Diffusion of "Following" Links in Microblogging Networks

Jing Zhang, Zhanpeng Fang, Wei Chen, *Member, IEEE*, and Jie Tang, *Senior Member, IEEE*

Abstract—When a "following" link is formed in a social network, will the link trigger the formation of other neighboring links? We study the diffusion phenomenon of the formation of "following" links by proposing a model to describe this link diffusion process. To estimate the diffusion strength between different links, we first conduct an analysis on the diffusion effect in 24 triadic structures and find evident patterns that facilitate the effect. We then learn the diffusion strength in different triadic structures by maximizing an objective function based on the proposed model. The learned diffusion strength is evaluated through the task of link prediction and utilized to improve the applications of follower maximization and followee recommendation, which are specific instances of influence maximization. Our experimental results reveal that incorporating diffusion patterns can indeed lead to statistically significant improvements over the performance of several alternative methods, which demonstrates the effect of the discovered patterns and diffusion model.

Index Terms—Link diffusion, triad formation, social network

1 Introduction

00 (. ,). ( ). . ( ). . - - _ $0 \le t - t' \le \delta$, 0 , (. .,).

- *J. Zhang and Z. Fang are with the Department of Computer Science and Technology, Tsinghua University, Beijing 100084, China. E-mail: {zhangjing12, fzp13}@mails.tsinghua.edu.cn.*
- *W. Chen is with Theory Group, Microsoft Research, Beijing 100080, China. E-mail: weic@microsoft.com.*
- *J. Tang is with the Department of Computer Science and Technology, Tsinghua University, Beijing 100084, China, and Tsinghua National Laboratory for Information Science and Technology (TNList). E-mail: jietang@tsinghua.edu.cn.*

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A

"following" link cascade model.

Organization.

2 "FOLLOWING" LINK CASCADE MODEL

neighboring links

A **1.** *Diffusion effect between links decays over time.*

discovery probability $g_{e'e}$ *diffusion probability* $h_{e'e}$

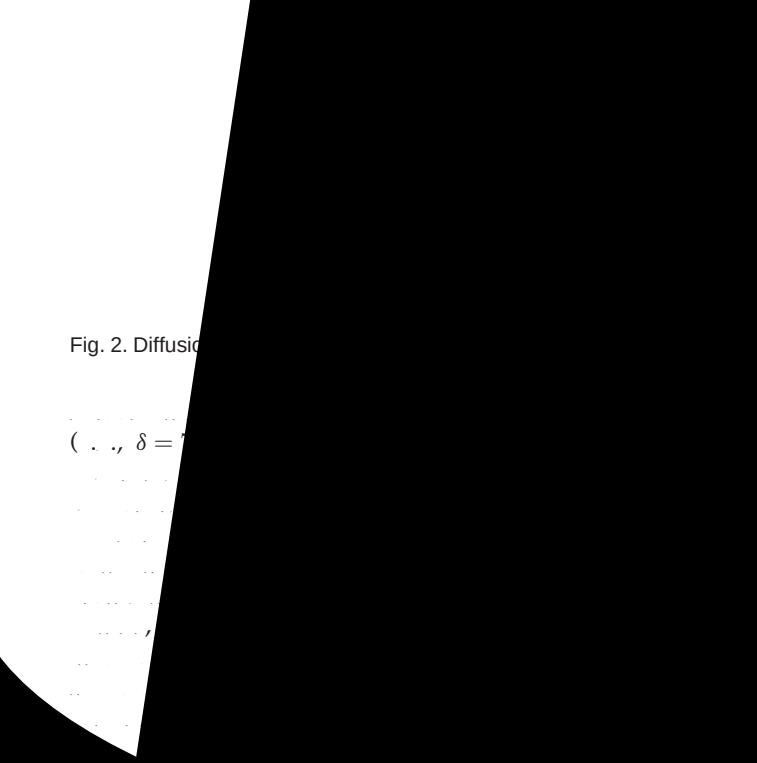


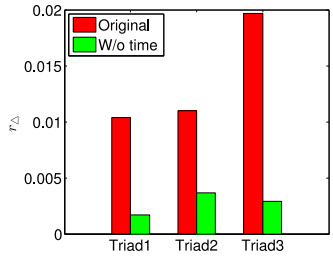
Fig. 2. Diffusio

3.1 Data Collection

3.2 Observations

$$r_{\triangle} = \frac{|C^{+}_{\triangle}|}{|C_{\triangle}|}. \quad (1)$$

Pattern significance.



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≤ 0.05,

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0,000 .

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0.0 ,

B _ C C

_ B B

A _ C. $\forall$ _ , 0,

e_{AC}.

A C _ , C

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C .

$\forall$

- . , , , e_{AC}

_

. $\forall$, , ,

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Diffusion decay.

, δ $1, 2, 3, 5, 7$ 10 .

δ, $r_\triangle$ -

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$r_\triangle$.

δ , $r_\triangle$,

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, $r_\triangle$.

(.),

B A C, A'

C' .

(.), B A C

, B

C A

A' C' . , B -

C

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$r_\triangle$ δ . ,

(. ., $t = \perp$),

, $r_\triangle$. -

, $r_\triangle$ (

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Other observations. ,

- , A B.

A C _ , C (- , -

. , 0-). , -

C . e_{BA}, - -

$\forall$, e_{AB}, e_{AB} e_{BA}.

- . , , , e_{AC} -

_ A B

B C -

. $\forall$, , A B (+).

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A C.

(- , , - ,

? - , -)

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- , A C

B C

- , C A (+ $-$ 0).

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B A , B -

A' C A'

C' , A' C

B C.

Summary. ,

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(+) - , -
, A C , -
A C B C (+ − 0 ,).

4 MODEL LEARNING

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Likelihood function. ,
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, $\theta = \{h_{e'e}, g_{e'e}\}$ -
. ,
(e', e). , $h_{e'e}$
, $g_{e'e}$ (e', e)
(e

$y_{e'e}$, e'
e $[t_{e'}, t_e]$, $t_{e'}$
t_e, e' e . , $y_{e'e}$
, e' e $t_{e'}$

$$\begin{aligned} y_{e'e} &= 1 - h_\triangle g_\triangle \sum_{t=t_{e'}}^{t_e} (1-g_\triangle)^{t-t_{e'}} \\ &= h_\triangle (1-g_\triangle)^{t_e - t_{e'}+1} + (1-h_\triangle). \end{aligned} \tag{6}$$

, .
$e \in \mathcal{E}$
δ . -
e' , $y_{ee'}$ $e' \in R_e$, R_e
e $t_e + \delta$. , -
$y_{ee'}$. ( ), , $t_{e'}$
t_e t_e $t_e + \delta$, .
-

$$\log \mathcal{L} = \sum_{e \in \mathcal{E}} \left\{ \log \sum_{\vec{\alpha}_{S_e}} \prod_{e' \in S_e} x_{e'e}^{\alpha_{e'}} y_{e'e}^{1-\alpha_{e'}} + \sum_{e' \in R_e} \log y_{ee'} \right\}.$$

EM algorithm.
. , $q(e|\vec{\alpha}_{S_e}) = \frac{p(e|\vec{\alpha}_{S_e})}{p(e|S_e)}$
,
-

$$\begin{aligned} \log \mathcal{L} &= \sum_{e \in \mathcal{E}} \left\{ \log \sum_{\vec{\alpha}_{S_e}} \hat{q}(e|\vec{\alpha}_{S_e}) \frac{p(e|\vec{\alpha}_{S_e})}{\hat{q}(e|\vec{\alpha}_{S_e})} + \sum_{e' \in R_e} \log y_{ee'} \right\} \\ &\geq \sum_{e \in \mathcal{E}} \left\{ \sum_{\vec{\alpha}_{S_e}} \hat{q}(e|\vec{\alpha}_{S_e}) \log \frac{p(e|\vec{\alpha}_{S_e})}{\hat{q}(e|\vec{\alpha}_{S_e})} + \sum_{e' \in R_e} \log y_{ee'} \right\}, \end{aligned}$$

^ , -
. , $\hat{q}(e|\vec{\alpha}_{S_e}) \log \hat{q}(e|\vec{\alpha}_{S_e})$
, .
$Q(\theta, \hat{\theta})$,

$$Q(\theta, \hat{\theta}) = \sum_{e \in \mathcal{E}} \left\{ \sum_{\vec{\alpha}_S} \right.$$

$$h_{\triangle} = \frac{\sum_{(e',e)\in C_{\triangle}^{+}} \hat{D}_{e'e} + \sum_{(e',e)\in C_{\triangle}^{-}} \hat{B}_{e'e}}{|C_{\triangle}|}, \quad (12)$$

$$g_{\triangle} = \frac{\sum_{(e',e)\in C_{\triangle}^{+}} \hat{A}_{e'e}}{\sum_{(e',e)\in C_{\triangle}^{-}} \hat{B}_{ee'}(\delta+1) + \sum_{(e',e)\in C_{\triangle}^{+}} \hat{D}_{e'e}(t_e - t_{e'}+1)}. \quad (13)$$

. ( ) ( ), $C_{\triangle}^{+}$ $C_{\triangle}^{-}$.
$A_{e'e}$, $B_{e'e}$ $D_{e'e}$
, , $A_{e'e}$ $B_{e'e}$
. ( ) ( ), $D_{e'e}$

$$D_{e'e} = B_{e'e} + A_{e'e} - A_{e'e}B_{e'e}. \quad (14)$$

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A- 1. .

: $G = (V, E, t)$
: $\theta = \{h_{\triangle}, g_{\triangle}\}$
$h_{\triangle}$ $g_{\triangle}$ (0,)

E- , $e \in \mathcal{E}$
$e' \in S_e$
$x_{e'e}$. ( )
$y_{e'e}$. ( )
$e' \in S_e$
$A_{e'e}$. ( )
$B_{e'e}$. ( )
0 $D_{e'e}$. ( )
$e' \in R_e$
$B_{ee'}$. ( )
- , $\triangle = 1$ 24
$h_{\triangle}$. ( )
$g_{\triangle}$. ( )
Convergence

5 APPLICATIONS

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Follower maximization. v,
k S v
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i
v. $u \notin S$,
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$(S \cup \{u\})$ (-),
(S)
S. (.
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S v
, . , e'
e . ( ).
, S, , S (S) R .
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v , .0. , -
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Followee maximization.
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v, k
v , v
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A- 2. / .

: $G = (V, E)$, v, k
: / S
$S = \emptyset$ $R-$ 0,000
$i = 1$ *to* k
$u \in V \backslash S$
$s_u = 0$
$r = 1$ *to* R
$s_u += |FCM(S \cup \{u\})|$
$s_u = s_u / R$
$S = S \cup \{argmax_{u \in V \backslash S} s_u\}$

6 EXPERIMENTS

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6.1 Experimental Setup

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Evaluation metrics.

$\{h_\triangle\}$ $\{g_\triangle\}$

$p(e|S_e)$

S_e . (0)

e . e

$p(e|S_e) > \tau$.

τ 0 0. ,

τ.

( ),

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$p(e|S_e)$

Comparison methods.

Basic.

(. ,

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SVM.

LRC.

Collaborative filtering (CF):

u, u

. u

w, u

w.

, u v

$$CF\_score(u,v) = \sum_w I(w,v) sim(w,u),$$

$sim(w,u)$ w u,

. .,

$I(w,v)$ w v 0

. $\{v\}$ u

$CF\_score(u,v)$.

SimRank.

u , v

0 . $\{v\}$

u .

Katz.

u , v

u v.

Random-random model (RR).

v, u w

, w v

. e_{uv}

(u,w,v) .

, u v

$$RR\_score(u,v) = \frac{1}{|F(u)|} \sum_w I(u,w) I(w,v) \frac{1}{|F(w)|},$$

$|F(u)|$

u, $I(u,w)$ u w 0

. $\{v\}$ u

$RR\_score(u,v)$.

Preferential attachment with communities (PAC).

u

v, , β,

u

u , $1-\beta$, u

. , α, v

(. .,

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, $1-\alpha$, v

.

u v

$$PAC\_score(u,v) = \beta\left(\alpha \frac{|N(v)|}{\sum_{v\in C(u)} |N(v)|} + (1-\alpha)\frac{1}{|C(u)|}\right) + (1-\beta)\left(\alpha \frac{|N(v)|}{\sum_{v\in V} |N(v)|} + (1-\alpha)\frac{1}{|V|}\right),$$

$|N(v)|$ v. $C(u)$

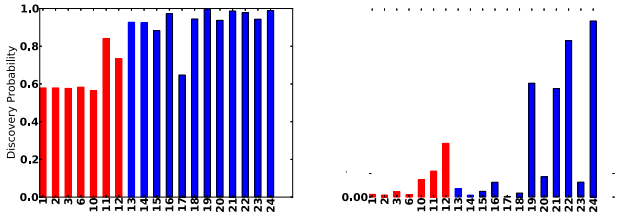
u,

$0\,.V$

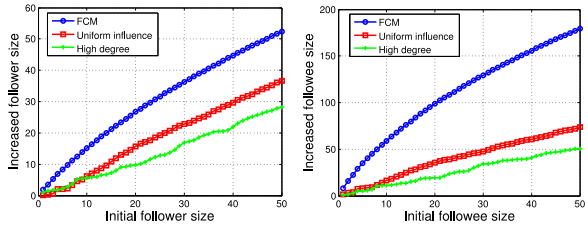
u,

u.

$\alpha \quad \beta \quad 0 \quad 0.$.



(a) Discovery Probabilities



(a) Follower maximization (b) Followee maximization

Fig. 11. Results for "following" influence maximization on Twitter. *X*-axis: the number of initial users. *Y*-axis: the number of newly activated users.

Per-triad analysis.

Model parameter analysis.

Delay analysis.

Convergence analysis.

6.3 Application Improvement

7 RELATED WORK

Diffusion model and influence maximization.

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