Chair of Computer Science 5
RWTH Aachen University

Analysis of Overlapping Communities in Signed Complex Networks

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Agenda

- Introduction to OCD
- Related Work
- Motivation & Research Questions
- Overlapping Community Detection (OCD) Algorithms for Signed Networks
- Evaluation
- Results
- Conclusion and Outlook

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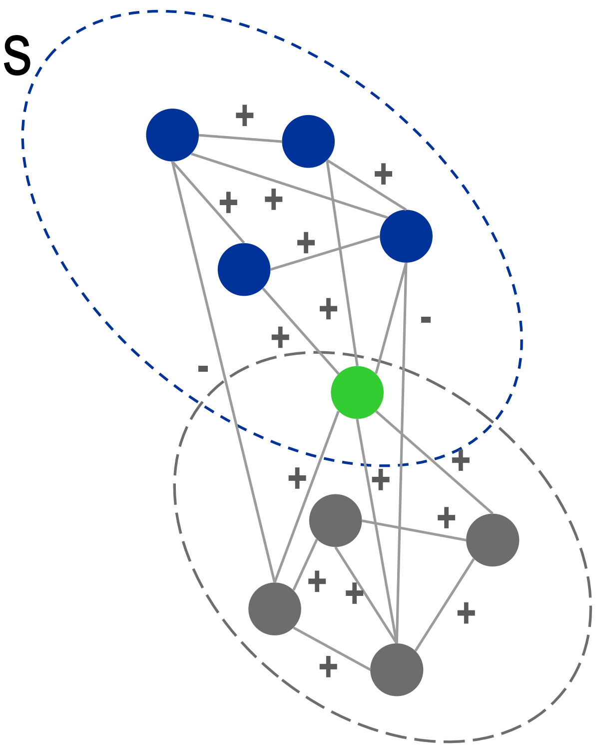
Introduction to OCD in Signed Networks

- Community detection as an important part of network analysis
- Two key characteristics of signed social networks
  - Nodes in the overlapping communities
  - Relations with signs
- Community structure

Inside Communities
- Dense
- Positive

Between Communities
- Negative
- Sparse



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Motivation

- Practical application of OCD in signed networks like
  - Informal learning networks
  - Review sites
  - Open source developer networks
- Contribute to the current research on OCD in signed networks with the following difficiencies
  - Few algorithms
  - No comparison between available algorithms

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Related Work on Community Detection in Signed Graphs

- Non-overlapping community detection
  - Agent-based finding and extracting communities (FEC) [YaCL07]
  - Two-step approach by maximizing modularity and minimizing frustration [AnMa12]
  - Clustering re-clustering algorithm (CRA) [AmPi13]
- Overlapping community detection
  - Signed Disassortative Degree Mixing and Information Diffusion Algorithm (SDMID) [ShKl15]
  - Signed Probabilistic Mixture Model (SPM) [CWYT14]
  - Multi-objective Evolutionary Algorithm based on Similarity for Community Detection in Signed Networks (MEA_s-SN) [LiLJ14]

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Research Questions

- How do Signed Disassortative degree Mixing and Information Diffusion (SDMID), Signed Probabilistic Mixture model (SPM) and Multi-objective Evolutionary Algorithm (MEA) perform in comparison with each other, in terms of knowledge-driven and statistical metrics?
- What are the structural properties of covers detected by SDMID, SPM and MEA and how do they differ?

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Signed Disassortative Degree Mixing and Information Diffusion Algorithm: Phase 1

Identify leaders

- Calculate Local Leadership Value (LLD) using effective degree (ED) and normalized disassortativeness (DASS)

$$ED(i) = \frac{Max(|in^{+}(i)| - |in^{-}(i)|, 0)}{|in^{+}(i)| + |in^{-}(i)|} \qquad DASS(i) = \frac{\sum_{j \in Nei(i)} (\deg(i) - \deg(j))}{\sum_{j \in Nei(i)} (deg(i) + deg(j))}$$

$$LLD(i) = \alpha \times DASS(i) + (1 - \alpha) \times ED(i)$$

- Identify local leaders:

$$\forall j \in Nei(i), LLD(i) \geq LLD(j)$$

- Identify global leaders:

$$|FL(i)| > \frac{\sum_{j \in LL} |FL(j)|}{|LL|}$$

where FL: Follower Set, LL: Local Leader Set

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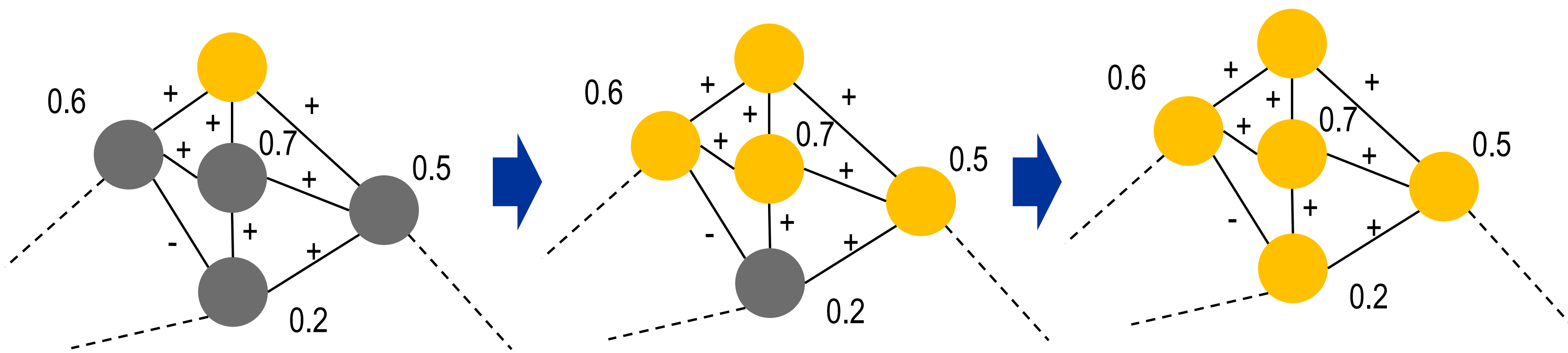
Signed Disassortative Degree Mixing and Information Diffusion Algorithm: Phase 2

Cascading (network coordination game)

- Assign a leader node *k* behavior *B* and all other nodes behavior *A*
- Node *i* with current behavior *A* will change its behavior to that (*B*) of its neighbors, if the potential payoff p_B(i) is above a predefined threshold, i.e. LLD:

$$p_B(i) = \frac{|\{u|u \in Nei^{+}(i) \text{ and } behavior(u) = B\}| - |\{v|v \in Nei^{+}(i)\ and\ behavior(v) = B\}|}{|\{u|u \in Nei^{+}(i)\ and\ behavior(u) = B\}| + |\{v|v \in Nei^{+}(i)\ and\ behavior(v) = B\}|}$$



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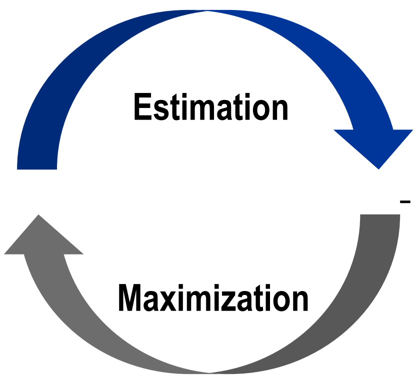
Signed Probabilistic Mixture Model

- Based on Expectation-Maximization (EM) method
- Maximize the log function of the marginal likelihood of the signed network:

$$P(E|\omega,\theta) = \prod_{e_{ij}\in E}\left(\sum_{rr}\omega_{rr}\,\theta_{ri}\theta_{rj}\right)^{A_{ij}^{+}}\left(\sum_{rs(r\neq s)}\omega_{rs}\,\theta_{ri}\theta_{sj}\right)^{A_{ij}^{-}}$$



Use ω,θ to compute

- ○ The probability of a positive edge from a community *r* : p_1
- ○ The probability of a negative edge from two communities *r* and *s*: p_2

Update ω,θ with p_1 and p_2 by maximizing $lnP(E|\omega,\theta)$

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Multi-Objective Evolutionary Algorithm Based on Similarity for Community Detection in Signed Networks

- Based upon structural similarity between adjacent nodes

$$s(u,v) = \frac{\sum_{x \in B(u) \cap B(v)} \Psi(x)}{\sqrt{\sum_{x \in B(u)} w_{ux}^2} \cdot \sqrt{\sum_{x \in B(v)} w_{vx}^2}}$$

where $\Psi(x) = 0, \text{if } w_{ux} < 0 \text{ and } w_{vx} < 0;\ w_{ux}\, w_{vx}, otherwise$

- Objective functions
  - Maximize the sum of positive similarities within communities
  - Maximize the sum of negative similarities between communities

- Optimal solution is selected with MOEA/D (multiobjective evolutionary algorithm based on decomposition) [ZhLi07]
  - Decomposition into scalar optimization
  - Simultaneous optimization of these subproblems

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Evaluation Metrics

- **Normalized mutual information**: regards M_{ik}, $M_{il'}$ as two random variables and determines the mutual information (M_i: membership vector, k: k-th community in detected cover, l': l'-th community in real cover)
- **Signed modularity**: measures the strength of a community partition by taking into account the degree distribution

$$Q_{SO} = \frac{1}{2(w^+)_e + 2|(w^-)_e|} \sum_{e_{ij}} \left[w_{ij} - \left(\frac{w_i^+ w_j^+}{2(w^+)_e} - \frac{w_i^- w_j^-}{2|(w^-)_e|} \right) \right] \delta(C_i, C_j),$$

where $\delta(C_i, C_j)$: No.of communities e_{ij} resides

- **Frustration**: normalized weighted weight sum of negative edges inside communities and positive edges between communities

$$Frustration = \frac{\alpha \times |(w_{intra}^-)_e| + (1-\alpha) \times |(w_{inter}^+)_e|}{(w^+)_e + |(w^-)_e|}$$

- **Execution time**

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Synthetic Network Generator

- Comes from the idea of [LiLJ14] and is based on the Lancichinetti-Fortunato-Radicchi (LFR) model (directed and unweighted) and a model from [YaCL07]
- Parameters
  - From LFR: no. of nodes, average/max degree, minus exponents for the degree and community size distributions which are power laws, min/max community size, no. of overlapping nodes, no. of communities, fraction of edges that each node shares with other communities.
  - From [YaCL07]: proportion of negative edges inside communities P_- and proportion of positive edges between communities P_+

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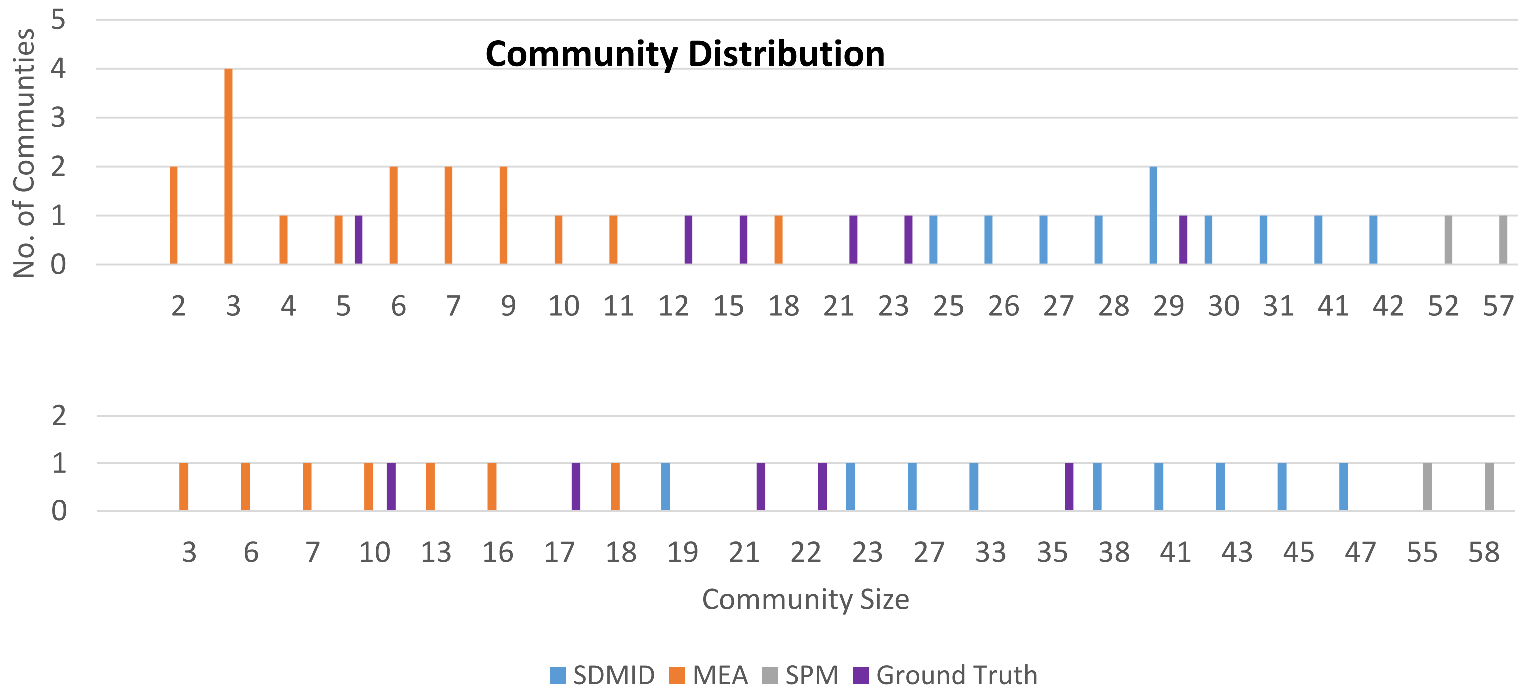
Experiments on Benchmark Networks: Community Structure (1)

- SDMID has a more similar community distribution in comparison to the ground truth
- SPM detects the biggest community sizes

Maxc=35

Maxc=40



Parameters: n=100, k=3, maxk=6, μ=0.1, t_1=-2.0, t_2=-1.0, minc=5, on=5, om=2, P_-=0.01, P_+=0.01

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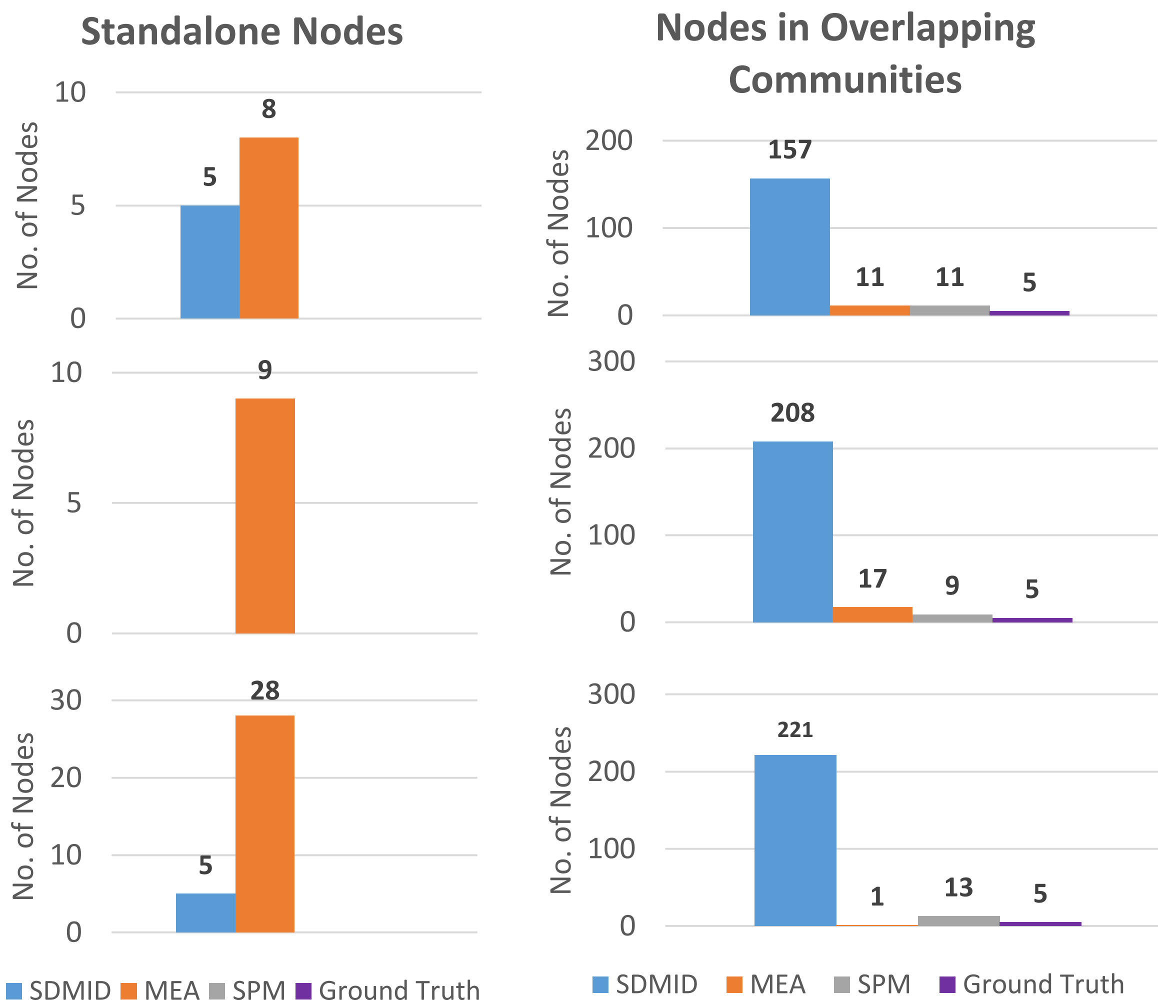
Experiments on Benchmark Networks: Community Structure (2)

- MEA detects the highest number of standalone nodes
  - SDMID also identifies some of the nodes as standalone
- SDMID assigns most of the nodes as overlapping



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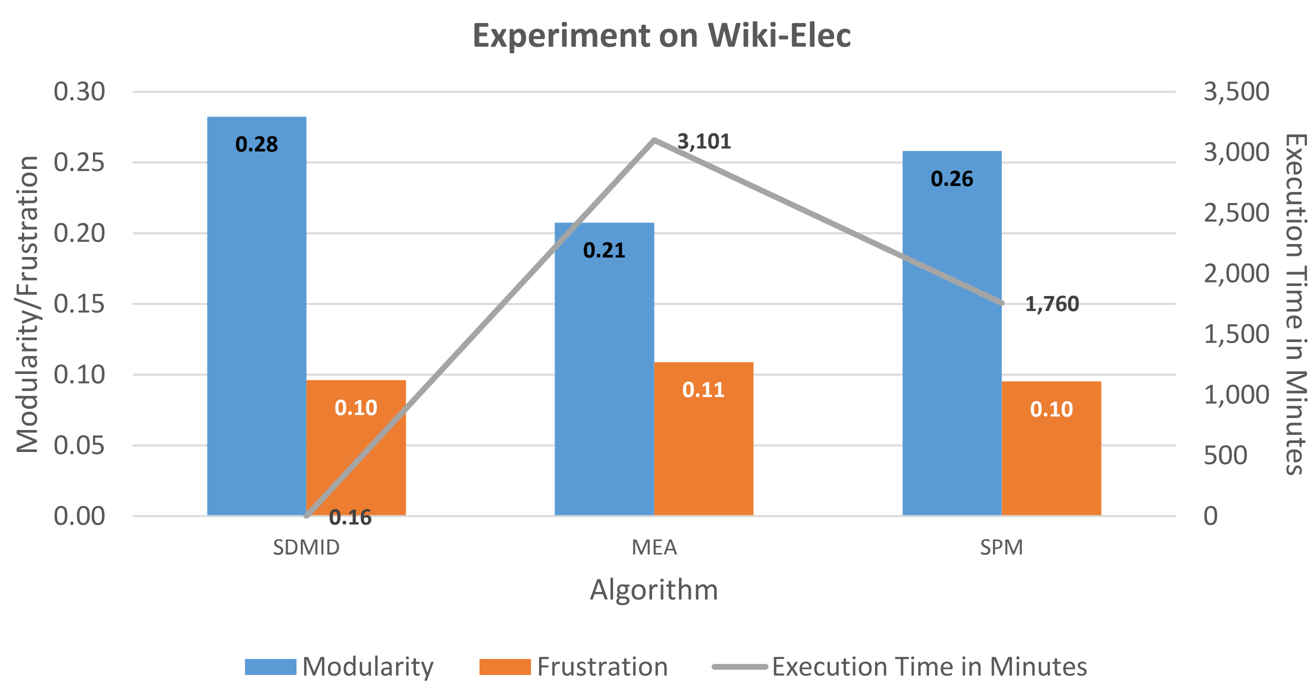
Experiment on Real World Network Wiki-Elec: Metric Values

- SDMID has the highest modularity value
- SDMID and SPM obtain the lowest frustration values
- SDMID is the best regarding the execution time



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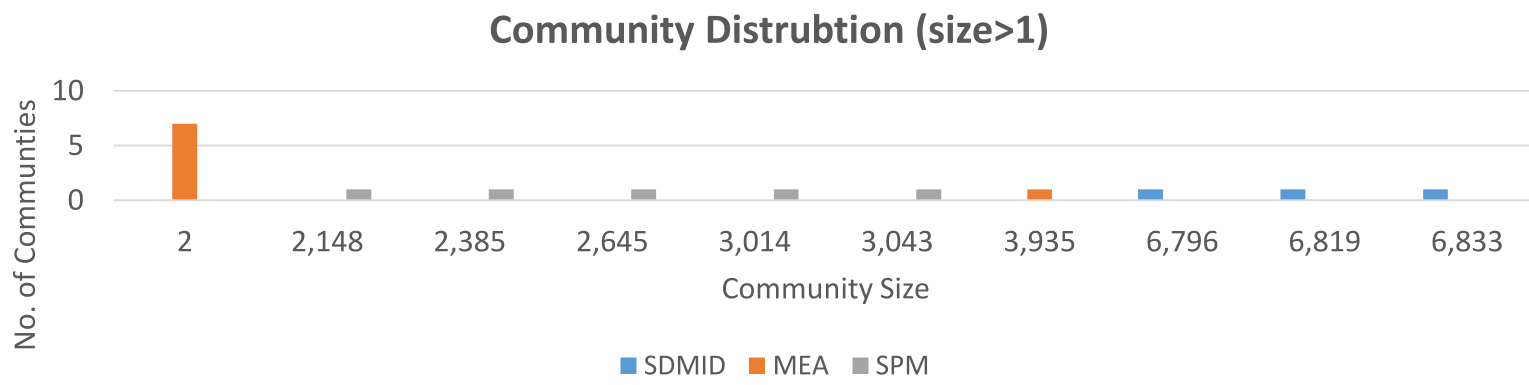
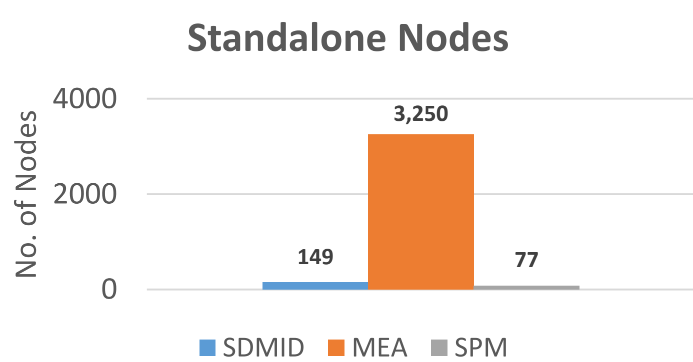
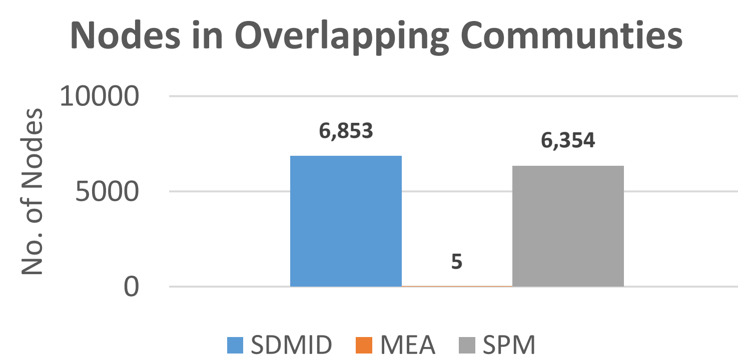
Experiments on Real World Network Wiki-Elec: Community Structure

- MEA detects most of the nodes as standalone and most of the nodes are in one community
- Fewest number of standalone nodes observed in SDMID and SPM
- SDMID and SPM approximately detect high number of overlapping ndoes







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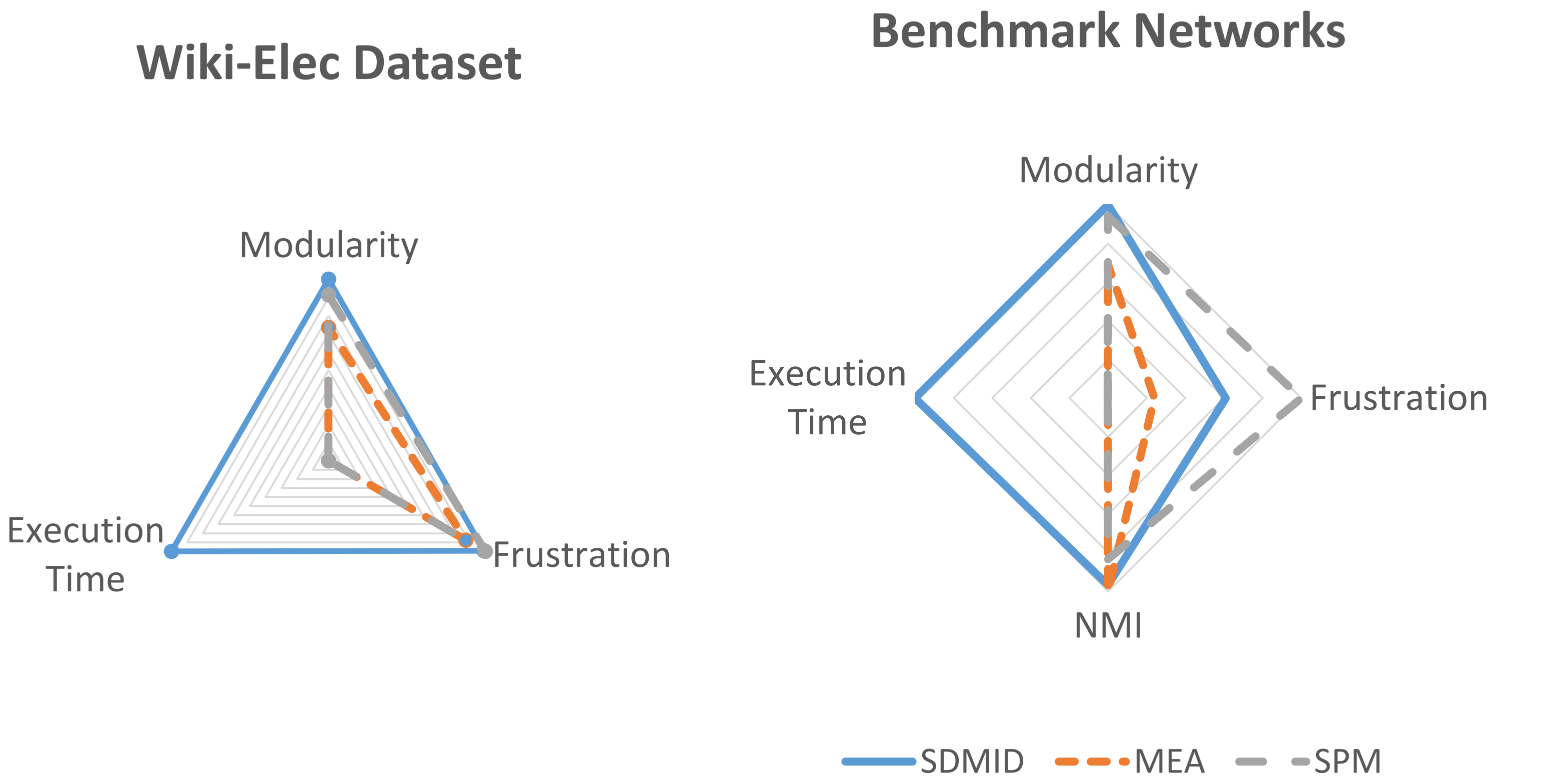
Experiment Summary: Evaluation Radar

- In Wiki-Elec, SDMID has the best performance regarding modularity, execution time and frustration
- In Benchmark networks, SDMI has better performance regarding modularity, execution time and NMI
  - Performance of SPM is better regarding Frustration



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Experiment Summary: Community Structure

- SDMID
  - Big-sized communities
  - Large areas of overlapping
- MEA_s-SN
  - Small-sized communities
  - Few nodes in the overlapping area
  - Large number of stand-alone nodes
- SPM
  - Predefined number of communities k
  - Large areas of overlapping with a small k

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Conclusion & Message

- We compared SDMID, SPM and MEA OCD algorithms from different aspects
- There are few algorithms for overlapping community detection in signed networks
- Currently SDMID and SPM are the best options to be applied on datasets in signed networks
  - SDMID is the fastest and has the highest modularity
  - SDMID obtained the best performance on the real world network Wiki-Elec
- SDMID might be a better choice when diffusion of opinions is preferred across community borders

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Thank you !