

Topology-guided Graph Transformer for Recommender Systems

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Motivation

GNNs suffer from sparsity and noise

- Message passing relies only on observed edges, which is hard to capture missing (unobserved) user-item relations.
- The noisy or spurious interactions can propagate misleading signals, thereby distorting the encoding of user/item representations.

Transformers ignore graph topology

- Global all-pair attention can theoretically model hidden dependencies. Yet, CF's ID embeddings (randomly initialized) lack semantic supervision, making attention scores become unreliable.
- Existing positional encodings (PEs) insufficiently capture the bipartite graph structure.

Methods

Our Core Idea: From ID-driven to Topology-driven Attention for Collaborative Filtering

Contrib. #1: Topology-guided Graph Transformer (ToBE)

- Replace ID-based attention with **purely topology-guided self-attention (TGSA)**.
- The attention weights depend only on **topological PEs**.

$$\mathbf{z}_i^{\top} \cdot \left(\mathbf{z}_j^{\top} \cdot \mathbf{e}_j^{\top} \right)$$

Positional Encoding Positional Encoding ID Embedding

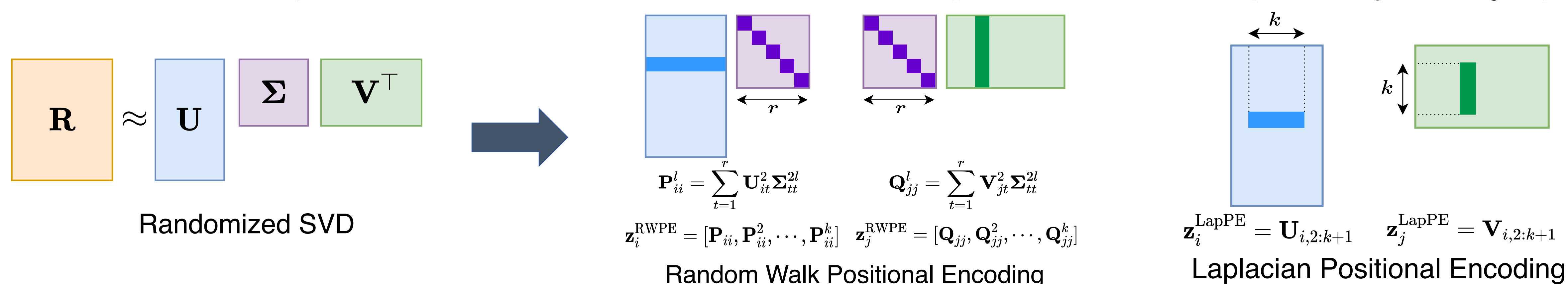
$$\mathbf{e}_{i,A}^{(l)} = \frac{\mathbf{q}_i^{(l)\top} \cdot \frac{1}{J} \sum_{j=1}^J \mathbf{k}_j^{(l)} \mathbf{v}_j^{(l)\top} + \mathbf{q}_i'^{(l)\top} \mathbf{k}_i'^{(l)} \mathbf{v}_i'^{(l)}}{\mathbf{q}_i^{(l)\top} \cdot \frac{1}{J} \sum_{j=1}^J \mathbf{k}_j^{(l)} + \mathbf{q}_i'^{(l)\top} \mathbf{k}_i'^{(l)}}$$

PE $\mathbf{q}_i^{(l)} = \zeta \left(\mathbf{W}_q^{(l)} \mathbf{z}_i \right)$
 $\mathbf{k}_j^{(l)} = \zeta \left(\mathbf{W}_k^{(l)} \mathbf{z}_j \right)$

ID $\mathbf{v}_j^{(l)} = \mathbf{W}_v^{(l)} \mathbf{e}_j^{(l-1)}$

Contrib. #2: Two Bipartite-specific PEs

- Random Walk PE** → captures *local* structural context.
- Laplacian PE** → captures *global* graph geometry.



Results

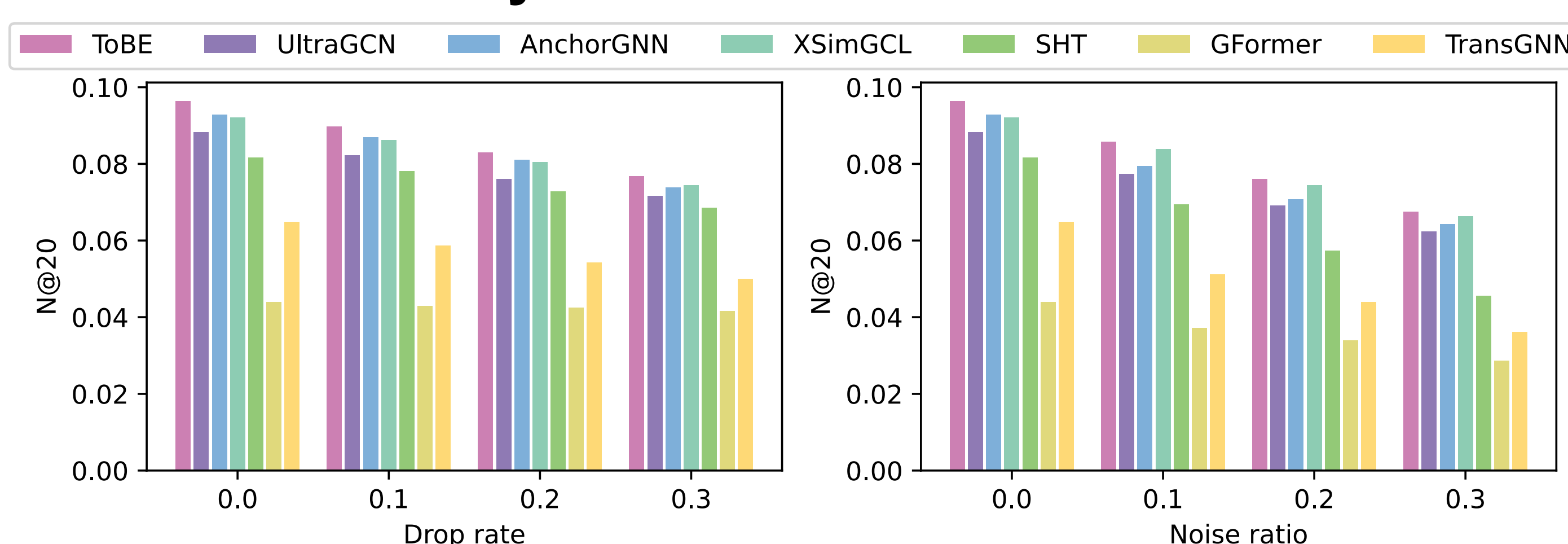
Main Results

Dataset	Metric	NGCF	LightGCN	UltraGCN	GEBEP	AnchorGNN	SGL	DirectAU	XSimGCL	SHT	GFormer	TransGNN	ToBE	Improv.
Yelp	P@20	0.0321	0.0420	0.0471	0.0264	<u>0.0492</u>	0.0389	0.0447	0.0489	0.0437	0.0240	0.0352	0.0508	3.25%
	R@20	0.0734	0.0931	0.1050	0.0578	<u>0.1090</u>	0.0903	0.1002	0.1089	0.0966	0.0529	0.0772	0.1133	3.94%
	N@20	0.0603	0.0777	0.0882	0.0492	<u>0.0928</u>	0.0752	0.0851	0.0921	0.0817	0.0439	0.0649	0.0964	3.88%
Gowalla	P@20	0.0402	0.0578	0.0574	0.0288	<u>0.0589</u>	0.0559	0.0512	0.0573	0.0535	0.0338	0.0437	0.0605	2.72%
	R@20	0.1544	0.2017	0.1955	0.0880	<u>0.2023</u>	0.1906	0.1750	0.2017	0.1847	0.1119	0.1490	0.2074	2.52%
	N@20	0.1154	0.1557	0.1477	0.0740	<u>0.1580</u>	0.1494	0.1357	0.1562	0.1453	0.0913	0.1155	0.1639	3.73%
Amazon-Book	P@20	0.0538	0.0506	0.0532	0.0171	<u>0.0538</u>	0.0464	0.0459	0.0531	0.0382	-	0.0324	0.0543	0.93%
	R@20	0.0487	0.1158	0.1159	0.0349	<u>0.1178</u>	0.1007	0.0998	0.1157	0.0817	-	0.0680	0.1199	1.78%
	N@20	0.0573	0.1046	0.1062	0.0316	<u>0.1066</u>	0.0882	0.0885	0.1028	0.0706	-	0.0594	0.1073	0.66%
Tmall	P@20	0.0259	0.0347	0.0405	0.0175	<u>0.0413</u>	0.0381	0.0412	0.0408	0.0374	-	0.0262	0.0430	4.12%
	R@20	0.0494	0.0650	0.0753	0.0311	<u>0.0769</u>	0.0711	0.0768	0.0758	0.0696	-	0.0480	0.0802	4.29%
	N@20	0.0434	0.0587	0.0699	0.0298	<u>0.0710</u>	0.0647	0.0706	0.0702	0.0630	-	0.0427	0.0744	4.79%
Movielens-1M	P@20	0.2736	0.2812	0.2828	0.1742	<u>0.2876</u>	0.2848	0.1060	0.1841	0.2853	0.2093	0.2766	0.2885	0.31%
	R@20	0.2338	0.2420	0.2479	0.1313	<u>0.2488</u>	0.2485	0.1240	0.1858	0.2388	0.1533	0.2256	0.2628	5.63%
	N@20	0.3542	0.3709	0.3790	0.2298	<u>0.3787</u>	0.3772	0.1429	0.2488	0.3645	0.2592	0.3557	0.3838	1.27%
Alibaba-iFashion	P@20	0.0121	<u>0.0139</u>	0.0088	0.0079	0.0132	0.0134	0.0135	0.0137	0.0116	0.0133	0.0079	0.0148	6.47%
	R@20	0.0896	<u>0.0960</u>	0.0583	0.0507	0.0873	0.0886	0.0898	0.0906	0.0761	0.0879	0.0519	0.0980	2.08%
	N@20	0.0494	<u>0.0564</u>	0.0336	0.0306	0.0515	0.0523	0.0542	0.0537	0.0443	0.0518	0.0291	0.0580	2.84%

Ablation Study

Dataset	Yelp			Gowalla		
Metric	P@20	R@20	N@20	P@20	R@20	N@20
ToBE	0.0508	0.1133	0.0964	0.0605	0.2074	0.1639
w/o LapPE	0.0499	0.1112	0.0946	0.0597	0.2050	0.1617
w/o RWPE	0.0489	0.1092	0.0926	0.0590	0.2032	0.1596
No PE	0.0135	0.0288	0.0236	0.0108	0.0349	0.0257
PE + ID emb.	0.0262	0.0579	0.0475	0.0279	0.0934	0.0711
No TGSA	0.0481	0.1071	0.0914	0.0577	0.1999	0.1574
No LGC	0.0464	0.1039	0.0875	0.0575	0.1979	0.1553
No self-loop	0.0502	0.1119	0.0958	0.0599	0.2063	0.1629

Robustness Analysis



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