On Your Social Network De-anonymizablity: Quantification and Large Scale Evaluation with Seed Knowledge

Shouling Ji, Weiqing Li, and Raheem Beyah

Georgia Institute of Technology

Neil Zhenqiang Gong

University of California, Berkeley

Prateek Mittal

Princeton University

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Communications Assurance & Performance Group

Outline

- Introduction and Motivation
- System Model
- De-anonymization Quantification
- Evaluation and Observations
- Conclusion and Future Works

De-anonymization Attack

- Structured/Graph Data

De-anonymization Attack

- Structured/Graph Data
  - Social Networks

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- Structured/Graph Data
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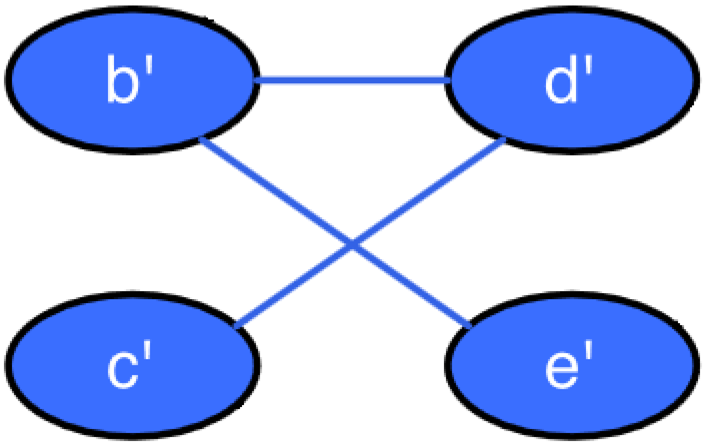
  - Mobility Traces

De-anonymization Attack

- Structured/Graph Data
  – Social Networks
  – Mobility Traces
  – Email Networks

De-anonymization Attack

The Anonymized Graph
(e.g. Facebook)



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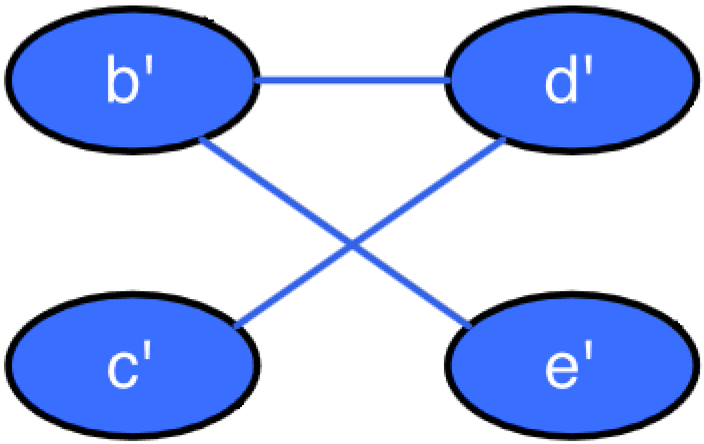
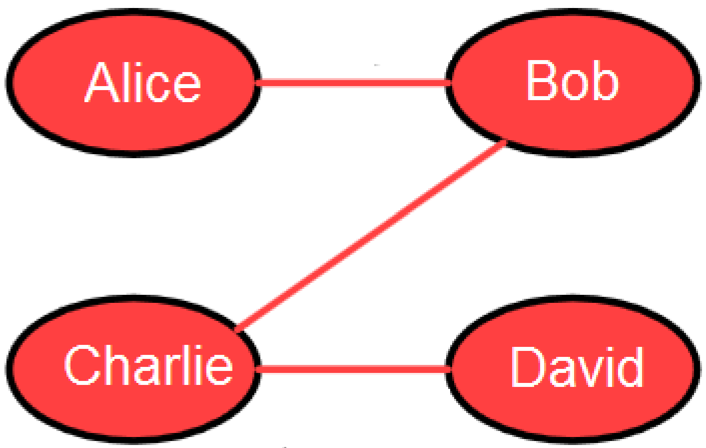


The Auxiliary Graph
(e.g. Flicker)



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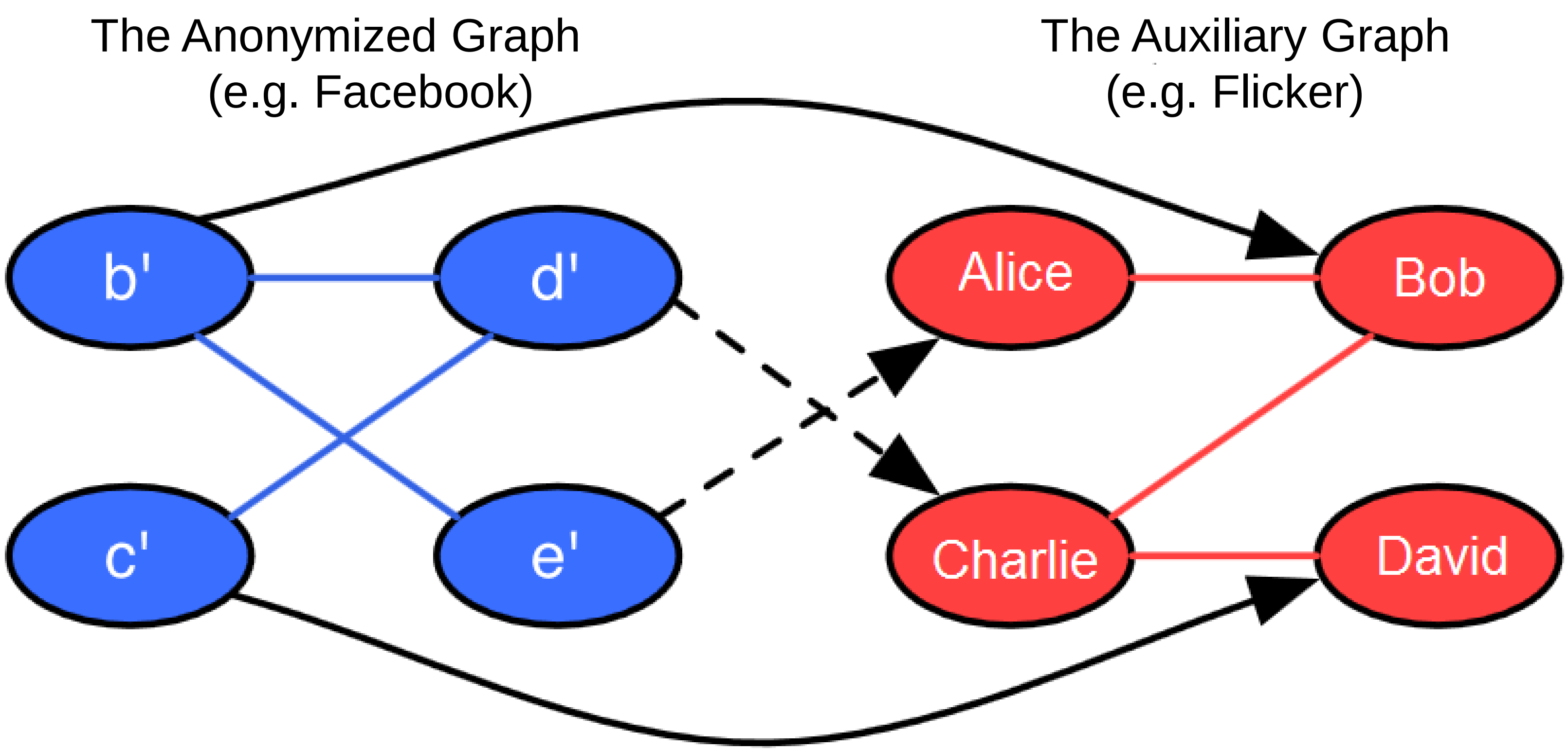

Narayanan-Shmatikov attack (IEEE S&P 2009)

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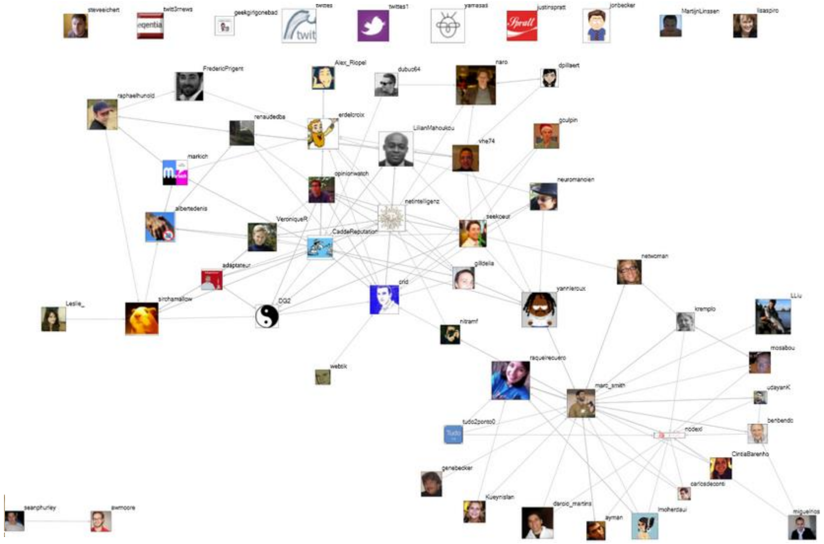

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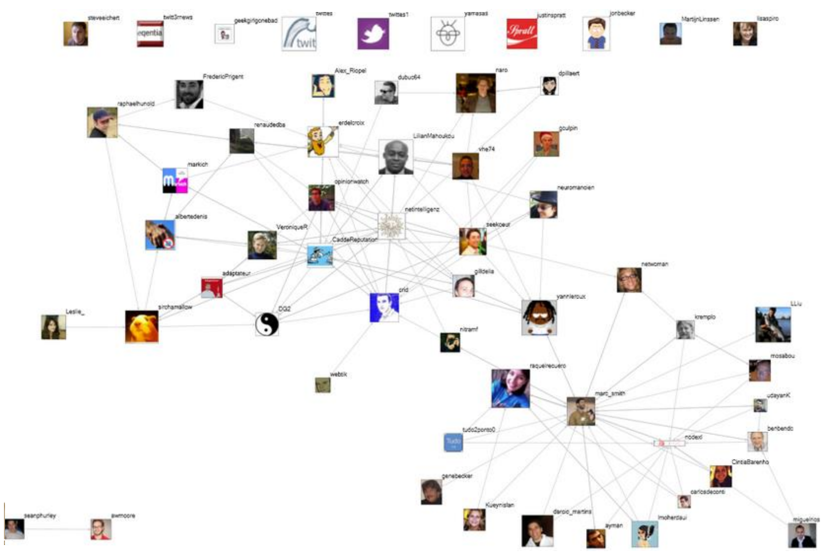

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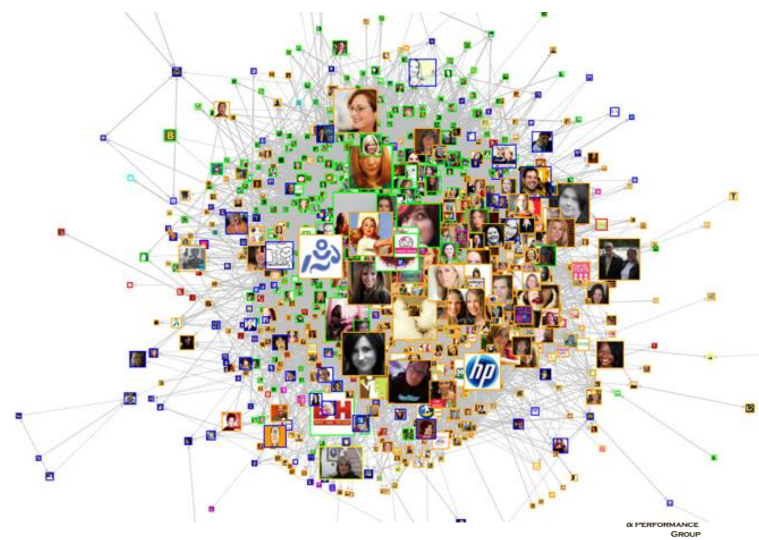

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  - 3.3M users, 53M edges
- Result: 30.8% of the users are successfully de-anonymized

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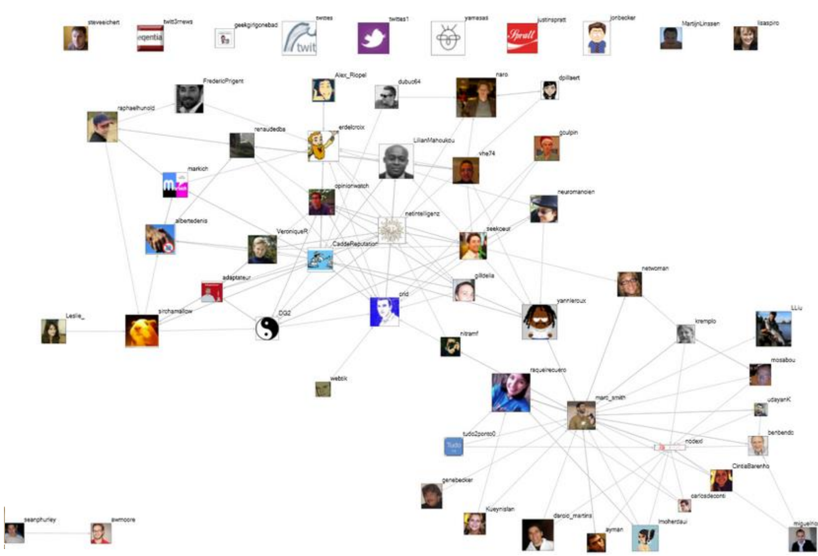

Heuristics

Eccentricity
Edge directionality
Node degree
Revisiting nodes
Reverse match

User mapping

Flicker

Motivation

- Question 1: *Why social networks are vulnerable to structure based de-anonymization attacks?*

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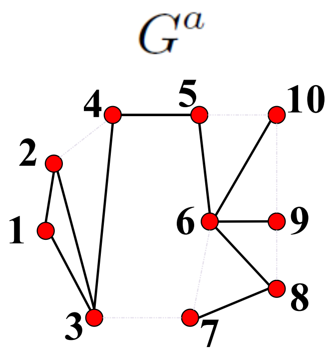
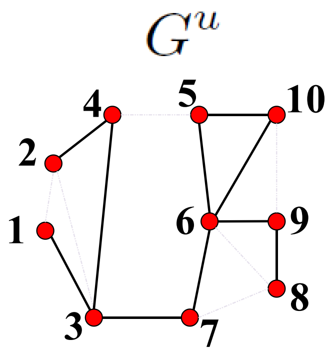
- Question 2: *How de-anonymizable a social network is?*
- Question 3: *How many users within a social network can be successfully de-anonymized?*

System Model

- Anonymized Data (G^a)
- Auxiliary Data (G^u)





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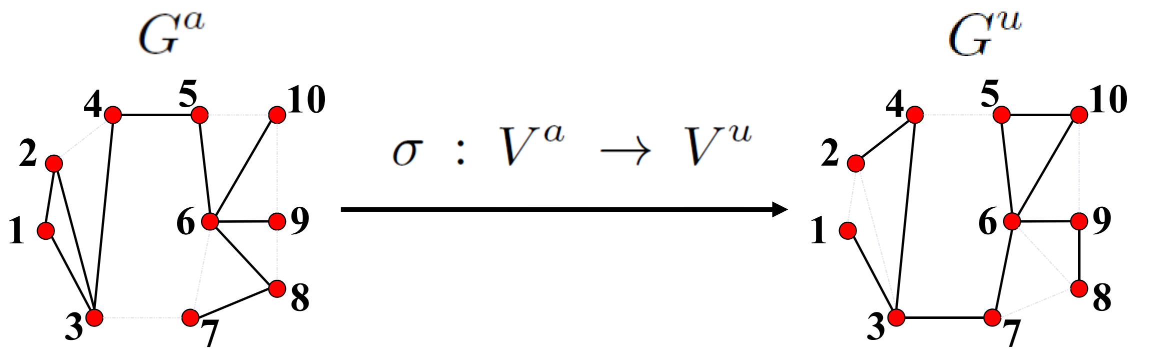

System Model

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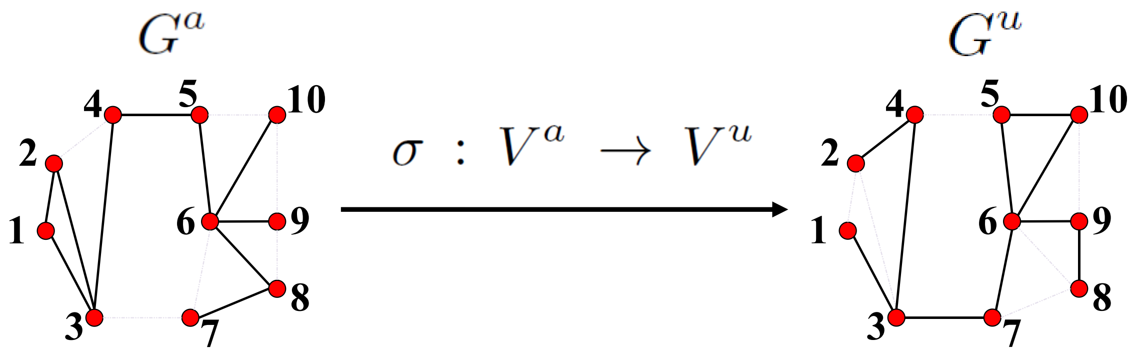
- Auxiliary Data (G^u)
- De-anonymization (σ)
- Measurement(Δ_σ)



De-anonymization Error (DE) on a user mapping $(i, i') \in \sigma$

$$\Delta_{\sigma:(i,j)}(s) = \left|\sigma\left(E_i^a(S^a)\right)\backslash E_j^u(S^u)\right| + \left|\sigma^{-1}\left(E_j^u(S^u)\right)\backslash E_i^a(S^a)\right|$$

$$\Delta_\sigma(\mathrm{S}) = \sum_{(i,j)\in\sigma} \Delta_{\sigma:(i,j)}(S)$$

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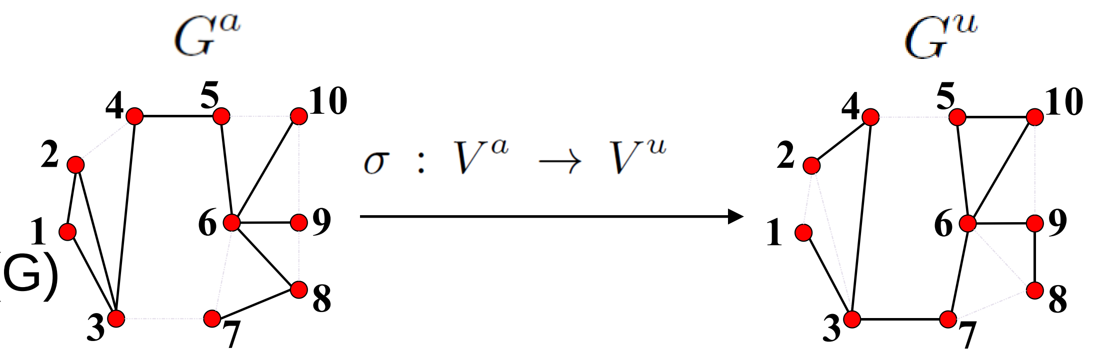
- De-anonymization (σ)
- Conceptual Underlying Graph (G)



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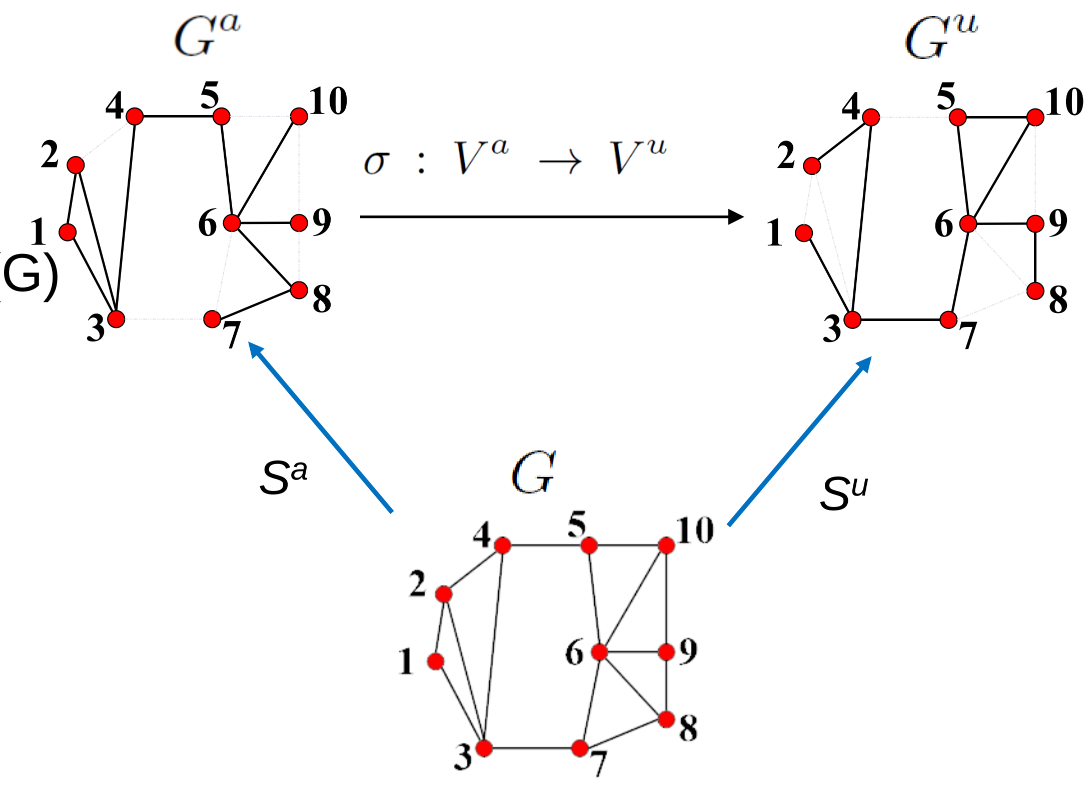

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- Conceptual Underlying Graph:
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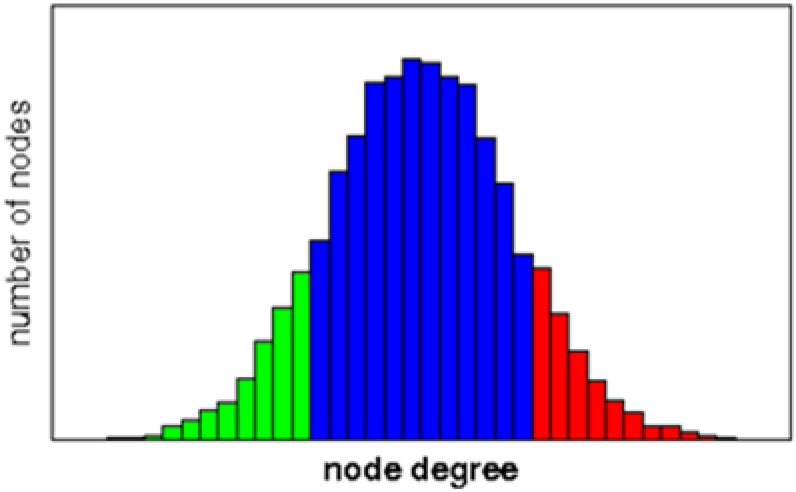
The ER Model Degree Distribution



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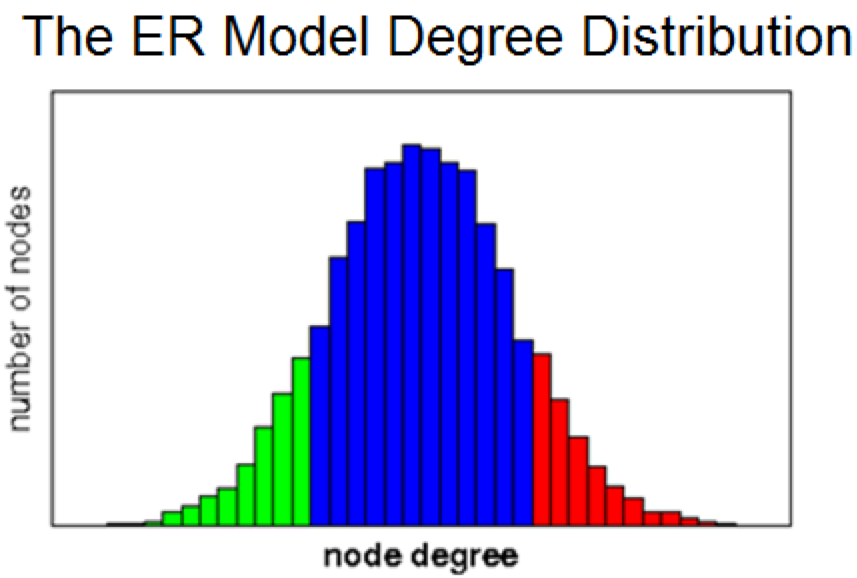

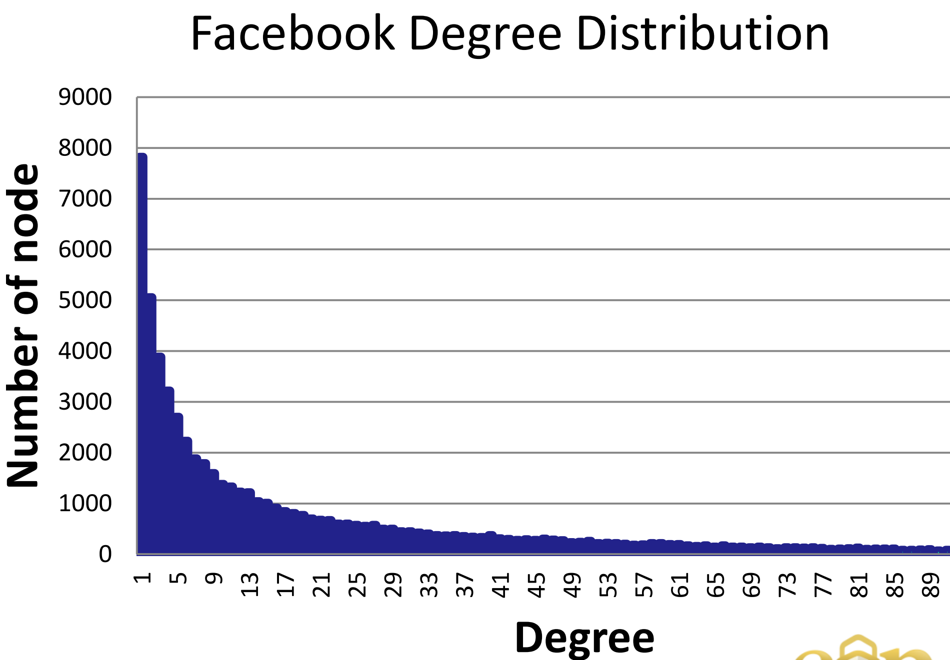

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- Conceptual Underlying Graph:
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- Quantifications
  - Mathematically shown the conditions needed
    - Seed based perfect *de-anonymization*
    - *Structure based* perfect *de-anonymization*
    - *Error tolerant de-anonymization*

Evaluation

- Datasets

TABLE I. DATASET STATISTICS.

Name	n	m	ρ	$\bar{d}$
Hyves	1,402,673	2,777,419	2.82E-06	3.96
Douban	154,908	327,162	2.73E-05	4.22
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Orkut	3,072,441	117,185,083	2.48E-05	76.28
Flickr	80,513	5,899,882	1.82E-03	146.56

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  - Number of nodes (n)
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  - Graph density (ρ)

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  - Social media (e.g. LiveJournal 4 million nodes, 43 million edges)

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  - Email network (e.g. Enron 33 thousand nodes, 180 thousand edges).

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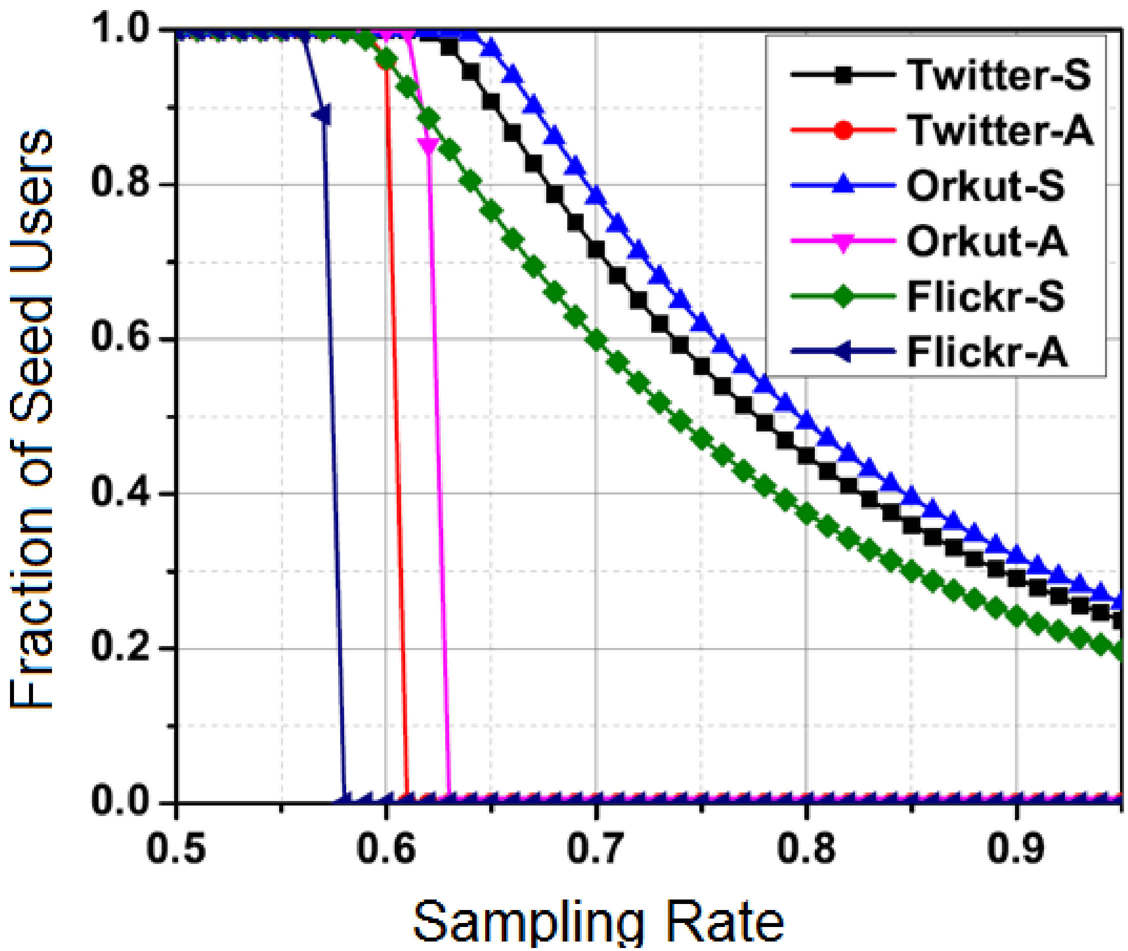
Evaluation

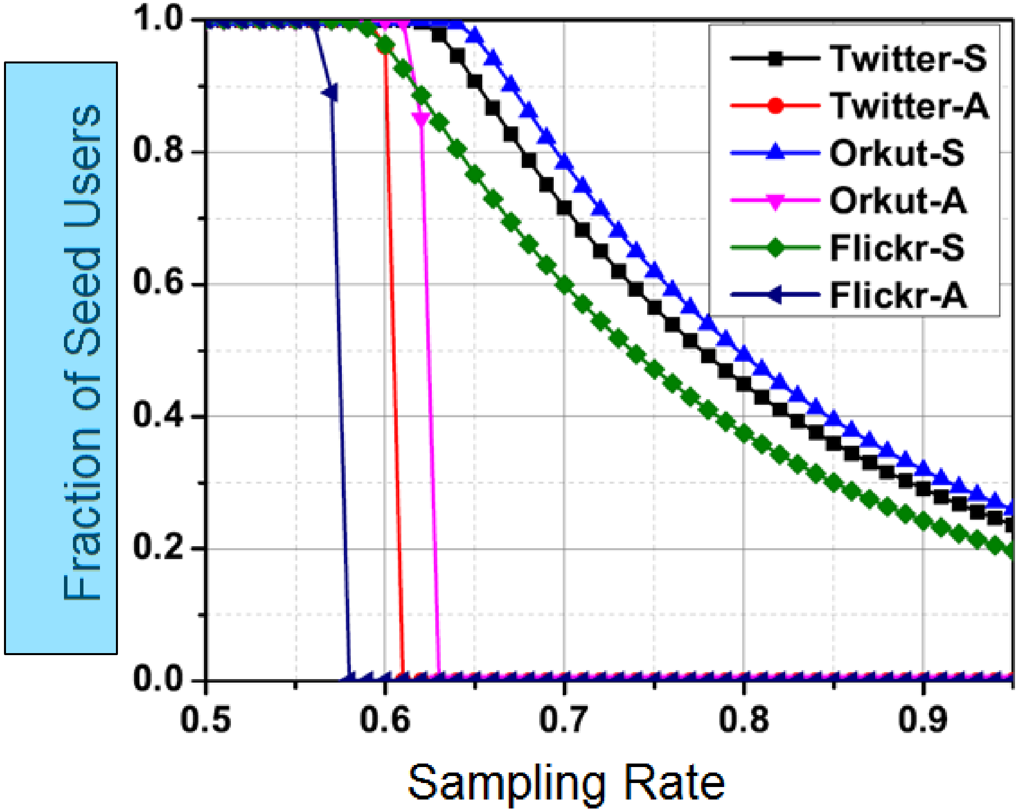
Perfect De-anonymization Analysis on seed users versus sampling rate



Georgia Institute of Technology

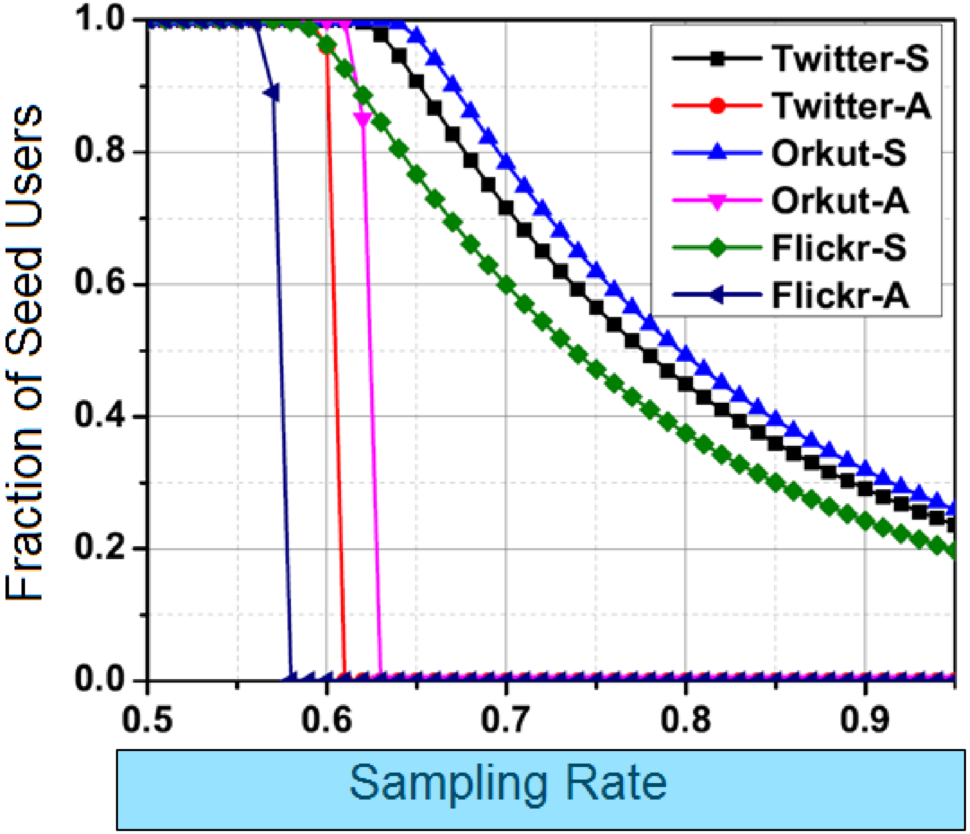
Evaluation

- The y-axis: number of pre-determined users needed.



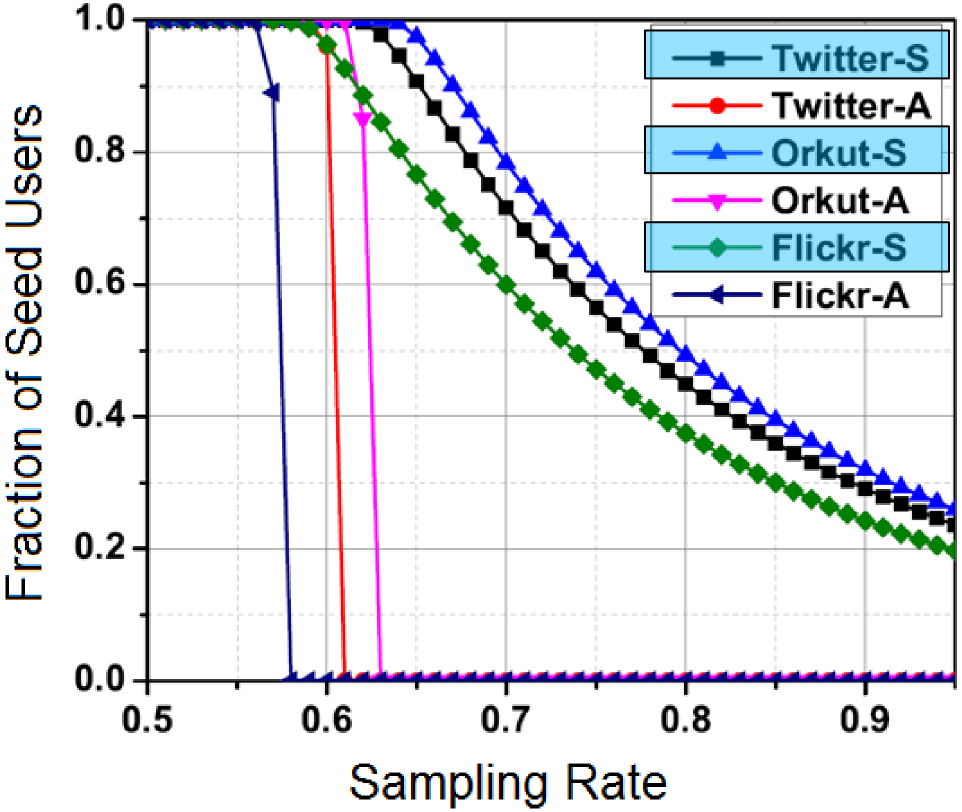
Evaluation

- The y-axis: number of pre-determined users needed.
- The x-axis: sampling rate needed.



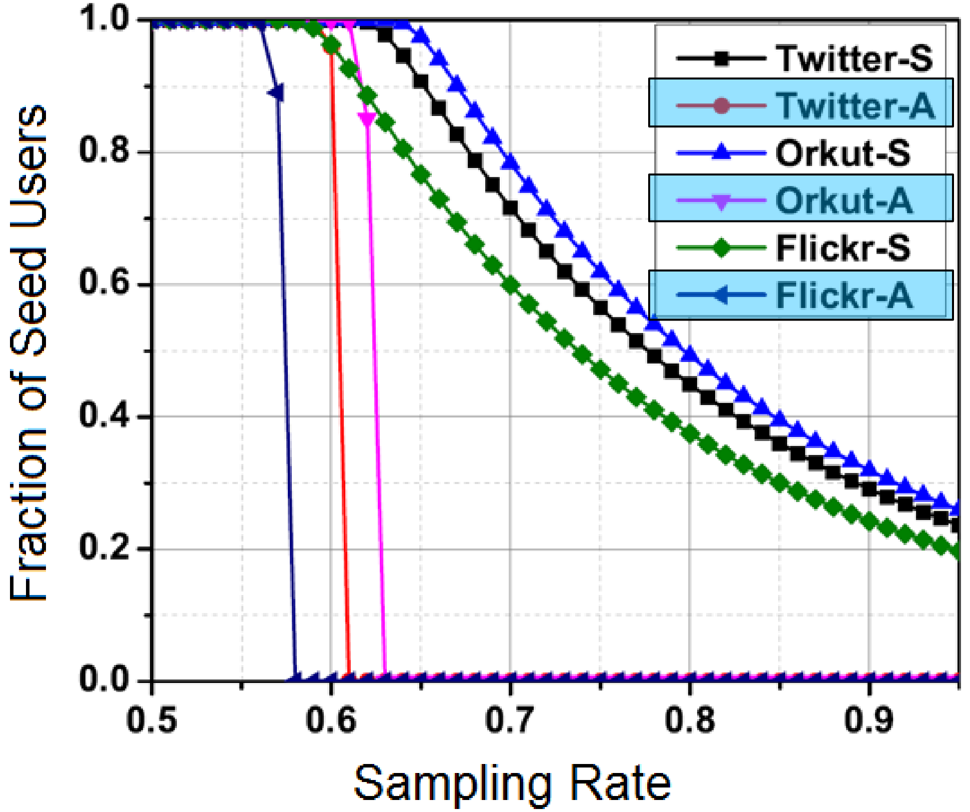
Evaluation

- The y-axis: number of pre-determined users needed.
- The x-axis: sampling rate needed.
- *-S: de-anonymization with only seed information.



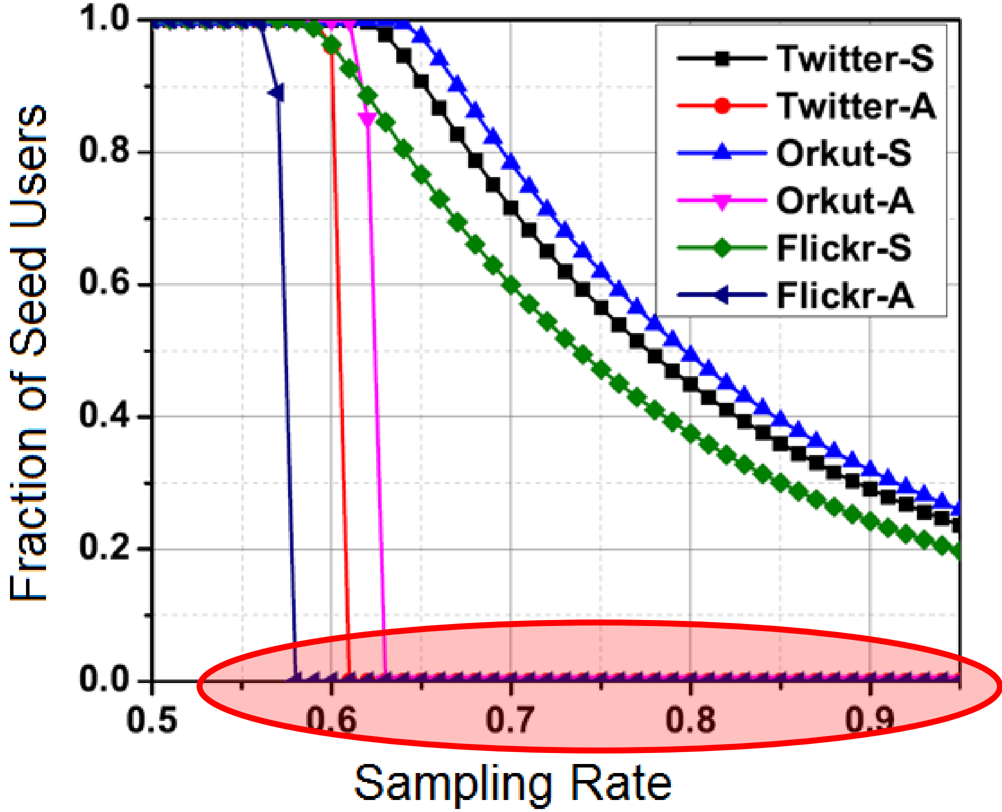
Evaluation

- The y-axis: number of pre-determined users needed.
- The x axis: sampling rate needed.
- *-S: de-anonymization with only seed information.
- *-A: de-anonymization with seed and structural information



Evaluation

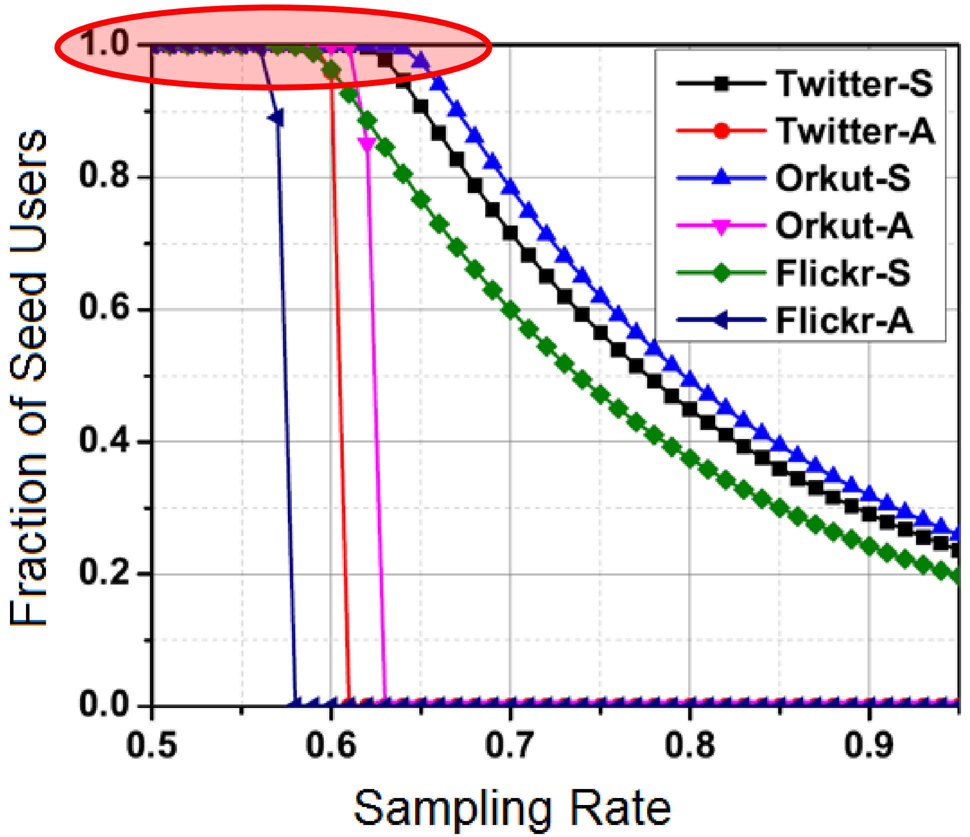
- When sampling rate is large no seeds needed for perfect de-anonymization.



Evaluation

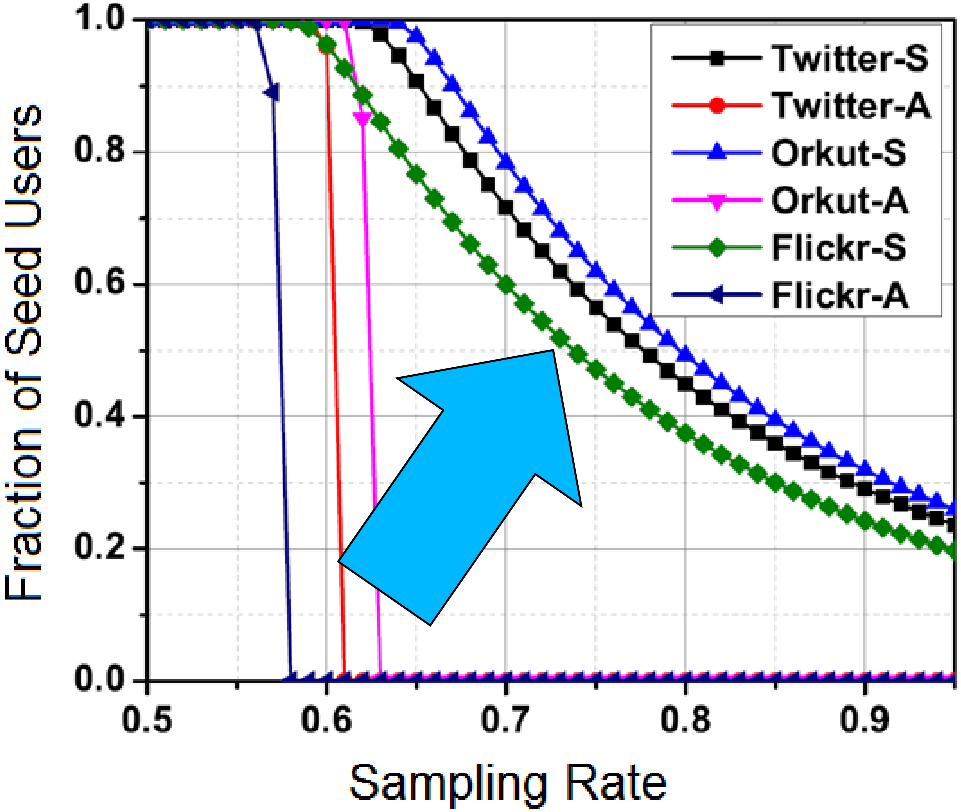
- When sampling rate is large no seeds needed for perfect de-anonymization.

- When sampling rate is small all users need to be seed users for perfect de-anonymization.



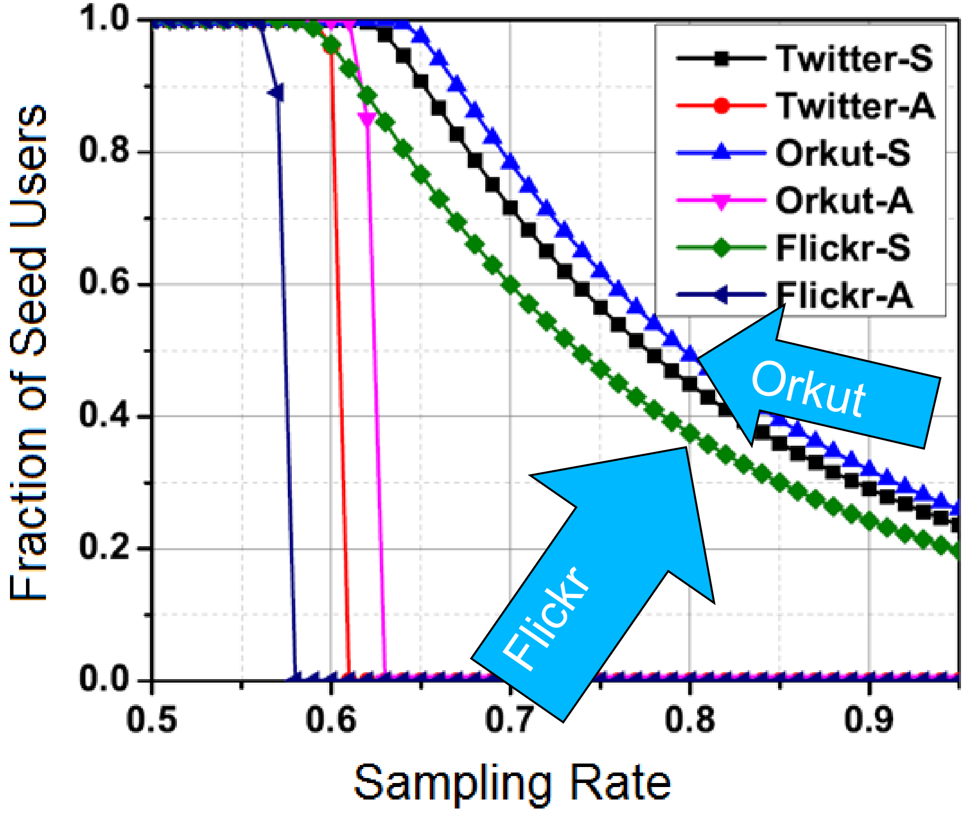
Evaluation

- Using only seed information, fewer seed users are required with lower sampling rate.



Evaluation

- Graphs with higher density requires fewer seed users.
  - Orkut density of 2.48E-5
  - Flicker density of 1.82E-3



Conclusion and Future Works

- Conclusion
  - Theoretical quantification with no degree distribution requirement.
  - Large-scale de-anonymizability evaluation.
- Future works
  - New mathematical model
  - Defense techniques

Thank you!

Questions?

Acknowledgement

We thank the anonymous reviewers very much for their valuable comments!