Structure and tie strengths in a mobile communication network

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Analysis of a large-scale weighted network of one-to-one human communication

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Overview

1. Social networks
2. Constructing the network
3. Network characterisation
4. Percolation
5. Diffusion processes on networks
6. Conclusion

Social networks

- Social network paradigm in the social sciences: Social life consists of the flow and exchange of norms, values, ideas, and other social and cultural resources channelled through the social network

- Traditional approach:
    - Data from questionnaires; $N \approx 10^2$
    - Scope of social interactions wide
    - Strength based on recollection

- New approach:
    - Electronic records of interactions; $N \approx 10^6$
    - Scope of social interactions narrower
    - Strength based on measurement

COMPLEMENTARY APPROACHES

- Constructed network is a proxy for the underlying social network

More Sociology: The Weak Ties Hypothesis

- M. Granovetter, Am. J. Sociol. 78, 1360-1380, 1973.
- "The strength of a tie is a (probably linear) combination of the amount of time,the emotional intensity, the intimacy(mutual confiding), and the reciprocal services which characterize the tie."
- Formulates the weak ties hypothesis:
  The relative overlap of two individual's friendship networks varies directly with the strength of their tie to one another.
- The cohesive power of weak ties: important in e.g. obtaining new information

Our Research Questions

- How are large empirical, one-to-one social networks organised?
- Can we verify some ideas from network sociology?
- Especially: what is the role of tie strength

i) locally, within small network neighbourhoods,

ii) globally, in relation to the whole network

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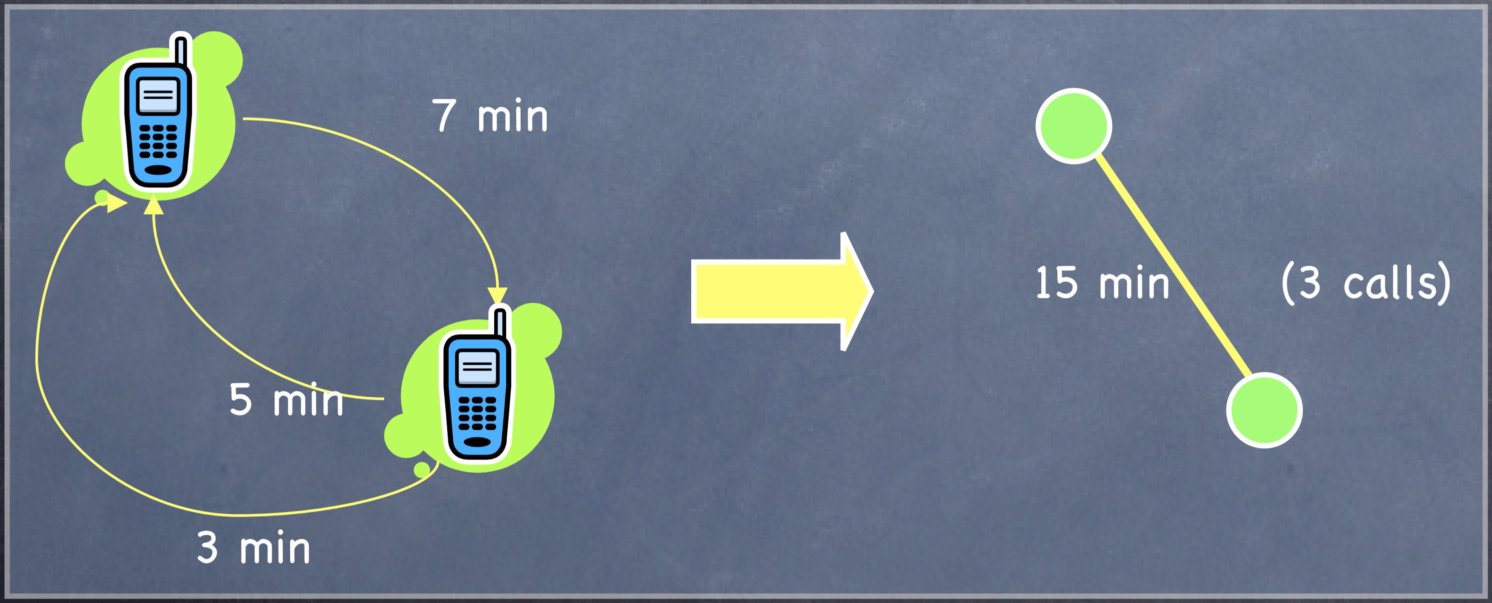
Constructing the network

- Data
  - One operator in a European country, 20% coverage
  - Aggregated from a period of 18 weeks
  - Over 7 million private mobile phone subscriptions
  - Voice calls within the operator
- Require reciprocity of calls for a link
- Quantify tie strength (link weight)



Aggregate call duration w_{ij}^{D}

Total number of calls w_{ij}^{N}

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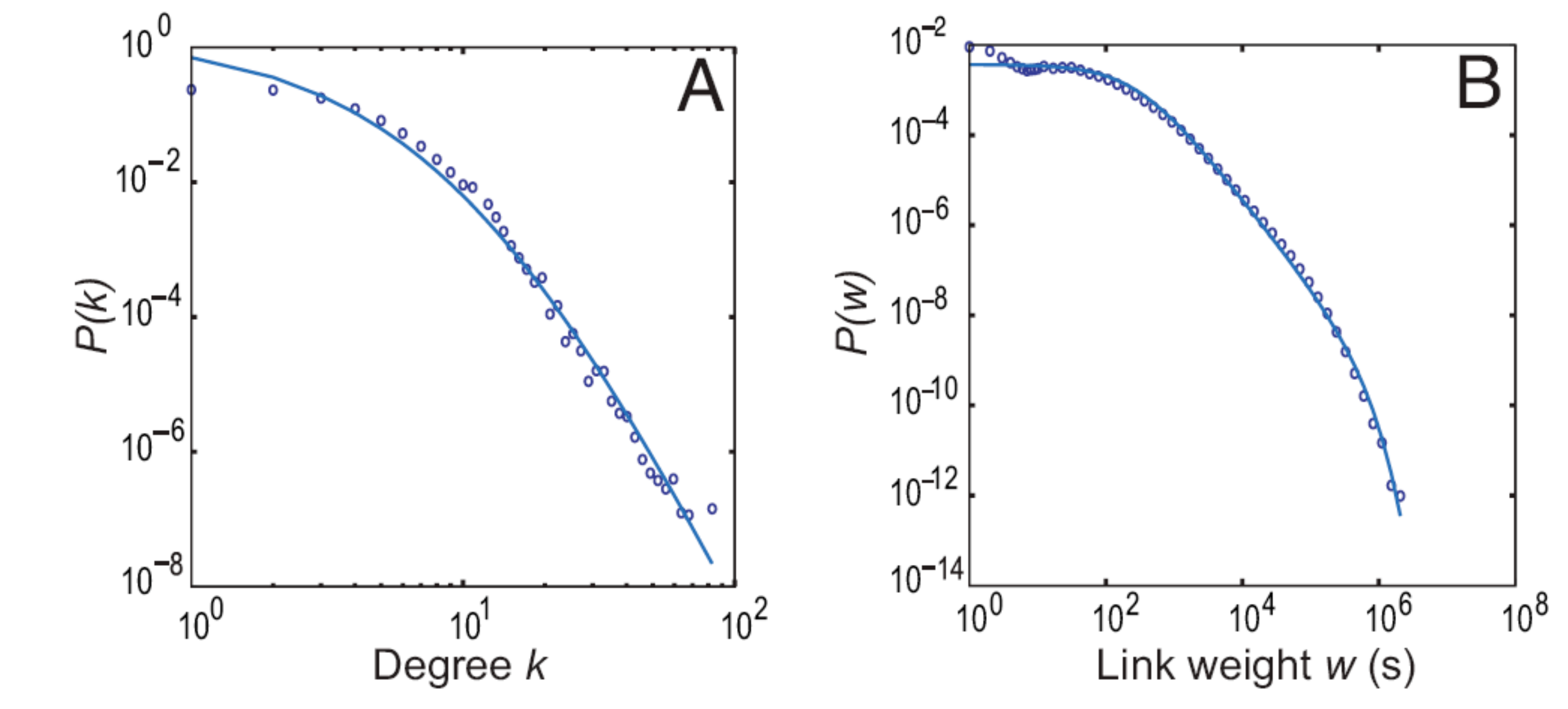
Network statistics



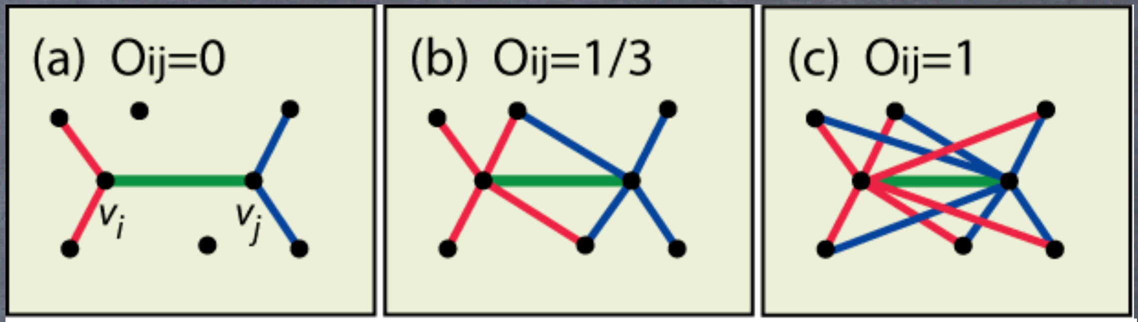
node degree = # of links

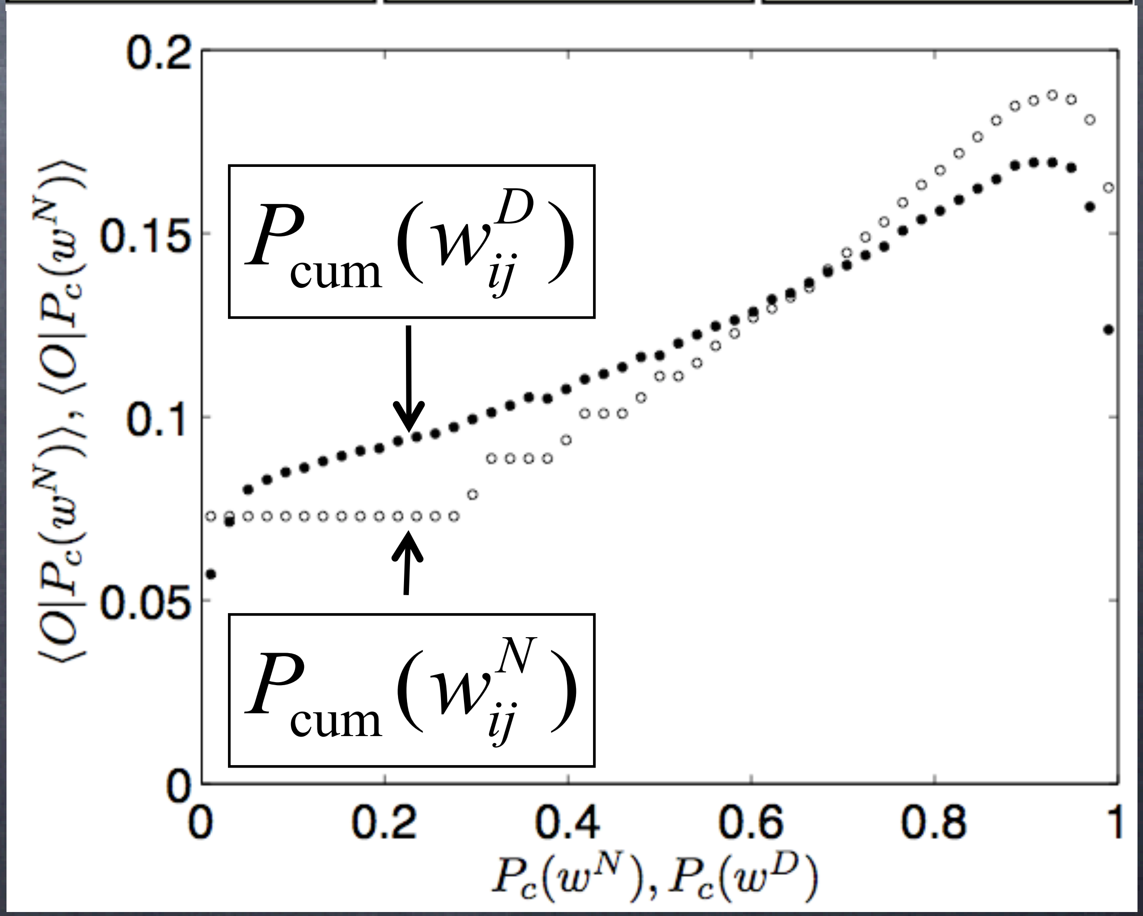
broad distribution: there are HUBS, nodes with large degree
power laws with exp cutoff provide reasonable fits (degree exponent ≈ -8.4)

however, e.g. the Internet, metabolic nets, protein interaction nets have much broader distributions, i.e. more and larger hubs

Local structure

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





- Weak ties hypothesis*: Relative overlap of two individual's friendship networks varies with the strength of their tie to one another

- Define **overlap** O_{ij} of edge (i,j) as the fraction of common neighbours

- Average overlap increases as a function of (cumulative) link weights

* M. Granovetter, The strength of weak ties, AJS **78**, 1360 (1973)

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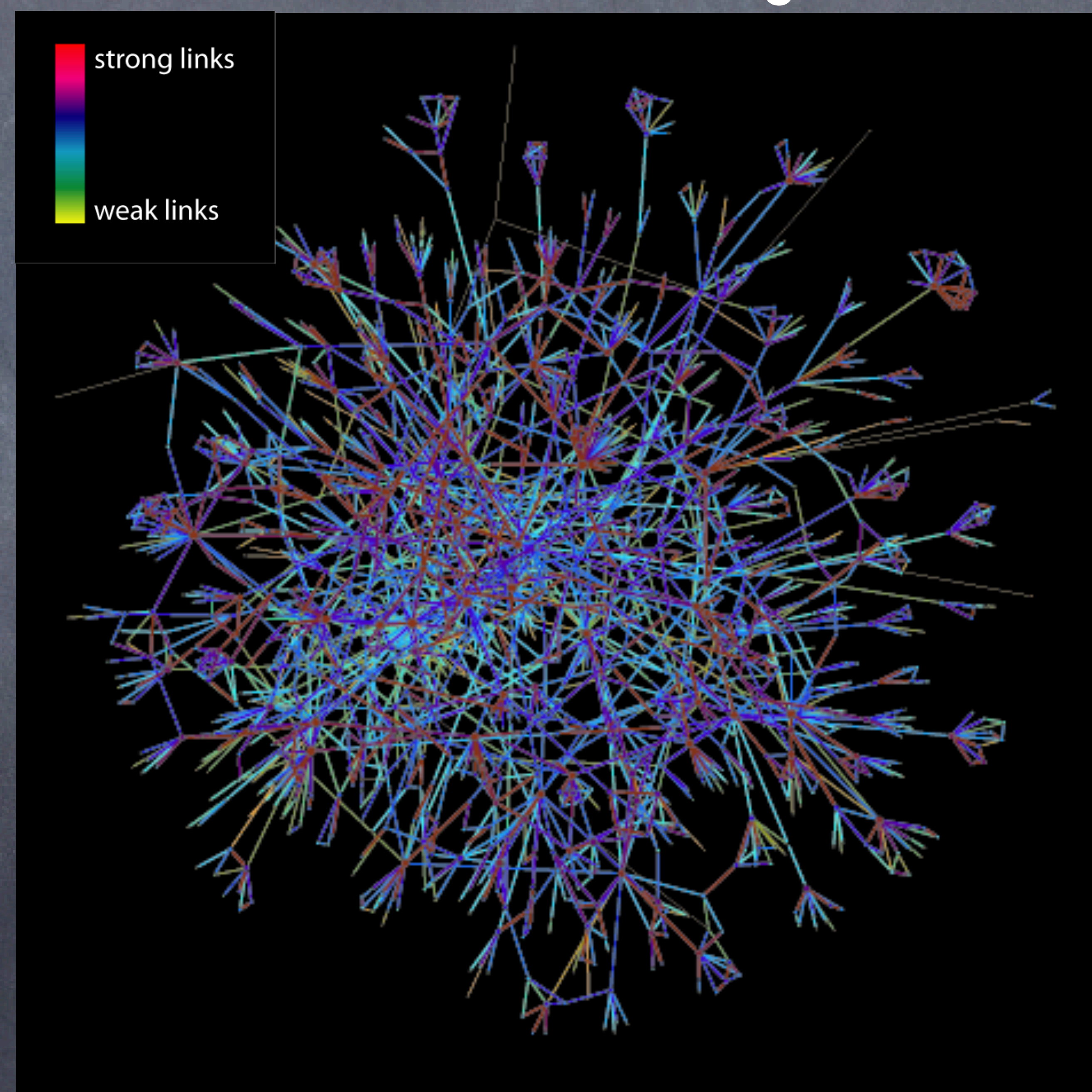
Percolation (global structure)

- Probe the **global role of links of different weight**
- Physicists' (and childrens') approach: Break to learn!
- Thresholding (percolation):
    - Remove links, one by one, based on their weight
- Control parameter f is the fraction of removed links
- We can move, in either direction, between the initial connected network (f=0) and the set of isolated nodes (f=1)

Global structure

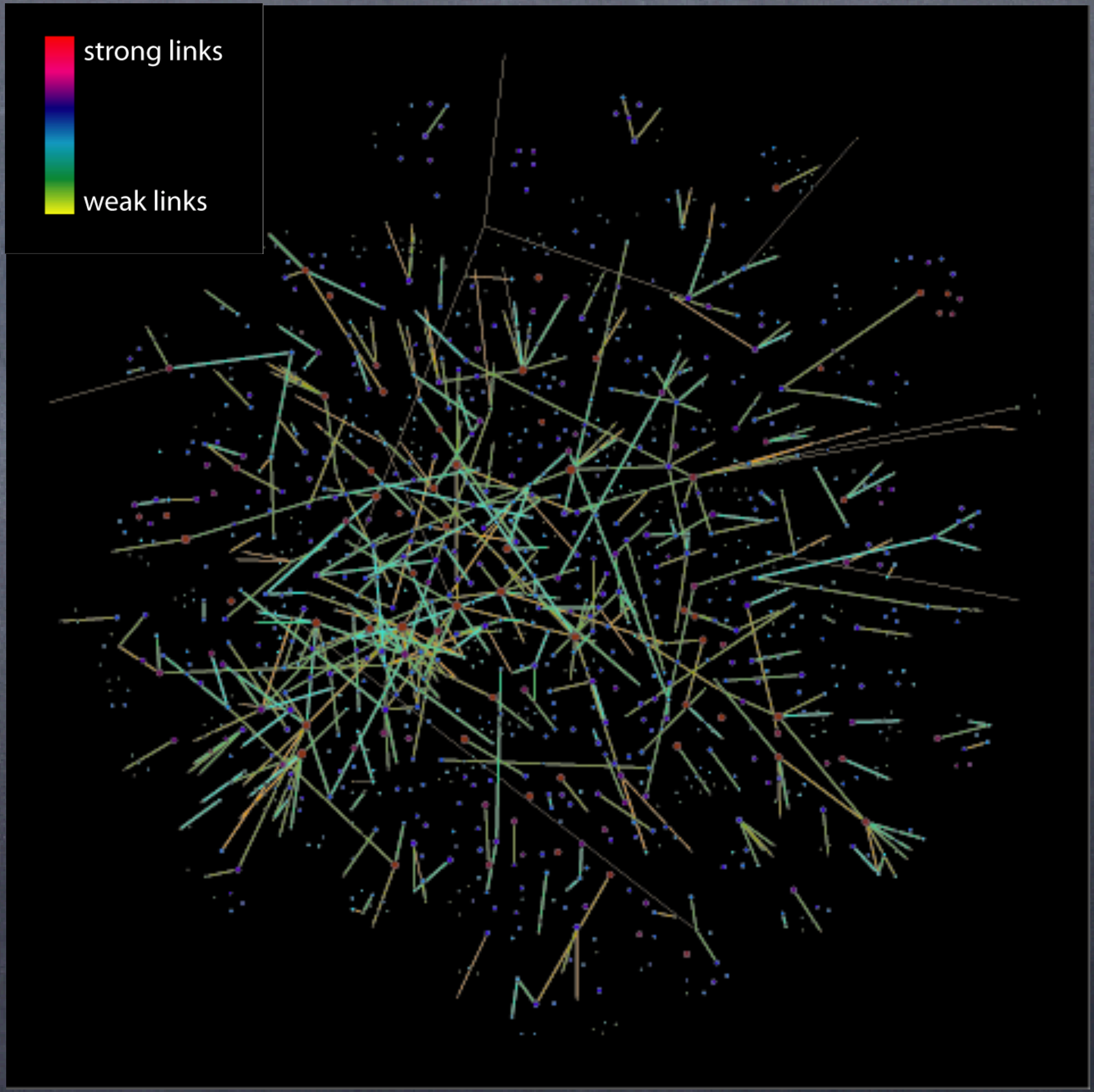
Initial connected network (f=0), small sample

⇒ All links are intact, i.e. the network is in its initial stage



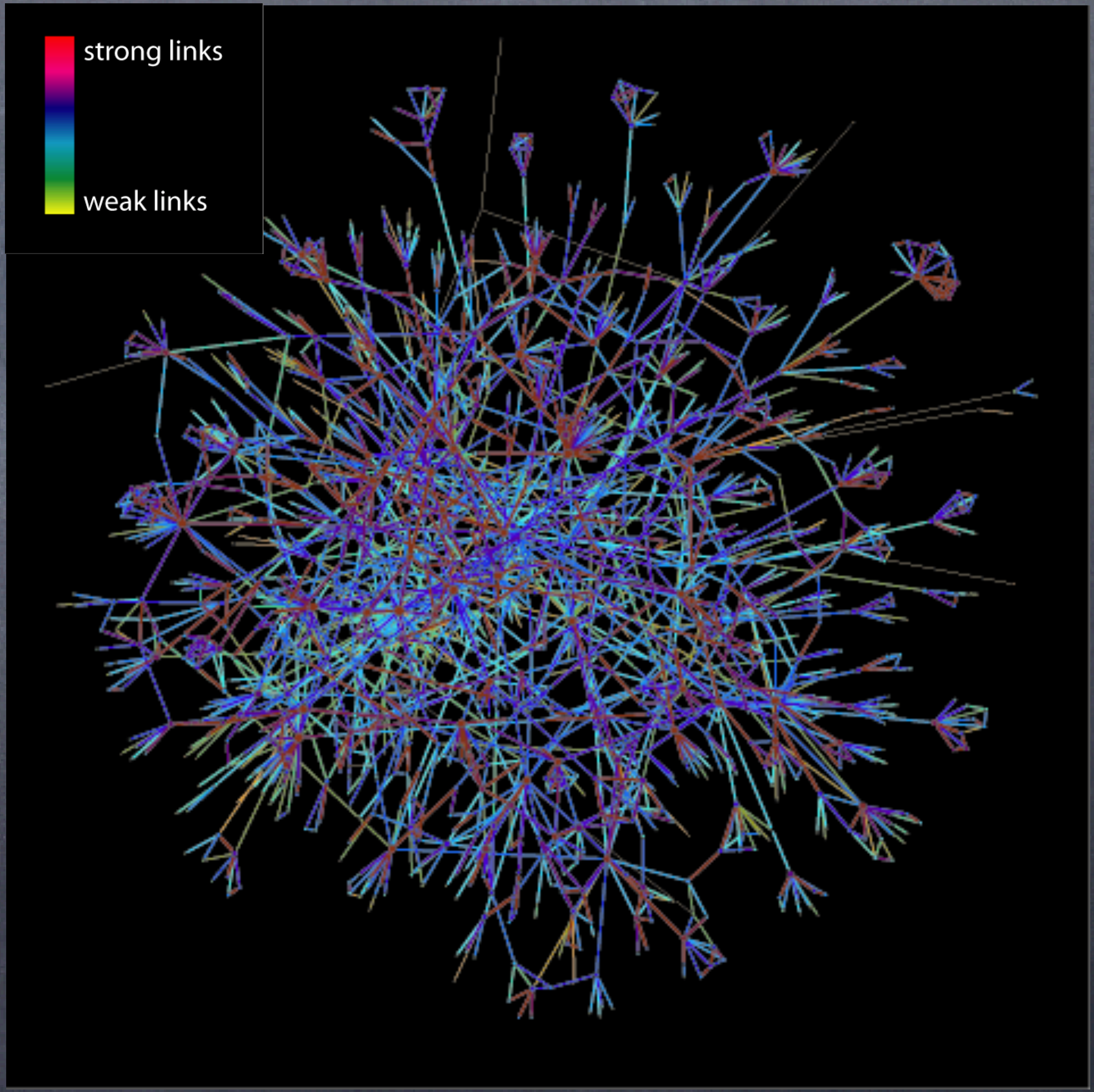
Global structure

Decreasing weight thresholded network (f=0.8)
⇒ 80% of the strongest links removed, weakest 20% remain



Global structure

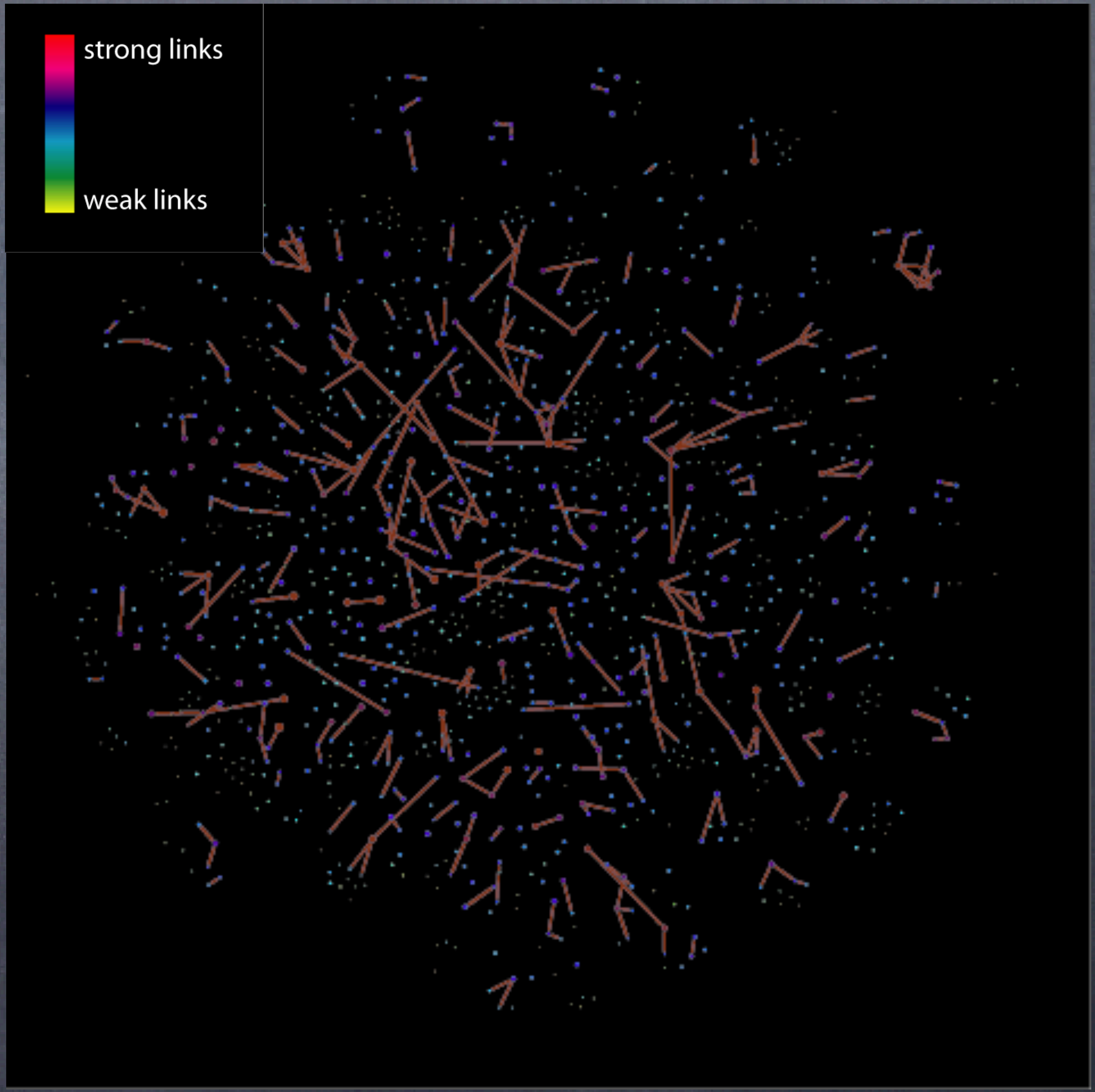
Initial connected network (f=0), small sample
⇒ All links are intact, i.e. the network is in its initial stage



Global structure

Increasing weight thresholded network (f=0.8)

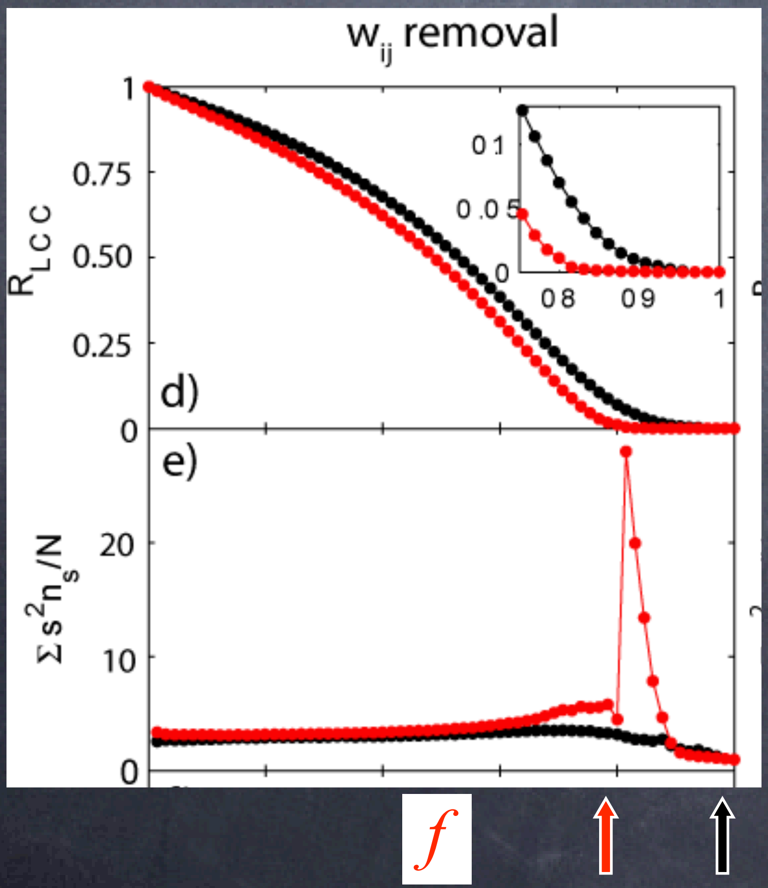
⇒ 80% of the weakest links removed, strongest 20% remain



Global structure

- Qualitative difference in the global role of weak and strong links
    - Phase transition when weak ties are removed first $f_c(\infty) \neq 1$
    - No phase transition when strong ties are removed first $f_c(\infty) = 1$
- Suggests a point of division between weak and strong links (f_c)

$$w_c = P^{-1}_{\text{cum}}(0.80) \approx 27\,\text{min}$$



$f^w_c(\infty) = 0.80 \pm 0.04$

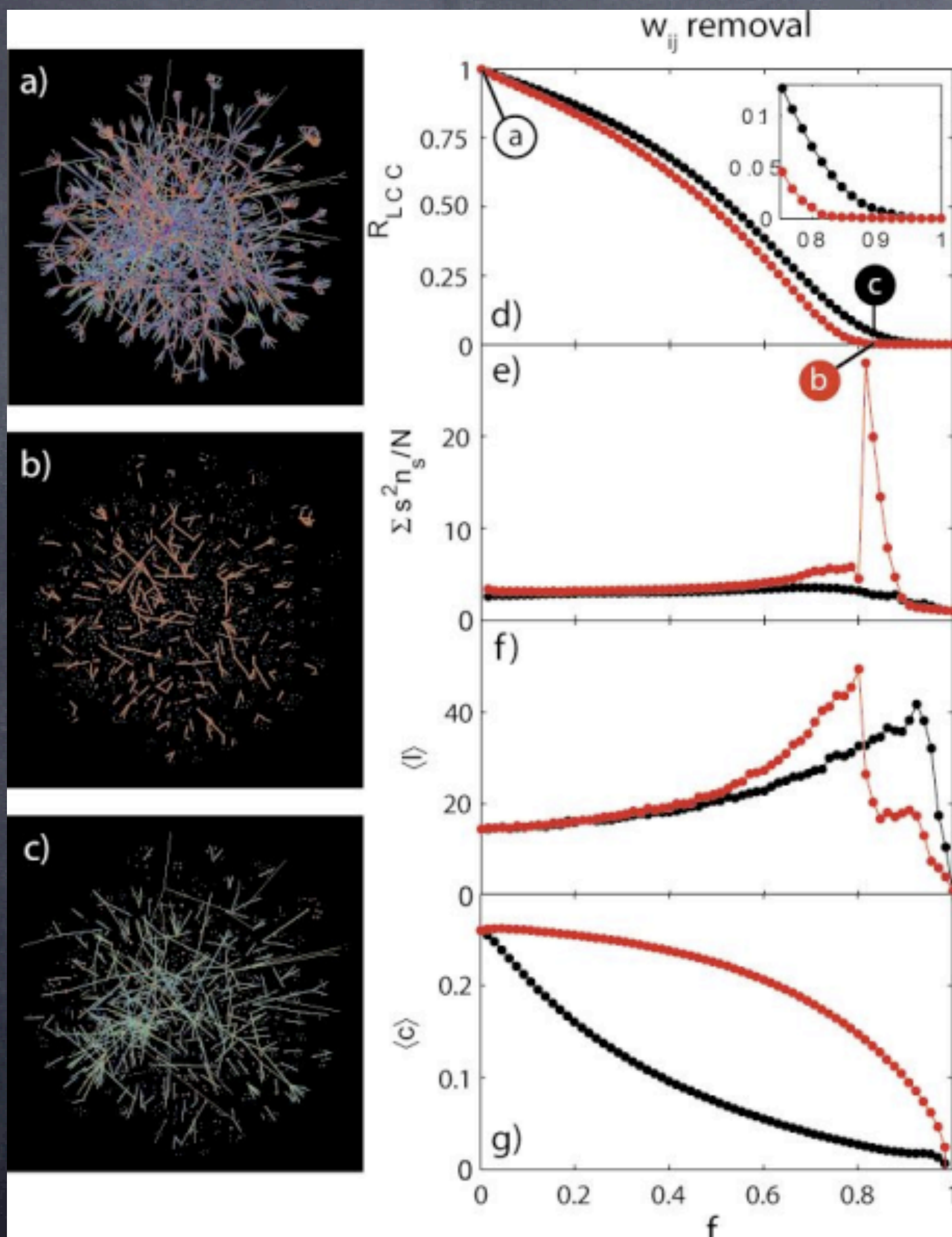
"globally connected" phase
"disconnected islands" phase

Order parameter R_{LCC}
- Def: fraction of nodes in LCC

Susceptibility S
- Def: average cluster size (excl. LCC)

$$\left[S = \sum_{s<s_{\max}} n_s s^2 \Big/ \sum_{s<s_{\max}} n_s s;\ \tilde{S} = \sum_{s<s_{\max}} n_s s^2 / N;\ C_i = t_i / 2k_i(k_i - 1) \right]$$

PERCOLATION ANALYSIS



red: weak links removed first
black: strong links removed first

- Order parameter R_{LCC}
  - Def: % of nodes in the largest connected component
  - Network collapses when f≥0.8
- Susceptibility S
  - Divergence indicates collapse of network
- Average shortest path <*l*> in L_{CC}
  - Diverges at percolation transition
- Clustering coefficient <*C*>
  - Def: fraction of interconnected neighbours, averaged over network
  - Decreases faster on strong link removal

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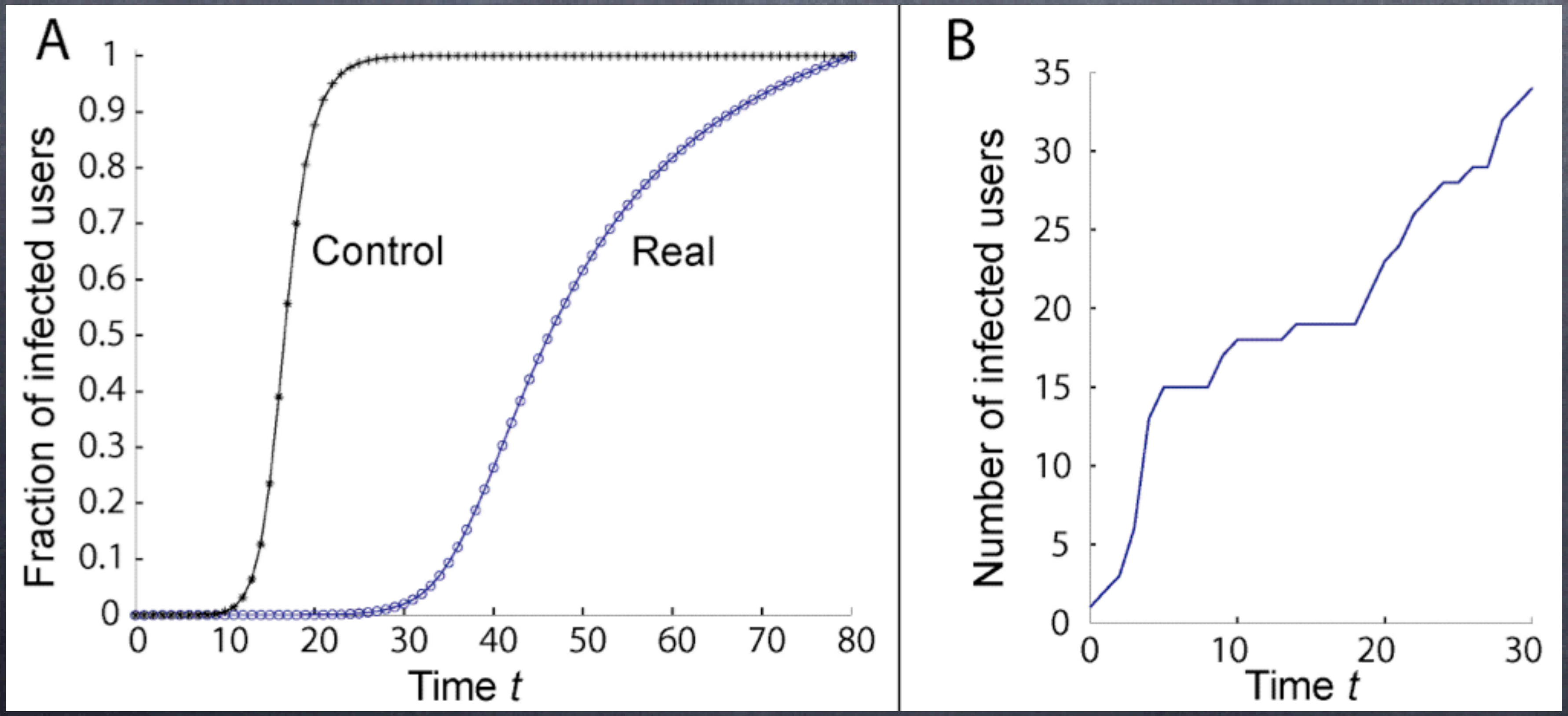
Diffusion of information

- Knowledge of information diffusion based on unweighted networks
- Use the present network to study diffusion on a weighted network
- Spreading simulation: infect one node as in SI-model in epidemiology

Real $p_{ij} = aw_{ij} \propto w_{ij}$

Control $p_{ij} = a\bar{w} \propto 1$



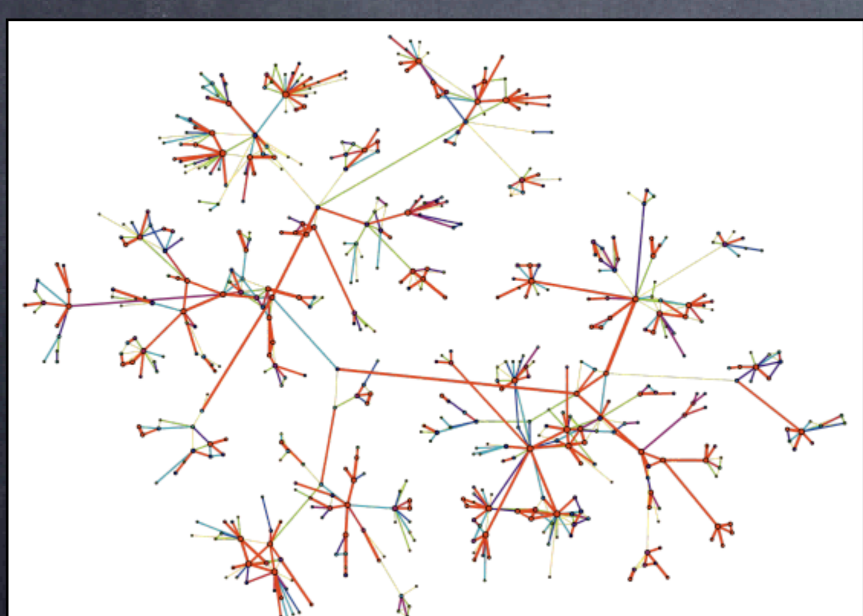
Weight-topology correlations

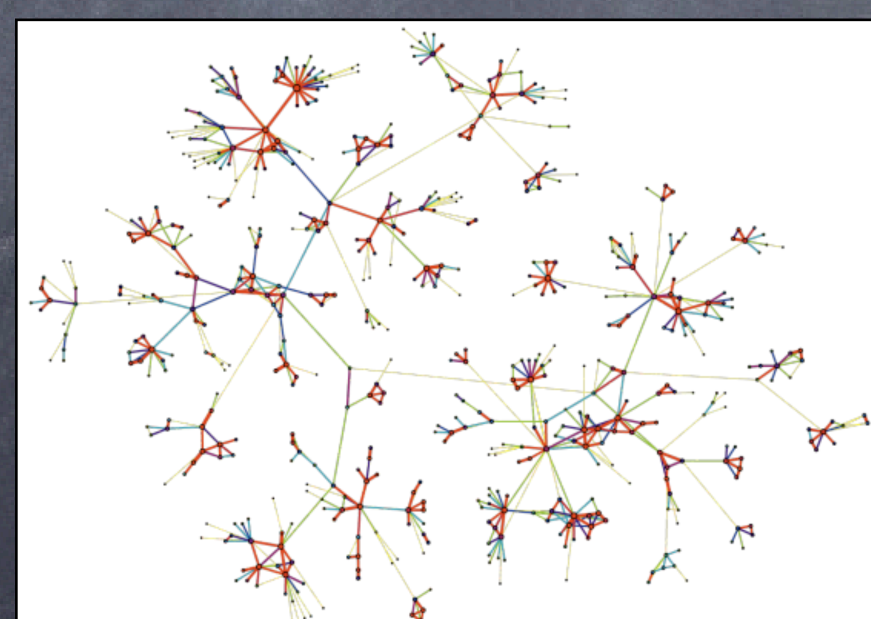
- What determines edge weights?
- Alternatives:
  - Dyadic hypothesis: weights do not depend on surroundings
  - The strength of weak ties hypothesis
  - Global efficiency hypothesis

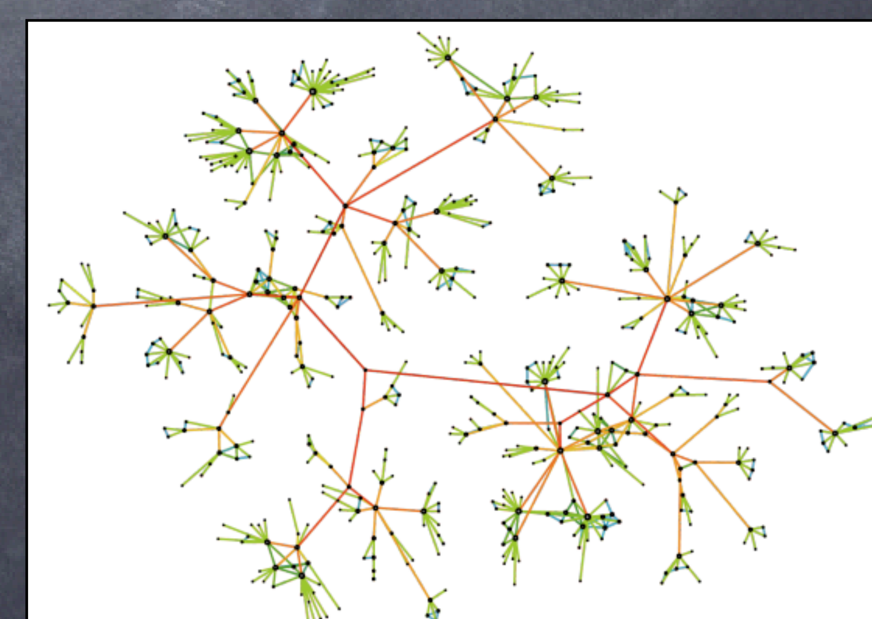
Weights local,
no correlations

**Empirical observation,
strength of weak ties**

Weights = betweenness,
global efficiency







Diffusion of information

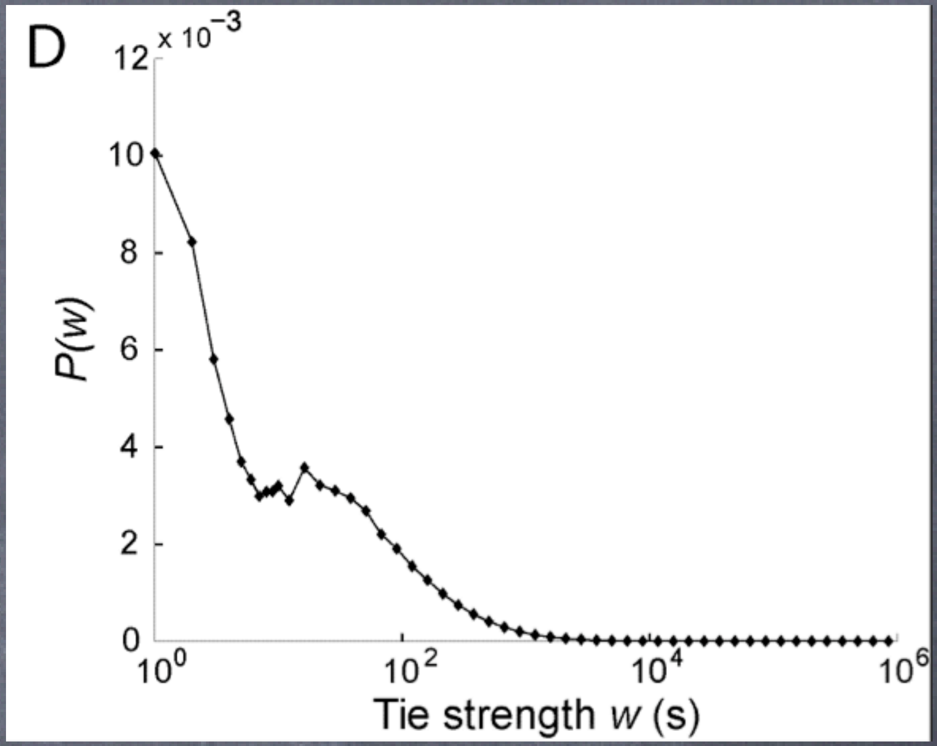
Where do individuals get their information?

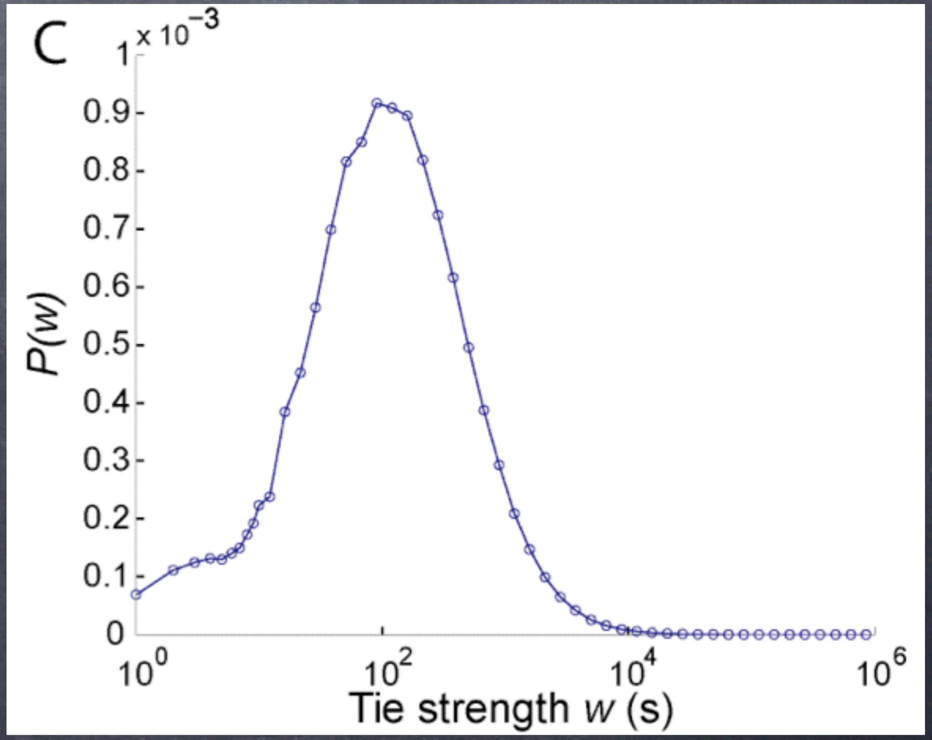
Control network

- First transmissions through weak ties

Real network

- First trns. through intermediate ties
- Weak ties: ✓ access to new information
  ✗ low transmission rate
- Strong ties: ✓ high transmission rate
  ✗ rarely access to new info





=> "Weakness of weak and strong ties" in diffusion

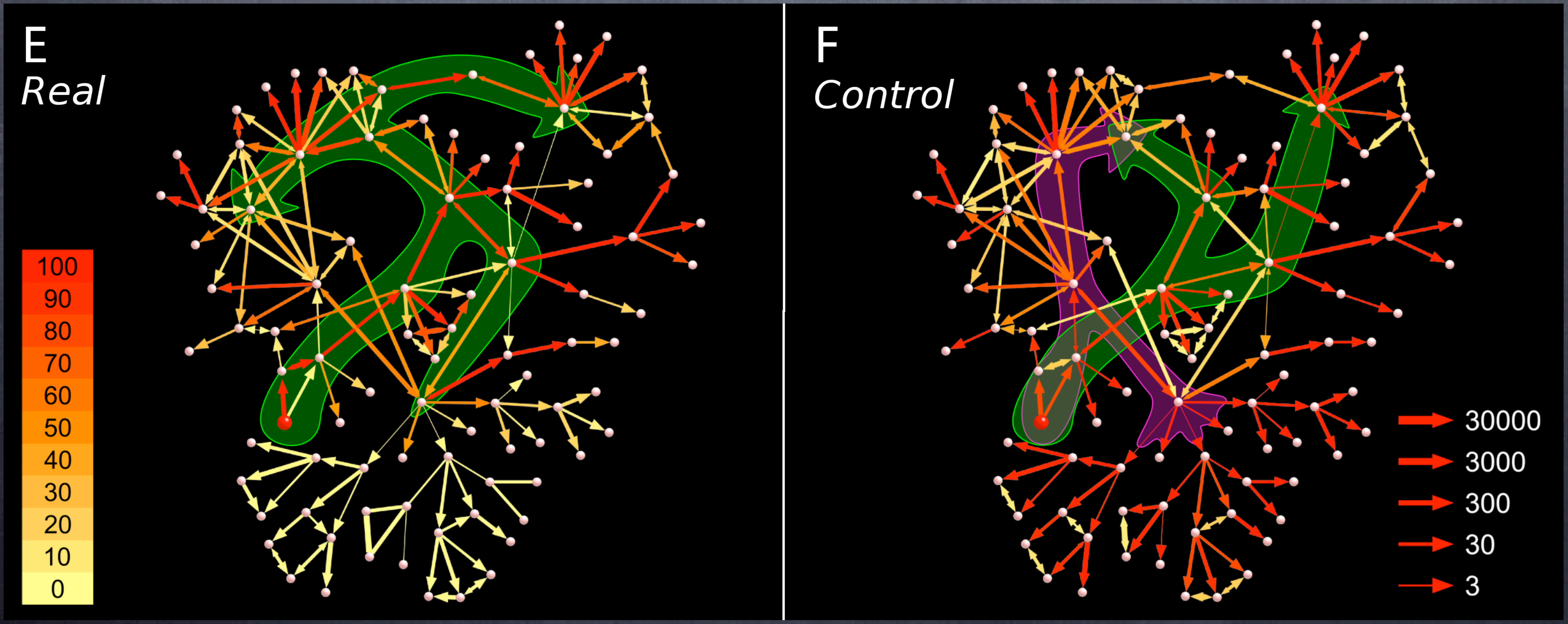
Diffusion of information

Impact on overall information flow in the network?

- Start spreading 100 times (large red node)
- Information flows differently due to the local organisational principle

(1) Real: information flows along a strong tie backbone

(2) Control: information flows mainly along the shortest paths



Overview

Conclusions

- Local coupling between network topology and tie strengths
  - Strong ties: neighbourhoods tend to overlap
- Weak ties (PT) are qualitatively different from strong ties
  - Weak ties more important for global connectivity
- First-time diffusion ⇒ "Weakness of weak and strong ties"

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- See also news stories: Science **314**, 914 (2006); Nature **449**, 644 (2007);
Der Spiegel 18/2008, p 148

http://www.lce.hut.fi/~jsaramak/

http://www.physics.ox.ac.uk/users/Onnela/

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THANK YOU!