Information Aggregation on Networks: an Experimental Study

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People learn, form opinions and shape beliefs both
  - by collecting noisy private info
  - by observing choices of others (family, friends, ...)

The architecture of social network and one’s position in it
determines info set available to the agent
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Learning and info aggregation over networks
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• Learning and info aggregation over networks

• General setting
  • a group of agents are tied together by a social network
  • each observes noisy but informative signal about true state
  • all agents want to match the state
  • in every round, guess the state and observe neighbor’s guesses
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**Introduction, cont...**

- Theoretical literature
  - tend to focus on societies of infinite size
  - mild conditions are sufficient for full convergence to the truth in connected societies
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• What happens in finite but large societies?
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• What happens in finite but large societies?

• Casual observation:
  • in some cases opinions do not seem to converge to a consensus even in connected societies, while in other cases they do
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• What happens in finite but large societies?

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  • in some cases opinions do not seem to converge to a consensus even in connected societies, while in other cases they do

• THIS PAPER:
  • explore effects of network architectures on dynamics of belief formation over large networks
  • characterize architecture features that prevent info aggregation
1. **Theoretical literature**
   - Bayesian model
     - Gale and Kariv (2003), Acemoglu et al. (’11), Muller-Frank (’13), Mossel, Sly and Tamuz (’15)
   - Naive Model
     - de Groot (’74), deMarzo et al. (’03), Golub and Jackson (’10, 2012), Acemoglu and Ozdaglar (’11)
   - Other theories
     - Bala and Goyal (’98), Jackson and Watts (’03), Goyal and Vega Redondo (’05)

2. **Empirical studies**
   - lab experiments focus on relatively small networks
     - Choi et al (’05, ’12), Corrazzini et al (’12), Mueller-Frank and Neri (’14), Grimm and Mengel (’20), Chandrasekhar et al. (’20)
   - field studies
     - Chandrasekhar et al. (’20), Banerjee et al (’19), Breza et al (’19)
• 10 games with same network (18 members in a network)
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Networks’ roles are re-shuffled in each game
10 games with same network (18 members in a network)

Networks’ roles are re-shuffled in each game

What happens in each game

- Round 1:
  - each player gets private signal about the state (iid, 70% correct)
  - guess the state

- Rounds 2 onwards:
  - observe guesses of neighbors and guess the state

- Game ends: if no one changes her guess in three consecutive rounds or with prob 50% after round 50

Incentives:
- $20 for correct guess in random round of random game, $5 o/w
- show-up fee $10
Experimental Design

- 10 games with same network (18 members in a network)
- Networks’ roles are re-shuffled in each game
- What happens in each game
  - Round 1:
    - each player gets private signal about the state (iid, 70% correct)
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- Incentives:
  - $20 for correct guess in random round of random game, $5 o/w
  - show-up fee $10
This is game 1. You are now in round 1.

Please guess the color chosen by the computer and press Submit.

[Options: WHITE, BLUE]
This is game 1. You are now in round 2

Please guess the color chosen by the computer and press Submit.

Submit
• Most sessions had more than 18 subjects

• 18 are placed in the network, others are observers (random)

• Observers’ task
  • observe network structure
  • pick a position in the network whose payoff you will get if this game is selected for payment

• Measure *perceived* centrality (payoffs)

• How does perceived centrality match centrality indices?
• What do we expect in this network?
• Fast convergence to the right guess
  • Round 1: report own signal
  • Rounds 2 - 4: observe all r1 guesses (signals), report majority one
What do we expect in these networks?

- Fast convergence to the right guess
  - Round 1: report own signal
  - Round 2: hub observes all signals, reports majority one
  - Round 3 - 5: all members imitate the hub
Networks, cont...

Two Cores One Link

Two Cores with Three Links

What do we expect in these networks?

- Depends on the distribution of signals in each cluster
- Fast convergence to the right guess
- Fast convergence to the wrong guess
  - One Link: 10-8, 4 wrong in each cluster, red nodes wrong signals
- Slow convergence (more than 7 rounds) to the right guess
What do we expect in this network?
- Depends on the distribution of signals in each cluster
- Fast/slow convergence to the right/wrong guess
- Separation of centrality indices at the node level
<table>
<thead>
<tr>
<th></th>
<th>UCI</th>
<th>UCSD</th>
<th>TAU</th>
<th>total # sessions</th>
<th>total # subjects</th>
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<tbody>
<tr>
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<td>2</td>
<td>2</td>
<td>1</td>
<td>5 sessions</td>
<td>106 subjects</td>
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<tr>
<td>Star 18</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>7 sessions</td>
<td>141 subjects</td>
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<tr>
<td>One Gatekeeper</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>6 sessions</td>
<td>122 subjects</td>
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<tr>
<td>Single Mediator</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>4 sessions</td>
<td>82 subjects</td>
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<tr>
<td>Two Cores One Link</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>5 sessions</td>
<td>100 subjects</td>
</tr>
<tr>
<td>Two Cores Three Links</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>3 sessions</td>
<td>60 subjects</td>
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<tr>
<td>Complex</td>
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<td>2</td>
<td>0</td>
<td>4 sessions</td>
<td>80 subjects</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>34 sessions</td>
<td>691 subjects</td>
</tr>
</tbody>
</table>
First look at the data

- Identify structural features of networks
- Does network architecture affect long-run outcomes?
- Empirical strategy
  - last 5 games in each session
  - regression analysis with clustering at the session level
**Outcomes**

1. Game length

2. Frac correct last round guesses
   - Consensus in last round
     - 0.5 = fully polarized, 1 = full consensus
   - How often last round majority is correct

3. Agree-to-disagree state in last round
   - 7-11 or 8-10 or 9-9

4. Evolution of frac of correct guesses

5. Evolution of consensus
1. Big Brother: one observes everyone
   - Star, One Gatekeeper, Single Mediator

2. One Cluster: one large group of highly connected nodes
   - One Gatekeeper, Complete

3. Two Clusters
   - Two Cores One Link, Two Cores Three Links, Complex
Examples of Structural Features

One Gatekeeper

Two Cores Three Links

Big Brother
One Cluster

No Big Brother
Two Clusters
Outcome_{nm} = \beta_0 + \beta_1 \cdot \text{Architecture Feature}_n + \epsilon_{nm}

Results

- **Networks with Big Brother**
  - games last longer \( (p = 0.066) \)

- **Networks with One Cluster**
  - higher frac of correct last round guesses \( (p = 0.074) \)
  - higher chance that majority is correct \( (p = 0.026) \)
  - lower chance of agree-to-disagree \( (p = 0.009) \)
  - 7% in One Gatekeeper

- **Networks with Two Clusters**
  - marginally lower consensus \( (p = 0.097) \)
  - higher chance of agree-to-disagree \( (p = 0.021) \)
  - 24% in Two Cores One Link
Similar consensus rates
Decrease in how often majority is correct over time
Networks w/ a cluster aggregate info better than those w/out
Agree-to-disagree state declines sharply with a cluster
Networks with Big Brother do not respond to info quality

But they are sensitive to Big Brother info
  - frac of correct last round guesses: 66% → 79%
  - consensus rates: 78% → 83%
**Adding Links (Oversight)**

- **Star → One Gatekeeper**
  - frac of correct guesses increases
  - consensus rates stays same, but majority is correct more often
  - agree-to-disagree state is less frequent
• Two Cores One Link
  • distribution of signals 12-6, both hubs have correct signal

• Session 6, Game 7
  • left cluster: signals 6/9 correct, last guesses all correct
  • right cluster: signals 6/9 correct, last guesses 6/9 correct
  • frac of correct last round guesses is 83% and consensus is 83%

• Session 6, Game 10
  • left cluster: signals 8/9 correct, last guesses 7/9 correct
  • right cluster: signals 4/9 correct, last guesses all wrong
  • frac of correct last round guesses is 39% and consensus is 61%
Aggregate Network Measures

\[ \text{Outcome}_{nm} = \beta_0 + \beta_1 \cdot \text{Info}_{nm} + \beta_2 \cdot \text{Measure}_n + \epsilon_{nm} \]

- \( n \) - network type, \( m \) - match in a session
- cluster by session
- Info is % correct signals minus 0.7 (av quality info)
- Measures
  - Diameter
  - Density
Aggregate Network Measures: Results

- Frac Correct Guesses
  - positively corr with Density \((p = 0.02)\)
  - negatively corr with Diameter \((p = 0.004)\)

- Consensus
  - negatively corr with Diameter \((p = 0.002)\)

- Majority correct
  - positively corr with Density \((p = 0.007)\)

- Agree-to-Disagree
  - positively corr with Diameter \((p = 0.02)\)
• Network architectures matters
  • for long-run outcomes
  • evolution of outcomes over time

• Local information plays an important role
  • distribution of signals in networks with clusters
  • signal of Big Brother
  • oversight (‘unnecessary links’)

• Standard measures pick up some of these patterns
• How fast different nodes make up their minds?

• Do subjects change their mind (last guess \( \neq \) first guess)?

• Do you learn directly from your local connections (second guess \( \neq \) first guess)?

• Do subjects learn correctly (signal \( \neq \) last guess = state)?

• Which nodes are correct more often? (payoffs)
• Networks w/ Big Brother: hubs converge faster than others
• Networks w/ Two Cores: clusters take longer than ‘connectors’
Differentiation of centrality measures at the node level

- Degree centrality: blue > purple > red = green
- Betweenness: red = purple > blue > green
- Eigenvalue centrality: blue > purple > green > red
**Individual outcomes and node centrality**

\[
\text{Outcome}_{i_m} = \beta_0 + \beta_1 \cdot \text{Degree}_i + \beta_2 \cdot \text{Betweenness}_i + \beta_3 \cdot \text{Eigenvalue}_i + \\
\quad + \beta_4 \cdot \text{My Info}_{i_m} + \beta_5 \cdot \text{Network Info}_{i_m} + \epsilon_{i_m}
\]

**Results**

<table>
<thead>
<tr>
<th></th>
<th>Freq Correct (all rounds)</th>
<th>Correct (last round)</th>
<th>Changed Mind last – first</th>
<th>Learned Correctly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree</td>
<td>0.09**</td>
<td>0.12**</td>
<td>0.05</td>
<td>0.07*</td>
</tr>
<tr>
<td>Betweenness</td>
<td>-0.02</td>
<td>-0.03</td>
<td>0.01</td>
<td>-0.02</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>0.04</td>
<td>0.03</td>
<td>-0.24**</td>
<td>-0.09</td>
</tr>
</tbody>
</table>

significant at ** 5%, at * 10%
**Perceived Centrality: Observers**

- Most choose nodes with highest degree and best performance
- Some pick nodes with high betweenness

<table>
<thead>
<tr>
<th></th>
<th>Observers’ Choice</th>
<th>Theory</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>raw %</td>
<td>rescaled</td>
<td>degree</td>
</tr>
<tr>
<td>Blue</td>
<td>0.67</td>
<td>0.43</td>
<td>0.29</td>
</tr>
<tr>
<td>Red</td>
<td>0.10</td>
<td>0.27</td>
<td>0.12</td>
</tr>
<tr>
<td>Purple</td>
<td>0.15</td>
<td>0.19</td>
<td>0.18</td>
</tr>
<tr>
<td>Green</td>
<td>0.08</td>
<td>0.11</td>
<td>0.12</td>
</tr>
</tbody>
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Conclusions and Next Steps

- Variation in network-level outcomes is related to structure features of networks
  - networks w/ well connected group aggregate info better and have lower chance of agree-to-disagree state
  - networks w/ Big Brother do not respond to info quality but instead to Big Brother’s info
- Information aggregation does occur, but imperfectly
- Local information plays an important role
- Network position affects individual outcomes
  - hubs form their opinion faster than other members
  - nodes w/ higher degree are more likely to learn true state
  - nodes w/ higher eigenvalue are less likely to change their mind
- Observers’ choices (perceived centrality)
  - heterogeneity, matches actual nodes’ performance
- NEXT STEP: structural estimation of learning strategies
Additional Materials
Frequency of Correct Last Guesses

74% 79% 71% 76% 80% 69% 83%

Star 18 One Gate Single Mediator Equal Cores 3-Linked Cores Two Groups Complete 9 Comple
Consensus in the Last Round

- Star 18: 83%
- One Gate: 82%
- Single Mediator: 77%
- Equal Cores: 78%
- 3-Linked Cores: 82%
- Two Groups: 73%
- Complete 9: 88%
How Often Majority is Correct?

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Star 18</td>
<td>77%</td>
</tr>
<tr>
<td>One Gate</td>
<td>90%</td>
</tr>
<tr>
<td>Single Mediator</td>
<td>85%</td>
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<tr>
<td>Equal Cores</td>
<td>80%</td>
</tr>
<tr>
<td>3-Linked Cores</td>
<td>91%</td>
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<tr>
<td>Two Groups</td>
<td>86%</td>
</tr>
<tr>
<td>Complete 9</td>
<td>91%</td>
</tr>
</tbody>
</table>