Data-Driven Behavioral Analytics: Observations, Representations and Models

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http://www.meng-jiang.com/tutorial-cikm16.html

Tutorial in CIKM 2016, October 24, Indianapolis, IN

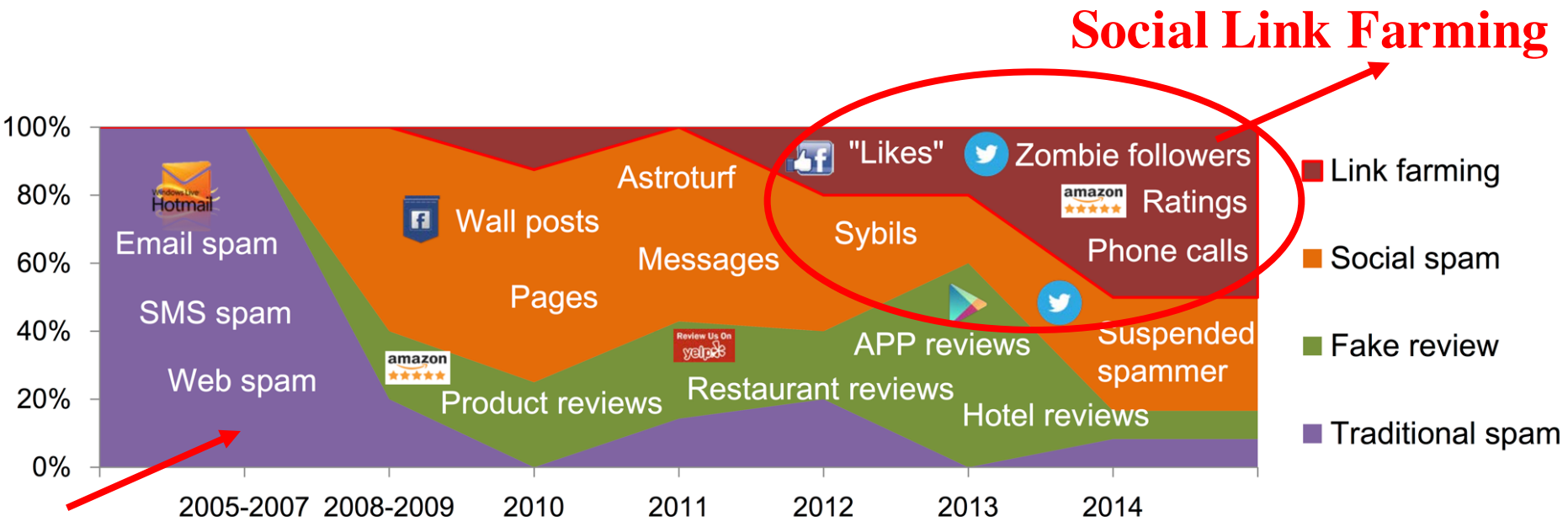
I. Mining behavior networks with social and spatiotemporal contexts

I.2. Suspicious behavior detection

Ill-gotten Facebook Likes

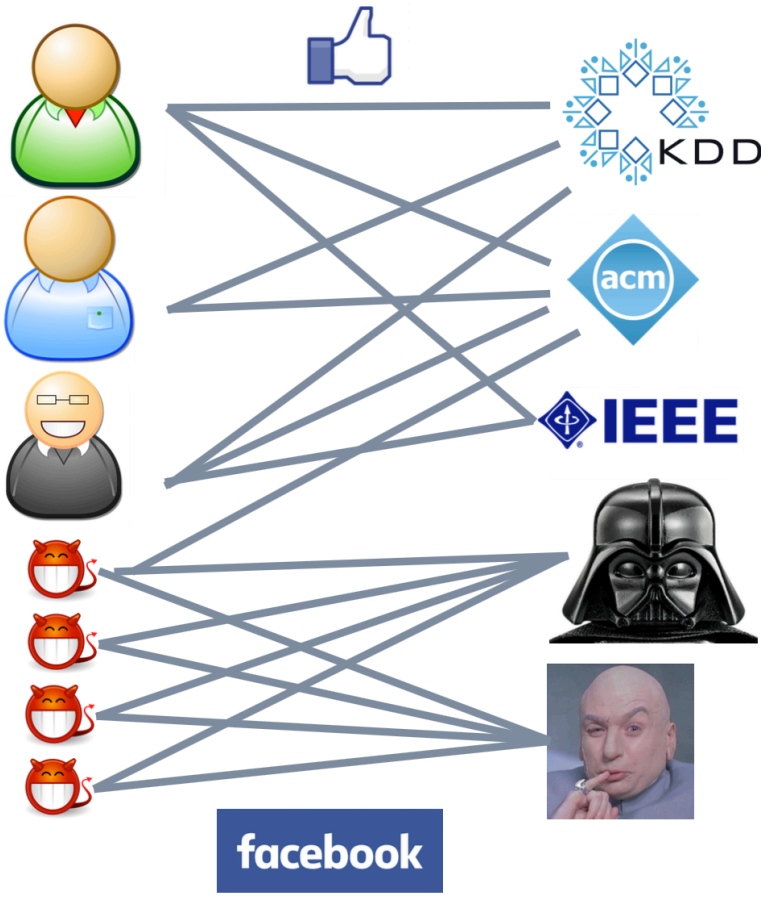
25,000 Facebook Likes	50,000 Facebook Likes	100,000 Facebook Likes	200,000 Facebook Likes
$265	$525	$1,000	$1,750
Lifetime Replacement Warranty	Lifetime Replacement Warranty	Lifetime Replacement Warranty	Lifetime Replacement Warranty
Dedicated 24/7 Customer Service	Dedicated 24/7 Customer Service	Dedicated 24/7 Customer Service	Dedicated 24/7 Customer Service
100% Risk Free, Try Us Today	100% Risk Free, Try Us Today	100% Risk Free, Try Us Today	100% Risk Free, Try Us Today
Order starts within 24 - 48 hours	Order starts within 24 - 48 hours	Order starts within 24 -48 hours	Order starts within 24 -48 hours
Order completed within 22 days	Order completed within 35 days	Order completed within 35 days	Order completed within 35 days

Suspicious Behavior Detection



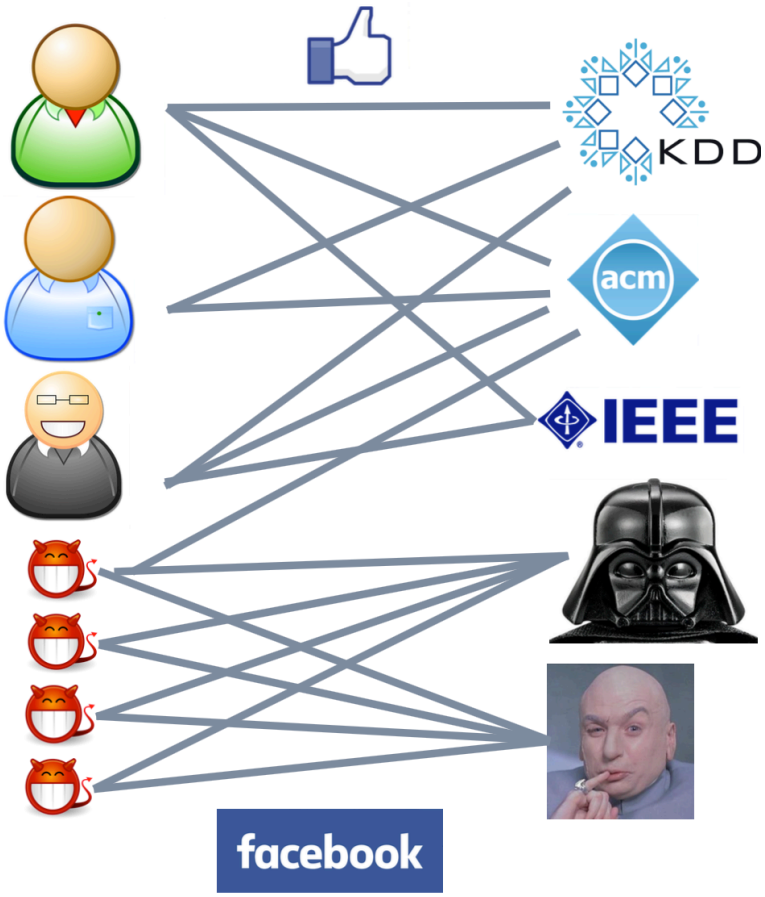
Meng Jiang, Peng Cui and Christos Faloutsos.
Suspicious Behavior Detection: Current Trends and Future Directions.
IEEE Intelligent Systems (ISSI), 2016.

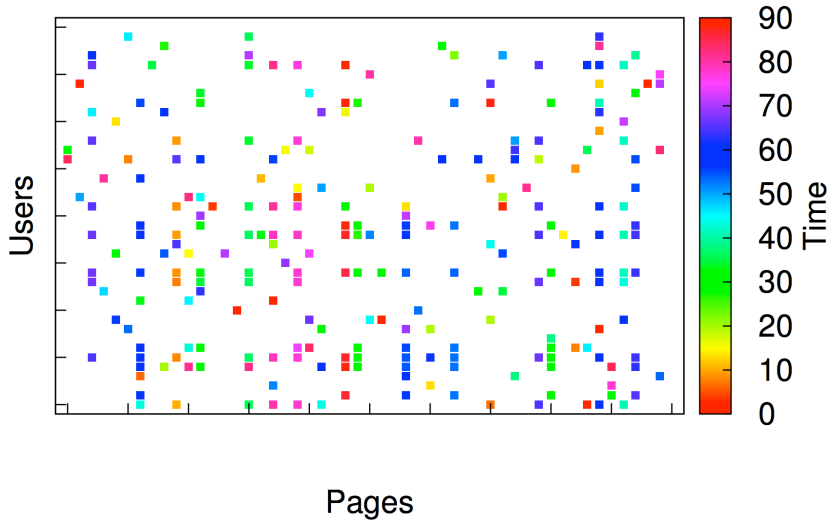
Ill-gotten Facebook Likes



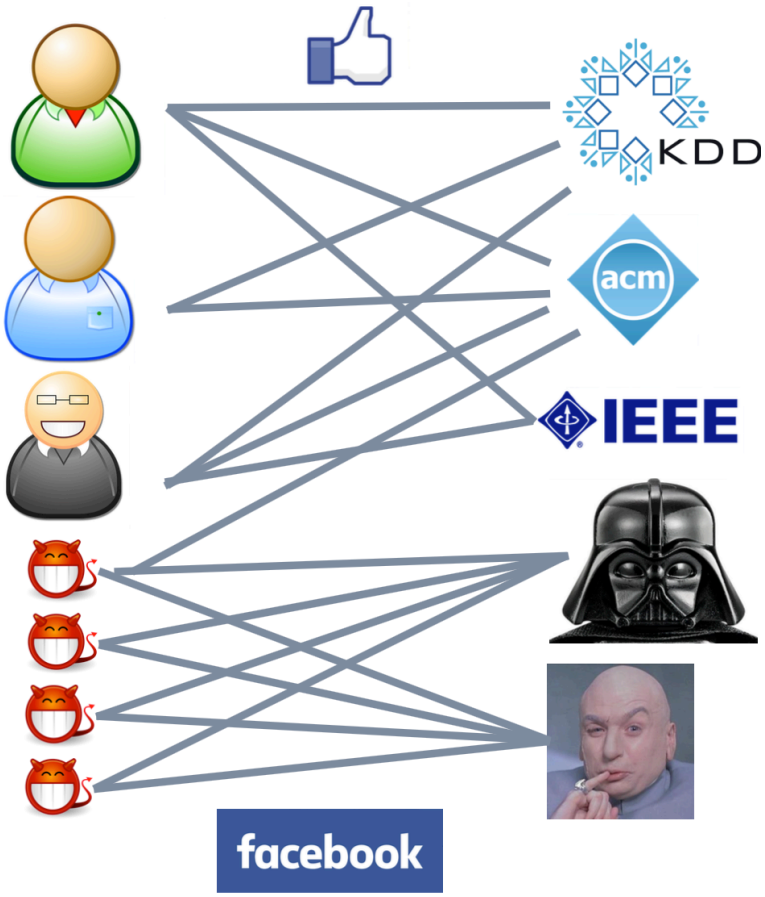
Beutel et al. **CopyCatch: Stopping Group Attacks by Spotting Lockstep Behavior in Social Neworks.** *WWW*, 2013.

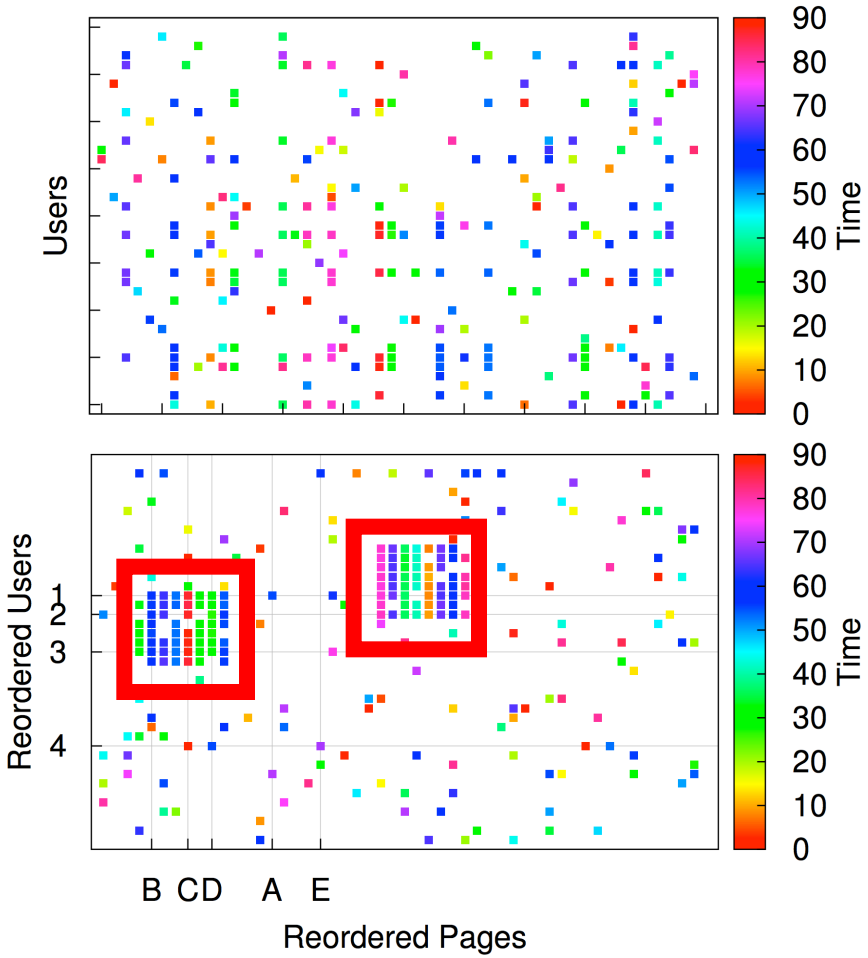
Observation: Graphical View





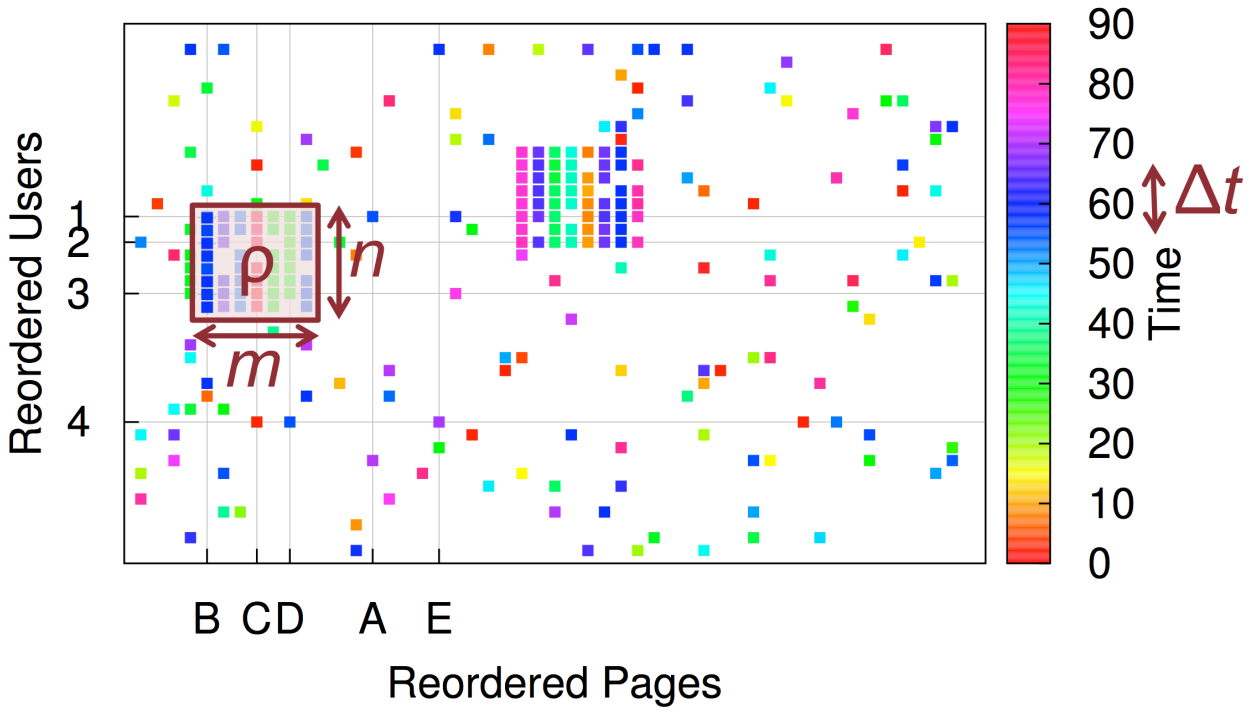
Observation: Reorder Matrix



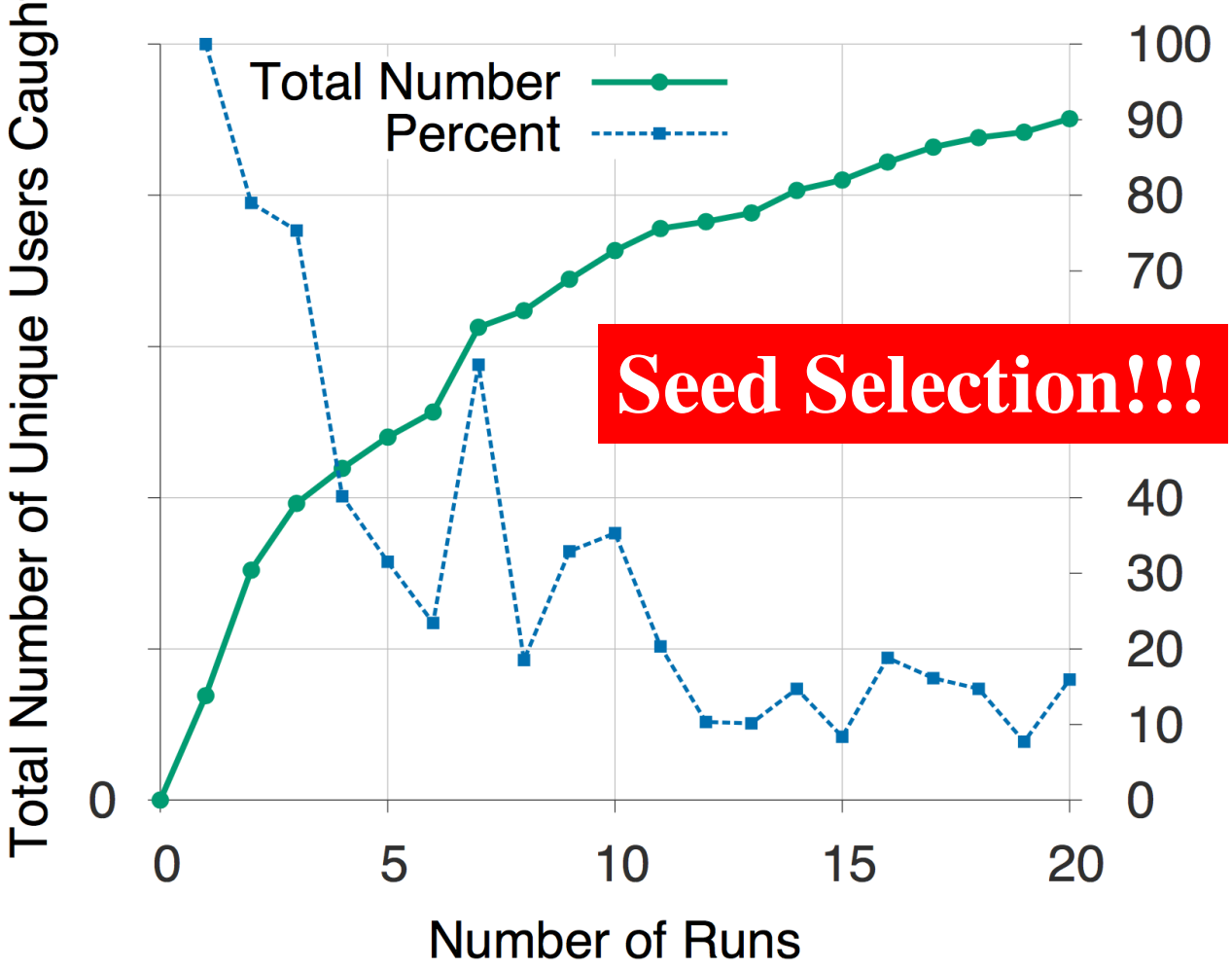


Algorithm: Seed + Search

- **CopyCatch**
  - "Near Bipartite Core": n users, m Pages, ϱ, Δt



Experimental Result

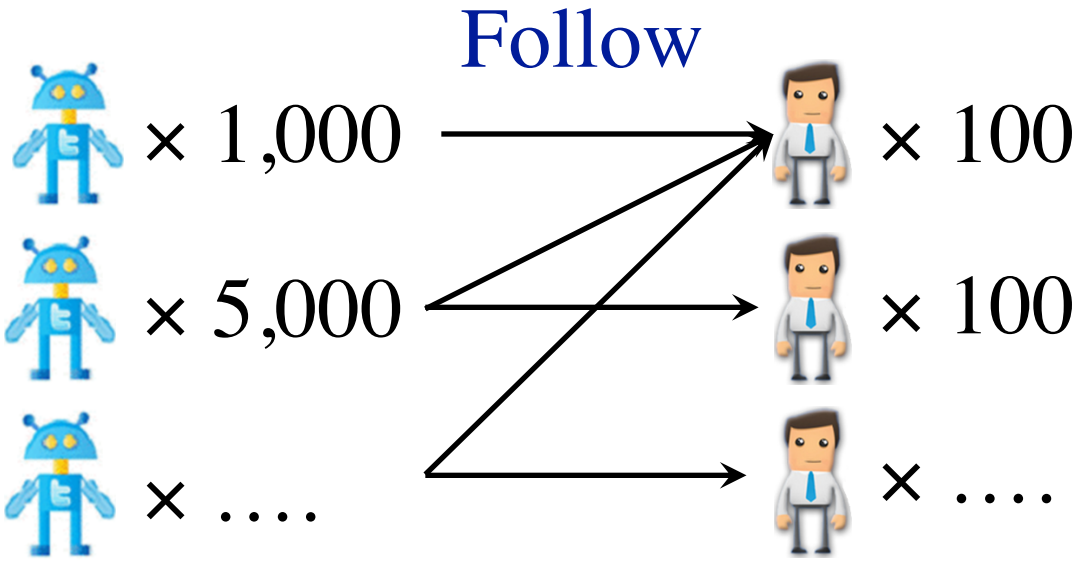


Serious Problem in Weibo

Experience-driven approaches:

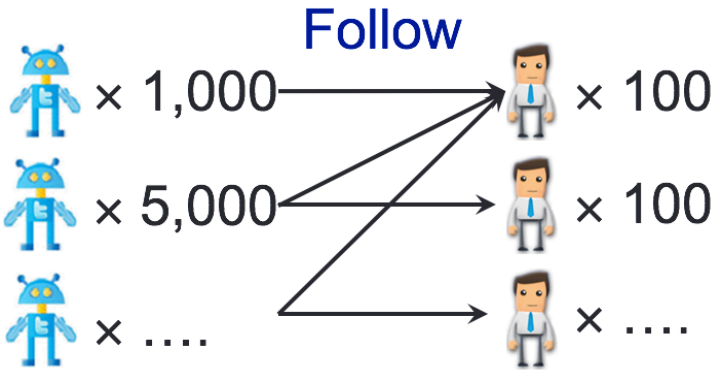
features of #followees, #hashtags, #URLs…

Zombie Followers

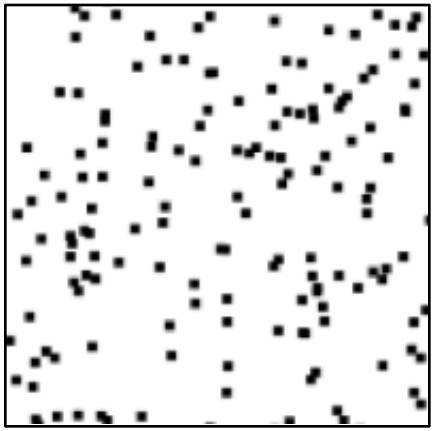


Jiang et al. **Inferring Strange Behavior from Connectivity Pattern in Social Networks.** *PAKDD*, 2014.

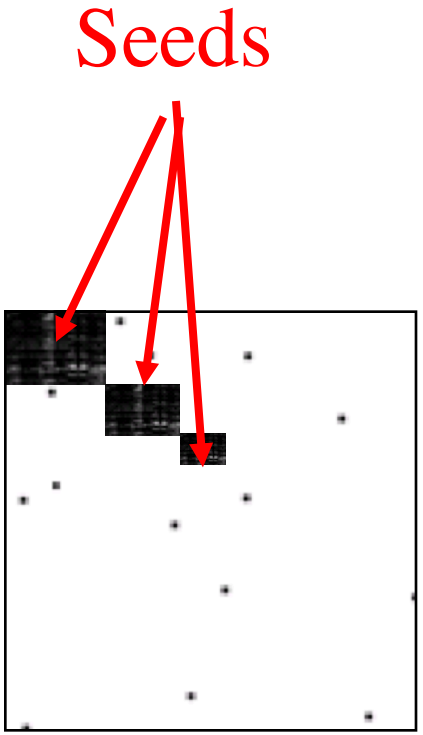
Observation: Reorder Matrix



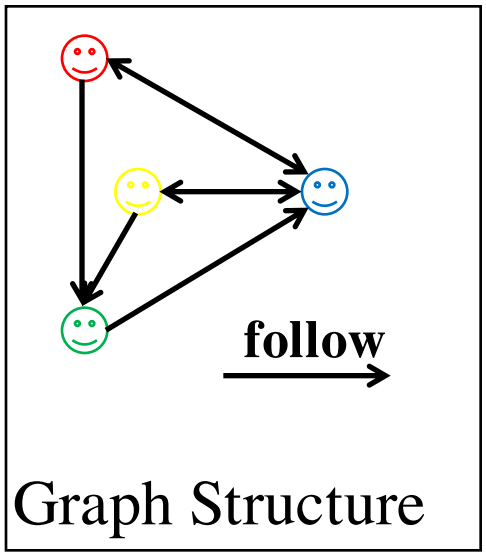
Given

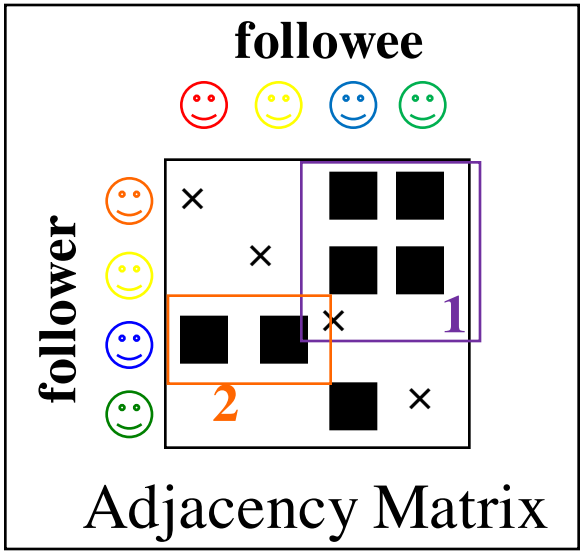


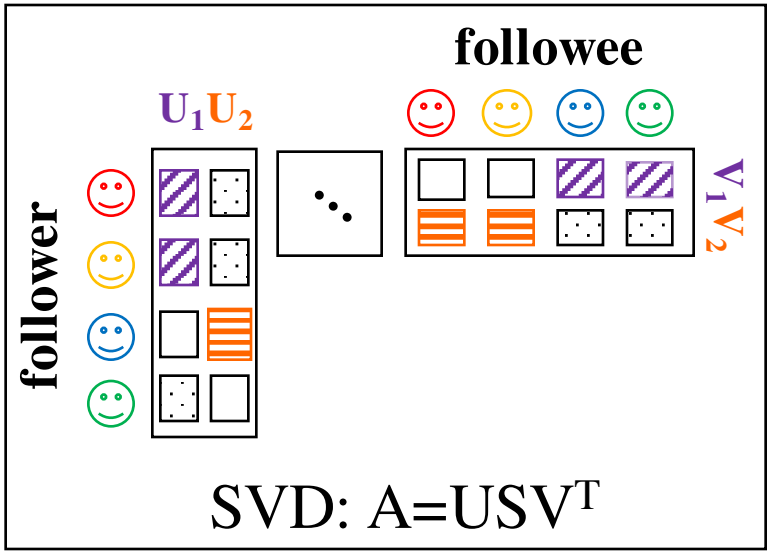
Reorder



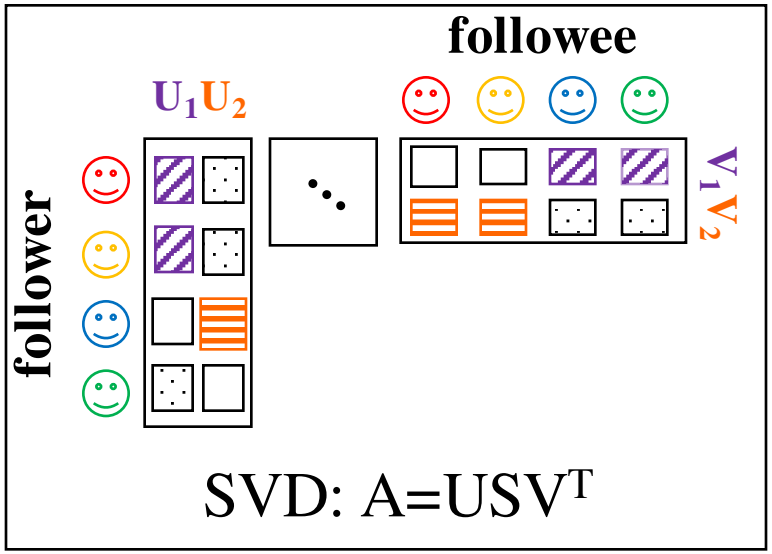
Representation: SVD Reminder



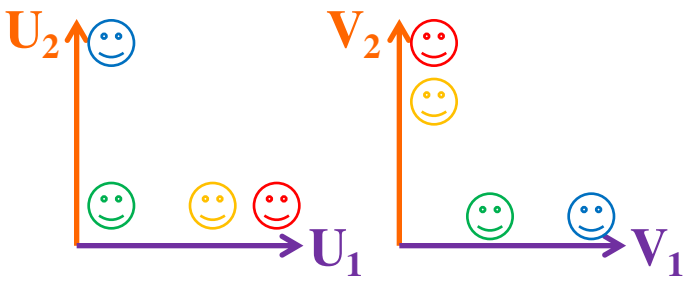




Representation: Spectral Subspace



Pairs of singular vectors:

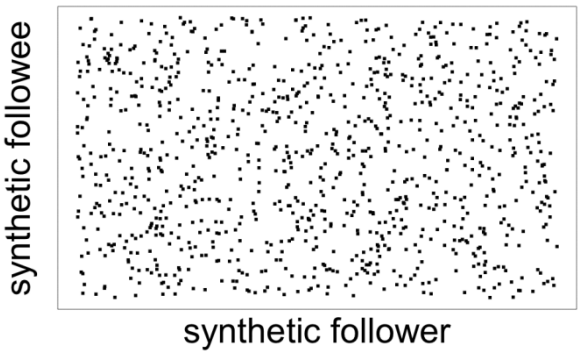


"Spectral Subspace Plot"

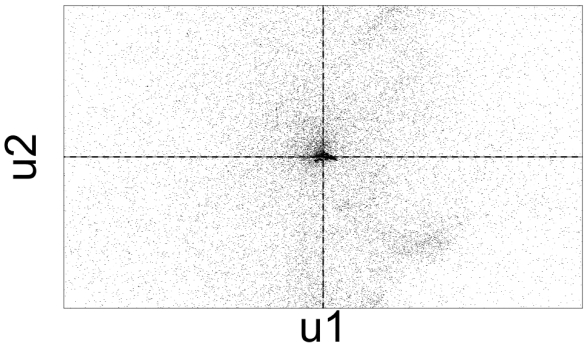
Spectral Subspace Plot: Case #0

- NO lockstep behavior: Scatter

Adjacency Matrix



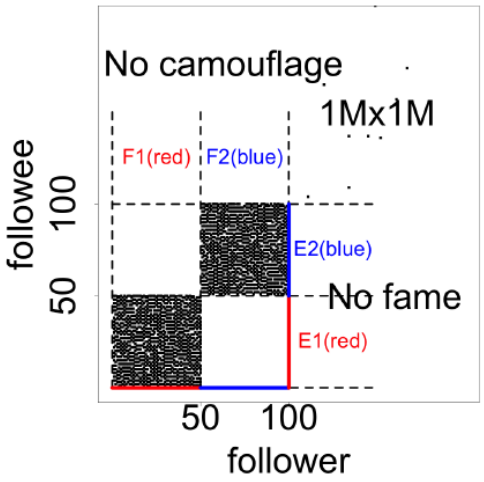
Spectral Subspace Plot



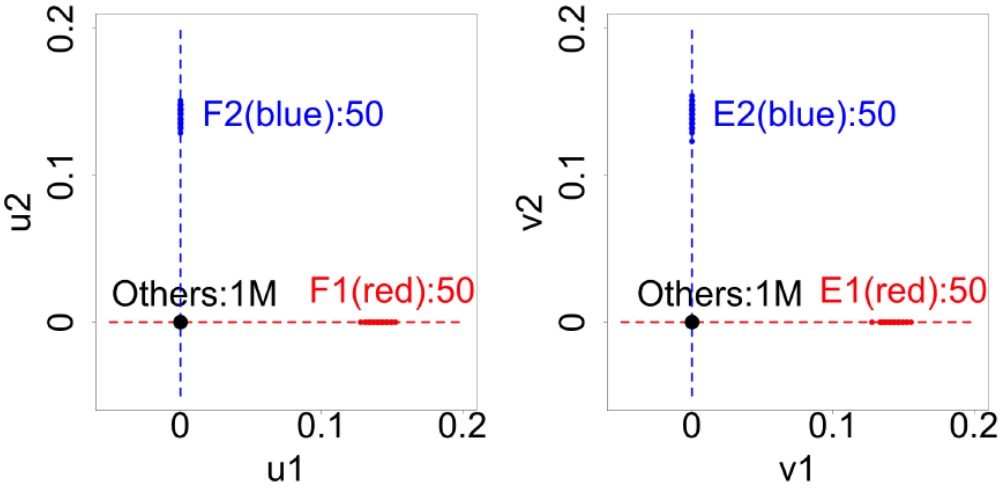
Spectral Subspace Plot: Case #1

- Non-overlapping lockstep: "Rays"

Adjacency Matrix



Spectral Subspace Plot

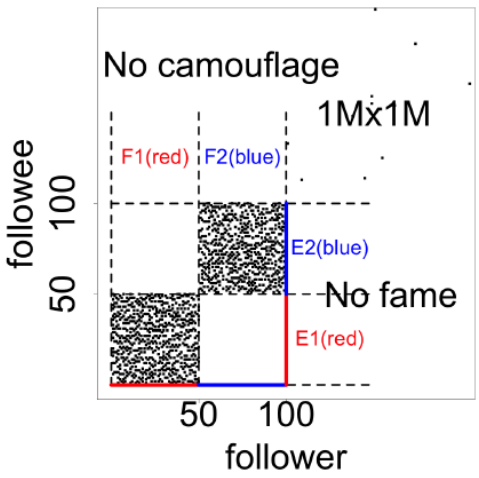


Rule 1 (short "rays"): two blocks, high density (90%), no "camouflage", no "fame"

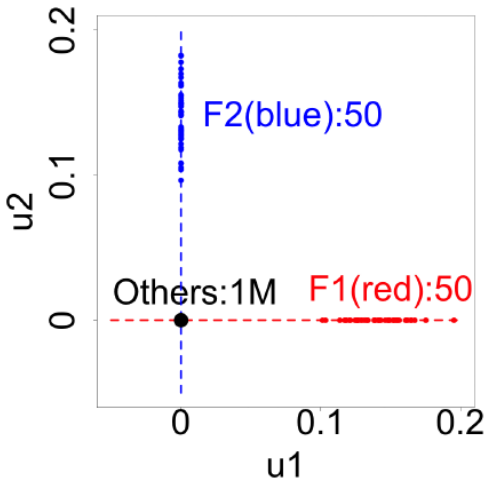
Spectral Subspace Plot: Case #2

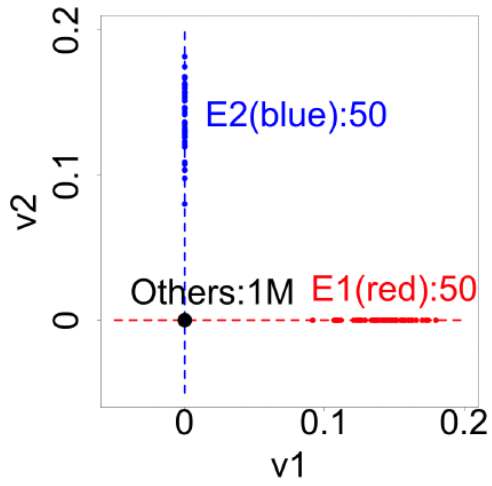
- Non-overlapping: Low density, Elongation

Adjacency Matrix



Spectral Subspace Plot



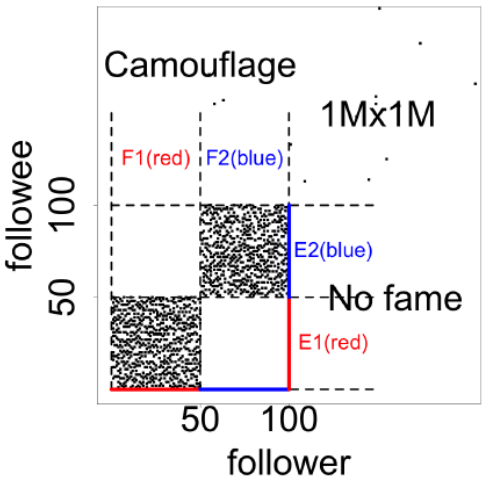


Rule 2 (long "rays"): two blocks, low density (50%), no "camouflage", no "fame"

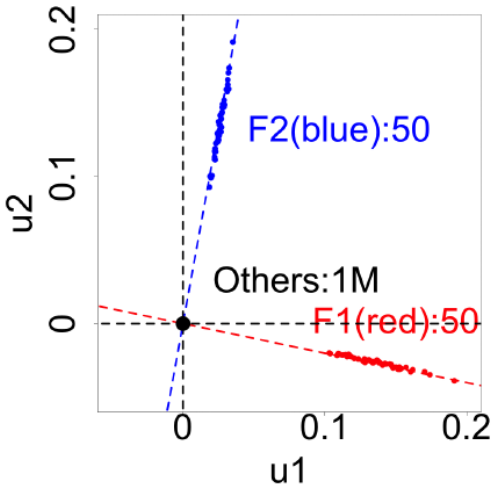
Spectral Subspace Plot: Case #3

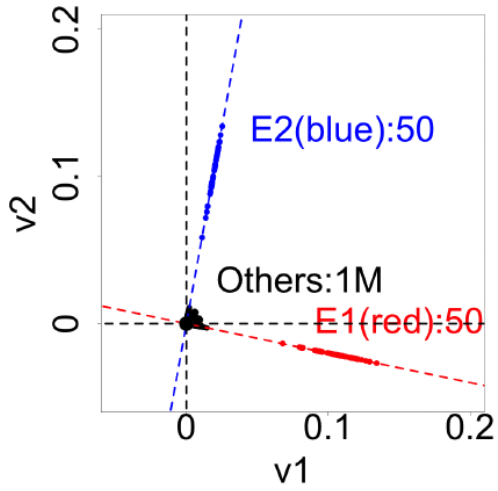
- Non-overlapping: Camouflage/Fame, Tilting

Adjacency Matrix



Spectral Subspace Plot



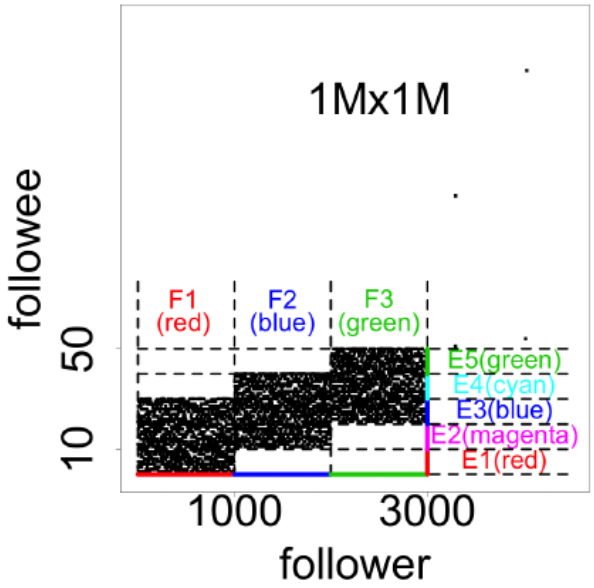


Rule 3 (tilting "rays"): two blocks, with "camouflage", no "fame"

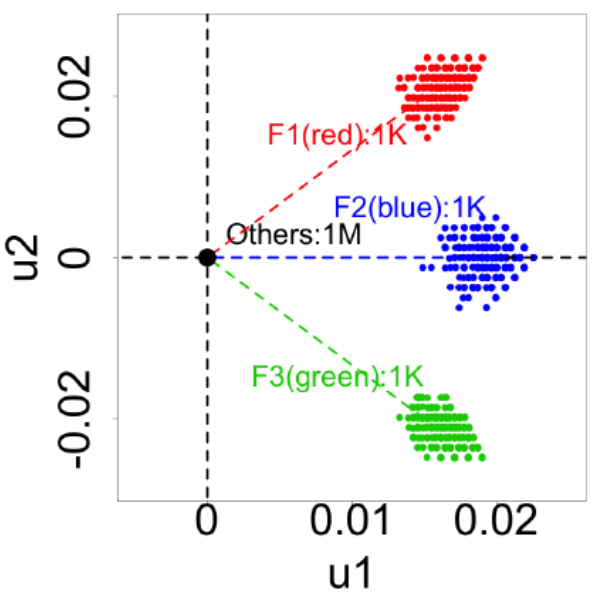
Spectral Subspace Plot: Case #4

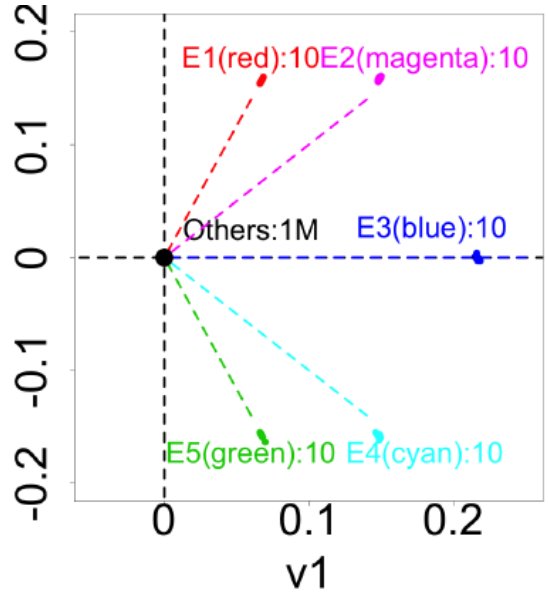
- Overlapping: "Staircase", "Pearls"

Adjacency Matrix



Spectral Subspace Plot





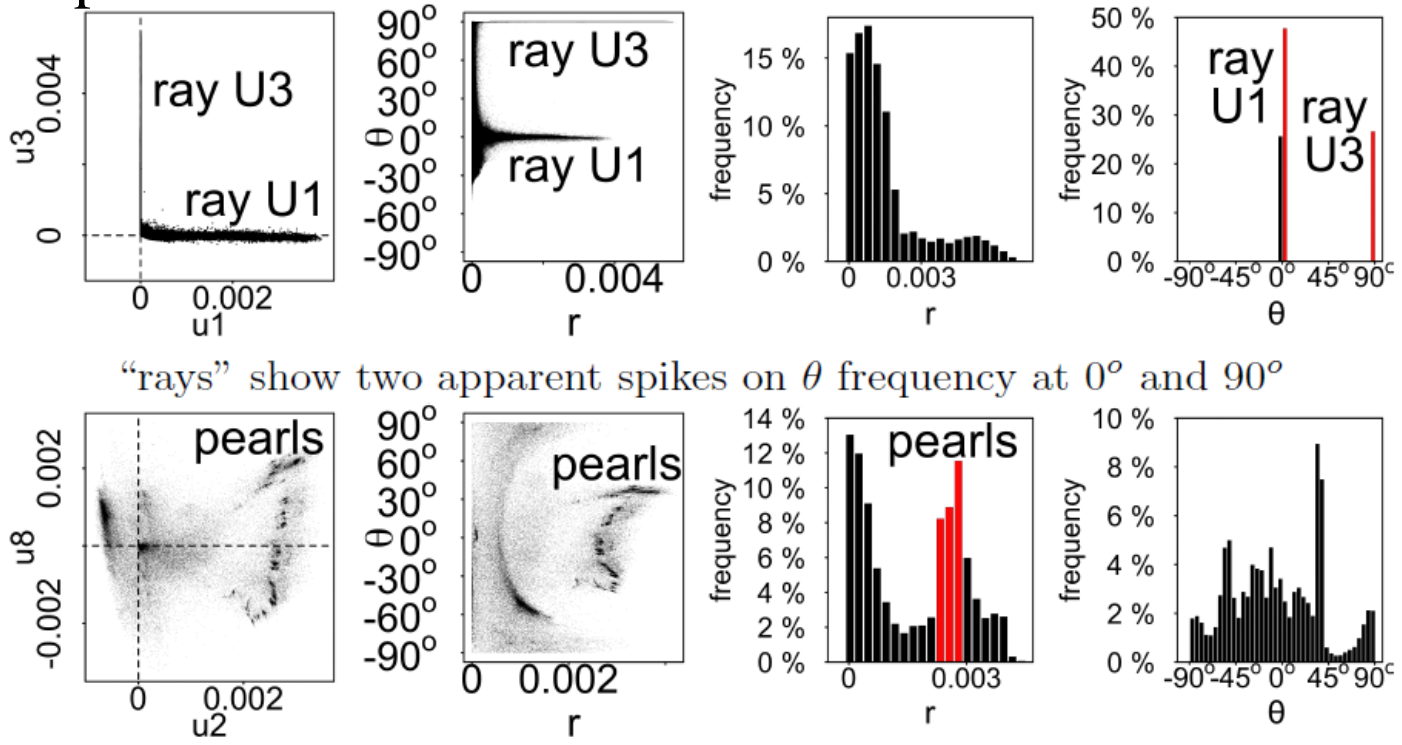
Rule 4 ("pearls"): a "staircase" of three partially overlapping blocks.

Algorithm: Reading & LockInfer

Spectral Subspace Plot

Polar Coordinate Transform

Histograms



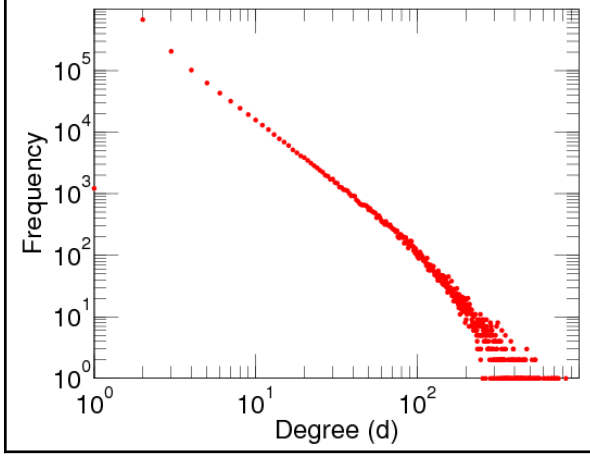
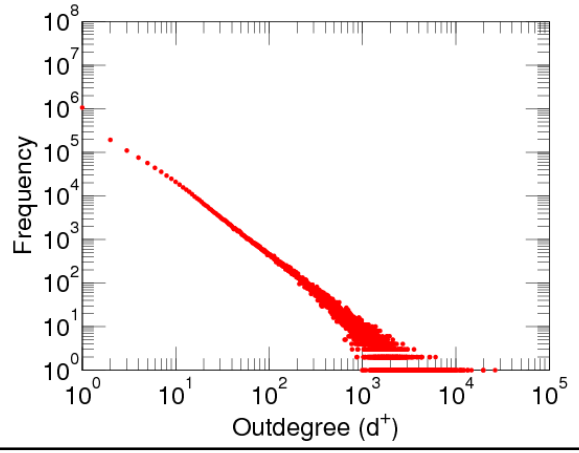
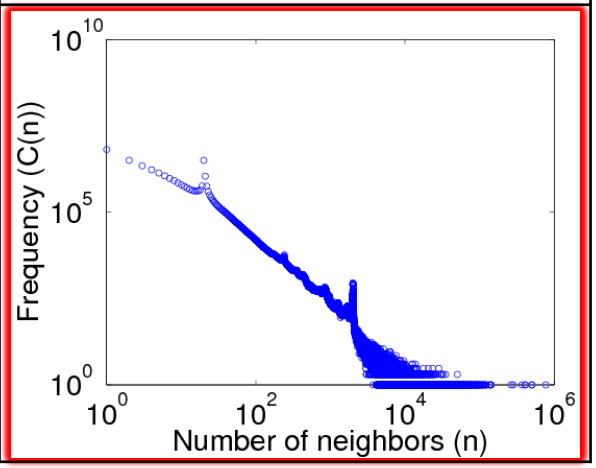
"rays" show two apparent spikes on θ frequency at 0^o and 90^o

"pearls" show a spike on r frequency at a much-greater-than-zero value

High precision but low recall!!!

Out-Degree Distributions

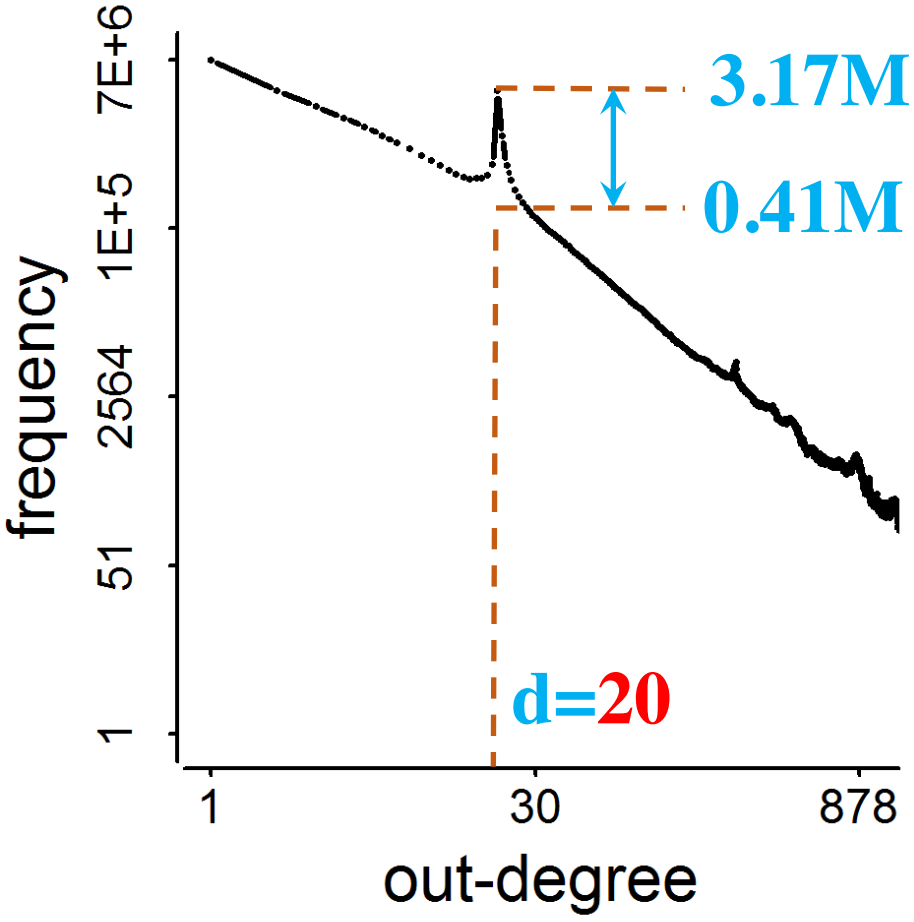
- **Power-law distribution** [Faloutsos *et al*. SIGCOMM; Broder *et al*. Computer Networks; Chung *et al*. PNAS]

DBLP **Author**-publication	**Flickr** **User**-user	**Twitter** **Who**-follows-whom
		

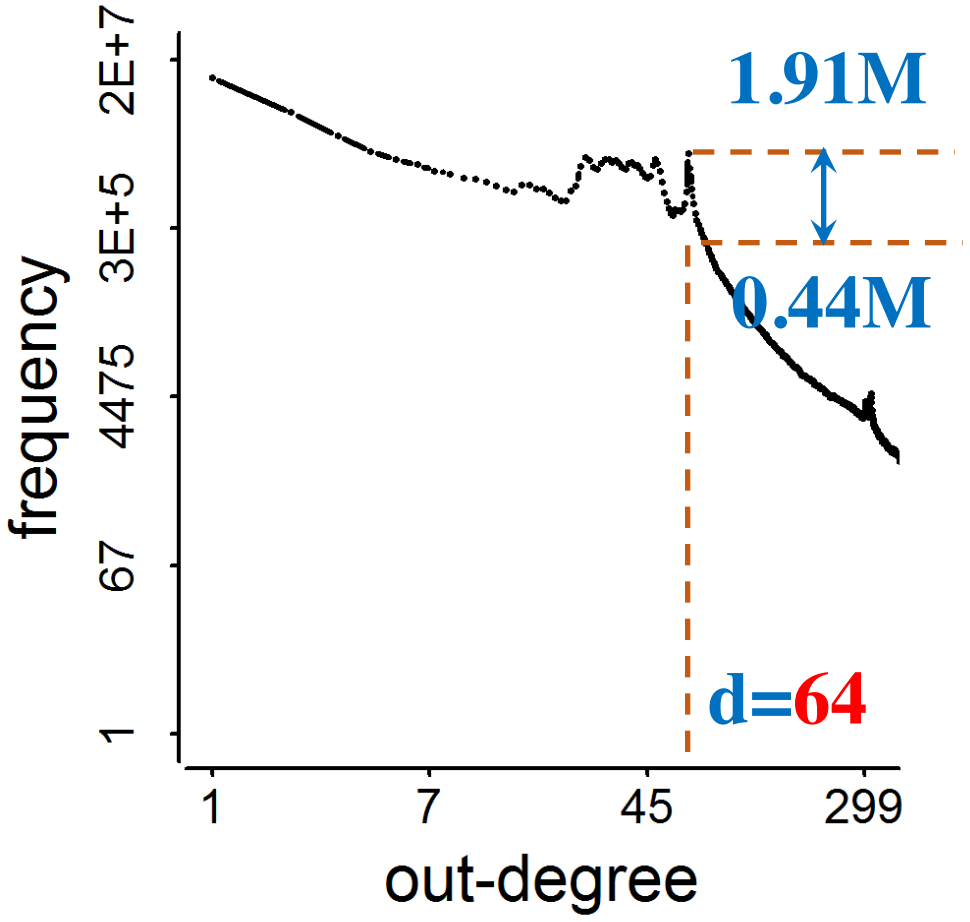
[konect.uni-koblenz.de/networks/]

Spikes!

2009 41M

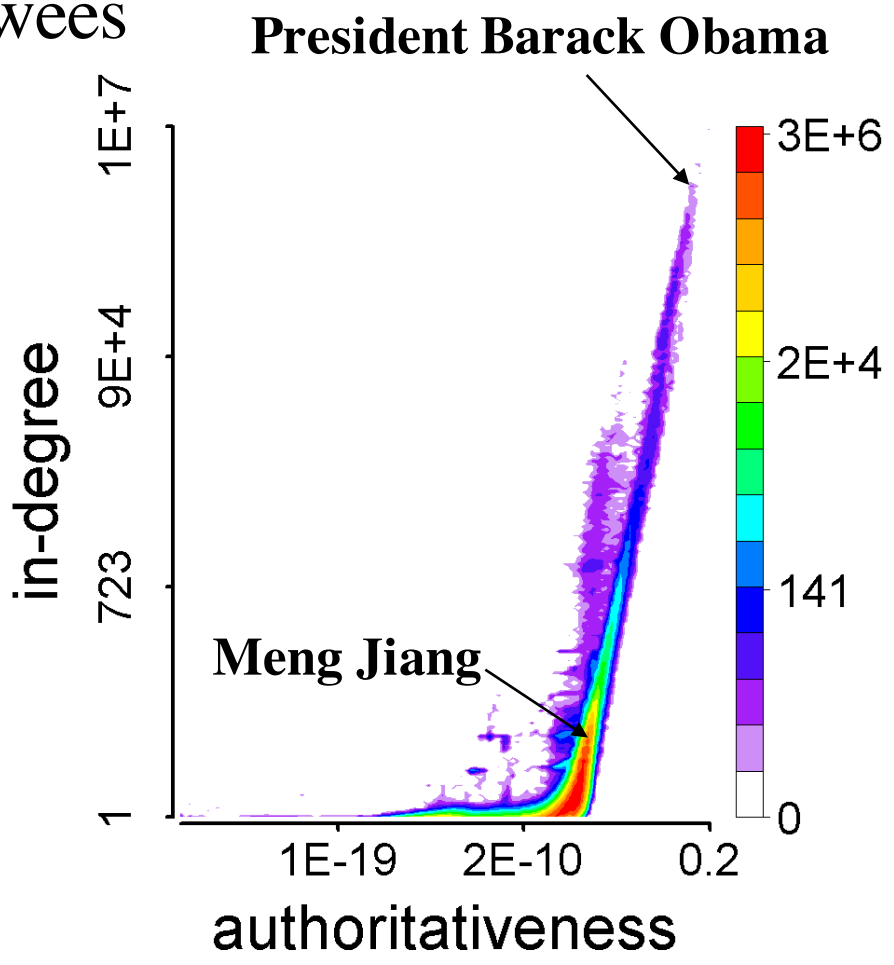


2011 117M



Observation: How They Behave

- Feature space of followees [Kleinberg. JACM]



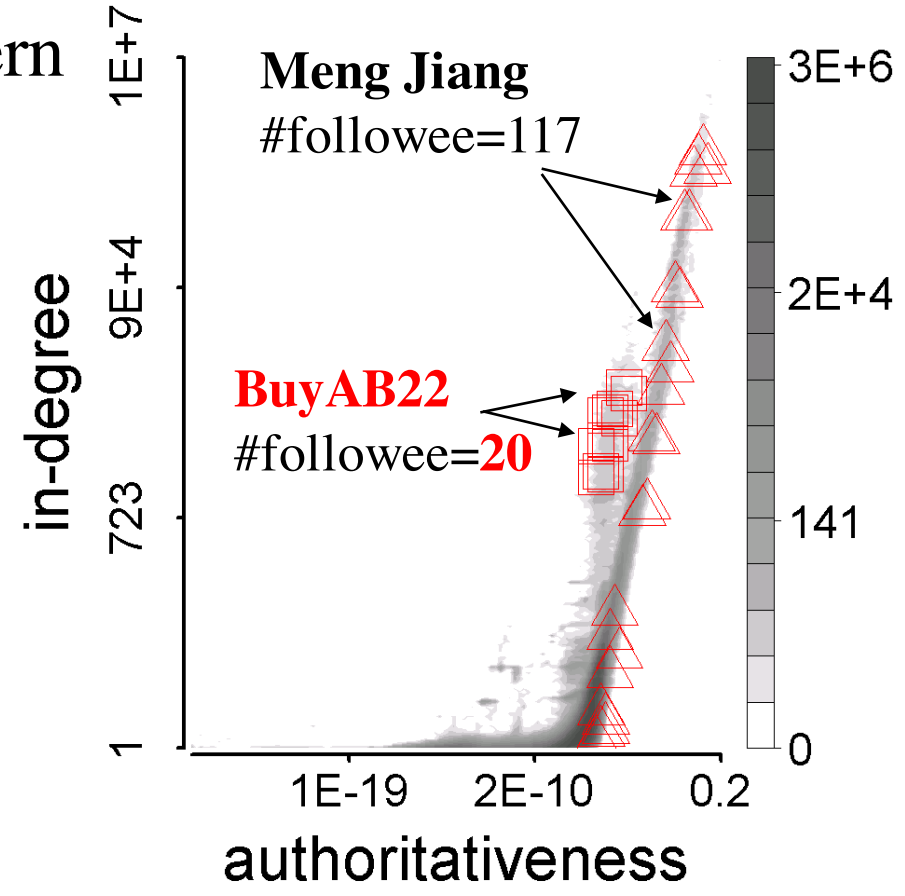
Observation: How They Behave

- Who are their followees?
- Their behavioral pattern
  - **Synchronized**

Similar with each other

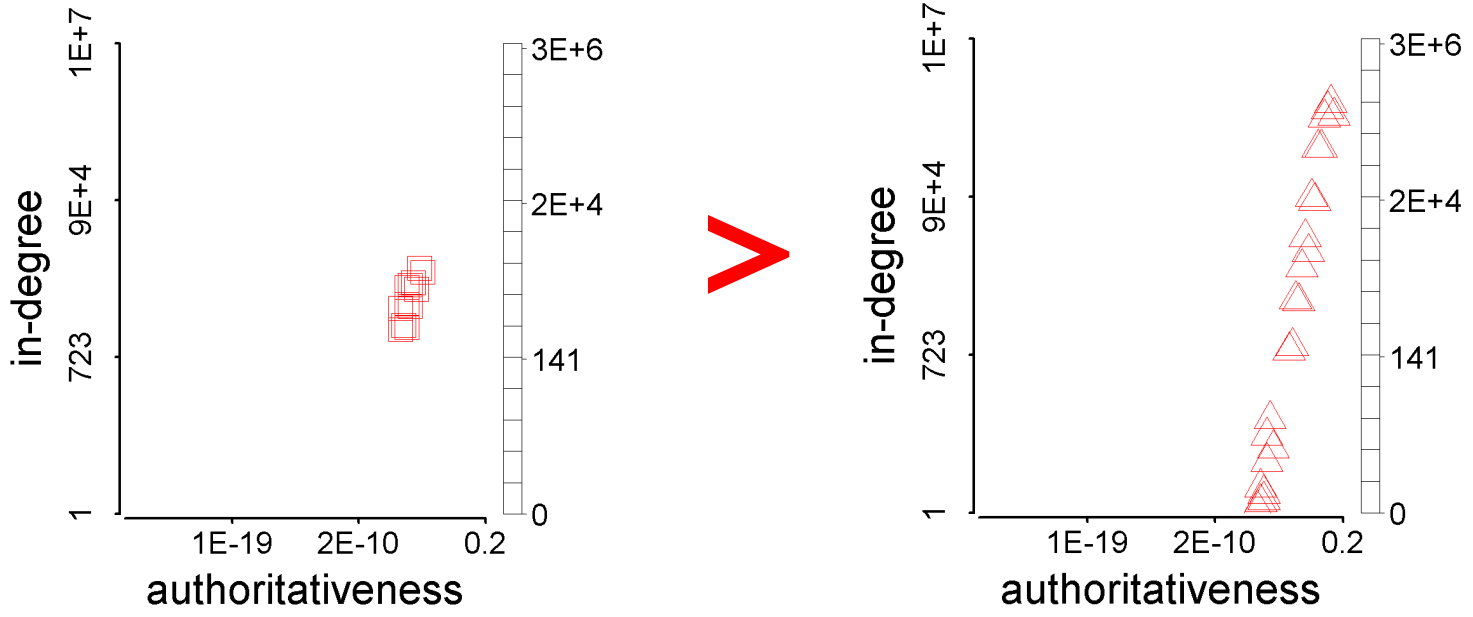
  - **Abnormal**

Different from the majority



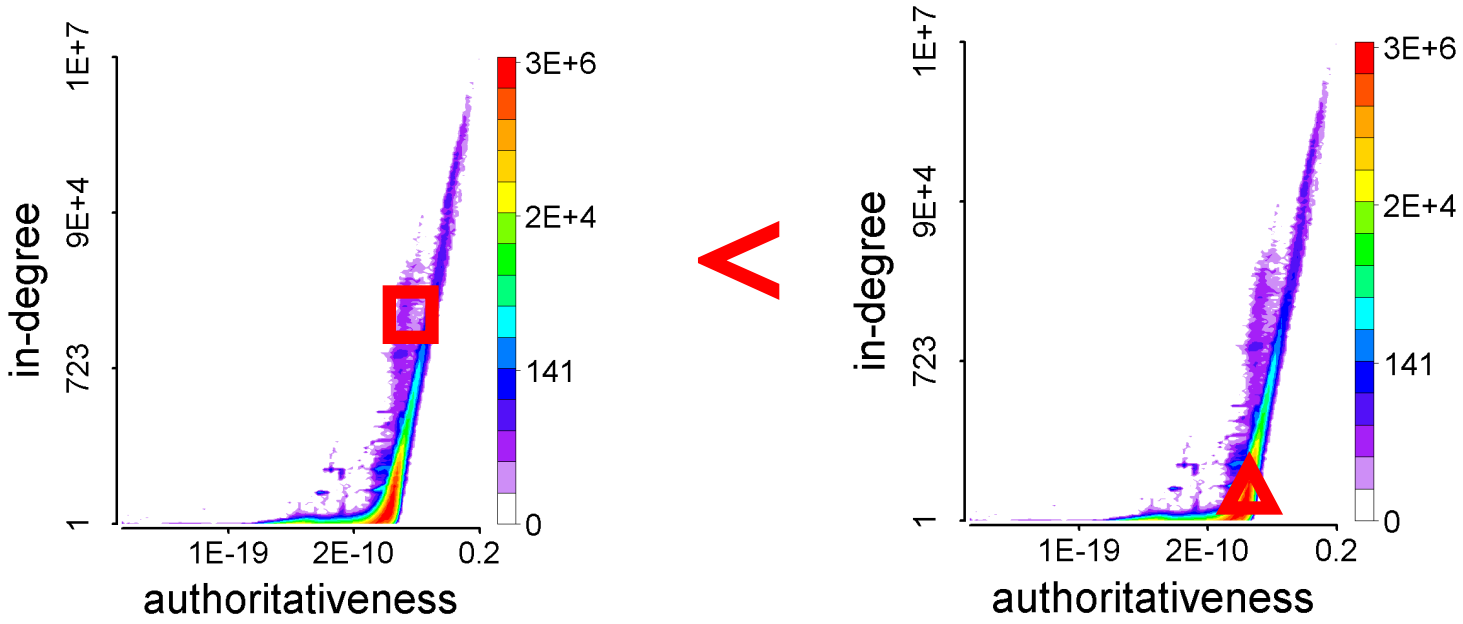
Represent Synchronicity

$$sync(u) = \frac{\sum_{(v,v') \in \mathcal{F}(u) \times \mathcal{F}(u)} \mathbf{p}(v) \cdot \mathbf{p}(v')}{d(u) \times d(u)}$$

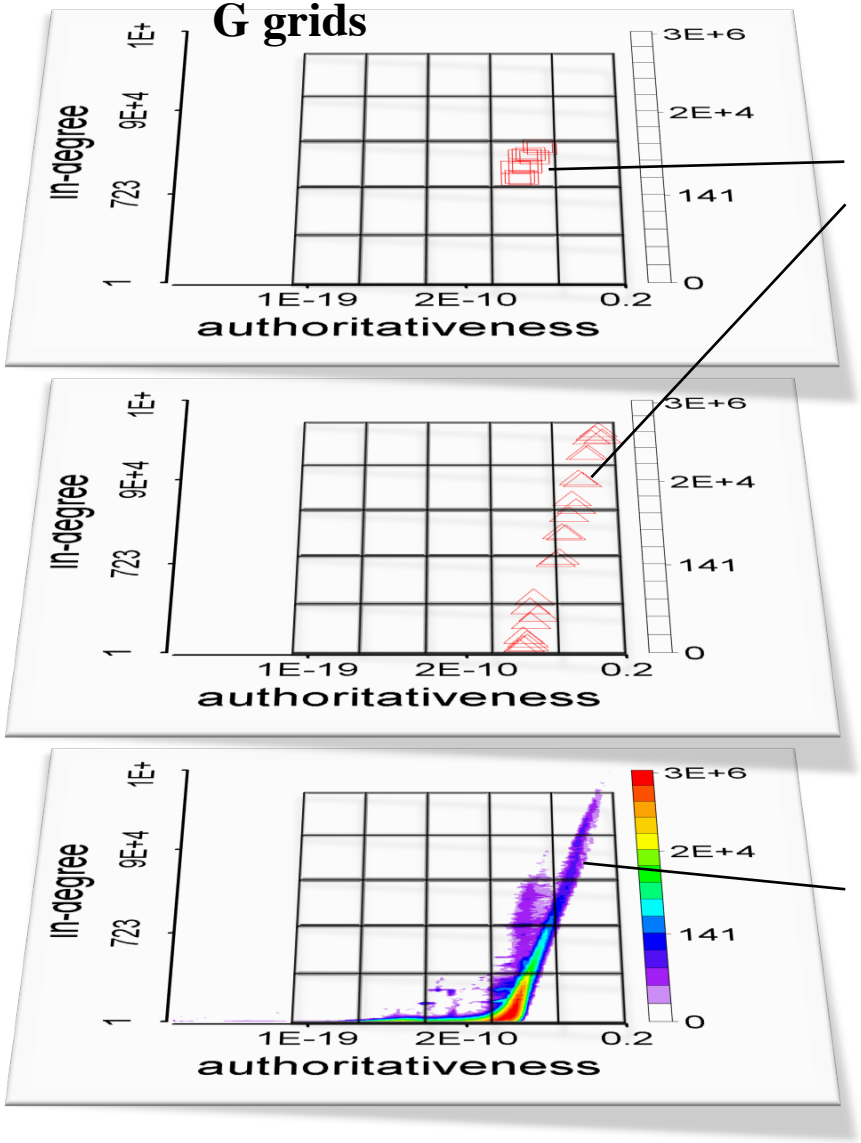


Represent Normality

$$norm(u) = \frac{\sum_{(v,v') \in \mathcal{F}(u) \times \mathcal{U}} \mathbf{p}(v) \cdot \mathbf{p}(v')}{d(u) \times N}$$



Theorem: Synchronicity vs. Normality



fp_g: #foreground points in grid **g**
$\sum fp_g = F = d(u)$ (#followees of **u**)

Given normality

$$n = \sum(fp_g/F)\,(bp_g/B) = \sum f_g b_g,$$

find minimal synchronicity

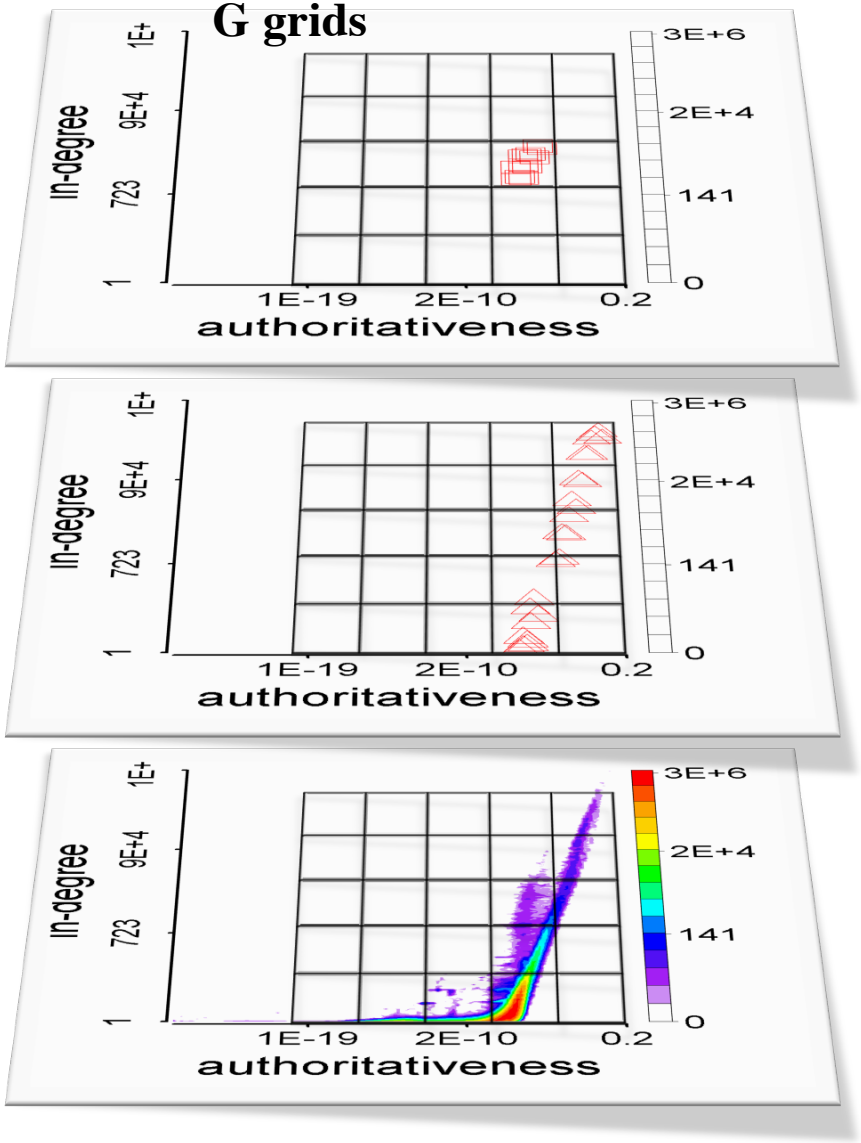
$$s = \sum(fp_g/F)\,(fp_g/F) = \sum f_g^2$$

where

$$\sum f_g = 1, \sum b_g = 1$$

bp_g: #background points in grid **g**
$\sum bp_g = B = N$ (#all users)

Theorem: Synchronicity vs. Normality



Solution.

Lagrange multiplier:

minimize $s(f_g) = \sum f_g^2$

subject to $\sum f_g = 1, \sum f_g b_g = n$

Lagrange function:

$F(f_g, \lambda, \mu) = (\sum f_g^2) + \lambda(\sum f_g - 1) + \mu(\sum f_g b_g - n)$

Gradients:

$$\begin{cases} \nabla_{f_g} F = 2 f_g + \lambda + \mu b_g = 0 \\ \nabla_{\lambda} F = \sum f_g - 1 = 0 \\ \nabla_{\mu} F = \sum f_g b_g - n = 0 \end{cases}$$

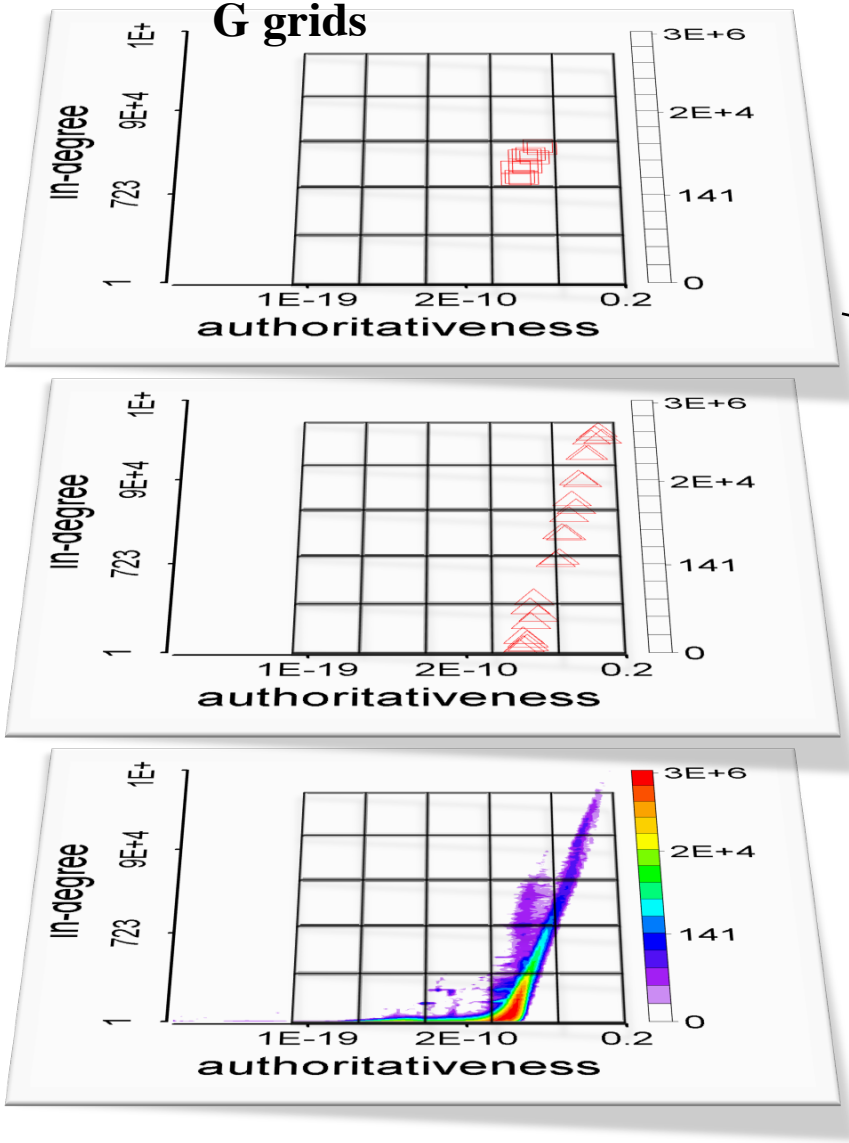
$$\begin{cases} 2 + \lambda G + \mu = 0 & \times \Sigma \\ 2n + \lambda + \mu s_b = 0 & \times b_g \Sigma \\ 2 s_{min} + \lambda + \mu n = 0 & \times f_g \Sigma \end{cases}$$

where $s_b = \sum b_g^2$.

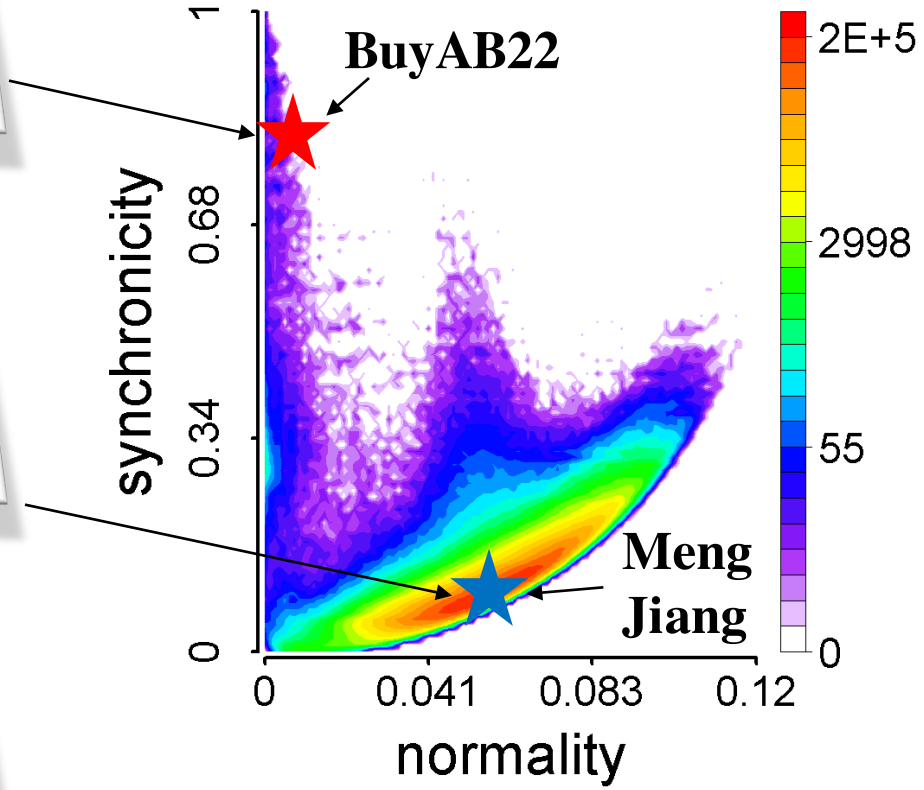
Therefore,

$$s_{min} = \frac{-G n^2 + 2n - s_b}{1 - G s_b}$$

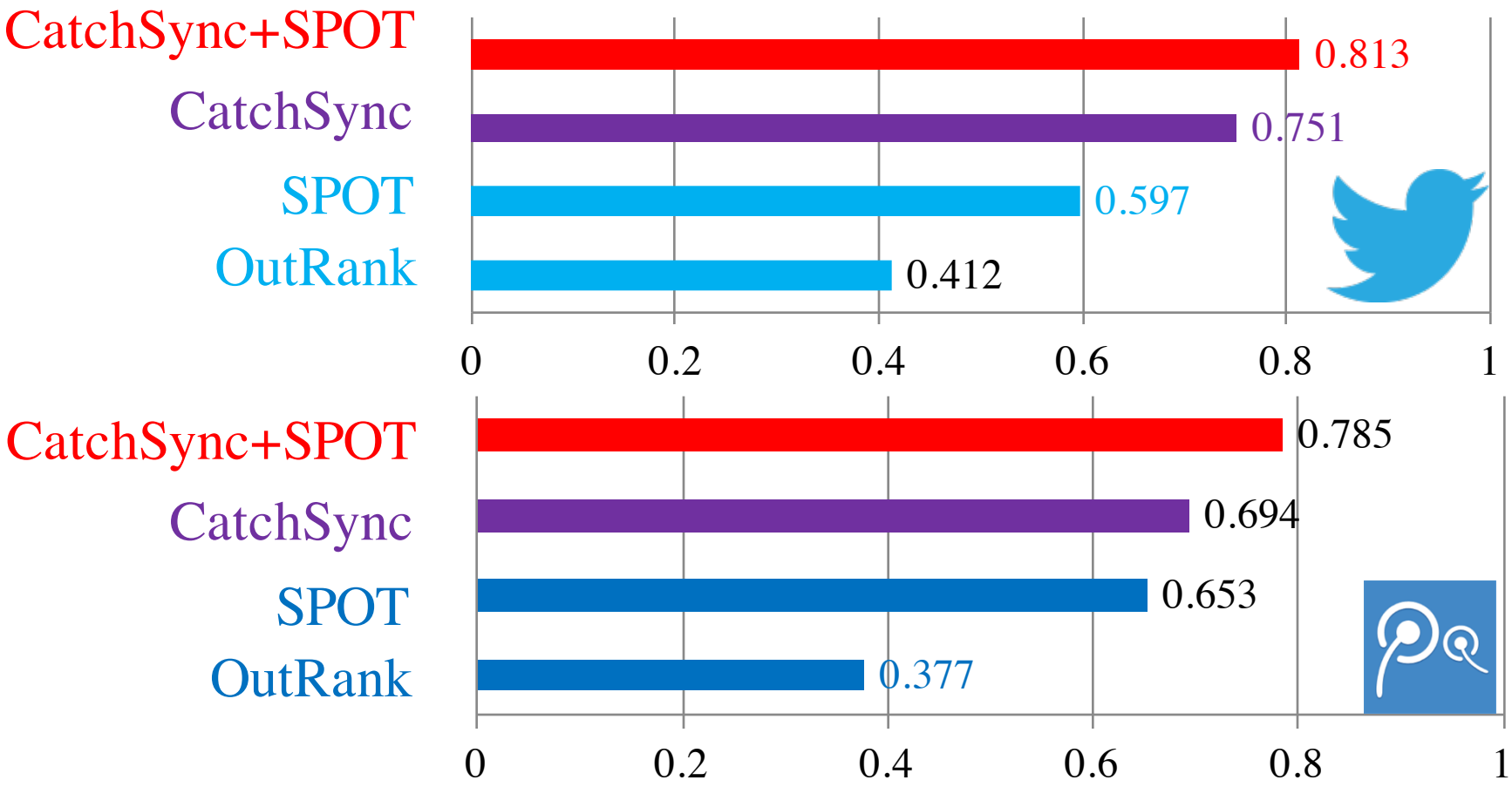
CatchSync Algorithm



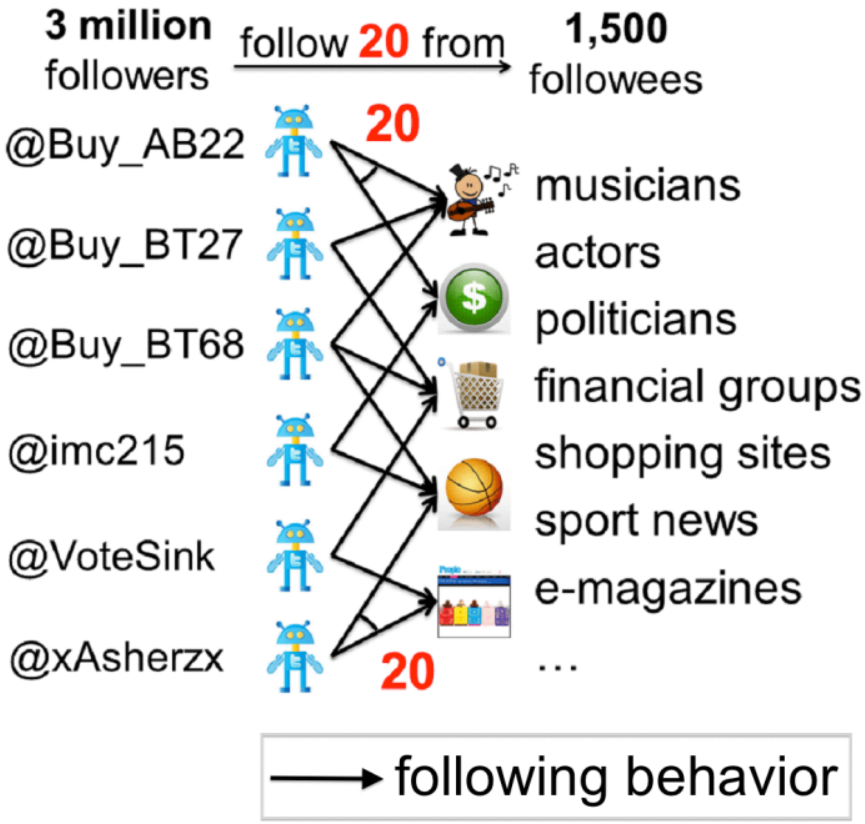
$$s_{min} = \frac{-G\,n^2 + 2\,n - s_b}{1 - G\,s_b}$$

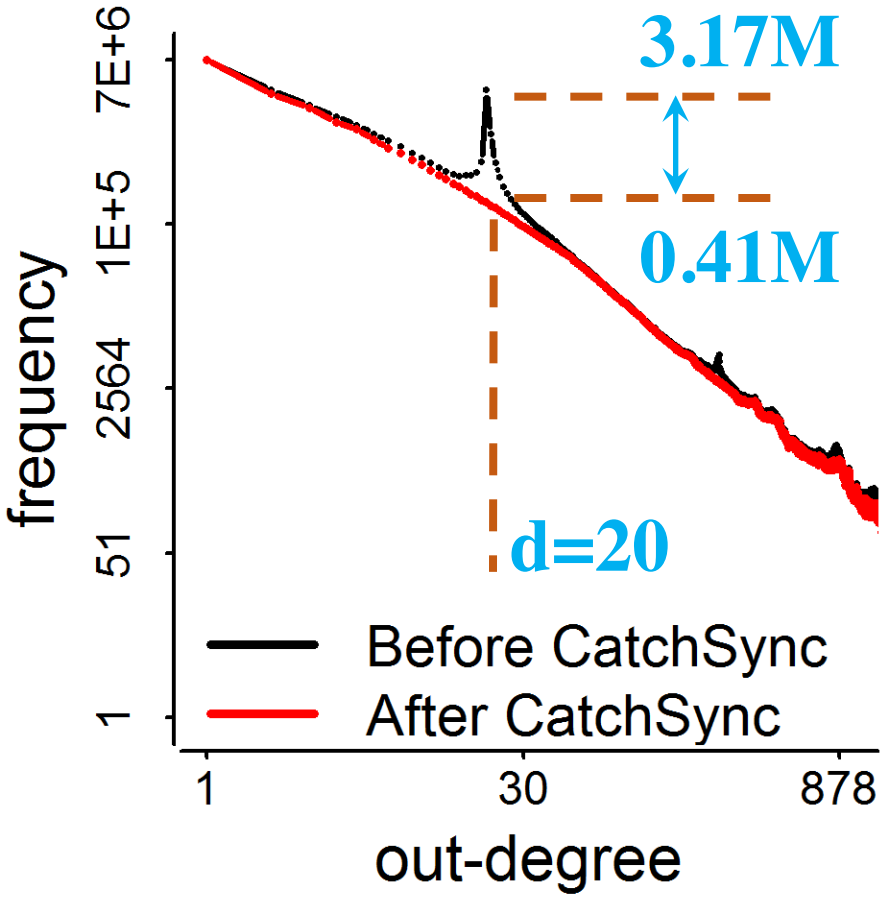


Experimental Results



Experimental Results





Impact

- **M. Jiang**, P. Cui, A. Beutel, C. Faloutsos and S. Yang. "CatchSync: Catching Synchronized Behavior in Large Directed Graphs" in **KDD'14 Best Paper Finalist**, Aug 2014. (#citations = **36**)
- Taught in
  - **CMU 15-826:** Multimedia Databases and Data Mining
  - **UMich EECS 598:** Graph Mining and Exploration at Scale
  - **ASONAM'16 Tutorial:** "Identifying Malicious Actors on Social Media" by S. Kumar, F. Spezzano, V.S. Subrahmanian
- Deployed in Weibo? Unfortunately, in July 2014…

Acknowledgement

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Microsoft Research
微软亚洲研究院
Tencent 腾讯

References

D. Blei, A. Ng, and M. Jordan. "Latent dirichlet allocation." JMLR, 2003.

J. Herlocker, J. Konstan, L. Terveen, J. Riedl. "Evaluating collaborative filtering recommender systems." ACM TOIS, 2004.

Y. Koren, R. Bell, C. Volinsky. "Matrix factorization techniques for recommender systems." Computer, 2009.

Y. Koren. "Factorization meets the neighborhood: A multifaceted collaborative filtering model." KDD, 2008.

Y. Koren. "Collaborative filtering with temporal dynamics." CACM, 2010.

M. Balabanovic and Y. Shoham. "FAB: Content-based, collaborative recommendation." CACM, 1997.

N. Liu and Q. Yang. "Eigenrank: A ranking-oriented approach to collaborative filtering." SIGIR, 2008.

N. Liu, M. Zhao, and Q. Yang. "Probabilistic latent preference analysis for collaborative filtering." CIKM, 2009.

References

H. Ma, H. Yang, M. Lyu, and I. King. "Sorec: Social recommendation using probabilistic matrix factorization." CIKM, 2008.

H. Ma, T. Zhou, M. Lyu, and I. King. "Improving recommender systems by incorporating social contextual information." ACM TOIS, 2011.

H. Ma, D. Zhou, C. Liu, M. Lyu, and I. King. "Recommender systems with social regularization." WSDM, 2011.

J. Leskovec, A. Singh, and J. Kleinberg. "Patterns of influence in a recommendation network." PAKDD, 2006.

P. Massa and A. Paolo. "Trust-aware recommender systems." RecSys, 2007.

M. Jamali and E. Martin. "TrustWalker: A random walk model for combining trust-based and item-based recommendation." KDD, 2009.

H. Ma, I. King, and M. Lyu. "Learning to recommend with social trust ensemble." SIGIR, 2009.

H. Ma. I. King, and M. Lyu. "Learning to recommend with explicit and implicit social relations." ACM TIST, 2011.

References

M. Faloutsos, P. Faloutsos, and C. Faloutsos. "On power-law relationships of the internet topology." SIGCOMM, 1999.

A. Broder, R. Kumar, F. Maghoul, P. Raghavan, S. Rajagopalan, R. Stata, A. Tomkins, and J. Weiner. "Graph structure in the web." Computer Networks, 2000.

F. Chung and L. Lu. "The average distances in random graphs with given expected degrees." PNAS, 2002.

J. Kleinberg. "Authoritative sources in a hyperlinked environment." JACM, 1999.

H. Kwak, C. Lee, H. Park, and S. Moon. "What is Twitter, a social network or a news media?" WWW, 2010.

B. Hooi, H.A. Song, A. Beutel, N. Shah, K. Shin, and C. Faloutsos. "Fraudar: Bounding graph fraud in the face of camouflage." KDD, 2016.

C. Aggarwal and J. Han. "Frequent pattern mining." Springer, 2014.

J. Han, J. Pei, B. Mortazavi-Asl, Q. Chen, U. Dayal, and M. Hsu. "FreeSpan: Frequent pattern-projected sequential pattern mining." KDD, 2000.

References

X. Yan and J. Han. "gspan: Graph-based substructure pattern mining." ICDM, 2003.

X. Yan and J. Han. "CloseGraph: Mining closed frequent graph patterns." KDD, 2003.

Y. Sun, J. Han, X. Yan, P.S. Yu, and T. Wu. "PathSim: Meta path-based top-k similarity search in heterogeneous information networks." VLDB, 2011.

Y. Sun, Y. Yu, and J. Han. "Ranking-based clustering of heterogeneous information networks with star network schema." KDD, 2009.

Y. Sun, J. Han, P. Zhao, Z. Yin, H. Cheng, and T. Wu. "RankClus: Integrating clustering with ranking for heterogeneous information network analysis." EDBT, 2009.

Y. Sun, R. Barber, M. Gupta, C. Aggarwar, and J. Han. "Co-author relationship prediction in heterogeneous bibliographic networks." ASONAM, 2011.

A. El-Kishky, Y. Song, C. Wang, C.R. Voss, and J. Han. "Scalable topical phrase mining from text corpora." VLDB, 2014.

J. Liu, J. Shang, C. Wang, X. Ren, and J. Han. "Mining quality phrases from massive text corpora." SIGMOD, 2015.

References

X. Ren, A. El-Kishky, C. Wang, F. Tao, C.R. Voss, and J. Han. "Effective entity recognition and typing by relation phrase-based clustering." KDD, 2015.

X. Ren, W. He, M. Qu, C.R. Voss, H. Ji, and J. Han. "Label noise reduction in entity typing by heterogeneous partial-label embedding." KDD, 2016.

C. Wang, M. Danilevsky, N. Desai, Y. Zhang, P. Nguyen, T. Taula, and J. Han. "A phrase mining framework for recursive construction of a topical hierarchy." KDD, 2013.

E.E. Papalexakis, C. Faloutsos, N.D. Sidiropoulos. "ParCube: Sparse parallelizable tensor decompositions." PKDD, 2012.

D. Koutra, U. Kang, J. Vreeken, and C. Faloutsos. "VOG: Summarizing and understanding large graphs." SDM, 2014.

R. Gupta, A. Halevy, X. Wang, S.E. Whang, and F. Wu. "Biperpedia: An ontology for search applications." VLDB, 2014.

M. Yahya, S. Whang, R. Gupta, and A. Halevy. "ReNoun: Fact extraction for nominal attributes." EMNLP, 2014.

A. Halevy, N. Noy, S. Sarawagi, S.E. Whang, and X. Yu. "Discovering structure in the universe of attribute names." WWW, 2016.

References

Q. Li, Y. Li, J. Gao, B. Zhao, W. Fan, and J. Han. "Resolving conflicts in heterogeneous data by truth discovery and source reliability estimation." SIGMOD, 2014.

Q. Li, Y. Li, J. Gao, L. Su, B. Zhao, M. Demirbas, W. Fan, and J. Han. "A confidence-aware approach for truth discovery on long-tail data." VLDB, 2014.

F. Ma, Y. Li, Q. Li, M. Qiu, J. Gao, S. Zhi, L. Su, B. Zhao, H. Ji, and J. Han. "Faitcrowd: Fine grained truth discovery for crowdsourced data aggregation." KDD, 2015.

Y. Li, J. Gao, C. Meng, Q. Li, L. Su, B. Zhao, W. Fan, and J. Han. "A survey on truth discovery." KDD Explorations Newsletter, 2016.

S. Zhi, B. Zhao, W. Tong, J. Gao, D. Yu, H. Ji, and J. Han. "Modeling truth existence in truth discovery." KDD, 2015.

S. Kumar, R. West, and J. Leskovec. "Disinformation on the Web: Impact, characteristics, and detection of Wikipedia hoaxes." WWW, 2016.

S. Kumar, F. Spezzano, and V.S. Subrahmanian. "Identifying malicious actors on social media." ASONAM, 2016. (tutorial)

Thank you!

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