MCDAN: A Multi-Scale Context-Enhanced Dynamic Attention Network for Diffusion Prediction

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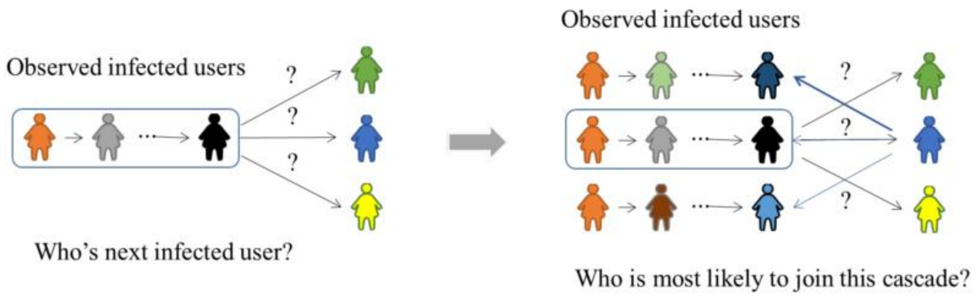
Reported by Yuyang Lai

Introduction

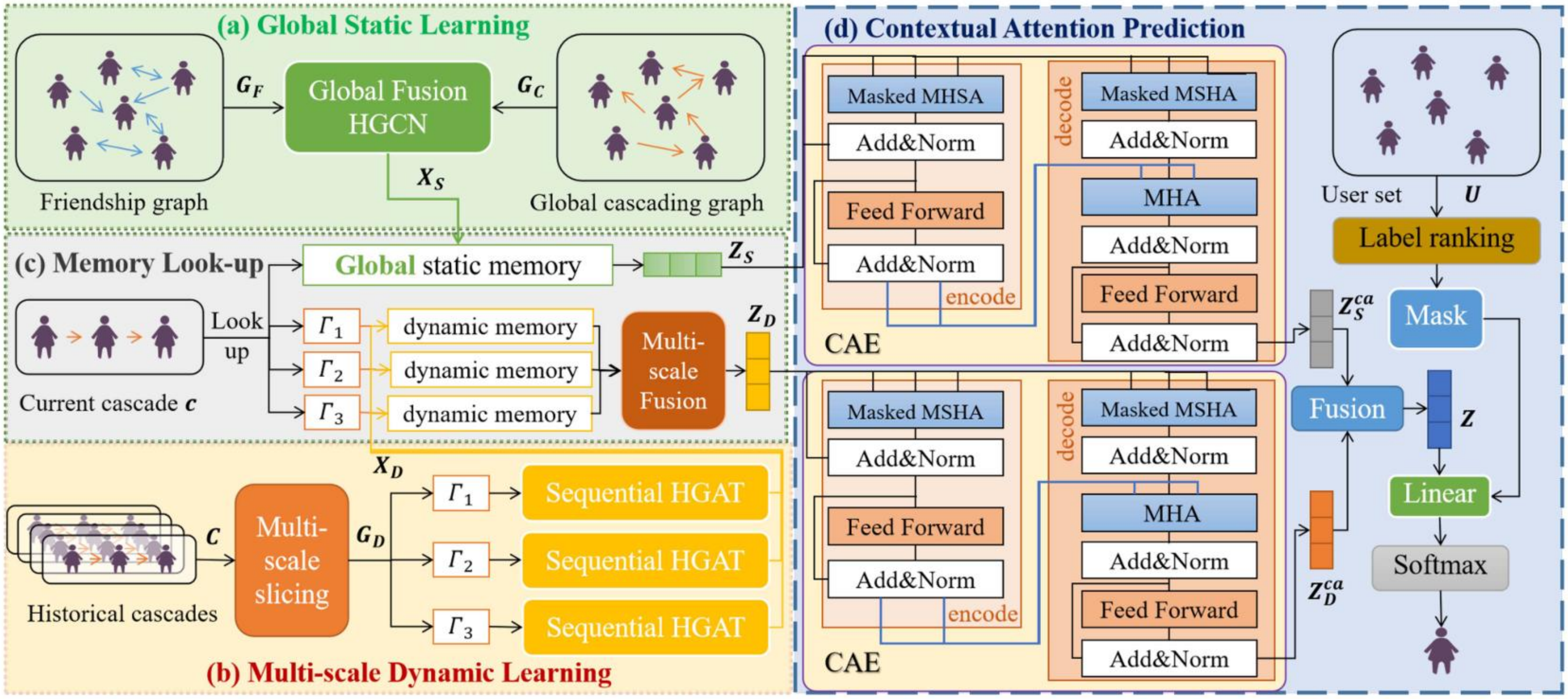


Extracting global interactive relationship among users from the social network and historical cascades.

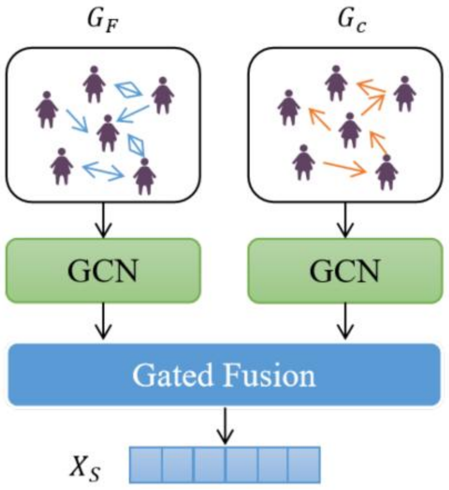
Proposing a multi-scale sequential hypergraph attention module to capture the dynamic preference of users at different time scales.

Designing a contextual attention enhancement module to strengthen the interaction of user representations within the current cascade.

Constructing a susceptibility label for each user based on user susceptibility analysis and use the rank of this label for auxiliary prediction.


(a) Global Static Learning
G_F
Global Fusion HGCN
G_C
Friendship graph
X_S
Global cascading graph
(c) Memory Look-up
Global static memory
Z_S
Look up
Γ_1
Γ_2
Γ_3
dynamic memory
dynamic memory
dynamic memory
Multi-scale Fusion
Z_D
Current cascade c
X_D
C
Multi-scale slicing
G_D
Sequential HGAT
Sequential HGAT
Sequential HGAT
Historical cascades
(b) Multi-scale Dynamic Learning
(d) Contextual Attention Prediction
Masked MHSA
Add&Norm
Feed Forward
Add&Norm
encode
decode
Masked MSHA
Add&Norm
MHA
Add&Norm
Feed Forward
Add&Norm
CAE
Masked MSHA
Add&Norm
Feed Forward
Add&Norm
encode
decode
Masked MSHA
Add&Norm
MHA
Add&Norm
Feed Forward
Add&Norm
CAE
User set
U
Label ranking
Mask
Z_S^{ca}
Fusion
Z
Linear
Z_D^{ca}
Softmax

Method



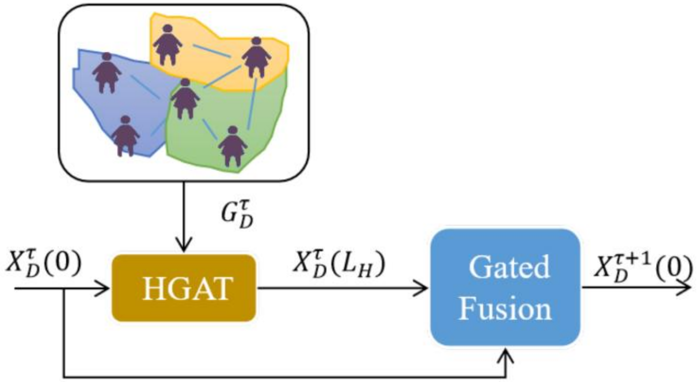
$$X_F(l+1) = ReLU(\widetilde{D}_F^{-\frac{1}{2}} \widetilde{A}_F \widetilde{D}_F^{-\frac{1}{2}} X_F(l) W_F) \quad (1)$$

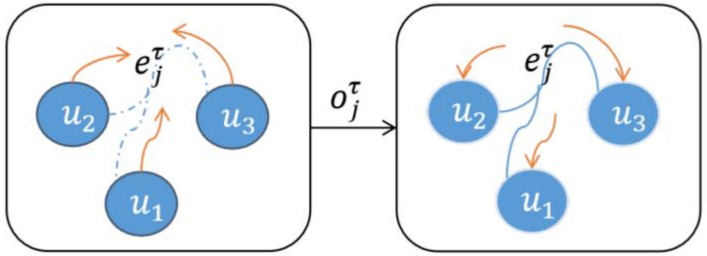
$$X_C(l+1) = ReLU(\widetilde{D}_C^{-\frac{1}{2}} \widetilde{A}_C \widetilde{D}_C^{-\frac{1}{2}} X_C(l) W_C) \quad (2)$$

$$X_S = \alpha X_F + (1-\alpha) X_C \quad (3)$$

$$\alpha = \frac{exp(W_S^T \sigma(W_1 X_F))}{exp(W_S^T \sigma(W_1 X_F)) + exp(W_S^T \sigma(W_1 X_C))} \quad (4)$$

Method





Nodes to hyperedge　　Hyperedge to nodes

$$Z_D = \sum_{\Gamma \in \{\Gamma_1, \Gamma_2, \ldots, \Gamma_M\}} m_\Gamma Z_D^\Gamma$$
$$m_\Gamma = \frac{exp(W_D^T \sigma(W_m Z_D^\Gamma))}{\sum_\Gamma exp(W_D^T \sigma(W_m Z_D^\Gamma))} \qquad (12)$$

$$G_D = \{G_D^\Gamma | \Gamma = \Gamma_1, \Gamma_2, \ldots, \Gamma_M\}$$
$$G_D^\Gamma = \{G_D^\tau = (U^\tau, E_D^\tau) | \tau = 1, 2, 3, \ldots, \Gamma\} \qquad (5)$$

$$X_D = \{X_D^\Gamma | \Gamma = \Gamma_1, \Gamma_2, \ldots, \Gamma_M\}$$
$$X_D^\Gamma = SequentialHGAT(G_D^\Gamma) \qquad (6)$$

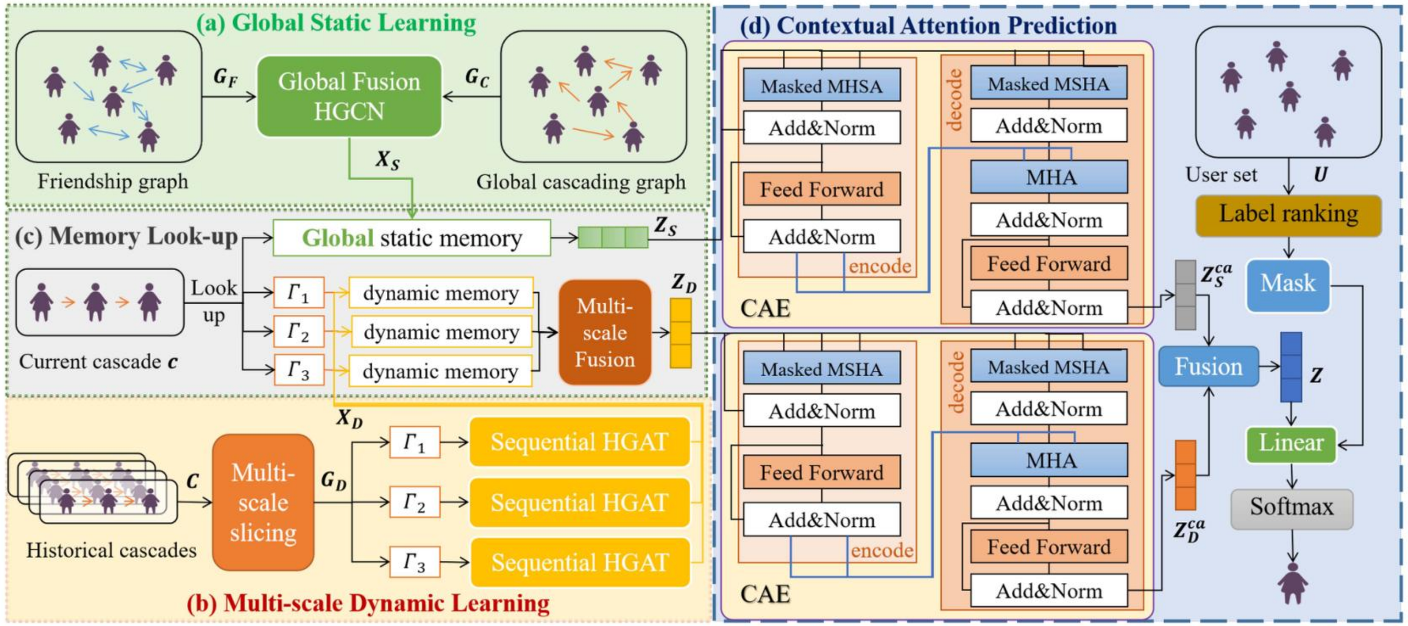
$$X_D^\tau(L_H) = HGAT(X_D^\tau(0), G_D^\tau) \quad \tau = 1, 2, 3, .., \Gamma \qquad (7)$$

$$X_D^{\tau+1}(0) = g_f X_D^\tau(0) + (1 - g_f) X_D^\tau(L_H) \qquad (8)$$
$$g_f = \frac{exp(W_{DH}^T \sigma(W_g X_D^\tau(0)))}{exp(W_{DH}^T \sigma(W_g X_D^\tau(0))) + exp(W_{DH}^T \sigma(W_g X_D^\tau(L_H)))} \qquad (9)$$

$$o_j^\tau(l+1) = ReLU\left(\sum_{u_i^\tau \in e_j^\tau} W_{h_1} x_i^\tau(l)\right) \qquad (10)$$

$$x_i^\tau(l+1) = ReLU\left(\sum_{e_j^\tau \in E_{D,i}^\tau} W_{h_2} o_j^\tau(l+1)\right) \qquad (11)$$

Method



$$Att(Q,K,V) = softmax\left(\frac{QK^T}{\sqrt{d_\Omega}}\right)V,$$
$$h_\omega^{ca} = Att(h_S^c W_\omega^{Q^{ca}}, Z_S^c W_\omega^{K^{ca}}, Z_S^c W_\omega^{V^{ca}}),$$
$$h_S^{ca} = [h_1^{ca}; h_2^{ca}; \ldots; h_\Omega^{ca}]W^{O^{ca}} \quad (15)$$

$$Z_S^{ca} = ReLU(h_S^{ca} W_{E_3} + b_3)W_{E_4} + b_4 \quad (16)$$

$$Z = \beta Z_S^{ca} + (1-\beta) Z_D^{ca} \quad (17)$$
$$\beta = \frac{exp(W_Z^T \sigma(W_2 Z_S^{ca}))}{exp(W_Z^T \sigma(W_2 Z_S^{ca})) + exp(W_Z^T \sigma(W_2 Z_D^{ca}))} \quad (18)$$

$$MaskedAtt(Q,K,V) = softmax\left(\frac{QK^T}{\sqrt{d_\Omega}} + \mathbb{M}\right)V,$$
$$h_\omega = MaskedAtt(Z_S W_\omega^Q, Z_S W_\omega^K, Z_S W_\omega^V),$$
$$h_S = [h_1; h_2; \ldots; h_\Omega]W^O \quad (13)$$

$$Z_S^c = ReLU(h_S W_{E_1} + b_1)W_{E_2} + b_2 \quad (14)$$

$$\hat{y} = softmax(W_p Z + Mask) \quad (19)$$

$$Loss(\theta) = -\sum_{t=2}^{|c|}\sum_{i=1}^{N} y_{ti} log(\hat{y}_{ti}) \quad (20)$$

Experiments

TABLE I
STATISTICS OF THE PREPROCESSED DATASETS IN OUR EXPERIMENTS

Datasets	Twitter	Douban	Android	Christianity
# Users	12,627	12,232	2,927	1,651
# Fri. Links	309,631	198,496	24,459	21,955
# Cas. Links	73,036	51,797	23,958	11,328
# Cascades	3,442	3,475	678	589
Avg. Length	32.60	21.76	42.05	26.02

TABLE II
OVERALL RESULTS WITH HITS@K SCORES FOR K = 10, 50, 100 ON FOUR PUBLIC DATASETS (%)

model	Twitter			Douban			Android			Christianity		
	@10	@50	@100	@10	@50	@100	@10	@50	@100	@10	@50	@100
DeepDiffuse	5.79	10.80	18.39	9.02	14.93	19.13	4.13	10.58	17.21	10.27	21.83	30.74
Topo-LSTM	8.45	15.80	25.42	8.57	16.53	21.47	4.56	12.63	16.53	12.28	22.63	31.52
NDM	15.21	28.23	32.30	10.00	21.13	30.14	4.85	14.24	18.97	15.41	31.36	45.86
SNIDSA	25.37	36.64	42.89	16.23	27.24	35.59	5.63	15.22	20.93	17.74	34.58	48.76
FOREST	28.67	42.07	49.75	19.50	32.03	39.08	9.68	17.73	24.08	24.85	42.01	51.28
Inf-VAE	14.85	32.72	45.72	8.94	22.02	35.72	5.98	14.70	20.91	18.38	38.50	51.05
DyHGCN	31.88	45.05	52.19	18.71	32.33	39.71	9.10	16.38	23.09	26.62	42.80	52.47
MS-HGAT	33.50	49.59	58.91	21.33	35.25	42.75	10.41	20.31	27.55	28.80	47.14	55.62
Topic-HGAT	35.12	51.41	61.15	23.50	37.58	45.66	11.76	21.72	29.39	30.02	48.73	57.80
RotDiff	35.90	52.46	61.21	22.16	38.23	46.37	11.44	23.04	31.30	32.37	56.25	66.74
MCDAN(ours)	**38.45**	**55.78**	**64.25**	**49.39**	**58.58**	**62.81**	**11.89**	**25.10**	**32.79**	**35.49**	**56.92**	**67.41**

TABLE III
OVERALL RESULTS WITH MAP@K SCORES FOR K = 10, 50, 100 ON FOUR PUBLIC DATASETS (%)

model	Twitter			Douban			Android			Christianity		
	@10	@50	@100	@10	@50	@100	@10	@50	@100	@10	@50	@100
DeepDiffuse	5.87	6.80	6.39	6.02	6.93	7.13	2.30	2.53	2.56	7.27	7.83	7.84
Topo-LSTM	8.51	12.68	13.68	6.57	7.53	7.78	3.60	4.05	4.06	7.93	8.67	9.86
NDM	12.41	13.23	14.30	8.24	8.73	9.14	2.01	2.22	2.93	7.41	7.68	7.86
SNIDSA	15.34	16.64	16.89	10.02	11.24	11.59	2.98	3.24	3.97	8.69	8.94	9.72
FOREST	19.60	20.21	21.75	11.26	11.84	11.94	5.83	6.17	6.26	14.64	15.45	15.58
Inf-VAE	19.80	20.66	21.32	11.02	11.28	12.28	4.82	4.86	5.27	9.25	11.96	12.45
DyHGCN	20.87	21.48	21.58	10.61	11.26	11.36	6.09	6.40	6.50	15.64	16.30	16.44
MS-HGAT	22.49	23.17	23.30	11.72	12.52	12.60	6.39	6.87	6.96	17.44	18.27	18.40
Topic-HGAT	23.71	24.53	24.66	12.70	13.61	13.72	6.80	7.53	7.68	18.98	19.85	19.99
RotDiff	24.06	24.82	24.95	11.70	12.54	12.66	6.96	7.45	7.56	19.81	20.91	21.05
MCDAN(ours)	**25.89**	**26.69**	**26.81**	**40.70**	**41.13**	**41.19**	**7.47**	**8.04**	**8.15**	**22.88**	**23.78**	**23.94**

Experiments

TABLE IV
ABLATION STUDY WITH HITS@K SCORES FOR K = 10, 50, 100 ON FOUR PUBLIC DATASETS (%)

model	Twitter			Douban			Android			Christianity		
	@10	@50	@100	@10	@50	@100	@10	@50	@100	@10	@50	@100
MCDAN	**38.45**	**55.78**	**64.25**	**49.39**	**58.58**	**62.81**	**11.89**	**25.10**	**32.79**	**35.49**	**56.92**	**67.41**
w/o G	32.02	49.94	60.27	28.97	42.72	49.11	10.88	22.61	29.99	32.59	51.12	64.96
w/o M	38.16	54.96	63.17	39.65	52.43	57.58	11.58	22.92	30.61	31.47	52.46	62.05
w/o C	35.41	50.49	58.55	20.50	34.86	41.97	11.11	21.45	28.67	31.92	52.46	61.38
w/o L	34.94	51.64	60.58	45.77	55.64	60.05	11.34	21.06	28.44	32.14	52.90	66.29

Note that we use underlining to mark the results of the most effective component.

TABLE V
ABLATION STUDY WITH MAP@K SCORES FOR K = 10, 50, 100 ON FOUR PUBLIC DATASETS (%)

model	Twitter			Douban			Android			Christianity		
	@10	@50	@100	@10	@50	@100	@10	@50	@100	@10	@50	@100
MCDAN	**25.89**	**26.69**	**26.81**	**40.70**	**41.13**	**41.19**	**7.47**	**8.04**	**8.15**	**22.88**	**23.78**	**23.94**
w/o G	19.90	20.72	20.87	19.68	20.30	20.39	6.63	7.17	7.27	20.34	21.23	21.42
w/o M	25.18	25.96	26.08	29.89	30.50	30.57	6.99	7.50	7.61	20.20	21.14	21.28
w/o C	23.59	24.29	24.40	11.17	11.87	11.97	6.85	7.29	7.39	19.26	20.16	20.28
w/o L	22.73	23.49	23.62	37.36	37.81	37.87	7.09	7.52	7.62	19.64	20.52	20.71

Note that we use underlining to mark the results of the most effective component.

Experiments

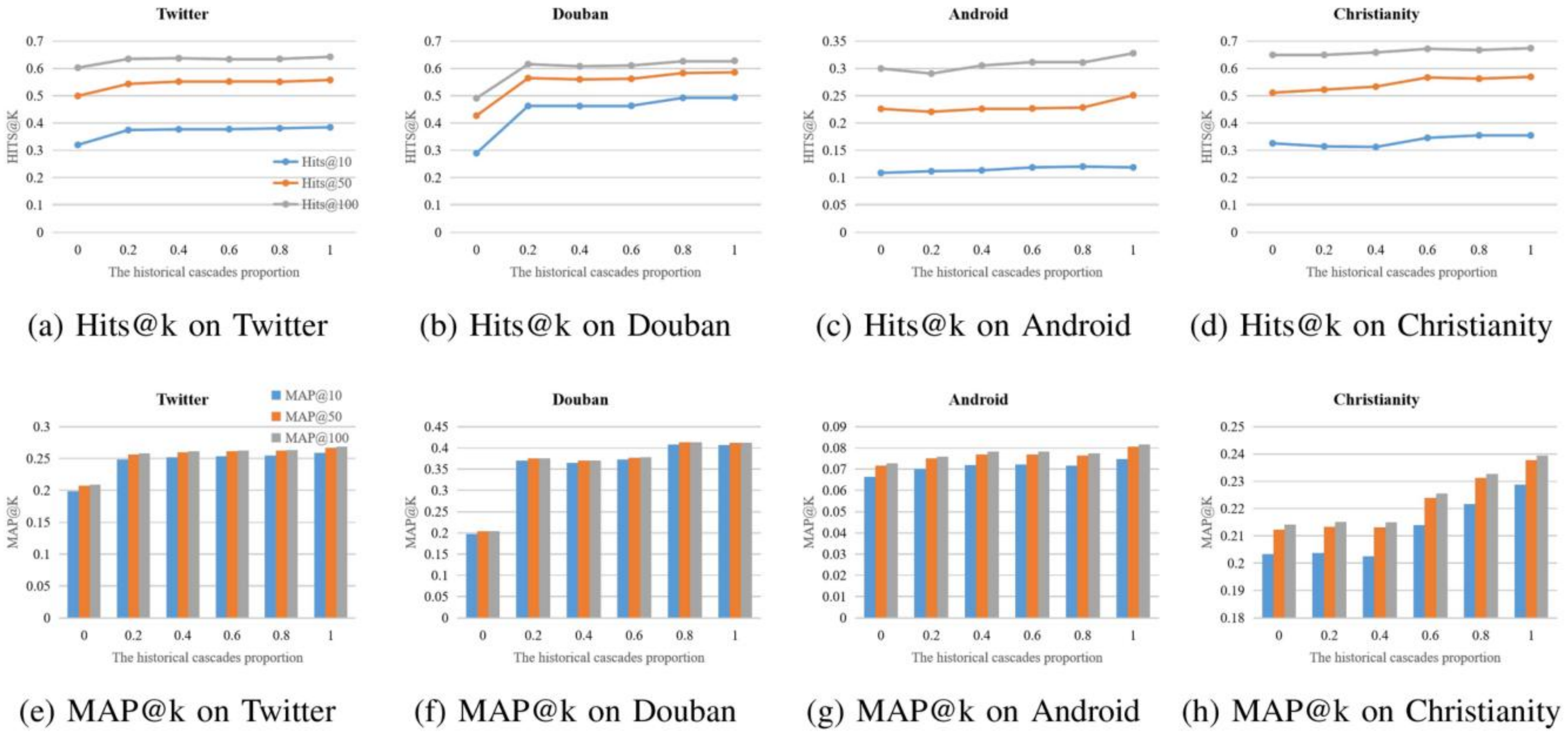


Fig. 6. Results of the impact of the historical cascades proportion on the four public datasets.

Experiments

TABLE VI
RESULTS OF THE IMPACT OF THE NUMBER OF TIME SCALES M ON FOUR PUBLIC DATASETS (%)

M	Γ	Twitter			Douban			Android			Christianity		
		@10	@50	@100	@10	@50	@100	@10	@50	@100	@10	@50	@100
1	8	38.16	54.96	63.17	39.65	52.43	57.58	11.58	22.92	30.61	31.47	52.46	62.05
3	**4,8,16**	**38.45**	**55.78**	**64.25**	**49.39**	**58.58**	**62.81**	**11.89**	**25.10**	**32.79**	**35.49**	**56.92**	**67.41**
5	2,4,8,16,32	34.86	52.04	61.25	45.11	54.96	59.88	10.65	22.92	31.24	32.37	50.89	65.63

Hits@k scores for k = 10, 50, 100.

TABLE VII
RESULTS OF THE IMPACT OF THE NUMBER OF TIME SCALES M ON FOUR PUBLIC DATASETS (%)

M	Γ	Twitter			Douban			Android			Christianity		
		@10	@50	@100	@10	@50	@100	@10	@50	@100	@10	@50	@100
1	8	25.18	25.96	26.08	29.89	30.50	30.57	6.99	7.50	7.61	20.20	21.14	21.28
3	**4,8,16**	**25.89**	**26.69**	**26.81**	**40.70**	**41.13**	**41.19**	**7.47**	**8.04**	**8.15**	**22.88**	**23.78**	**23.94**
5	2,4,8,16,32	22.90	23.68	23.82	34.79	35.26	35.33	6.88	7.44	7.56	20.27	21.22	21.43

MAP@k scores for k = 10, 50, 100.

Experiments

TABLE VIII
INSUSCEPTIBLE LABEL THRESHOLD SETTING

t_{ratio}	Twitter				Douban				Android				Christianity			
	0.02	0.04	0.06	0.08	0.02	0.04	0.06	0.08	0.02	0.04	0.06	0.08	0.02	0.04	0.06	0.08
# insusceptible users	252	505	757	1010	244	489	734	978	58	117	175	234	33	66	99	132

TABLE IX
RESULTS OF THE IMPACT OF THE CASCADE LENGTH ON FOUR PUBLIC DATASETS (%)

Max_{len}	Twitter			Douban			Android			Christianity		
	@10	@50	@100	@10	@50	@100	@10	@50	@100	@10	@50	@100
200	**38.45**	**55.78**	**64.25**	**49.39**	**58.58**	**62.81**	**11.89**	25.10	32.79	**35.49**	**56.92**	67.41
300	37.91	54.92	63.21	49.09	58.12	62.74	11.57	25.21	32.72	34.15	56.47	67.63
400	37.78	54.58	62.75	49.06	57.93	62.67	11.42	**25.44**	**32.87**	33.48	55.58	**68.30**
500	37.69	54.31	62.63	48.82	57.72	62.61	11.72	**25.44**	32.64	33.04	55.13	68.08

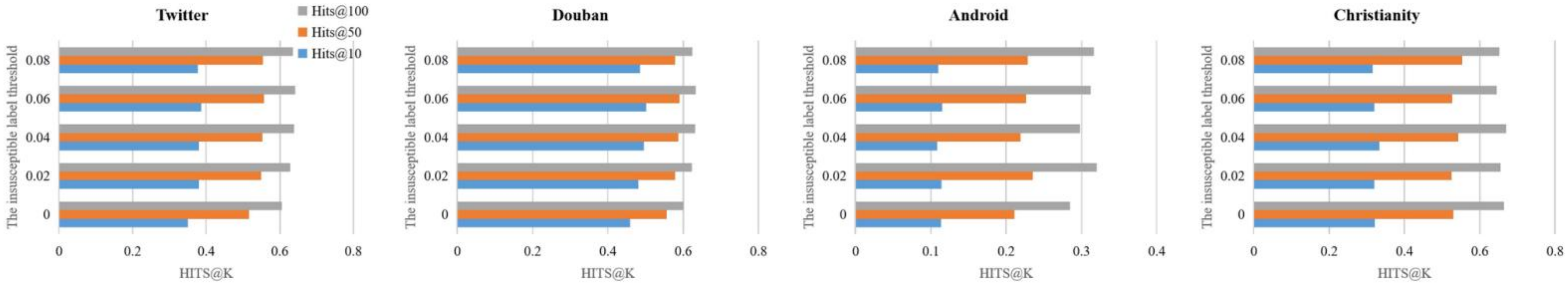
Hits@k scores for k = 10, 50, 100. Note that Max_{len} denotes the maximum length of the cascades.

TABLE X
RESULTS OF THE IMPACT OF THE CASCADE LENGTH ON FOUR PUBLIC DATASETS (%)

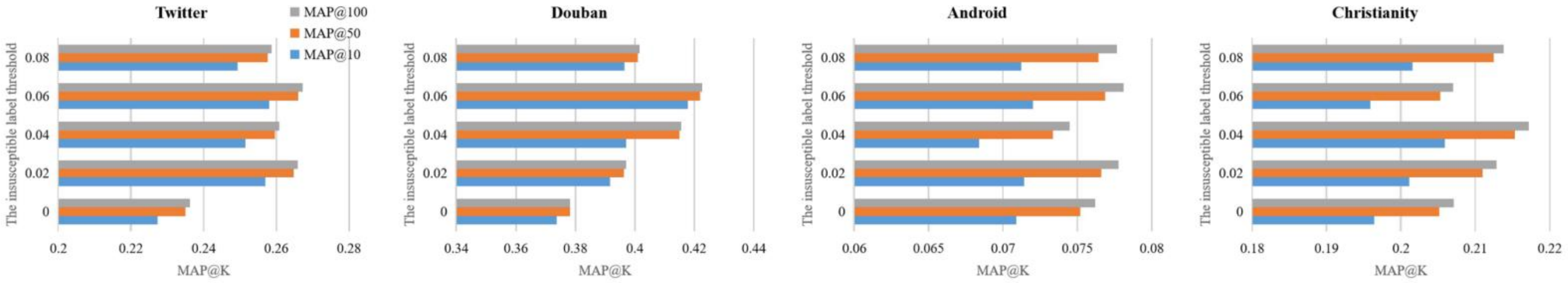
Max_{len}	Twitter			Douban			Android			Christianity		
	@10	@50	@100	@10	@50	@100	@10	@50	@100	@10	@50	@100
200	**25.89**	**26.69**	**26.81**	**40.70**	**41.13**	**41.19**	**7.47**	**8.04**	**8.15**	**22.88**	**23.78**	**23.94**
300	25.37	26.16	26.27	40.45	40.87	40.94	7.43	8.03	8.14	22.46	23.44	23.60
400	24.76	25.54	25.65	40.26	40.67	40.73	7.37	7.99	8.10	22.32	23.31	23.50
500	24.20	24.97	25.09	40.04	40.46	40.53	7.37	7.96	8.06	22.06	23.05	23.24

MAP@k scores for k = 10, 50, 100. Note that Max_{len} denotes the maximum length of the cascades.

Experiments



(a) Hits@k on Twitter (b) Hits@k on Douban (c) Hits@k on Android (d) Hits@k on Christianity



(e) MAP@k on Twitter (f) MAP@k on Douban (g) MAP@k on Android (h) MAP@k on Christianity

Fig. 7. Results of the impact of the insusceptible label threshold on the four public datasets.

Thank you!