Network Characteristics and Efficient Coordination

Frank Thuijsman

joint work with
Abhimanu Khan, Ronald Peeters, Philippe Uyttendaele
Outline

1 Introduction
2 A Simulation Study
3 Characteristics
4 Results
5 Other Networks
6 More Types
Assumptions:

1. $a > c, d > b$: pure equilibria $(P, P)$ and $(R, R)$;
2. $a > d$: payoff on $P$ Pareto dominates payoff on $R$;
3. $c > b$: in case of mis-coordination, $R$ is safer.
Population of Players

Assumptions:

1. even number of players;
2. players are connected in (social) network;
3. at discrete stages 1, 2, 3, ... players are randomly matched to other players;
4. at each stage each player chooses $P$ or $R$ by imitating neighbor with highest payoff;
5. neighbors include self.
We want to investigate the influence of network characteristics:

1. on convergence to the efficient outcome $P$;
2. on the speed of convergence to a homogeneous population.
Scale-Free Networks

Method of construction

Motivation:
Scale-free networks match empirical data on networks
Few nodes with high degree, many nodes with low degree.
Scale-Free Networks

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Few nodes with high degree, many nodes with low degree.
We created scale-free networks with 100, 200 and 300 nodes.
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- 25 networks with average degree 4;
- 25 networks with average degree 6;
- 25 networks with average degree 8.
We created scale-free networks with 100, 200 and 300 nodes. For each of these we examined:
- 25 networks with average degree 4;
- 25 networks with average degree 6;
- 25 networks with average degree 8.
This gave a total of 225 different networks.
For each of 225 networks we used 300 random initializations.
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These initializations were made by creating 25 random colorings for each of 12 fixed fractions of $P$ nodes.
For each of 225 networks we used 300 random initializations.

These initializations were made by creating 25 random colorings for each of 12 fixed fractions of $P$ nodes.

We used the following 12 fractions:
0.01, 0.02, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50.
For each of 225 networks we used 300 random initializations. These initializations were made by creating 25 random colorings for each of 12 fixed fractions of $P$ nodes.

We used the following 12 fractions:
0.01, 0.02, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50.

This gave 67,500 different initializations.
For each of 67,500 initializations we ran 25 simulations.
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Network Simulations

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At each stage all nodes were randomly paired to other nodes.
Network Simulations

For each of 67,500 initializations we ran 25 simulations.

This gave a total of 1,687,500 simulations.

Each simulation ran until all nodes were of the same type.

At each stage all nodes were randomly paired to other nodes.

Each node played the strategy that did best among its neighbors (each node is one of its own neighbors).
An Example on a Scale Free Network

Initially 20% $P$, type 1, white

Average Degree 4

<table>
<thead>
<tr>
<th></th>
<th>$P$</th>
<th>$R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P$</td>
<td>6, 6</td>
<td>0, 3</td>
</tr>
<tr>
<td>$R$</td>
<td>3, 0</td>
<td>4, 4</td>
</tr>
</tbody>
</table>
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Average Degree 4

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An Example on a Scale Free Network

Initially 20% $P$, type 1, white

Average Degree 4
Network Specific Characteristics (NSC)

- **Size:**
- **Density:**
- **Degree:**
- **Power:**
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Results</th>
<th>Other Networks</th>
<th>More Types</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Network Specific Characteristics (NSC)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Size:** number of nodes
- **Density:**
- **Degree:**
- **Power:**
### Network Specific Characteristics (NSC)

- **Size**: number of nodes
- **Density**: fraction of links used in network
- **Degree**:
- **Power**:
<table>
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<th>Characteristics</th>
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</tr>
</thead>
<tbody>
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<td><strong>Size:</strong> number of nodes</td>
<td></td>
</tr>
<tr>
<td><strong>Density:</strong> fraction of links used in network</td>
<td></td>
</tr>
<tr>
<td><strong>Degree:</strong> mean and s.d. of degree per node</td>
<td></td>
</tr>
<tr>
<td><strong>Power:</strong></td>
<td></td>
</tr>
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### Network Specific Characteristics (NSC)

- **Size**: number of nodes
- **Density**: fraction of links used in network
- **Degree**: mean and s.d. of degree per node
- **Power**: mean and s.d. of power per node
Initial Assignment of Strategies (IAS)

- **Share of P nodes:**
- **Degree of P nodes:**
- **Power of P nodes:**
- **Segregation of P nodes:**
- **Segregation of R nodes:**
Initial Assignment of Strategies (IAS)

- **Share of P nodes**: fraction of P nodes
- **Degree of P nodes**: 
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- **Share of P nodes**: fraction of P nodes
- **Degree of P nodes**: mean and s.d. of degree per P node
- **Power of P nodes**: sum, mean and s.d.
- **Segregation of P nodes**:
- **Segregation of R nodes**:
Initial Assignment of Strategies (IAS)

- **Share of P nodes**: fraction of $P$ nodes
- **Degree of P nodes**: mean and s.d. of degree per $P$ node
- **Power of P nodes**: sum, mean and s.d.
- **Segregation of P nodes**: measure using random walks
- **Segregation of R nodes**: same
Variables to Explain

- Payoff Dominant Wins:
- Mean Convergence Time:
Variables to Explain

- **Payoff Dominant Wins**: proportion of $P$ wins
- **Mean Convergence Time**: 
Variables to Explain

Payoff Dominant Wins:
proportion of P wins

Mean Convergence Time:
just what it says
Variables to Explain

- **Payoff Dominant Wins**: proportion of $P$ wins
- **Mean Convergence Time**: just what it says

Each of these is measured over 25 runs for any specific choice of initialized network.
Number of Initializations for $P$ Wins Proportions
Regression Analysis on *Payoff Dominant Wins*

For the Scale Free Networks Examined:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coef.</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>.000166</td>
<td>positive</td>
</tr>
<tr>
<td>Degree: mean</td>
<td>.013205</td>
<td>positive</td>
</tr>
<tr>
<td>Share of <em>P</em> nodes</td>
<td>2.175143</td>
<td>positive</td>
</tr>
<tr>
<td>Degree of <em>P</em> nodes: stdev</td>
<td>.012700</td>
<td>positive</td>
</tr>
<tr>
<td>Segregation (norm.) of <em>P</em> nodes</td>
<td>-.053167</td>
<td>negative</td>
</tr>
<tr>
<td>Segregation (norm.) of <em>R</em> nodes</td>
<td>-.107330</td>
<td>negative</td>
</tr>
<tr>
<td>Constant</td>
<td>.121343</td>
<td>—</td>
</tr>
<tr>
<td>Number of obs.</td>
<td>67,500</td>
<td></td>
</tr>
<tr>
<td>R-squared</td>
<td>0.8402</td>
<td></td>
</tr>
</tbody>
</table>
Regression Analysis on *Convergence Time*

For the Scale Free Networks Examined:

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<tr>
<th>Variable</th>
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<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>.002208</td>
<td>positive</td>
</tr>
<tr>
<td>Degree: mean</td>
<td>-.379215</td>
<td>negative</td>
</tr>
<tr>
<td>Share of <em>P</em> nodes</td>
<td>.302001</td>
<td>positive</td>
</tr>
<tr>
<td>Degree of <em>P</em> nodes: stdev</td>
<td>.113038</td>
<td>positive</td>
</tr>
<tr>
<td>Segregation (norm.) of <em>P</em> nodes</td>
<td>-.806758</td>
<td>negative</td>
</tr>
<tr>
<td>Segregation (norm.) of <em>R</em> nodes</td>
<td>1.765975</td>
<td>positive</td>
</tr>
<tr>
<td>Constant</td>
<td>3.551547</td>
<td>—</td>
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<tr>
<td>Number of obs.</td>
<td>67,500</td>
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<tr>
<td>R-squared</td>
<td>0.4596</td>
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Classification Tree Analysis on *Payoff Dominant Wins*

For the Scale Free Networks Examined:

<table>
<thead>
<tr>
<th>Selection</th>
<th>Convergence to $P$</th>
<th>Number of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original dataset</td>
<td>mean 63.2%</td>
<td>std 42.2%</td>
</tr>
<tr>
<td>Segregation (norm.) of $P$ nodes $&lt; 1.313$</td>
<td>79.7%</td>
<td>32.2%</td>
</tr>
<tr>
<td>Segregation (norm.) of $P$ nodes $\geq 1.313$</td>
<td>11.2%</td>
<td>23.0%</td>
</tr>
</tbody>
</table>
Small World Networks

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An Example on a Small World Network

Initially 20% $P$, type 1, white

Rewiring prob. 0.2

Average Degree 4

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We created scale-free networks with 100, 200 and 300 nodes.
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For each of these we examined:

- 10 networks with average degree 4;
- 10 networks with average degree 6;
- 10 networks with average degree 8.
We created scale-free networks with 100, 200 and 300 nodes.

For each of these we examined:

- 10 networks with average degree 4;
- 10 networks with average degree 6;
- 10 networks with average degree 8.

This gave a total of 90 different networks.
Network Initializations

For each of 90 networks we used 720 random initializations.
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These initializations were made by creating 10 random colorings, for each of 12 fixed fractions of $P$ nodes, for each of 6 different re-wiring probabilities.
Network Initializations

For each of 90 networks we used 720 random initializations.

These initializations were made by creating 10 random colorings, for each of 12 fixed fractions of $P$ nodes, for each of 6 different re-wiring probabilities.

We used the following 12 fractions:
0.01, 0.02, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50.
For each of 90 networks we used 720 random initializations.

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We used the following 12 fractions:
0.01, 0.02, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50.

And re-wiring probabilities: 0, 0.2, 0.4, 0.6, 0.8, 1
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0.01, 0.02, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50.

And re-wiring probabilities: 0, 0.2, 0.4, 0.6, 0.8, 1

This gave 64,800 different initializations.
<table>
<thead>
<tr>
<th>Network Simulations</th>
</tr>
</thead>
</table>

For each of 64,800 initializations we ran 10 simulations.
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This gave a total of 648,000 simulations.
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Each simulation ran until all nodes were of the same type.
Network Simulations

For each of 64,800 initializations we ran 10 simulations.

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Each simulation ran until all nodes were of the same type.

At each stage all nodes were randomly paired to other nodes.
Network Simulations

For each of 64,800 initializations we ran 10 simulations.

This gave a total of 648,000 simulations.

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At each stage all nodes were randomly paired to other nodes.

Each node played the strategy that did best among its neighbors (each node is one of its own neighbors).
Number of Initializations for $P$ Wins Proportions for SWN
Small World Regression Analysis on Payoff Dominant Wins

For the Small Data Set of Small World Networks Examined:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coef.</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>.000085</td>
<td>positive</td>
</tr>
<tr>
<td>Degree: mean</td>
<td>.033065</td>
<td>positive</td>
</tr>
<tr>
<td>Degree: stdev</td>
<td>-.005834</td>
<td>negative</td>
</tr>
<tr>
<td>Share of $P$ nodes</td>
<td>2.456533</td>
<td>positive</td>
</tr>
<tr>
<td>Degree of $P$ nodes: stdev</td>
<td>.015220</td>
<td>positive</td>
</tr>
<tr>
<td>Segregation (norm.) of $P$ nodes</td>
<td>-.014965</td>
<td>negative</td>
</tr>
<tr>
<td>Segregation (norm.) of $R$ nodes</td>
<td>-.931433</td>
<td>negative</td>
</tr>
<tr>
<td>Constant</td>
<td>.757578</td>
<td>—</td>
</tr>
</tbody>
</table>

Number of obs. 64,800
R-squared 0.8261
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Number of Initializations for Convergence Time for SWN
For the Small Data Set of Small World Networks Examined:

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<th>Variable</th>
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<th>Effect</th>
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</thead>
<tbody>
<tr>
<td>Size</td>
<td>0.004134</td>
<td>positive</td>
</tr>
<tr>
<td>Degree: mean</td>
<td>-0.256099</td>
<td>negative</td>
</tr>
<tr>
<td>Degree: stdev</td>
<td>-1.742573</td>
<td>negative</td>
</tr>
<tr>
<td>Share of $P$ nodes</td>
<td>-0.590169</td>
<td>negative</td>
</tr>
<tr>
<td>Segregation (norm.) of $P$ nodes</td>
<td>-0.954044</td>
<td>negative</td>
</tr>
<tr>
<td>Segregation (norm.) of $R$ nodes</td>
<td>-5.030866</td>
<td>negative</td>
</tr>
<tr>
<td>Constant</td>
<td>13.109070</td>
<td>—</td>
</tr>
</tbody>
</table>

Number of obs. 64,799  
R-squared 0.3382
**Small World Classification Tree Analysis**

For the Small Data Set of Small World Networks Examined:

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<th>Number of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original dataset</td>
<td>mean</td>
<td>std</td>
</tr>
<tr>
<td>Segregation (norm.) of $P$ nodes &lt; 1.210</td>
<td>88.3%</td>
<td>24.2%</td>
</tr>
<tr>
<td>Segregation (norm.) of $P$ nodes ≥ 1.210</td>
<td>10.5%</td>
<td>22.6%</td>
</tr>
</tbody>
</table>
Comparison of Results for Scale-Free and Small World Networks

1. In both cases Size and Share of P nodes have a positive effect on efficient coordination.
2. In both cases Segregation of P nodes and Segregation of R nodes have a negative effect on efficient coordination.
3. In both cases Segregation of P nodes is the most important variable to decide on convergence to P or to R.
A Scale Free Network with 3 Types

Initial distr.
(0.4; 0.2; 0.2)

Average Degree 4

\[ \begin{array}{ccc}
P & R & S \\
\hline
P & 6,6 & 0,3 & 0,1 \\
R & 3,0 & 4,4 & 1,2 \\
S & 1,0 & 2,1 & 3,3 \\
\end{array} \]
A Scale Free Network with 3 Types

Initial distr. (0.4; 0.2; 0.2)
Average Degree 4

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A Scale Free Network with 3 Types

Initial distr.
(0.4; 0.2; 0.2)

Average Degree 4
A Small World Network with 3 Types

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<th>R</th>
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<td>0,3</td>
<td>0,1</td>
</tr>
<tr>
<td>R</td>
<td>3,0</td>
<td>4,4</td>
<td>1,2</td>
</tr>
<tr>
<td>S</td>
<td>1,0</td>
<td>2,1</td>
<td>3,3</td>
</tr>
</tbody>
</table>

Initial distr. (0.4; 0.2; 0.2)

Rewiring prob. 0.2

Average Degree 4
A Small World Network with 3 Types

Initial distr. (0.4; 0.2; 0.2)

Rewiring prob. 0.2

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A Small World Network with 3 Types

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A Small World Network with 3 Types

Initial distr.
(0.4; 0.2; 0.2)

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A Small World Network with 3 Types

<table>
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<th>P</th>
<th>R</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>6, 6</td>
<td>0, 3</td>
<td>0, 1</td>
</tr>
<tr>
<td>R</td>
<td>3, 0</td>
<td>4, 4</td>
<td>1, 2</td>
</tr>
<tr>
<td>S</td>
<td>1, 0</td>
<td>2, 1</td>
<td>3, 3</td>
</tr>
</tbody>
</table>

Initial distr.
(0.4; 0.2; 0.2)

Rewiring prob. 0.2

Average Degree 4
Six Runs in Parallel

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Six Runs in Parallel

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Thank you for your Attention!
Comments will be appreciated!

Presentation and paper will soon be available at https://dke.maastrichtuniversity.nl/f.thuijsman/