Venice, April 7th, 2011
INSITE Meeting

The artificial world of the Pardus game: First lessons

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Establishing a socio-economic laboratory

- Establish a socio-economic laboratory for socio-economic behavior, behavioral economics, ...
- Evolving, multirelational organisation of human society
- Applications: Social balance, Weak Ties, Triadic Closure
- Massive multiplayer online game

Computational social science

Small-scale questionnaire-based

Large-scale datasets from electronic media
(mobile phone, email, Facebook, ...)

Dynamics and organization of large social systems

Lazer et al., Science 323, 721-724 (2009)
Onnela et al., PNAS 104, 7332 (2007)
Lambiotte et al., Physica A 387, 5317 (2008)
Kossinets and Watts, Science 311, 88–90 (2006)

Establishing a socio-economic laboratory

Dynamics and organization of specific aspects of large social systems

↓

Can we do better?

Socio-economic laboratories of whole human societies

Massive multiplayer online games

www.pardus.at

Players live an alternative life, in a virtual universe interacting with many others

- 375,000 registered players
- 15,000 active players
- Online since 2004

Bainbridge, Science 317, 472 (2007)
Szell and Thurner, Social Networks 32, 313-329 (2010)

The framework of the game

- Economic life

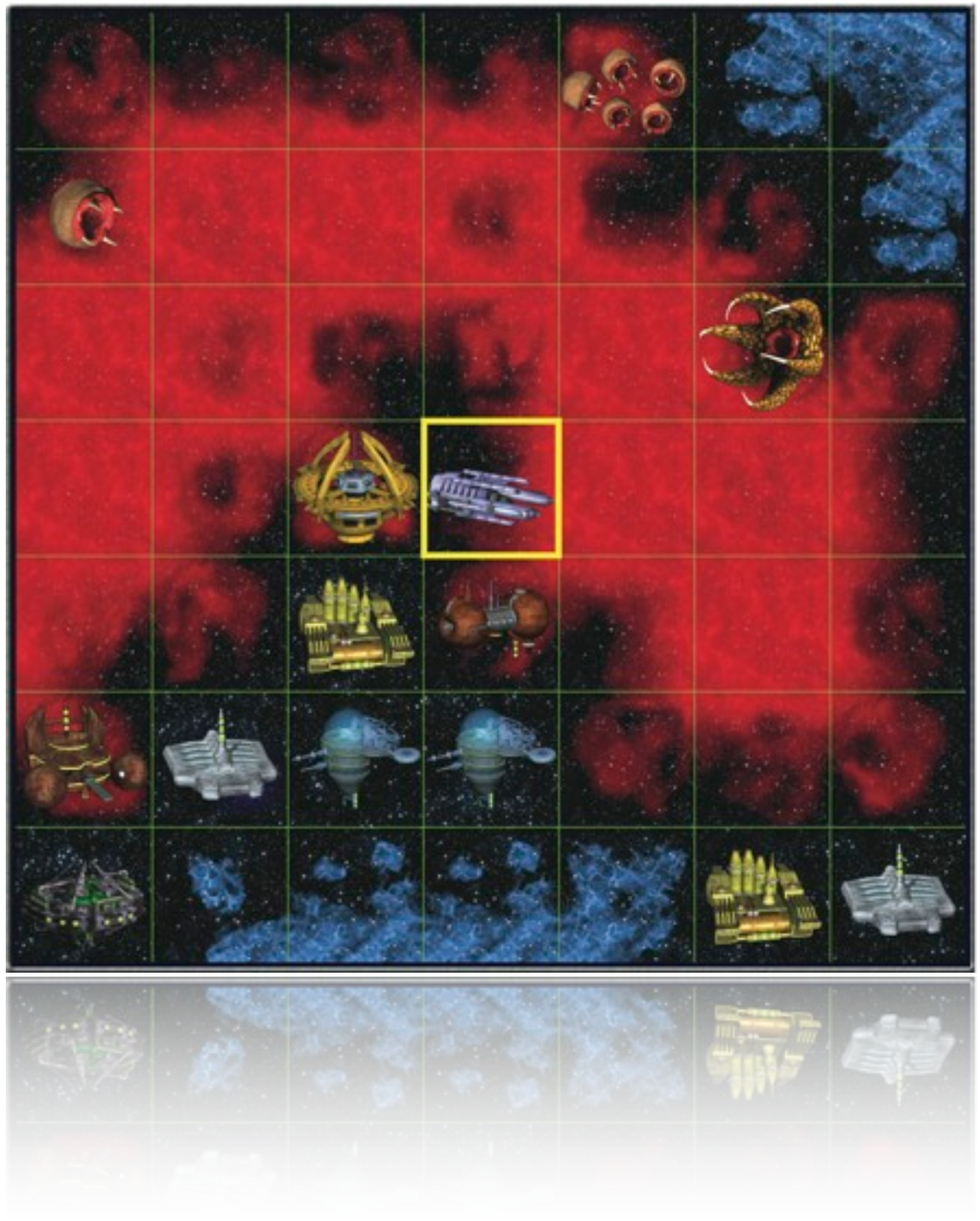
  Trade, produce, make profit
  Spend money on ships, ...

- Social life

  Chat, forum, make friends
  Alliance diplomacy

- Exploratory life (“Science”)

  Universe and lifeforms



no rules, no goals

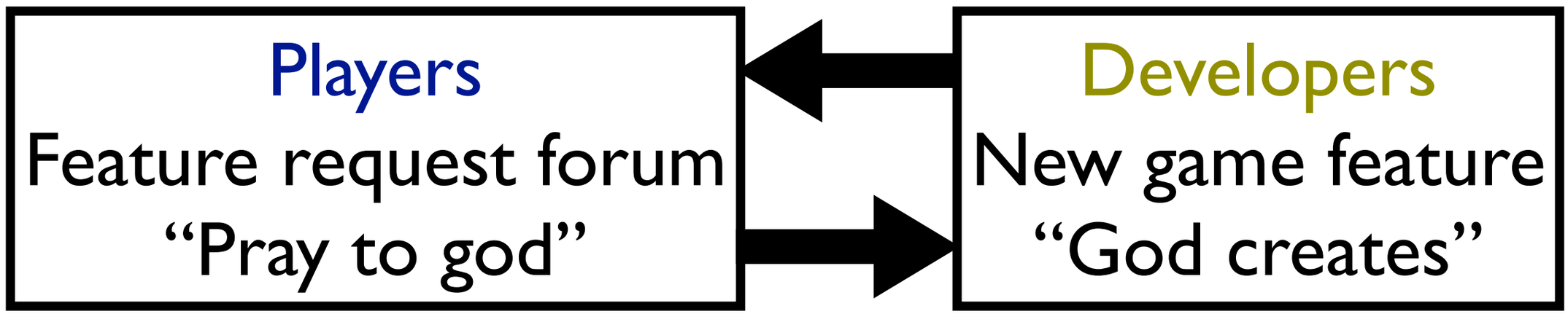
Innovation 1: In-World

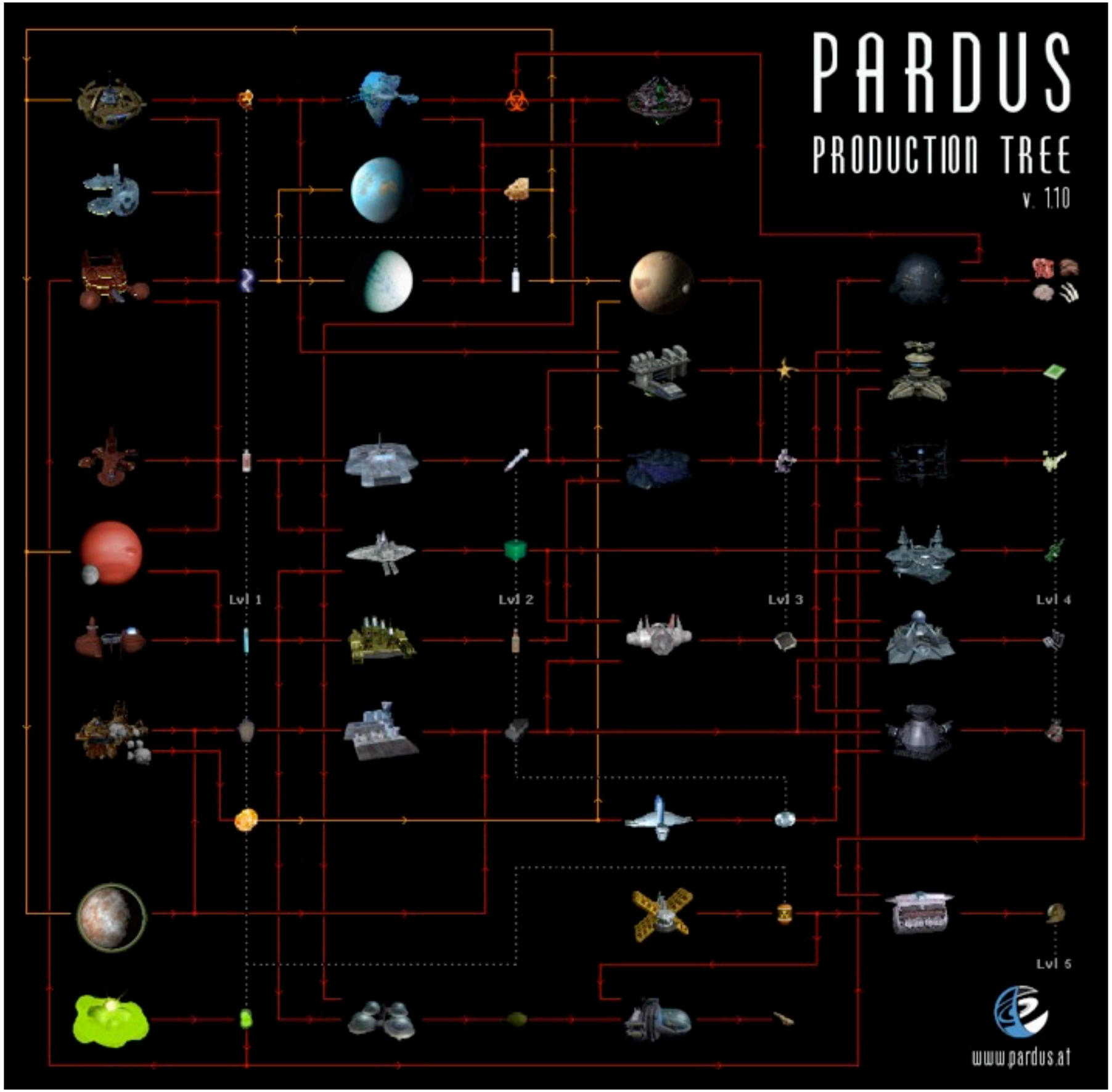
Emergence of complex social behavior

- Hierarchical groups
- Cartels, banks
- Experiments: "Communism"
- Political parties
- Organized attacks + wars
  over territory, resources, ...

Innovation 2: Out-World

Innovation 3: Player - Developer




PARDUS
PRODUCTION TREE
v. 1.10
Lvl 1
Lvl 2
Lvl 3
Lvl 4
Lvl 5
www.pardus.at

Innovation 4: "Science"

All my helpers have stopped black-marketing data.

Anyone black-marketing drugs, I would appreciate a PM if you're willing to log all your trades. It's pretty simple

In particular, I'd like to have someone with any amount of sneakiness and/or haggling, and also non-TSS members.

Additional[ly], I'd prefer it if someone would peer-review one item in my work. I [d]erived a formula that should compute the average number of drug trades that can occur "before" the black market closes, [in]cluding traps and bribes, given the percent chance that the BM stays open.

I'll outline the method I used, to make it simpler to verify:

1. I used a special-case discrete negative binomial distribution (r=1) to represent the number of trades, "k", before it closes once (hence r=1), if "p" is the probability of the BM staying open:

   $$f(k) = (1-p) \cdot p^k$$

   so as an example, if the BM stays open for 60% of trades, the chance that the 2nd trade will be the last trade before the BM closes is 0.4*0.6^2, or about 14.4%. But this only gave me the probability that for trial number "k", the BM would close on the following trade.
2. To calculate the average number of trades that occur before the BM closes, I would have to sum all the probabilities starting from trade zero (since the BM can shut down on the first trade) until they add up to 50%. That will be the average number of trades before the BM closes since 50% of the time it will close before that, and 50% of the time it will close after that. This then, represents the summation, and "s" represents the trade *before* the BM closes:

   $$(1-p) \cdot \sum_{k=0}^{s} p^k = 0.50$$
3. But I want a closed-form equation that I don't have to iteratively sum every time I log more data. This is a variation on the first equation here that I used to remove the summation for a closed-form solution:

   $$\sum_{k=m}^{s} p^k = \frac{p^m - p^{s+1}}{1-p}$$
4. And finally, substituting that for the summation (the "1-p" terms cancel), simplifying, and solving for "s" yielded:

   $$s = \frac{\ln 0.5}{\ln p} - 1$$

   Again, "s" is the average number of trades over many illegal BM trades you can expect before the BM closes on the *next* trade. But it's more useful to know on which trade the BM can be expected to shutdown since when the BM shuts down, the drugs are still sold for money successfully.

To find out on which trade the BM will most often shut down, just remove the "- 1" at the end. Plug in the chance that the BM will stay open for "p", and solve for "s" in this equation:

I'd prefer it if someone would peer-review my work

Data available

- All actions by all players
- Over 2000 days, with timestamp
- Ongoing generation of new data
- Unobtrusive

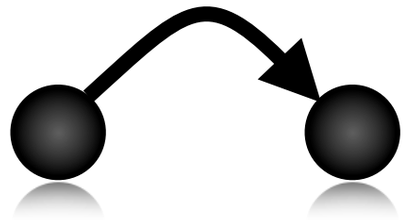
3 Universes

First lessons: Quantitative Sociology

- Show usefulness of online game for research
- Establish validity of virtual environment
- Compare with existing "real world" studies
- Check classical sociological hypotheses

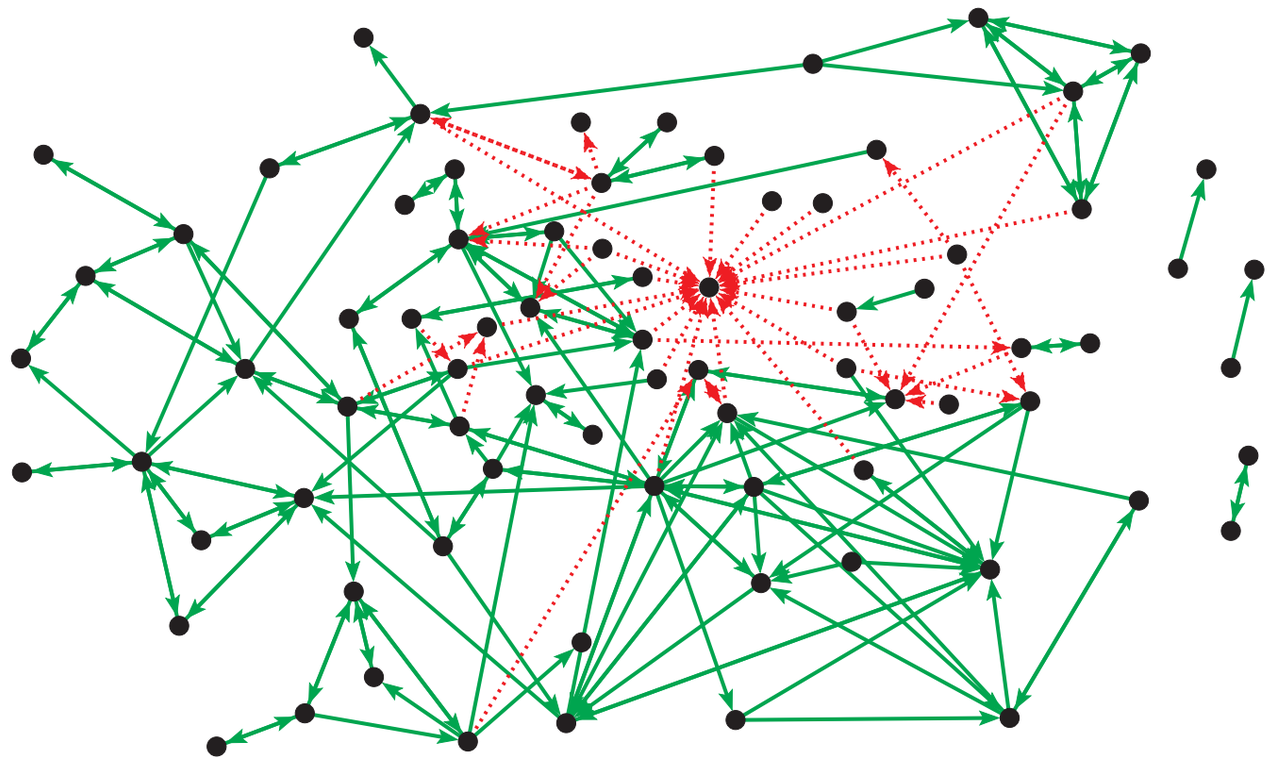
Six types of social networks

Directed one-to-one interactions



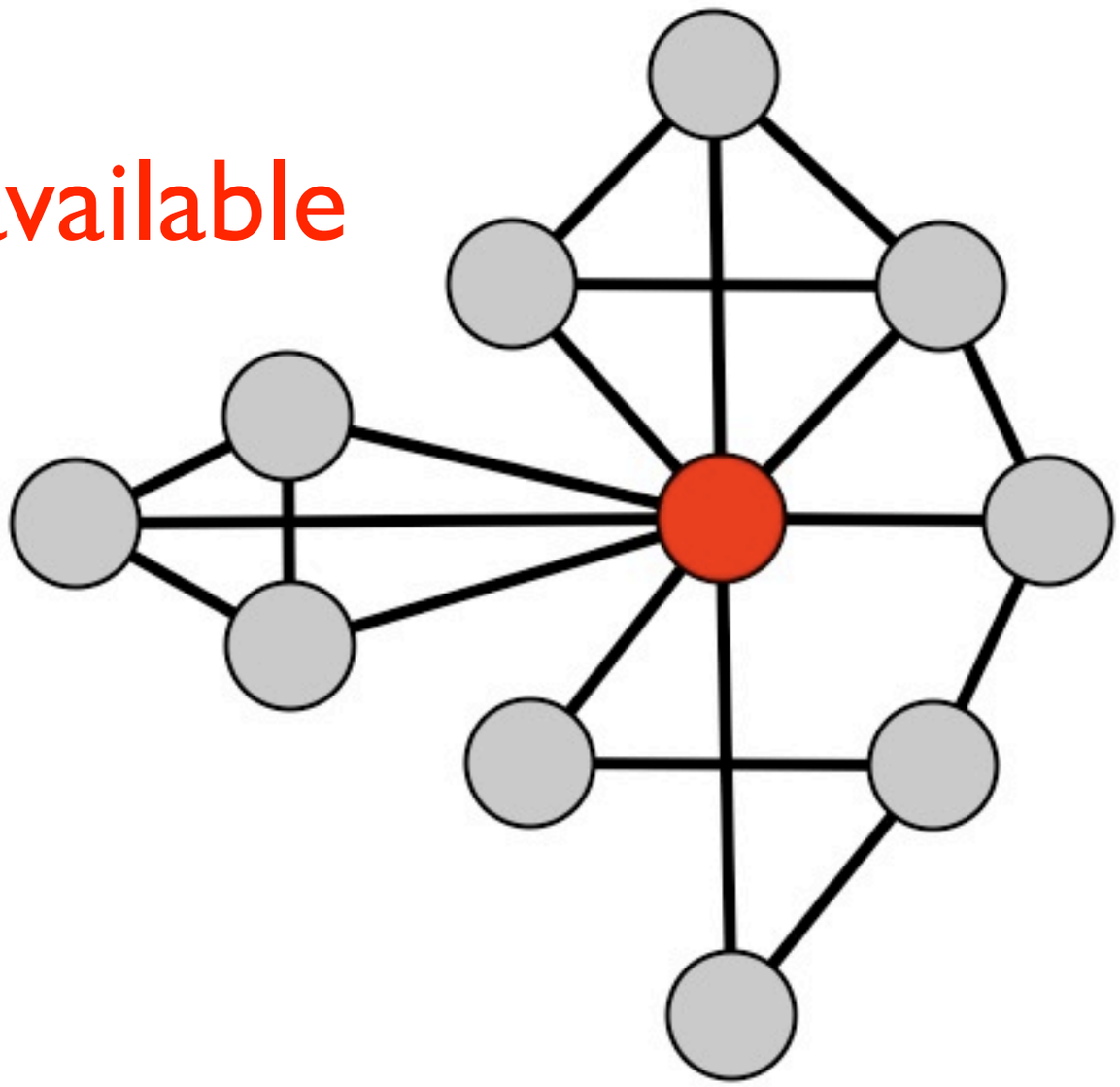
Positive	Negative
Friendship	Enmity
Communication	Attack
Trade	Bounty

Part I MULTIPLEXITY



The importance of being multiplex

Usually:
Nature of relations unavailable

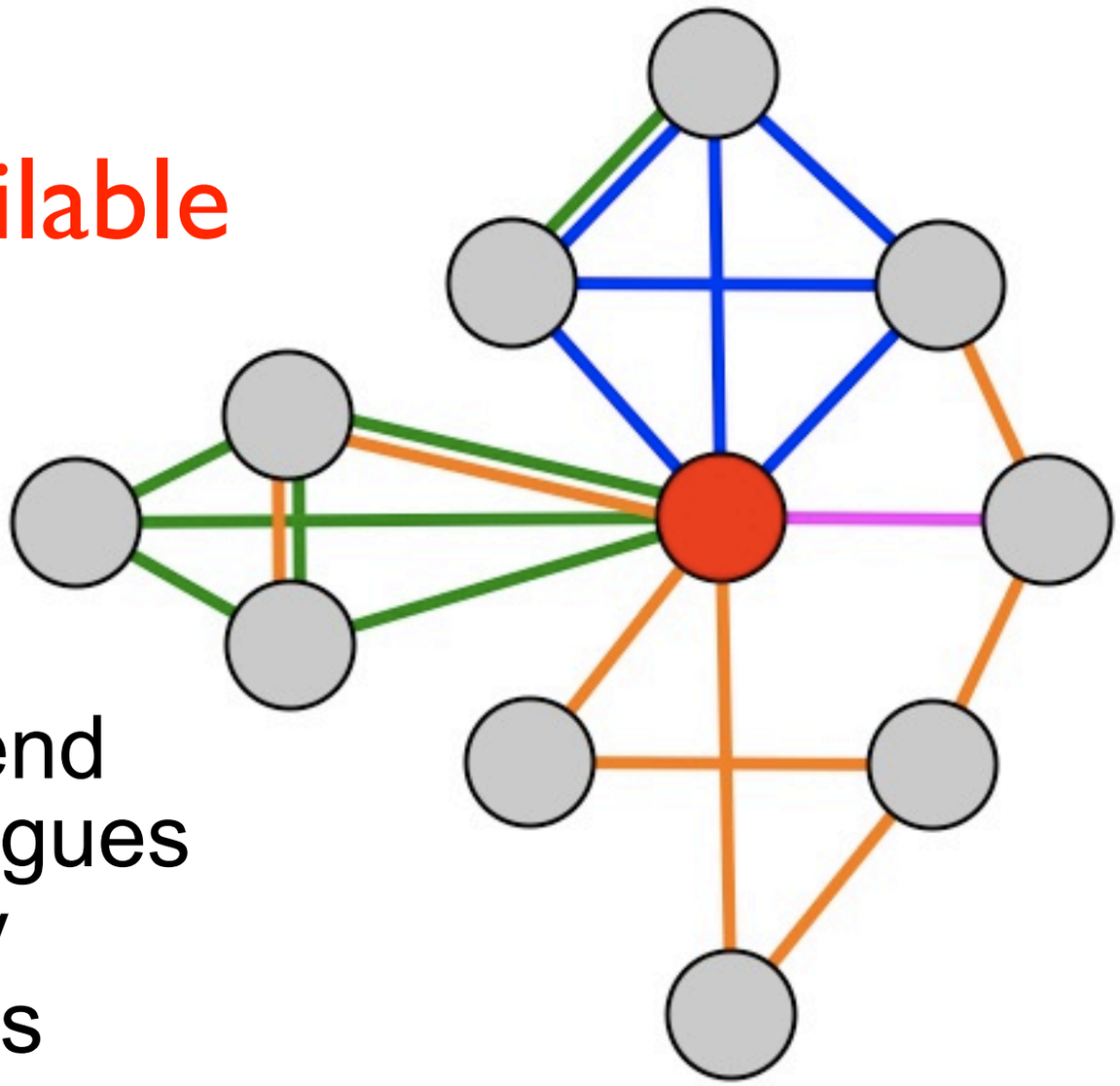


The importance of being multiplex

Here:

Nature of relations available

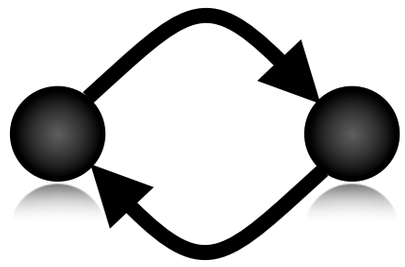
Multiplex network



Girlfriend
Colleagues
Family
Friends

Structural differences between positive and negative interactions

Reciprocity



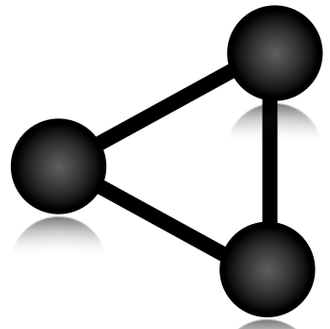
If I * you, do you * me?

	Positive			Negative		
	Friends	PMs	Trades	Enemies	Attacks	Bounties
N	4,313	5,877	18,589	2,906	7,992	2,980
r	0.68	0.84	0.57	0.11	0.13	0.20
C	0.25	0.28	0.43	0.03	0.06	0.01
C/C^{rand}	109.52	45.71	131.95	6.13	37.27	13.88
$\rho(k^{\mathrm{in}}, k^{\mathrm{out}})$	0.88	0.98	0.93	0.11	0.64	0.31
	YES			NO		

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

Structural differences between positive and negative interactions

Clustering



If I * others, do they * each other?

	Positive			Negative		
	Friends	PMs	Trades	Enemies	Attacks	Bounties
N	4,313	5,877	18,589	2,906	7,992	2,980
r	0.68	0.84	0.57	0.11	0.13	0.20
C	0.25	0.28	0.43	0.03	0.06	0.01
C/C^{rand}	109.52	45.71	131.95	6.13	37.27	13.88
$\rho(k^{\mathrm{in}}, k^{\mathrm{out}})$	0.88	0.98	0.93	0.11	0.64	0.31
	YES			NO		

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

Structural differences between positive and negative interactions

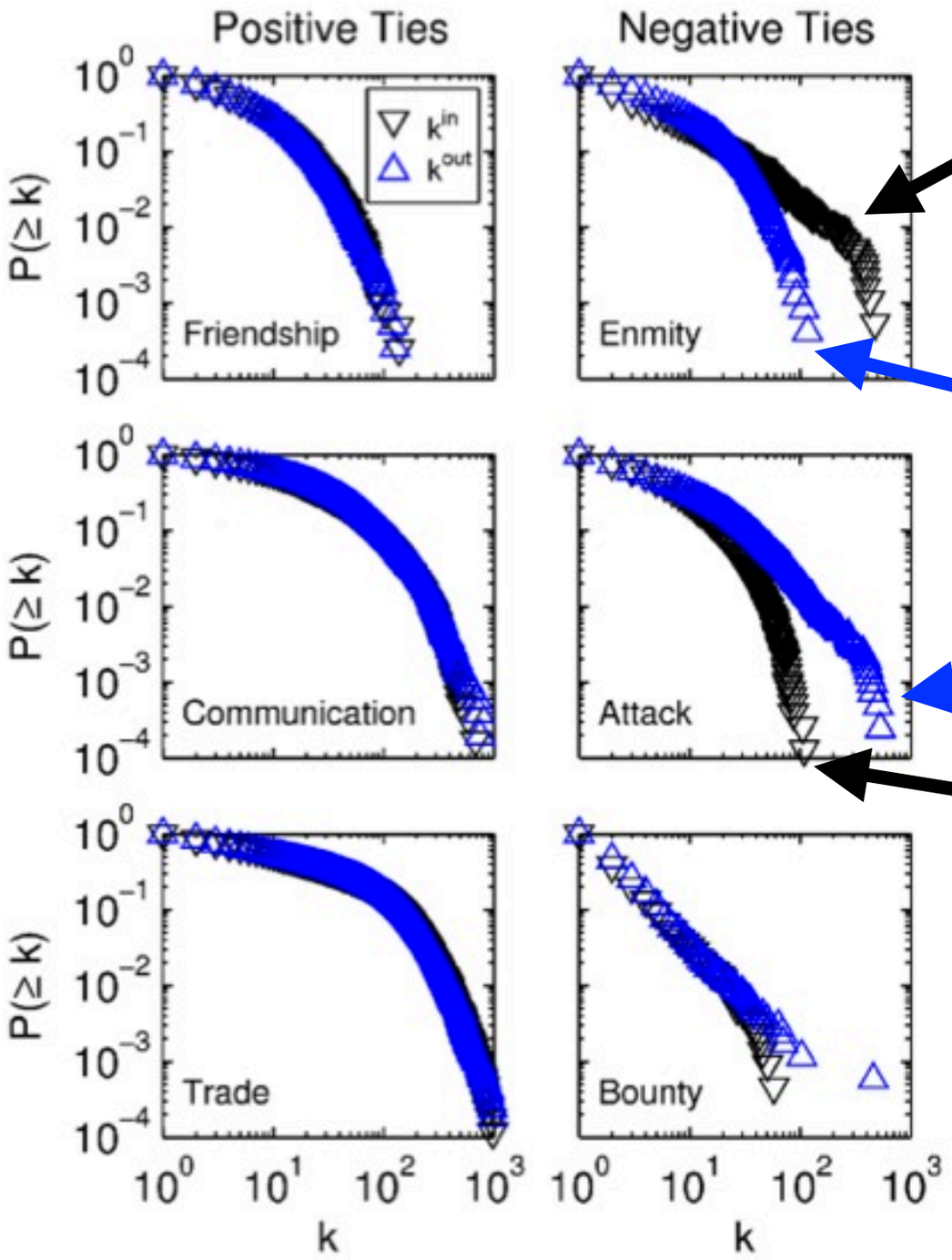
In/Out degree correlation

If I * few/many others, do few/many others * me?

	Positive			Negative		
	Friends	PMs	Trades	Enemies	Attacks	Bounties
N	4,313	5,877	18,589	2,906	7,992	2,980
r	0.68	0.84	0.57	0.11	0.13	0.20
C	0.25	0.28	0.43	0.03	0.06	0.01
C/C^{rand}	109.52	45.71	131.95	6.13	37.27	13.88
$\rho(k^{\mathrm{in}}, k^{\mathrm{out}})$	0.88	0.98	0.93	0.11	0.64	0.31
	YES			NO		

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

Structural differences between positive and negative interactions



Being marked as enemy

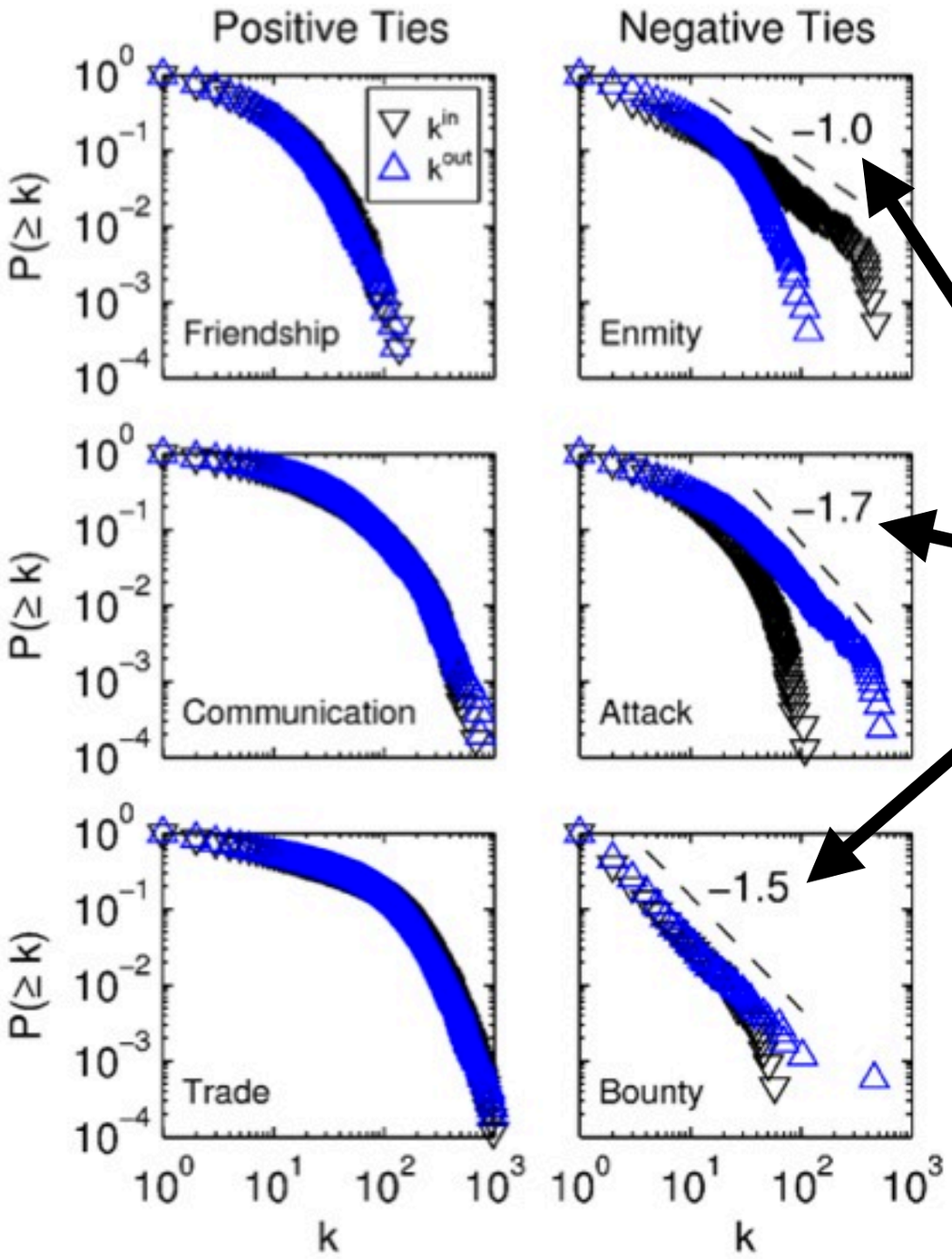
Marking somebody as enemy

Attacking somebody

Being attacked

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

Structural differences between positive and negative interactions



Conflict leads to fat tails

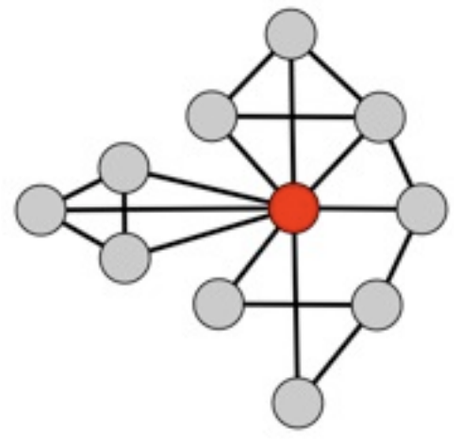
Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

The importance of being multiplex

Ignorance of relation types

↓

Loss of essential information!



	Positive			Negative			
	Friends	PMs	Trades	Enemies	Attacks	Bounties	All
N	4,313	5,877	18,589	2,906	7,992	2,980	18,819
r	0.68	0.84	0.57	0.11	0.13	0.20	0.59
C	0.25	0.28	0.43	0.03	0.06	0.01	0.42
C/C^{rand}	109.52	45.71	131.95	6.13	37.27	13.88	109.93
$\rho(k^{\mathrm{in}}, k^{\mathrm{out}})$	0.88	0.98	0.93	0.11	0.64	0.31	0.95

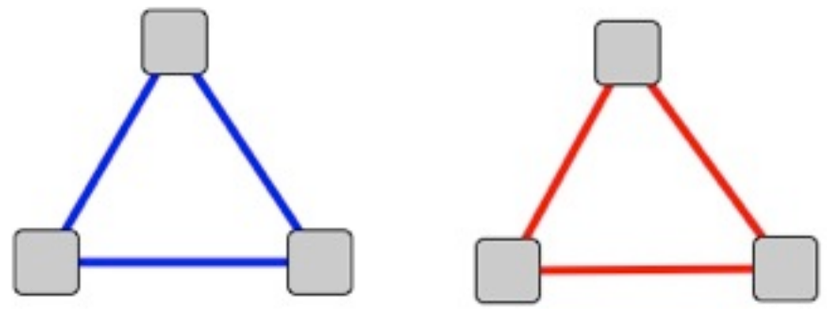
Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

Network-network interactions

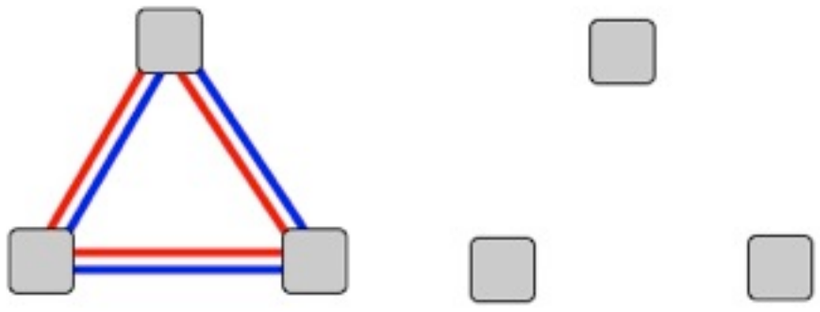
Description of co-existence of links

- Link overlap (Jaccard coefficient)

Low



High



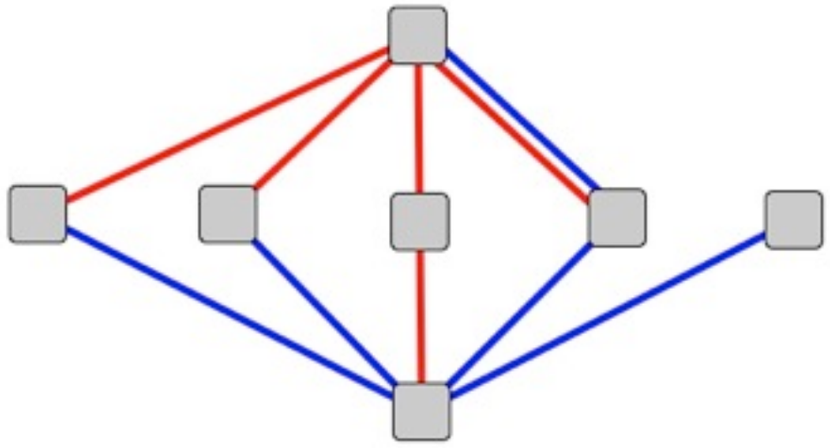
Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

Network-network interactions

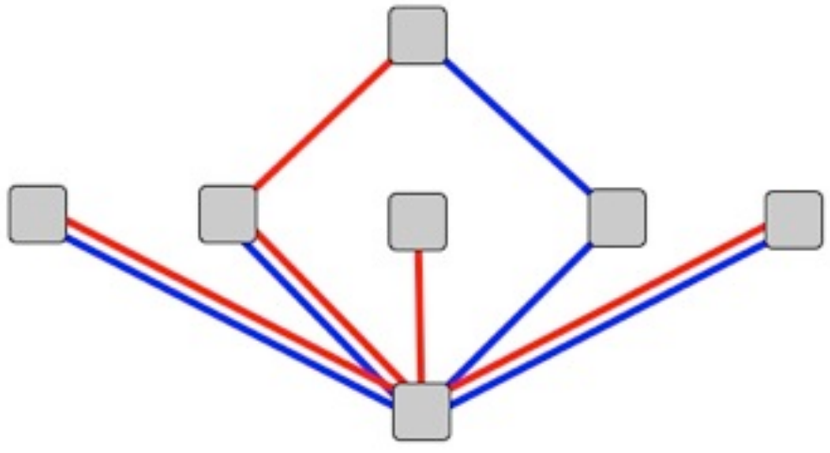
Description of co-existence of links

- Link overlap (Jaccard coefficient)
- Degree correlation

Low

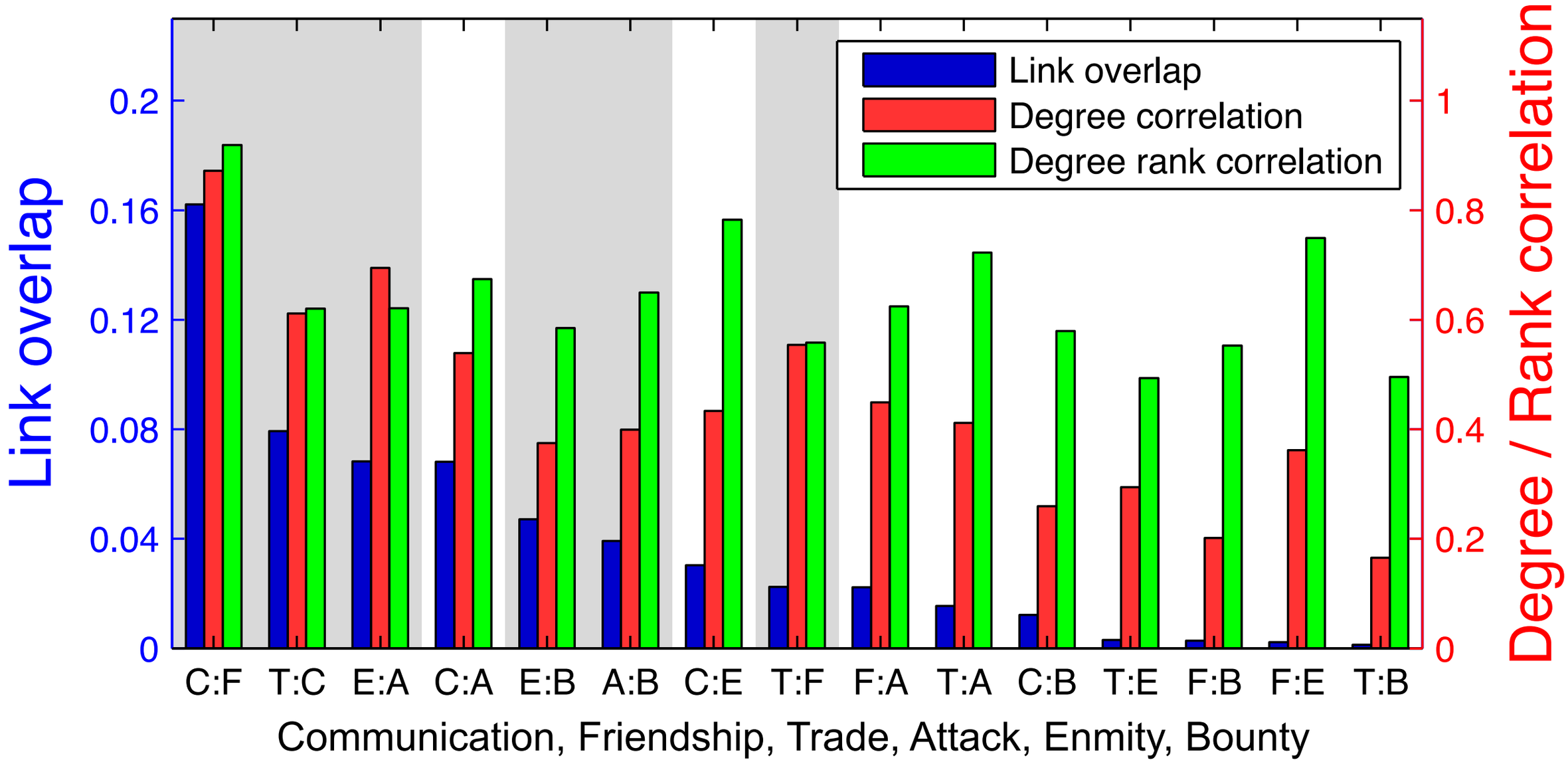


High



Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

Network-network interactions

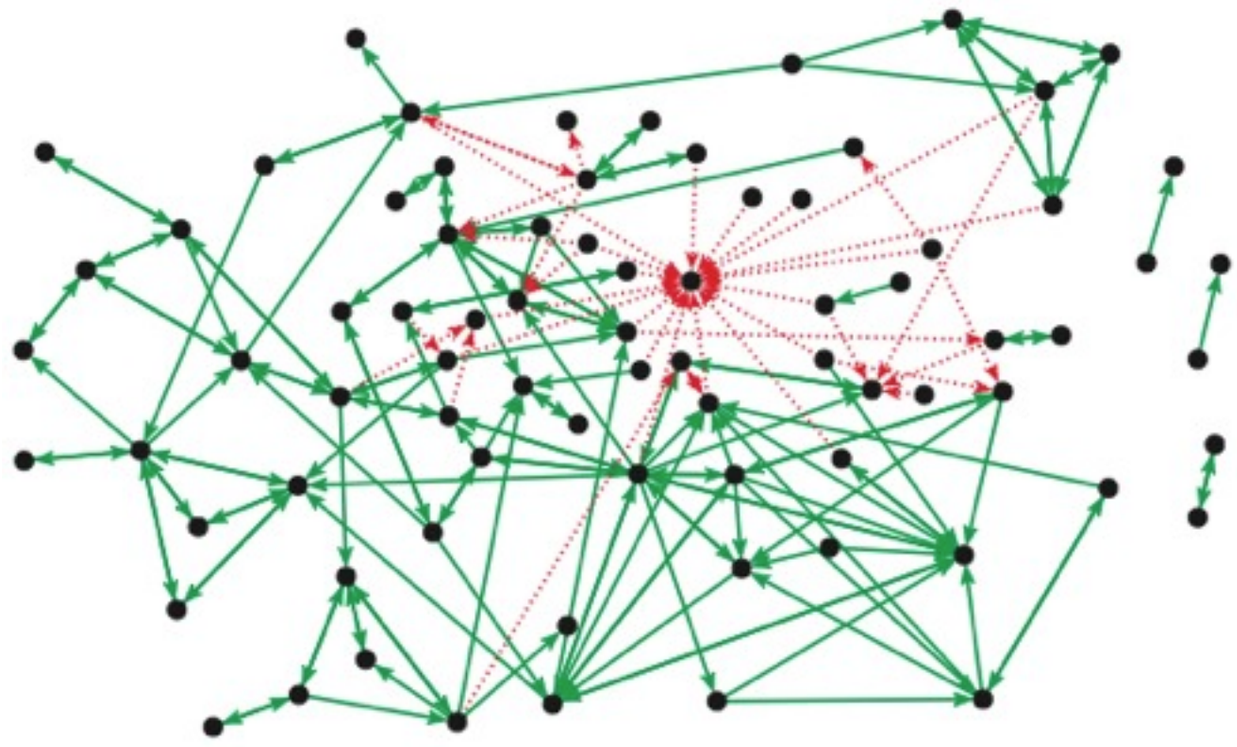


Different roles in different networks

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

Application: Social balance theory

Social balance: Theory about balance and cognitive dissonance in social networks

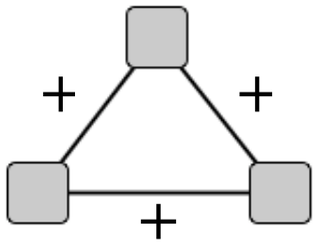
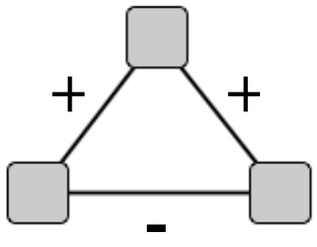
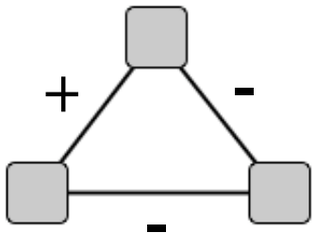
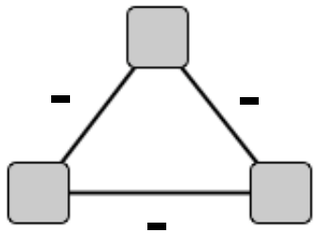


Multiplex network of friends (+) and enemies (-)

Heider, Journal of Psychology 21, 107-112 (1946)
Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

Application: Social balance theory

Multiplex network of friends (+) and enemies (-)

				
Strong formulation of balance	B	U	B	U
Weak formulation of balance	B	U	B	B
N_Δ	26,329	4,428	39,519	8,032
$N_{\Delta,r}$	10,608	30,145	28,545	9,009
z	71	-112	47	-5

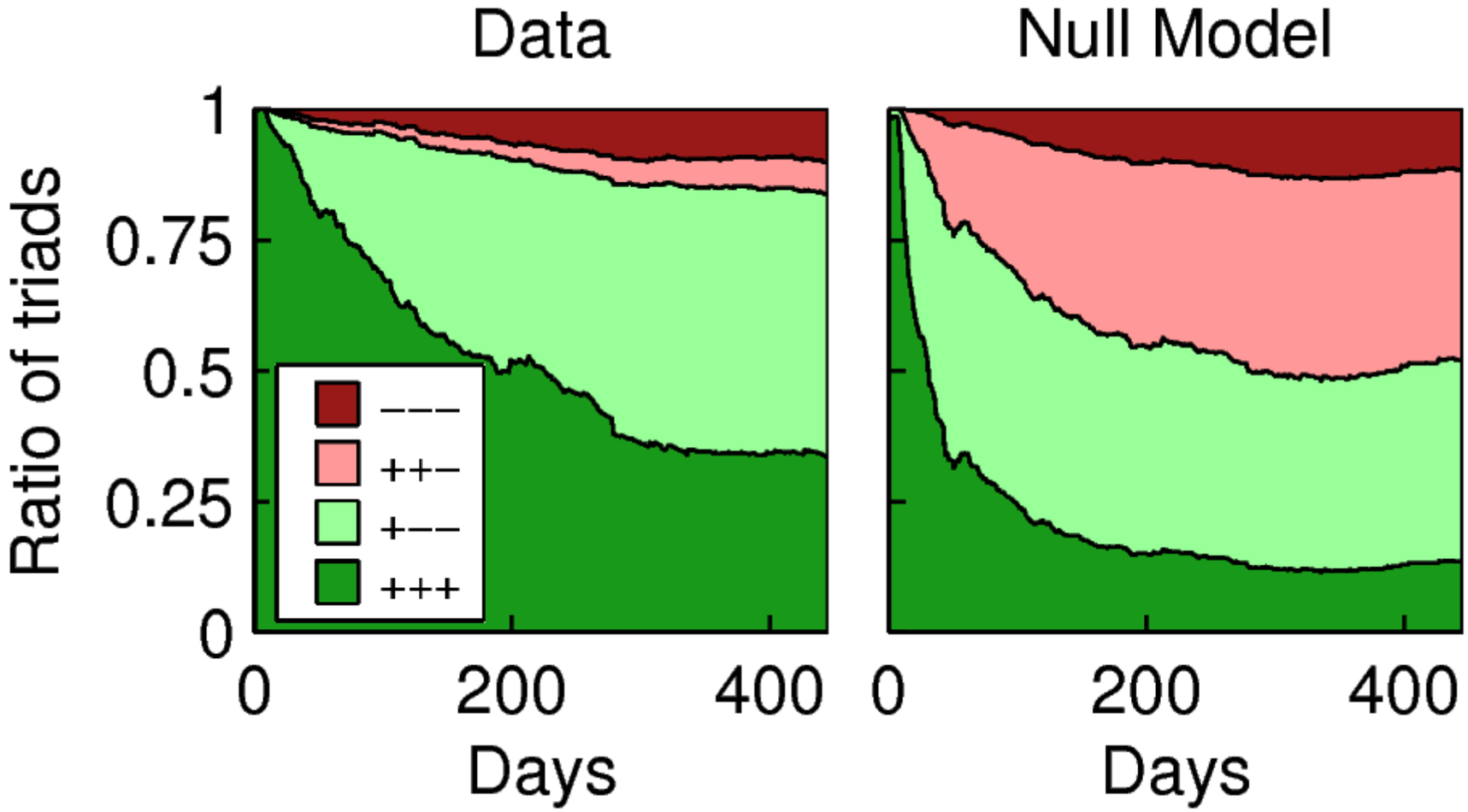
Evidence for overrepresenation of balanced triads

Evidence for underrepresenation of unbalanced triads

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Leskovec, Huttenlocher and Kleinberg, ACM WWW Int Conf on World Wide Web (2010)

Application: Social balance theory

Multiplex network of friends (+) and enemies (-)



Evidence for overrepresenation of balanced triads

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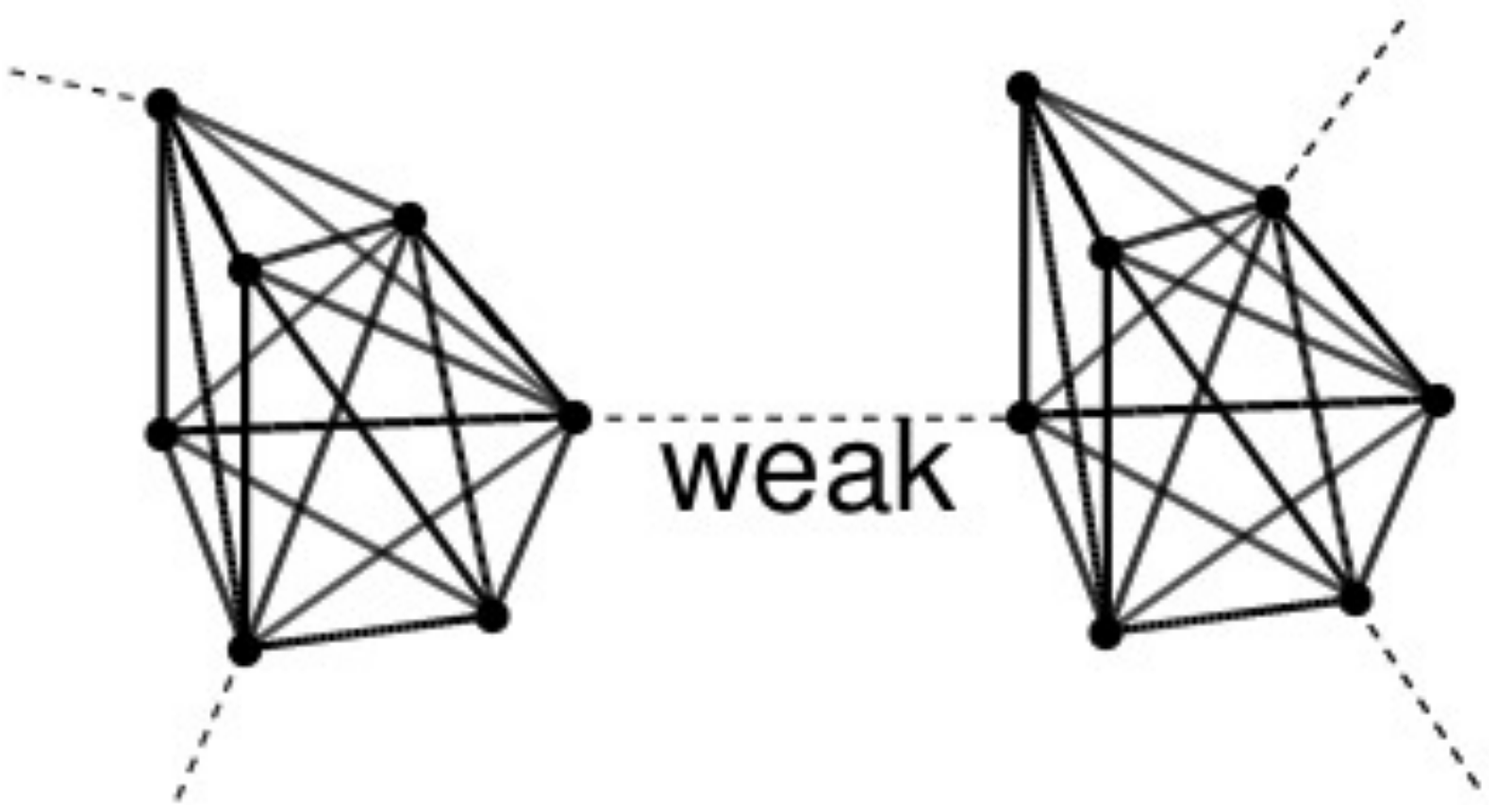
Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Leskovec, Huttenlocher and Kleinberg, ACM WWW Int Conf on World Wide Web (2010)

Application: Weak ties hypothesis

"Communities are connected by weak ties"



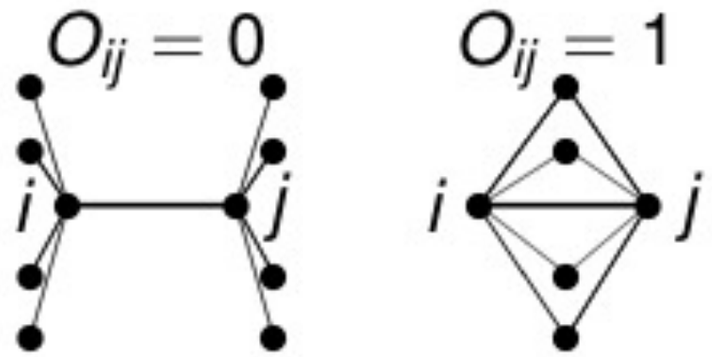
Granovetter, Amer. Journal of Soc. 87, 27 (1973)

Application: Weak ties hypothesis

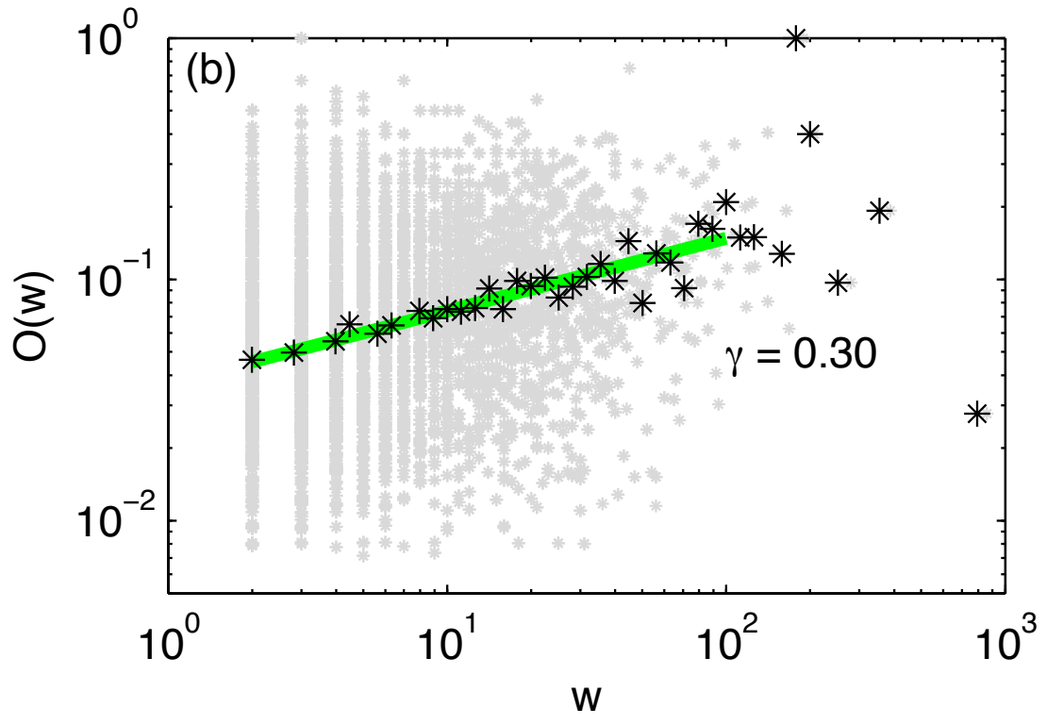
Preliminary assumption

"The degree of overlap of two individual's friendship networks varies directly with the strength of their tie to one another"

$$O_{ij} := \frac{n_{ij}}{(k_i - 1) + (k_j - 1) - n_{ij}}$$



"strength" ≡ *w* PMs exchanged



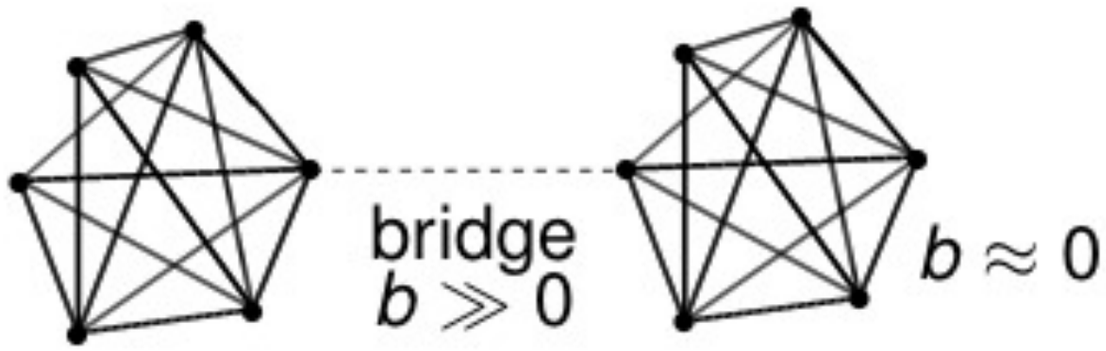
$$O \sim \sqrt[3]{w}$$

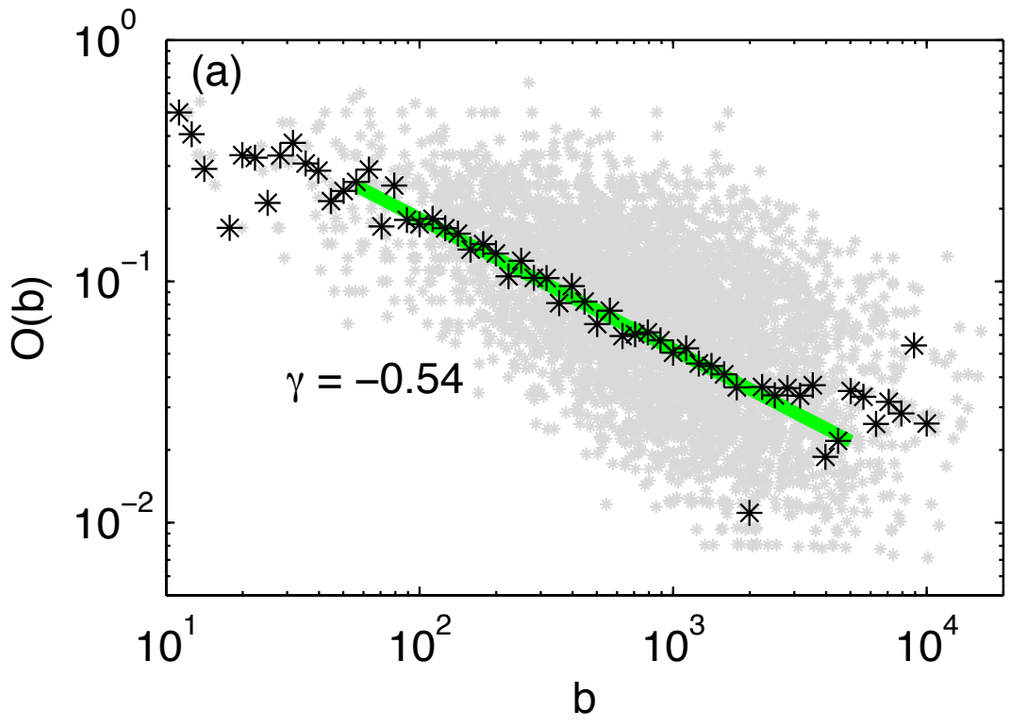
Szell and Thurner, Social Networks 32, 313-329 (2010)
Granovetter, Amer. Journal of Soc. 87, 27 (1973)

Application: Weak ties hypothesis

"bridges are weak ties"

$$b_{ij} := \sum_{m \in \mathcal{N}} \sum_{n \in \mathcal{N} \setminus \{m\}} \frac{\rho_{mn}(l_{ij})}{\rho_{mn}}$$



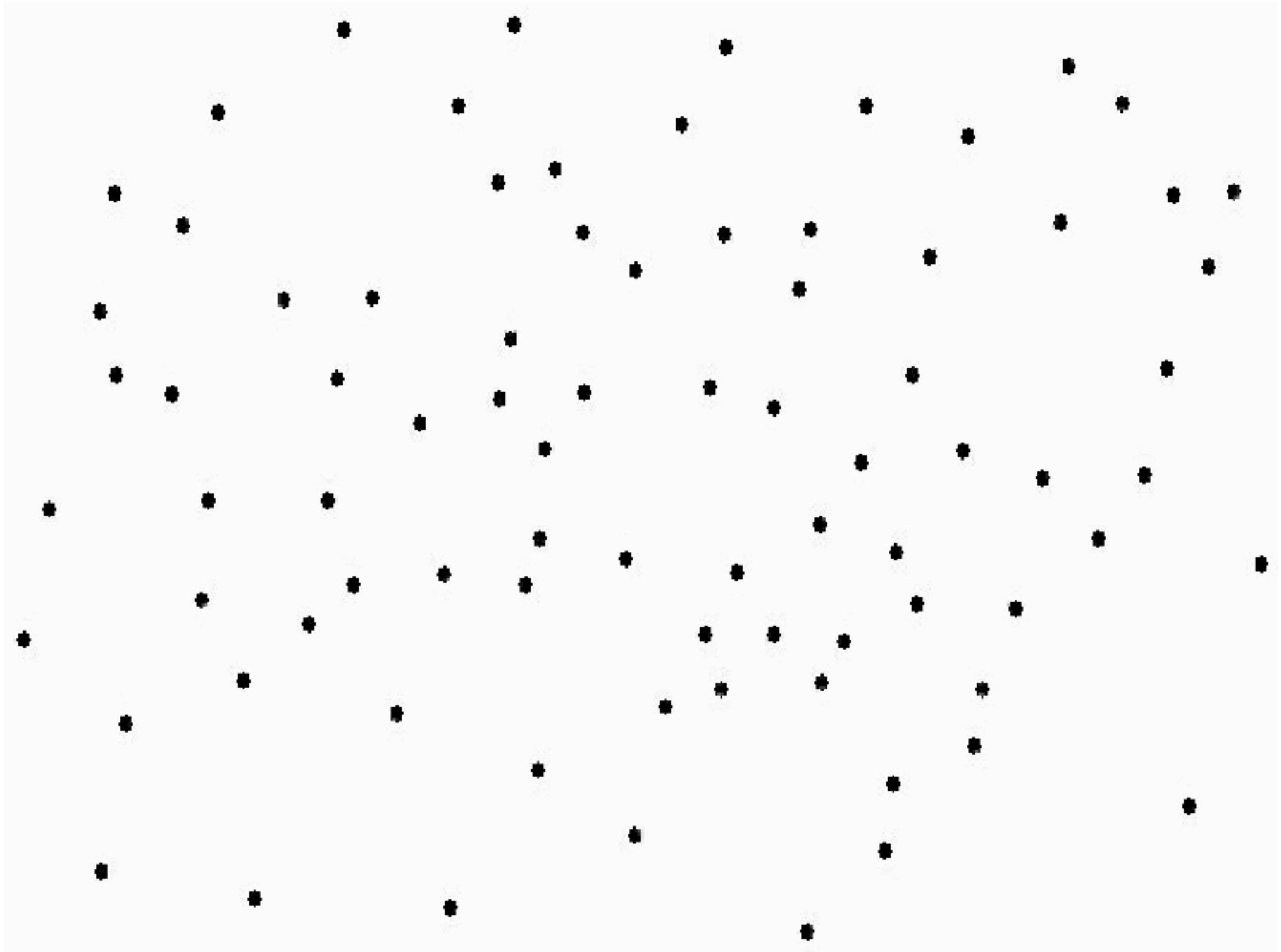


$$O \sim \sqrt{\frac{1}{b}}$$

Similar in mobile phone networks

Onnela et al, New Journal of Phys. 9, 6 (2007)
Szell and Thurner, Social Networks 32, 313-329 (2010)
Granovetter, Amer. Journal of Soc. 87, 27 (1973)

Part II NETWORK EVOLUTION



Preferential attachment

Does network growth follow PA?

If yes:

1) Linking probability $P(k) \sim k^{\alpha}, \quad \alpha = 1$

2) Degree distribution follows power law

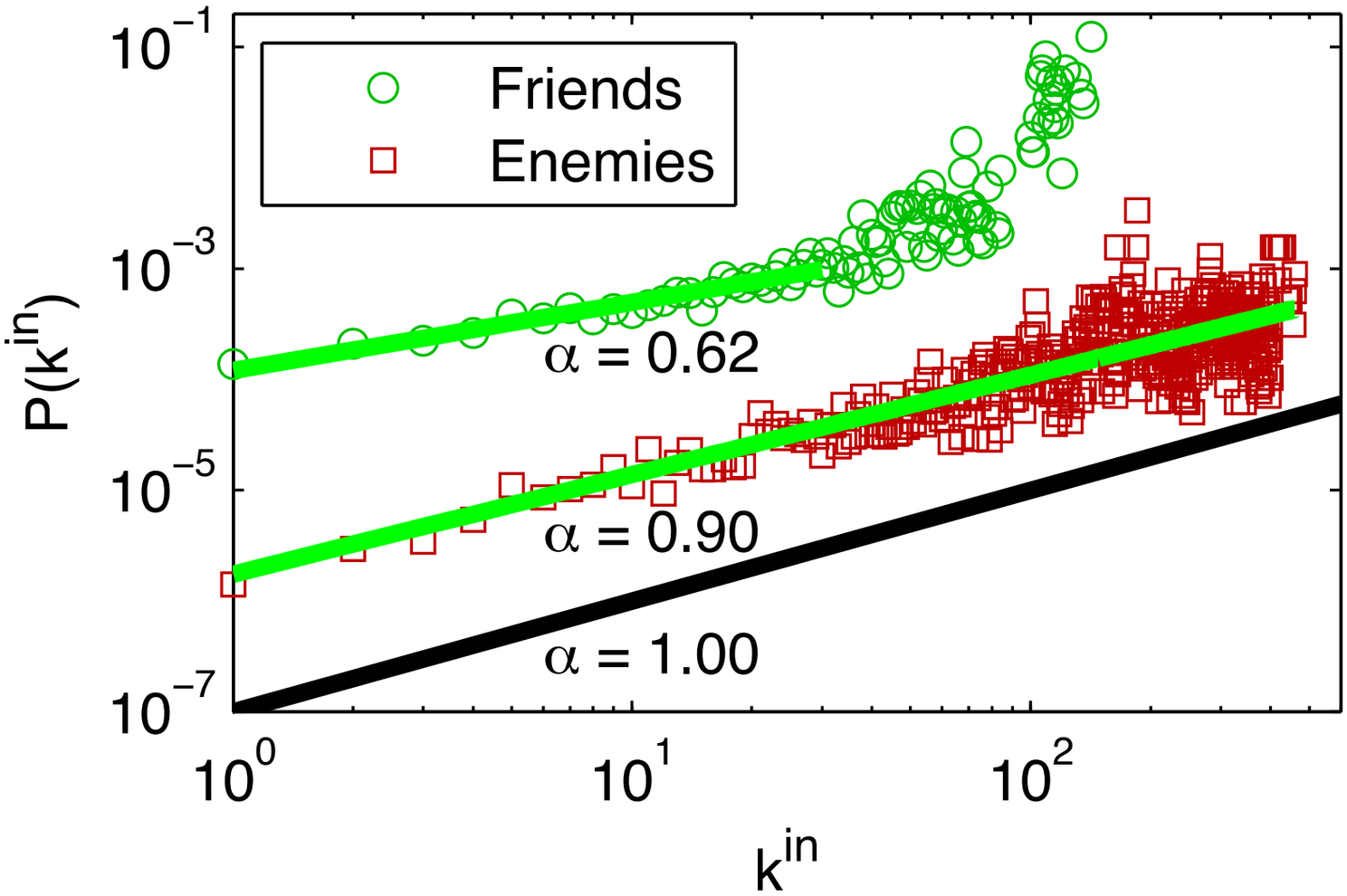
Barabási and Albert, Science 286, 509 (1999)

Preferential attachment I)

I) Linking probability $P(k) \sim k^{\alpha}, \quad \alpha = 1$

✗ Friends

✓ Enemies



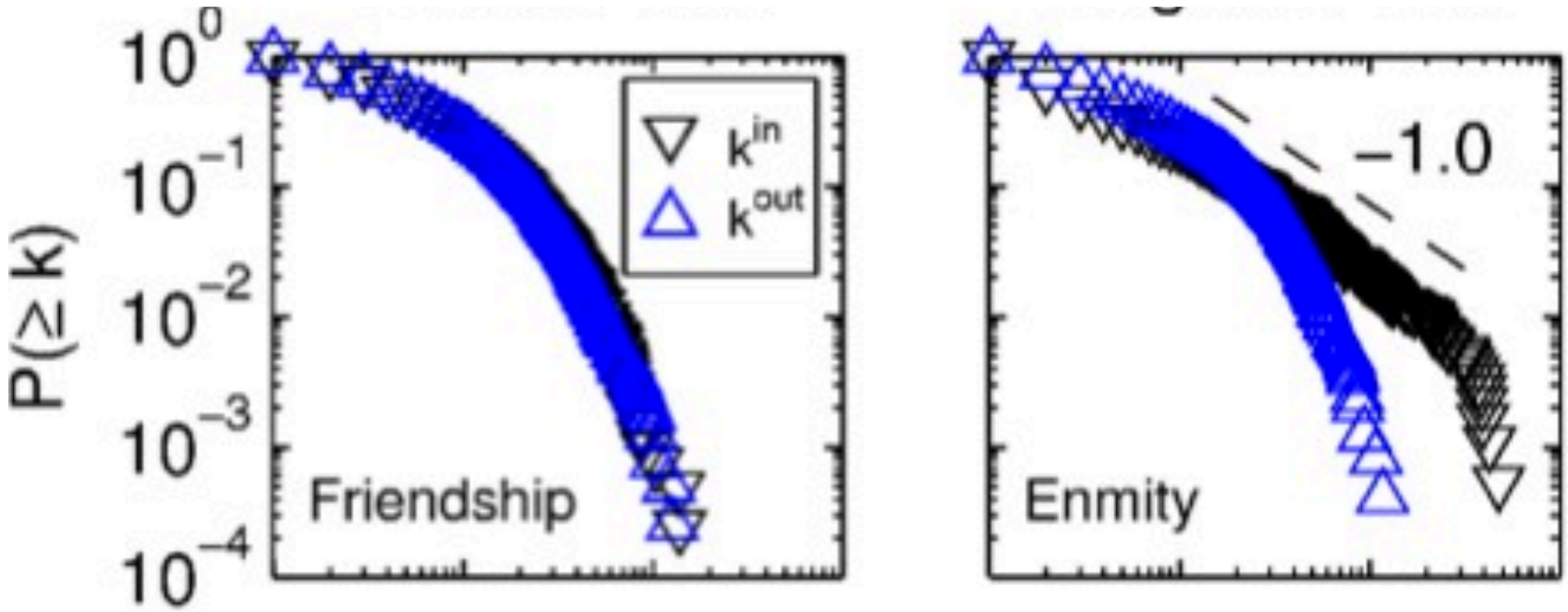
Szell and Thurner, Social Networks 32, 313-329 (2010)

Preferential attachment 2)

2) Degree distribution follows power law

✗ Friends

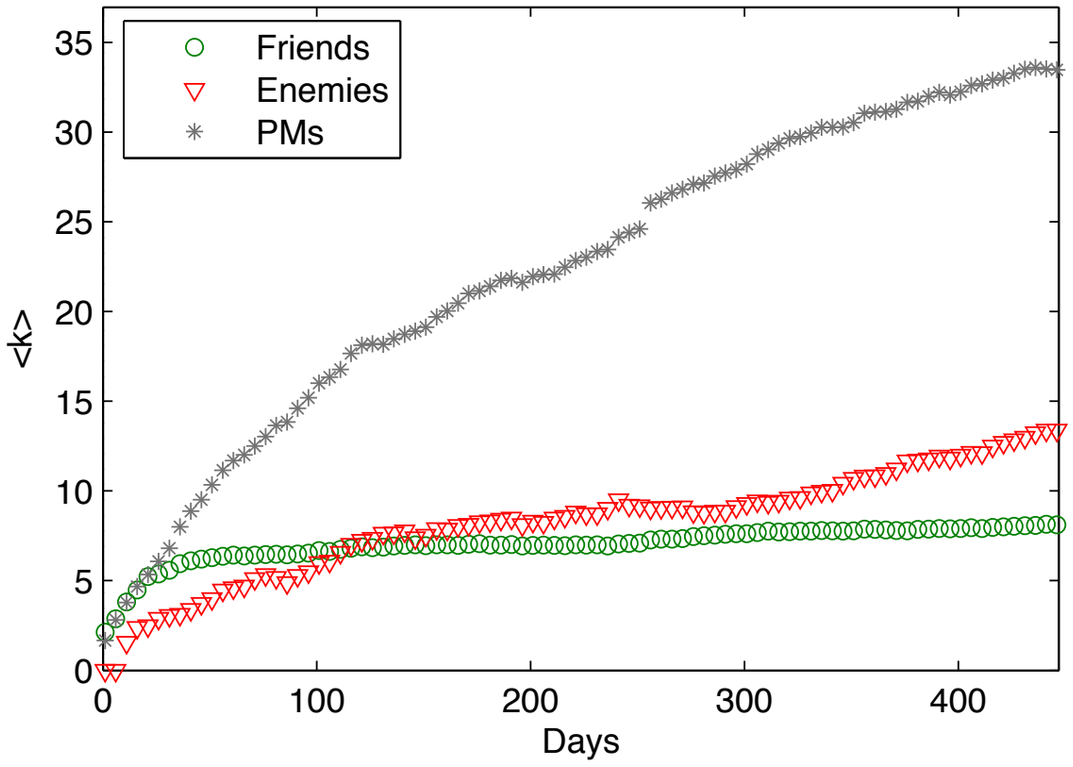
✓ Enemies



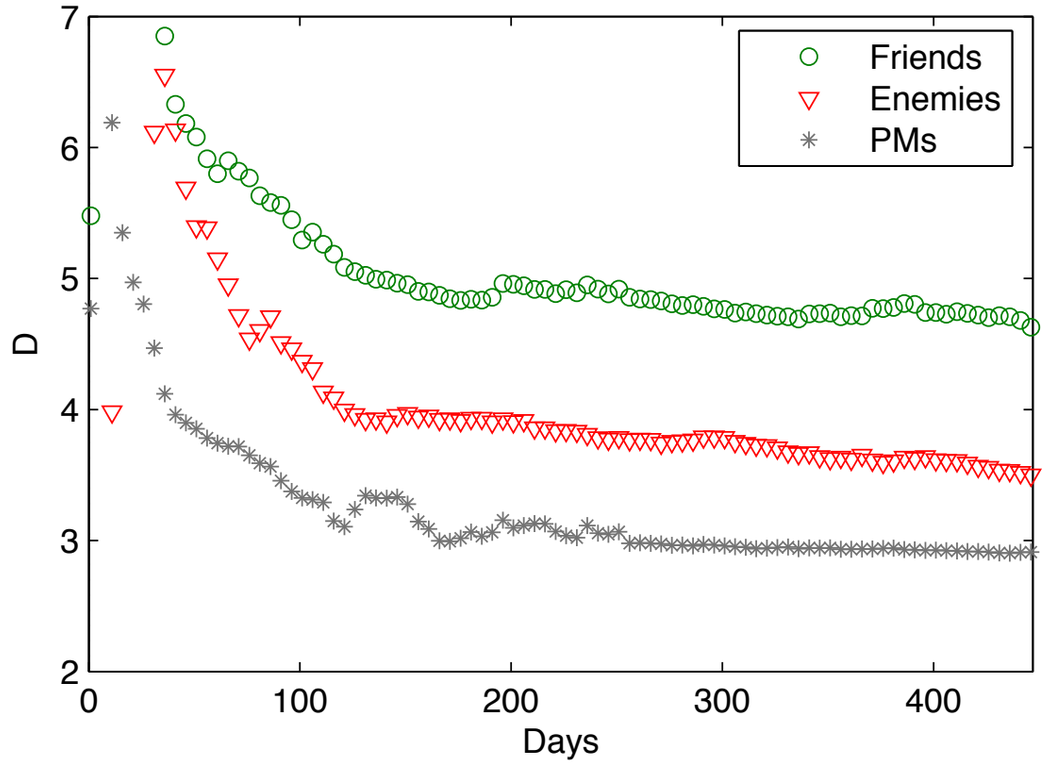
→ Cannot apply Preferential Attachment naively!

Densification

Average degrees grow

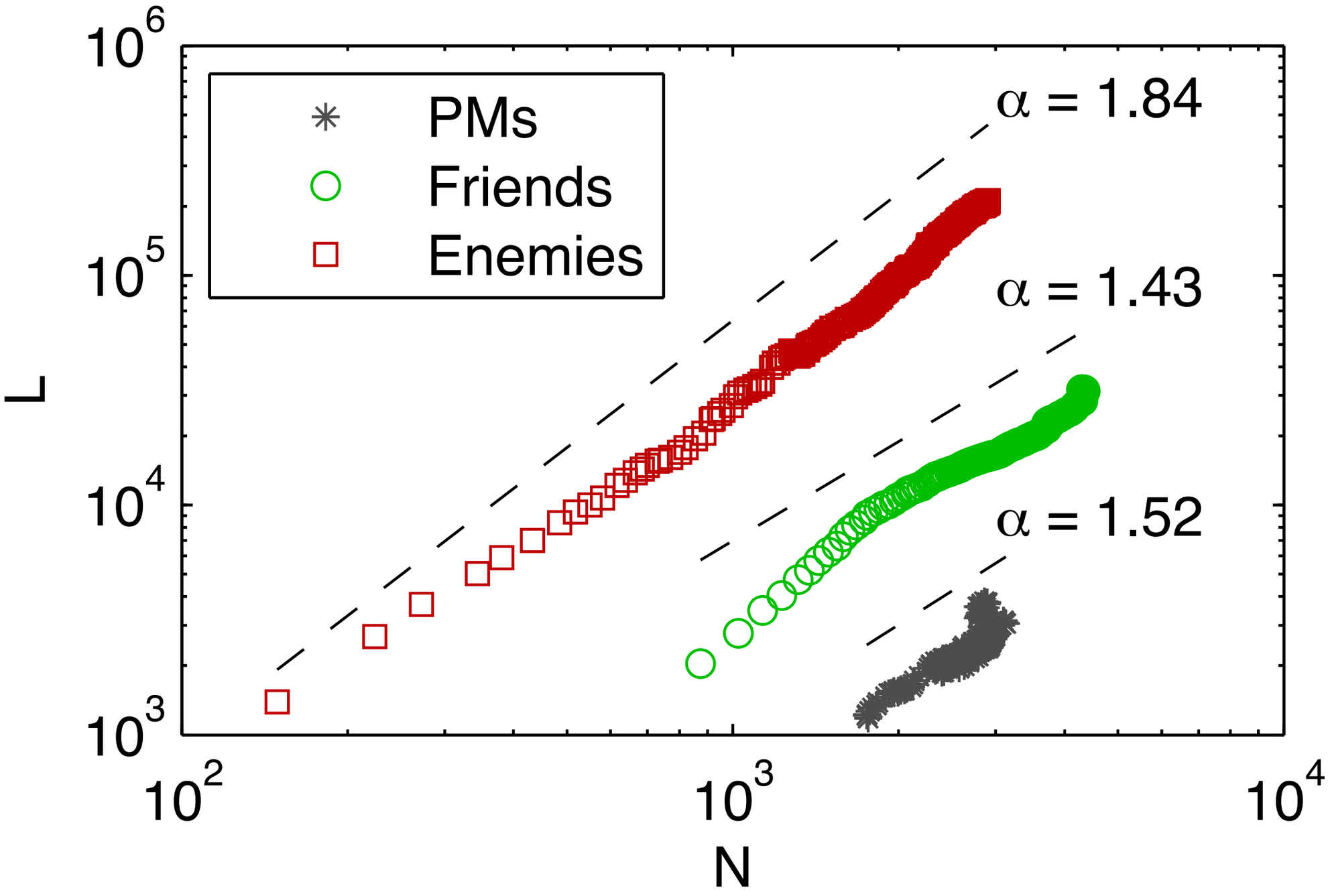


Diameters shrink



Leskovec et al, ACM TKDD 1 (2007)
Szell and Thurner, Social Networks 32, 313-329 (2010)

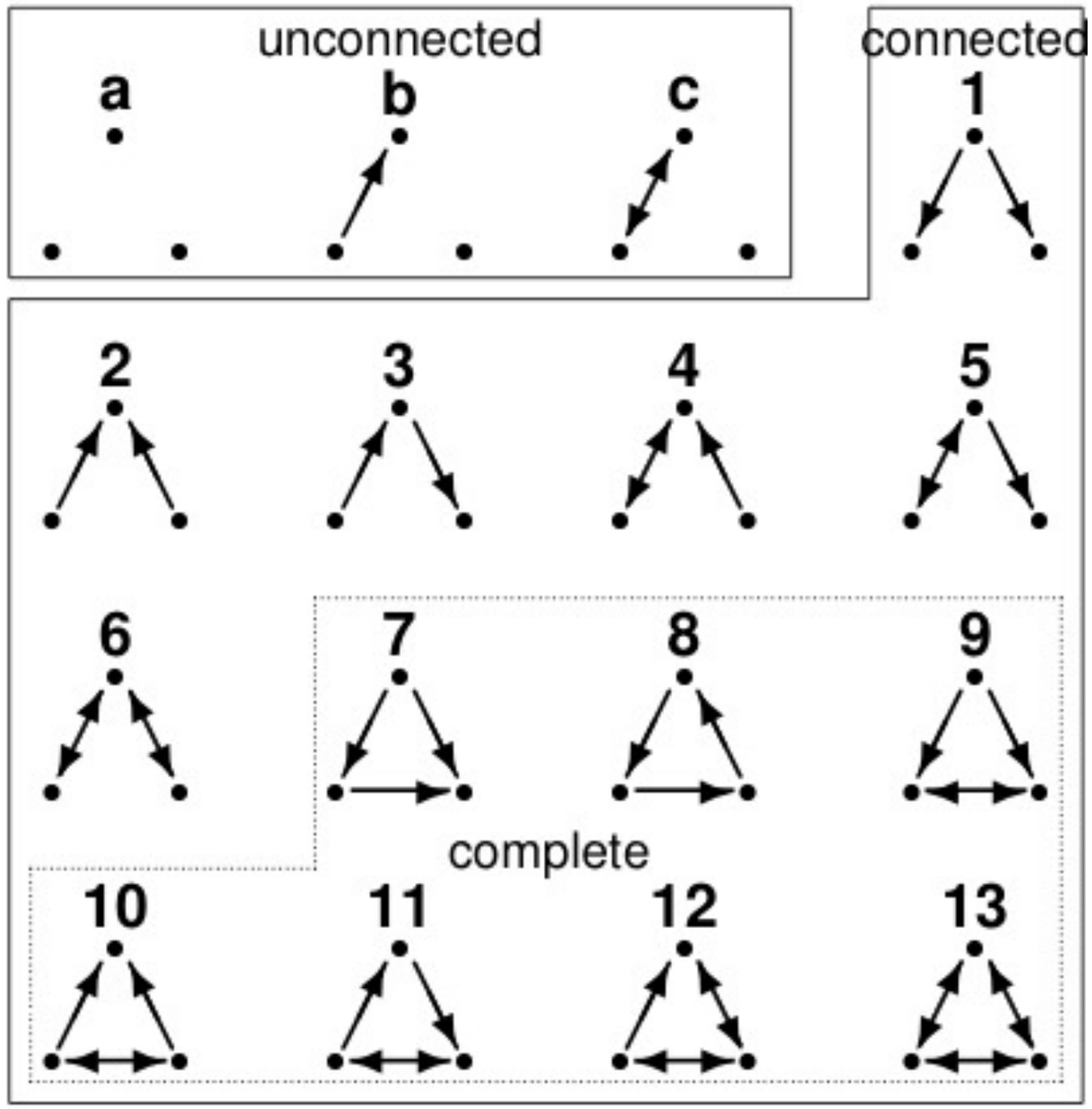
Accelerated Growth



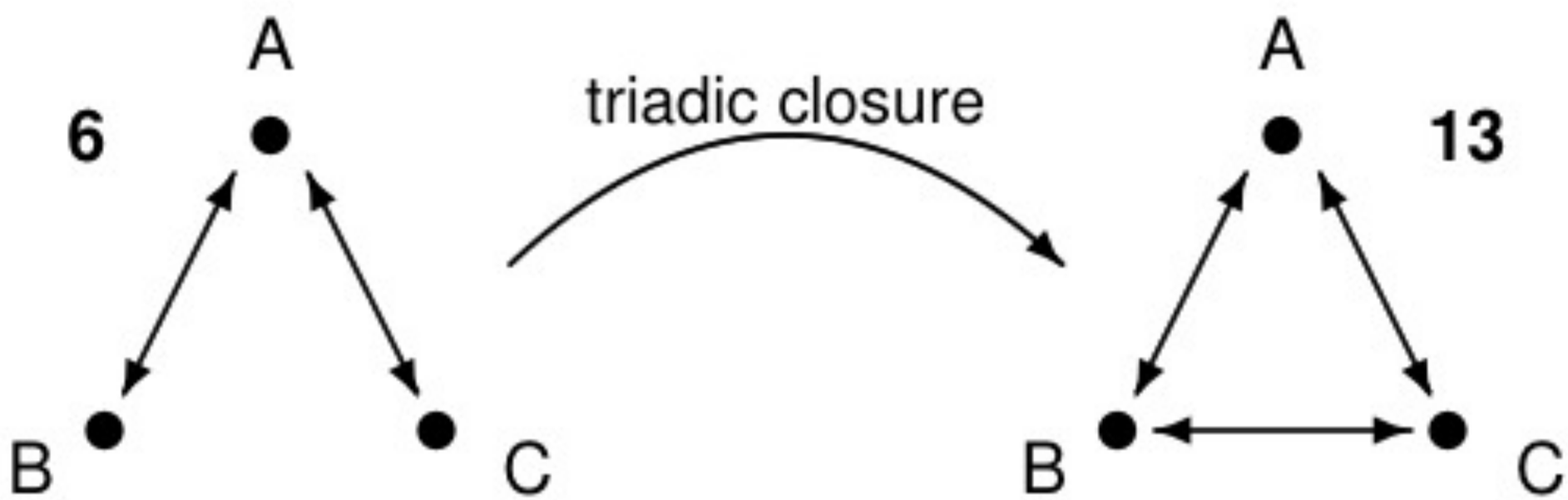
Dorogovtsev and Mendes, PRE 63, 25101 (2001)
Bettencourt et al, PNAS 104, 7301 (2007)
Szell and Thurner, Social Networks 32, 313-329 (2010)

Application: Triadic Closure

Directed triad classes



Application: Triadic Closure



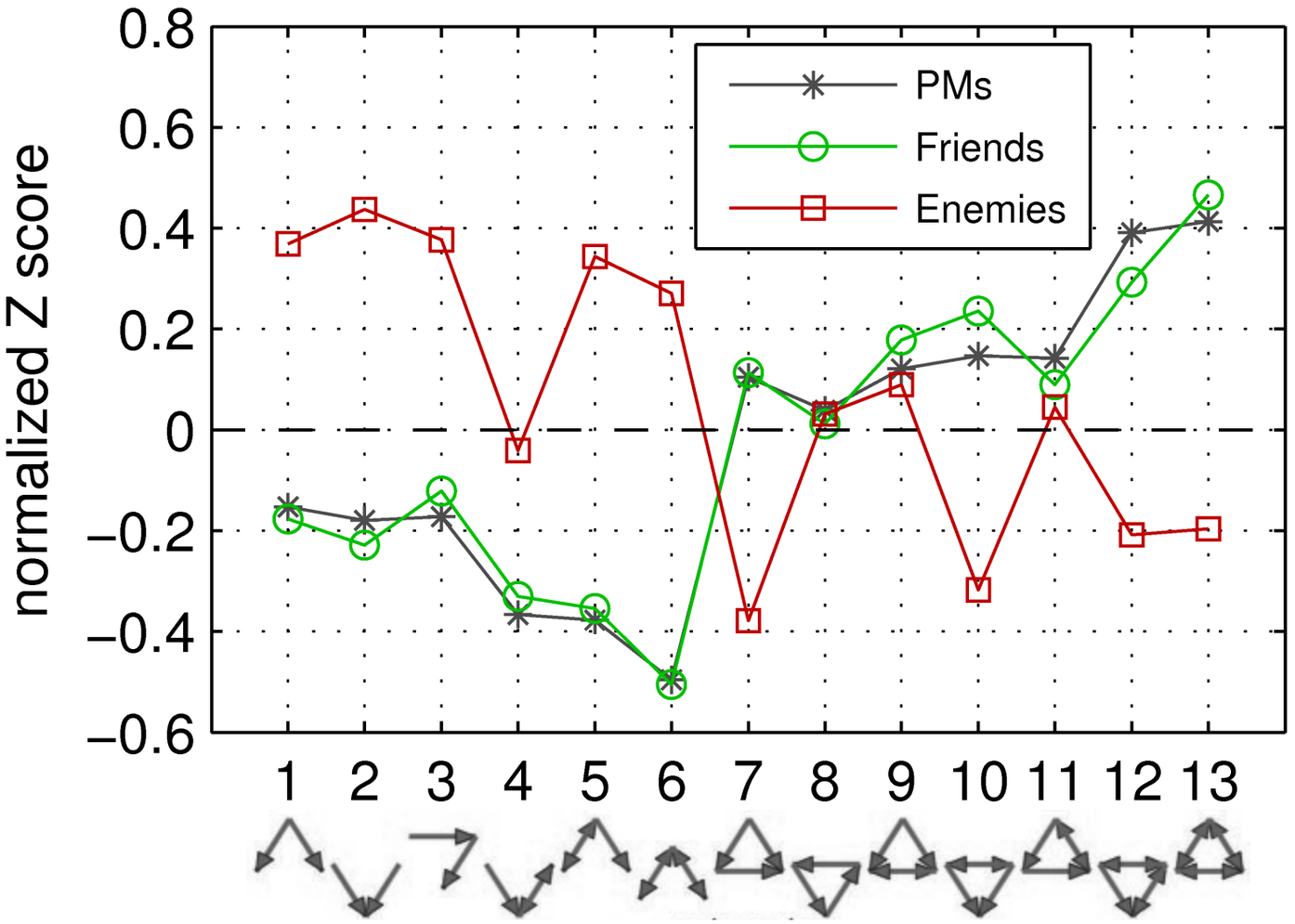
More generally

Expect over-representation of complete triads in friend networks

Granovetter, Amer. Journal of Soc. 87, 27 (1973)

Application: Triadic Closure

Triad significance profile = Statistical significances of triad classes in the network compared to random networks

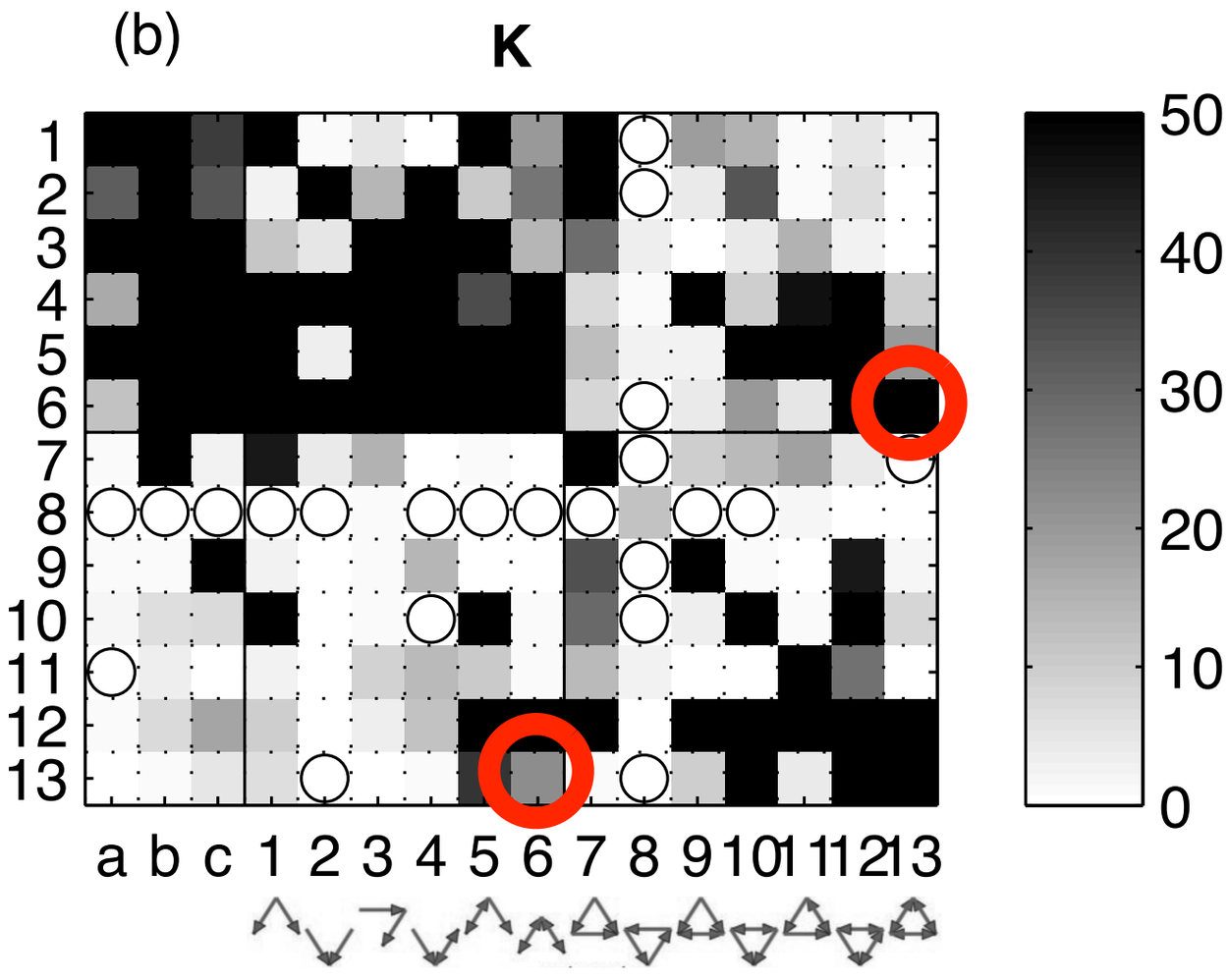


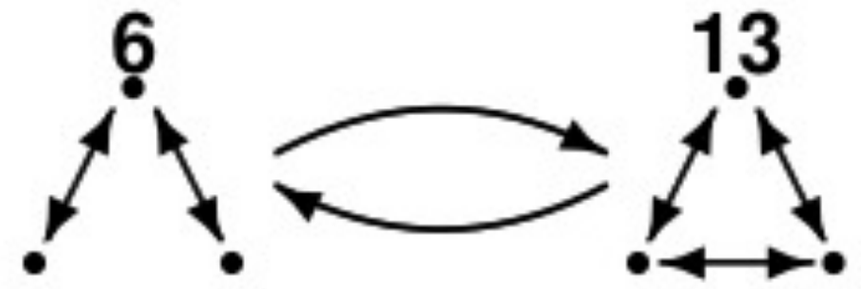
Indicates triadic closure

Szell and Thurner, Social Networks 32, 313-329 (2010)

Application: Triadic Closure

Measure all transitions between triad classes over time interval

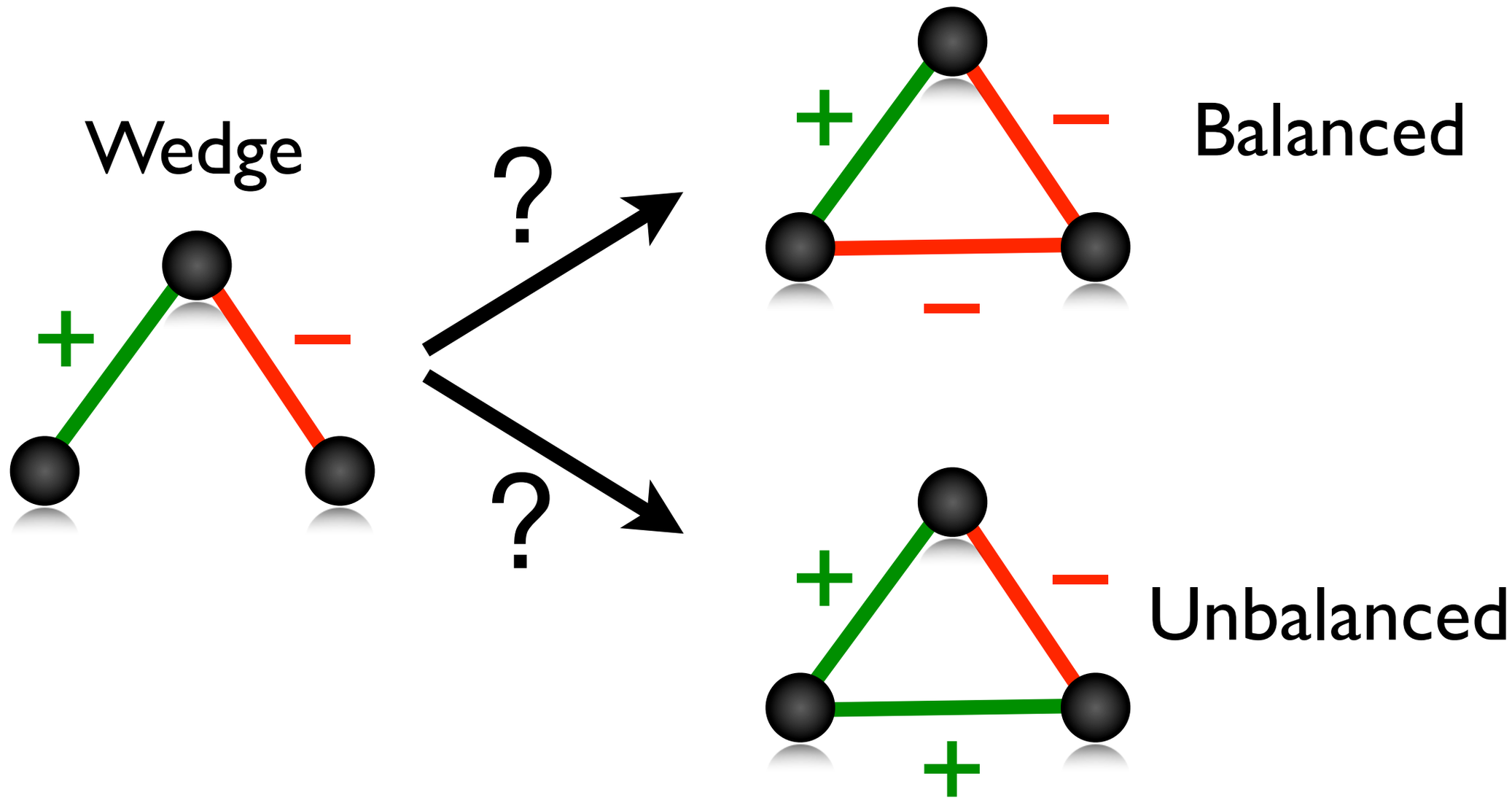




- Explicit quantitative evidence for triadic closure
- Provide transition probabilities for modeling

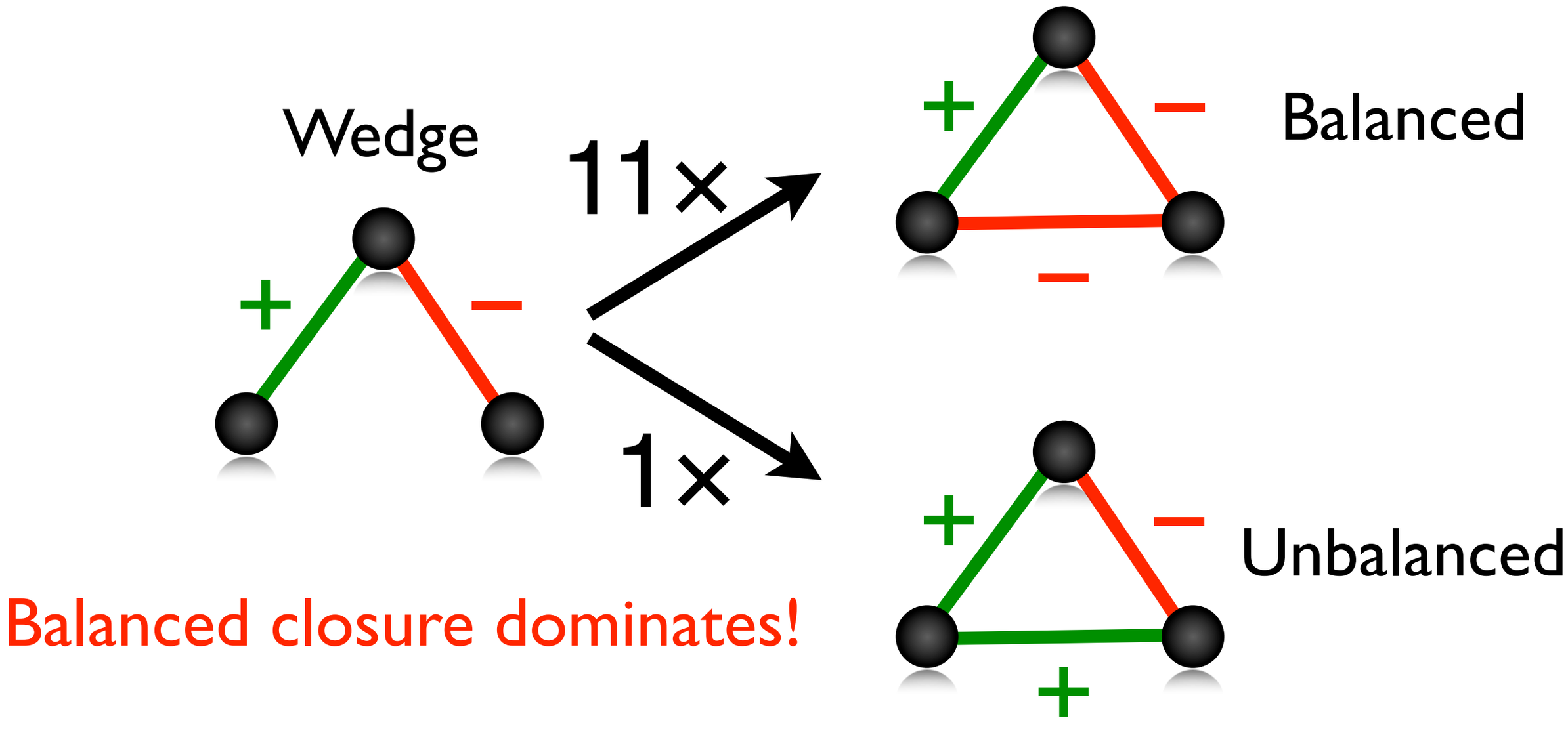
Szell and Thurner, Social Networks 32, 313-329 (2010)

Application: Signed Triadic Closure



Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

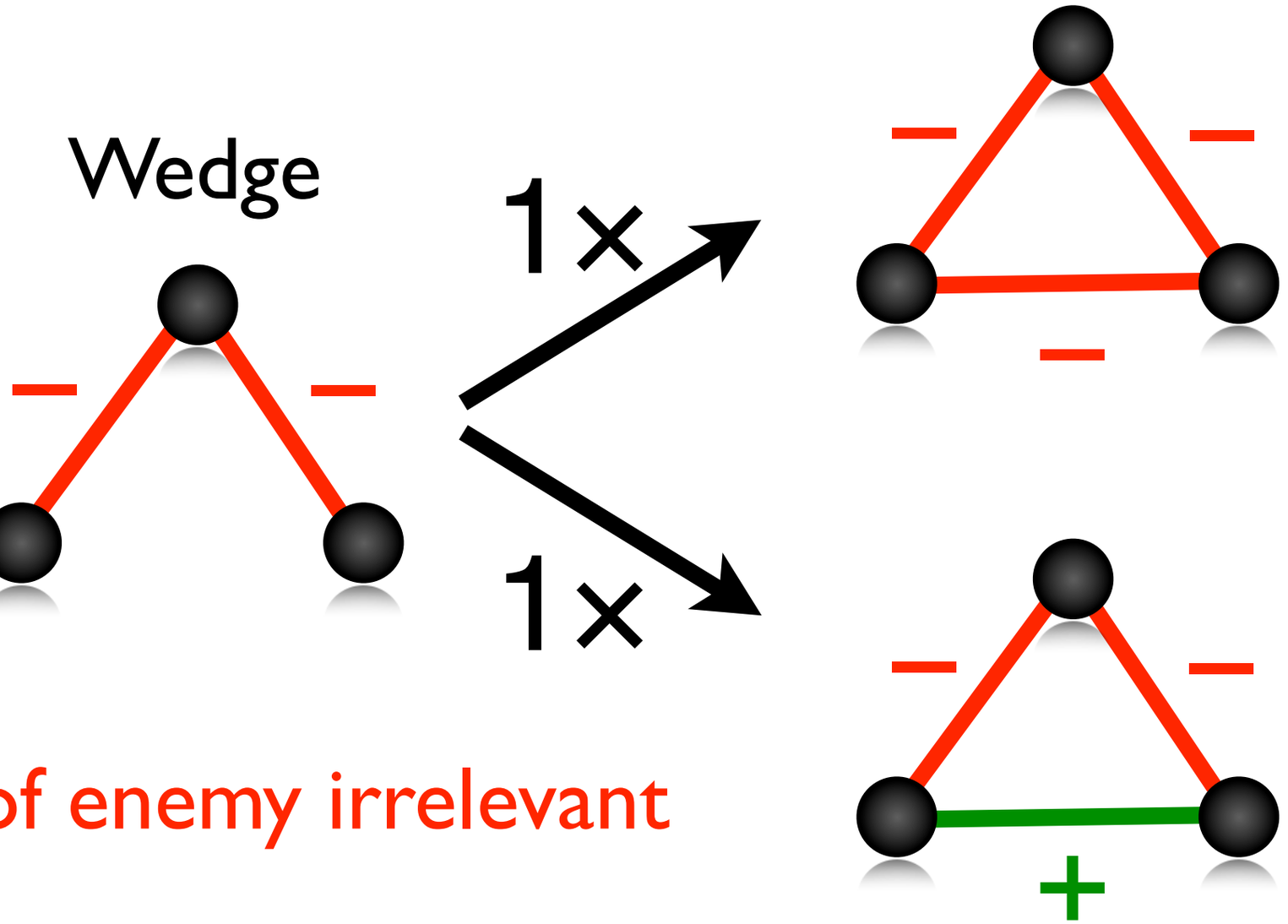
Application: Signed Triadic Closure



Balanced closure dominates!

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

Application: Signed Triadic Closure



Enemy of enemy irrelevant

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

Summary

- Establish a large-scale socio-economic laboratory
- Structural differences between pos. and neg. ties
- Multiplex Network: Social balance, Weak ties hyp.
- Network Evolution: Triadic Closure

Contact

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Articles

Szell M, Lambiotte R and Thurner S: *Multirelational organization of large-scale social networks in an online world*, PNAS 107, 13636-13641 (2010)

Szell M and Thurner S: *Measuring social dynamics in a massive multiplayer online game*, Social Networks 32, 313-329 (2010)