Inferring Strange Behavior from Connectivity Pattern in Social Networks

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Carnegie Mellon University

What is Strange Behavior?

- "Who-follows-whom" network with **billions** of edges: Twitter, Weibo, etc.

What is Strange Behavior?

- Sell followers: “Become a Twitter Rockstar”

0.9 TWD per edge

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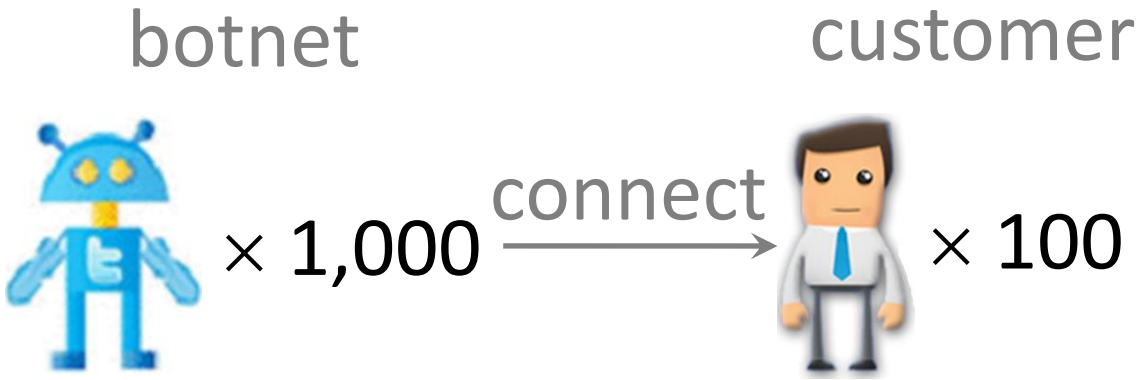
What is Strange Behavior?



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What is Strange Behavior?

#follower↑+1,000

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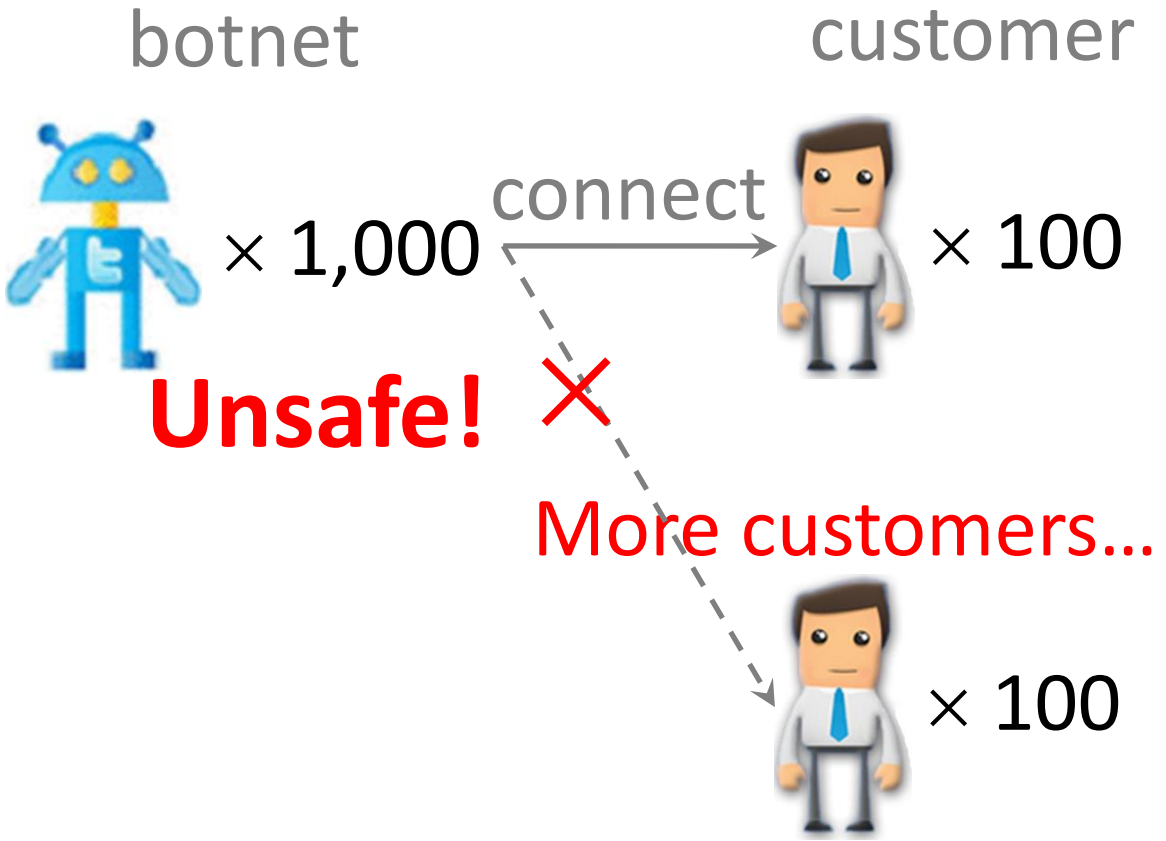
What is Strange Behavior?



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What is Strange Behavior?

botnet

customer

× 1,000 connect

× 100

More customers…

× 5,000 connect

× 100

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What is Strange Behavior?

botnet customer


× 1,000 connect

× 100

I want more followers…


× 5,000 connect

× 100

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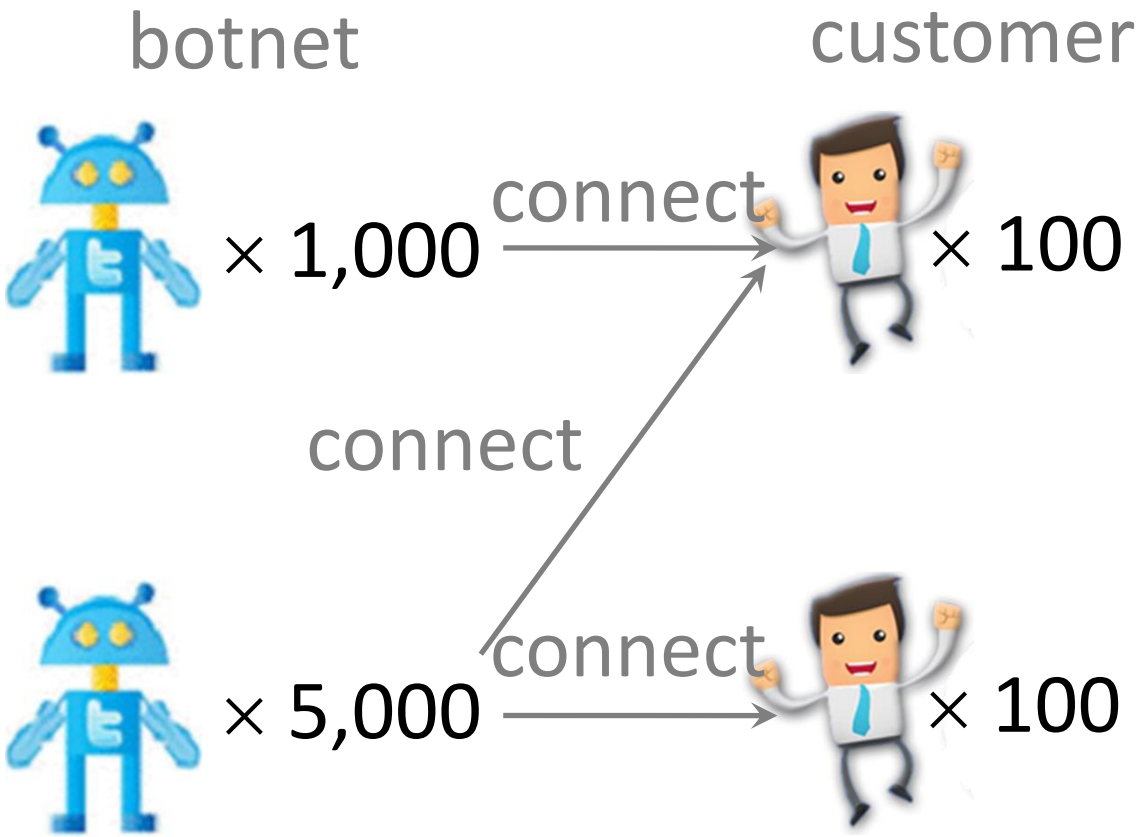
What is Strange Behavior?



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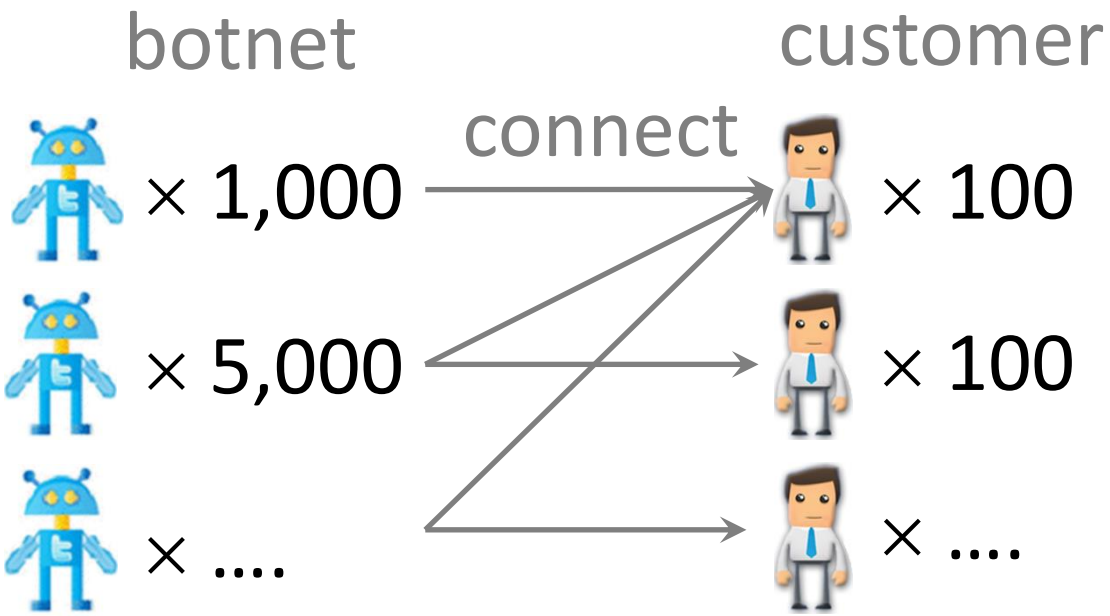
What is Strange Behavior?



More groups of customers

More groups of botnets

More companies….

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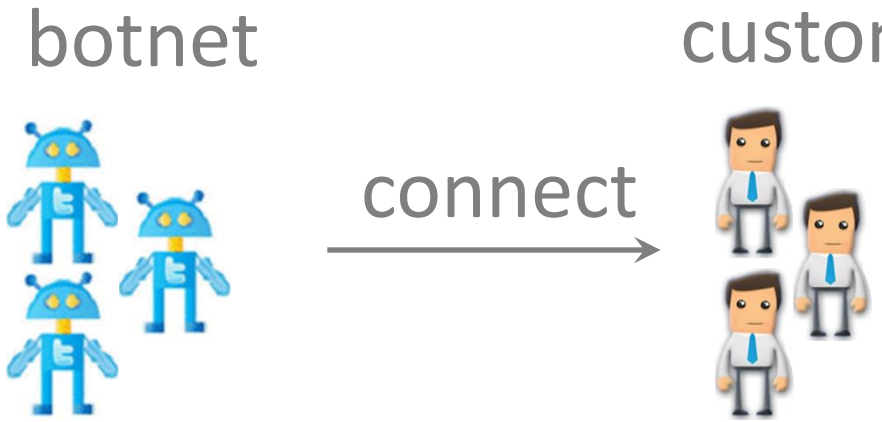
What is Strange Behavior?



Detect dense biparitite cores!

How can we evade detection?

Some other activity!

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What is Strange Behavior?

botnet

customer

connect

"Camouflage":
may connect
to popular idols
to look normal

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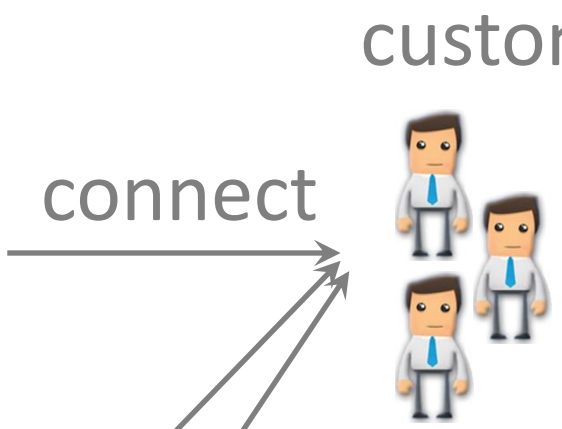
What is Strange Behavior?



"Fame":
may have
a few honest
followers

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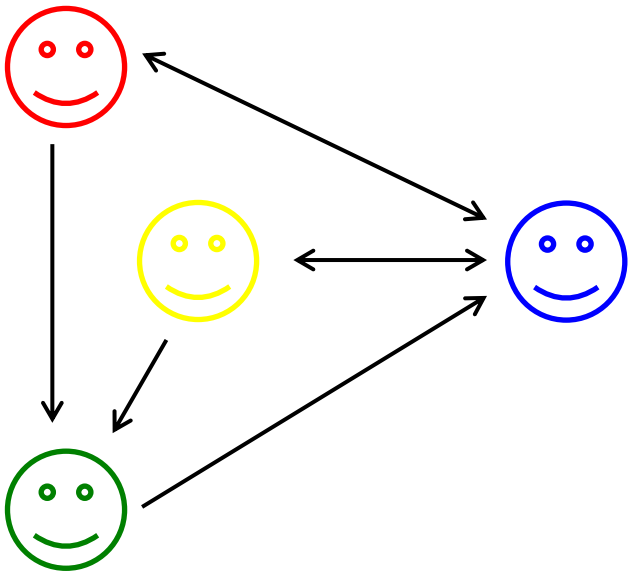
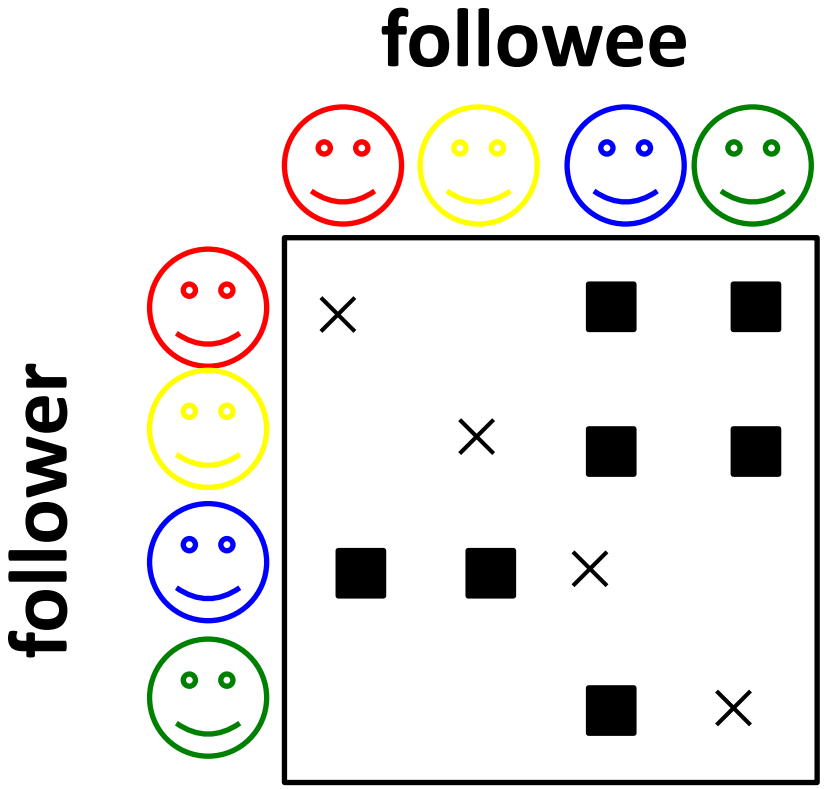
Adjacency Matrix Reminder



Graph Structure

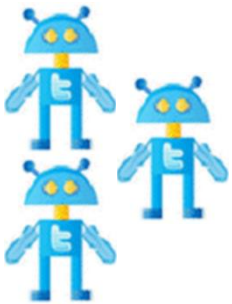


Adjacency Matrix

Strange ⟶ Lockstep Behavior

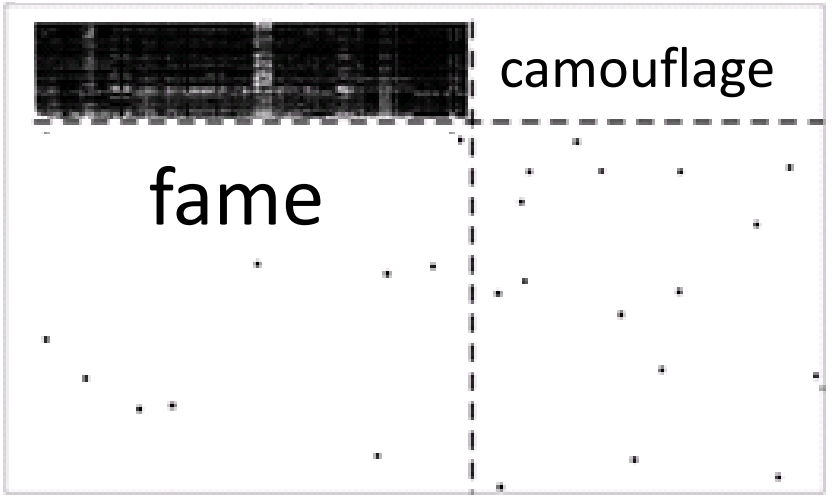
botnet

customer



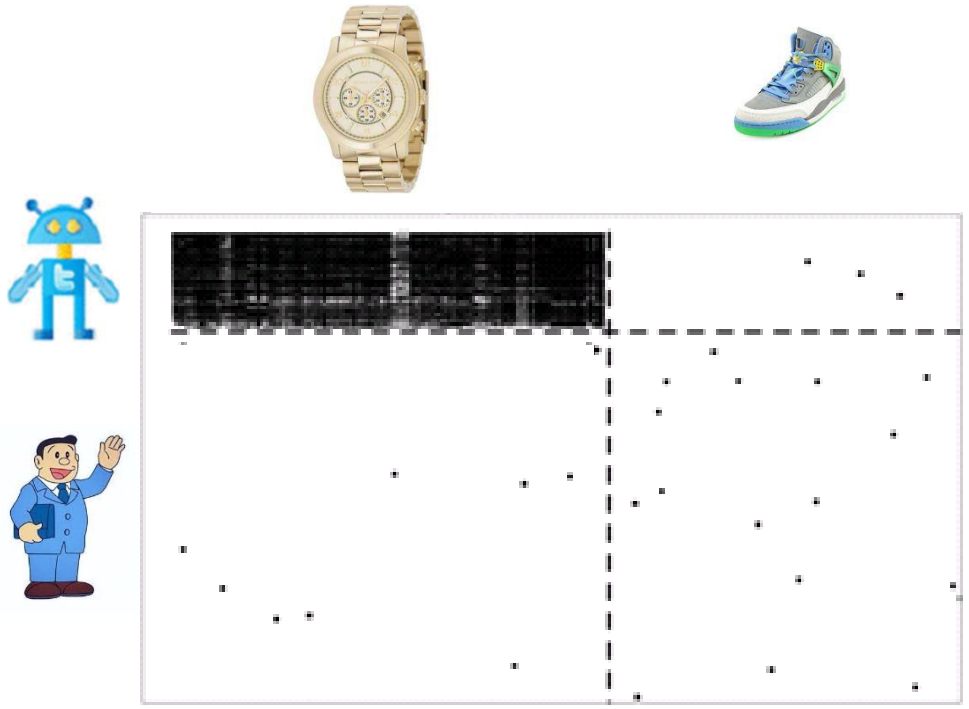
connect

- Groups
- Acting together
- Little other activity



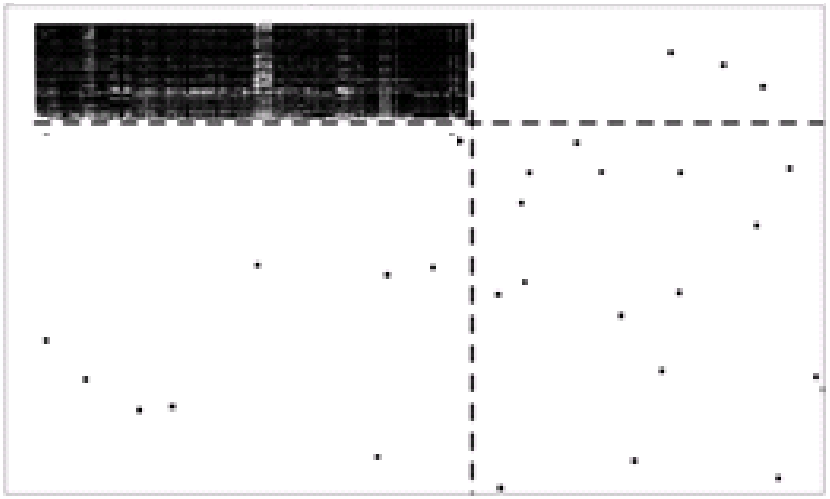
More Applications

- eBay reviews



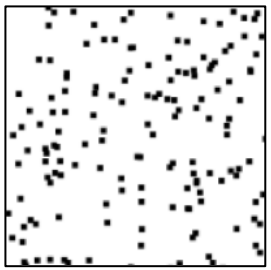
More Applications

- Facebook “Likes”

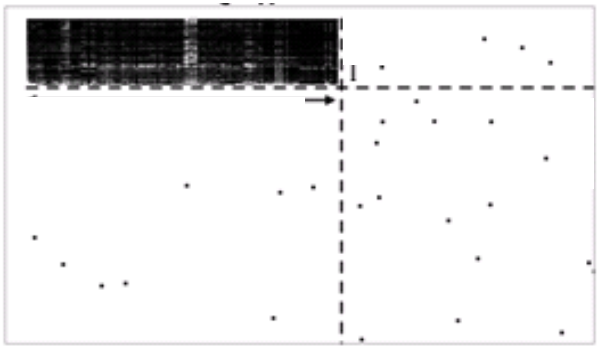


Problem Definition

- Given adjacency matrix



reordering

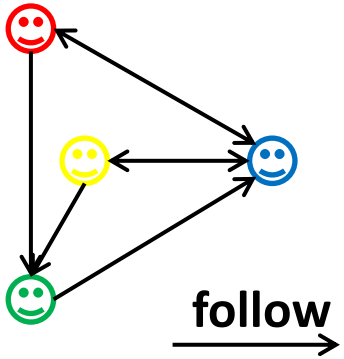


- Find Strange = “Lockstep” Behavior

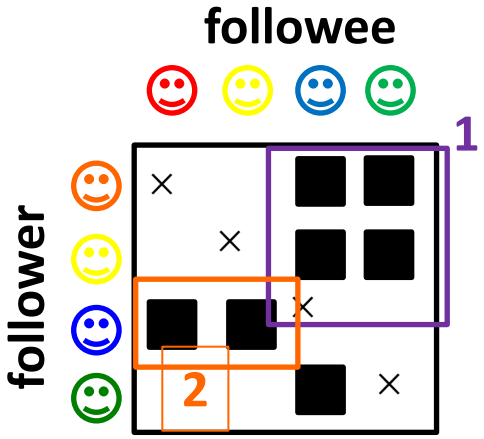
Outline

- Method
  - SVD Reminder
  - “Spectral Subspace Plot”
  - BP-based Algorithm
- Experiments
  - Dataset
  - Real Data
  - Synthetic Data

SVD Reminder

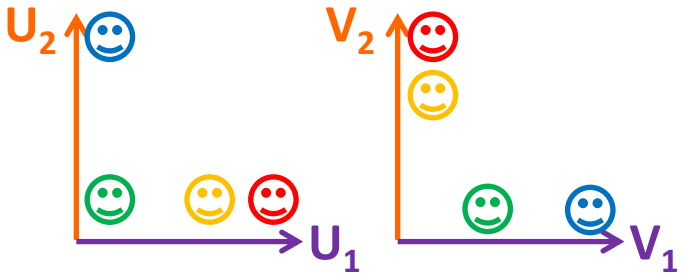


Graph Structure



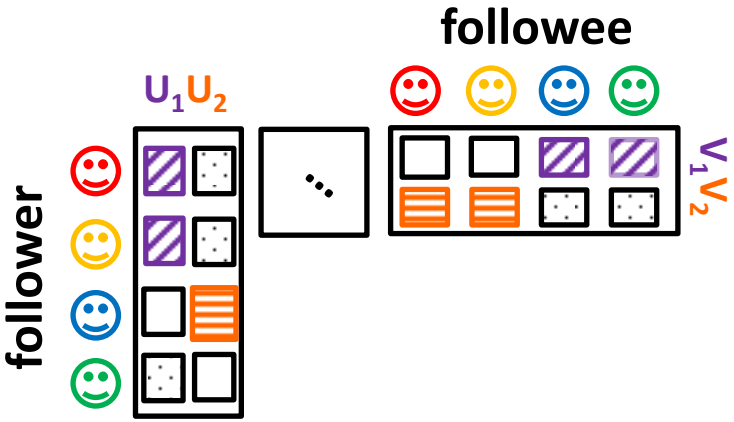
Adjacency Matrix

Pairs of singular vectors:



"Spectral Subspace Plot"

SVD: $A=USV^T$



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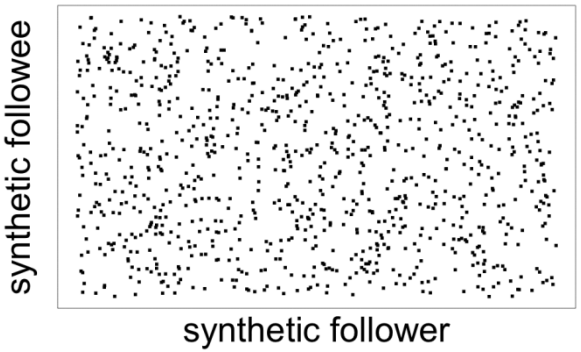
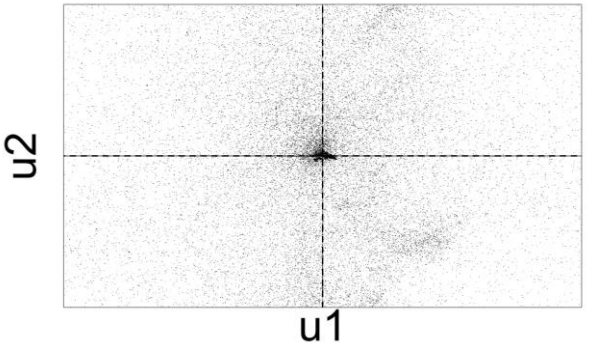
Lockstep and *Spectral Subspace Plot*

- Case #0: No lockstep behavior in random power law graph of 1M nodes, 3M edges
- Random ⟷ "Scatter"

Adjacency Matrix



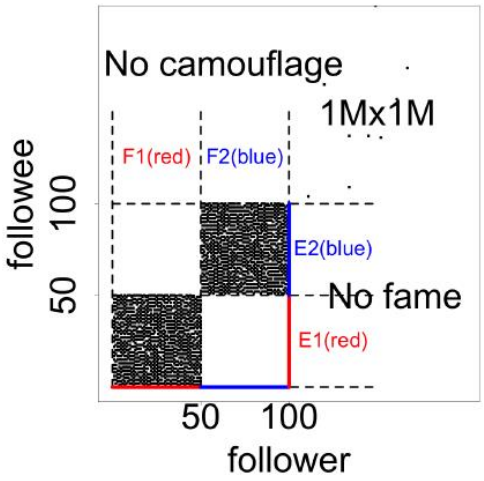
Spectral Subspace Plot



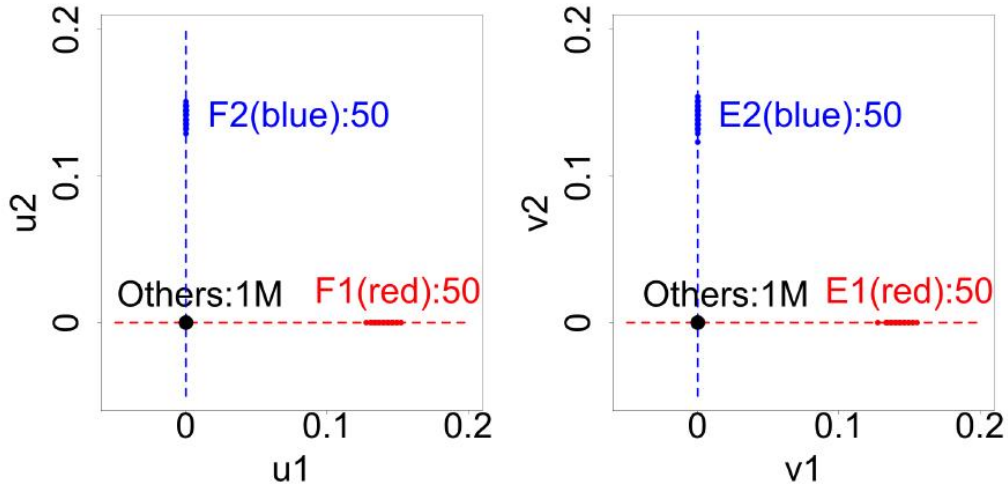
Lockstep and *Spectral Subspace Plot*

- Case #1: non-overlapping lockstep
- "Blocks" $\longleftrightarrow$ "Rays"

Adjacency Matrix



Spectral Subspace Plot

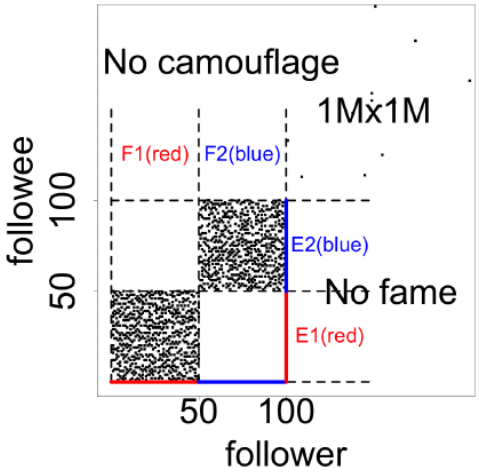


Rule 1 (short "rays"): two blocks, high density (90%), no "camouflage", no "fame"

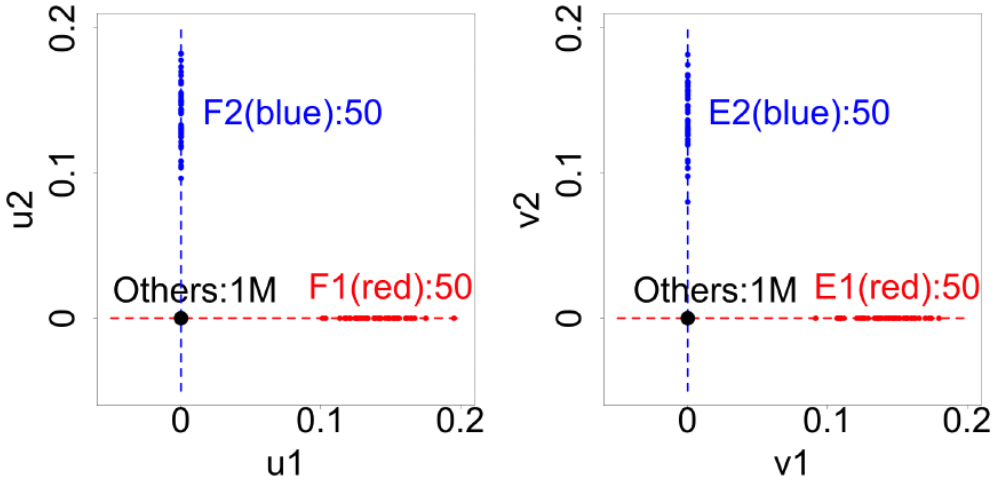
Lockstep and *Spectral Subspace Plot*

- Case #2: non-overlapping lockstep
- "Blocks; low density" ⟷ Elongation

Adjacency Matrix



Spectral Subspace Plot

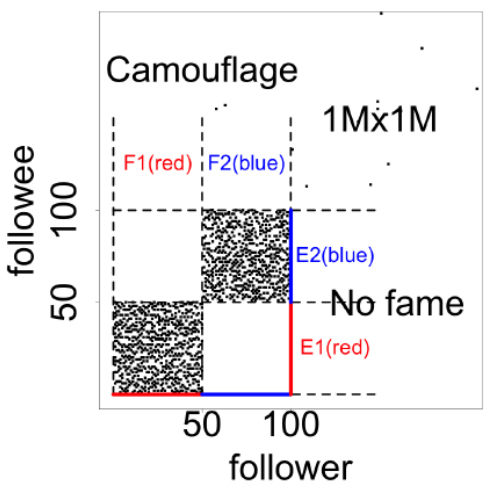


Rule 2 (long "rays"): two blocks, low density (50%), no "camouflage", no "fame"

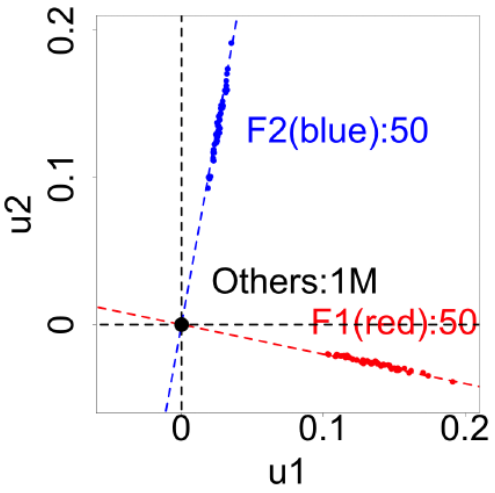
Lockstep and *Spectral Subspace Plot*

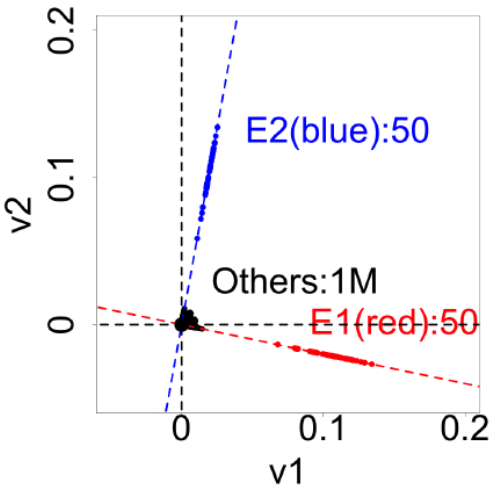
- Case #3: non-overlapping lockstep
- "**Camouflage**" (or "Fame") ⟷ Tilting "Rays"

Adjacency Matrix



Spectral Subspace Plot



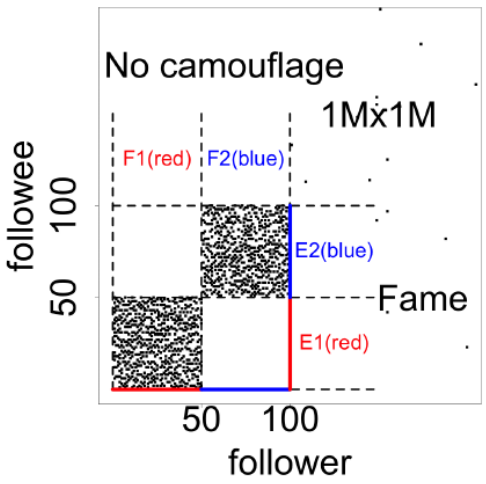


Rule 3 (tilting "rays"): two blocks, with "camouflage", no "fame"

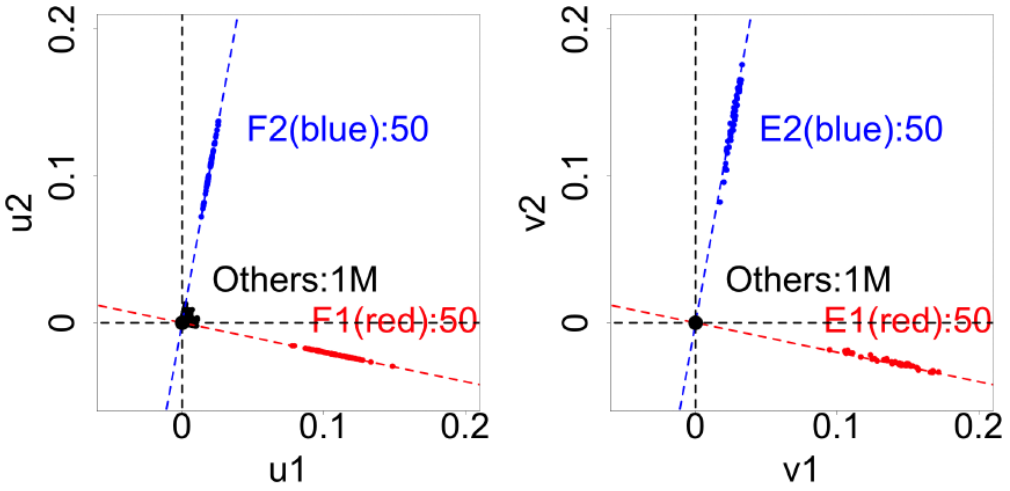
Lockstep and *Spectral Subspace Plot*

- Case #3: non-overlapping lockstep
- "Camouflage" (or "**Fame**") ⟷ Tilting "Rays"

Adjacency Matrix



Spectral Subspace Plot



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

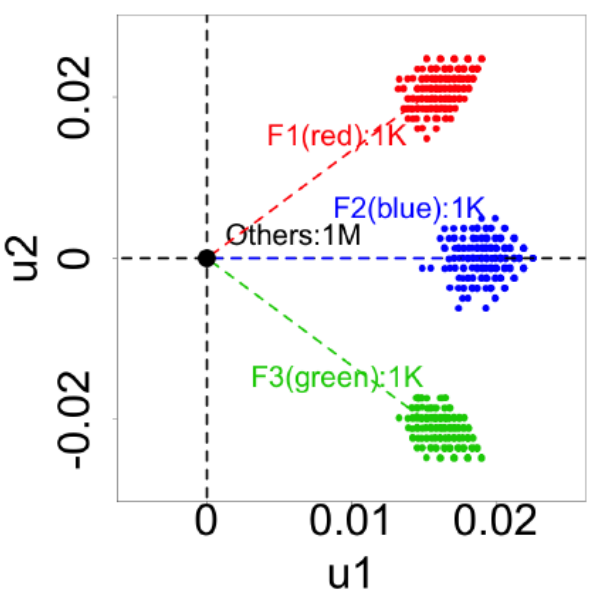
Lockstep and *Spectral Subspace Plot*

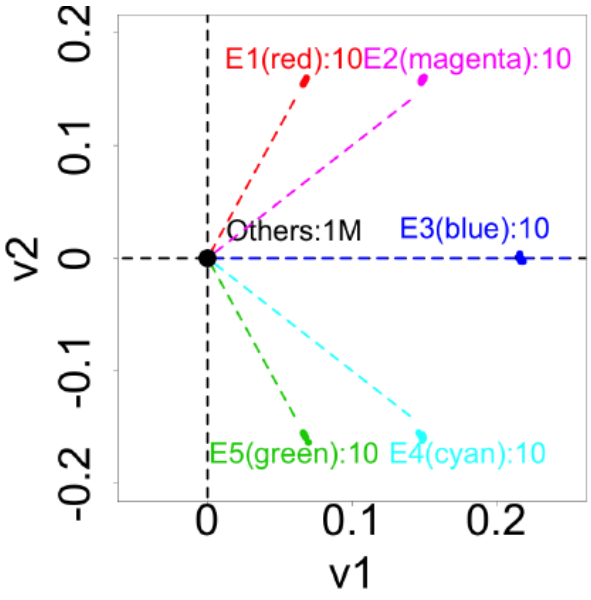
- Case #4: ? lockstep
- "?" ⟷ "Pearls"

Adjacency Matrix

?

Spectral Subspace Plot

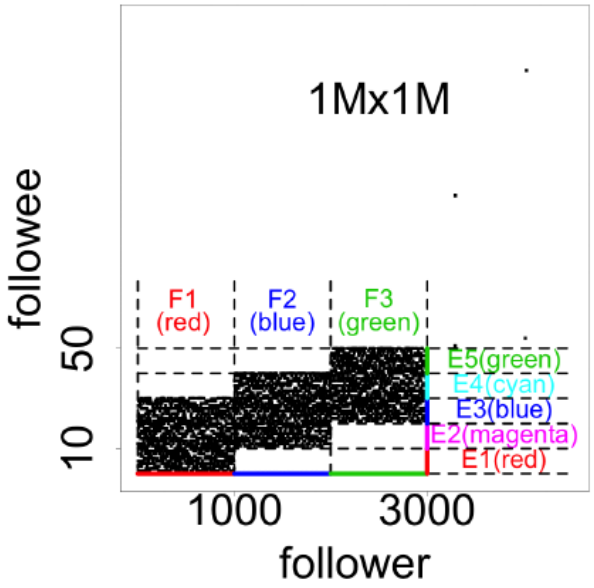




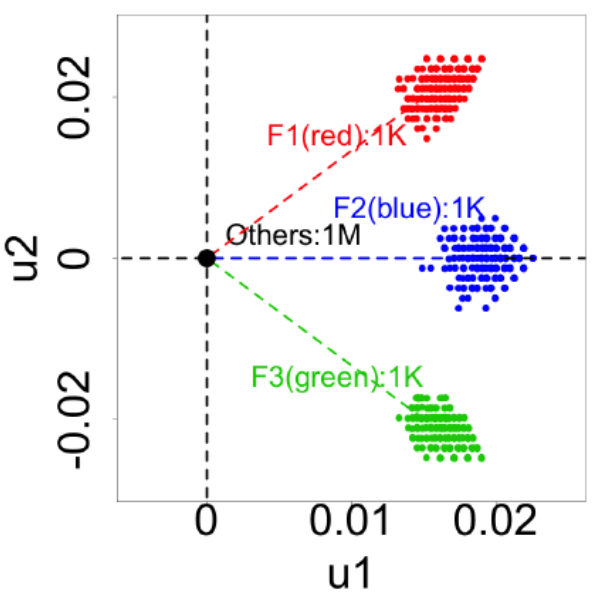
Lockstep and *Spectral Subspace Plot*

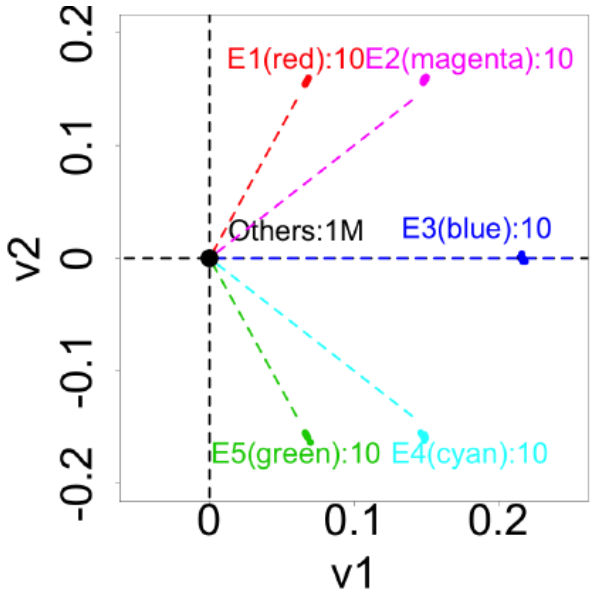
- Case #4: **overlapping** lockstep
- "**Staircase**" ⟷ "Pearls"

Adjacency Matrix



Spectral Subspace Plot





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

Outline

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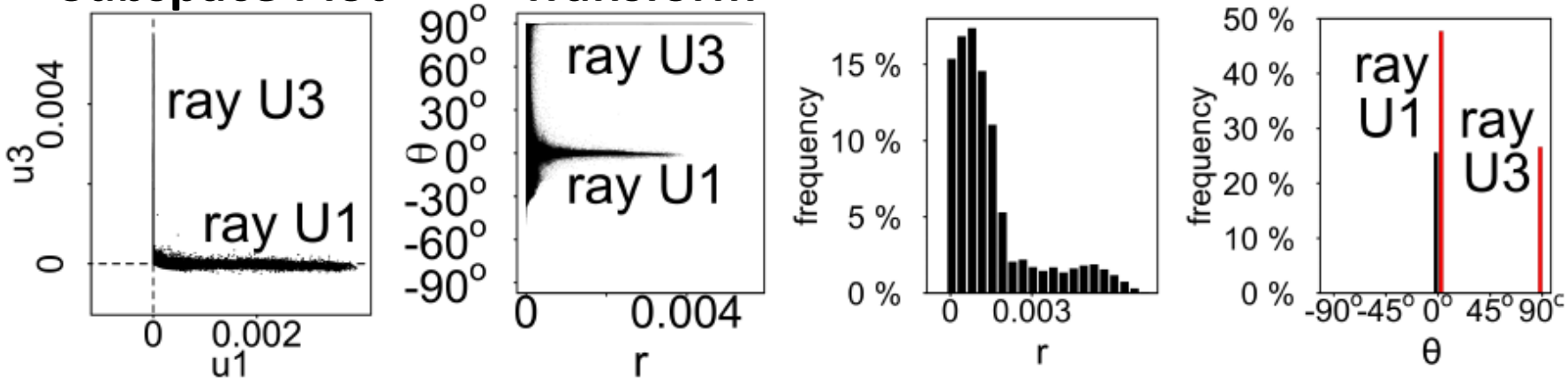
Algorithm

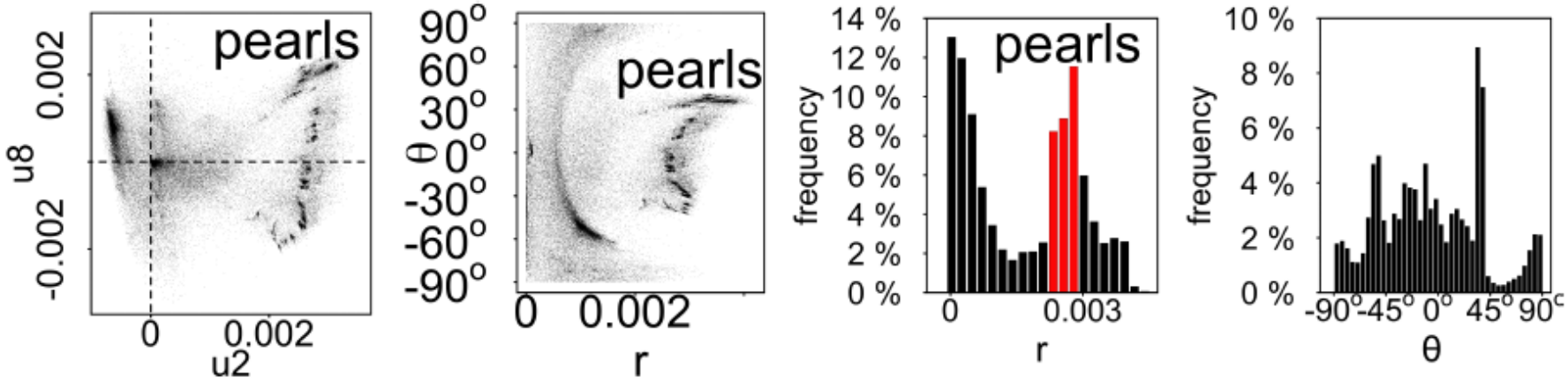
- Step 1: Seed selection
  - Spot “Rays” and “Pearls”
  - Catch seed followers
- Step 2: Belief Propagation
  - Blame followees with strange followers
  - Blame followers with strange followees

Automatically Spot "Rays" and "Pearls"

Spectral Subspace Plot | **Polar Coordinate Transform** | **Histograms**



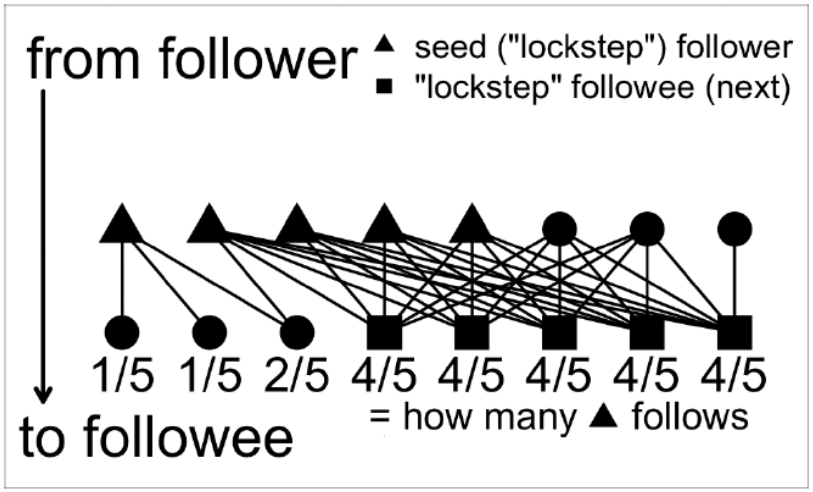
"rays" show two apparent spikes on θ frequency at 0^o and 90^o



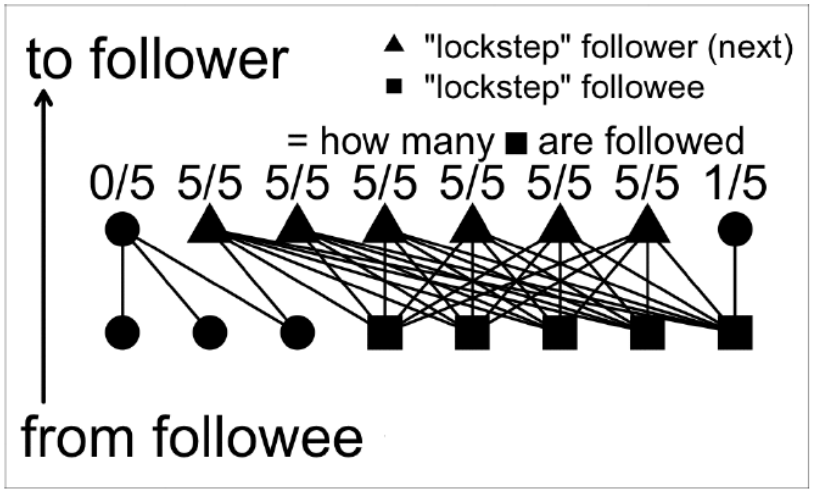
"pearls" show a spike on r frequency at a much-greater-than-zero value

BP-based Algorithm

- Blame followees with strange followers
- Blame followers with strange followees



(a) select "lockstep" followees: from (seed) followers to followees



(b) select "lockstep" followers: from followees to followers

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Dataset

- Tencent Weibo
- 117 million nodes (users)
- 3.33 billion directed edges

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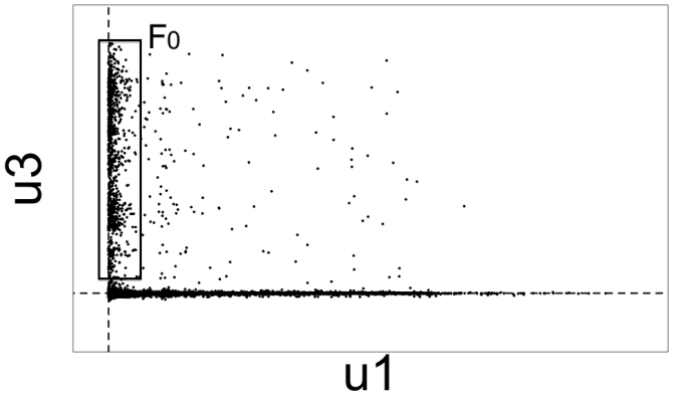
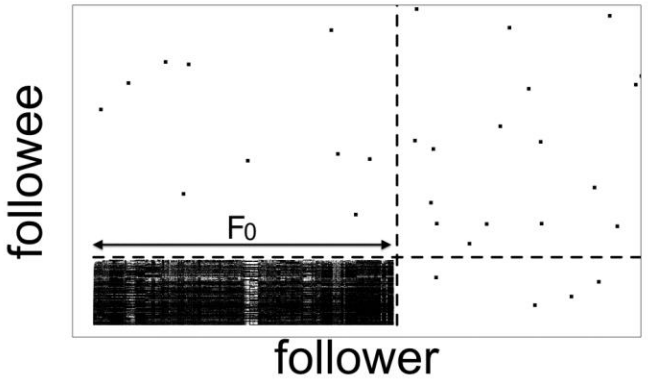
Real Data

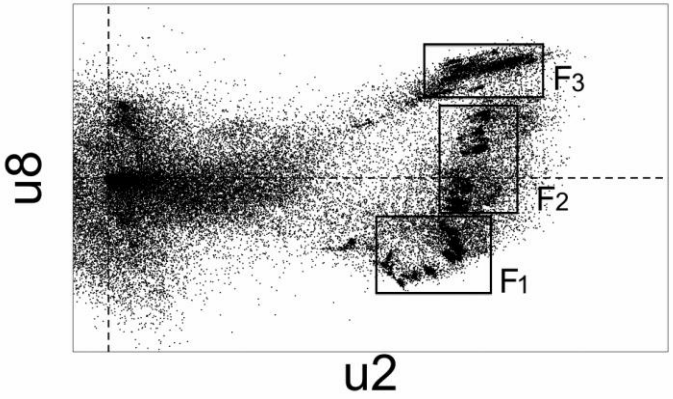
“Rays”



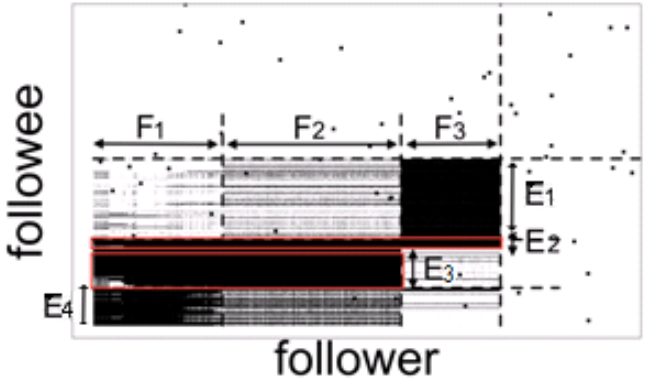
“Block”



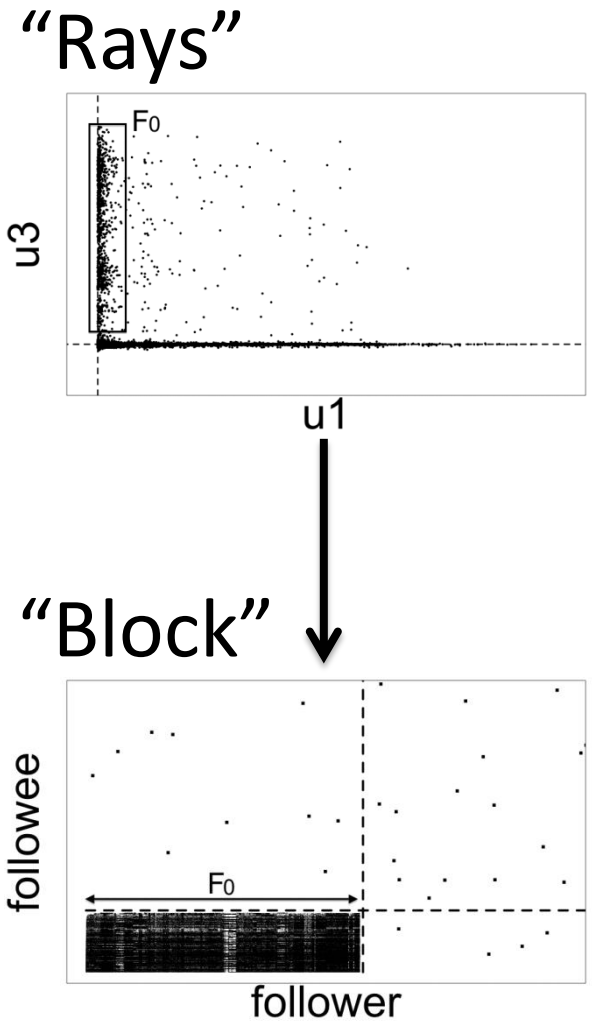
“Pearls”



“Staircase”



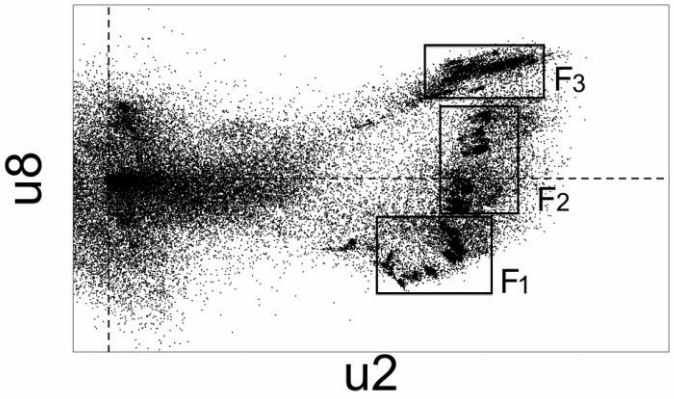
Real Data



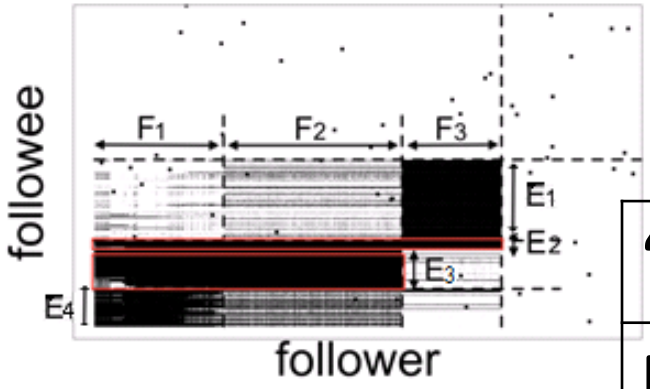
	“ray” F_0	“p
Num. seeds	100	
Size of block	$83,208 \times 30$	3, 1
Density	81.3%	
Camouflage	0.14%	
Fame	0.05%	
Out-degree	231±109	
In-degree	2.0±1.4	

Real Data

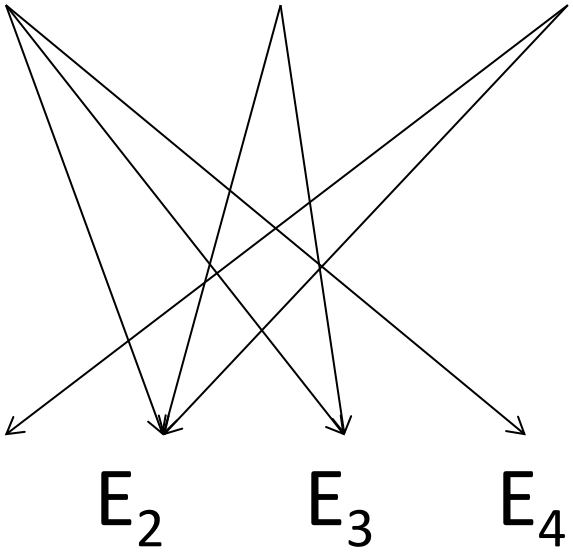
"Pearls"



"Staircase"



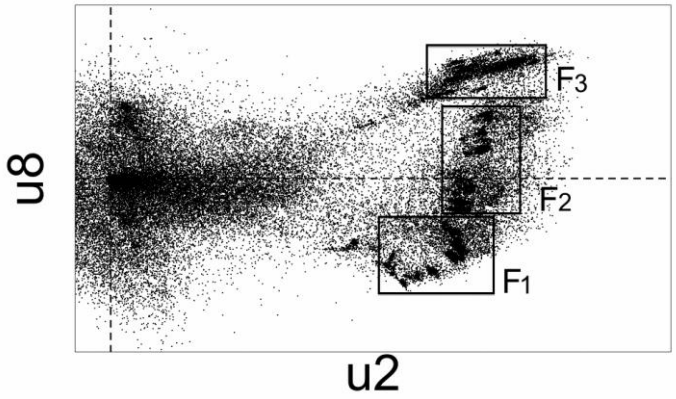
3,188 in F_1 7,210 in F_2 2,457 in F_3



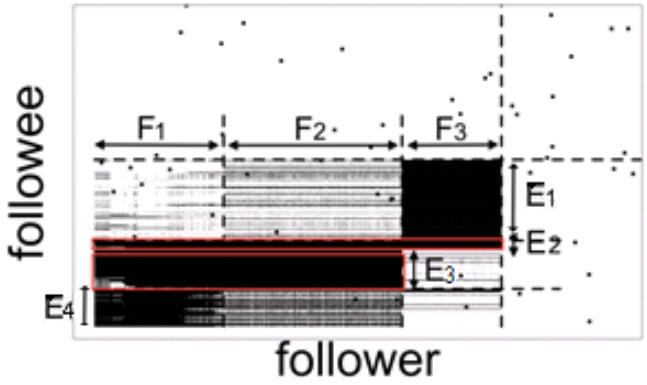
"F-E"	F_1-…	F_2-…	F_3-…
Density	91.3%	92.6%	89.1%

Real Data

"Pearls"



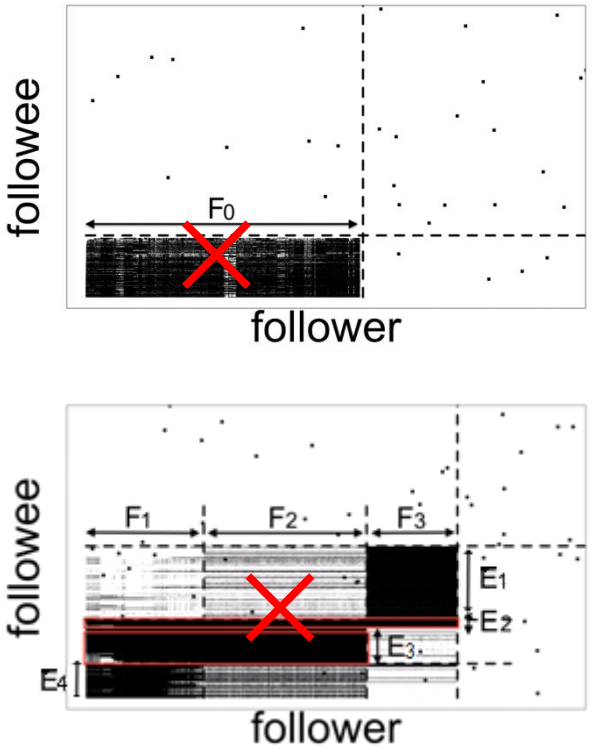
"Staircase"

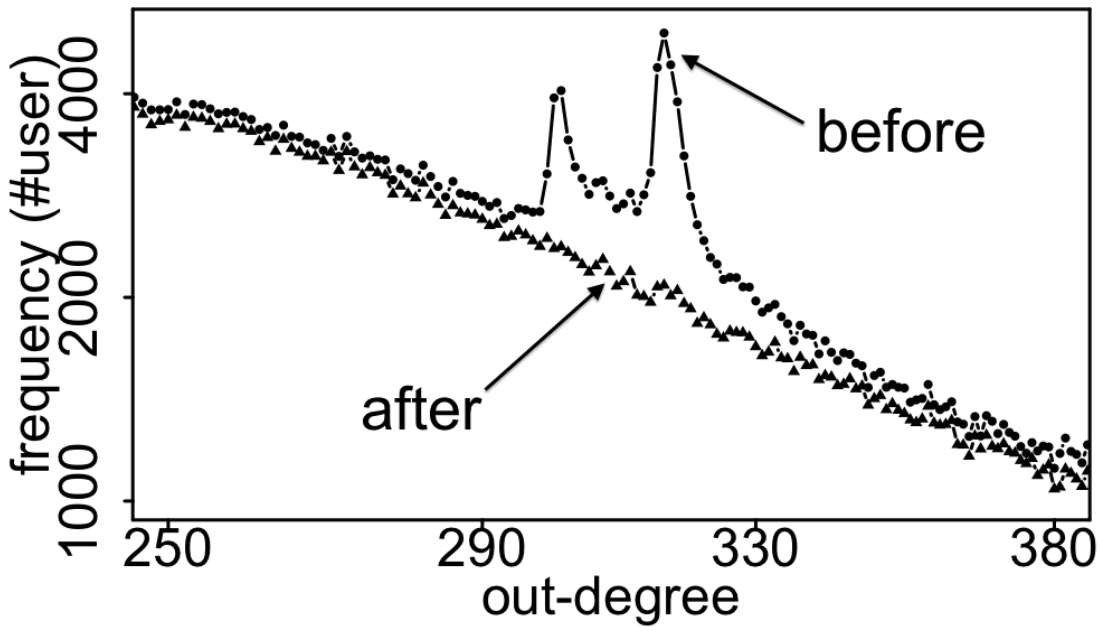


	"pearl" F_1	"pearl" F_2	"pearl" F_3	"pearl" Total
	1,239	107	990	—
)	$3,188 \times 135$	$7,210 \times 79$	$2,457 \times 148$	$10,952 \times 370$
	91.3%	92.6%	89.1%	43.1%
	0.06%	0.10%	0.05%	0.07%
	1.93%	1.94%	1.72%	1.73%
	310±7	312±7	304±5	310±7
	[illegible]	[illegible]	[illegible]	[illegible]

Real Data

- Spikes on the out-degree distribution



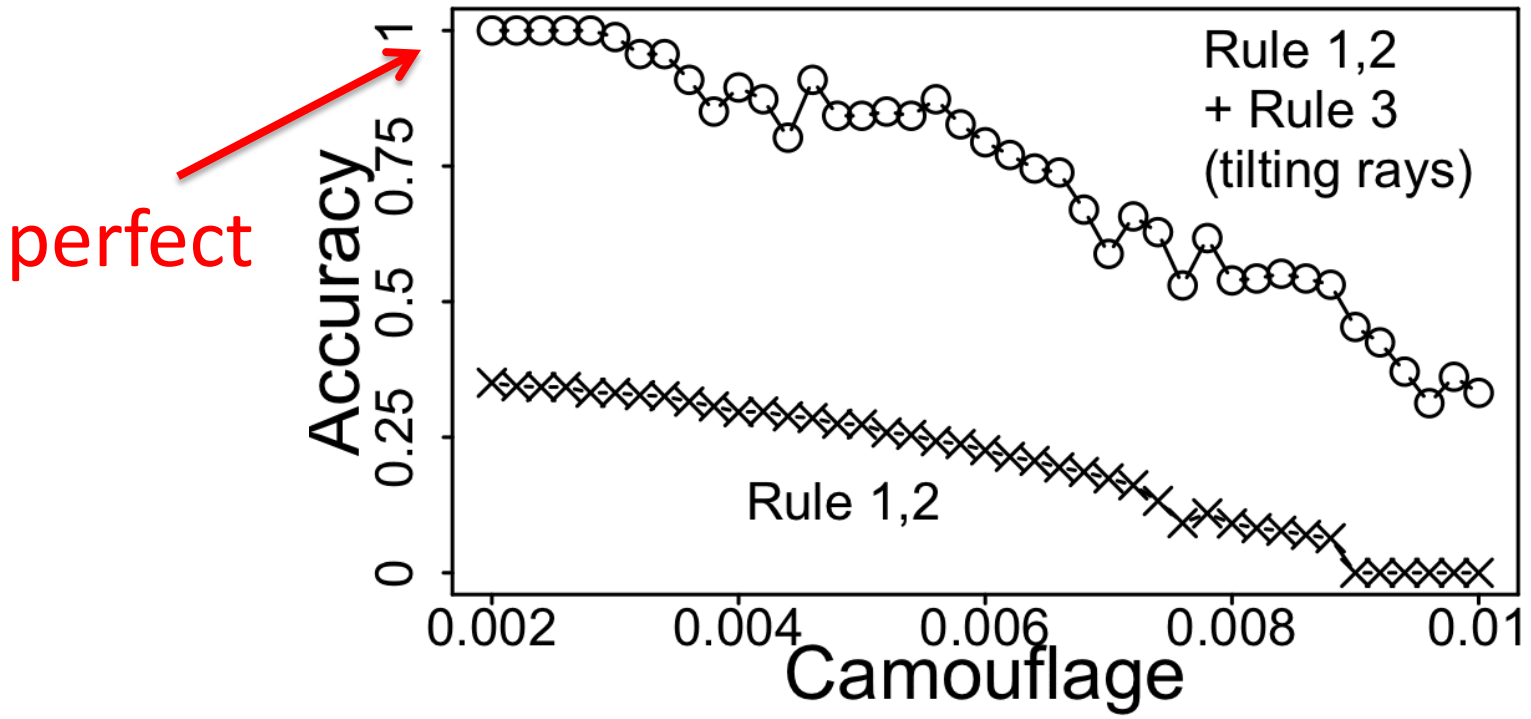


Outline

- Method
  - SVD Reminder
  - “Spectral Subspace Plot”
  - BP-based Algorithm
- Experiments
  - Dataset
  - Real Data
  - Synthetic Data

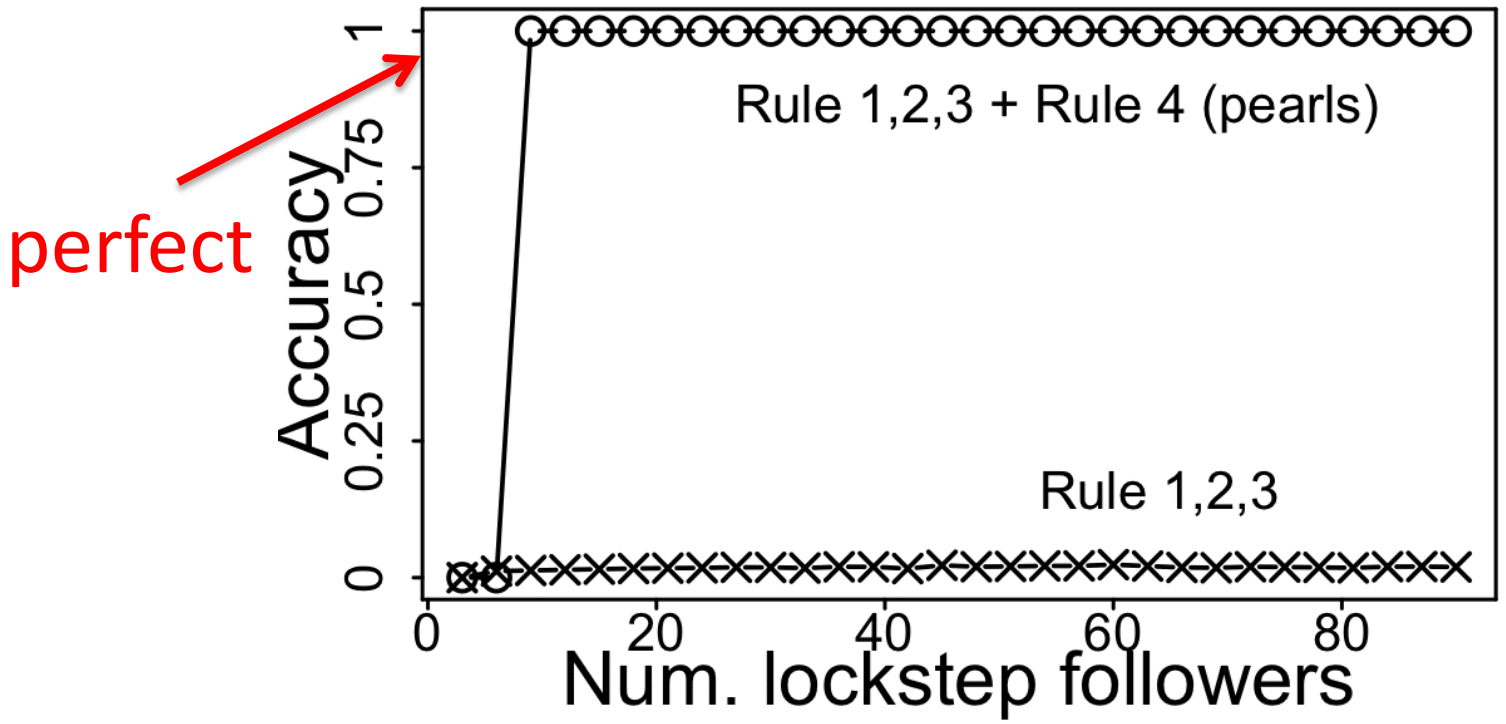
Synthetic Data

- Inject lockstep behavior with "**camouflage**"



Synthetic Data

- Inject **overlapping** lockstep behavior



Contributions

- Different types of lockstep behavior
- A handbook (rules) to infer lockstep behavior with connectivity patterns
- An algorithm to catch the suspicious nodes
- Remove spikes on out-degree distribution

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Thank you!