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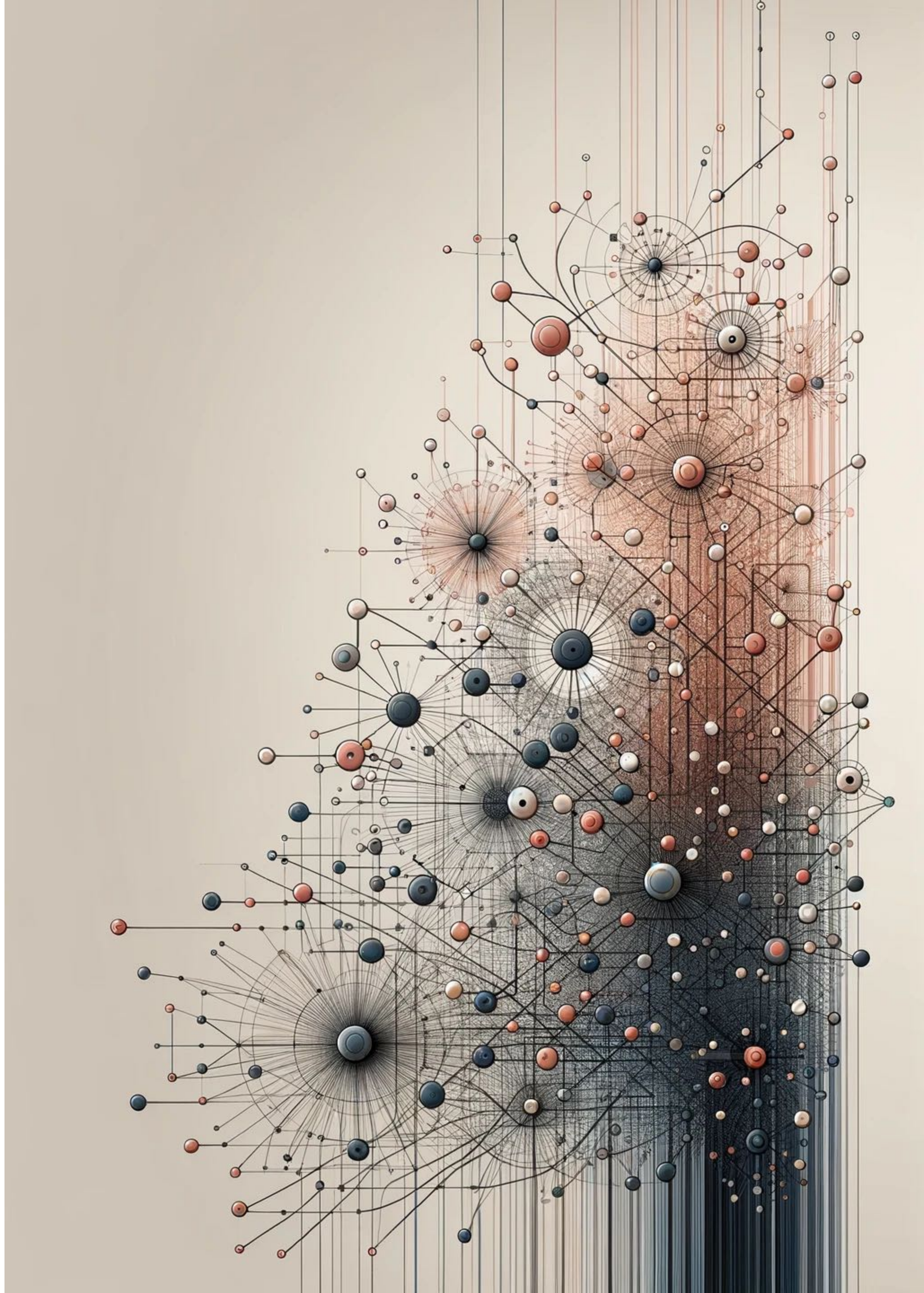
Analisi e Visualizzazione delle Reti Complesse

NS05 - Homophily

Prof. Rossano Schifanella



Homophily

Surrounding contexts

- We focus on
  - structural properties
  - link formation processes
  - personal characteristics
  - similarities between individuals
- **surrounding contexts:** factors that exist outside the nodes and the edges of a network but that can affect the evolution of the system

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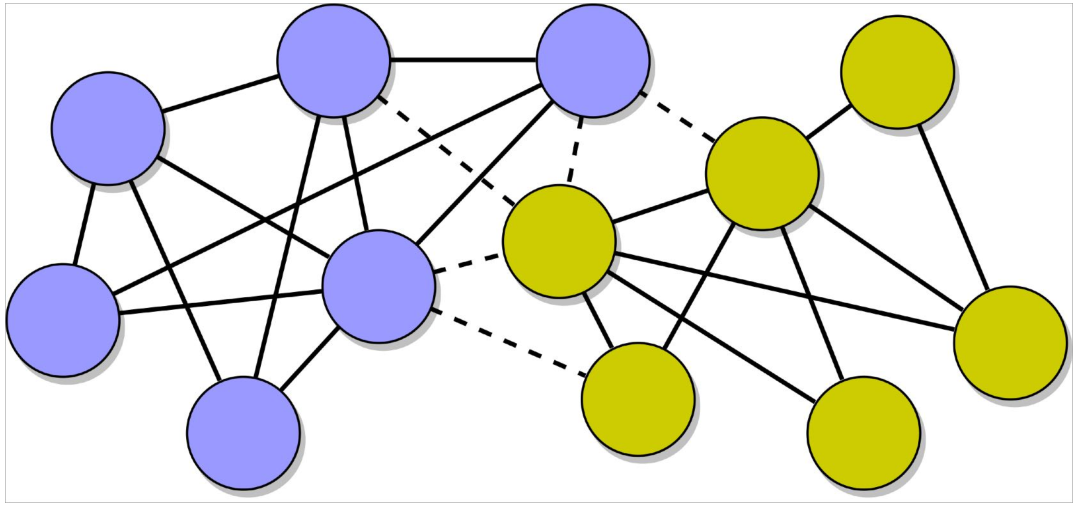
Homophily

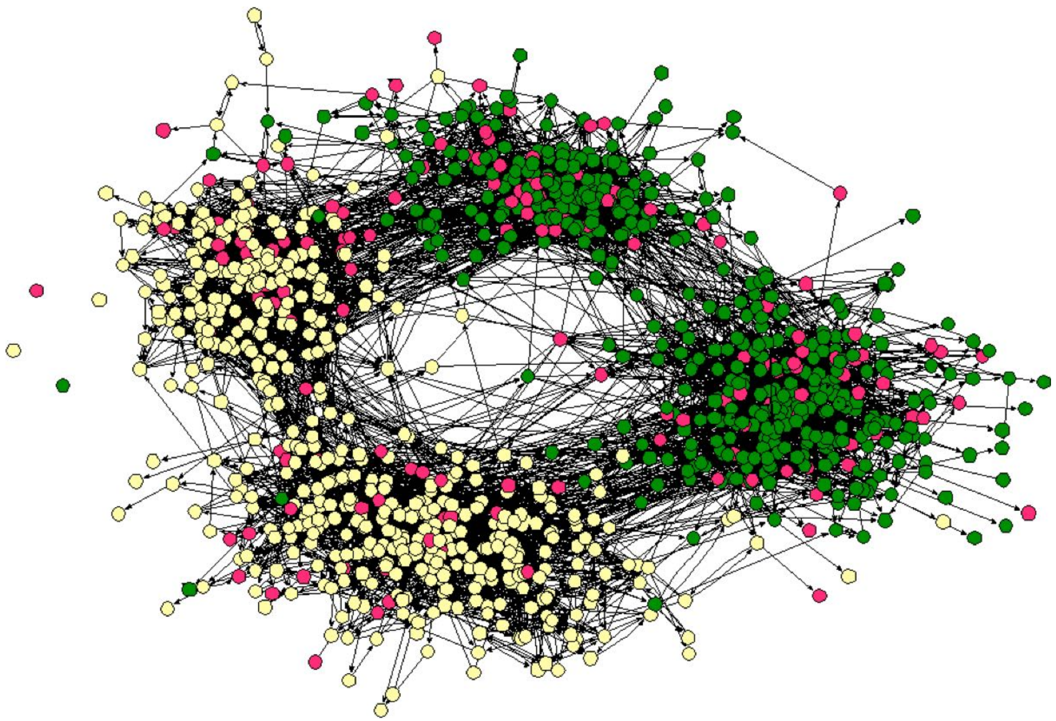
- The principle that **we tend to be similar to our friends**
- This makes your friends not statistically significant as a random sample of the population
- Similarities
  - immutable characteristics
    - e.g., race and ethnic dimensions
  - mutable characteristics
    - e.g., occupation, level of affluence, interests, beliefs, opinions, activities, place where they live
- We all have exceptions however, overall, this observation empirically holds

Birds of a feather flock together



Example: middle and high school

- In real social networks, we find:
    - **intrinsic triadic closure**
    - **contextual characteristics** that influence similarities, and that shape the network
- In this example, the circle's color represents students of different races
- **Important:** the formation of a link is likely to be the effect of a **combination of effects**
    - **intrinsic structure + context**



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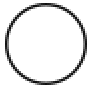
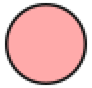
Measuring homophily

Simple test:

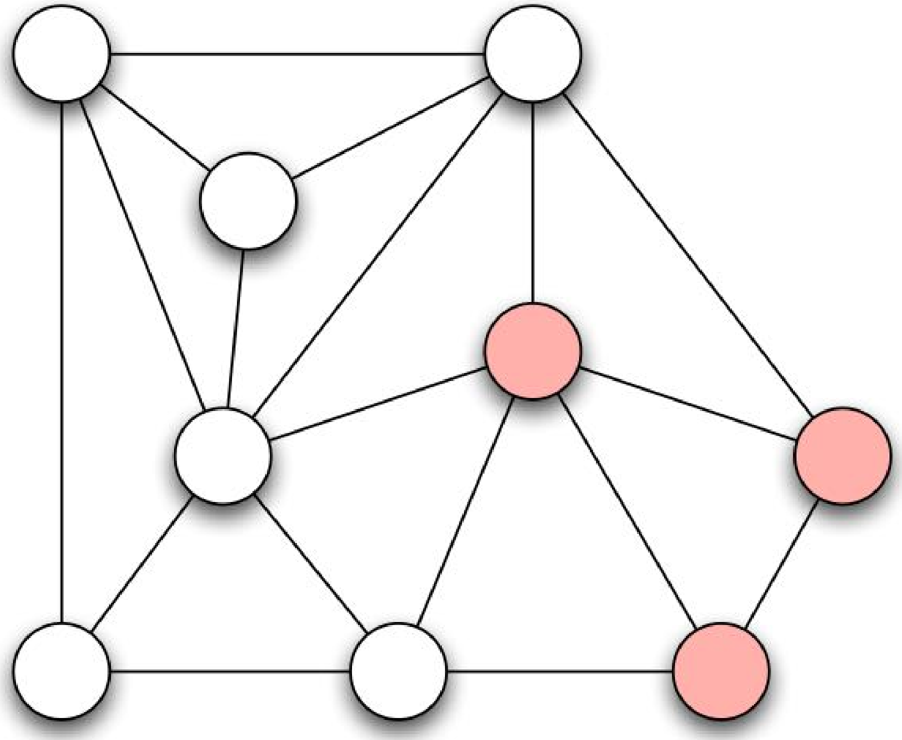
1. let's assign randomly a color to each node
2. count the number of cross-color edges
3. compare numbers with the actual network



$p = \frac{6}{9} = \frac{2}{3}$



$q = \frac{3}{9} = \frac{1}{3}$



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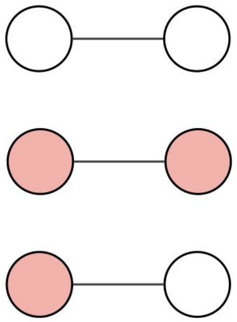
Fraction of white nodes: $p = \frac{2}{3}$ Fraction of pink nodes: $q = \frac{1}{3}$

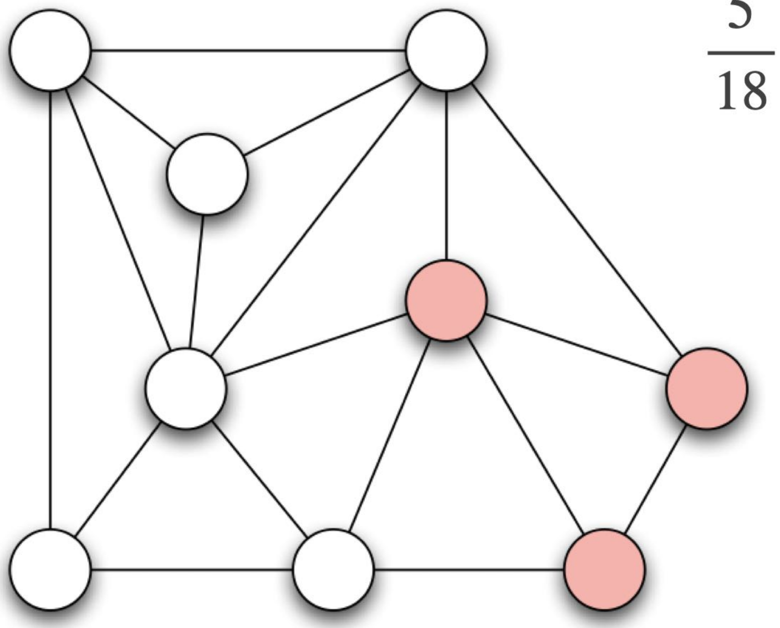
Cross-characteristic edges = number of non-homophilic edges over all edges



$$p \cdot p = p^2 = \frac{4}{9}$$

$$q \cdot q = q^2 = \frac{1}{9}$$

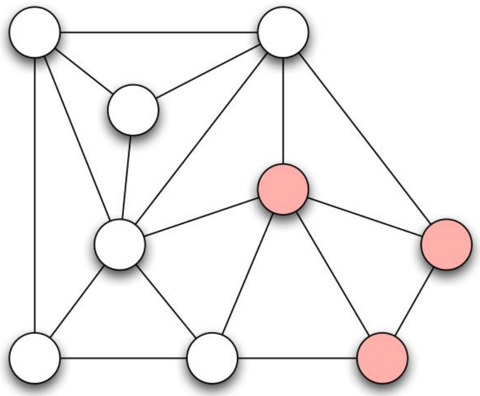
$$2 \cdot p \cdot q = 2\frac{2}{3}\frac{1}{3} = \frac{4}{9}$$



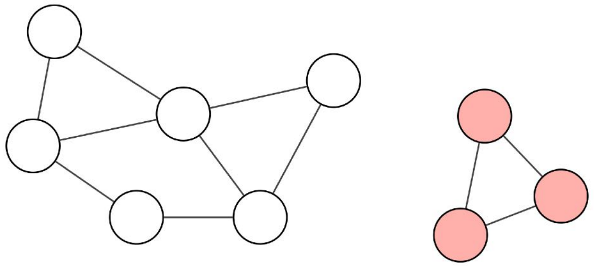
$$\frac{5}{18}$$

$$\frac{5}{18} < \frac{4}{9}$$

Homophily test: if the fraction of cross-types edges is significantly less than $2pq$, then there is a signal of homophily



$\frac{5}{18} < \frac{4}{9} \Rightarrow \text{homophily}$

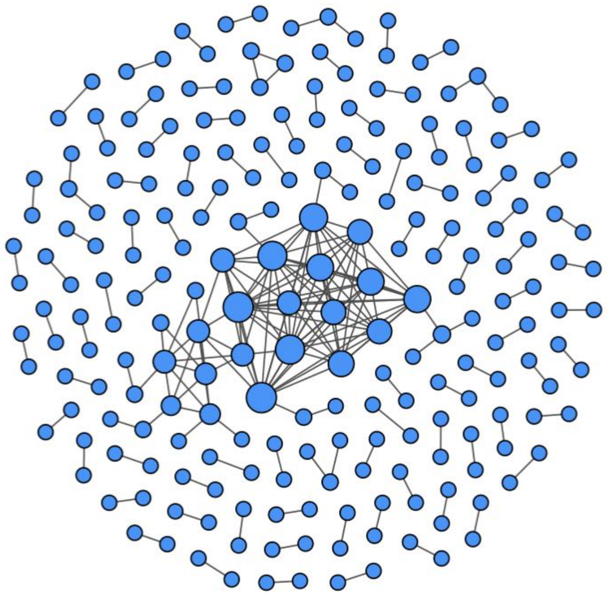


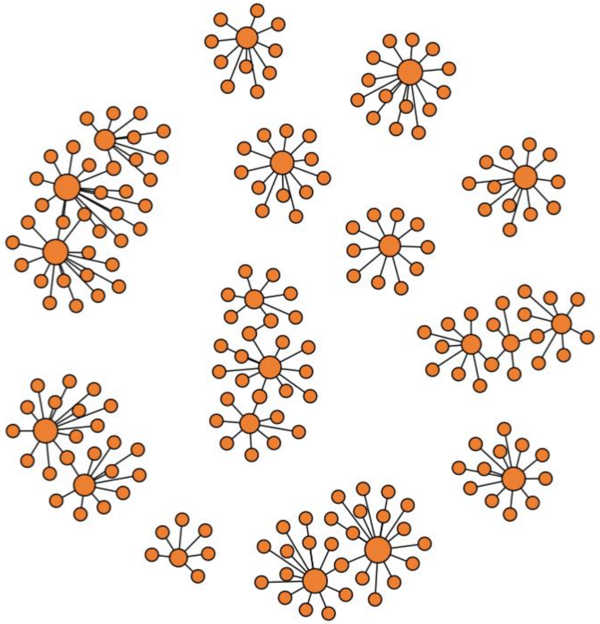
$0 < \frac{4}{9} \Rightarrow \text{perfect homophily}$

- Standard measures of statistical significance (quantifying the significance of a deviation below a mean) can be used to define "significantly less than".
- **Inverse homophily:** $\text{cross-edges} \gg 2pq$

Degree assortativity

- A.k.a. degree correlation
- **Assortative networks** have a core-periphery structure with hubs in the core
  - Ex: social networks
- **Disassortative networks** have hub-and-spoke (or star) structure
  - Ex: Web, Internet, food webs, bio networks





Measuring assortativity by neighbors

A way to compute the degree assortativity is by measuring the **degree correlation function**:

- **the correlation between the degree and the average degree of the neighbors of nodes with that degree**.

Let's calculate the average degree of i's neighbors, first:

$$k_{nn}(i) = \frac{1}{k_i} \sum_j A_{ij} k_j$$

With a little abuse of notation, let's define the degree correlation function as the average of all the $k_{nn}(i)$ for all the nodes whose degree is k.

$$k_{nn}(k) = \langle k_{nn}(i) \rangle_{i:k_i=k}$$

To visually check the network assortativity, we plot:

$$(k, k_{nn}(k))$$

It is possible to prove that, in a neutral network (i.e., where there is no correlation between a node's degree and its neighbors' average degree), plotting results in a horizontal line.

- Reference:
  - See Chapter 7 of [ns3] for more mathematical insights

Example

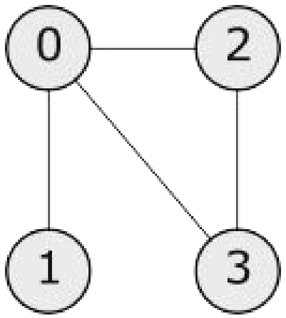
node i with k_i neighbors

$k_{nn}(i) = \frac{1}{k_i} \sum_j a_{ij} k_j$

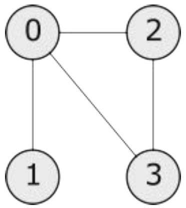
that is the average of i's neighbors' degrees

Let's compute $k_{nn}(i)$ for each node:

$k_{nn}(0) = \frac{1}{3}(2+2+1) = \frac{5}{3}$
$k_{nn}(1) = 3$
$k_{nn}(2) = \frac{1}{2}(3+2) = \frac{5}{2}$
$k_{nn}(3) = \frac{1}{2}(3+2) = \frac{5}{2}$

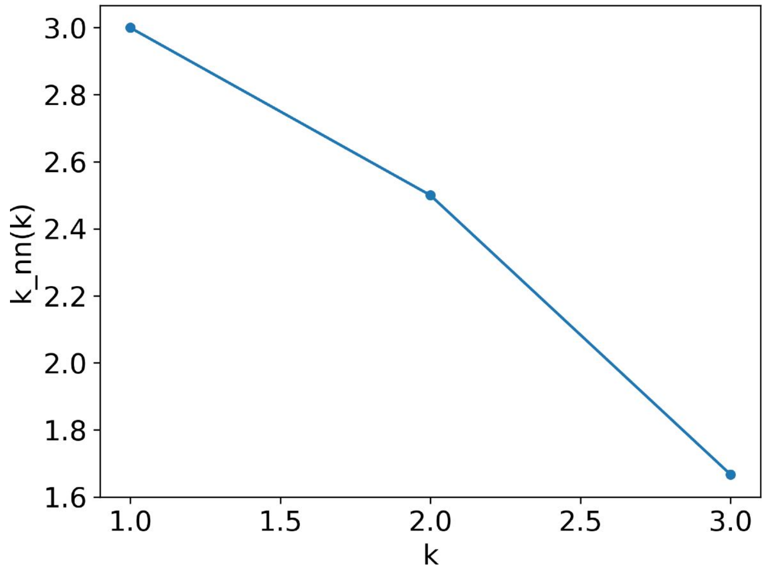


Example



$k_{nn}(0) = \frac{5}{3}, \quad k_{nn}(1) = 3, \quad k_{nn}(2) = \frac{5}{2}, \quad k_{nn}(3) = \frac{5}{2}$

Let us plot $(k, k_{nn}(k))$

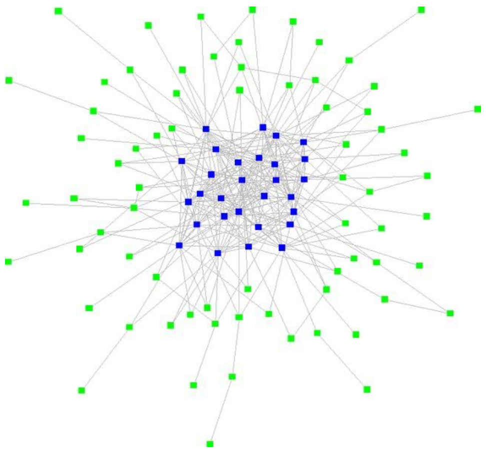


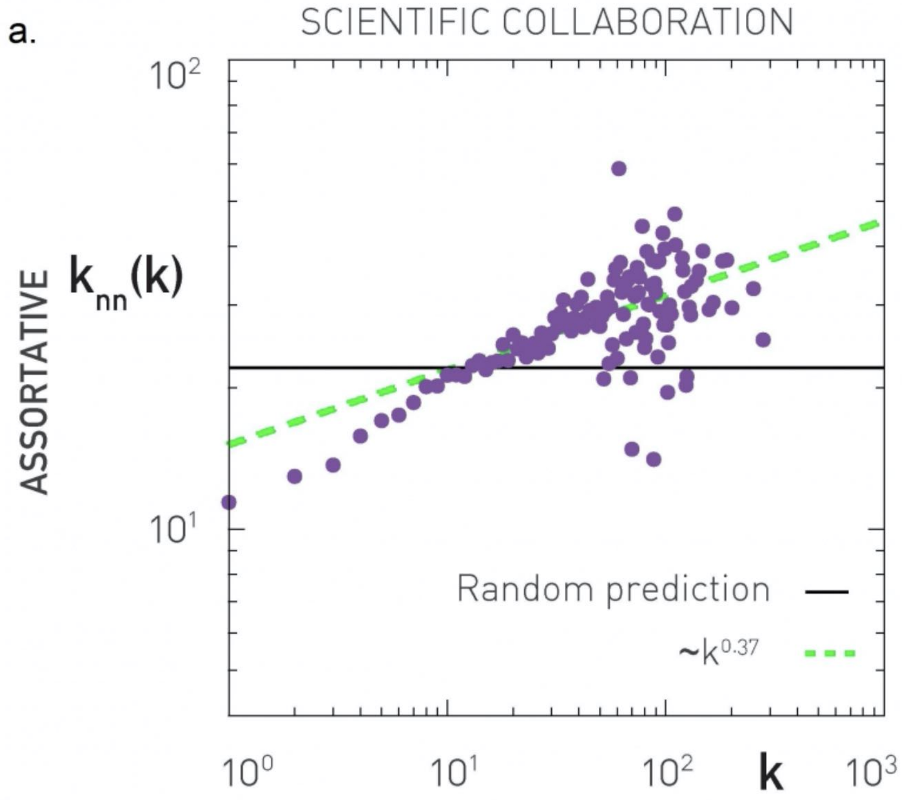
Positive assortativity

- **Scientific collaboration network**

The increase with k indicates that the network is assortative.

- ex. core-periphery

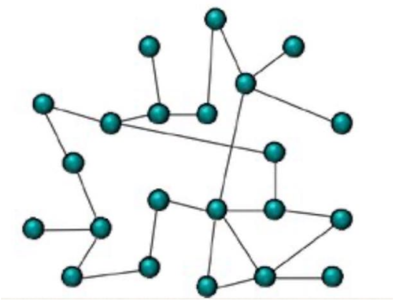


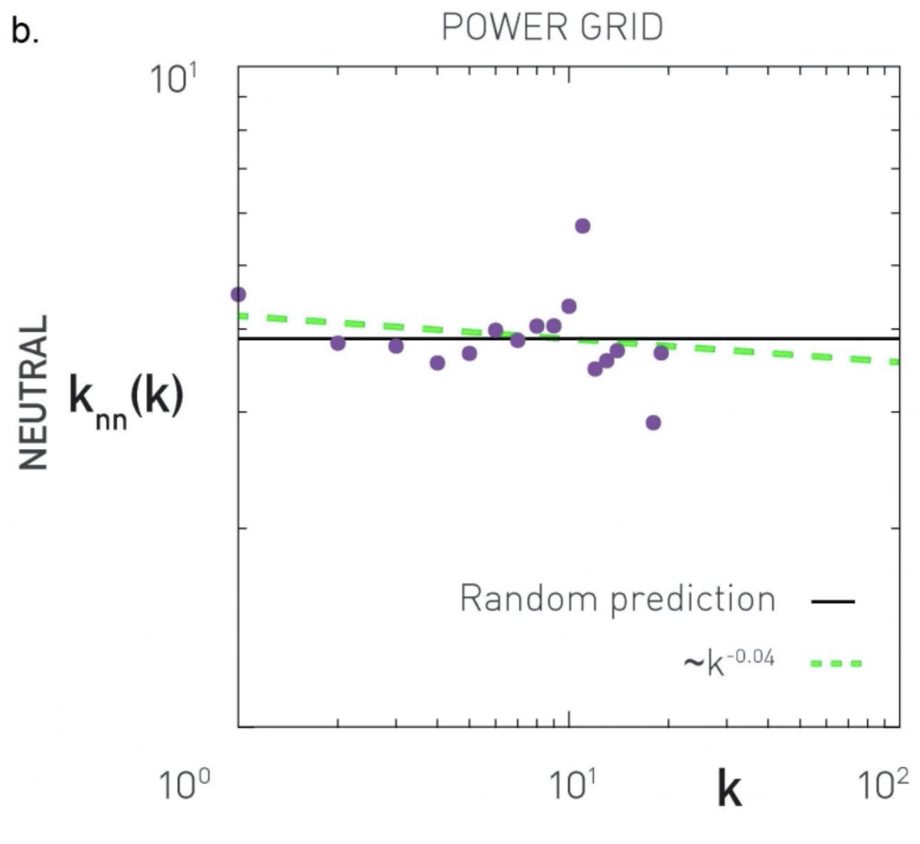


Neutral assortativity

- **Power grid**

The horizontal indicates the lack of degree correlations, in line with our expectations for neutral networks.

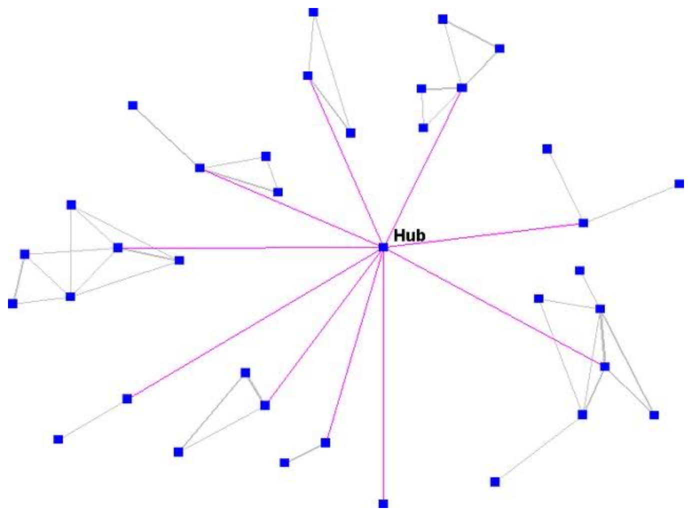


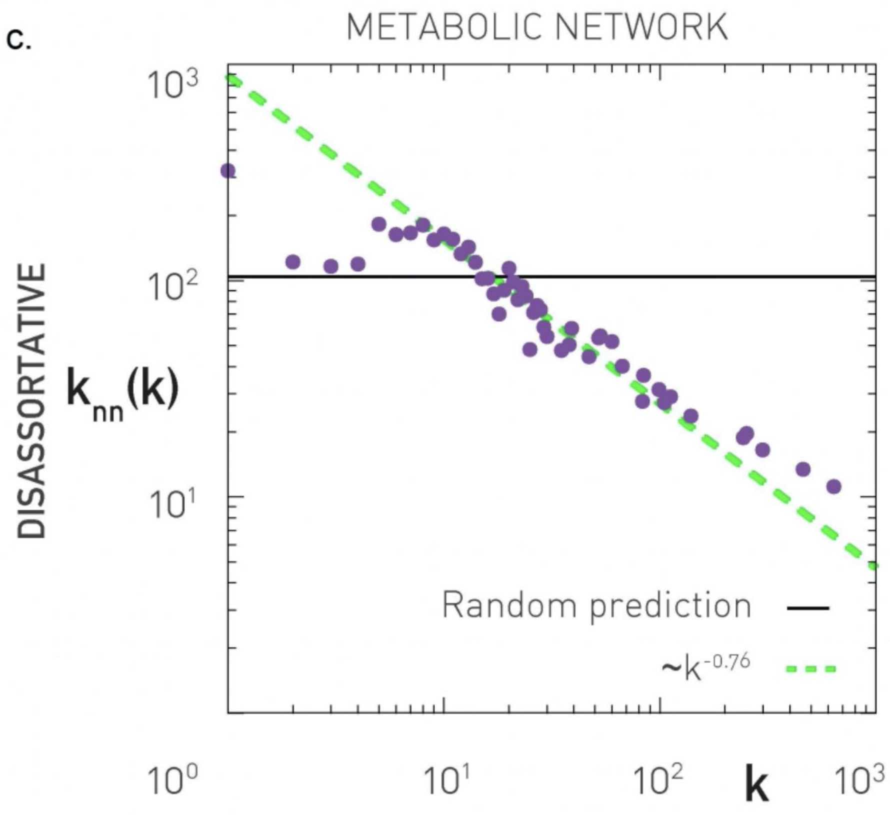


Negative assortativity

- **Metabolic Network**

The decreasing documents the network's disassortative nature.





Mechanisms Underlying Homophily: Selection and Social Influence

Underlying mechanisms of homophily

- Two possible mechanisms by which homophily (also assortativity) emerges naturally:

1. **Selection:** similar nodes become connected
    - especially, but not limited to, in case of immutable attributes
2. **(Social) influence:** connected nodes become more similar over time
    - it applies to mutable attributes

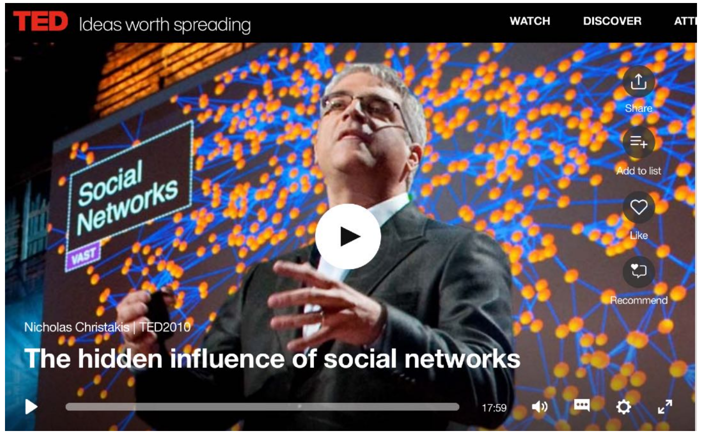
- It can also be a bad thing.
    - For example "echo chambers" and "groupthink" are situations where your friends are like you, diversity is killed, and you are only exposed to opinions that reinforce your pre-existing beliefs

The interplay of selection and social influence

- **longitudinal methodology:**
  - observe a network (connections and individual behaviors) for a long period
  - observe **both factors in action**
  - this makes it possible to see the **behavioral changes that occur after changes in an individual's network connections**, as opposed to the **changes to the network that occur after an individual changes his or her behavior**.
  - how do we quantify the impact?
- Example 1: drug dependency:
  - Students show a greater likelihood to use drugs when their friends do
  - Important for how to design interventions
  - Is targeting students who use drugs enough? influence vs. selection

Example 2: obesity "contagion"

- dataset: 12,000 people
- they tracked obesity status and social network structure over 32 years
- obese vs. non-obese: there is a tendency toward clustering
- homophily test: passed
- The problem is to understand **why** is this the case
    i. **Selection?**
    ii. **Confounding effects:** homophily that correlates with something else?
    iii. **Social influence?**
- Authors observe (i) and (ii) but **mainly (iii)** hinting at a form of "contagion" effect
    - [The hidden influence of social networks, Nicholas Christakis, TED2010]



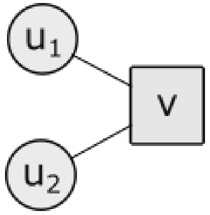
Affiliation

Affiliation

- **Can we represent the surrounding context through networks?**
- An **affiliation network** is a network in which actors are connected via their **membership in groups** of some kind.
- **foci** (or groups): **focal points** of social interaction
- a **focus**: social, psychological, legal, or physical entities around which joint activities are organized (e.g. workplaces, voluntary organizations, hangouts, etc.)
- We can use **bipartite graphs**

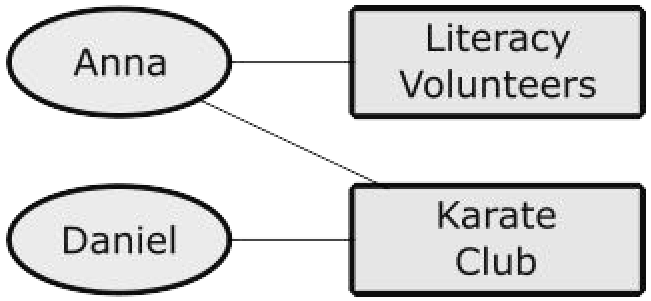
$G = (U, V, E)$ where U are persons and V are foci

$\forall (u, v) \in E : u \in U \land v \in V$



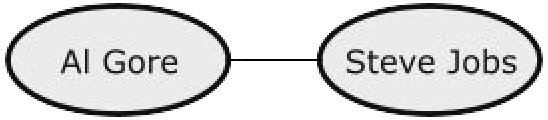
Affiliation networks

- Can I complement my affiliation network with a social network?

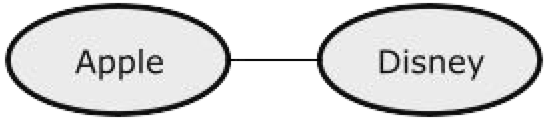


Using projections

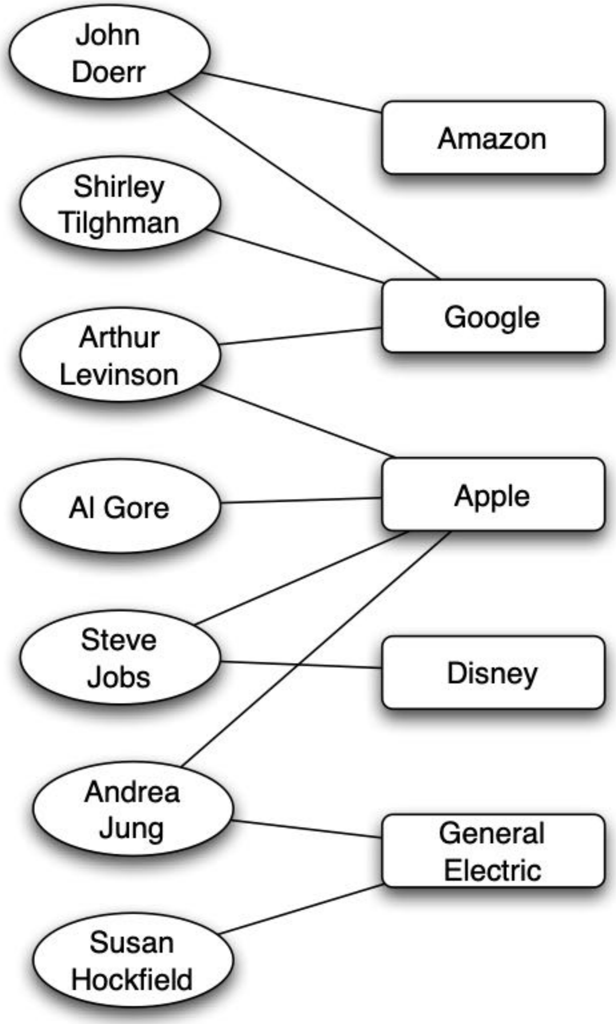
- Example: memberships to corporate boards of directors
- **Projection 1:** Network of interaction among board members



- **Projection 2:** Network of interaction among companies

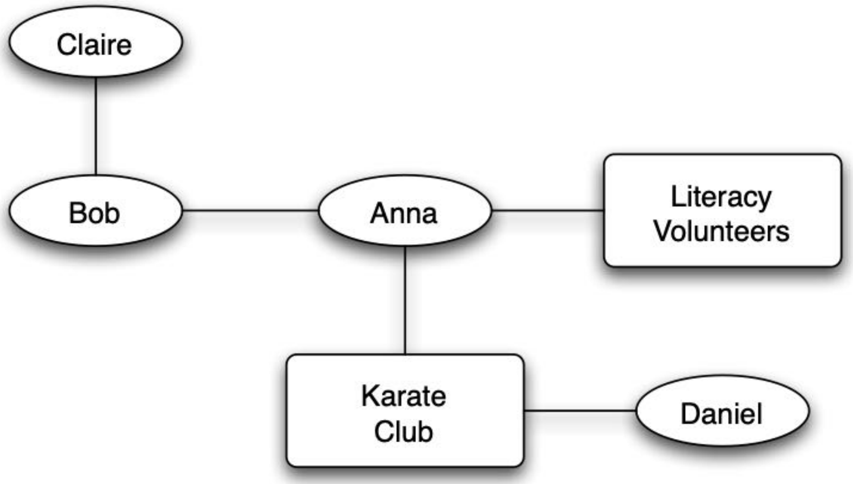


- Can you do the same with the movie networks?

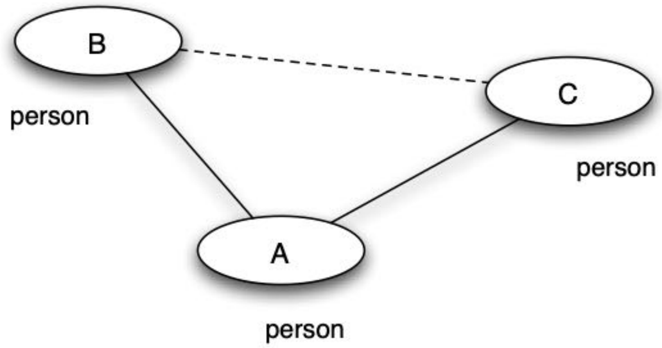


Co-evolution of social and affiliation nets

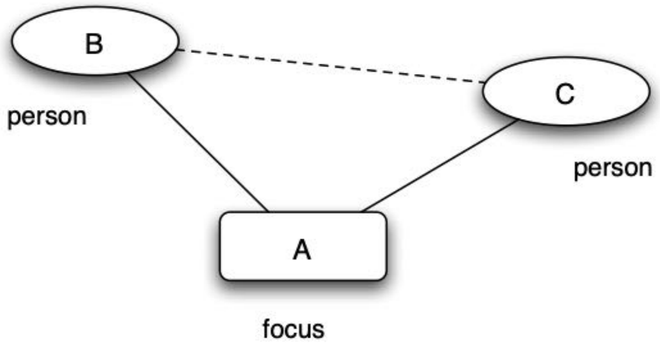
- Both social and affiliation networks change over time
- We want to merge the information from both networks
  - **social-affiliation networks**
- Can we predict new link formation?



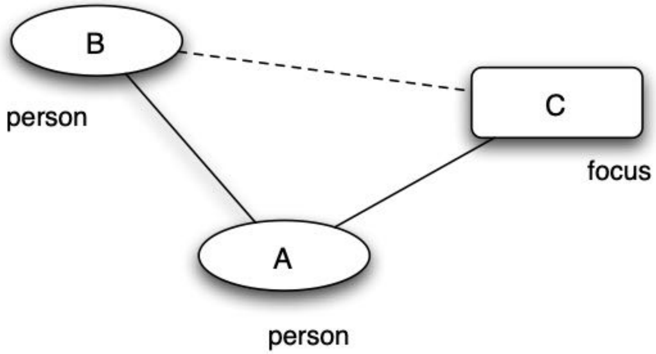
Closures



(a) *Triadic closure*



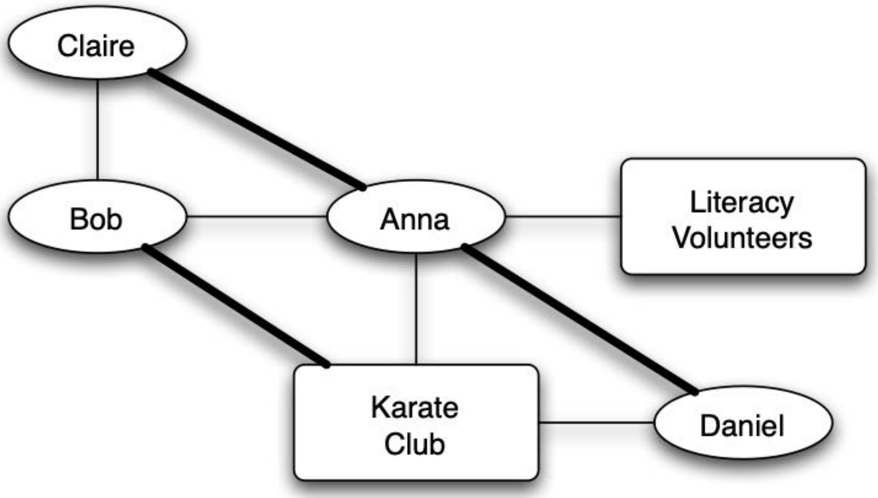
(b) *Focal closure*



(c) *Membership closure*

More on Closures

- **In which links is more likely that the following factors played a role?**
  - Friendship transitivity?
  - Focal closure
  - Membership closure



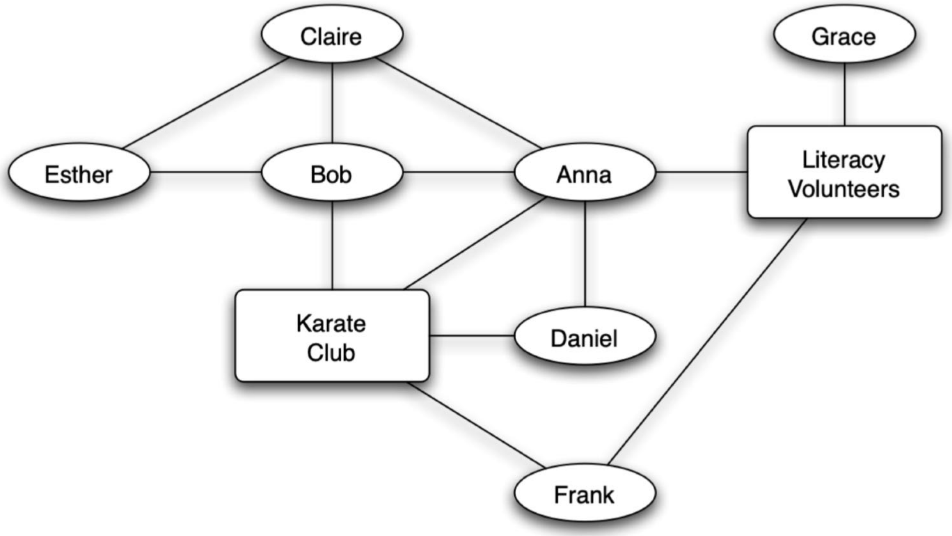
Tracking Link Formation in Online Data

Data from online platforms

- **caveat:** it is never a priori clear how much one can extrapolate from digital interactions to interactions that are not computer-mediated, or even from one computer-mediated setting to another.

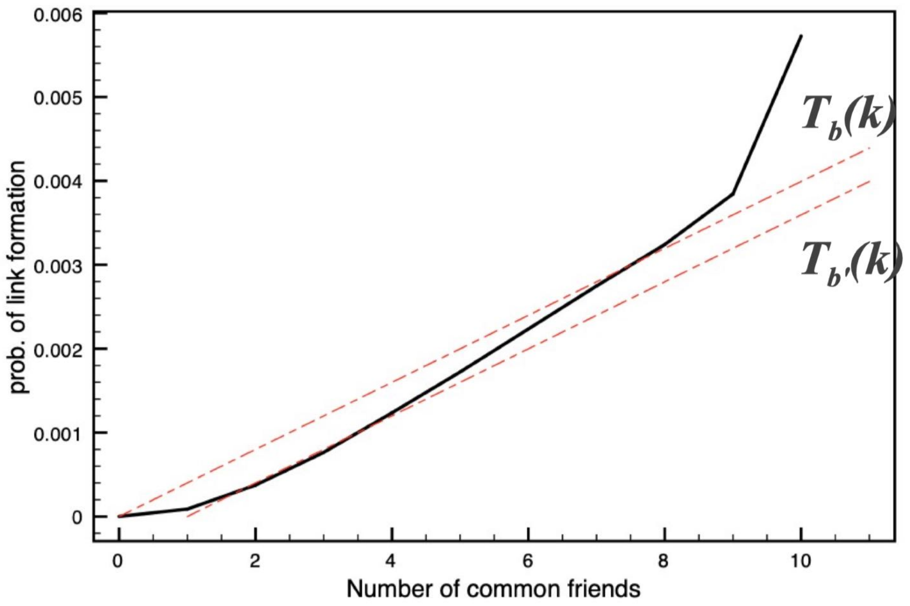
Triadic closure: numerical questions

- How much is likely for a link to form if it has the effect of closing a triangle?
- How much more likely is a link to form if it closes many triangles?



Experimental setting

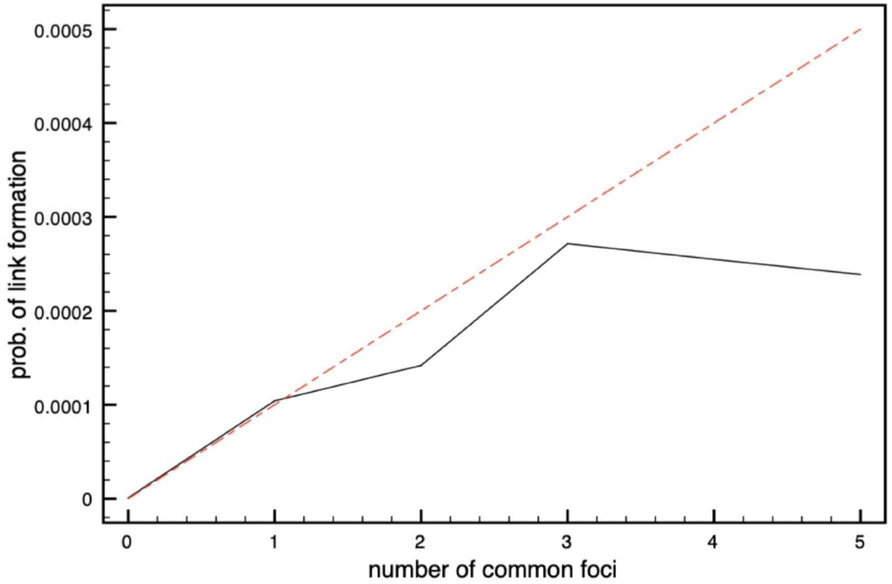
- Two snapshots of the network at time t and t'
- For each k, identify all pairs of nodes who have exactly k friends in common at time t, but who are not directly connected by an edge
- $T(k)$ = the fraction of these pairs that have formed an edge by t'
  - empirical probability that a link will form between two people with k friends in common
- 2 people having a friend in common, have an independent small probability p to connect each other, $(1-p)^k$ probability the link fails to form
- Two baselines:
  - $T_{baseline}(k) = 1 - (1-p)^k$
  - $T_{baseline'}(k) = 1 - (1-p)^{k-1}$



- Reference:
    - Kossinets and Watts, e-mail communication among roughly 22,000 undergraduate and graduate students over a one-year period at a large U.S. university
- **The common friends assumption is too simple!**
- There is "something" more than this

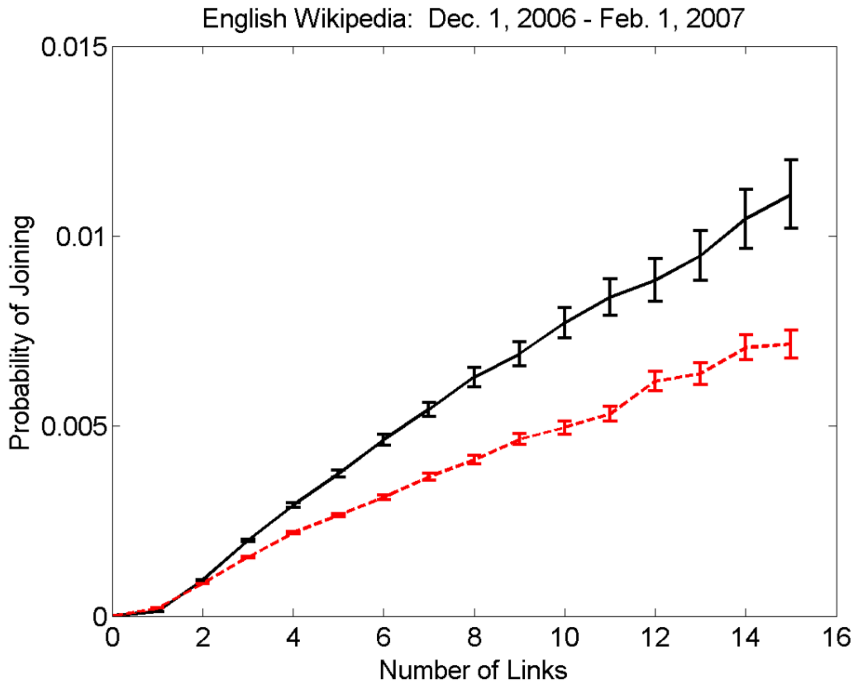
Focal closure: looking for evidence

- **focal closure:** what is the probability that two people form a link as a function of the number of foci they are jointly affiliated with?
- email dataset + information on class schedules for each student
    - Empirical evidence: it turns **downward** and appears to approximately **level off**
    - subsequent shared classes after the first produce a **diminishing returns** effect



Membership closure: Wikipedia case study

- **membership closure:** what is the probability that a person becomes involved with a particular focus as a function of the number of friends already involved?
- Probability of joining a community based on k exposure via social ties (black) versus similarity ties (red)
- social connections via direct communication on the user talk page
- Reference:
    - Feedback Effects between Similarity and Social Influence in Online Communities

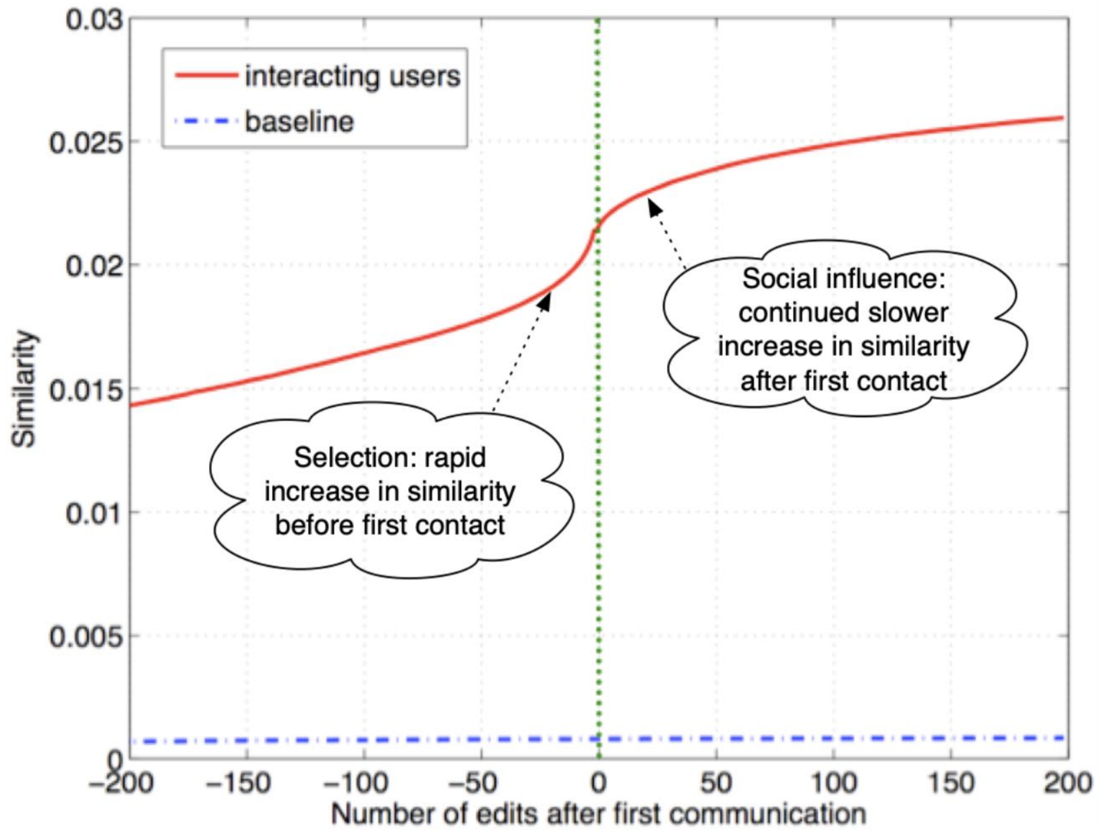


(a) *Wikipedia*

- A and B editors; $NA(X)$ is the number of articles edited by editor X

$$sim(A,B) = \frac{NA(A) \cap NA(B)}{NA(A) \cup NA(B)}$$

- Average similarity of two editors on Wikipedia, relative to time (0) at which they first communicated
- Time (x-axis) measured in discrete units, where each unit is a single Wikipedia action taken by either of the two editors
- **Both selection and influence effects at work!**
- dashed blue line: baseline for non-interacting editors



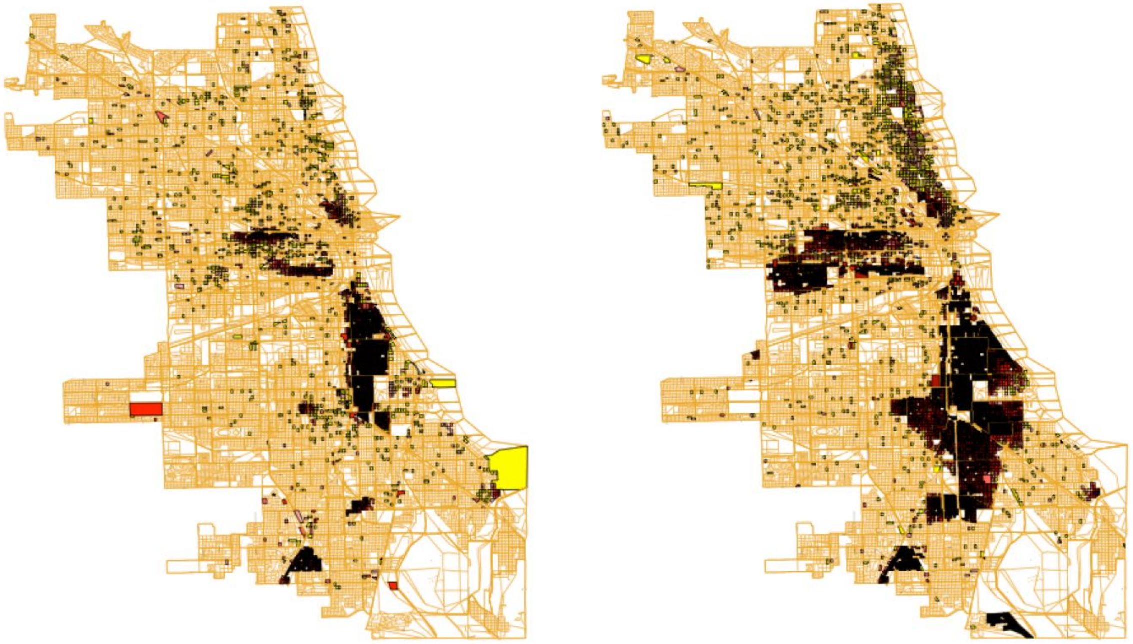
Discussion

- **Diminishing effect over k**
- **Multiple effects** that operate simultaneously on the formation of a link
- **Homophily suggests that friends tend to have similar characteristics**
  - triadic closure
  - focal closure
  - membership closure

A Spatial Model of Segregation

Natural spatial signature in cities

Formation of homogeneous (according to some type or class) neighbors in cities



(a) *Chicago, 1940* (b) *Chicago, 1960*

Blocks colored yellow and orange the percentage of African-Americans is below 25, while in blocks colored brown and black the percentage is above 75

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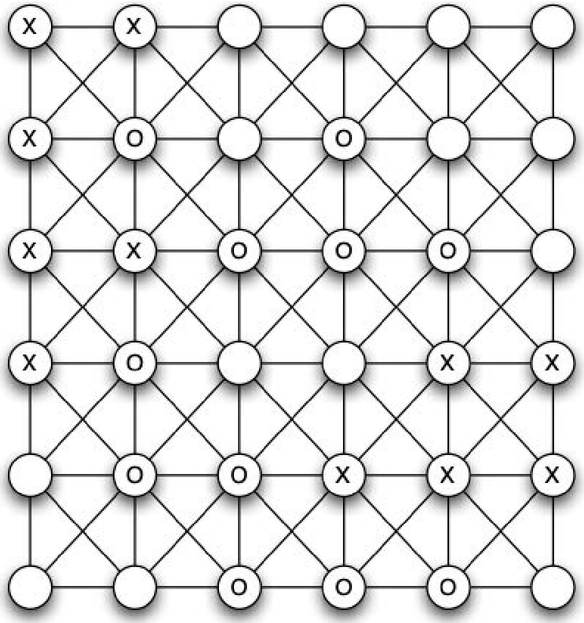
The Schelling Model

- **Can global spatial segregation arise from the effect of homophily operating at a local level?**
- Assumption: no individual want segregation explicitly
- Agents:
  - two types
  - immutable characteristics
- Agents reside in a cell of a grid
  - some cells contain agents
  - some other cells are unpopulated
- Neighbors: 8 other cells "touching" an agent

- **Each agent wants to have at least t neighbors of their type**
- If an agent finds **< t neighbors** of the same type, then they are **unsatisfied**
- **If unsatisfied, they want to move**

X	X				
X	O		O		
X	X	O	O	O	
X	O			X	X
	O	O	X	X	X
		O	O	O	

(a) *Agents occupying cells on a grid.*



(b) *Neighbor relations as a graph.*

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The dynamics of movements

- **Agents move in a sequence of rounds**
- If there is no empty cells around an unsatisfied agent:
  - **move the agent randomly** or
  - **leave the agent there**

X1*	X2*				
X3	O1*		O2		
X4	X5	O3	O4	O5*	
X6*	O6			X7	X8
	O7	O8	X9*	X10	X11
		O9	O10	O11*	

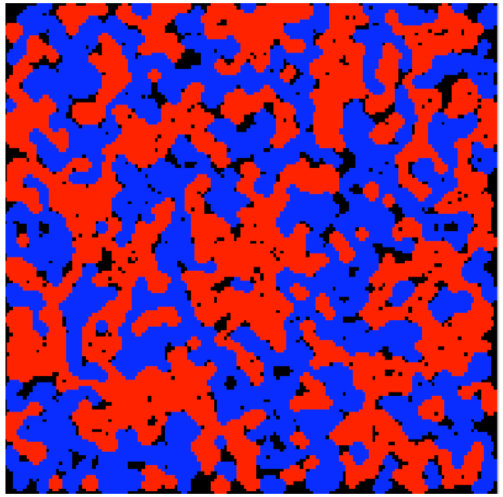
(a) *An initial configuration.*

X3	X6	O1	O2		
X4	X5	O3	O4		
	O6	X2	X1	X7	X8
O11	O7	O8	X9	X10	X11
	O5	O9	O10*		

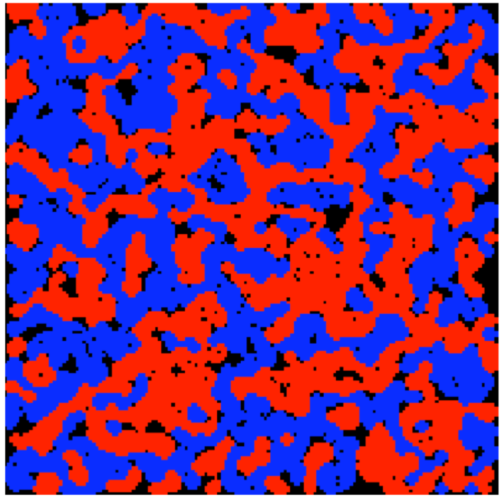
(b) *After one round of movement.*

Larger examples

- Computer simulations to look for patterns at a larger scale
- We want to run different simulations and make some comparisons ⇒ integrated pattern?
- on the right: two runs of a simulations of the Schelling model with a threshold t of 3
    - 150x150 grid
    - 10,000 agents
- Segregation emerges even when agents accept to be a minority!



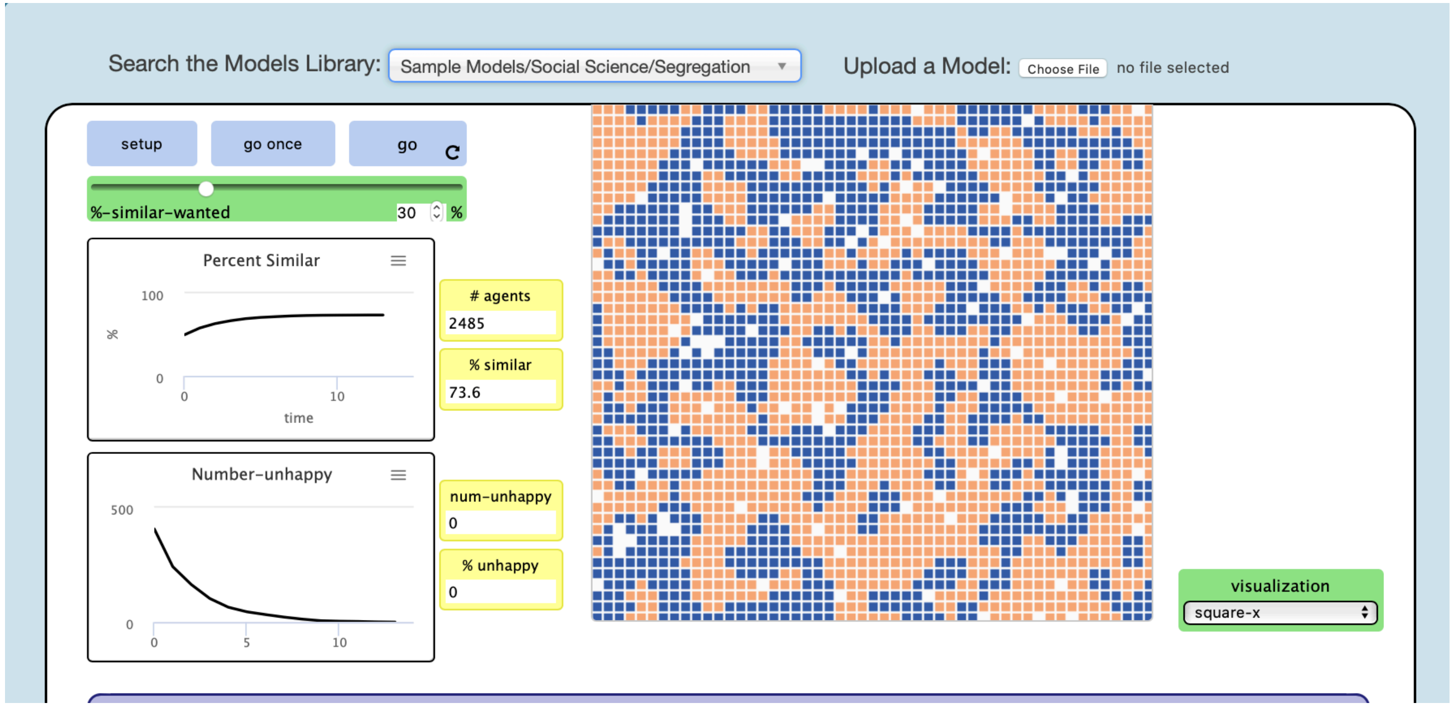
(a) *A simulation with threshold 3.*



(b) *Another simulation with threshold 3.*

NetLogo

Agent-based simulations



Try it out!

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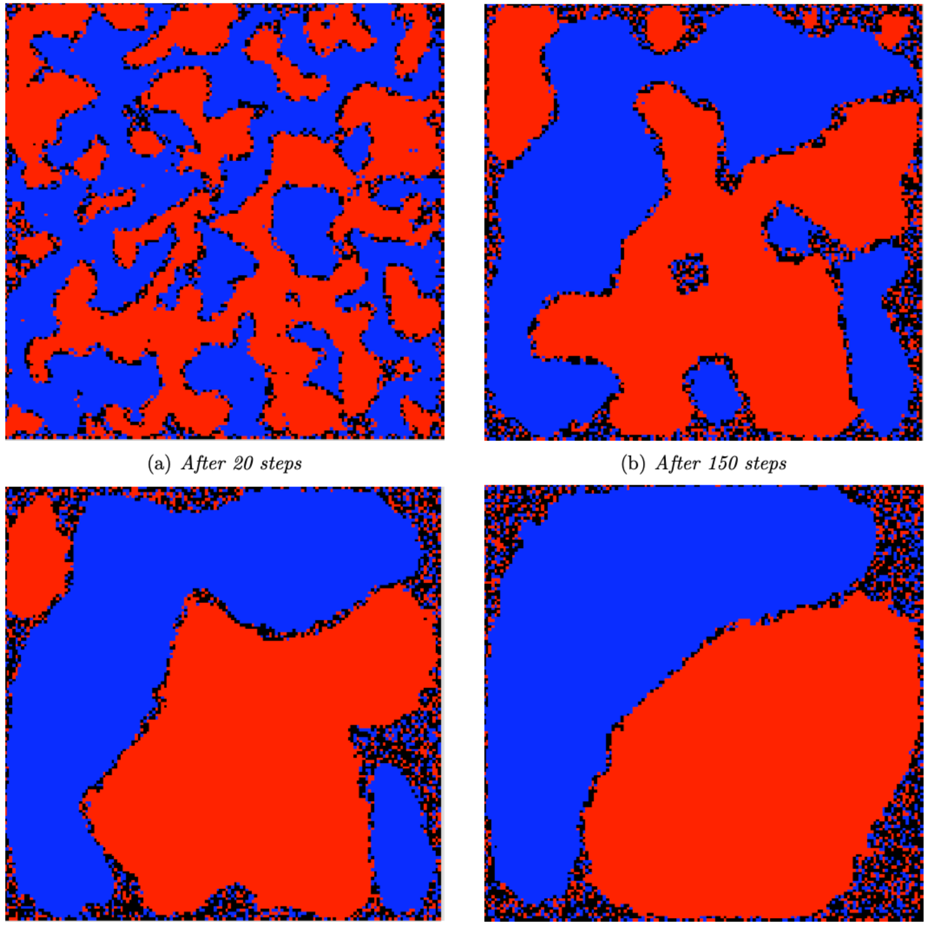
Interpretation of the model

- Optimistic hypothesis: an agent would be perfectly happy to be in minority with $t = 3$
- Realizations, as the one in the example, are possible
  - **segregated realizations are more likely**
- The basic (random) reasons behind segregation are at work even in an idealized setting where agents are perfectly happy of being a minority

x	x	o	o	x	x
x	x	o	o	x	x
o	o	x	x	o	o
o	o	x	x	o	o
x	x	o	o	x	x
x	x	o	o	x	x

If t is larger, segregation is amplified



(a) *After 20 steps*

(b) *After 150 steps*

(c) *After 350 steps*

(d) *After 800 steps*

Reading material

References

[ns1] **Chapter 2 (2.1)**

[ns2] **Chapter 4 (4.1-4.5)**

Q&A