2024 KDD（CCF-B）

STONE

A **S**patio-**T**emporal **OOD** Learning Framework Kills Both Spatial and Temporal Shifts

24.9.10

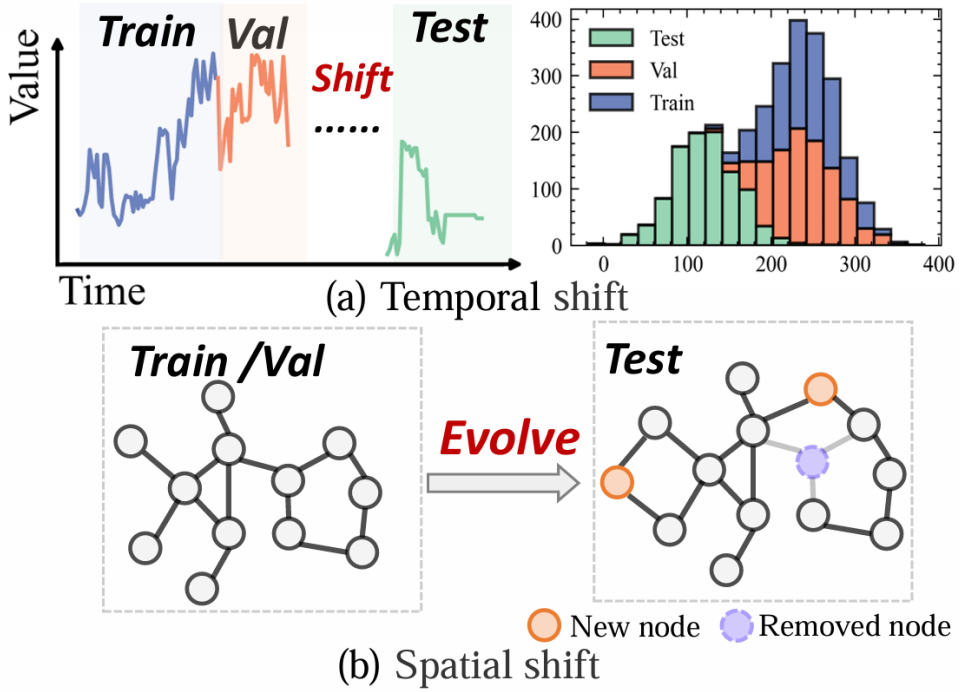
Presented by Yyyq

01 问题描述

- **IID假设：测试和训练数据独立地来自同一环境**
- OOD时空学习方法主要集中在时间偏移上，而**忽略了显著的空间变化**
- **空间偏移：**道路网络扩大，新的节点出现，现有节点消失。

训练环境≠测试环境

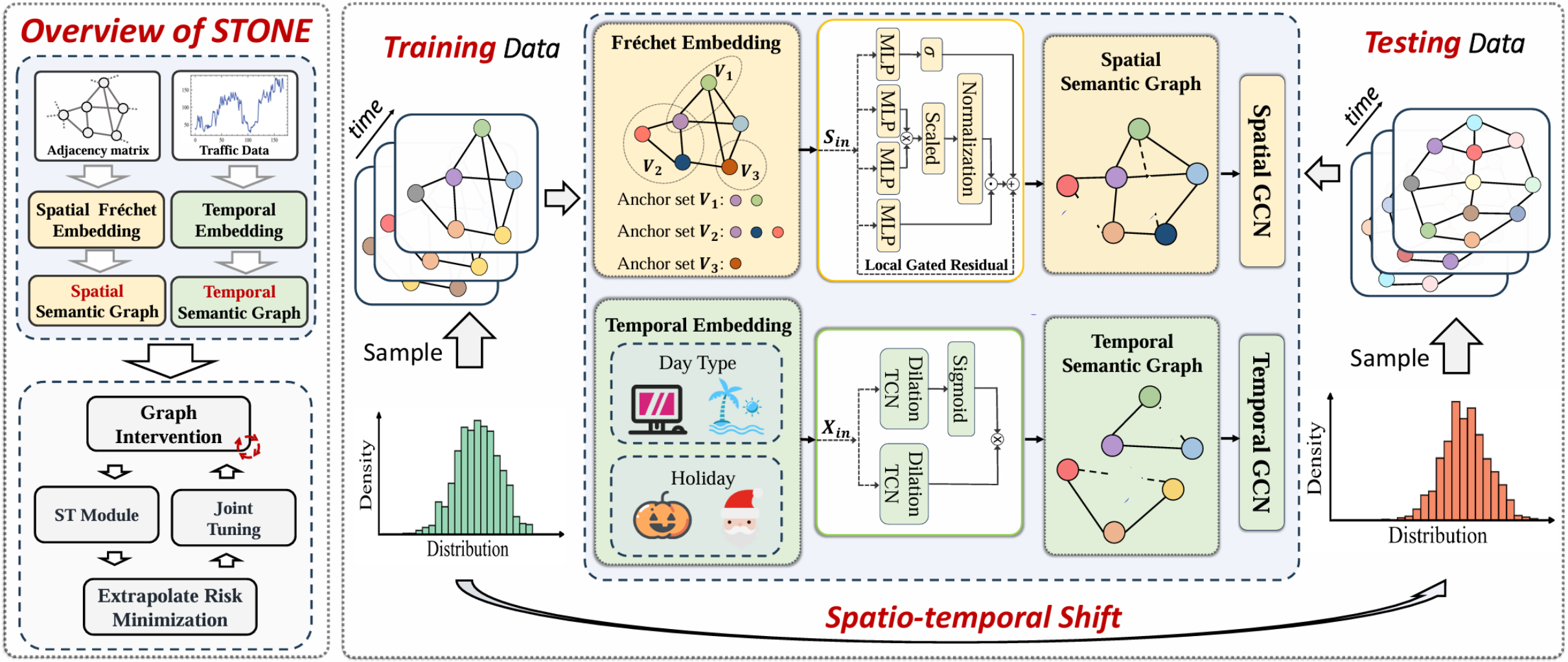
- 训练集 时间数据分布 ≠ 测试集 时间数据分布
- 训练集 空间图 ≠ 测试集 空间图



02 创新点

- **首次全面研究时空OOD学习**：同时考虑了时间转移和结构转移。
- **STONE框架**：
  - **时空语义图学习**，学习节点之间的不变节点依赖关系
  - **图干预机制**，增强生成环境的多样性
- 在OOD场景中实现了具有竞争力的**泛化和可扩展性。**

03 整体结构


Overview of STONE
Adjacency matrix
Traffic Data
Spatial Fréchet Embedding
Temporal Embedding
Spatial Semantic Graph
Temporal Semantic Graph
Graph Intervention
ST Module
Joint Tuning
Extrapolate Risk Minimization
Training Data
time
Sample
Density
Distribution
Fréchet Embedding
V_1
V_2
V_3
Anchor set V_1:
Anchor set V_2:
Anchor set V_3:
S_{in}
MLP
MLP
MLP
MLP
σ
Scaled
Normalization
Local Gated Residual
Spatial Semantic Graph
Spatial GCN
Temporal Embedding
Day Type
Holiday
X_{in}
Dilation TCN
Dilation TCN
Sigmoid
Temporal Semantic Graph
Temporal GCN
Testing Data
time
Sample
Density
Distribution
Spatio-temporal Shift

04 算法设计：时空图学习模块

➢ 空间语义图学习

- **节点嵌入：Fréchet嵌入方法**

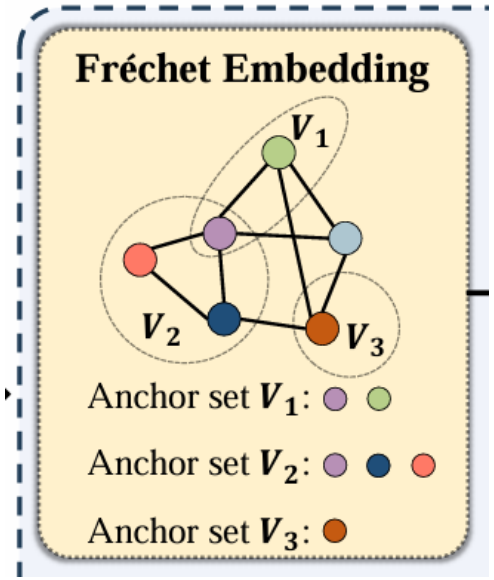
→选择锚点集

→ 计算节点与锚点集之间的距离（相对位置）

→ 距离转换为向量（节点间关系）

灵活响应空间变化

良好的扩展性



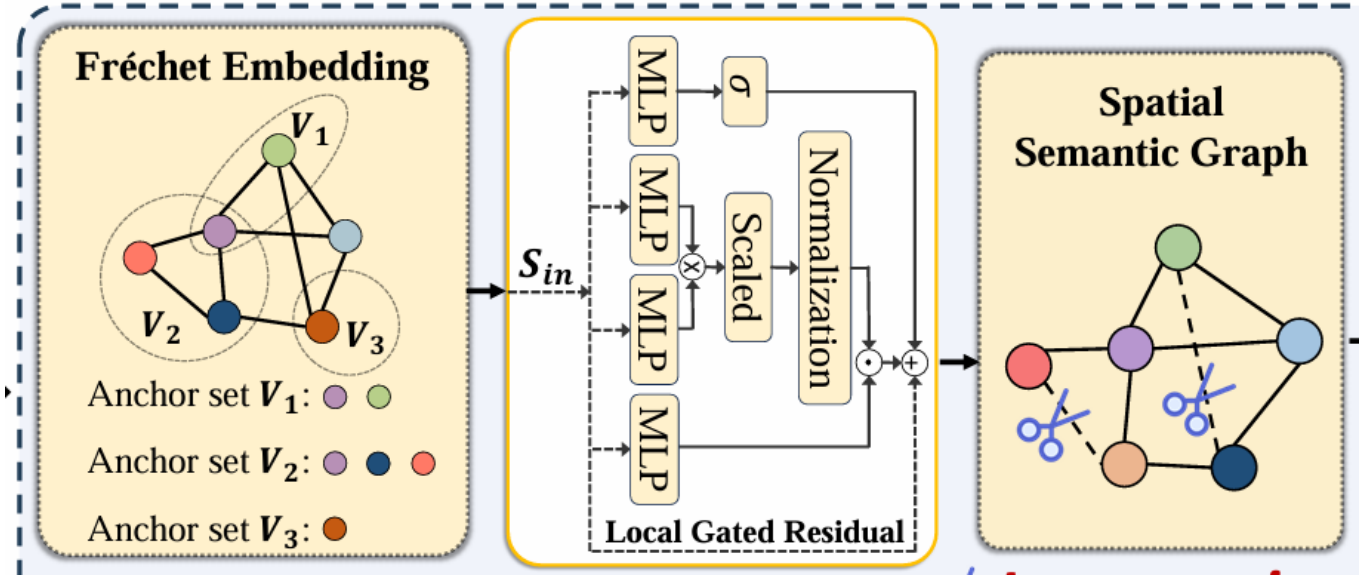
04 算法设计：时空图学习模块

- **空间语义图学习**
  - **节点嵌入：Fréchet嵌入方法**
  - **门控transformer**

→ 两个MLP层将嵌入向量映射到特征空间

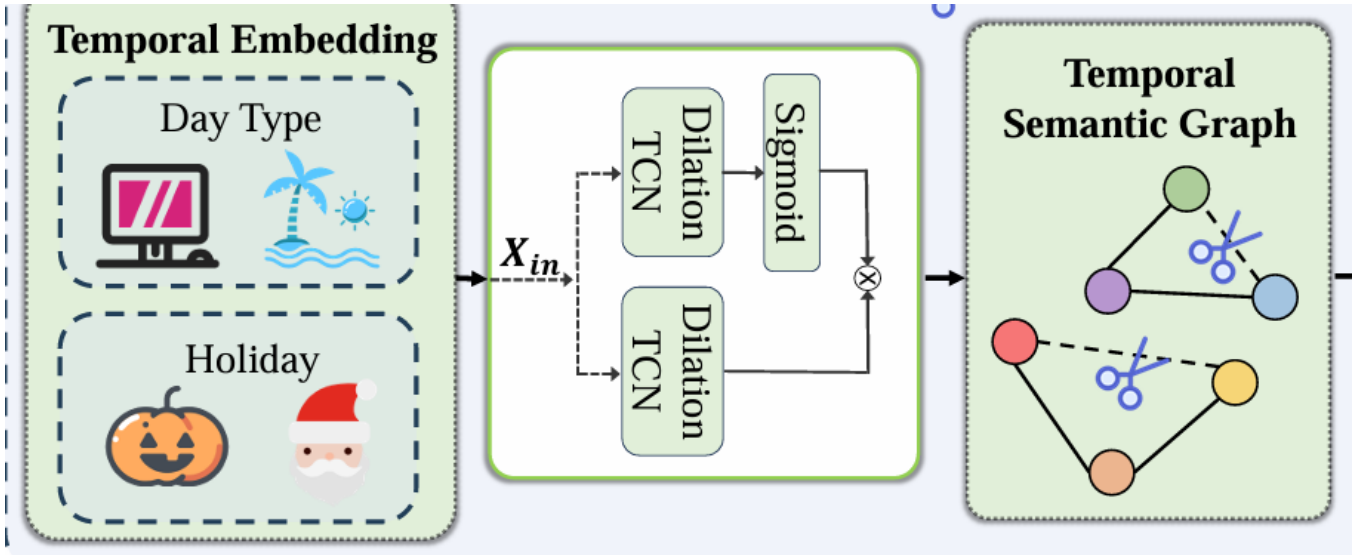
→自注意力机制生成空间语义图

→ 使用门控机制过滤掉冗余信息



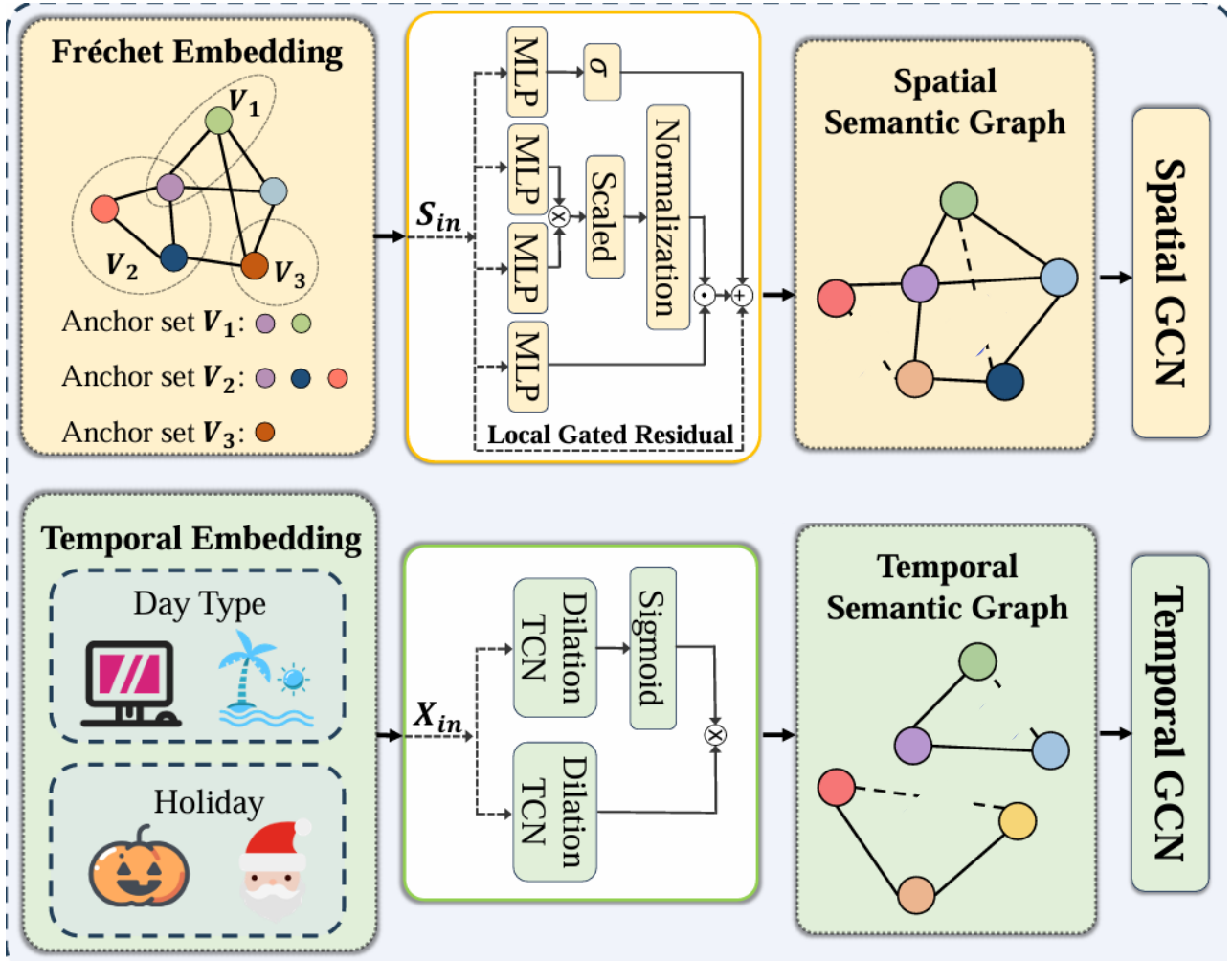
04 算法设计：时空图学习模块

- **时间语义图学习**
  - **时序位置嵌入**：日期类型和假期
  - **TCN**：提取时间趋势
  - **自注意力机制**：计算节点之间的相似性，生成时间语义图



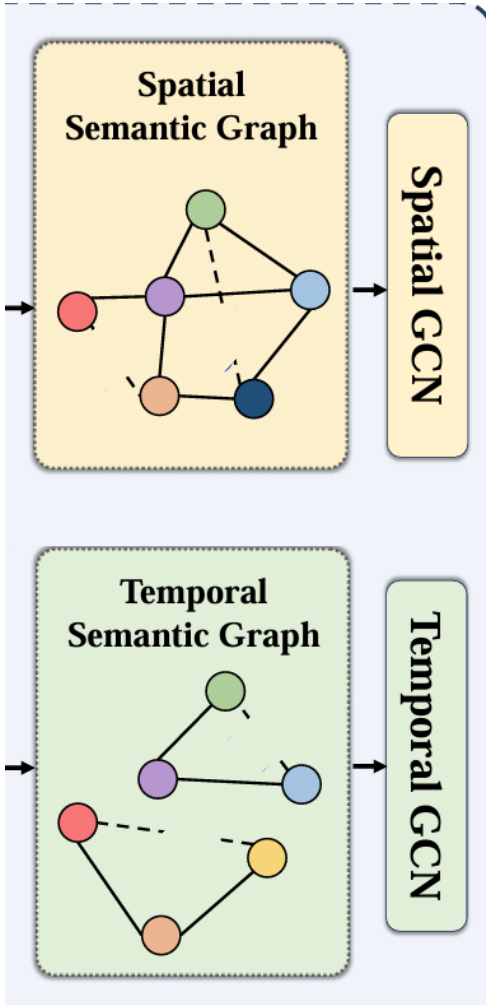
04 算法设计：时空图学习模块

- 空间语义图学习
- 时间语义图学习
- 时空GCN



04 算法设计：时空OOD学习模块

- **噪声干扰**
  - 在嵌入层的输出中加入随机噪声，模拟空间位移
- **时空图干预机制**
  - 干预矩阵：（掩码矩阵）用于决定是否掩码语义图中的对应边
  - 模拟时空变化



04 算法设计：解码器和优化损失

- **解码器**
- **优化损失函数**
  - **不变风险最小化**（Invariant Risk Minimization, IRM）

通过最小化不同环境下的损失方差，

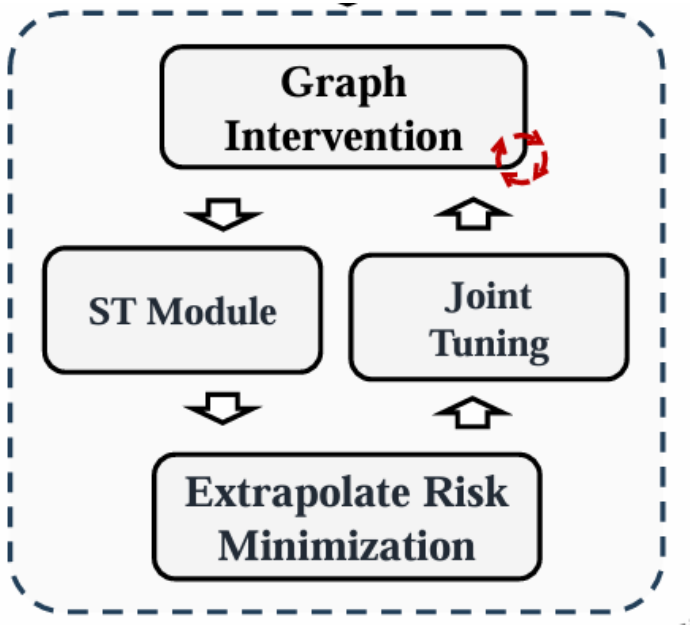
鼓励模型学习到在多种分布下都表现良好的特征。

  - **探索-外推风险**（Explore-to-Extrapolate Risk）

通过增加干预矩阵的方差，

鼓励模型探索和外推超出观察数据的环境，

从而提高模型对未知分布的适应能力。



05 实验：数据集

Data	# of nodes
SD	716
GBA	2,352

Dataset		STSD	STGBA
Training	Time span	1/2019-8/2019	1/2019-8/2019
	Nodes	550	1809
Val	Time span	9/2019-10/2019	9/2019-10/2019
	Removed Nodes	55	180
	New Nodes	55	180
Test	Time span	11/2020-12/2020	11/2020-12/2020
	Removed Nodes	55	180
	New Nodes	55/82/110	180/270/360

屏蔽 10% 的节点

新添 10% 的节点

屏蔽 10% 的节点

新添 10% /15%/20%的节点

05 实验：模型的泛化性能

STSD dataset with ratio of new nodes: (10%/15%/20%)

Model		HL	STGCN [53]	GWNet [47]	STNN [51]	CaST [48]	CauSTG [64]	Ours
3 horizon	MAE	29.66/29.78/29.69	26.62/24.88/23.52	18.86/21.58/**19.12**	39.82/40.23/35.58	24.23/24.05/23.89	26.42/25.31/26.17	**18.16**/**19.36**/19.32
	RMSE	44.55/44.66/44.52	36.49/34.55/34.84	**29.40**/**30.25**/34.27	58.02/58.66/54.59	38.42/38.06/37.75	40.01/40.17/39.89	29.67/31.42/**31.40**
	MAPE	21.43/21.45/21.41	48.51/40.54/30.76	18.90/18.62/18.44	39.53/39.27/20.76	20.73/20.79/30.76	23.04/21.38/22.16	**15.50**/**16.69**/**16.87**
6 horizon	MAE	52.05/52.31/52.19	34.35/33.32/32.05	27.15/27.01/27.62	39.78/40.20/35.82	35.96/35.71/35.49	40.01/41.76/40.93	**26.32**/**26.23**/**26.24**
	RMSE	75.30/75.51/75.34	**40.38**/42.82/45.97	42.89/41.70/41.35	57.77/58.43/54.91	55.47/55.00/54.63	60.34/66.21/66.31	41.76/**40.79**/**40.91**
	MAPE	39.43/39.41/39.36	55.77/49.54/43.31	30.88/30.36/30.12	40.40/40.13/44.21	36.35/36.47/36.39	41.46/41.82/42.17	**22.08**/**26.16**/**26.48**
12 horizon	MAE	94.13/94.61/94.44	45.28/47.07/46.71	**39.31**/39.14/40.32	43.02/43.42/41.51	61.63/61.21/60.86	64.13/66.00/65.34	41.05/**36.17**/**36.19**
	RMSE	128.11/128.59/128.36	64.04/64.67/65.64	58.09/57.63/59.60	62.31/62.89/63.39	90.39/89.74/89.19	89.42/90.16/91.02	**55.26**/**53.79**/**54.10**
	MAPE	82.08/81.94/81.85	56.49/57.87/68.57	45.47/44.89/44.62	43.36/43.10/48.88	60.40/60.72/60.52	65.37/65.31/65.04	**35.55**/**38.57**/**38.94**

STGBA dataset with ratio of new nodes: (10%/15%/20%)

Model		HL	STGCN [53]	GWNet [47]	STNN [51]	CaST [48]	CauSTG [64]	Ours
3 horizon	MAE	27.09/26.94/26.97	19.36/25.19/35.65	19.23/**17.56**/18.53	37.48/37.33/37.55	26.86/26.78/26.82	30.14/30.41/31.13	**17.67**/18.73/**18.83**
	RMSE	40.37/40.16/40.15	29.13/34.78/36.27	30.01/29.34/32.62	54.31/54.18/54.43	37.05/36.95/36.99	41.03/42.86/43.02	**27.84**/**29.98**/**30.13**
	MAPE	18.90/18.86/18.83	15.82/26.85/30.33	13.71/14.77/**12.86**	31.78/31.94/31.96	34.83/35.20/37.94	36.13/37.40/36.93	**12.82**/**12.84**/12.91
6 horizon	MAE	47.04/46.80/46.85	25.68/33.73/35.86	28.10/25.24/26.71	37.07/36.93/37.15	36.89/36.78/36.85	40.35/41.14/41.66	**25.35**/**25.16**/**25.37**
	RMSE	67.46/67.14/67.15	43.77/46.36/48.49	42.78/**37.81**/40.28	53.85/53.71/53.97	51.37/51.23/51.29	55.39/55.49/55.43	**37.80**/38.55/**38.88**
	MAPE	34.53/34.45/34.41	21.38/34.40/39.09	20.88/20.41/19.09	31.55/31.69/31.73	43.37/43.80/43.50	46.15/46.18/46.24	**18.17**/**18.21**/**18.39**
12 horizon	MAE	84.85/84.45/84.50	**34.50**/48.59/50.90	39.91/38.94/39.24	41.16/41.03/41.23	58.87/58.67/58.79	63.15/64.28/64.05	36.35/**36.04**/**36.51**
	RMSE	114.83/114.34/114.36	59.81/66.16/68.18	57.91/56.40/57.33	59.67/59.55/59.77	81.25/80.99/81.12	88.31/89.35/89.02	**53.20**/**52.80**/**53.55**
	MAPE	70.53/70.73/70.25	33.18/46.94/51.19	30.53/32.80/28.83	34.16/34.31/34.36	65.61/66.31/65.79	70.14/70.64/70.64	**28.38**/**28.47**/**28.74**

05 实验：模型的可扩展性

ST-SD dataset with ratio of new nodes: (10%/15%/20%)

Model		HL	STGCN [53]	GWNet [47]	STNN [51]	CaST [48]	CauSTG [64]	Ours
3 Horzion	MAE	29.64/30.57/29.85	36.19/34.46/29.59	19.58/19.58/19.58	42.56/44.52/36.37	23.37/22.24/21.75	42.56/44.52/39.37	**17.22**/**18.92**/**18.51**
	RMSE	43.26/44.51/43.69	48.46/42.91/41.29	30.11/**30.05**/29.76	61.74/65.06/55.62	36.11/34.11/33.27	61.74/65.06/59.62	**26.85**/30.43/**29.83**
	MAPE	21.48/21.56/21.32	48.74/39.05/29.69	19.02/19.35/**18.38**	37.23/36.00/25.38	19.40/20.30/20.19	37.23/36.00/25.38	**14.93**/**18.67**/18.60
6 Horzion	MAE	51.56/53.70/52.63	51.81/45.34/43.07	28.48/28.33/28.55	42.72/44.68/36.63	35.05/33.36/32.69	42.72/44.68/36.63	**24.91**/**26.31**/**25.71**
	RMSE	73.30/75.84/74.71	71.92/62.80/60.62	42.82/41.85/41.59	61.88/65.06/55.95	53.09/50.34/49.28	61.88/65.06/55.95	**38.60**/**40.71**/**40.01**
	MAPE	40.63/39.79/39.39	61.74/53.30/42.74	30.42/31.71/29.10	38.11/36.70/**25.19**	32.96/34.98/34.88	38.11/36.70/25.19	**22.03**/**30.77**/30.43
12 Horzion	MAE	93.11/97.12/95.46	76.75/68.71/66.13	41.98/41.40/42.12	45.01/47.31/42.13	59.80/57.15/56.06	45.01/47.31/42.13	**39.53**/**37.78**/**36.74**
	RMSE	125.86/130.04/128.33	109.81/95.18/92.64	63.23/60.96/61.35	65.25/68.45/64.07	86.98/83.12/81.46	65.21/68.42/64.03	**59.37**/**56.51**/**55.37**
	MAPE	85.42/83.31/82.39	74.37/75.54/60.52	46.56/44.25/43.58	40.51/43.05/42.82	52.78/87.73/57.30	41.33/43.02/44.11	**34.71**/**36.95**/**34.27**

ST-GBA dataset with ratio of new nodes: (10%/15%/20%)

Model		HL	STGCN [53]	GWNet [47]	STNN [51]	CaST [48]	CauSTG [64]	Ours
3 Horzion	MAE	26.67/25.65/26.16	26.14/32.97/35.14	21.64/**18.00**/21.39	36.98/36.41/37.70	25.88/25.60/26.17	30.15/27.21/29.87	**17.64**/18.25/**19.59**
	RMSE	39.20/37.91/38.44	35.91/46.41/46.11	32.79/**28.59**/32.98	52.98/52.94/54.37	35.19/34.98/35.72	40.04/39.15/40.61	**27.03**/29.73/**30.16**
	MAPE	18.26/18.13/18.19	21.99/30.60/35.59	14.62/14.87/16.48	29.24/31.54/31.58	30.26/34.56/33.17	34.13/35.16/36.03	**12.81**/**13.02**/**13.15**
6 Horzion	MAE	46.54/44.86/45.62	37.28/47.88/52.03	33.01/25.89/33.46	36.51/35.94/37.23	35.62/35.19/35.98	38.75/39.01/38.40	**25.73**/**24.87**/**25.46**
	RMSE	65.93/63.96/64.76	50.74/66.20/68.08	48.41/39.40/51.00	52.40/52.32/53.78	49.12/48.78/49.74	55.46/56.14/55.03	**37.55**/**38.82**/**39.54**
	MAPE	33.55/33.29/33.31	32.07/42.58/51.97	22.99/20.55/27.13	29.01/31.27/31.34	37.31/42.68/41.14	40.14/47.43/43.27	**18.61**/**18.69**/**19.08**
12 Horzion	MAE	84.24/81.34/82.46	57.31/74.33/80.60	49.10/39.92/53.09	39.89/39.46/40.86	56.85/55.97/57.40	61.24/64.39/65.15	**38.24**/**36.50**/**37.60**
	RMSE	112.84/109.71/110.98	77.88/101.28/105.41	69.42/58.67/79.15	67.16/57.30/58.88	78.24/77.21/78.94	84.32/86.42/85.22	**56.56**/**54.26**/**55.81**
	MAPE	68.55/70.37/67.85	47.28/63.89/74.58	35.51/32.68/43.06	31.04/33.31/33.67	54.58/63.70/61.18	59.10/68.91/64.32	**29.86**/**29.84**/**30.23**

05 实验：消融实验

Model	Generalization (All nodes)			Scalability (New nodes)		
	MAE	RMSE	MAPE	MAE	RMSE	MAPE
Ours	**18.17**	**29.67**	**15.51**	**17.23**	**26.85**	**14.93**
W/O Emb	21.91	32.24	26.79	21.64	31.84	25.30
W/O IL	19.66	<u>31.29</u>	17.83	20.49	32.23	20.49
W/O Noi	<u>19.36</u>	31.43	<u>16.69</u>	<u>18.92</u>	<u>30.43</u>	<u>18.67</u>

谢谢观看

MANY THANKS !

24.9.10