CS-E5740

Complex Networks

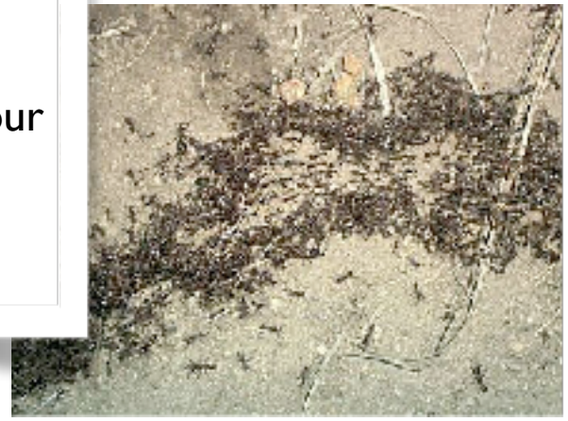
Social networks
Sociodynamic models

Course outline

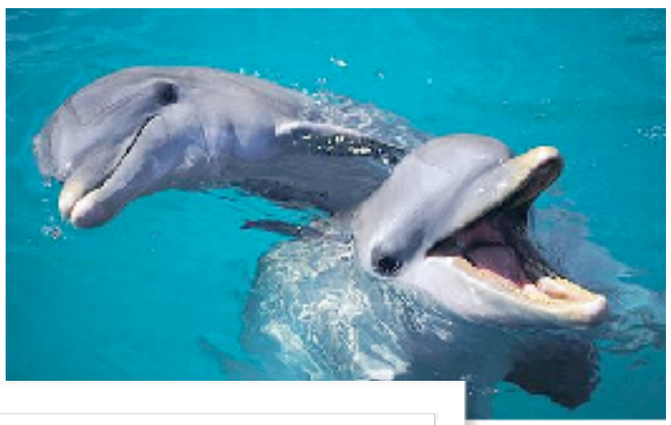
1. Introduction (motivation, definitions, etc.)
2. Static network models: random and small-world networks
3. Growing network models: scale-free networks
4. Percolation, error & attack tolerance of networks, epidemic models
5. Network analysis: key measures and characteristics
6. Social networks & (socio)dynamic models
7. Weighted networks
8. Clustering, sampling, inference
9. Temporal networks & multilayer networks

Many Animals Are Social

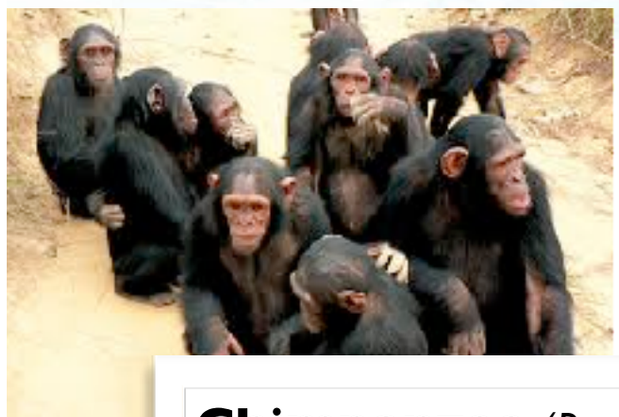
Social insects
•Each insect follows simple behavioural patterns
• No recurrent social ties, no memory
• Emergent colony-level behaviour
• Almost as if the colony is the organism and the insects its cells…



Wolf (*Canis Lupus*)
• A wolfpack has <10 members
• Usually all are family: adult parents & their offspring for the last 2-3 years

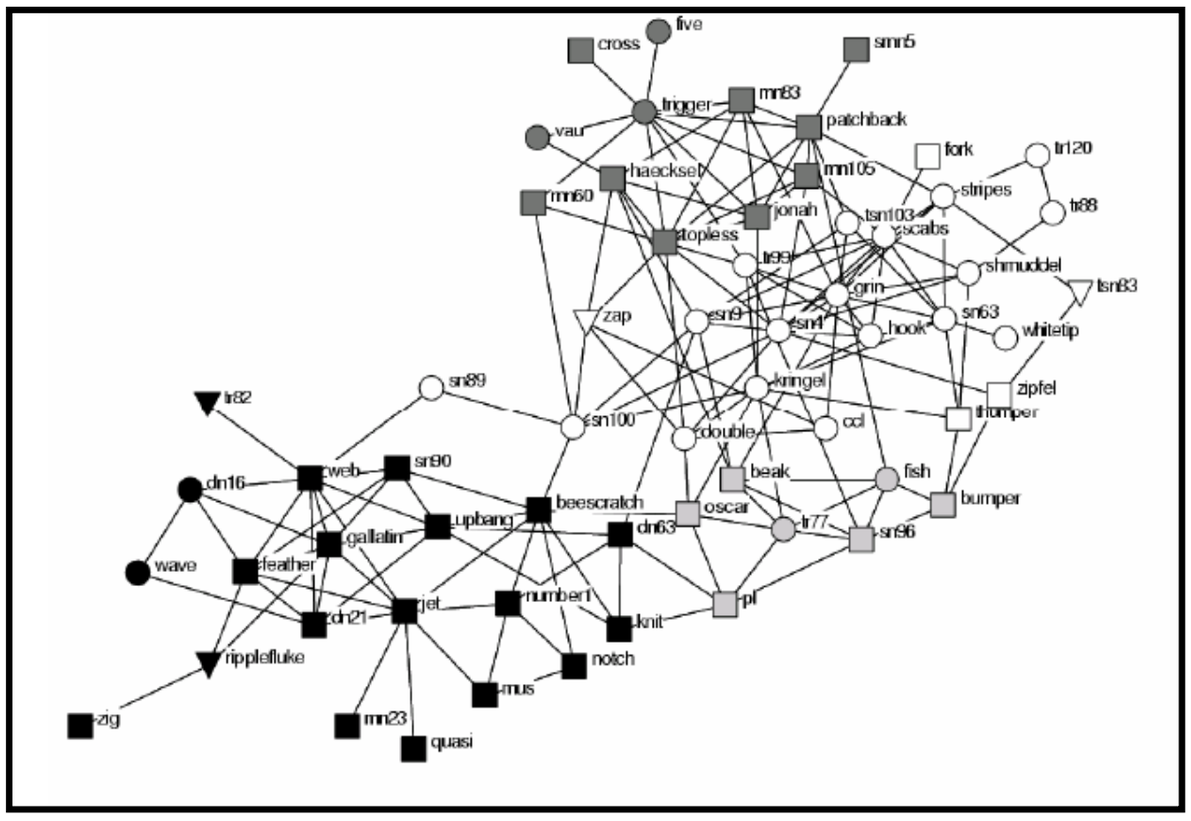


Bottlenose dolphin (*Tursiopsis Truncatus*)
• Groups ("pods") of typically 10-30 individuals but at times up to 1000
• There is social structure: strong and weak ties, subgroups, etc.



Chimpanzee (*Pan Troglodytes*)
• Groups of 30-40 members
• Social ties very important
• Relationship-reinforcing behaviour such as grooming very important
• Strong hierarchy

Example:
A Social Network of Bottlenose Dolphins



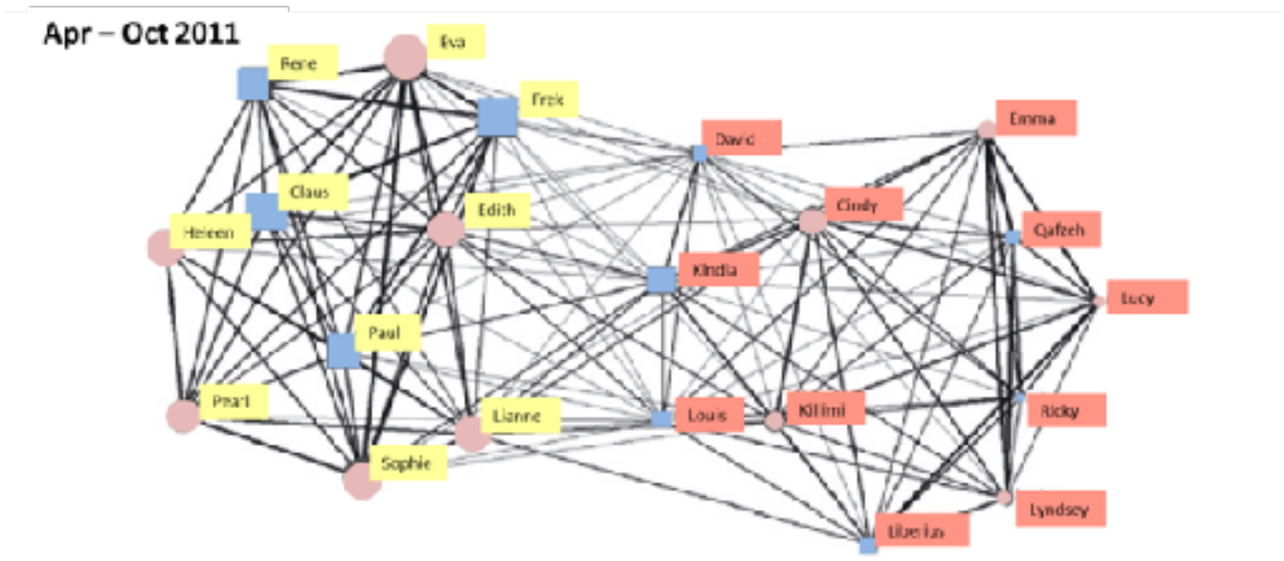
David Lusseau and M. E. J. Newman, *Proc. R. Soc. London B* **271**, S477-S481 (2004).

Network characteristics

- There is so-called "homophily": dolphins of the same age and gender like to form ties
- There are subgroups (see the visualisation on the left)
- Dolphins have different social roles (their standing in the network is different)

Dolphins & chimpanzees: many similarities with humans.

- High level of clustering (lots of triangles)
- Larger groups contain subgroups
- Homophily
- Large investments to relationship maintenance (chimpanzees: grooming)



Chimpanzee social network at Edinburgh zoo

http://www.living-links.org/

Humans differ from animals in that our networks are connected: small social groups are connected each other, forming larger groups, and so on, finally covering the whole planet.

This lecture:
from the micro to the macro level

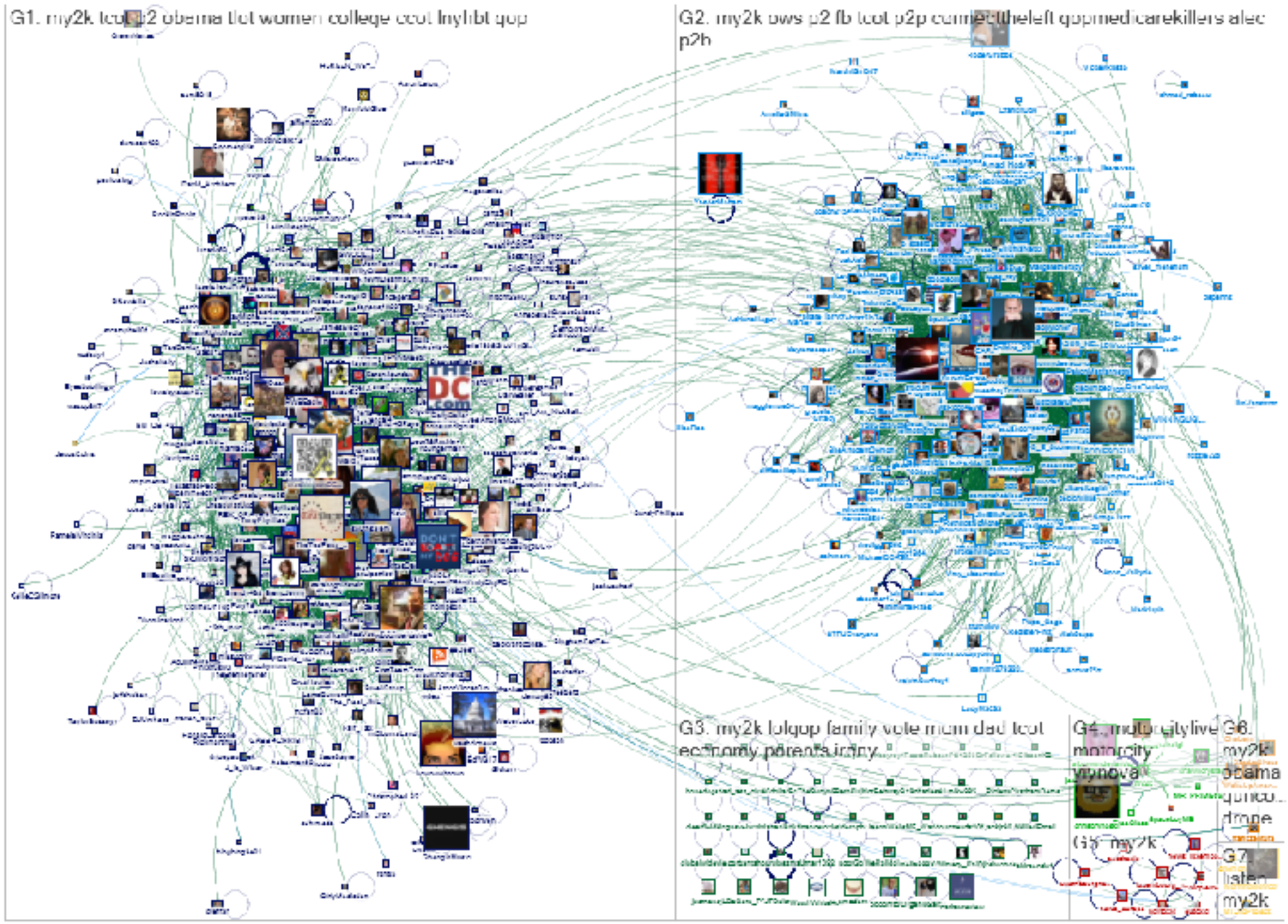
MICRO

MACRO

Homophily: "birds of a feather flock together"

- People tend to form social ties to others like them.
- Because of this, people's personal networks are (all too) homogeneous with regard to many sociodemographic, behavioral, and intrapersonal characteristics.
- This gives rise to "bubbles", information flows constrained between similar kinds of people.

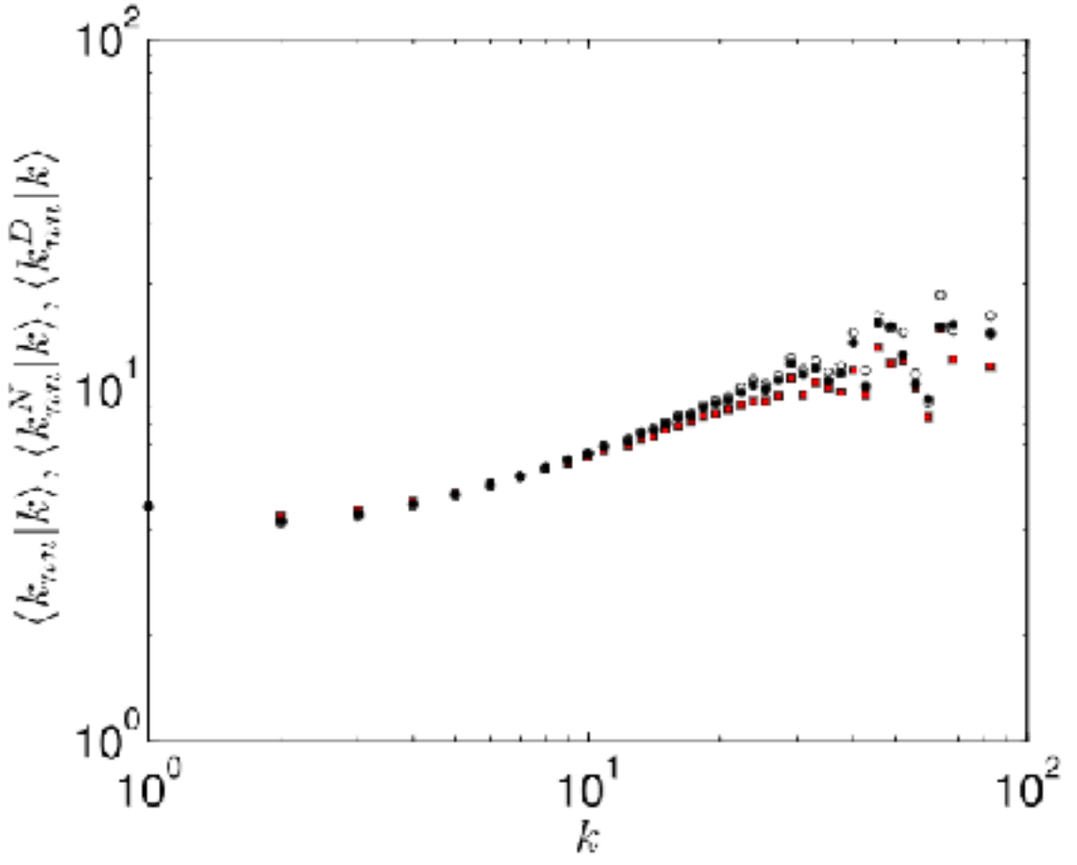
Negative side of homophily: polarized Twitter conversation on US politics… already in 2014.



Homophily: degree correlations

- As discussed earlier, social networks are degree-assortative: high-degree nodes link to other high-degree nodes

- This is one form of homophily.



Social ties → Egocentric networks → Social groups → Links between groups → Societal-level networks

Importance and maintenance cost of social ties

- Strong and supportive social relationships are fundamentally important for health and well-being, in both humans and other primates.

- Maintaining social ties comes at a cost: time and cognitive resources are finite.

- (Most) ties that are not maintained tend to decay.

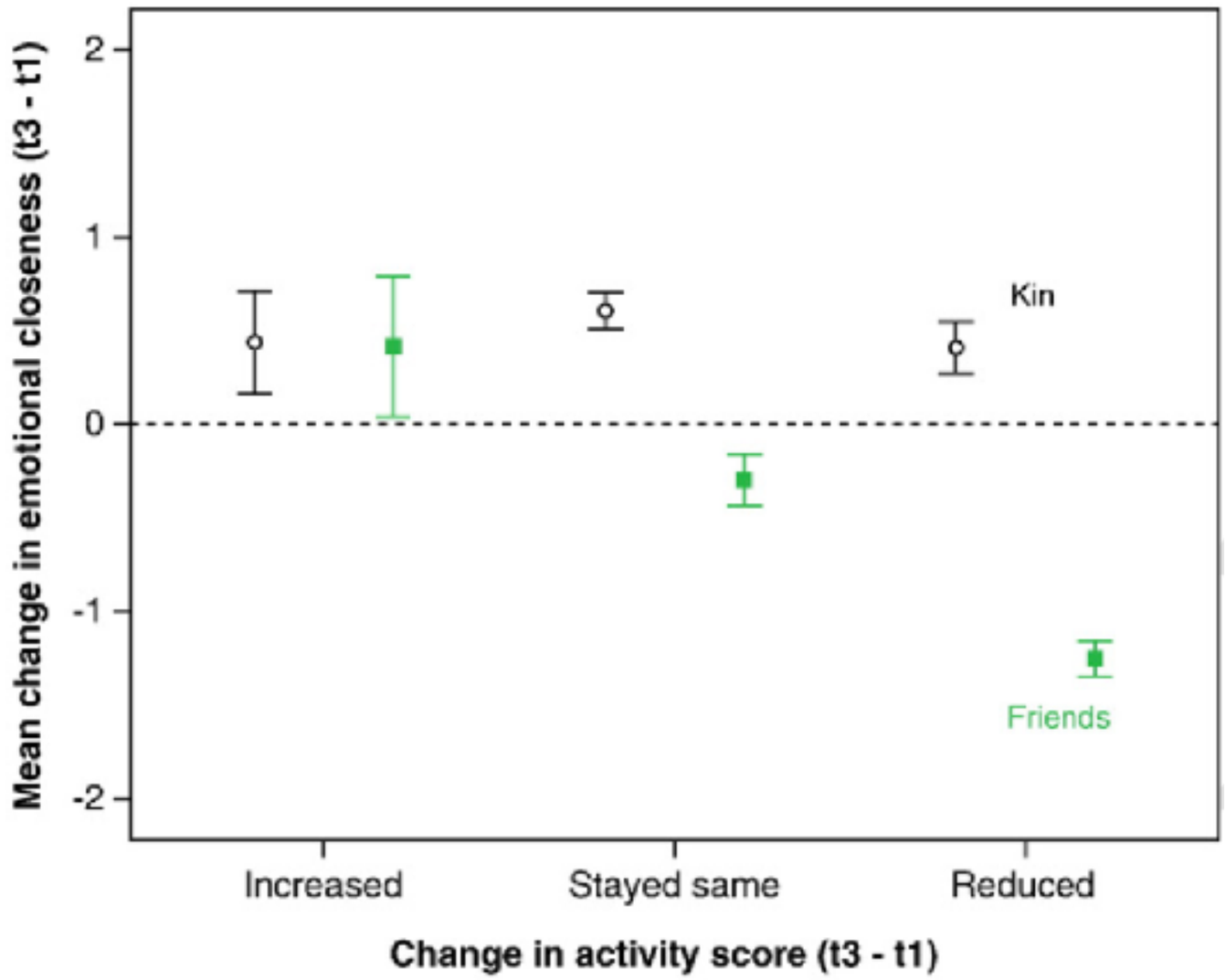
Importance and maintenance cost of social ties: grooming

[https://www.youtube.com/watch?v=ZfSx8BG-Gy4]

We groom too, just in different (and everchanging) ways.

Importance and maintenance cost of social ties: tie decay

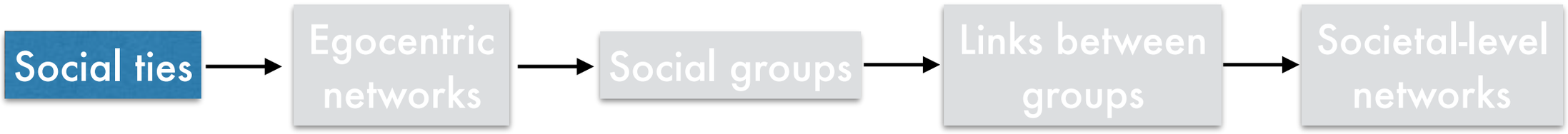
When it comes to tie decay, family is different from friends.



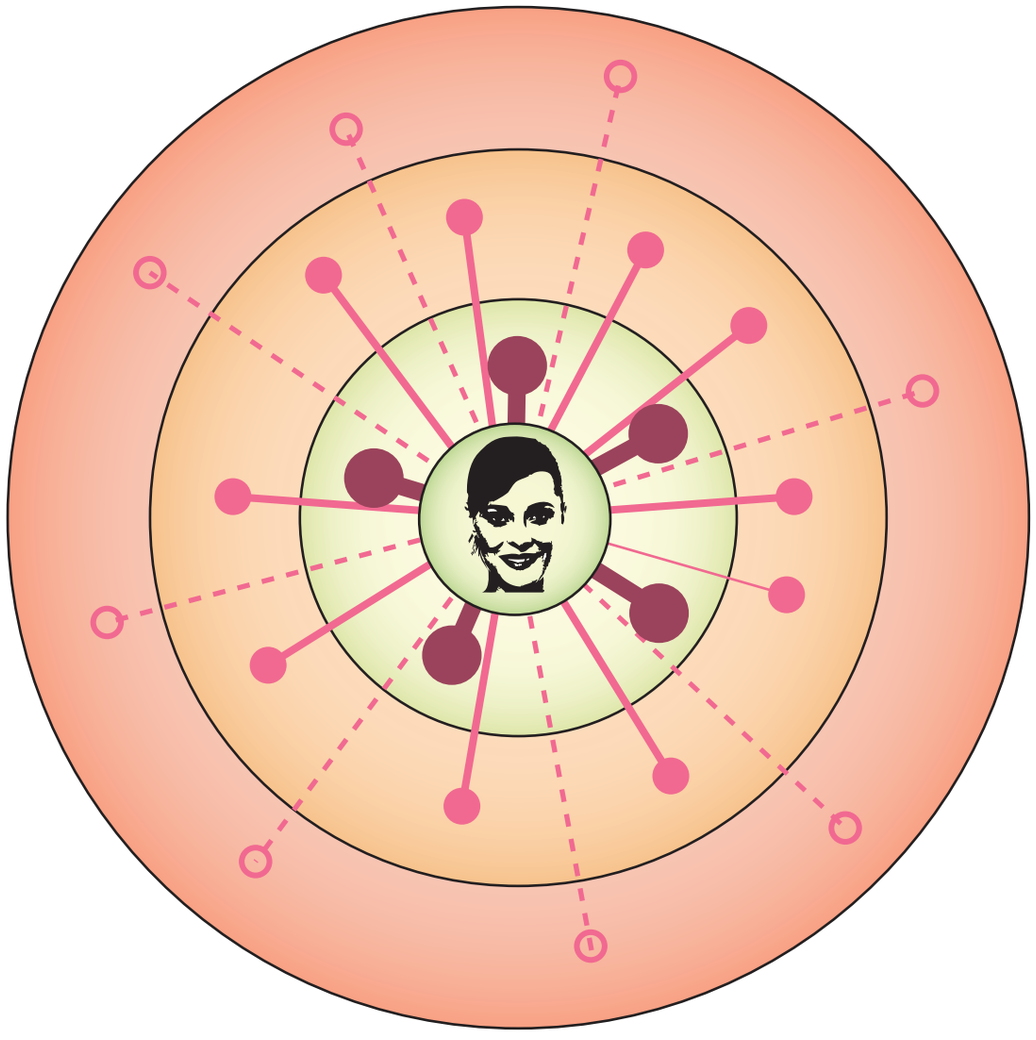
The costs of family and friends: an 18-month longitudinal study of brelationship maintenance and decay, Sam G.B. Roberts, Robin I.M. Dunbar, Evolution and Human Behaviour 2010

Strong and weak ties

- Social ties are different; there are weak and strong ties.
- We'll deal with the maths next week (lecture on weighted networks)
- Strong ties are costly to maintain but provide strong support
- Weak ties cheaper to maintain; they provide diversity and lead outside of one's closest social setting



Egocentric networks

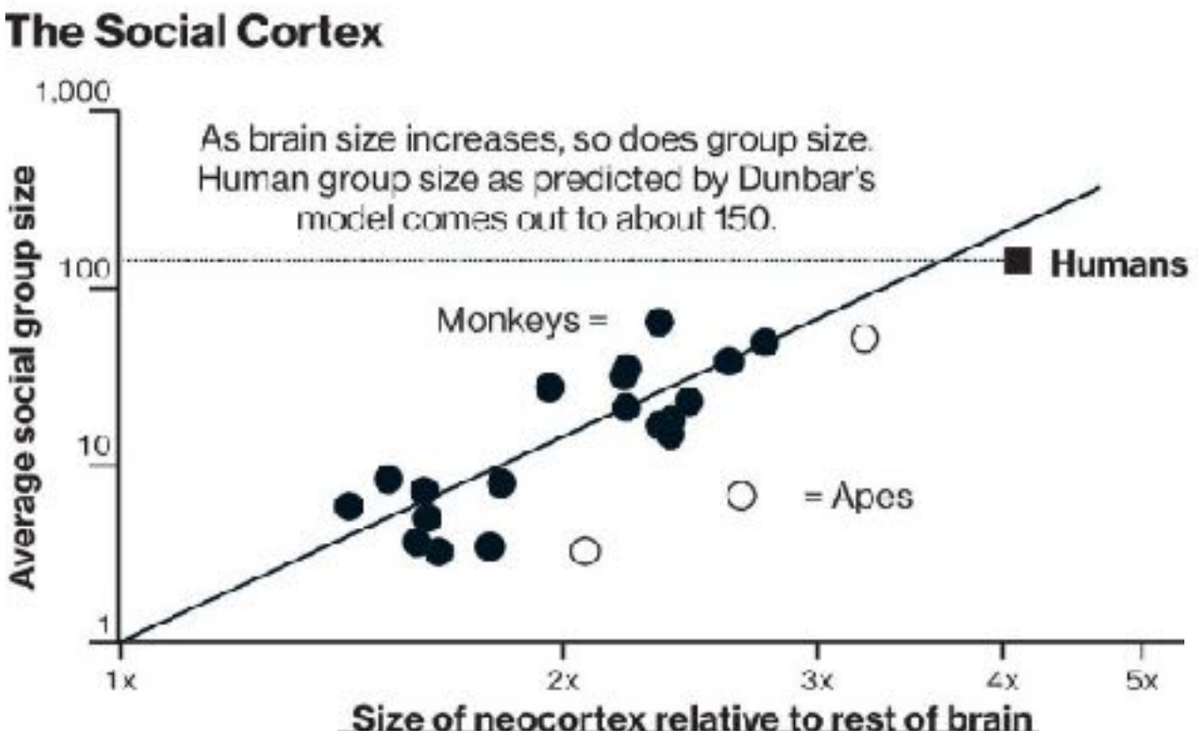


- Egocentric network: one individual ("ego") and her friends/ family/acquaintances ("*alters*")

- Typically, there are a few strong ties and many weaker ties

- This reflects the balance between costs and benefits of weak and strong ties (high/low cost, closeness/diversity)

Egocentric networks & constraints on maintaining social ties



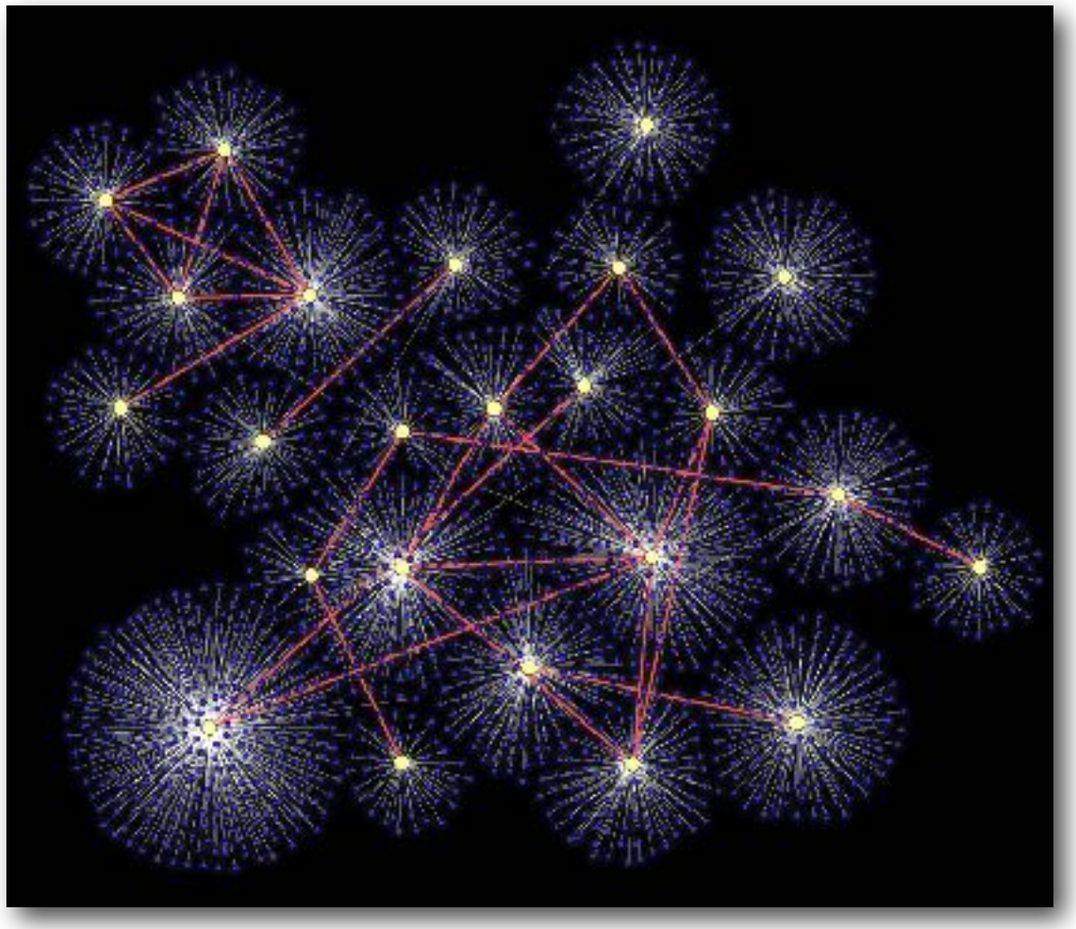
Dunbar, R.I.M. (1992) *Neocortex size as a constraint on group size in primates*, Journal of Human Evolution 22: 469-493

- **Dunbar's Number:** Personal network size is thought to be limited to ~150 alters

- **Motivation**:
  - Extrapolating the social group vs neocortex size from apes to humans
  - Constraints: available *time*; available *brainpower* and *memory*
  - Evolution: social group size of early humans

Experiment on Egocentric Nets: Personal Networks in Flux

- Data on 24 volunteer students for 18 months
- All outgoing calls with timestamps
- Students finished high school & went to university around month 6
- We divided the timeline into three 6-month intervals

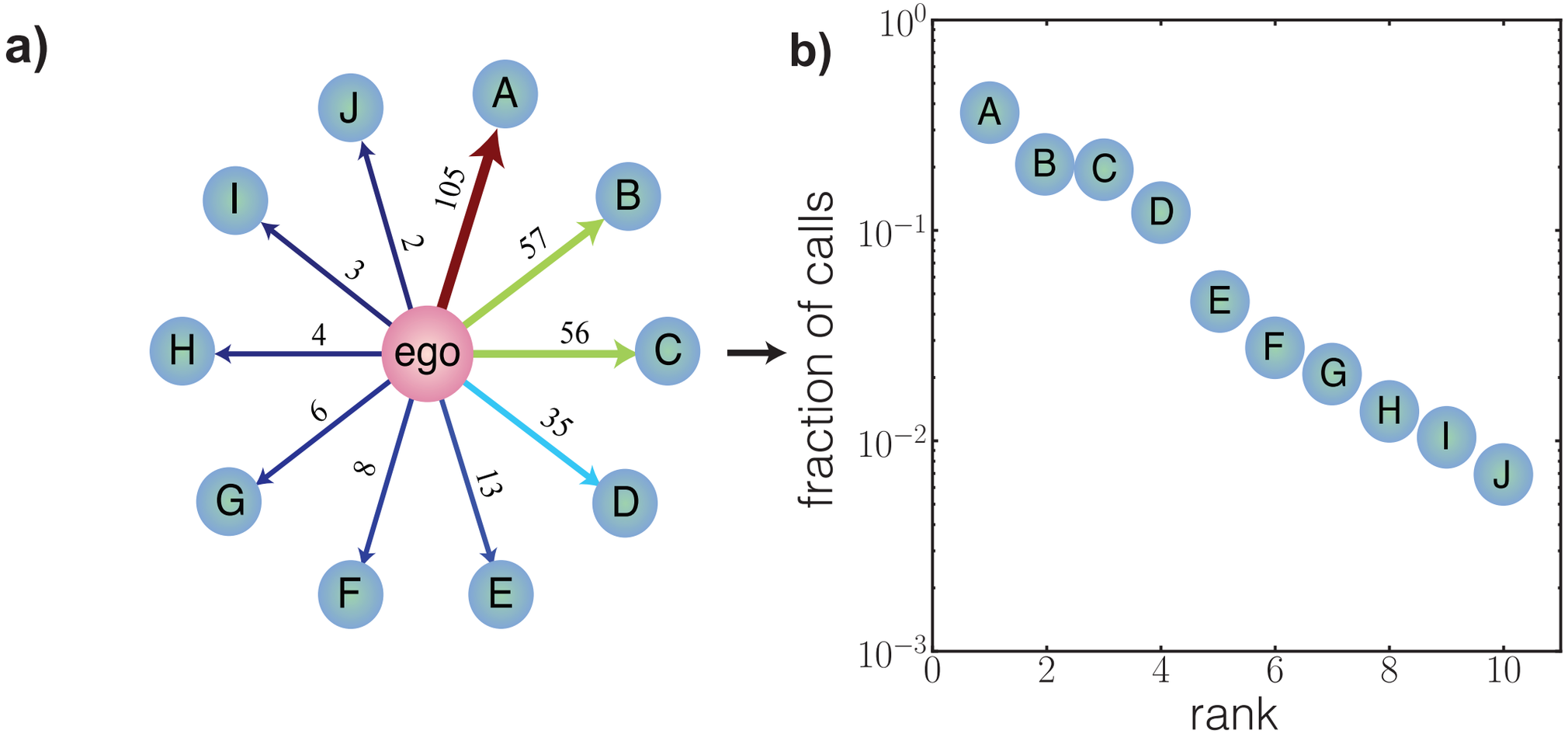


J. Saramäki, E.A. Leicht, E. López, S.G.B. Roberts, F. Reed-Tsochas, R.I.M. Dunbar, PNAS **111**, 2014

Aalto University
School of Science

UNIVERSITY OF OXFORD

"Social signatures" computed from mobile phone calls



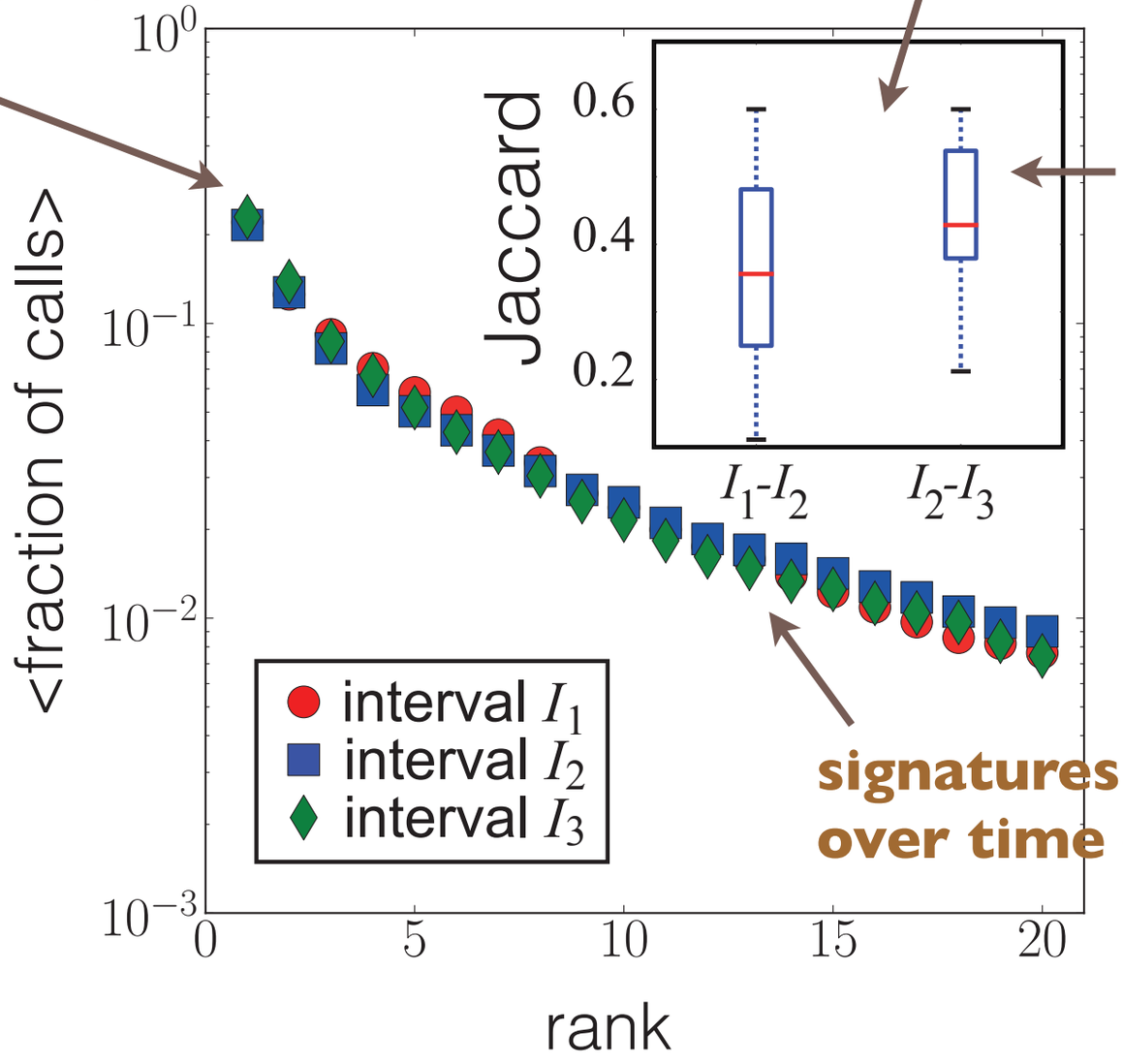
1) count calls to everyone in a 6-month interval

2) rank everyone, see what % of calls goes to #1, what % to #2, etc

Social signatures reflect the balance between weak and strong ties

very large numbers of calls concentrated at top ranks

large network turnover between intervals: old friends replaced by new friends



$$J(I_i, I_{i+1}) = \frac{|A(I_i) \cap A(I_{i+1})|}{|A(I_i) \cup A(I_{i+1})|}$$

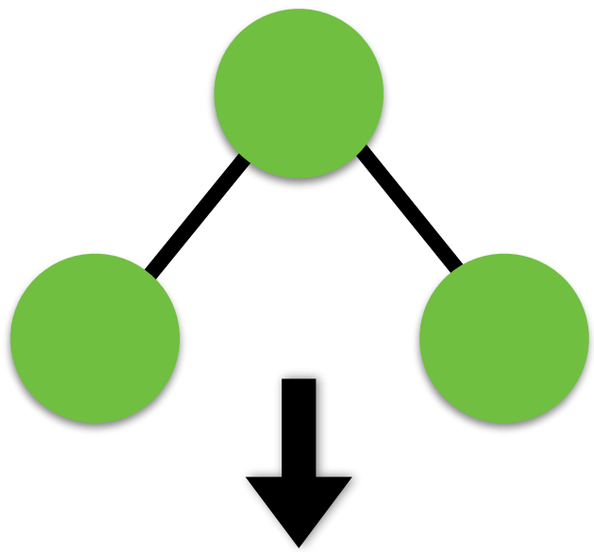
$A(I_i)$=one ego's set of alters in I_i

signatures do not change over time on average

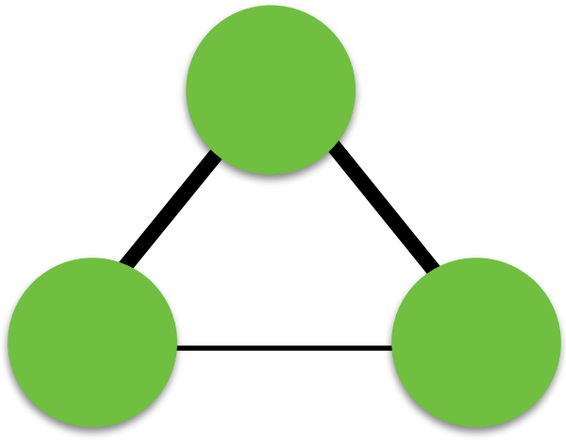
"How we shape our egocentric nets doesn't depend on who are in them."

Clustering Emerges from Triadic Closure

- As most networks, social networks are highly clustered: your friends tend to be friends too.
- Therefore the clustering coefficient is high.
- The mechanism that is thought to be responsible is called *triadic closure*



- You meet new friends through your old friends and triangles form.
- You meet new friends through common hobbies/interests/etc, and triangles form.

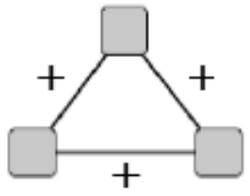
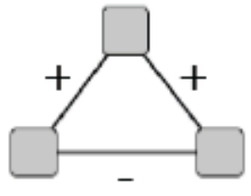
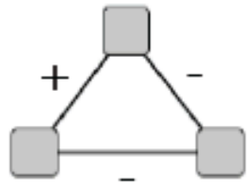
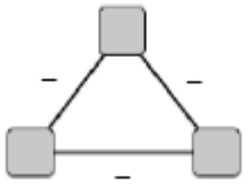


Social ties → Egocentric networks → Social groups → Links between groups → Societal-level networks

The theory of structural balance

- Include **signs** to interactions or relationships (positive/ negative, friend/enemy,…)

- What types of triangles are allowed?

				
Strong formulation of balance	B	U	B	U
Weak formulation of balance	B	U	B	B

- Strong formulation: product of signs must be positive

- e.g. "My enemy's enemy is my friend"

- Weak formulation: - - - is OK

Cartwright D, Harary F (1956) Structure balance: A generalization of Heider's theory. *Psych Rev* 63:277-93.

Davis JA (1967) Clustering and structural balance in graphs. *Human Relations* 20:181-187.

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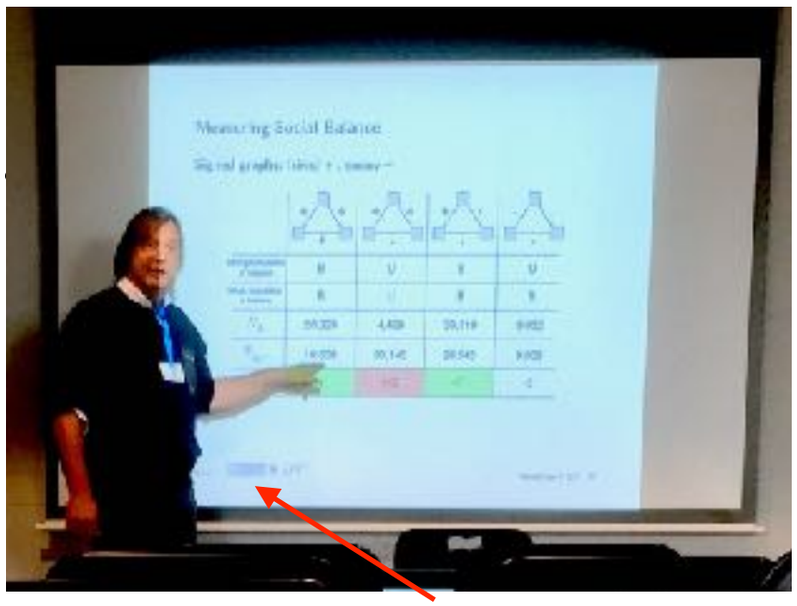
The theory of structural balance

Observation from an online game with millions of players: the weak formulation holds



M. Szell, R. Lambiotte, S.Thurner, PNAS 107, 13636

	+ + +	+ + −	+ − −	− − −
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_Δ^{rand}	10,608	30,145	28,545	9,009
z	71	-112	47	-5

Fig. 4. Different types of signed triads, balanced (B) or unbalanced (U) according to the strong or weak formulation of structural balance. In the table, we give the number of each type of triad in the friendship-enmity network, the expected number of such triads when averaged over 1000 sign-randomizations and the corresponding z-score (see [SI]). Triads $+++$ and $+--$ are over-represented, $++-$ triads are underrepresented with extraordinary significance.

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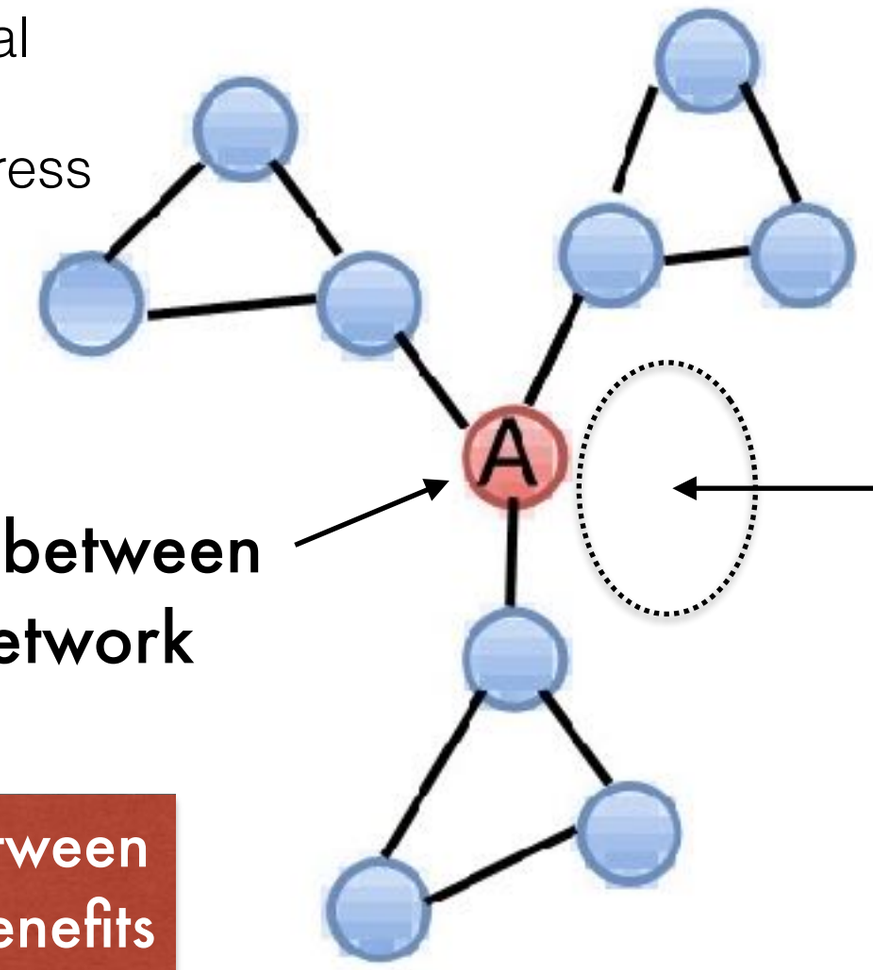
Structural Holes & Bridges

Burt, Ronald S. (1995). Structural Holes: The Social Structure of Competition. Harvard University Press



A is a "bridge" between parts of the network

There is a "structural hole" here because of missing connections

A can act as "broker" between parts of the network; A benefits from nonredundant information

By Backstrnt - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=40744979

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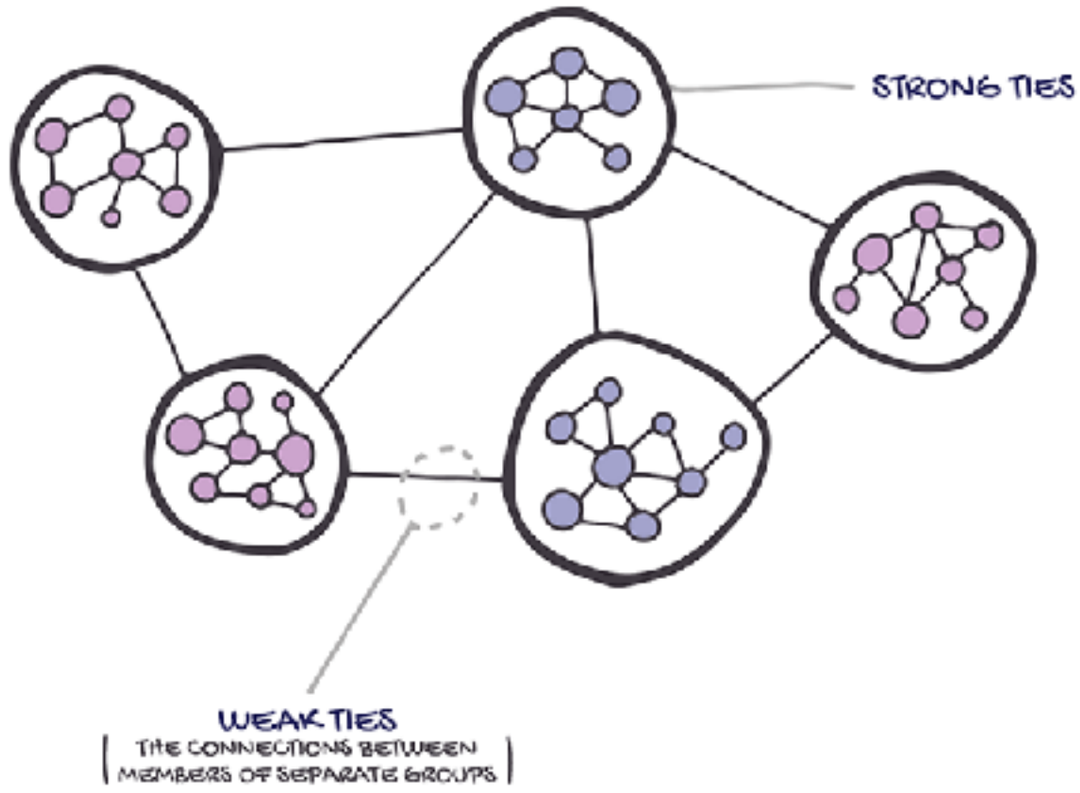
Weak/Strong Ties: Granovetter's Hypothesis

- **Hypothesis**:
  "The overlap between the circles of friendship of two persons depends directly on the strength of their tie"

- **Strong links are inside social groups** (overlap = triangles!)

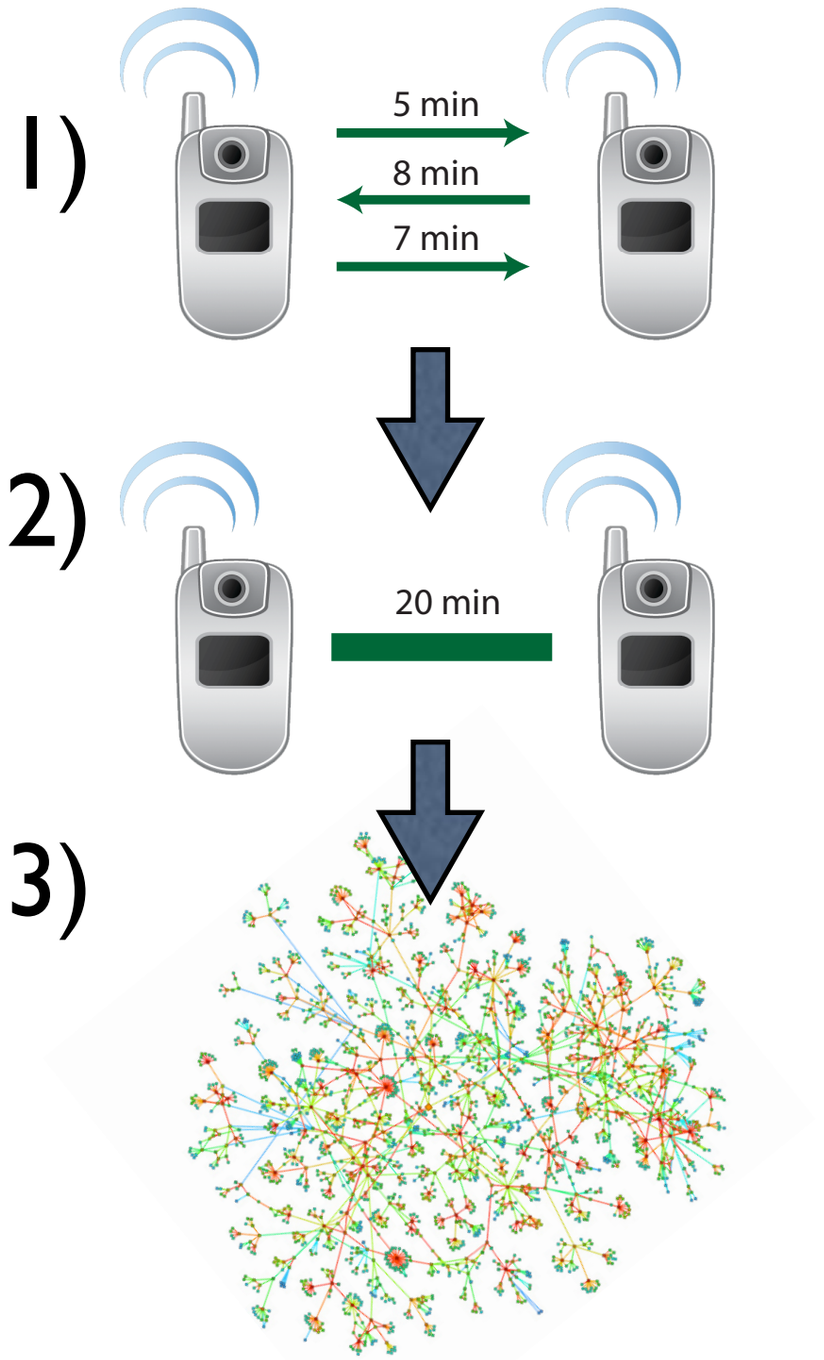
- **Weak links connect social groups** (like Burt's bridges).



[figure from: http://blog.headresourcing.com/networking-and-the-strength-of-weak-ties/]

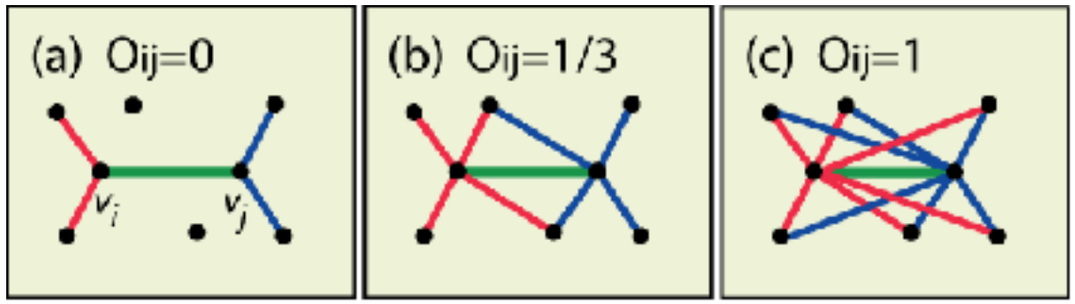
The Granovetter hypothesis in mobile communication networks

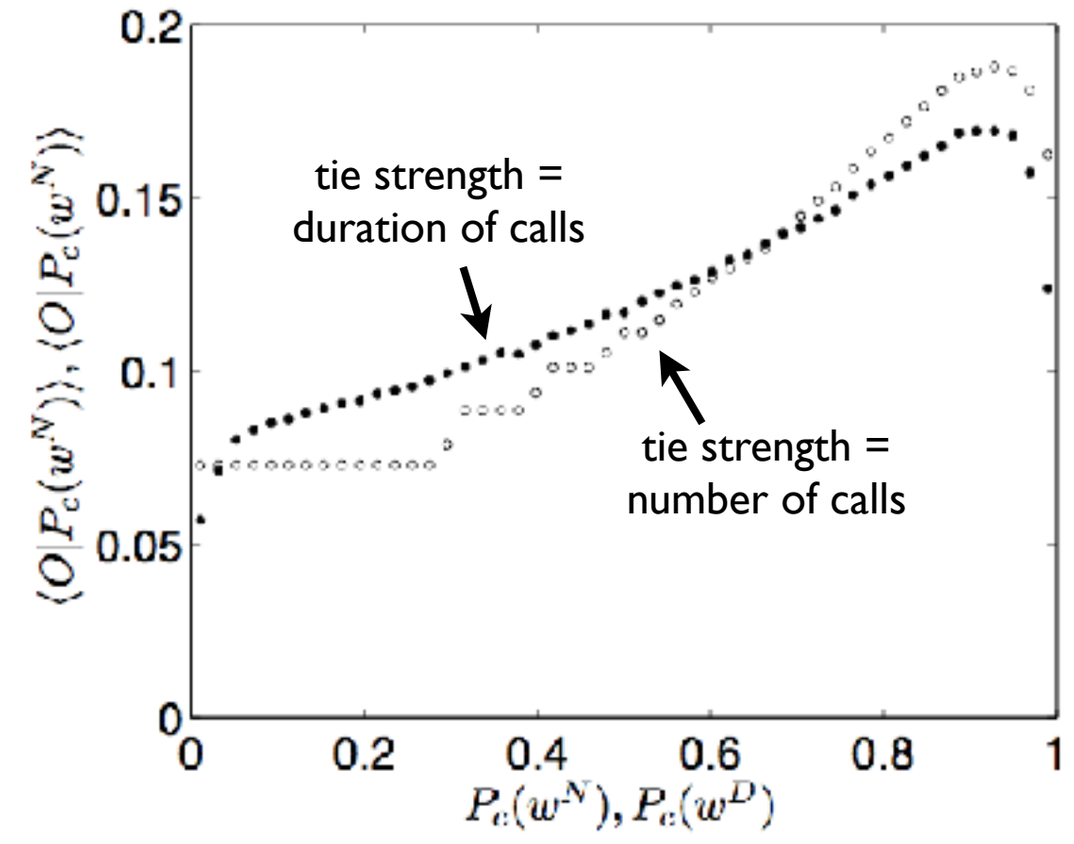
- Source data: call records of an European mobile operator
- ~7 million subscribers
- Data for 18 weeks
- Network construction: link persons (nodes) if they have called each other
- The strength of the link: total call minutes between A and B



Onnela, Saramäki, *et al.*,
Proc. Natl. Acad. Sci. (USA) **104**, 7332 (2007),
New Journal of Physics **9**, 179 (2007)

Verifying the Granovetter hypothesis





- Use the overlap O_{ij}

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

- Calculate average overlap as function of link weight
- There is an increasing tendency: Granovetter's hypothesis holds

Onnela, Saramäki, *et al.*,
Proc. Natl. Acad. Sci. (USA) **104**, 7332 (2007),
New Journal of Physics **9**, 179 (2007)

Social ties → Egocentric networks → Social groups → Links between groups → Societal-level networks

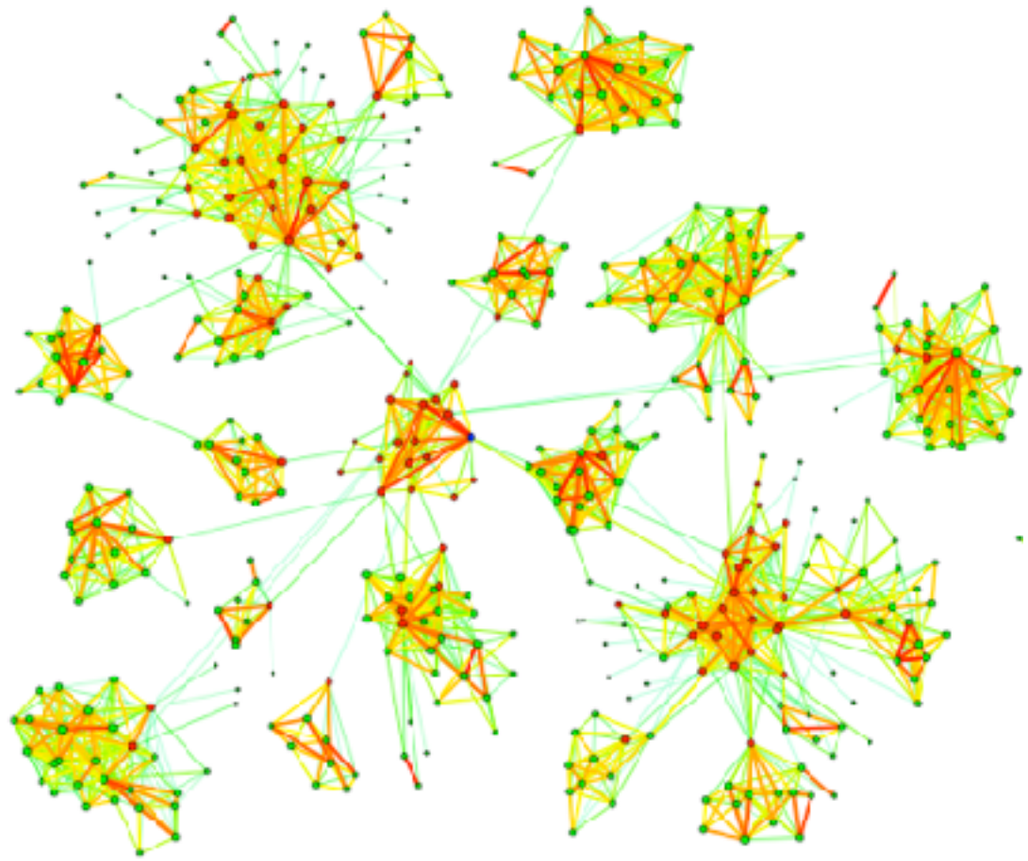
Burt, Granovetter, and Large-Scale Network Structure

- **Strong links** are "local", embedded in tightly clustered network neighbourhoods

- **Weak links** lead to "faraway places" in the network; they are bridges

- Therefore, weak links must be important for information flows and connectivity

- We'll explore this next week!



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Degree Distributions: No Broad Power Laws

- The degree distributions of social networks cannot be very broad power laws

- This is because no-one can have tens of thousands of friends!

- Rather, depending on network, exponential or very steep power-law-like distributions (exponent>3)

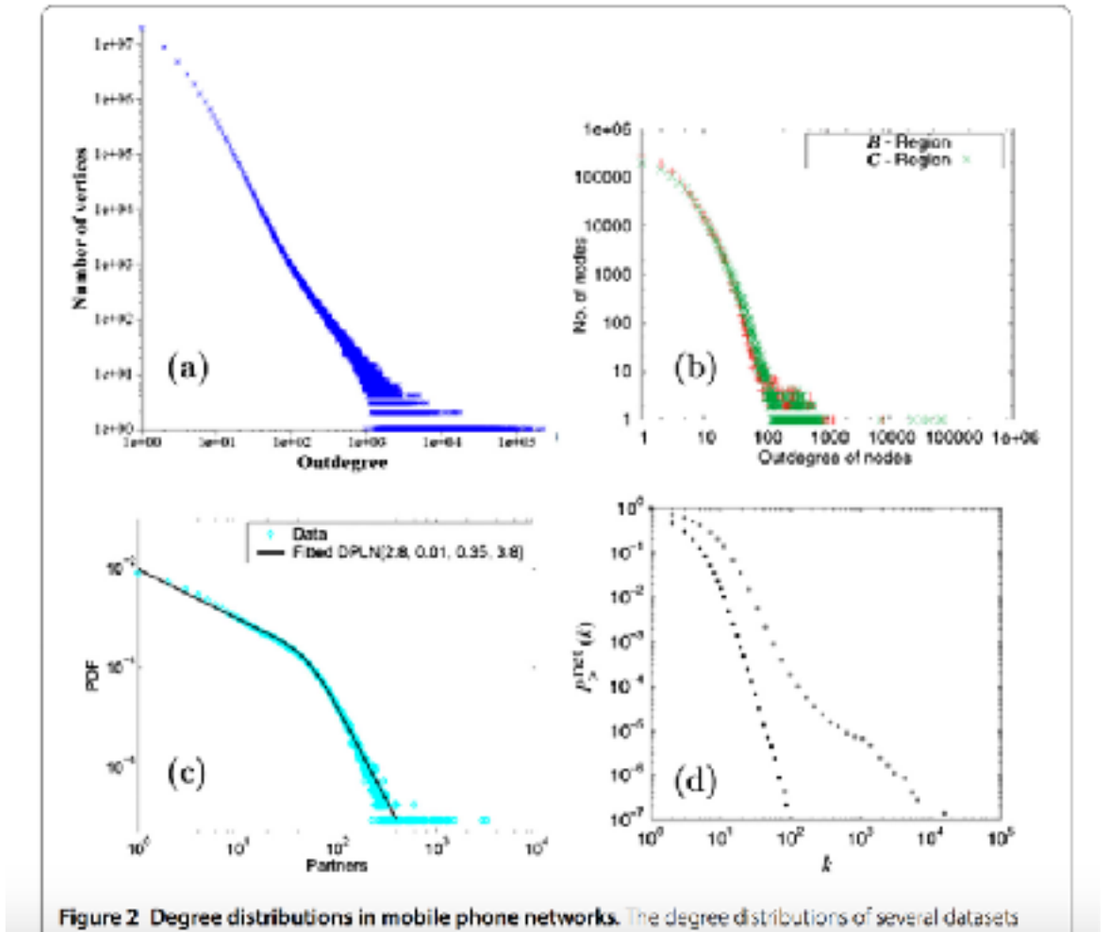

Figure 2 Degree distributions in mobile phone networks. The degree distributions of several datasets

From: A survey of results on mobile phone datasets analysis
VD Blondel, A Decuyper, G Krings
EPJ Data Science 4 (10)

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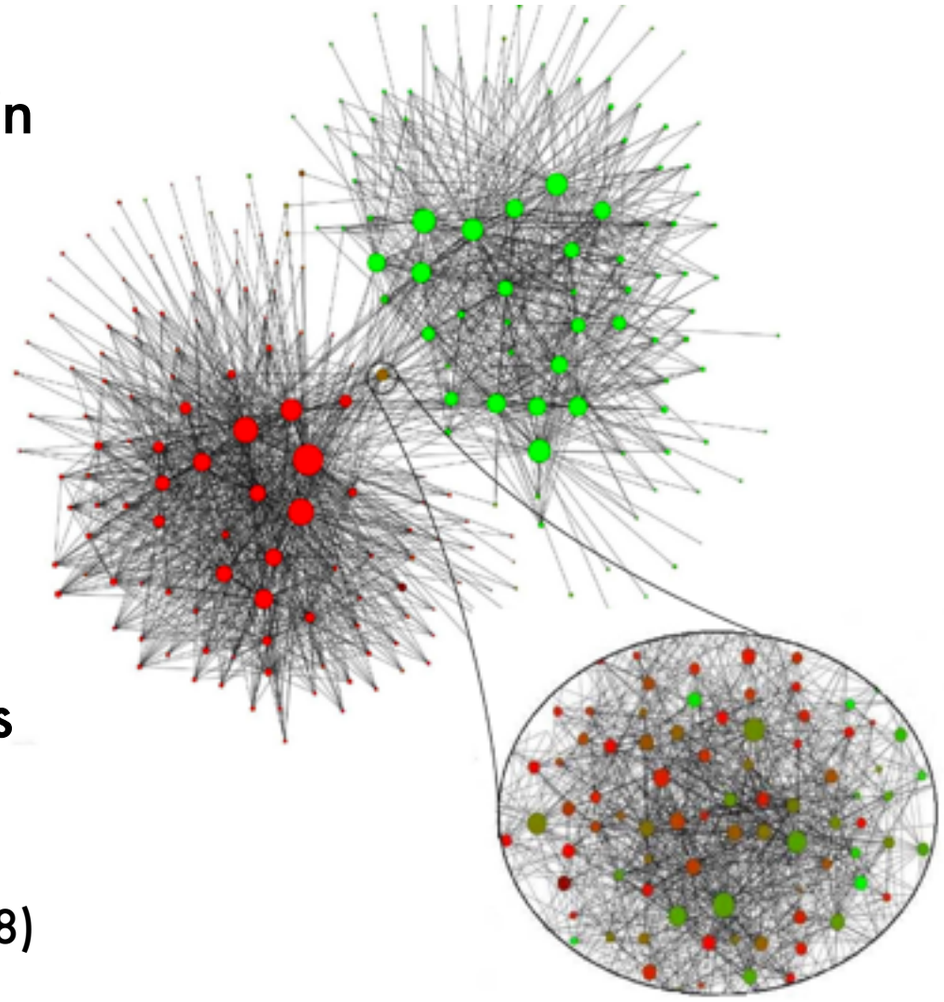
Societal-level Networks Are Geographically And Culturally Embedded

- Example: Mobile-phone calls in Belgium
- Network coarse-grained to groups ("communities") and their links
- The division between French and Dutch speaking Belgium is clearly visible
- From Blondel et al, J. Stat. Mech. (2008)



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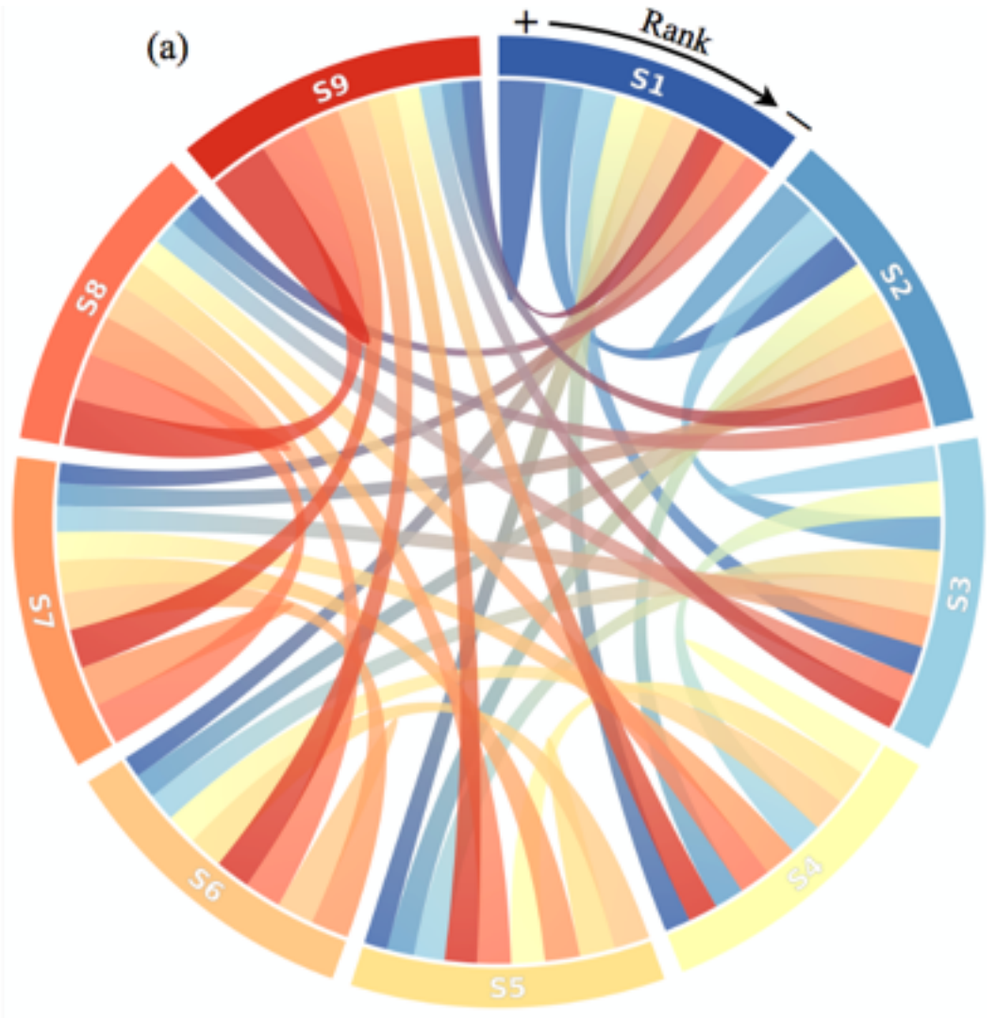
Societal-level Networks Display Social Stratification

- Most links within one's own social class or to neighboring classes
- This also reflects homophily
- Figure on the right from Yannick Leo et al, J. Royal Society Interface 13, 2016
- Based on mobile telephone call data from Mexico



Models of Social Networks

Models of network evolution

- Typical ingredients:
  - triadic closure,
  - random link creation

- Extra ingredients:
  - tie reinforcement and decay,
  - geography,
  - homophily/attraction
  - …

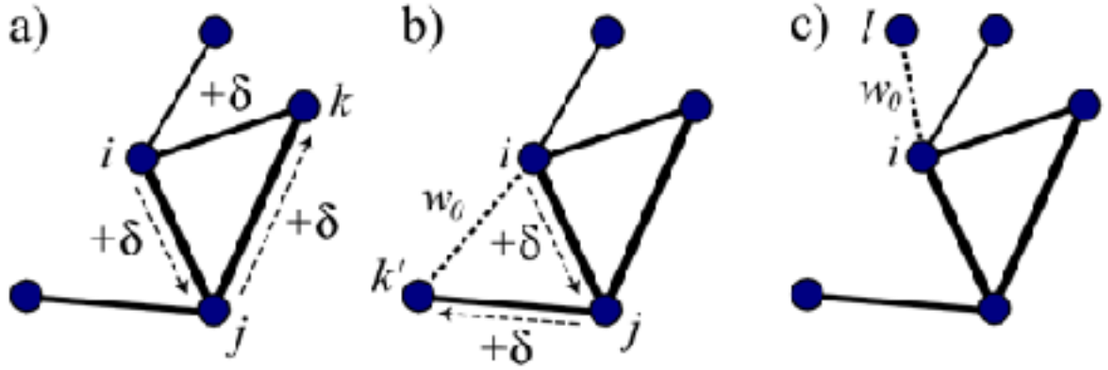
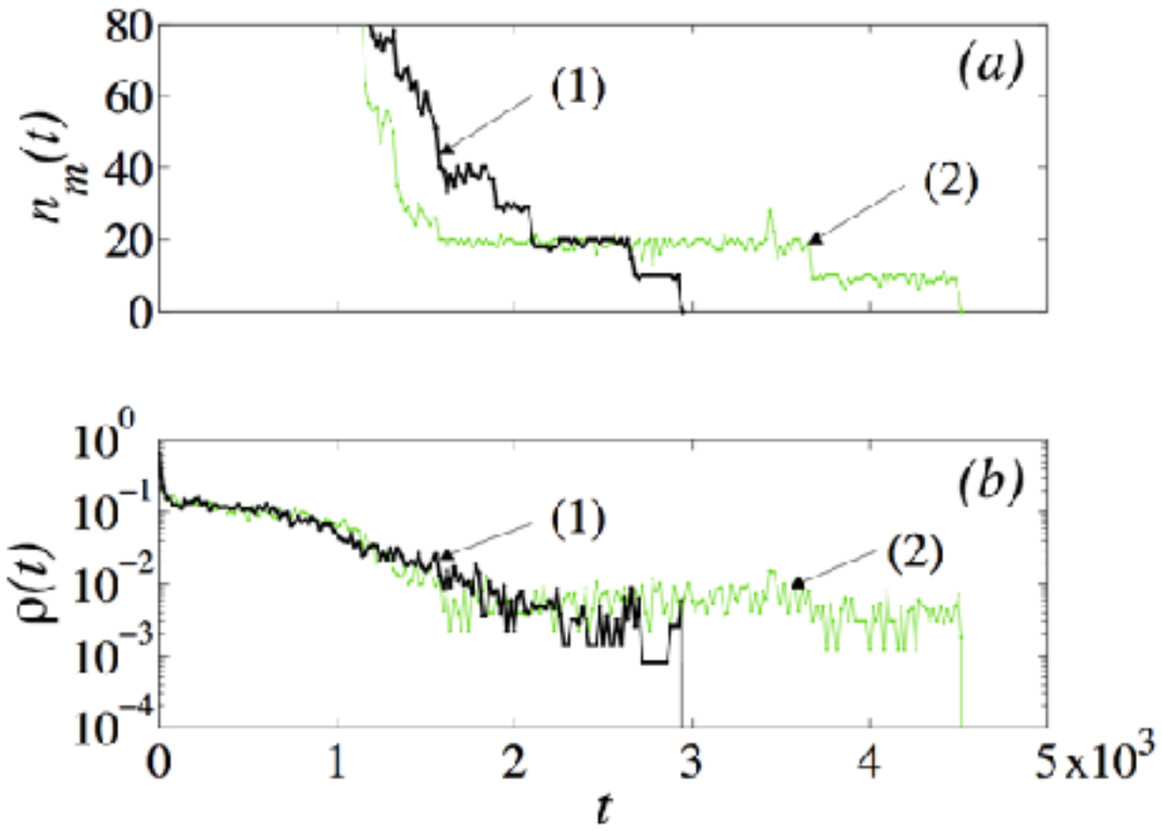


FIG. 1 (color online). The model algorithm. (a) A weighted local search starts from i and proceeds first to j and then to k, which is a neighbor of i. (b) The local search from i ends to k', which is not a neighbor of i. In this case link $w_{ik'}$ is established with probability p_Δ. (c) Node i creates a random link to random node l with probability p_r. In cases (a) and (b) the weights of involved links are increased by δ.

From Kumpula et al, Phys Rev Lett 99 (2007)

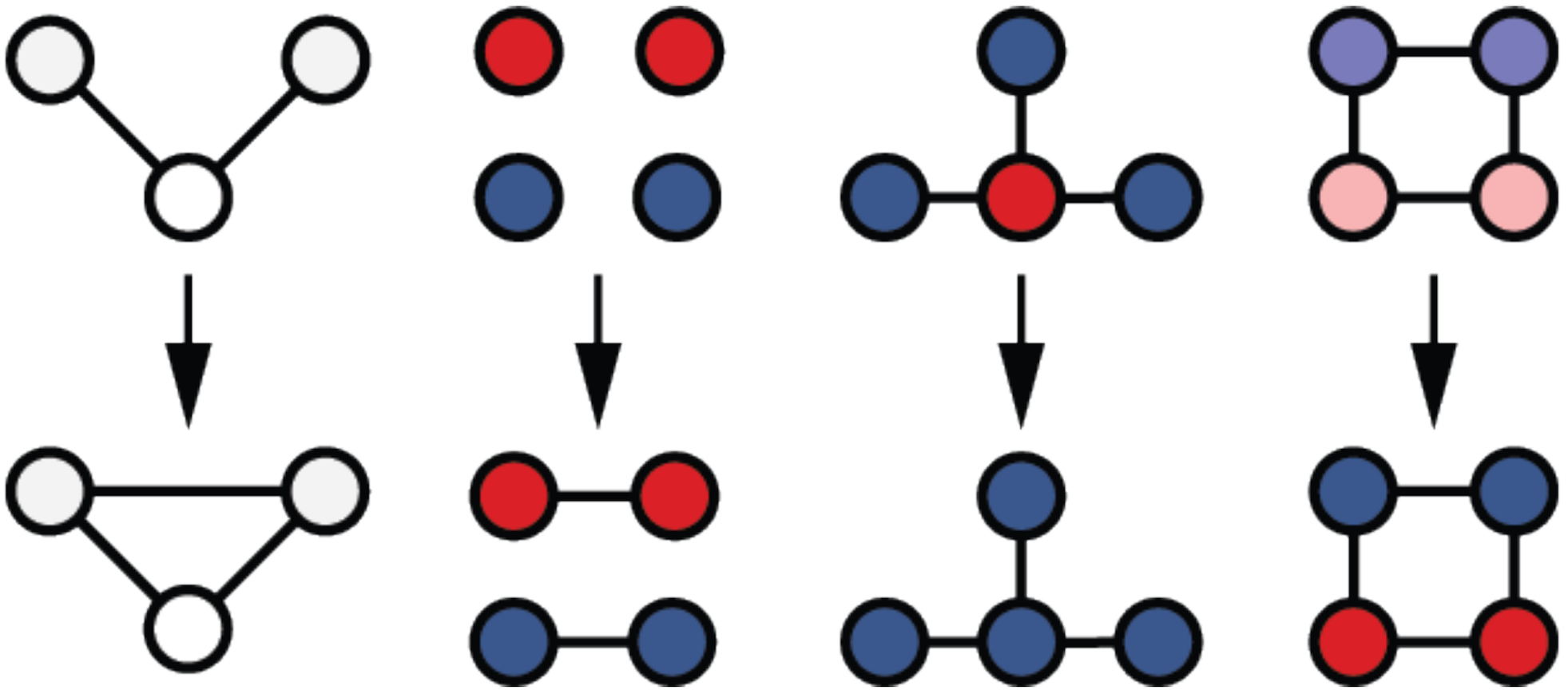
Models of social dynamics

- For simulating social processes that take place on networks
- Targets:
  - Understand possible outcomes
  - Understand how network structure affects outcome
  - Intervention strategies / seeding strategies
  - Understand which nodes are most important for the dynamics



From Toivonen et al, Phys Rev E 79 (2009)

Social network mechanism creating groups



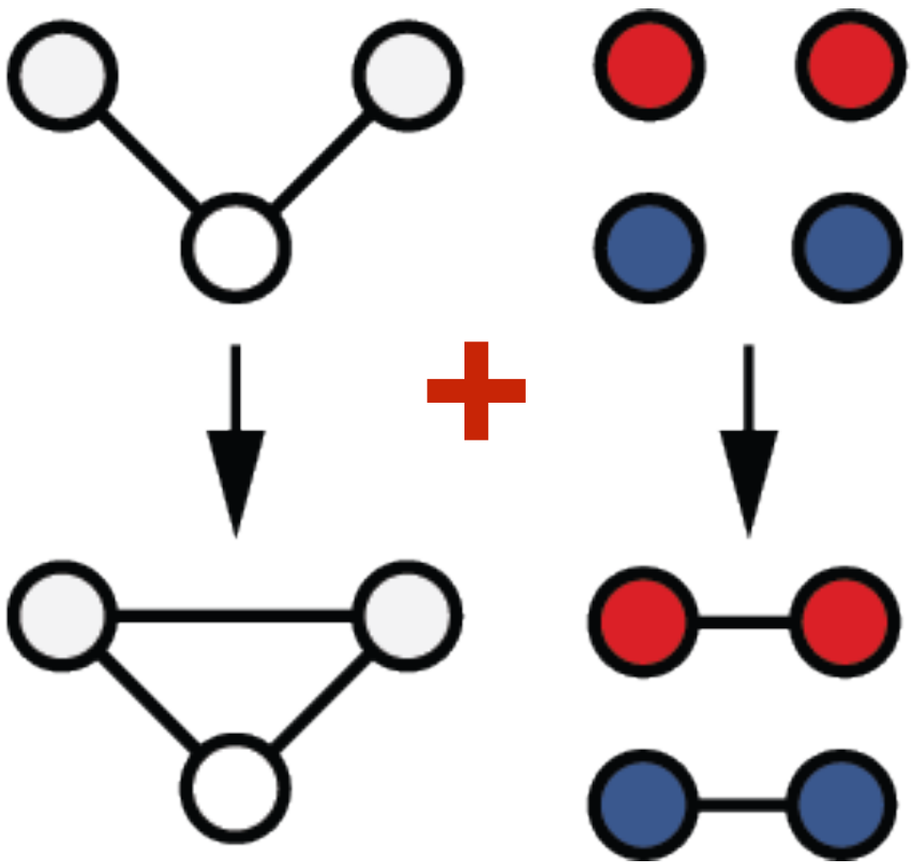
Triadic closure

Homophily

Influence

Biased assimilation

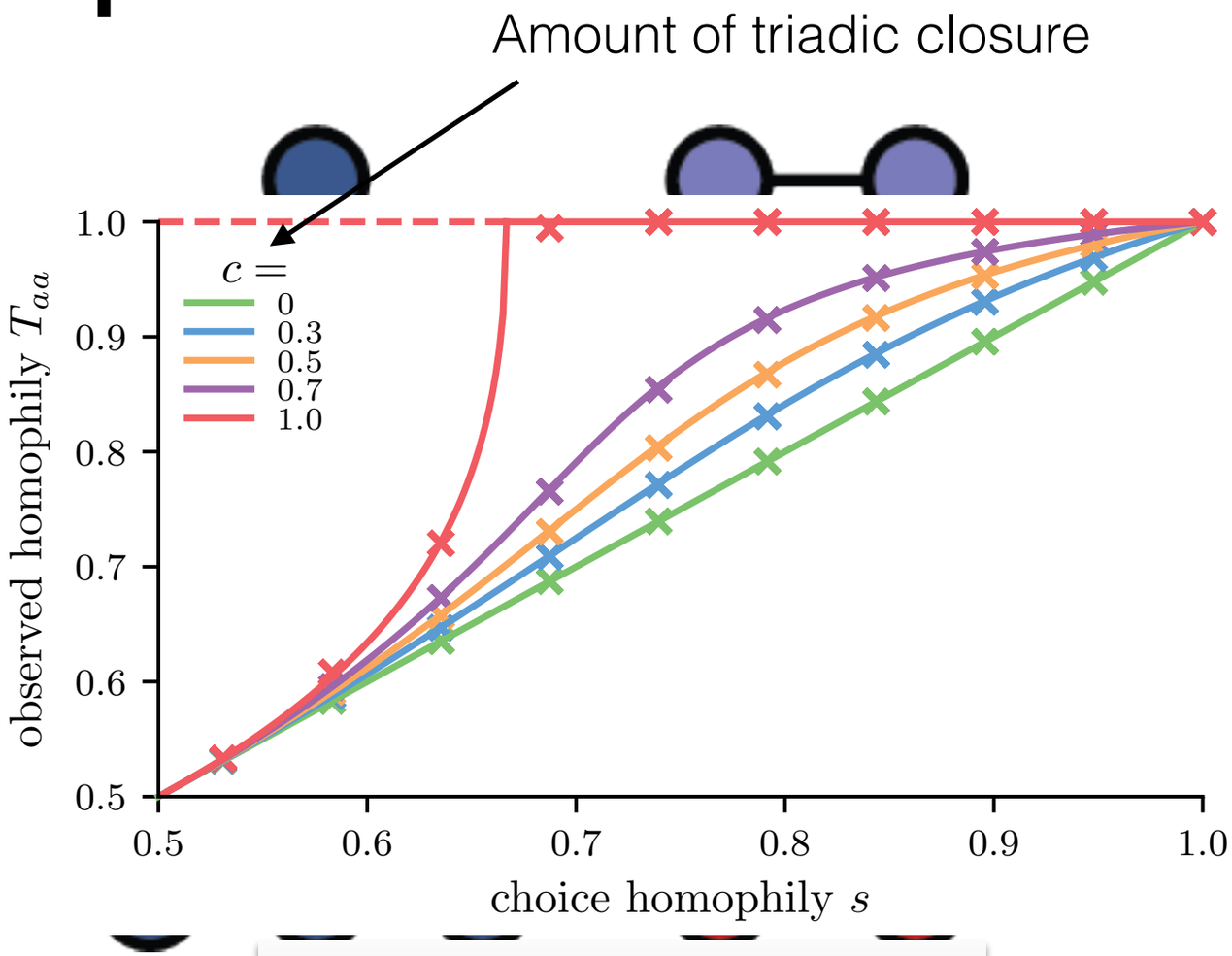
Social network mechanism creating groups



Triadic closure

Homophily

Infl…on



Asikainen et al "Cumulative effects of triadic closure in social networks" (2018)

The effects are cumulative

Models of social dynamics

- **SI** (susceptible-infectious)
  - models the spreading of information/rumours
- **SIR** (susceptible-infectious-recovered)
  - infected individuals cease spreading the rumour after some time period
- **Threshold model:**
  - like SI, but an individual needs to get the information from multiple sources before becoming infectious with it
- **the Voter model**
  - initially each node has a random opinion (+/-, up/down)
  - per each time step, individuals adopt the opinion of a random neighbour
  - this is continued, until consensus has been reached

see Castellano, Fortunato, Loreto: *Statistical Physics of Social Dynamics*, Rev. Mod. Phys. 81, 591–646 (2009)