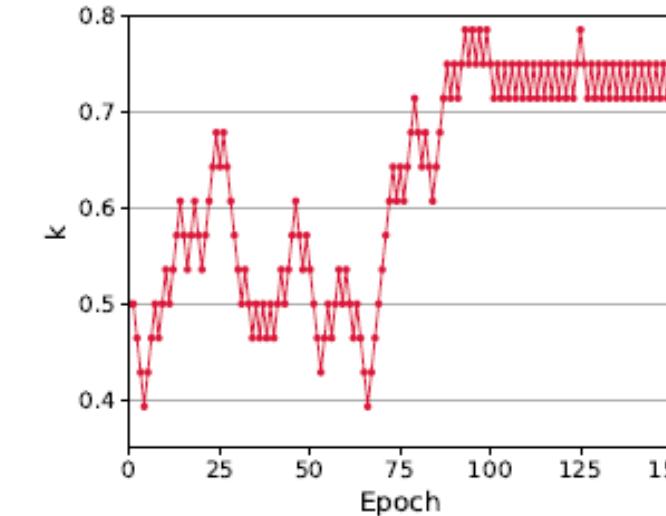
强化学习模块实验

固定k-自适应k模型表现



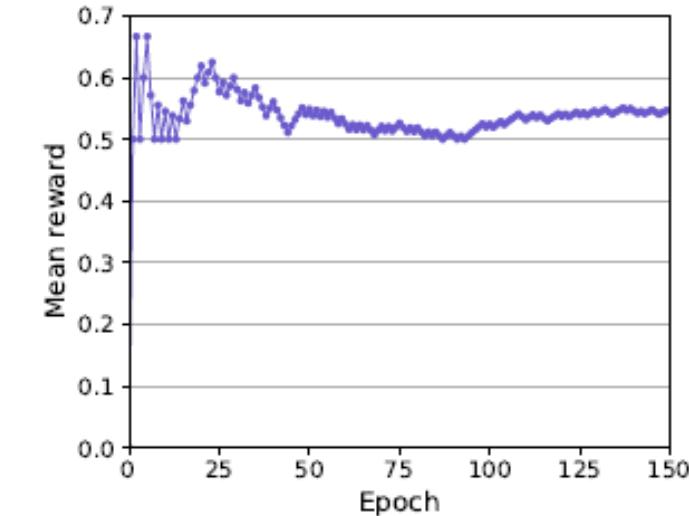
(a) Training process of SUGAR-FixedK and SUGAR on PTC.

K变化曲线



(b) Updating process of k on PTC.

平均奖励变化曲线



(c) Learning curve of RL on PTC.



谢谢各位，敬请批评指正！

THANKS