Statistical physics approaches to large-scale socio-economic networks

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Defensio for
Dr. rer. nat. (Physics)

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Christoph Dellago

Mar 20, 2012

Data from social systems is hard to get

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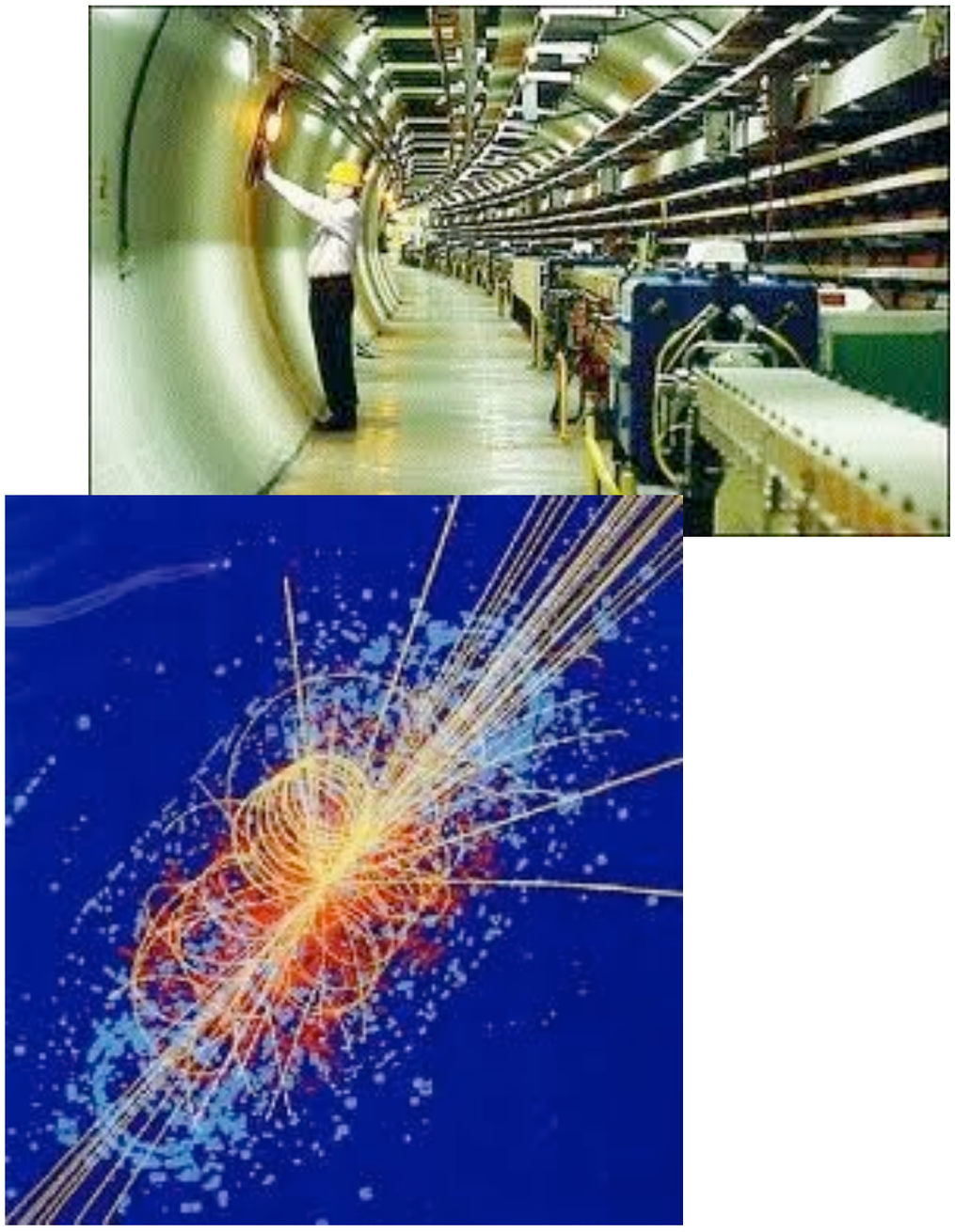


Collective human behavior is poorly understood

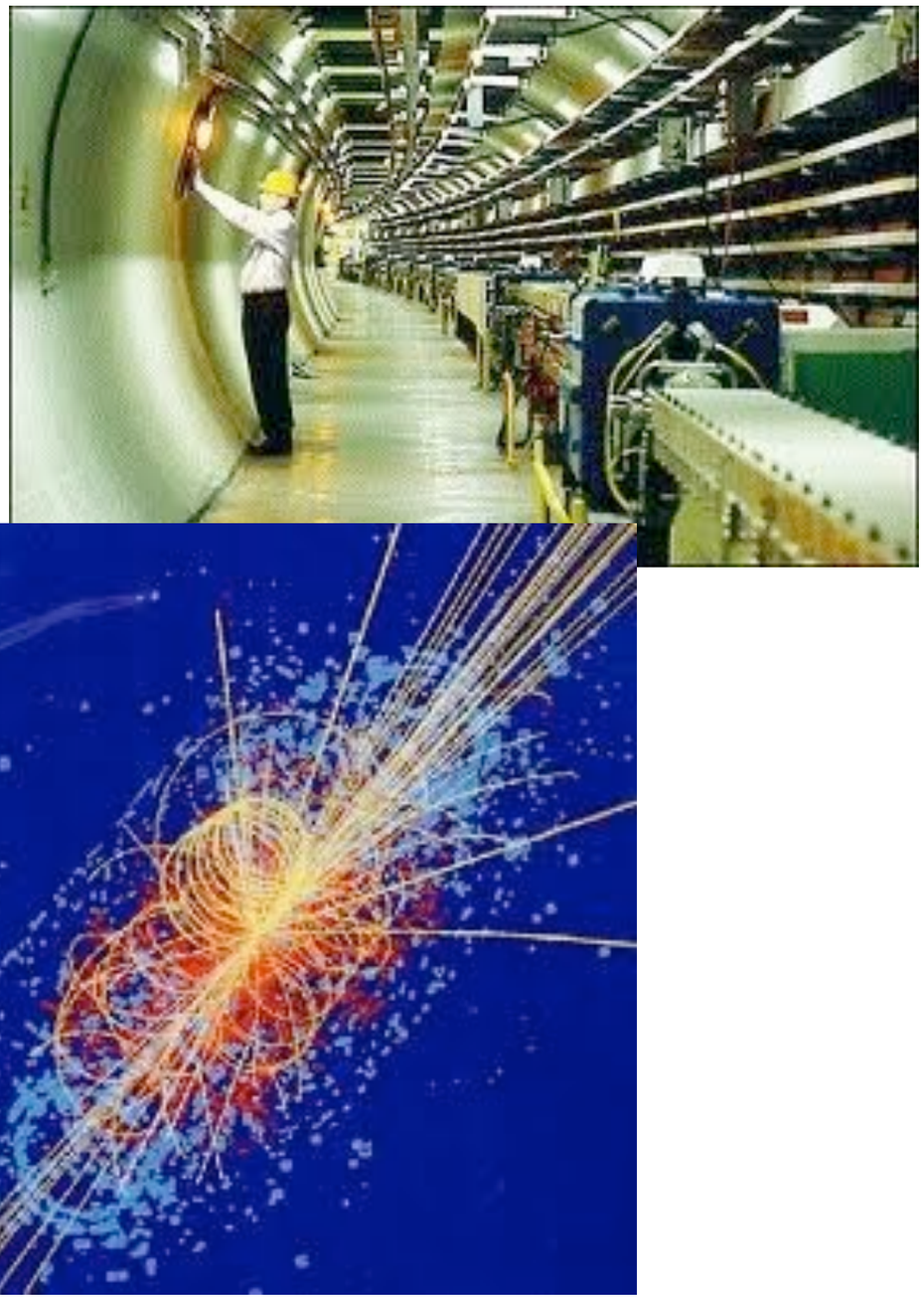
Social systems are Complex systems

- Many elements
- Strong interactions - Networks
- Emergence of macroscopic properties

Brain, traffic, internet, society, economy

Power laws, anomalous diffusion, etc.

Castellano, Fortunato and Loreto, Rev Mod Phys 81, 591-646 (2009)
Barabási and Albert, Science 286, 504 (2000)
Park and Newman, PRE 70, 066117 (2004)
Bak, Tang and Wiesenfeld, PRL 59, 381-384 (1987)
Metzler and Klafter, Phys Rep 339, 1-77 (2000)



Could THIS be a human society?

Massive multiplayer online games

www.pardus.at

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

- 400,000 registered players
- 12,000 active players
- Online since 2004

Complete data on human society!

Bainbridge, Science 317, 472 (2007)

The framework of the game

- Economic life

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

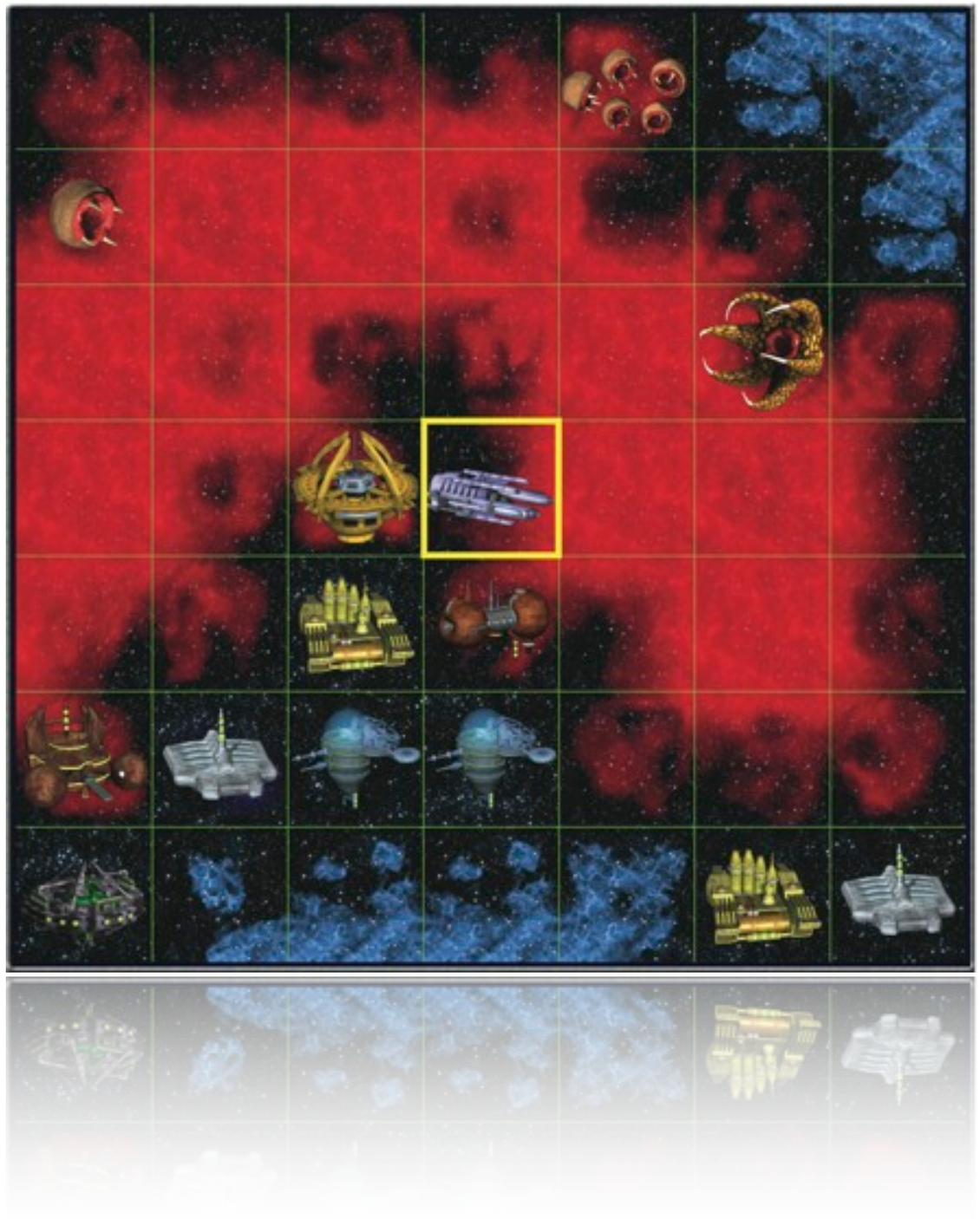
- Social life

  Chat, forum, messages
  Make friends

- Exploratory life (“Science”)

  Universe and lifeforms

No rules, No goals



Emergence of complex socio-economic behavior

- Hierarchical groups
- Cartels
- Political parties, diplomacy
- Organized attacks + wars over territory, resources, ...

Data available

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

Contributions of the thesis

1) Individual
   Human behavioral sequences, mobility

2) Network
   Social dynamics, testing classic hypotheses

3) Network-network
   Multi-relational organization

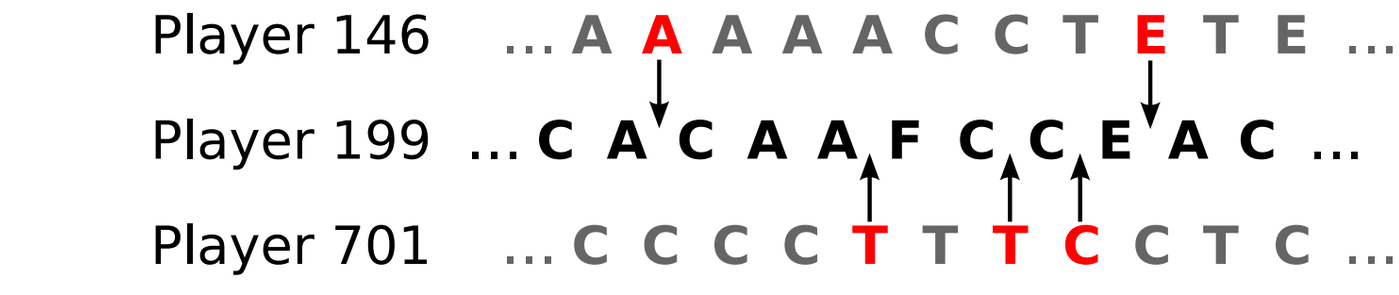
Show feasibility of "social labs"

Thurner, Szell and Sinatra, PLoS ONE 7, e29796 (2012)
Szell, Sinatra, Petri, Thurner and Latora, in review (2012)
Szell and Thurner, Social Networks 32, 313-329 (2010)
Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)

I) Individual: Behavioral codes

Alphabet of 8 letters = action types

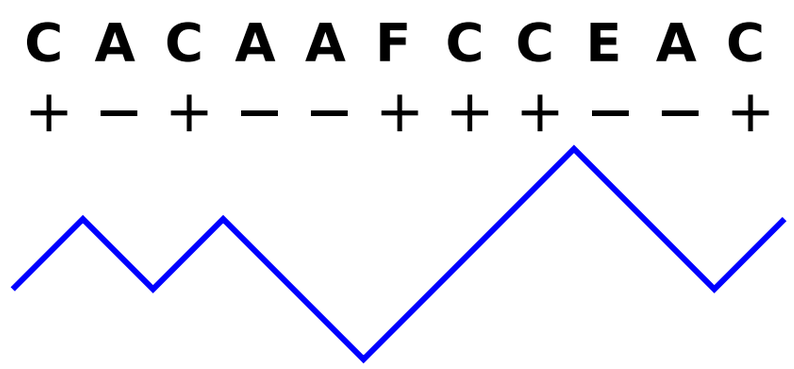
(a) Actions



Actions and received actions

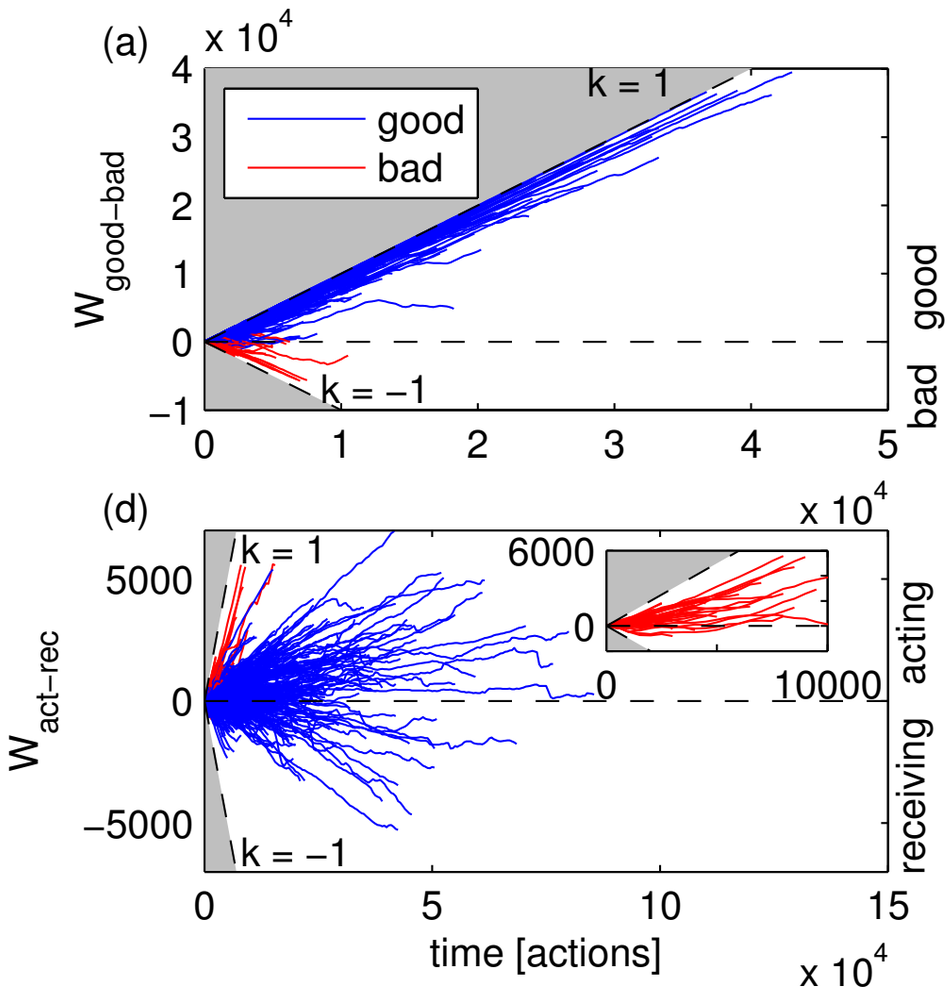
Player 199 ... C A A C A A T F C T C C E E A C ...

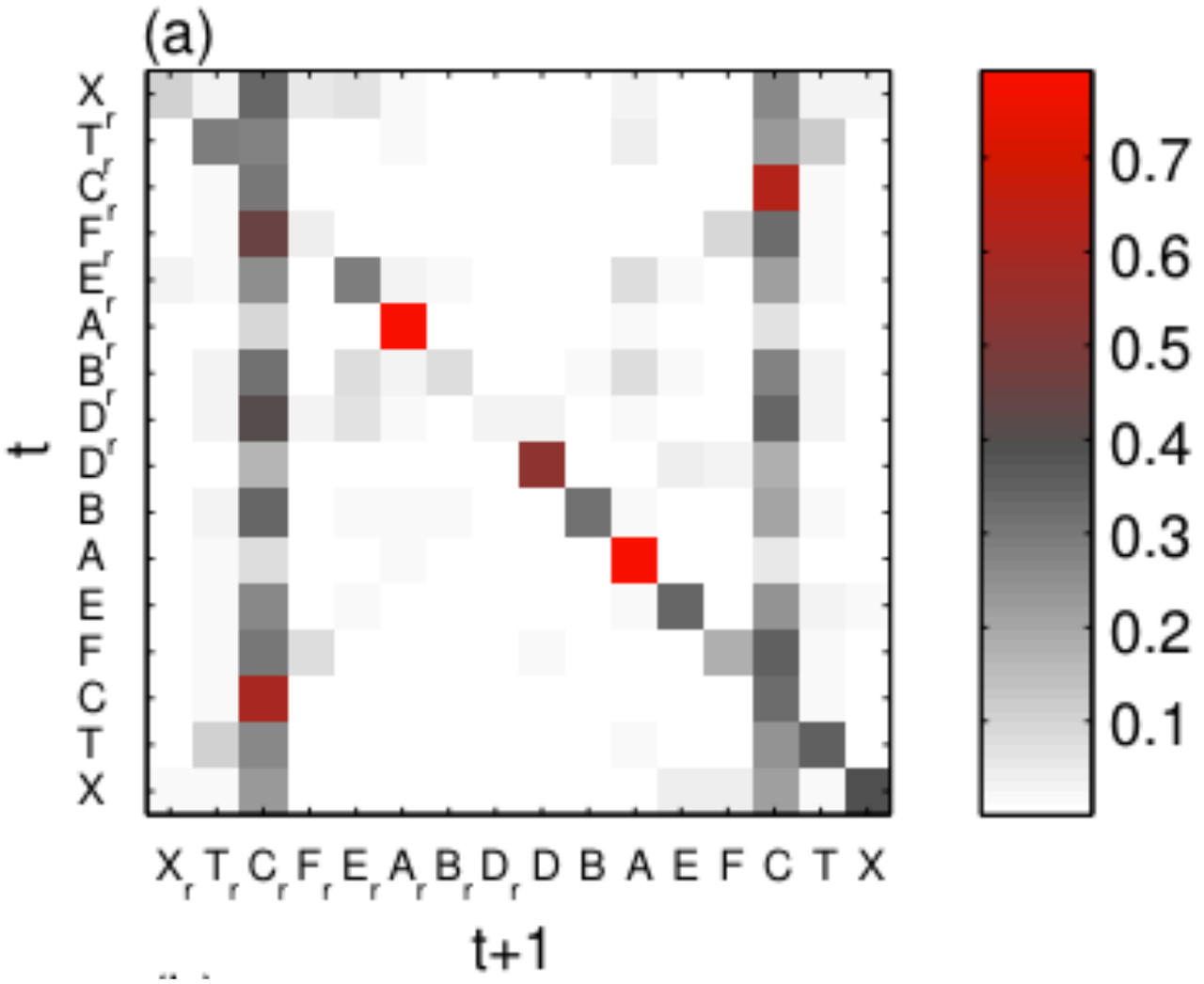
(b)



Stanley et al, Physica A 224, 302-321 (1996)

I) Individual: Behavioral codes





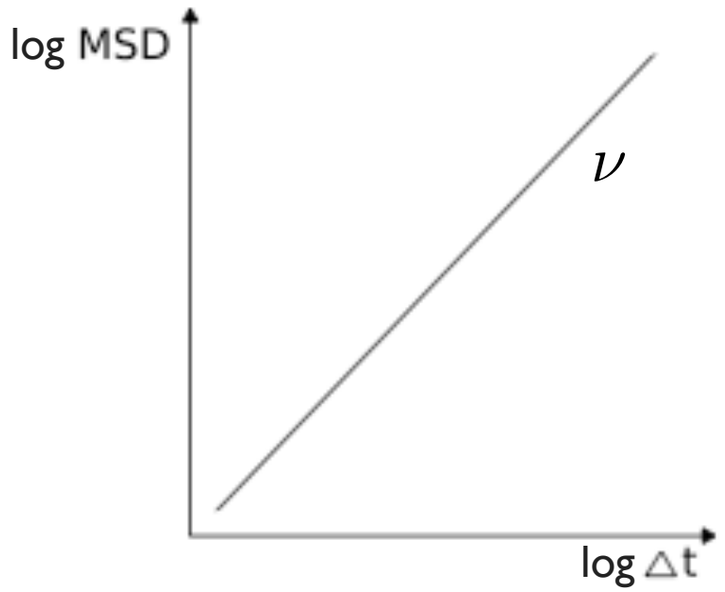
- Most players are “good”, “bad” players are dominant
- Attack is persistent, Communication is anti-persistent
- Receiving neg actions $\rightarrow$ Performing neg actions

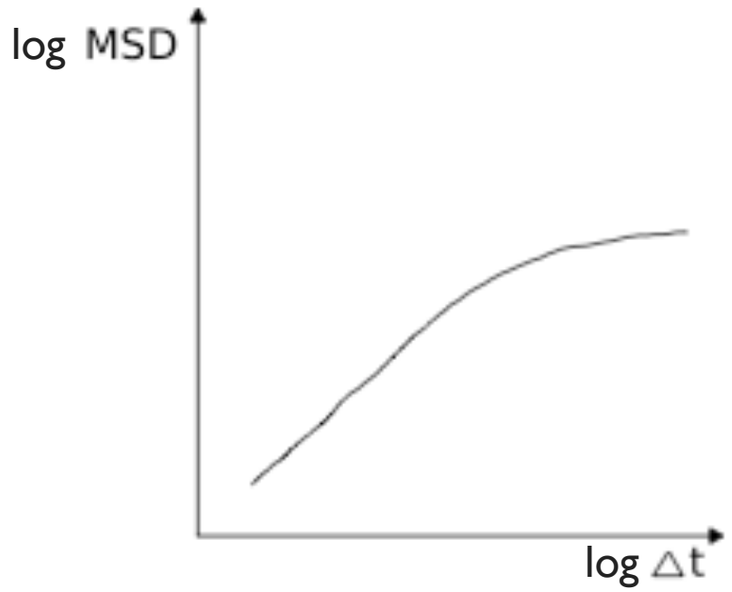
1) Individual: Mobility

Mean Square Displacement

finite universe

$$\nu = \lim_{t \to \infty} \frac{d}{dt}(\mathrm{MSD})$$





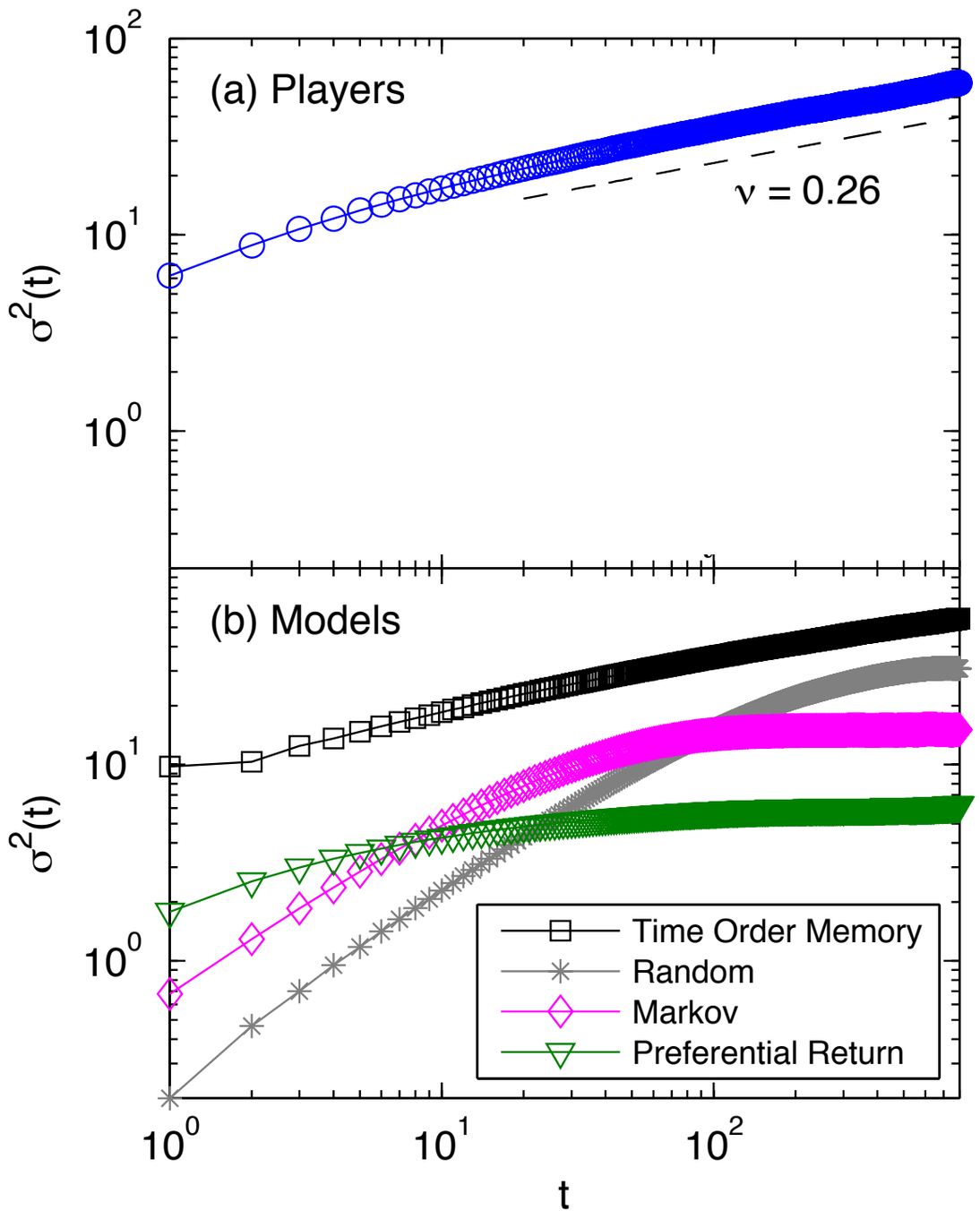
expect finite size effect

1) Individual: Mobility

$\nu = 0.26 < 1$

Subdiffusive

<u>Order</u> of visitations!



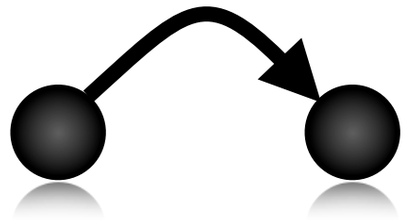
Players

Models

Song et al, Nature Physics 6, 818-823 (2010)

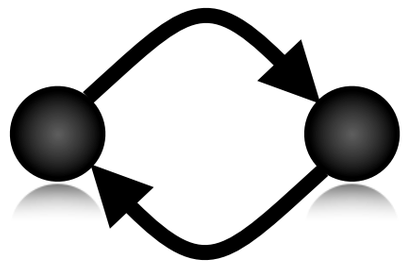
2) Network: 6 Types

Directed one-to-one interactions



Positive	Negative
Friendship	Enmity
Communication	Attack
Trade	Bounty

2) Network: Structural differences

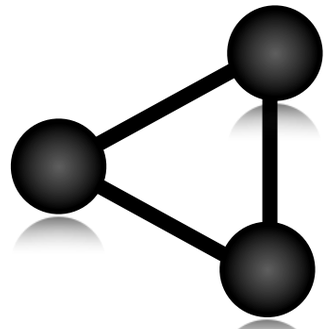
Reciprocity 

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
$\rho(k^{\text{in}}, k^{\text{out}})$	0.88	0.98	0.93	0.11	0.64	0.31

YES NO

2) Network: Structural differences

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
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$\rho(k^{\text{in}}, k^{\text{out}})$	0.88	0.98	0.93	0.11	0.64	0.31

YES NO

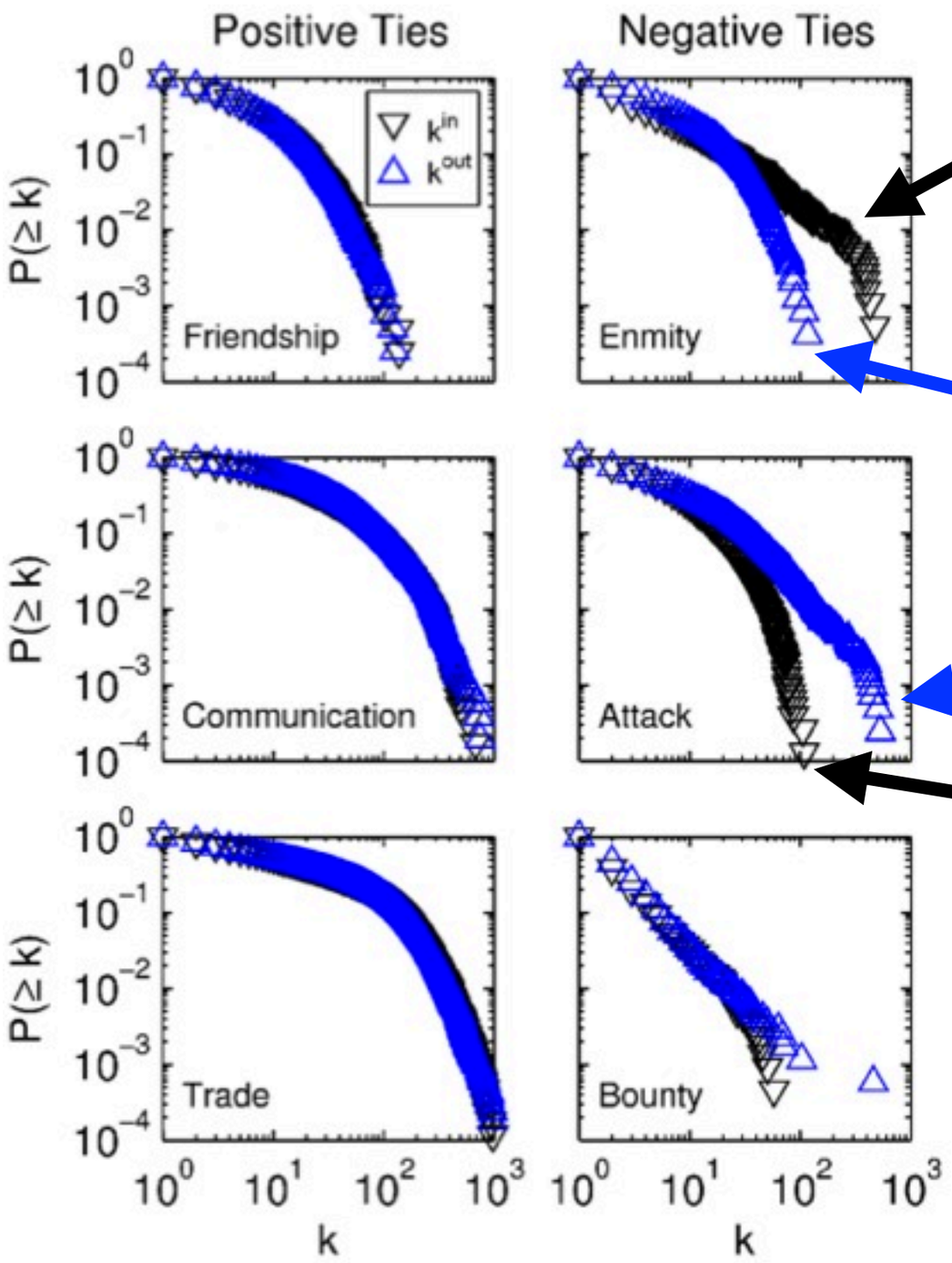
2) Network: Structural differences

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
$\rho(k^{\text{in}}, k^{\text{out}})$	0.88	0.98	0.93	0.11	0.64	0.31
	YES			NO		

2) Network: Structural differences



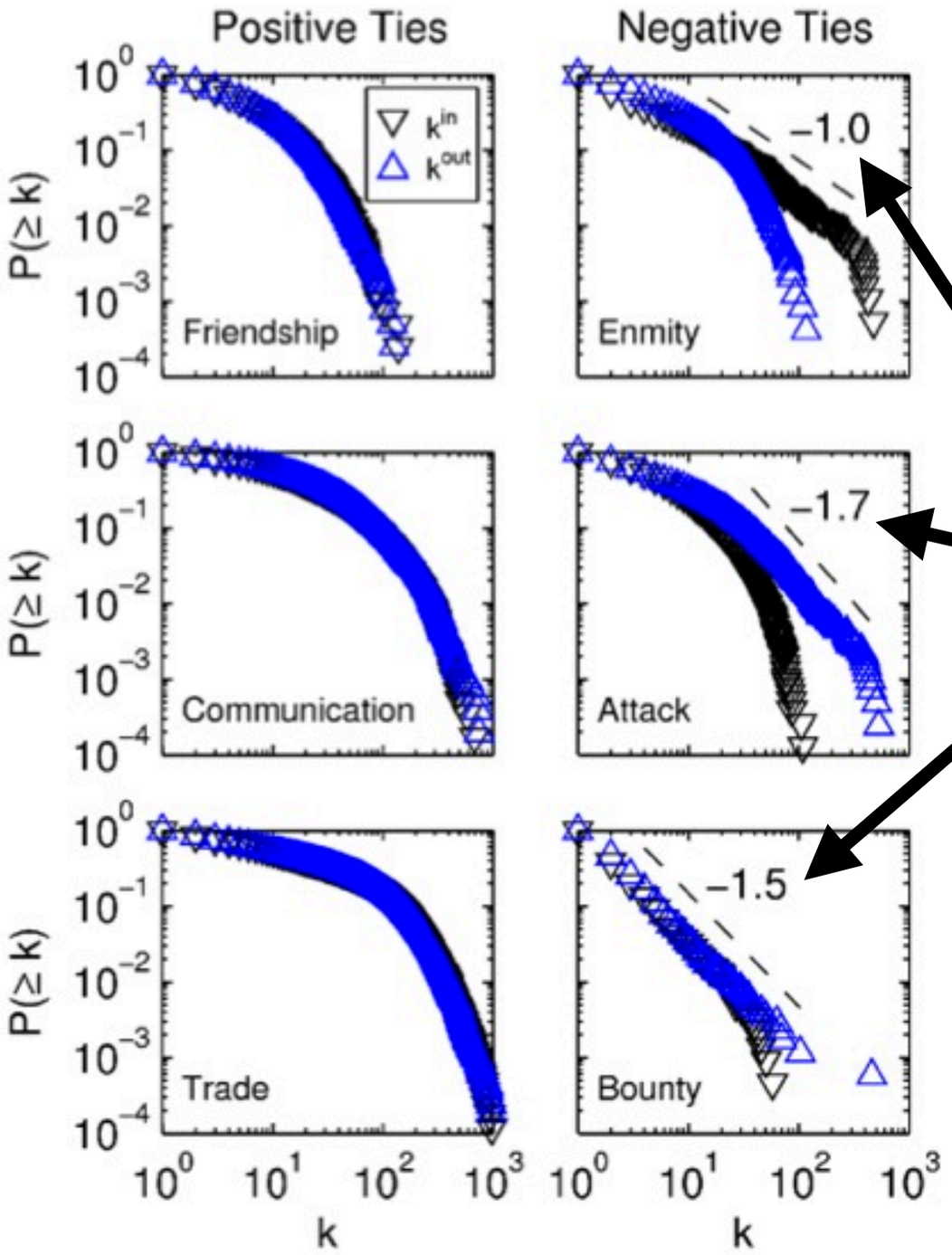
Being marked as enemy

Marking somebody as enemy

Attacking somebody

Being attacked

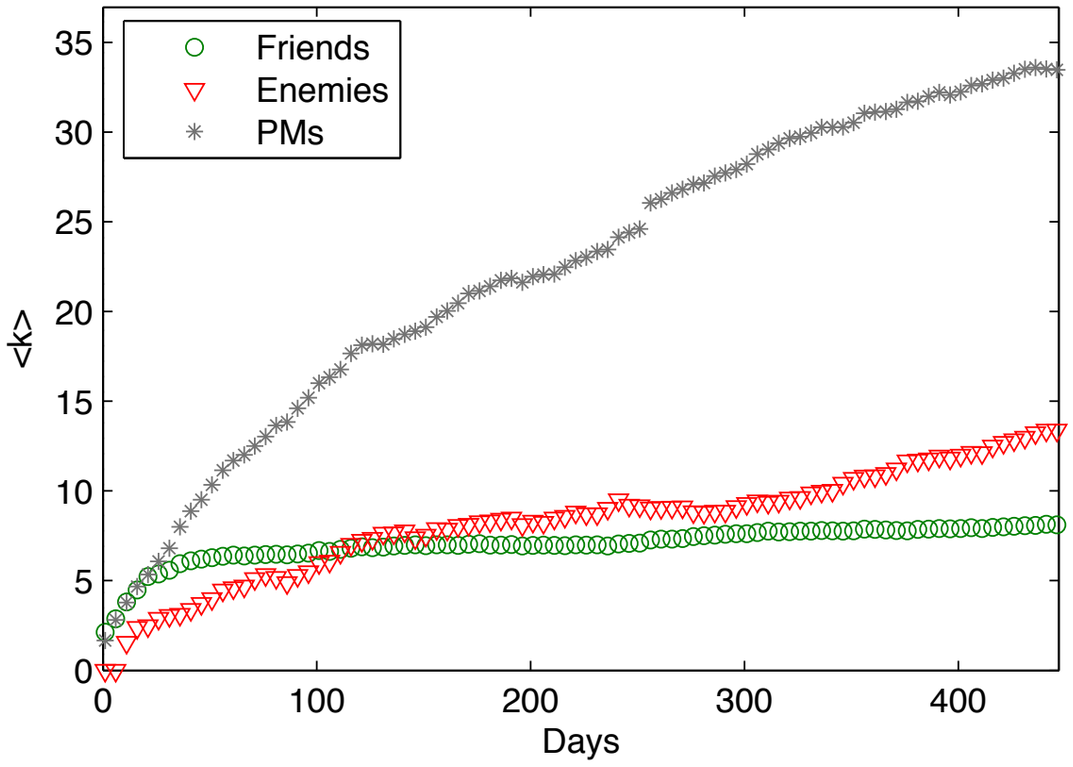
2) Network: Structural differences



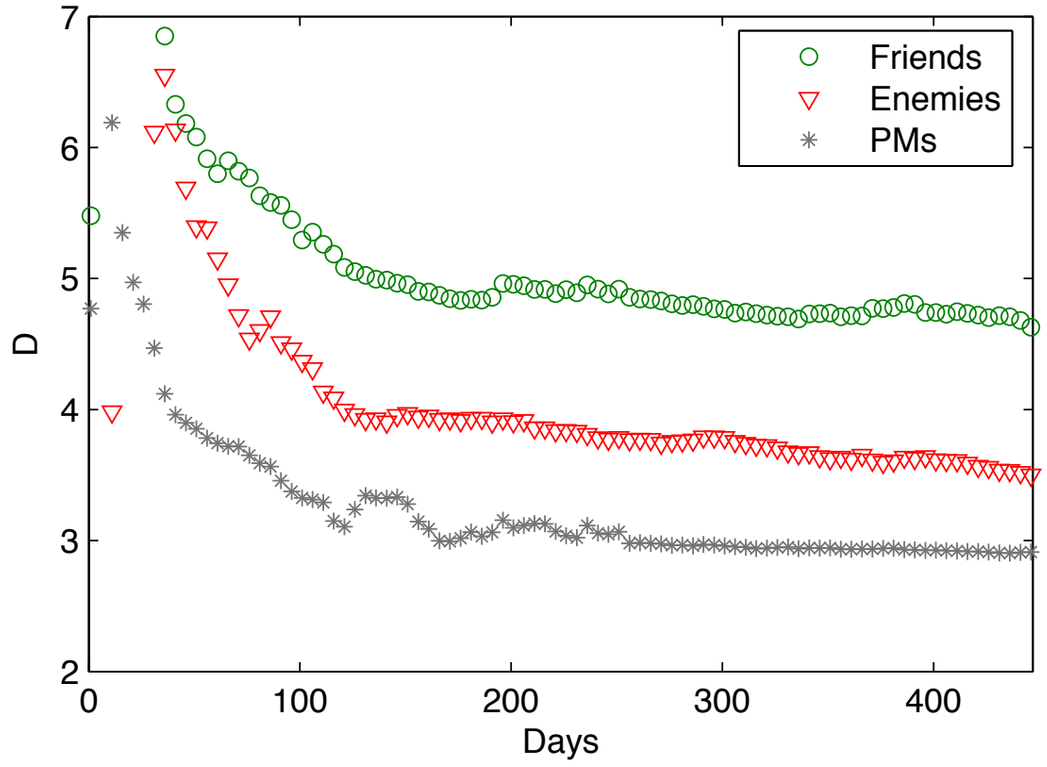
Conflict leads to fat tails

2) Network: Evolution

Average degrees grow



Diameters shrink

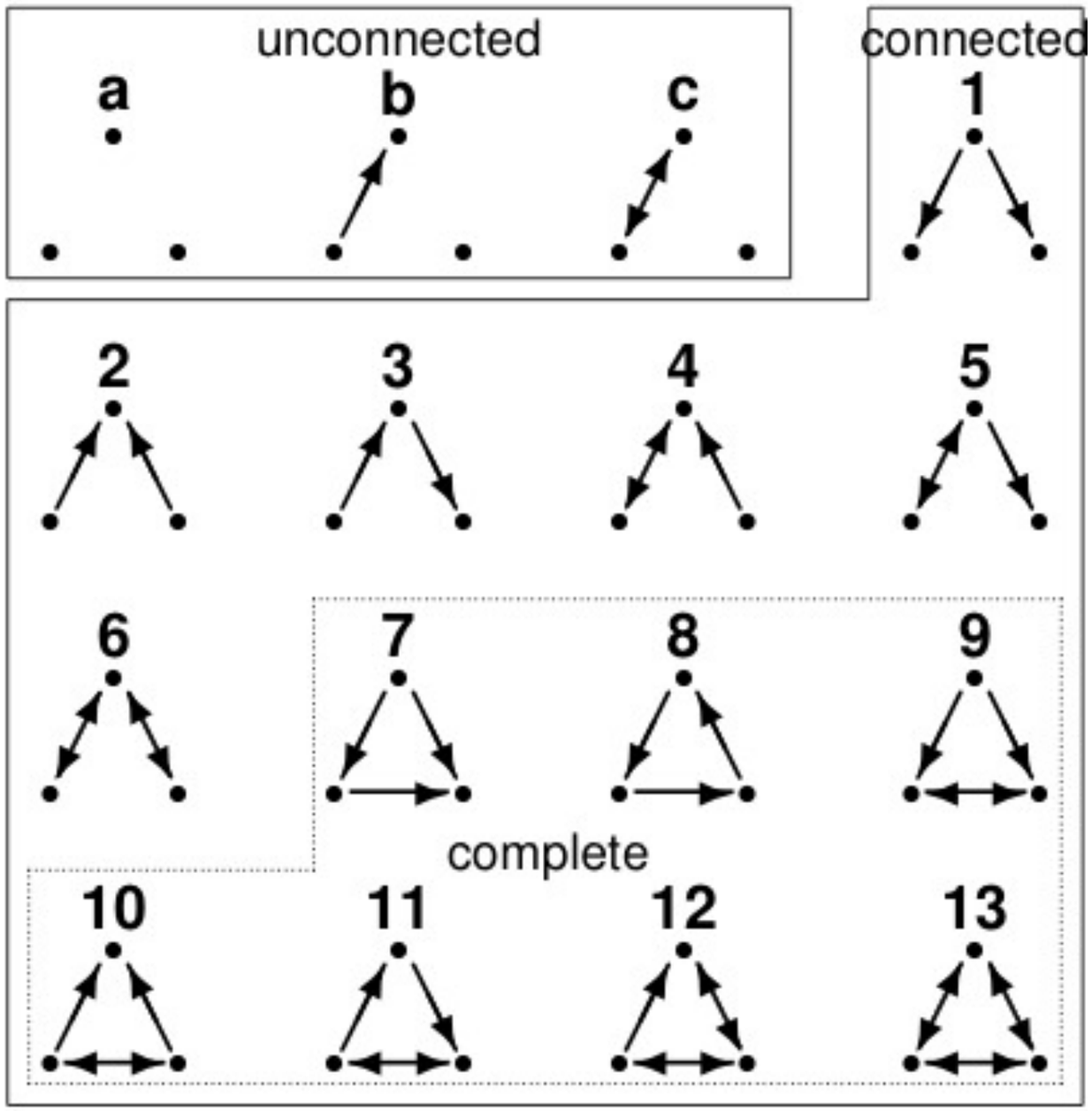


Densification

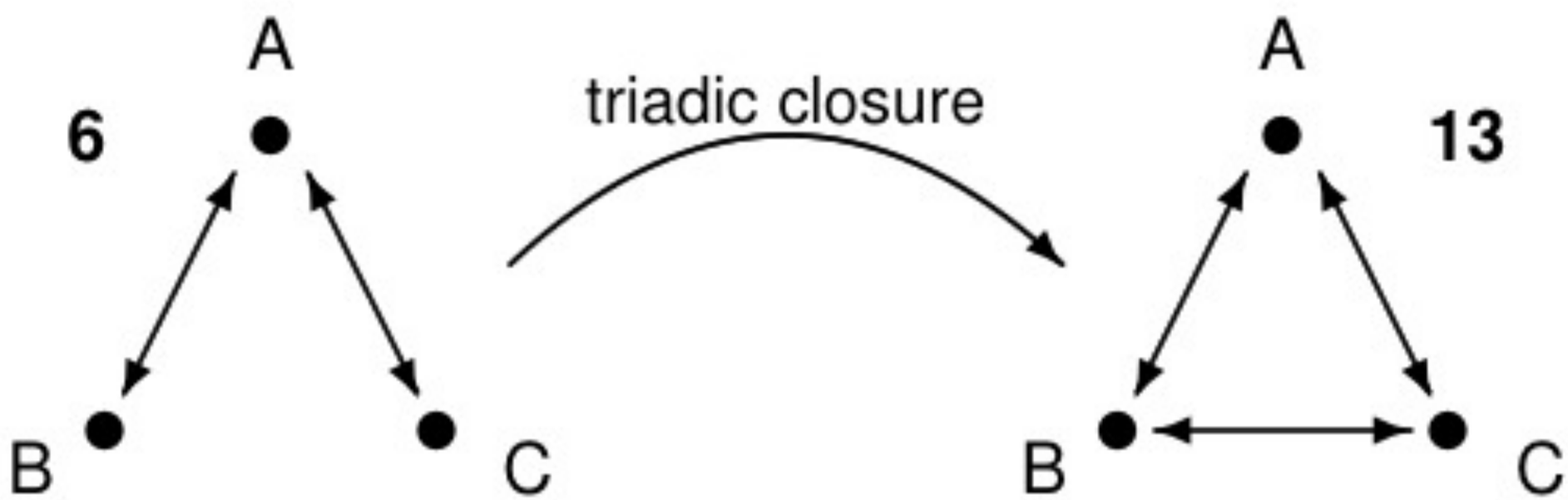
Leskovec et al, ACM TKDD 1 (2007)

2) Network: Triadic closure

Directed triad classes



2) Network: Triadic closure



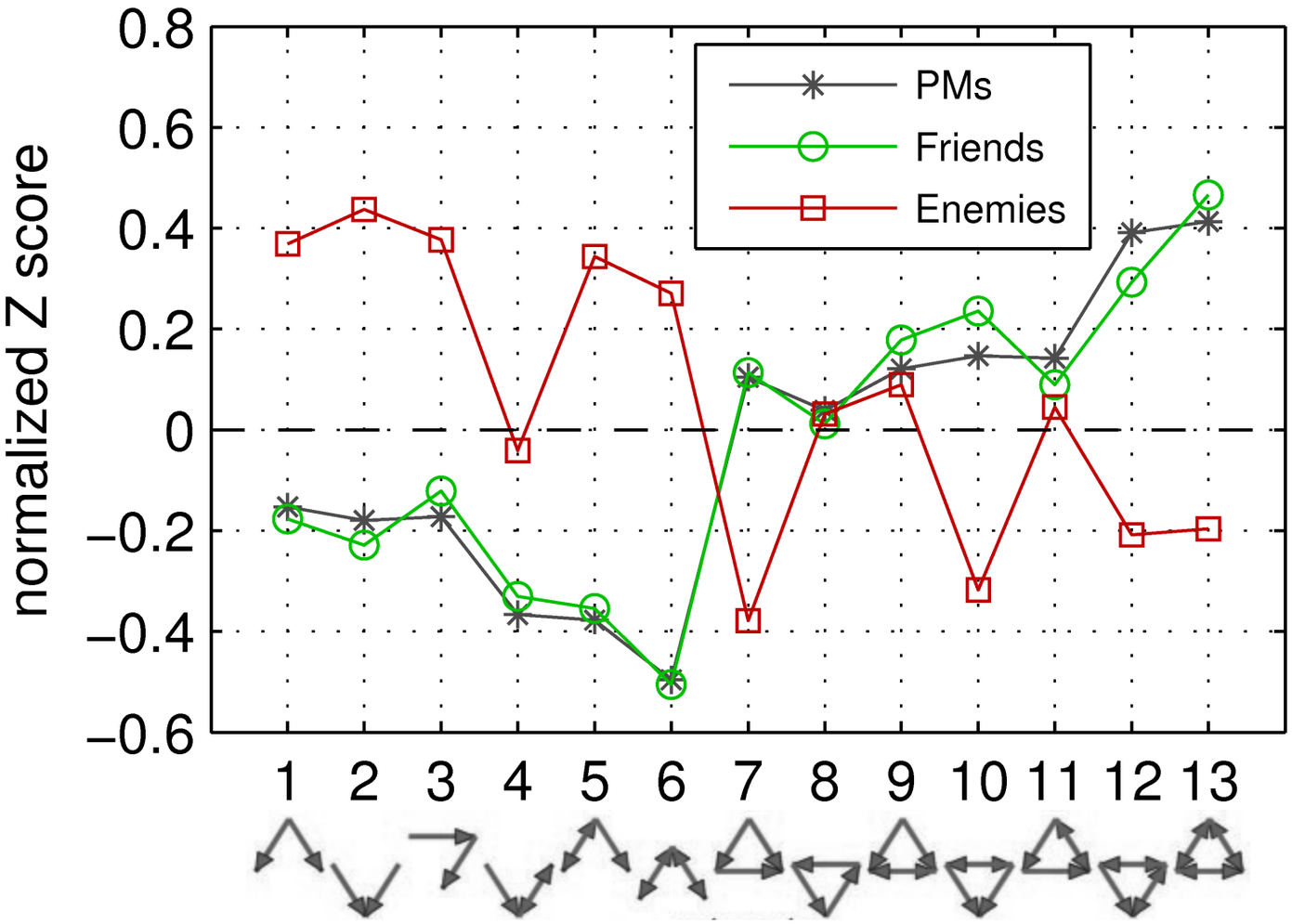
More generally

Expect over-representation of complete triads in friend networks

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

2) Network: Triadic closure

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

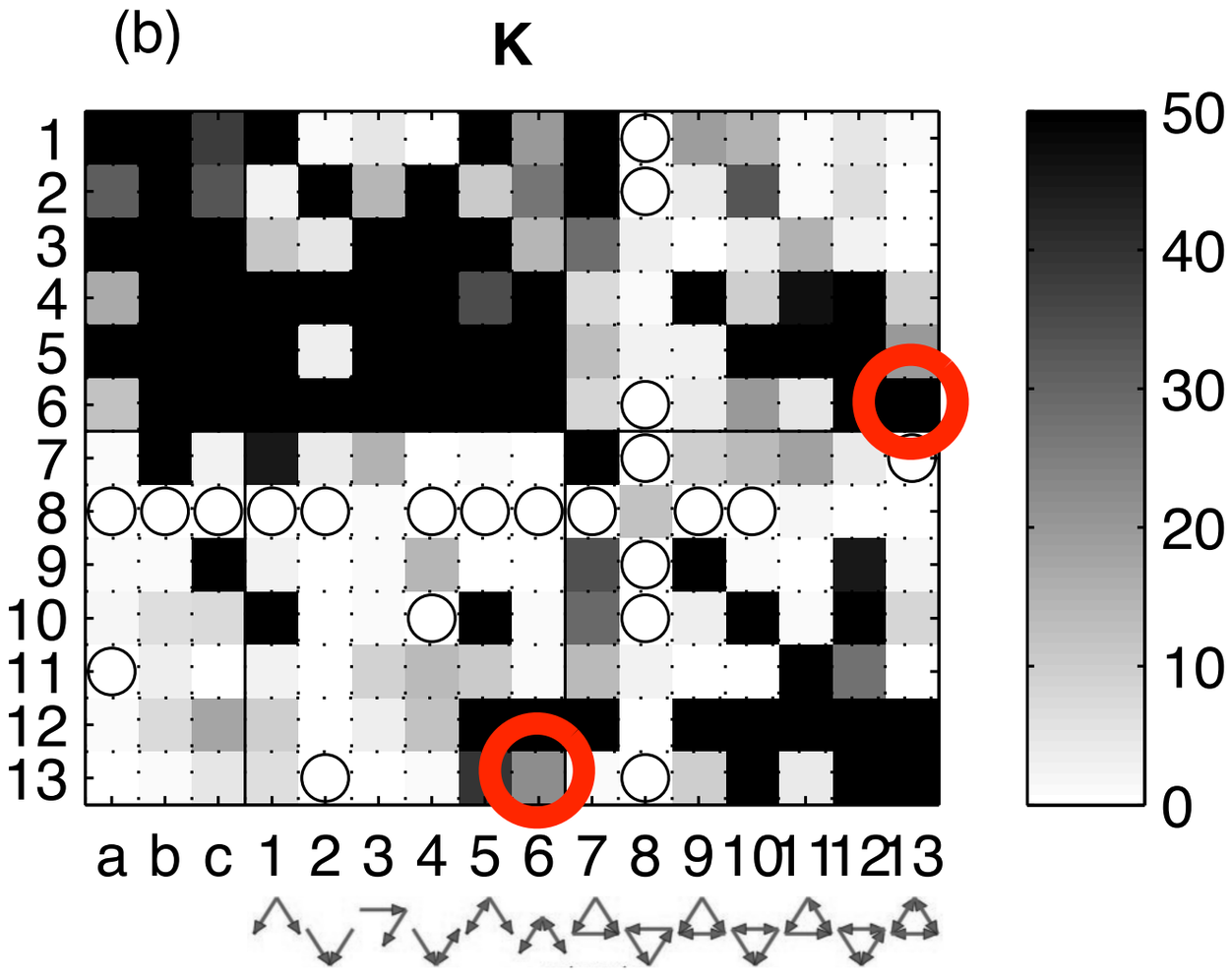


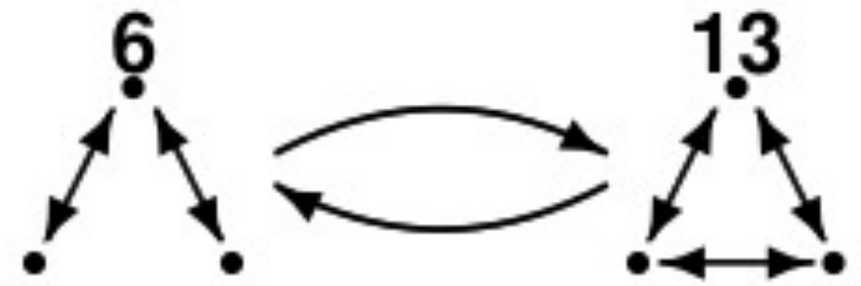
Indicates triadic closure

Milo et al., Science 298, 824-827 (2002)

2) Network: Triadic closure

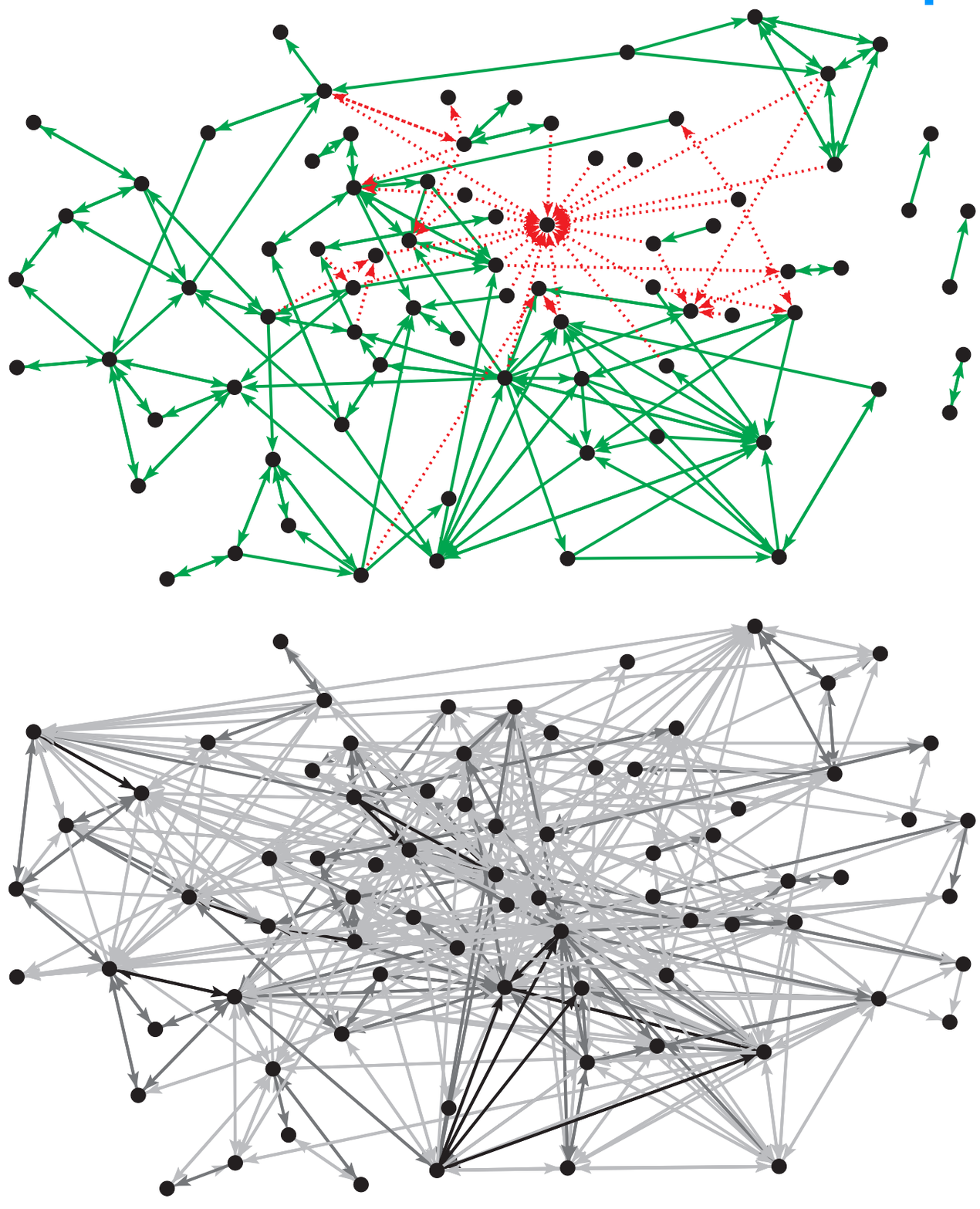
Measure all transitions between triad classes over time interval



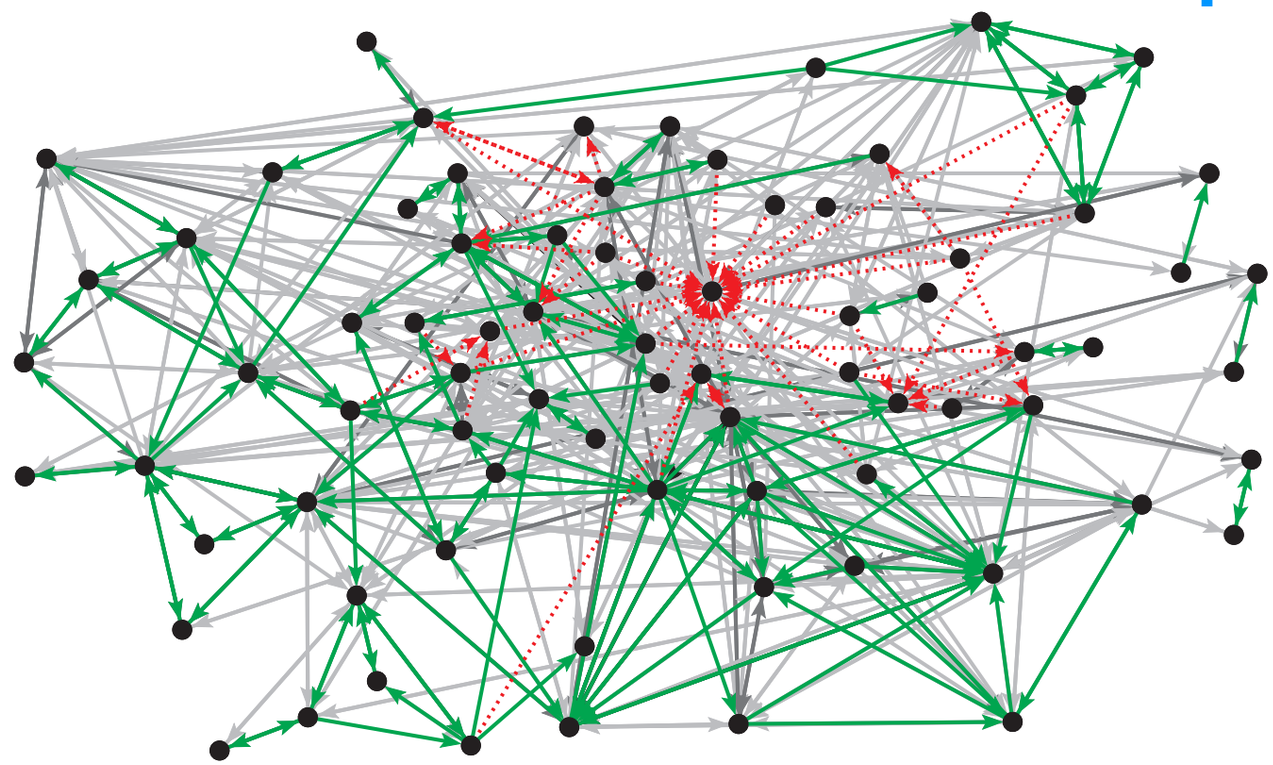


- Explicit quantitative evidence for triadic closure
- Provide transition probabilities for modeling

3) Network-network: Multiplexity

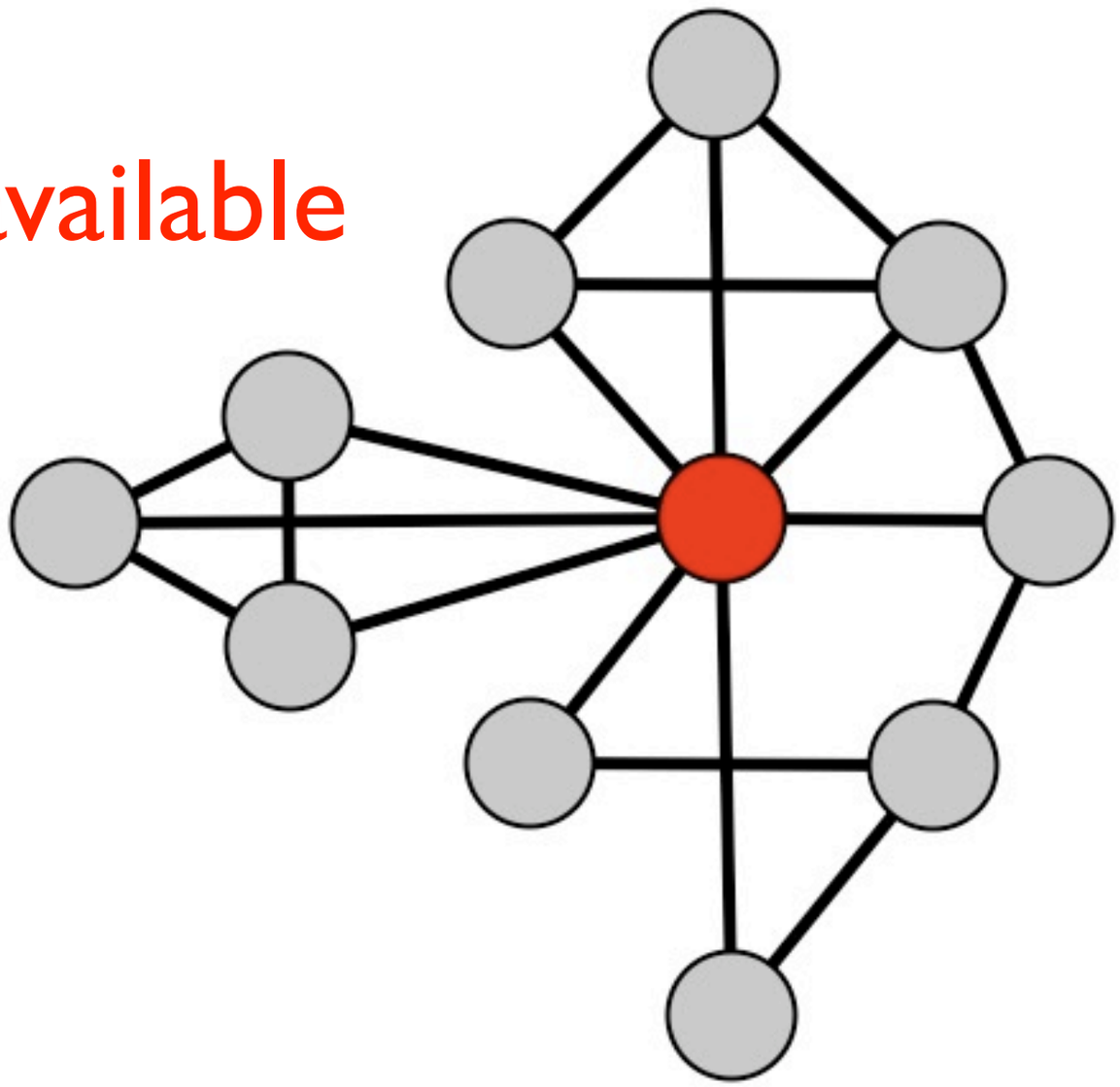


3) Network-network: Multiplexity



3) Network-network: Multiplexity

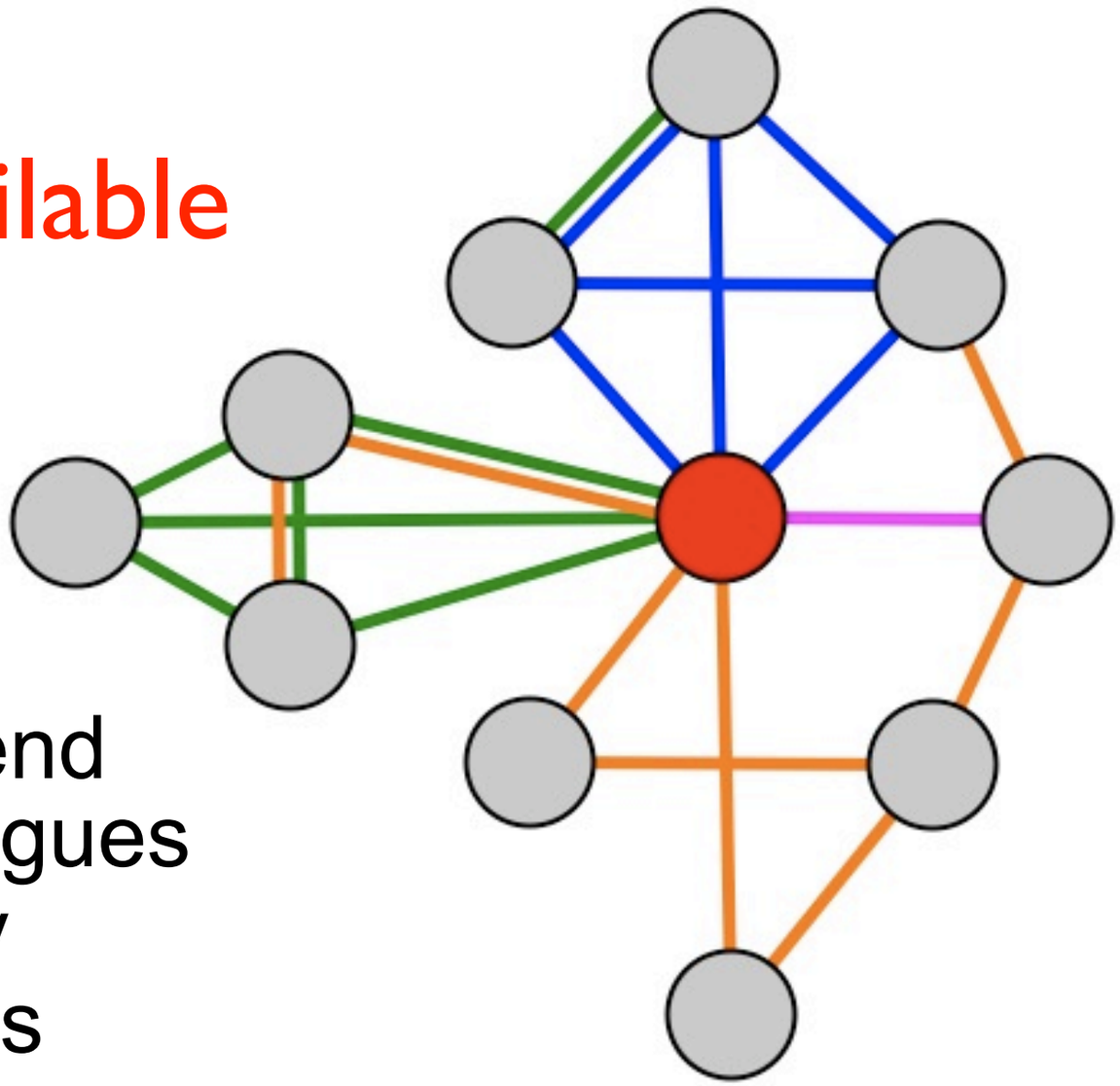
Usually:
Nature of relations unavailable



3) Network-network: Multiplexity

Here:
Nature of relations available

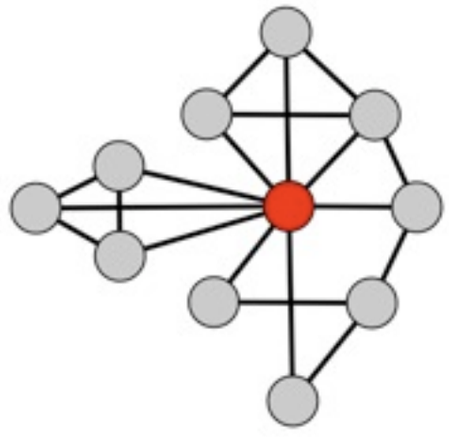
Multiplex network



Girlfriend
Colleagues
Family
Friends

3) Network-network: Multiplexity

Ignorance of relation types



Loss of essential information!

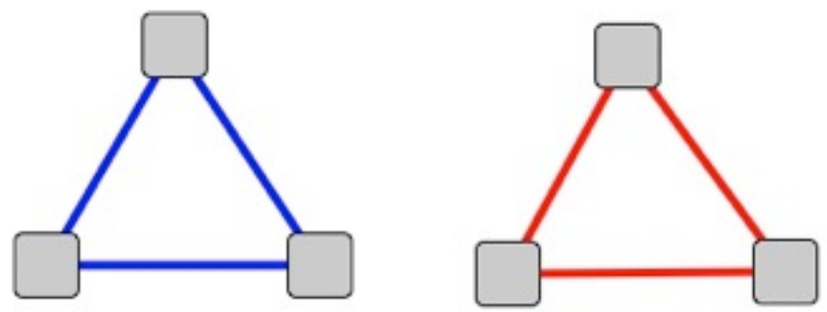
	Positive			Negative			
	Friends	PMs	Trades	Enemies	Attacks	Bounties	All
N	4,313	5,877	18,589	2,906	7,992	2,980	18,819
r	0.68	0.84	0.57	0.11	0.13	0.20	0.59
C	0.25	0.28	0.43	0.03	0.06	0.01	0.42
C/C^{rand}	109.52	45.71	131.95	6.13	37.27	13.88	109.93
$\rho(k^{\mathrm{in}}, k^{\mathrm{out}})$	0.88	0.98	0.93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

3) Network-network: Interactions

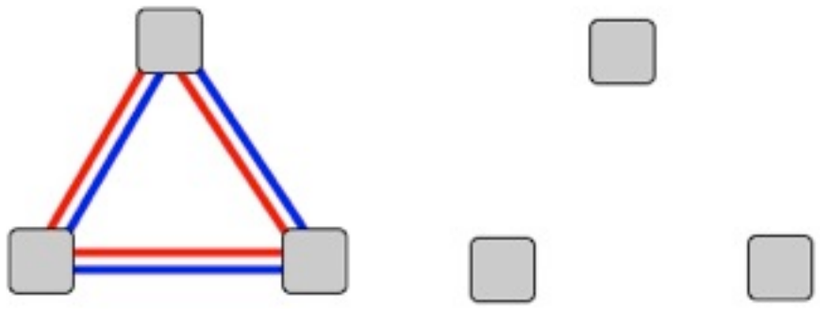
Description of co-existence of links

- Link overlap (Jaccard coefficient)

Low



High

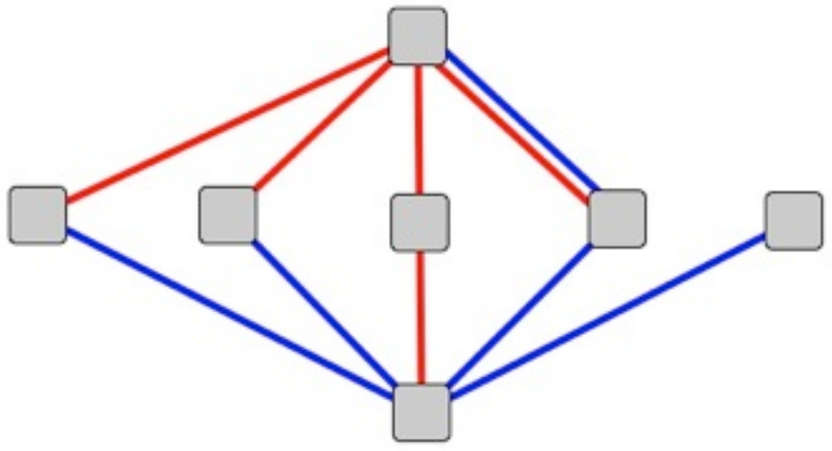


3) Network-network: Interactions

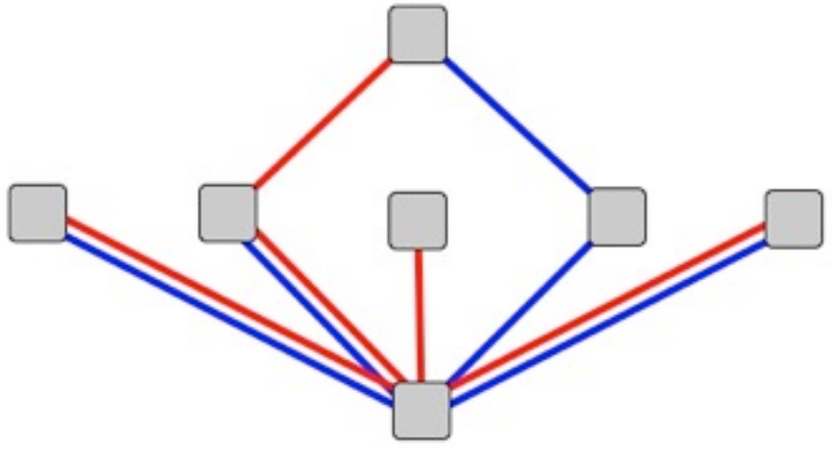
Description of co-existence of links

- Link overlap (Jaccard coefficient)
- Degree correlation

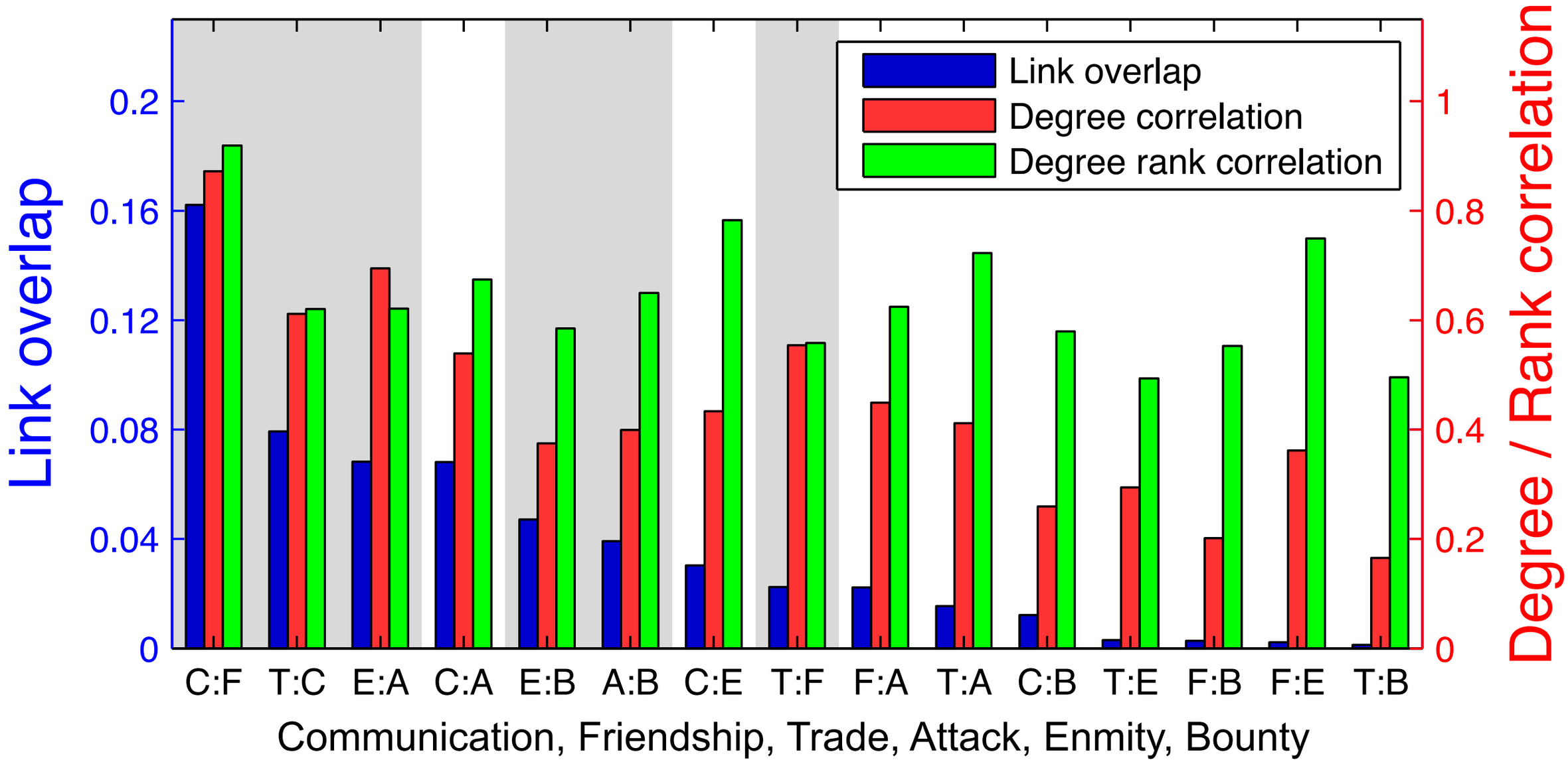
Low



High



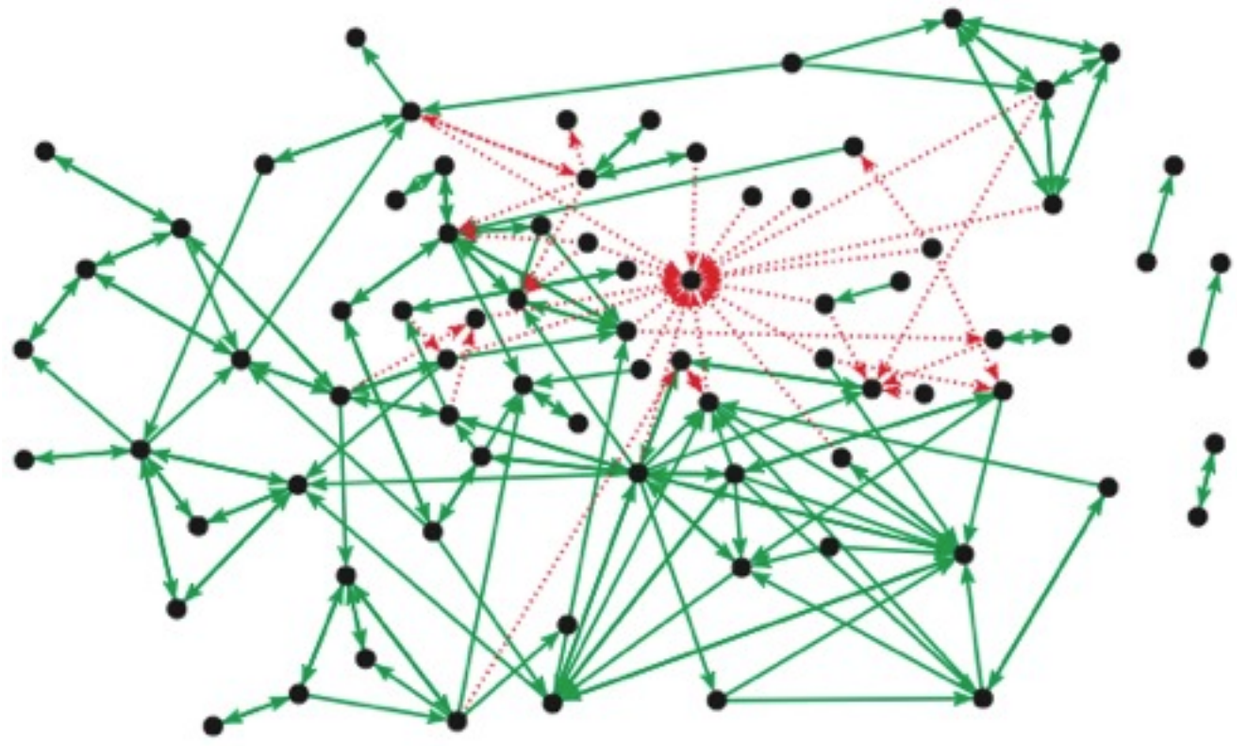
3) Network-network: Interactions



Different roles in different networks

3) Network-network: Social balance

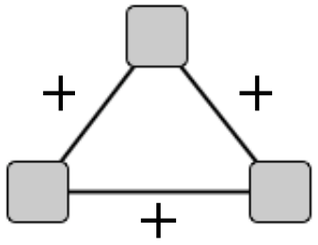
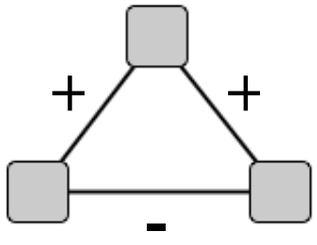
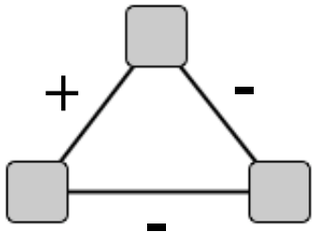
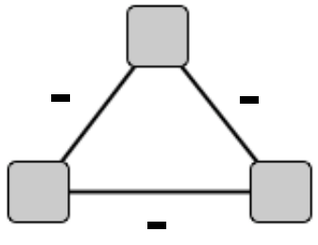
Theory about cognitive dissonance in social networks



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

Heider, Journal of Psychology 21, 107-112 (1946)

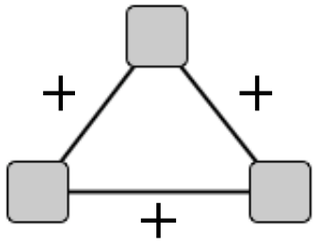
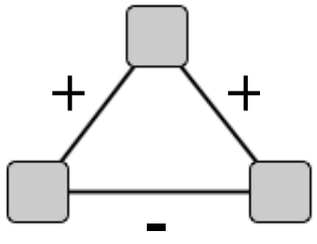
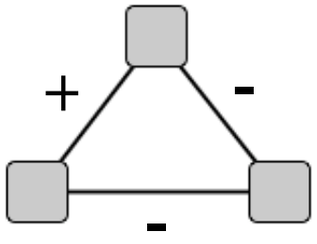
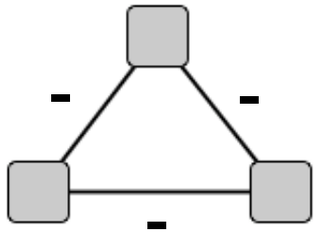
3) Network-network: Social balance

				
Strong formulation of balance	B	U	B	U

What does the data say?

Heider, Journal of Psychology 21, 107-112 (1946)

3) Network-network: Social balance

				
Strong formulation of balance	B	U	B	U
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

Leskovec, Huttenlocher and Kleinberg, ACM WWW Int Conf on World Wide Web (2010)

Summary

- Establish a large-scale socio-economic laboratory
- Structural differences between positive and negative tie networks
- Testing hypotheses: Triadic closure, Social balance
- Statistical physics approach

Collaborators

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Giovanni Petri

Roberta Sinatra

Vito Latora

Stefan Thurner

Institute

www.complex-systems.meduniwien.ac.at

Section for Science of Complex Systems