Neural Node Matching for Multi-Target Cross Domain Recommendation

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https://github.com/WujiangXu/NMCDR

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Introduction

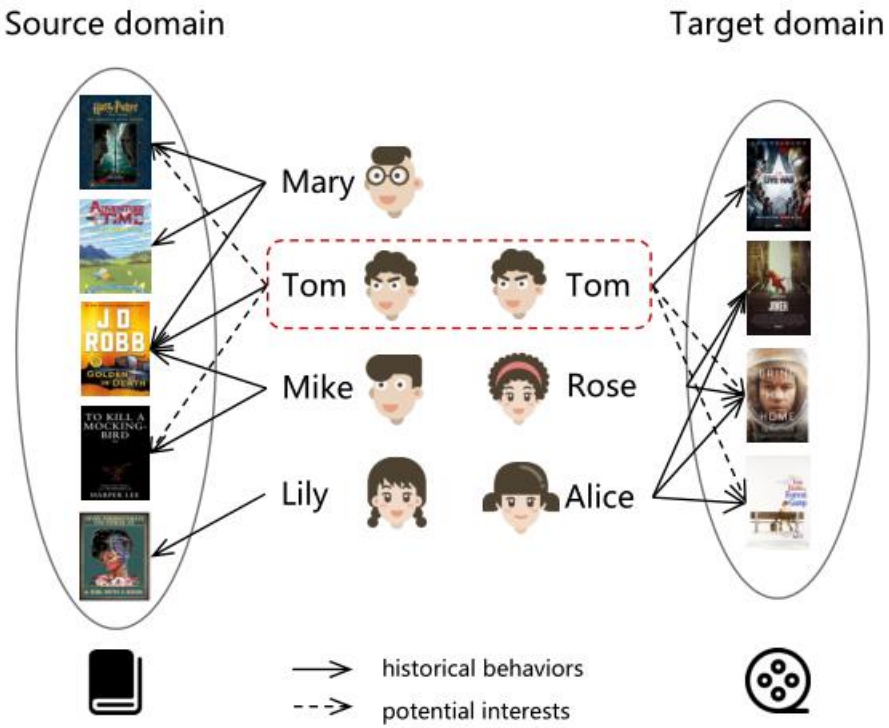
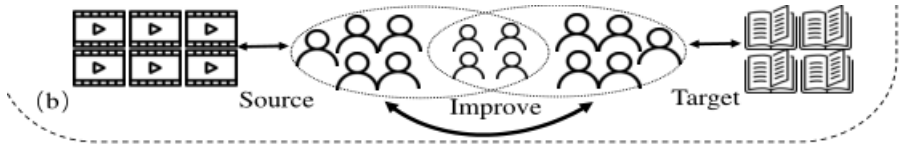


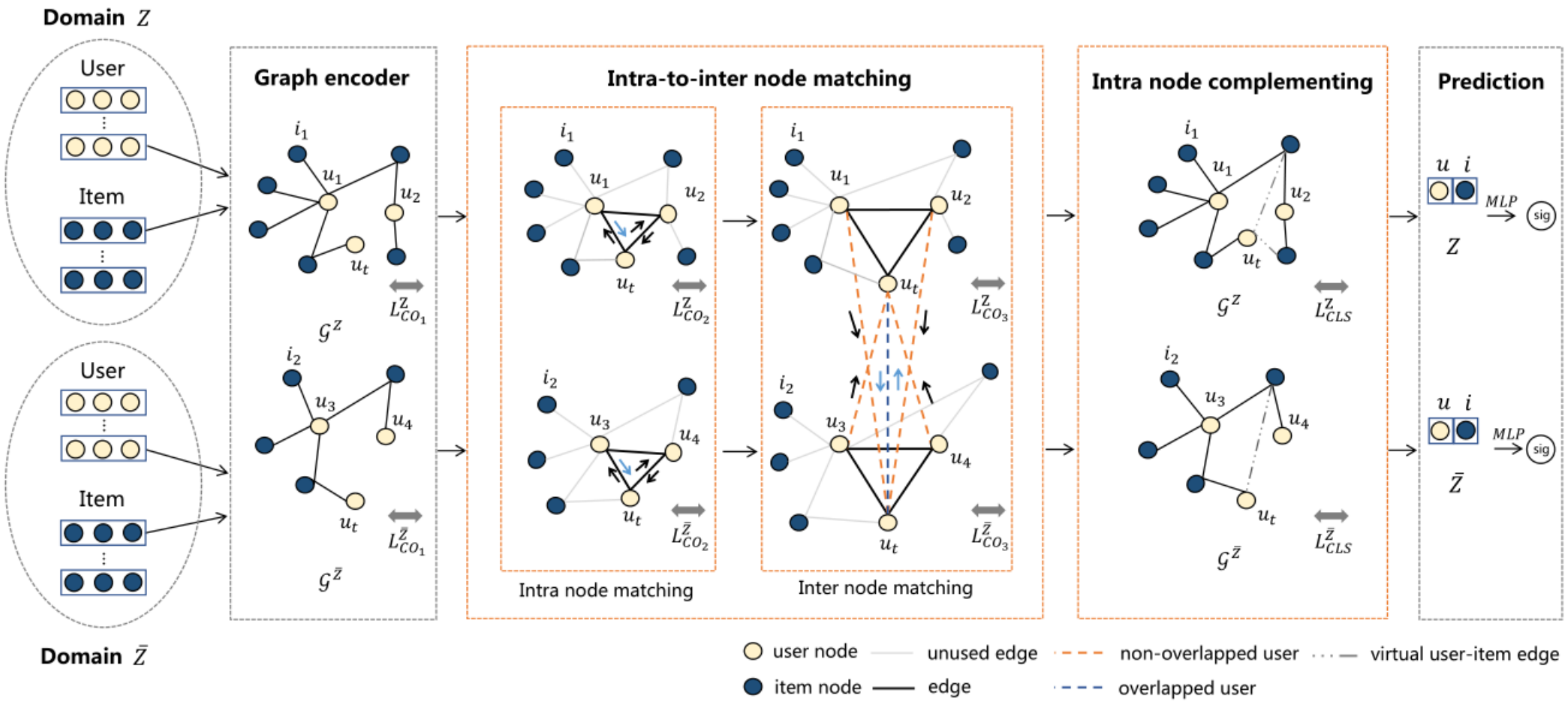
Fig. 1: The partially overlapped CDR scenarios.

it is challenging to guarantee the multi-target cross-domain recommendation performance with only quite a few over-lapping users

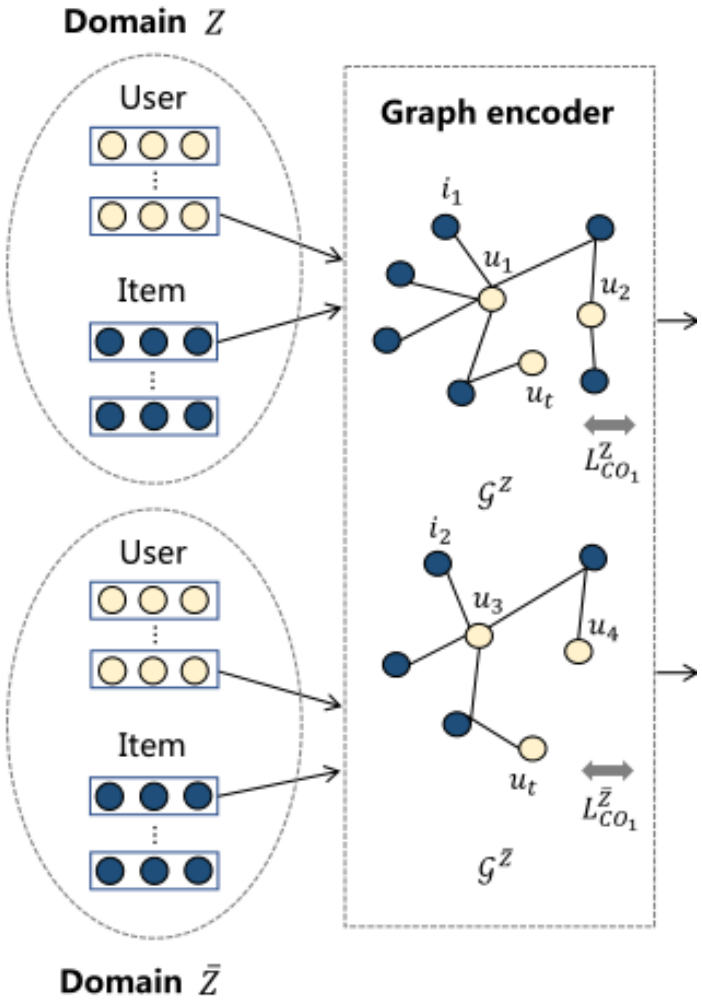


users may be under-represented based on their observed sparse interactions

Approach


Domain Z
User
Item
Graph encoder
Intra-to-inter node matching
Intra node matching
Inter node matching
Intra node complementing
Prediction
MLP
sig
Domain $\bar{Z}$
user node
item node
unused edge
edge
non-overlapped user
overlapped user
virtual user-item edge

Approach



$$\boldsymbol{E}^{Z} = \left[\boldsymbol{u}_1^{Z}, \cdots, \boldsymbol{u}_N^{Z}, \boldsymbol{v}_1^{Z}, \cdots, \boldsymbol{v}_M^{Z}\right]. \tag{1}$$

$$\boldsymbol{m}_{u_i^Z \leftarrow v_j^Z} = f_{u_i}(\boldsymbol{v}_j^{Z}, e_{u_i v_j}^{Z}), \tag{2}$$

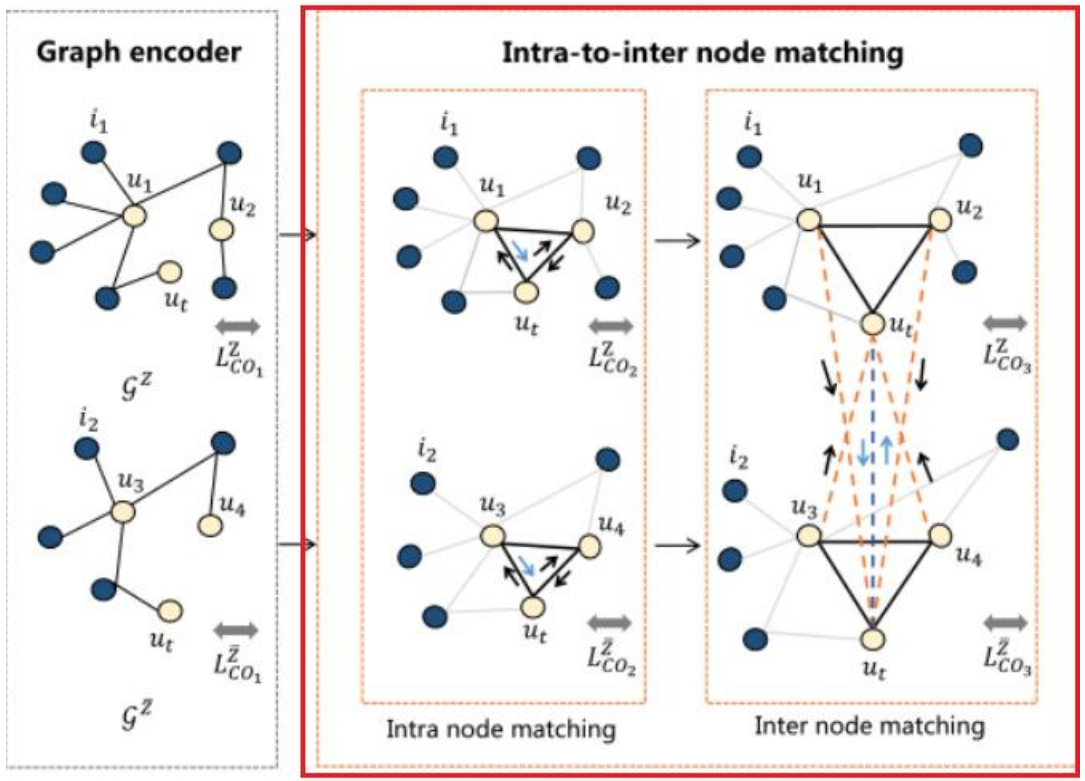
$$\boldsymbol{m}_{u_i^Z \leftarrow v_j^Z} = \frac{1}{|\mathcal{N}_{u_i^Z}|}(\boldsymbol{v}_j^{Z}\boldsymbol{W}_{hge}^{Z} + \boldsymbol{b}_{hge}^{Z})e_{u_i v_j}^{Z}, \tag{3}$$

$\mathcal{N}_{u_i^Z}$ denotes the first-hop neighbors of user u_i^Z.

$$\boldsymbol{u}_{g1_i}^{Z} = \mathrm{ReLU}(\tilde{\boldsymbol{m}}_{u_i^Z} + \sum_{v_j \in \mathcal{N}_{u_i^Z}} \boldsymbol{m}_{u_i^Z \leftarrow v_j^Z}), \tag{4}$$

$$\tilde{\boldsymbol{m}}_{u_i^Z} = \boldsymbol{u}_i^{Z}\boldsymbol{W}_{hge}^{Z}$$

Approach



$$u_i^Z = \begin{cases} \textit{head user}, & |\mathcal{N}_{u_i^Z}| \le \mathcal{K}_{head} \\ \textit{tail user}, & |\mathcal{N}_{u_i^Z}| > \mathcal{K}_{head} \end{cases} \tag{5}$$

$$\boldsymbol{m}_{u_i^Z \leftarrow u_k^Z}^{head} = f_{head}(\boldsymbol{u}_{g1_i}^Z, \boldsymbol{u}_{g1_k}^Z) \tag{6}$$

$$\boldsymbol{m}_{u_i^Z \leftarrow u_l^Z}^{tail} = f_{tail}(\boldsymbol{u}_{g1_i}^Z, \boldsymbol{u}_{g1_l}^Z) \tag{7}$$

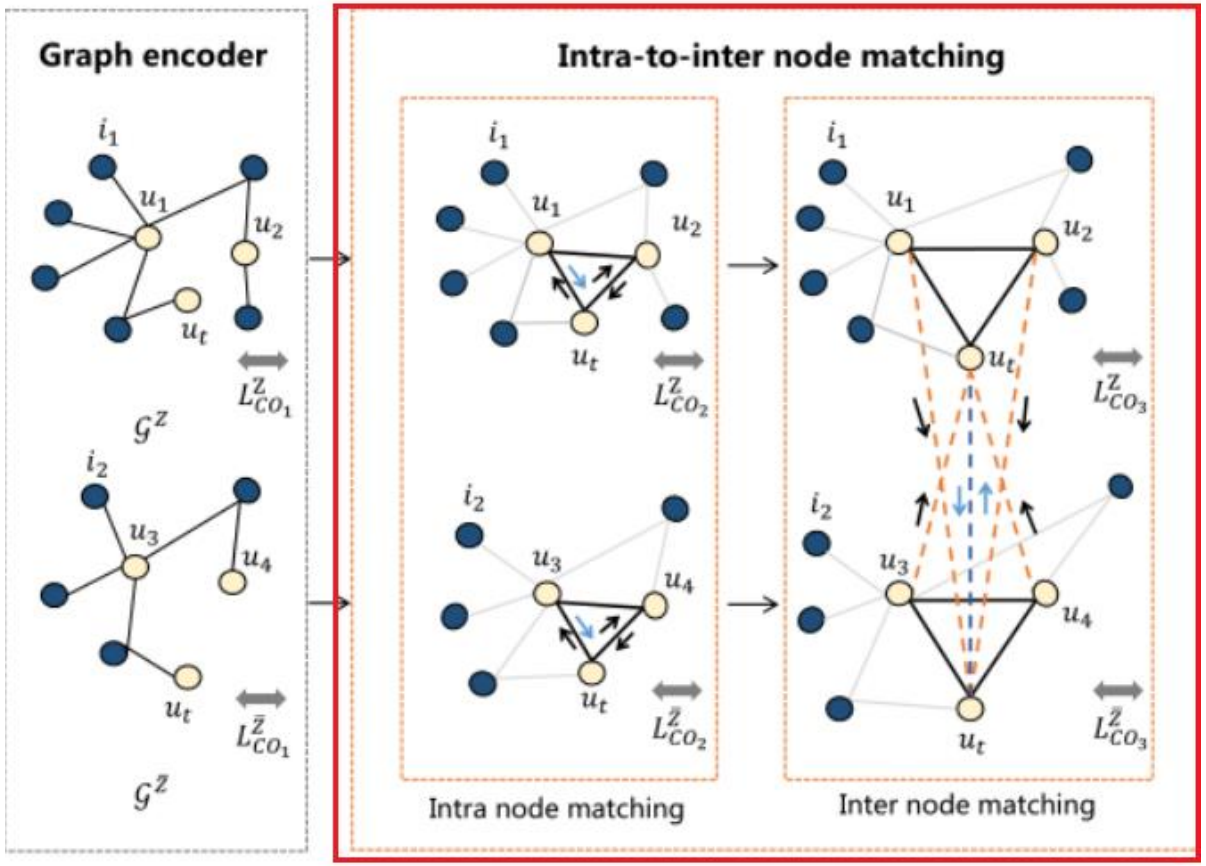
$$\begin{aligned} \boldsymbol{m}_{u_i^Z \leftarrow u_k^Z}^{head} &= \tfrac{1}{|\mathcal{N}_{u_i^Z}^{head}|}(\boldsymbol{u}_{g1_k}^Z \boldsymbol{W}_{head}^Z + \boldsymbol{b}_{head}^Z), \\ \boldsymbol{m}_{u_i^Z \leftarrow u_l^Z}^{tail} &= \tfrac{1}{|\mathcal{N}_{u_i^Z}^{tail}|}(\boldsymbol{u}_{g1_l}^Z \boldsymbol{W}_{tail}^Z + \boldsymbol{b}_{tail}^Z). \end{aligned} \tag{8}$$

$$\begin{aligned} \boldsymbol{u}_{head_i}^Z &= \mathrm{ReLU}\Big(\sum_{u_k \in \mathcal{N}_{u_i^Z}^{head}} \boldsymbol{m}_{u_i^Z \leftarrow u_k^Z}^{head}\Big), \\ \boldsymbol{u}_{tail_i}^Z &= \mathrm{ReLU}\Big(\sum_{u_l \in \mathcal{N}_{u_i^Z}^{tail}} \boldsymbol{m}_{u_i^Z \leftarrow u_l^Z}^{tail}\Big). \end{aligned} \tag{9}$$

$$\begin{aligned} \boldsymbol{H}_{igm}^Z &= \sigma(\boldsymbol{u}_{head_i}^Z \boldsymbol{W}_h^Z + \boldsymbol{b}_h^Z + \boldsymbol{u}_{tail_i}^Z \boldsymbol{W}_t^Z + \boldsymbol{b}_t^Z), \\ \boldsymbol{u}_{g2_i'}^Z &= \tanh\left((1 - \boldsymbol{H}_{igm}^Z) \odot \boldsymbol{u}_{head_i}^Z + \boldsymbol{H}_{igm}^Z \odot \boldsymbol{u}_{tail_i}^Z\right). \end{aligned} \tag{10}$$

$$\boldsymbol{u}_{g2_i}^Z = \boldsymbol{u}_{g2_i'}^Z + \boldsymbol{u}_{g1_i}^Z. \tag{11}$$

Approach



$$\boldsymbol{m}^{self}_{u_i^Z \leftarrow u_i^{\bar{Z}}} = f_{self}(\boldsymbol{u}^Z_{g2_i}, \boldsymbol{u}^{\bar{Z}}_{g2_i}),$$
$$\boldsymbol{m}^{other}_{u_i^Z \leftarrow u_r^{\bar{Z}}} = f_{other}(\boldsymbol{u}^Z_{g2_i}, \boldsymbol{u}^{\bar{Z}}_{g2_k}), \tag{12}$$

$$\boldsymbol{m}^{self}_{u_i^Z \leftarrow u_i^{\bar{Z}}} = \boldsymbol{u}^{\bar{Z}}_{g2_i}\boldsymbol{W}^Z_{self} + \boldsymbol{b}^Z_{self},$$
$$\boldsymbol{m}^{other}_{u_i^Z \leftarrow u_r^{\bar{Z}}} = \frac{1}{|\mathcal{N}^{cdr}_{u_i^Z}|}(\boldsymbol{u}^{\bar{Z}}_{g2_k}\boldsymbol{W}^Z_{other} + \boldsymbol{b}^Z_{other}), \tag{13}$$

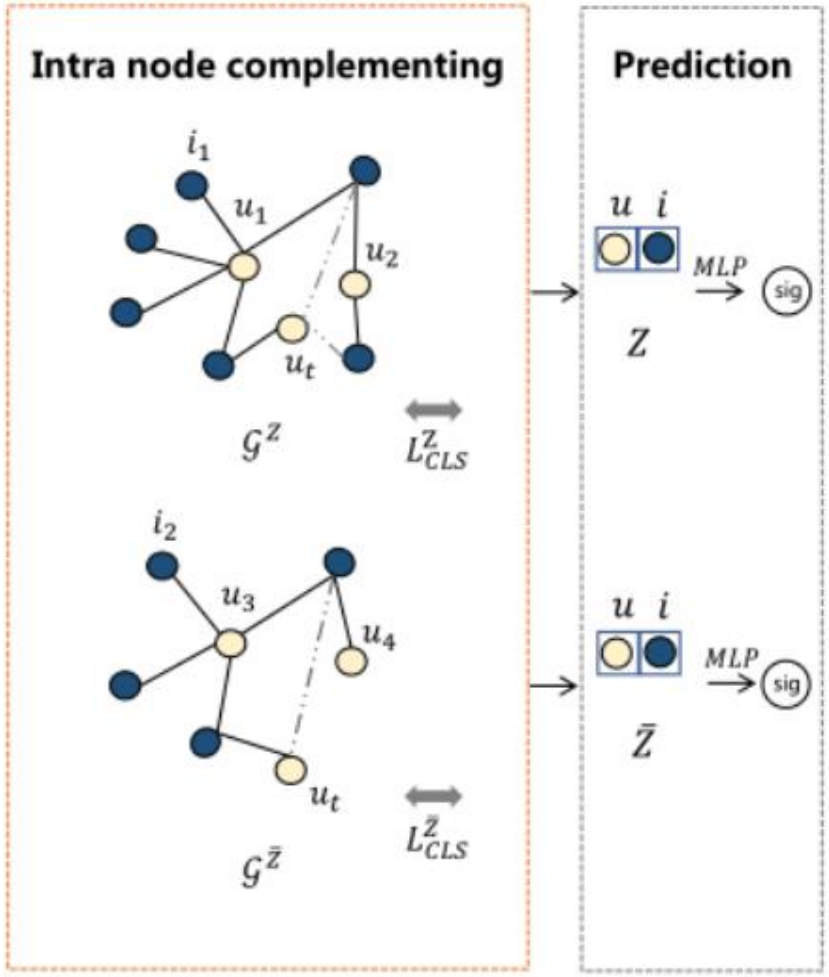
$$\boldsymbol{u}^Z_{self_i} = \mathrm{ReLU}(\boldsymbol{m}^{self}_{u_i^Z \leftarrow u_i^{\bar{Z}}}),$$
$$\boldsymbol{u}^Z_{other_i} = \mathrm{ReLU}\Big(\sum \boldsymbol{m}^{other}_{u_i^Z \leftarrow u_r^{\bar{Z}}}\Big). \tag{14}$$

$$\boldsymbol{u}^Z_{g3^*_i} = \boldsymbol{u}^Z_{g2_i}\boldsymbol{W}^Z_{cross} + \boldsymbol{u}^Z_{self_i}(1 - \boldsymbol{W}^{\bar{Z}}_{cross}),$$
$$\boldsymbol{u}^{\bar{Z}}_{g3^*_i} = \boldsymbol{u}^{\bar{Z}}_{g2_i}\boldsymbol{W}^{\bar{Z}}_{cross} + \boldsymbol{u}^{\bar{Z}}_{self_i}(1 - \boldsymbol{W}^Z_{cross}), \tag{15}$$

$$\boldsymbol{H}^Z_{cdr} = \sigma(\boldsymbol{u}^Z_{g3^*_i}\boldsymbol{W}^Z_s + \boldsymbol{b}^Z_s + \boldsymbol{u}^Z_{other_i}\boldsymbol{W}^Z_o + \boldsymbol{b}^Z_o),$$
$$\boldsymbol{u}^Z_{g3'_i} = \tanh\left((1 - \boldsymbol{H}^Z_{cdr}) \odot \boldsymbol{u}^Z_{g3^*_i} + \boldsymbol{H}^Z_{cdr} \odot \boldsymbol{u}^Z_{other_i}\right), \tag{16}$$

$$\boldsymbol{u}^Z_{g3_i} = \boldsymbol{u}^Z_{g3'_i} + \boldsymbol{u}^Z_{g2_i}. \tag{17}$$

Approach



$$\alpha_{u_i^Z v_j^Z} = \frac{\exp(\boldsymbol{u}^Z_{g3_i} \boldsymbol{v}_j^{Z^T})}{\sum_{v_j \in \mathcal{N}_{u_i^Z}} \exp(\boldsymbol{u}^Z_{g3_i} \boldsymbol{v}_j^{Z^T})}. \tag{18}$$

$$\boldsymbol{u}^Z_{g4_i} = \boldsymbol{u}^Z_{g3_i} + \sum_{v_j \in \mathcal{N}_{u_i^Z}} \alpha_{u_i^Z v_j^Z} \boldsymbol{v}_j^Z \boldsymbol{W}^Z_{ref} + \boldsymbol{b}^Z_{ref}, \tag{19}$$

$$\hat{y}^Z_{u_i,v_j} = \sigma(\text{MLPs}(\boldsymbol{u}^Z_{g4_i} || \boldsymbol{v}_j^Z)) \tag{20}$$

$$\ell(\hat{y}, y) = -[y \log \hat{y} + (1-y) \log(1-\hat{y})]. \tag{21}$$

$$\mathcal{L}^Z_{CO} = \sum_{u_i \in \mathcal{U}^Z, v_j \in \mathcal{V}^Z} \Big[w_1 \ell(\hat{y}^Z_{g0_{u_i v_j}}, y^Z_{u_i v_j}) + w_2 \ell(\hat{y}^Z_{g1_{u_i v_j}}, y^Z_{u_i v_j}) + w_3 \ell(\hat{y}^Z_{g2_{u_i v_j}}, y^Z_{u_i v_j}) + w_4 \ell(\hat{y}^Z_{g3_{u_i v_j}}, y^Z_{u_i v_j}) \Big], \tag{22}$$

$$\mathcal{L}^Z_{cls} = \sum_{\substack{u_i \in \mathcal{U}^Z, \\ v_j \in \mathcal{V}^Z}} \ell(\hat{y}^Z_{u_i v_j}, y^Z_{u_i v_j}). \tag{23}$$

$$\mathcal{L}_{total} = w_5 \mathcal{L}^Z_{CO} + w_6 \mathcal{L}^{\bar{Z}}_{CO} + w_7 \mathcal{L}^Z_{cls} + w_8 \mathcal{L}^{\bar{Z}}_{cls}. \tag{24}$$

Experiment

TABLE I: Statistics on the Amazon and MYbank datasets.

Dataset		Users	Items	Ratings	#Overlapping	Density
Amazon	Music	50,841	43,858	713,740	15,081	0.03%
	Movie	87,875	38,643	1,184,889		0.03%
Amazon	Cloth	27,519	9,481	161,010	16,337	0.06%
	Sport	107,984	40,460	851,553		0.02%
Amazon	Phone	41,829	17,943	194,121	7,857	0.03%
	Elec	27,328	12,655	170,426		0.05%
MYbank	Loan	147,837	1,488	304,409	6,530	0.14%
	Fund	65,257	1,319	86,281		0.10%

#Overlapping denotes the number of overlapping users across domains.

Experiment

TABLE II: Experimental results (%) on the bi-directional Music-Movie CDR scenario with different user overlapped ratio.

Methods	Music-domain recommendation										Movie-domain recommendation									
	$\mathcal{K}_u$=0.1%		$\mathcal{K}_u$=1%		$\mathcal{K}_u$=10%		$\mathcal{K}_u$=50%		$\mathcal{K}_u$=90%		$\mathcal{K}_u$=0.1%		$\mathcal{K}_u$=1%		$\mathcal{K}_u$=10%		$\mathcal{K}_u$=50%		$\mathcal{K}_u$=90%	
	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR
LR [29]	5.25	9.31	5.78	10.03	5.92	11.40	7.36	14.41	9.74	18.58	31.36	47.08	31.41	47.01	31.61	47.62	31.66	47.76	31.64	47.66
BPR [26]	2.97	6.63	2.92	6.77	2.67	5.76	2.79	6.15	2.92	6.26	21.63	35.59	21.65	35.61	21.79	35.78	22.00	36.09	21.97	36.14
NeuMF [25]	4.86	9.17	5.01	9.78	5.07	9.87	5.58	11.18	6.00	11.93	28.79	43.27	28.96	42.84	29.02	43.58	29.32	44.16	29.21	43.91
MMoE [30]	6.60	12.83	6.85	14.25	6.95	14.69	9.02	18.30	10.44	20.70	30.20	48.54	31.15	47.12	31.31	47.77	31.32	47.84	31.80	48.07
PLE [31]	6.66	13.12	6.89	14.26	7.25	14.60	9.00	17.64	10.08	19.78	31.72	47.47	31.83	47.46	31.96	47.89	32.04	47.89	32.02	48.03
CoNet [4]	7.03	14.10	7.26	14.40	7.48	15.24	9.61	19.47	10.19	20.75	31.06	47.07	31.26	47.24	31.30	47.42	31.40	47.55	31.37	47.51
MiNet [6]	5.19	11.42	5.67	11.85	6.24	12.43	8.84	17.16	9.37	17.69	29.95	44.78	30.22	45.25	29.85	45.01	29.58	44.84	29.67	45.13
GA-DTCDR [5]	7.03	14.03	7.17	14.53	7.26	14.60	9.54	19.17	10.16	19.97	31.56	47.36	31.61	47.41	31.70	47.63	31.90	47.77	31.85	47.81
DML [10]	6.81	13.08	7.32	13.54	7.99	15.58	9.58	18.66	10.55	20.33	26.36	40.84	27.06	41.47	27.44	41.63	27.36	41.76	27.42	41.86
HeroGraph [11]	6.59	13.40	7.44	13.89	7.02	14.49	9.15	18.55	10.34	20.33	32.05	48.14	32.22	48.38	32.16	48.40	32.23	48.52	32.18	48.43
PTUPCDR [12]	7.60	14.95	7.75	15.23	8.28	16.58	9.89	20.08	10.97	21.31	31.80	47.31	31.92	47.65	31.92	47.84	31.90	47.94	31.93	47.96
NMCDR	**8.29**	**16.28**	**8.43**	**16.52**	**8.50**	**17.00**	**11.26**	**21.58**	**12.28**	**23.19**	**33.39**	**50.22**	**33.57**	**50.67**	**33.70**	**50.91**	**33.96**	**51.13**	**33.94**	**51.12**
Improvement(%)	9.08	8.90	8.77	8.47	2.66	2.53	13.85	7.47	11.94	8.82	4.18	4.32	4.19	4.73	4.79	5.19	5.37	5.38	5.47	5.55

Experiment

TABLE III: Experimental results (%) on the bi-directional Cloth-Sport CDR scenario with different user overlapped ratio.

Methods	Cloth-domain recommendation										Sport-domain recommendation									
	$\mathcal{K}_u$=0.1%		$\mathcal{K}_u$=1%		$\mathcal{K}_u$=10%		$\mathcal{K}_u$=50%		$\mathcal{K}_u$=90%		$\mathcal{K}_u$=0.1%		$\mathcal{K}_u$=1%		$\mathcal{K}_u$=10%		$\mathcal{K}_u$=50%		$\mathcal{K}_u$=90%	
	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR
LR [29]	5.02	11.03	5.64	11.58	6.32	12.40	6.65	13.13	7.16	14.18	9.24	18.39	10.01	19.14	10.79	20.12	11.28	21.15	11.45	21.36
BPR [26]	2.52	5.65	2.60	5.70	2.70	5.87	2.66	5.93	2.74	5.93	2.38	5.13	2.44	5.33	2.64	5.88	2.74	6.04	2.79	6.04
NeuMF [25]	2.88	7.02	3.48	7.65	4.26	8.75	4.35	8.82	4.35	9.16	6.19	11.45	6.43	12.43	6.71	12.96	7.09	13.62	7.52	14.41
MMoE [30]	6.03	12.30	6.10	12.46	6.20	12.87	6.65	13.73	7.03	14.50	9.89	18.99	9.97	19.08	10.43	19.84	10.89	20.81	11.39	21.76
PLE [31]	5.85	11.62	6.02	11.85	6.29	12.51	7.00	14.01	7.15	14.35	9.98	18.35	10.01	18.44	10.49	19.68	11.31	20.87	11.39	21.05
CoNet [4]	6.02	12.06	6.13	12.52	6.26	12.85	6.88	14.02	7.33	14.79	9.59	18.30	9.68	18.49	9.84	18.63	10.84	20.52	11.23	21.35
MiNet [6]	5.07	10.40	5.24	10.61	5.41	10.87	6.17	12.51	6.66	13.35	8.37	16.05	8.62	16.62	8.84	16.98	9.72	18.30	10.58	19.96
GA-DTCDR [5]	5.61	12.13	5.68	12.28	6.22	12.90	7.04	14.06	7.59	14.85	10.71	20.28	10.75	20.34	10.91	20.55	11.63	21.86	12.25	22.96
DML [10]	5.37	10.63	5.44	10.90	5.59	11.10	6.31	12.57	6.55	12.96	6.51	12.42	6.53	12.49	6.62	12.73	7.05	13.47	7.75	14.99
HeroGraph [11]	6.21	12.30	6.34	12.53	6.37	12.75	7.06	13.90	7.51	14.75	10.45	19.53	10.52	19.91	11.06	20.74	11.77	21.73	12.24	22.75
PTUPCDR [12]	6.22	13.07	6.63	13.24	6.79	13.76	7.36	14.78	7.58	15.52	10.66	19.88	10.91	20.33	11.14	20.77	11.79	22.20	12.18	22.95
NMCDR	**8.40**	**16.57**	**8.50**	**16.63**	**8.87**	**17.73**	**9.26**	**18.33**	**9.54**	**19.05**	**13.52**	**25.36**	**13.79**	**25.53**	**14.06**	**26.15**	**14.91**	**27.54**	**15.17**	**28.10**
Improvement(%)	35.05	26.78	28.21	25.60	30.63	28.85	25.82	24.02	25.69	22.74	26.24	25.05	26.40	25.52	26.21	25.90	26.46	24.05	23.84	22.39

Experiment

TABLE IV: Experimental results (%) on the bi-directional Phone-Elec CDR scenario with different user overlapped ratio.

Methods	Phone-domain recommendation										Elec-domain recommendation									
	$\mathcal{K}_u$=0.1%		$\mathcal{K}_u$=1%		$\mathcal{K}_u$=10%		$\mathcal{K}_u$=50%		$\mathcal{K}_u$=90%		$\mathcal{K}_u$=0.1%		$\mathcal{K}_u$=1%		$\mathcal{K}_u$=10%		$\mathcal{K}_u$=50%		$\mathcal{K}_u$=90%	
	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR
LR [29]	4.12	7.83	4.54	8.75	5.96	12.03	13.06	23.29	15.03	26.58	19.67	31.43	19.99	31.91	19.98	32.48	20.88	33.83	21.29	34.47
BPR [26]	2.49	5.22	2.56	5.32	2.55	5.58	2.67	5.84	3.10	6.72	8.39	15.35	8.47	15.47	8.66	15.76	9.80	17.47	10.79	19.07
NeuMF [25]	3.45	6.73	3.54	7.07	4.01	8.34	7.79	14.36	10.40	18.65	15.82	25.25	16.04	26.12	16.27	26.17	17.12	27.43	17.77	28.60
MMoE [30]	3.95	8.71	4.18	9.05	7.54	15.56	13.66	24.85	16.08	28.67	20.16	32.07	20.27	32.83	20.85	33.24	21.05	34.05	21.64	34.88
PLE [31]	4.24	9.13	4.82	9.92	7.27	14.55	13.84	24.94	16.22	28.27	19.95	32.61	20.32	32.73	20.75	33.08	21.60	34.44	22.21	35.60
CoNet [4]	3.93	8.16	4.02	8.46	6.88	14.23	13.21	24.26	15.67	28.23	19.65	31.57	19.77	32.13	20.20	32.89	21.00	34.10	21.56	35.02
MiNet [6]	3.56	7.58	3.66	7.70	7.22	14.20	13.23	23.51	15.83	27.63	18.22	28.61	18.99	28.64	19.30	31.24	19.89	31.90	20.64	33.14
GA-DTCDR [5]	3.70	7.70	4.41	9.18	7.54	15.14	14.13	25.42	16.36	28.80	20.39	32.85	20.55	32.90	20.75	33.77	21.08	34.08	22.20	35.75
DML [10]	4.56	9.39	4.62	9.88	7.08	13.79	12.76	23.21	14.64	26.24	15.70	25.59	15.72	25.66	16.09	25.98	16.93	27.38	17.54	28.48
HeroGraph [11]	4.21	9.03	4.32	9.76	7.77	15.71	14.22	25.82	16.33	29.20	19.09	31.27	19.99	31.91	21.11	34.31	21.19	34.31	21.58	34.84
PTUPCDR [12]	4.29	8.88	4.65	9.18	8.24	16.30	14.51	25.82	16.84	29.39	20.51	32.73	20.60	32.94	20.93	33.89	21.80	35.17	22.31	35.86
NMCDR	**6.29**	**12.27**	**6.46**	**12.98**	**10.82**	**20.98**	**17.44**	**30.87**	**19.18**	**33.03**	**23.49**	**37.61**	**23.91**	**37.84**	**24.17**	**39.03**	**24.45**	**39.49**	**24.60**	**39.84**
Improvement(%)	37.93	30.67	38.92	31.38	31.31	28.71	20.19	19.56	13.90	12.39	14.53	14.49	16.06	14.88	14.50	13.76	12.16	12.28	10.26	11.10

Experiment

TABLE V: Experimental results (%) on the bi-directional Loan-Fund CDR scenario with different user overlapped ratio.

Methods	Loan-domain recommendation										Fund-domain recommendation									
	$\mathcal{K}_u$=0.1%		$\mathcal{K}_u$=1%		$\mathcal{K}_u$=10%		$\mathcal{K}_u$=50%		$\mathcal{K}_u$=90%		$\mathcal{K}_u$=0.1%		$\mathcal{K}_u$=1%		$\mathcal{K}_u$=10%		$\mathcal{K}_u$=50%		$\mathcal{K}_u$=90%	
	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR
LR [29]	47.34	67.59	47.42	67.73	47.65	67.88	47.75	67.82	47.87	68.08	21.97	34.57	22.08	35.65	25.24	36.83	29.70	46.14	31.48	50.98
BPR [26]	42.93	62.22	43.07	62.67	43.20	62.99	43.24	63.45	43.37	63.45	3.01	6.28	3.06	6.64	3.21	6.85	2.74	6.51	4.84	10.44
NeuMF [25]	46.20	66.66	47.27	67.21	47.74	67.92	48.01	68.19	47.95	68.27	21.53	33.86	21.87	34.07	25.34	37.66	30.78	48.81	30.14	48.73
MMoE [30]	45.23	66.45	45.86	66.88	46.87	67.58	47.81	68.60	47.92	68.55	20.49	34.88	20.59	35.04	20.70	36.53	31.92	52.32	35.84	57.20
PLE [31]	48.93	69.01	49.03	69.28	49.36	69.40	49.31	69.59	49.39	69.79	21.82	36.09	22.13	36.16	22.91	36.70	33.02	51.40	35.02	55.37
CoNet [4]	47.85	68.05	48.06	68.25	48.23	68.63	48.37	68.39	48.43	68.65	18.07	29.47	18.60	30.65	20.29	33.03	29.14	49.06	33.97	54.95
MiNet [6]	47.61	67.59	48.24	68.46	48.84	68.78	48.90	69.01	48.86	69.07	19.89	34.04	21.34	35.82	23.78	37.75	32.18	52.61	34.89	55.91
GA-DTCDR [5]	45.94	66.51	47.65	68.09	49.20	69.26	49.59	69.86	49.63	69.94	21.72	32.51	23.05	34.41	25.40	38.00	33.19	53.32	36.60	57.29
DML [10]	47.12	67.84	47.95	68.56	49.01	69.77	48.87	69.50	48.84	69.56	21.01	35.75	22.80	37.35	25.84	39.04	32.81	51.44	34.61	54.74
HeroGraph [11]	48.89	68.37	49.16	68.69	49.45	69.17	49.71	69.64	49.85	69.66	19.07	30.77	19.63	31.44	21.74	33.78	32.23	51.11	35.40	56.41
PTUPCDR [12]	48.01	68.48	48.32	68.84	49.14	69.32	49.55	69.91	49.54	69.93	22.13	36.05	22.84	36.83	24.14	37.75	33.24	53.03	35.61	56.24
NMCDR	**49.47**	**69.54**	**49.69**	**69.84**	**49.84**	**69.97**	**49.89**	**69.98**	**49.91**	**70.06**	**25.32**	**39.47**	**25.69**	**39.75**	**26.38**	**40.46**	**35.24**	**55.03**	**37.29**	**58.54**
Improvement(%)	1.10	0.77	1.07	0.80	0.79	0.29	0.36	0.10	0.12	0.17	14.41	9.37	11.45	6.43	2.09	3.64	6.02	3.21	1.89	2.18

Experiment

TABLE VI: Experimental results (%) on the bi-directional Cloth-Sport and Loan-Fund CDR scenarios under different density settings D_s.

Methods	Cloth-domain recommendation						Sport-domain recommendation						Loan-domain recommendation						Fund-domain recommendation					
	D_s=10%		D_s=50%		D_s=70%		D_s=10%		D_s=50%		D_s=70%		D_s=10%		D_s=50%		D_s=70%		D_s=10%		D_s=50%		D_s=70%	
	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR	NDCG	HR
LR [29]	2.41	5.38	2.87	6.20	3.21	6.95	2.47	5.42	2.61	5.79	4.20	8.61	23.30	32.84	31.03	42.66	38.90	53.03	14.54	23.03	18.33	28.43	19.89	30.67
BPR [26]	2.52	5.61	2.48	5.41	2.45	5.49	2.53	5.63	2.45	5.58	2.66	5.84	20.68	30.70	27.95	41.28	34.04	50.50	1.31	3.11	1.93	4.45	2.50	5.51
NeuMF [25]	2.61	5.78	2.74	5.96	2.75	5.96	2.48	5.39	2.68	5.90	3.37	7.02	23.62	33.13	31.41	45.04	37.55	54.66	15.31	23.43	17.47	25.79	19.17	27.84
MMoE [30]	2.67	5.93	2.92	6.35	3.37	7.34	2.66	5.91	2.84	6.25	4.35	9.02	23.40	32.71	30.34	42.70	36.11	52.24	15.78	25.25	18.46	27.87	19.12	29.83
PLE [31]	2.51	5.51	2.78	6.12	3.31	7.10	2.57	5.64	2.73	5.91	4.26	8.74	23.79	34.01	31.98	44.29	41.02	56.44	16.28	24.55	17.57	27.89	19.75	29.23
CoNet [4]	2.83	6.11	2.81	6.11	3.40	7.09	2.51	5.60	2.76	6.18	4.22	8.68	23.11	33.62	31.38	45.51	37.13	54.62	14.53	23.99	16.27	28.47	18.07	29.42
MiNet [6]	2.74	5.74	2.83	6.19	3.14	6.81	2.49	5.61	2.69	5.96	3.95	8.31	24.55	35.45	32.55	47.14	41.51	57.54	14.63	24.24	17.27	28.59	18.80	30.38
GA-DTCDR [5]	2.81	6.03	3.00	6.44	3.48	7.50	2.47	5.48	2.87	6.17	4.47	9.24	24.15	34.53	31.87	44.01	40.11	57.49	15.84	25.90	19.35	31.75	22.17	32.96
DML [10]	2.60	5.64	2.84	6.23	3.19	6.85	2.41	5.36	2.87	6.26	3.54	7.41	23.45	34.63	32.39	45.98	38.51	55.39	16.28	24.60	20.00	30.88	22.62	33.52
HeroGraph [11]	2.62	5.68	2.98	6.42	3.33	7.18	2.59	5.74	2.74	6.13	4.25	8.87	24.61	33.52	32.43	43.76	38.09	54.44	15.86	25.12	18.05	30.13	19.81	28.81
PTUPCDR [12]	2.77	6.03	2.89	6.21	3.62	7.72	2.38	5.35	2.82	6.34	4.32	8.88	23.76	34.17	32.26	45.67	40.81	53.97	16.54	26.06	19.11	32.26	20.82	32.35
NMCDR	**2.97**	**6.29**	**3.40**	**6.96**	**4.15**	**8.60**	**2.80**	**6.05**	**3.39**	**6.97**	**5.39**	**10.46**	**25.37**	**36.71**	**34.18**	**49.75**	**44.19**	**61.38**	**17.82**	**26.98**	**21.40**	**33.96**	**24.68**	**34.90**
Improvement(%)	4.95	2.95	13.33	8.07	14.64	11.40	5.26	2.37	18.12	9.94	20.58	13.20	3.09	3.55	5.01	5.54	6.45	6.67	9.46	3.53	7.00	5.27	9.11	4.12

Experiment

TABLE VII: Average statistics of online traffic logs for 1 day.

Dataset	Users	Items	Ratings	#Overlapping	Density
Loan	45,263,394	48,282	778,136,734		0.04%
Fund	801,349	1,039	479,504	488,836	0.06%
Account	4,856,675	9,816	9,149,842		0.02%

#Overlapping denotes the number of overlapped users across domains.

TABLE VIII: Experimental results of the online A/B testing from 12.1 to 12.15, 2022

	Loan Domain	Fund Domain	Account Domain
Control Group	10.50%	6.12%	1.89%
MMOE Group	12.14%	6.45%	2.11%
PLE Group	12.57%	6.69%	2.27%
DML Group	12.93%	6.81%	2.43%
NMCDR Group	**13.81%**	**7.13%**	**2.59%**
Improvement	6.81%	4.70%	6.58%

Experiment

TABLE IX: Experimental results (%) with different model variants. w/o denotes the model without the corresponding component variant.

Scenarios	Metrics	Model variants				Ours
		w/o-Igm	w/o-Cgm	w/o-Inc	w/o-Sup	
Music	NDCG@10	10.28	9.30	10.90	9.78	**11.26**
	HR@10	19.28	18.78	20.89	19.16	**21.58**
Movie	NDCG@10	32.84	31.96	33.60	32.60	**33.96**
	HR@10	48.73	48.01	50.48	48.93	**51.13**
Cloth	NDCG@10	9.14	7.35	8.95	8.38	**9.26**
	HR@10	17.99	15.14	17.65	17.59	**18.33**
Sport	NDCG@10	14.75	13.02	14.60	13.98	**14.91**
	HR@10	26.94	24.35	26.86	27.04	**27.54**
Phone	NDCG@10	16.50	14.42	17.05	17.09	**17.44**
	HR@10	29.47	25.37	29.70	29.82	**30.87**
Elec	NDCG@10	23.75	20.82	24.10	24.13	**24.45**
	HR@10	37.95	33.87	38.26	38.43	**39.49**
Loan	NDCG@10	49.69	49.40	49.76	49.67	**49.89**
	HR@10	69.83	69.32	69.89	69.79	**69.98**
Fund	NDCG@10	34.84	34.77	35.10	34.90	**35.24**
	HR@10	54.84	54.35	54.91	54.80	**55.03**

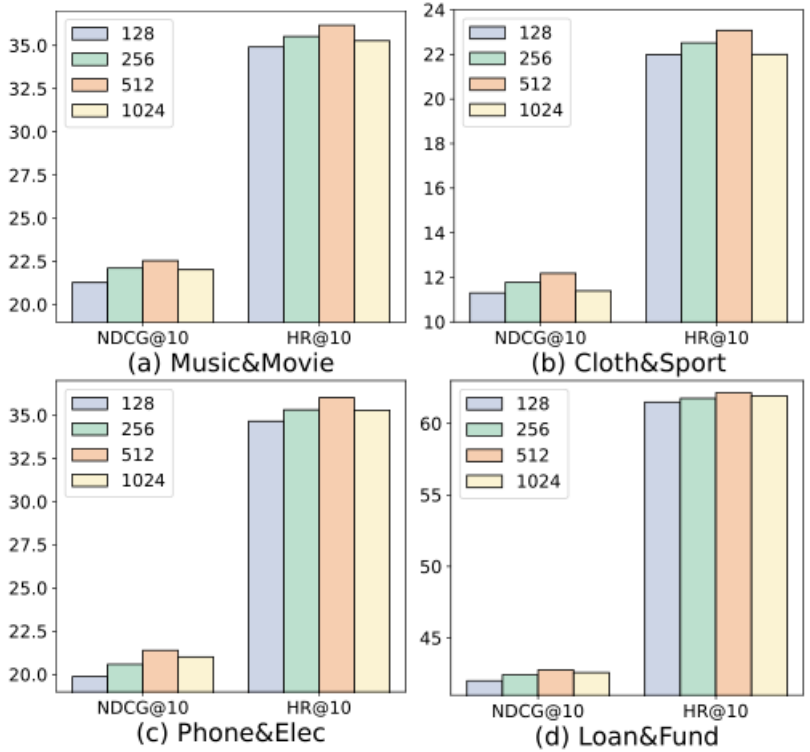


Fig. 3: Impact of number of matching neighbors.

w/o-Igm: we remove the intra node matching component

w/o-Cgm: we remove the inter node matching component

w/o-Inc: we remove the intra node complementing module

w/o-Sup: we remove the multiple supervisory signals

Experiment

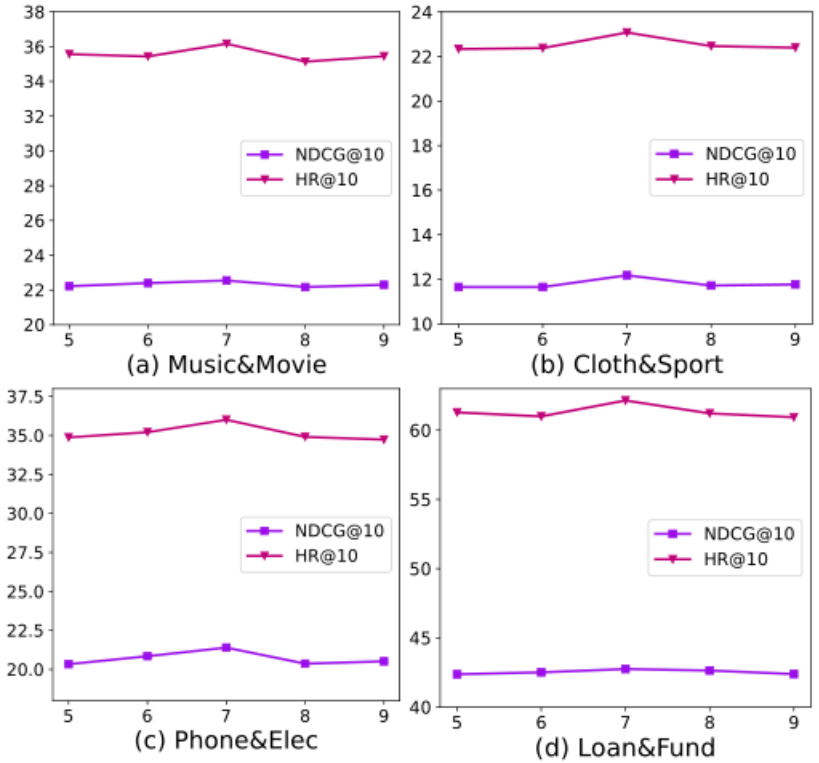


Fig. 4: Impact of threshold of head/tail user discrimination.

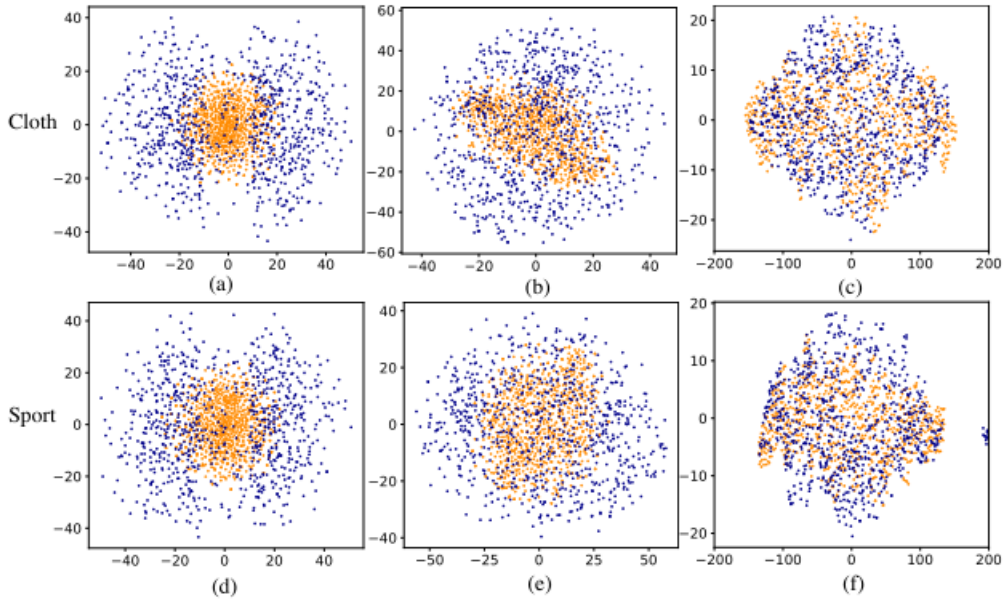


Fig. 5: The visualization of learned user representations for evaluating the effectiveness of NMCDR's each key component.

Thank you!