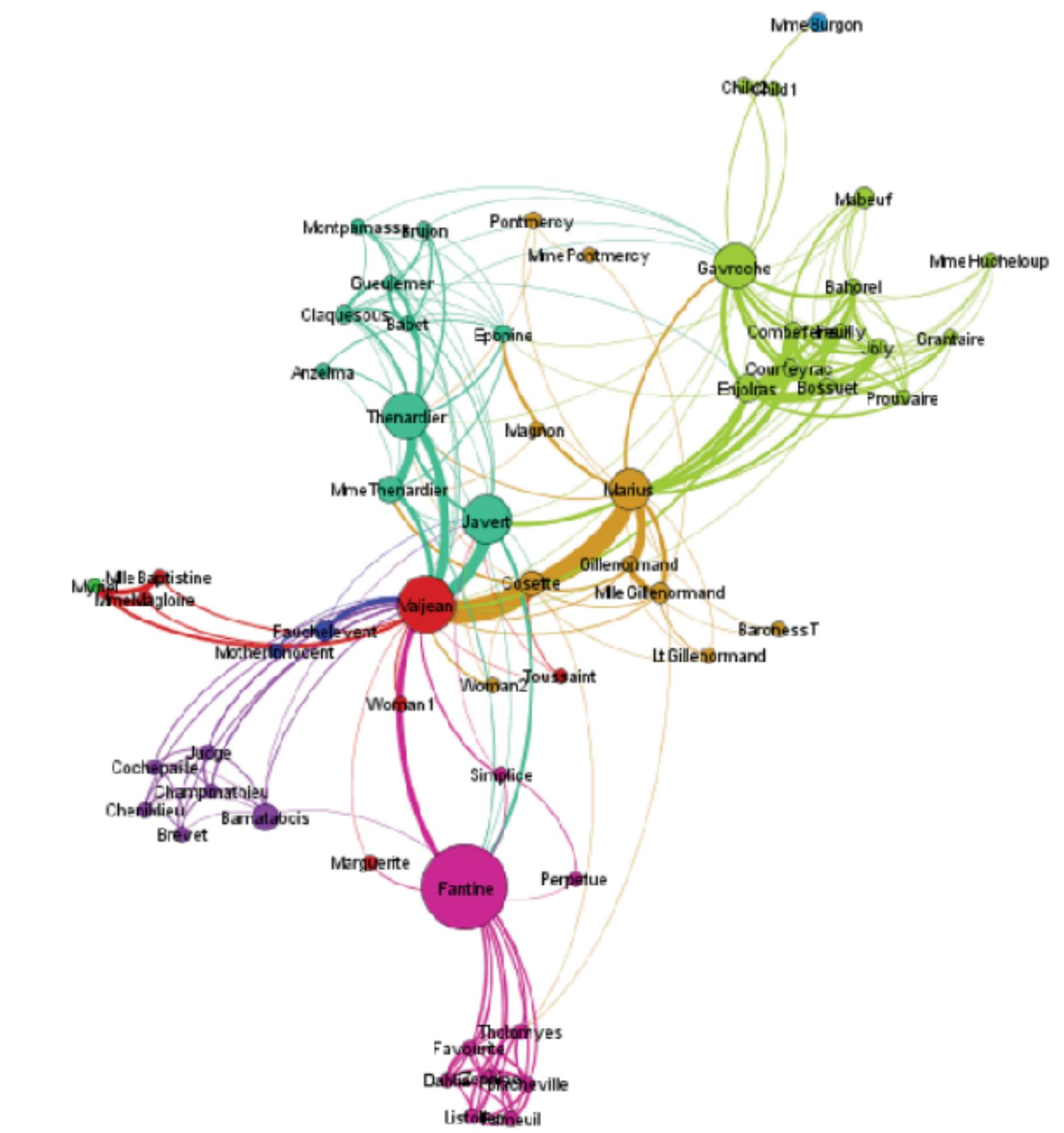


Lecture 21: Network analysis and visualization

Instructor: Michael Szell
Nov 15, 2023

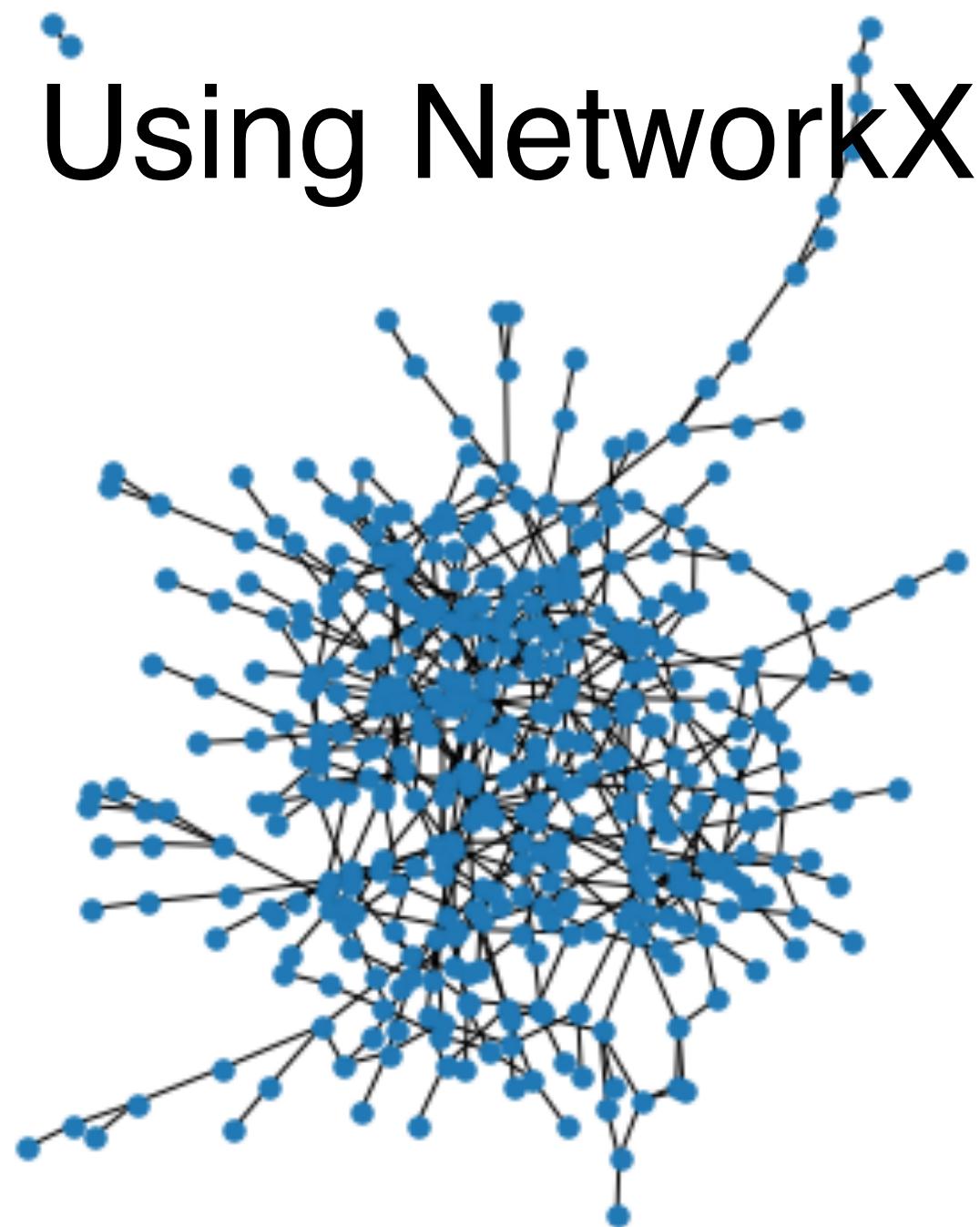


Today you will learn about analyzing and visualizing networks

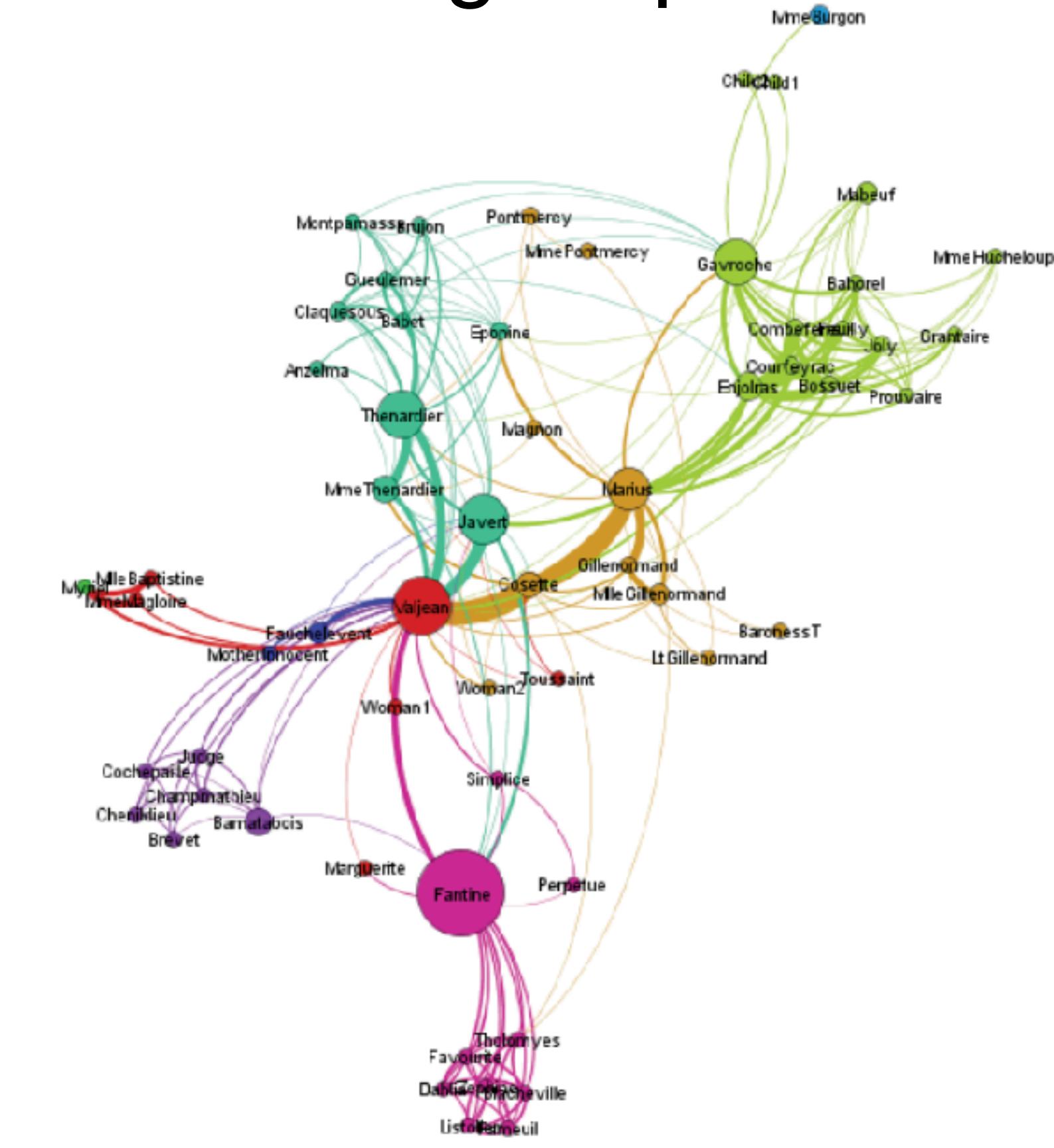
Centrality and community: Who is important?



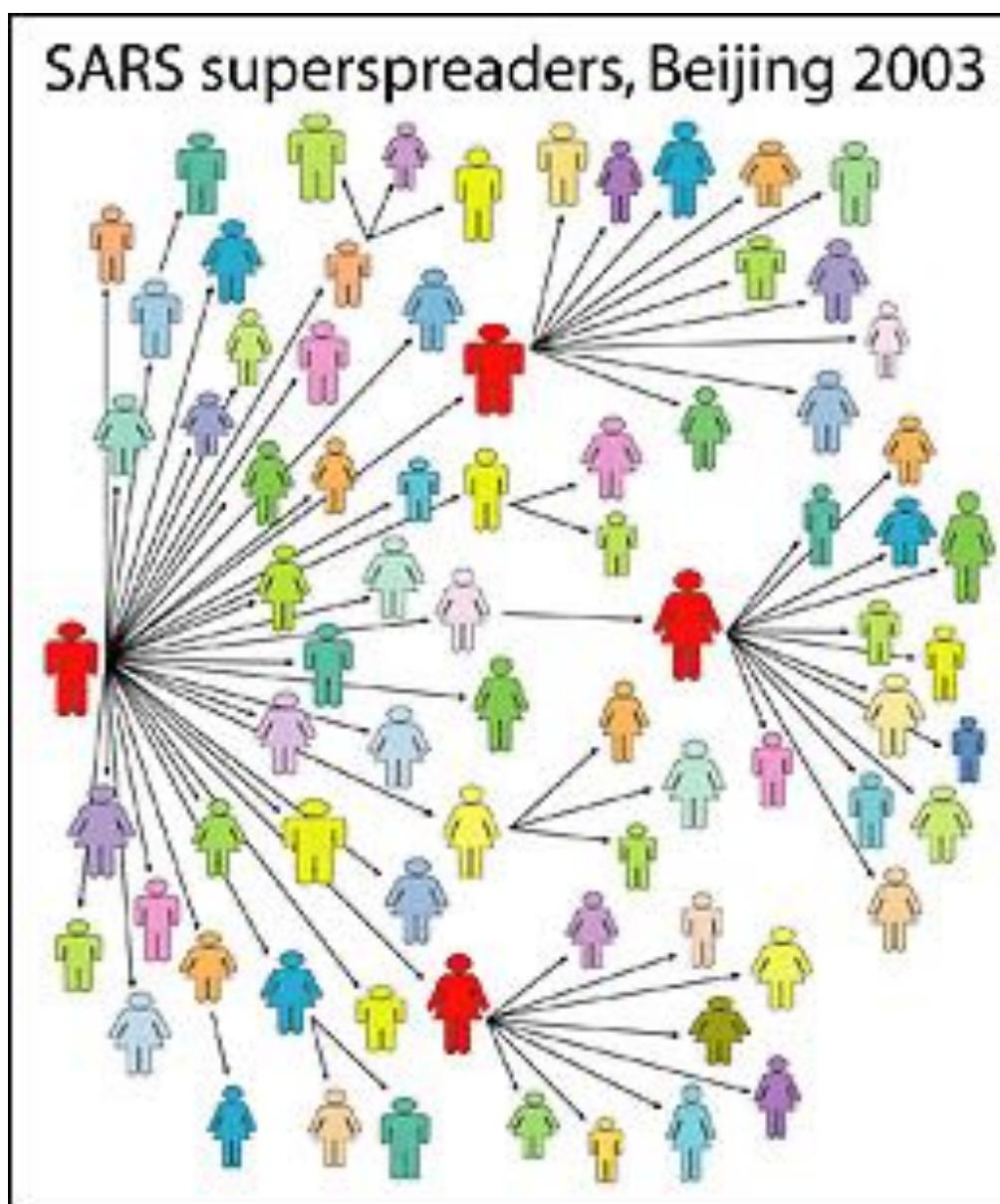
Using NetworkX



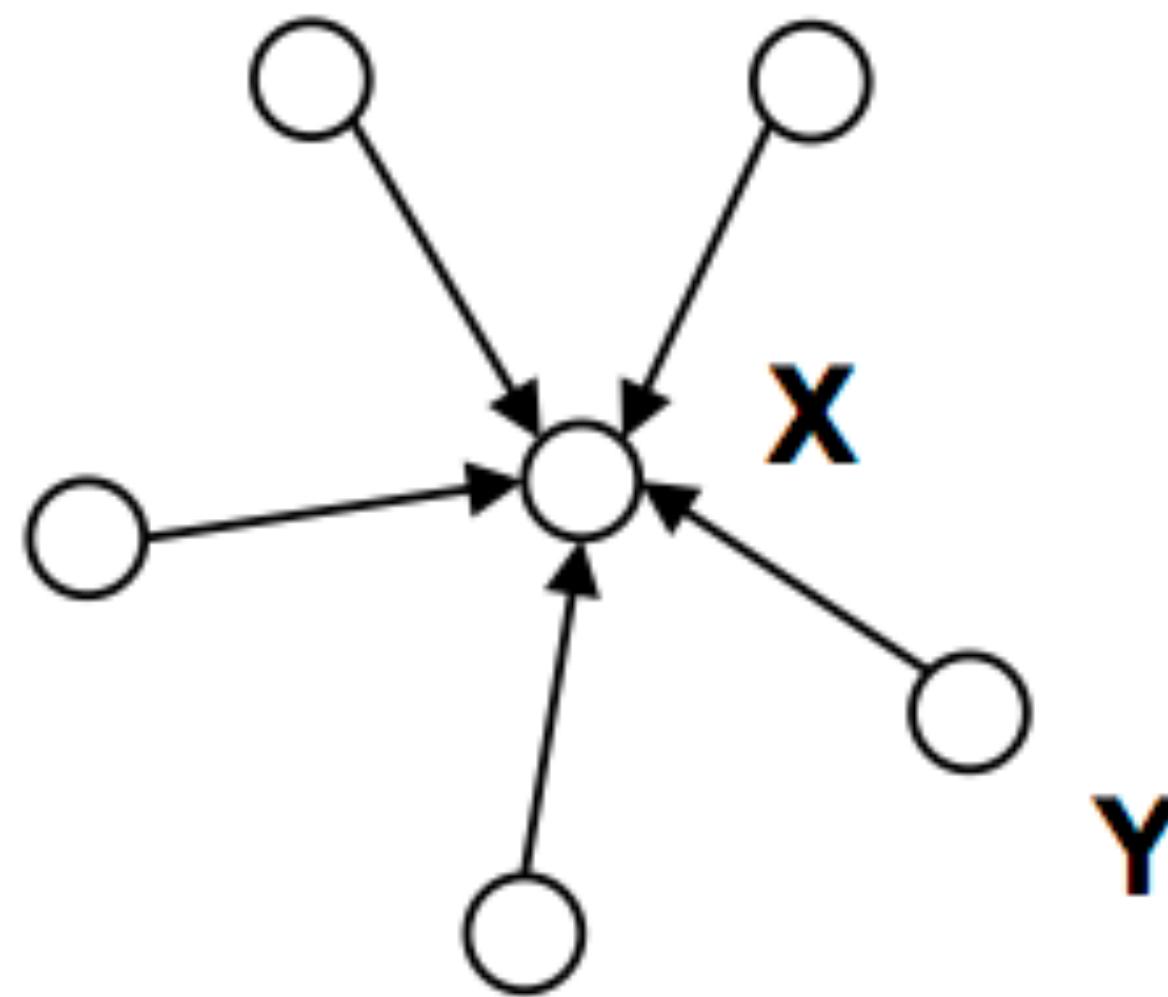
Using Gephi



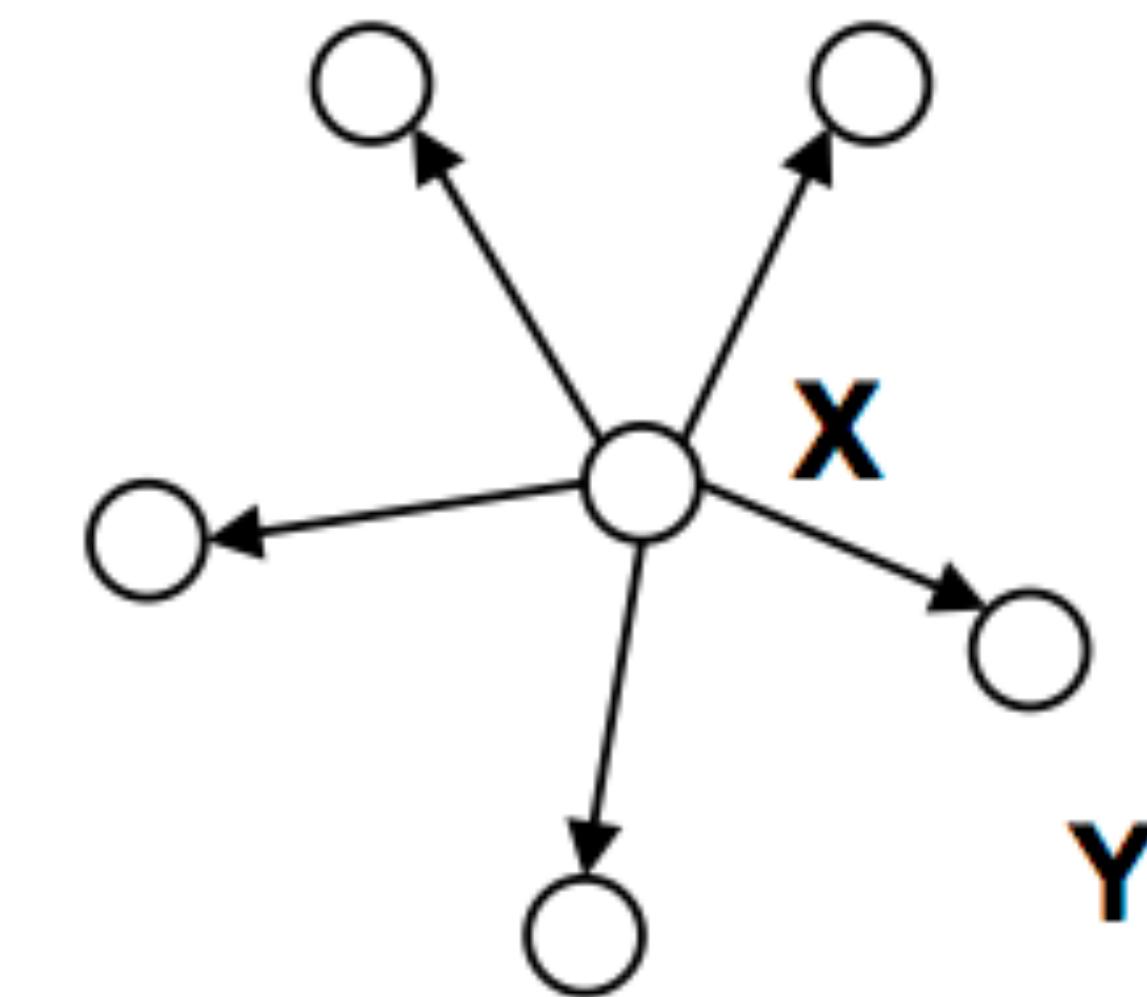
Centrality is a measure of a node's importance in the network



Degree can be a measure of importance

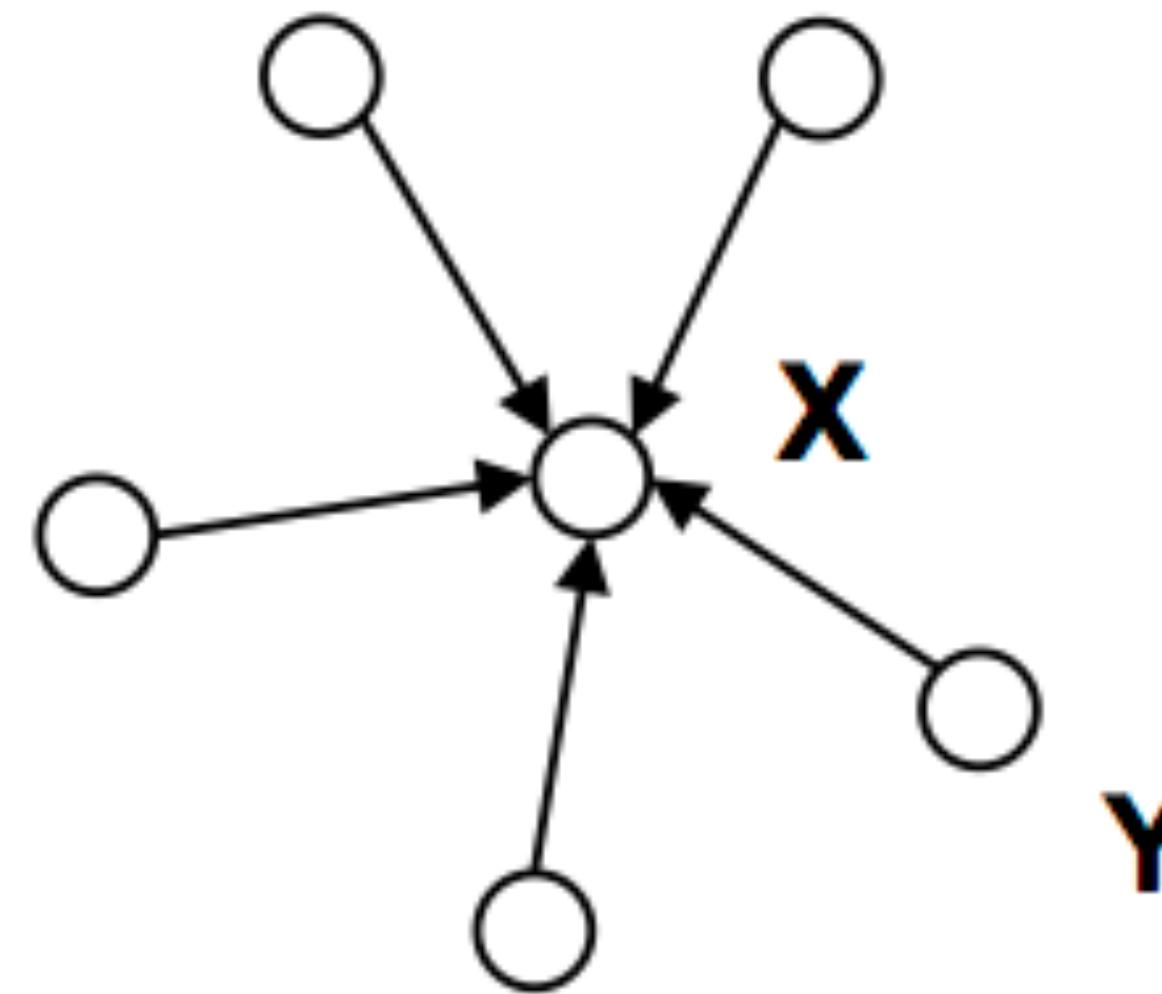


indegree



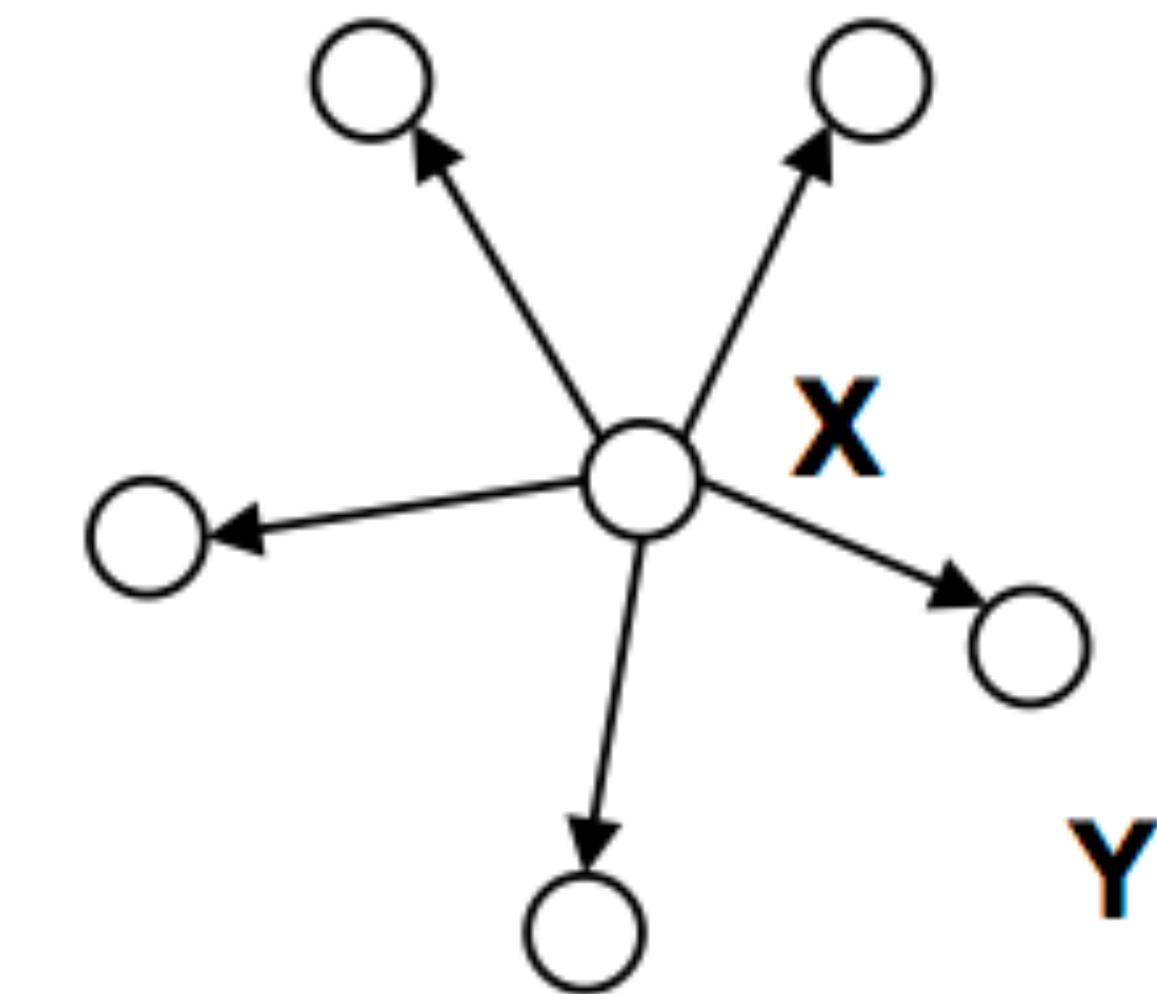
outdegree

Degree can be a measure of importance



indegree

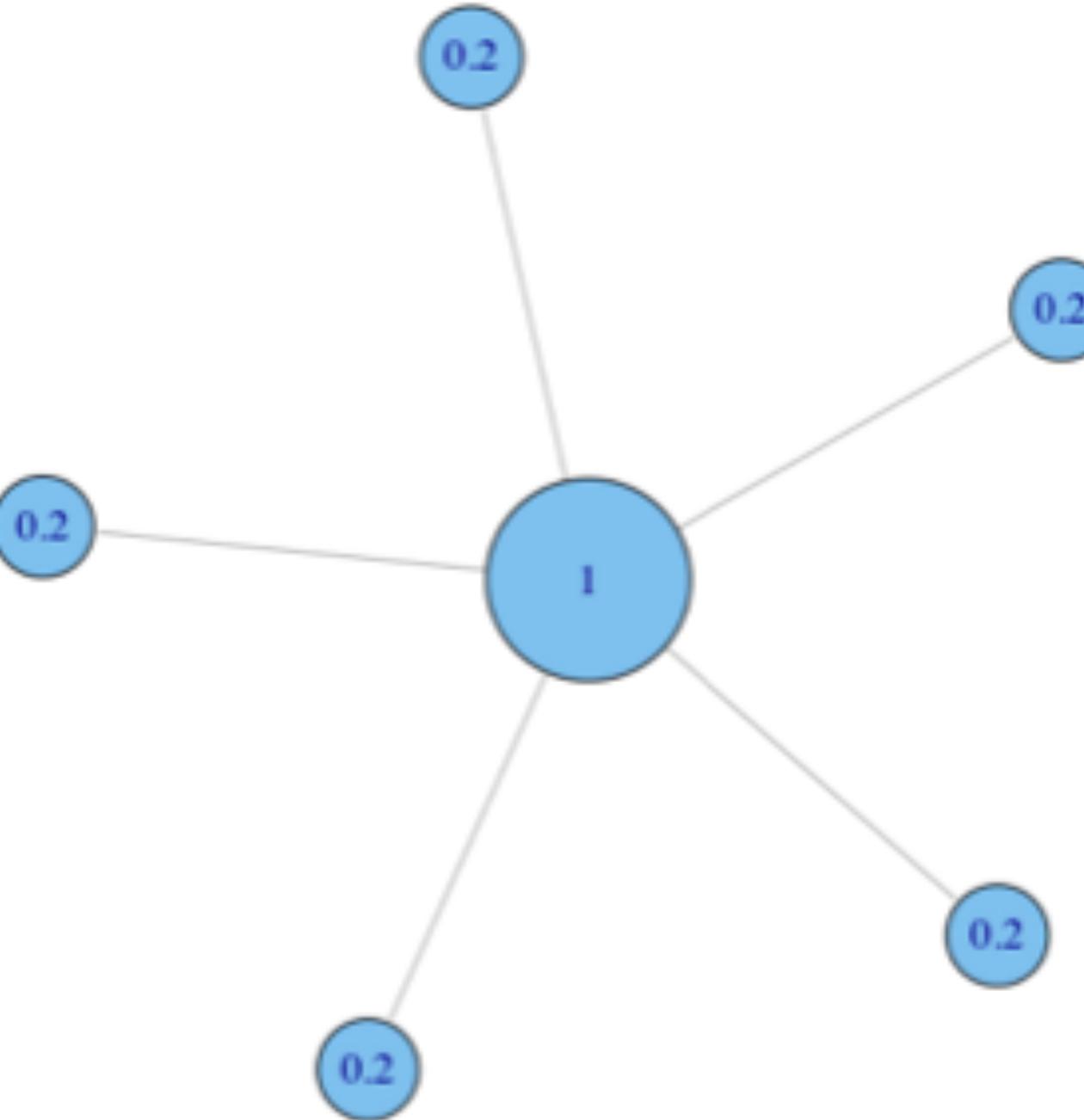
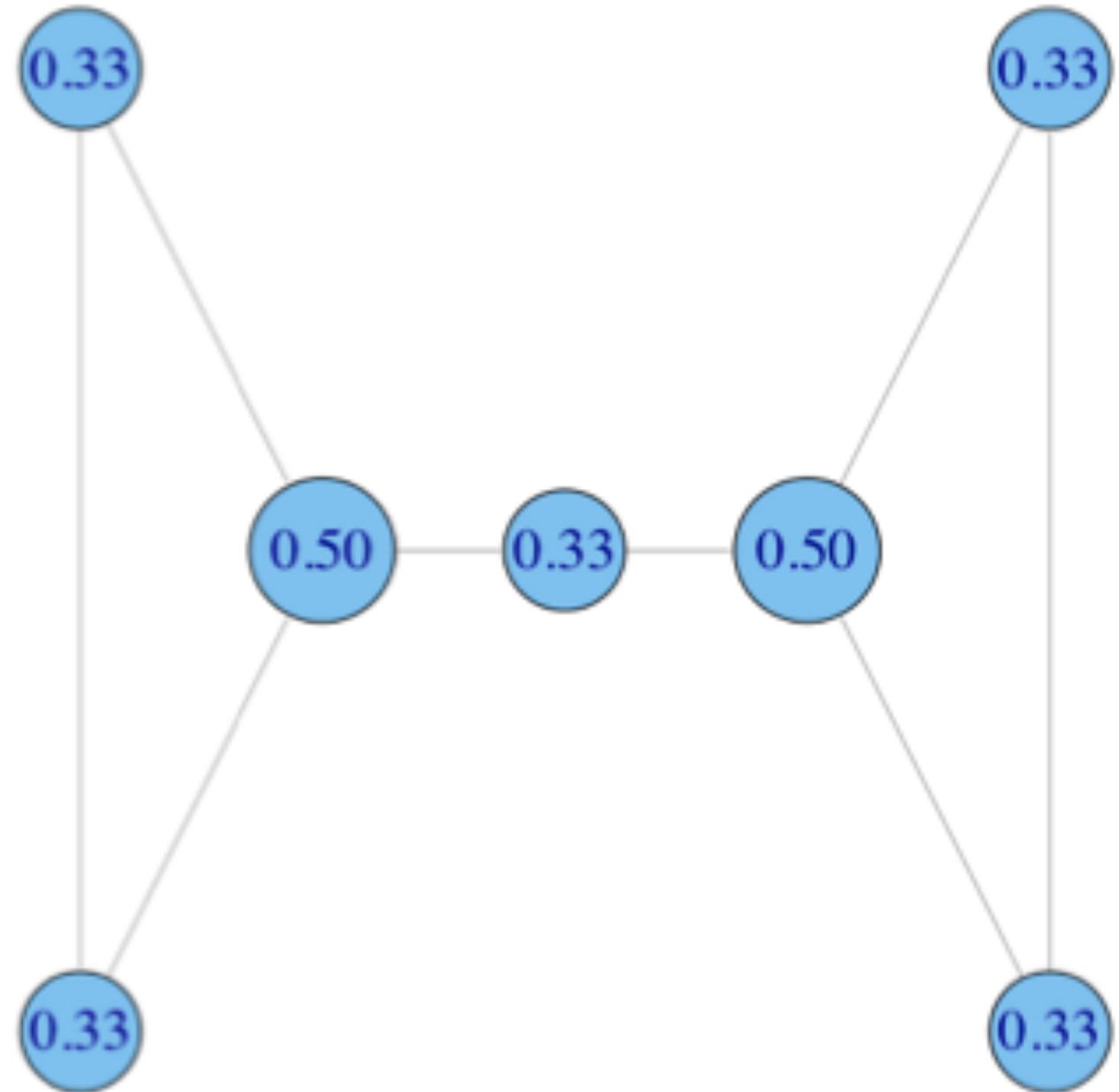
How popular you are



outdegree

How many people
you know

Degree centrality C_D measures the degree

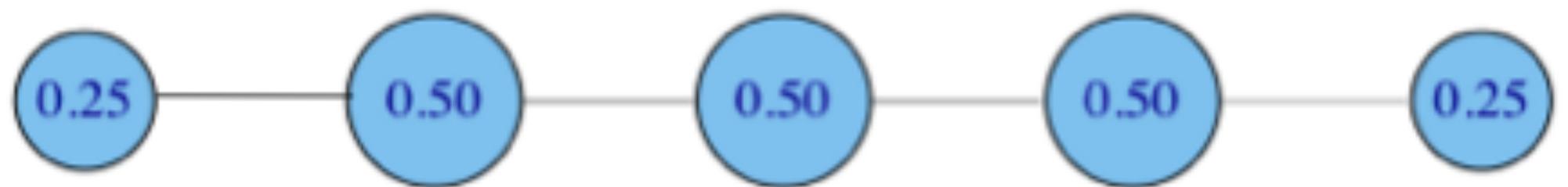


unnormalized

$$\tilde{C}_D(i) = k_i$$

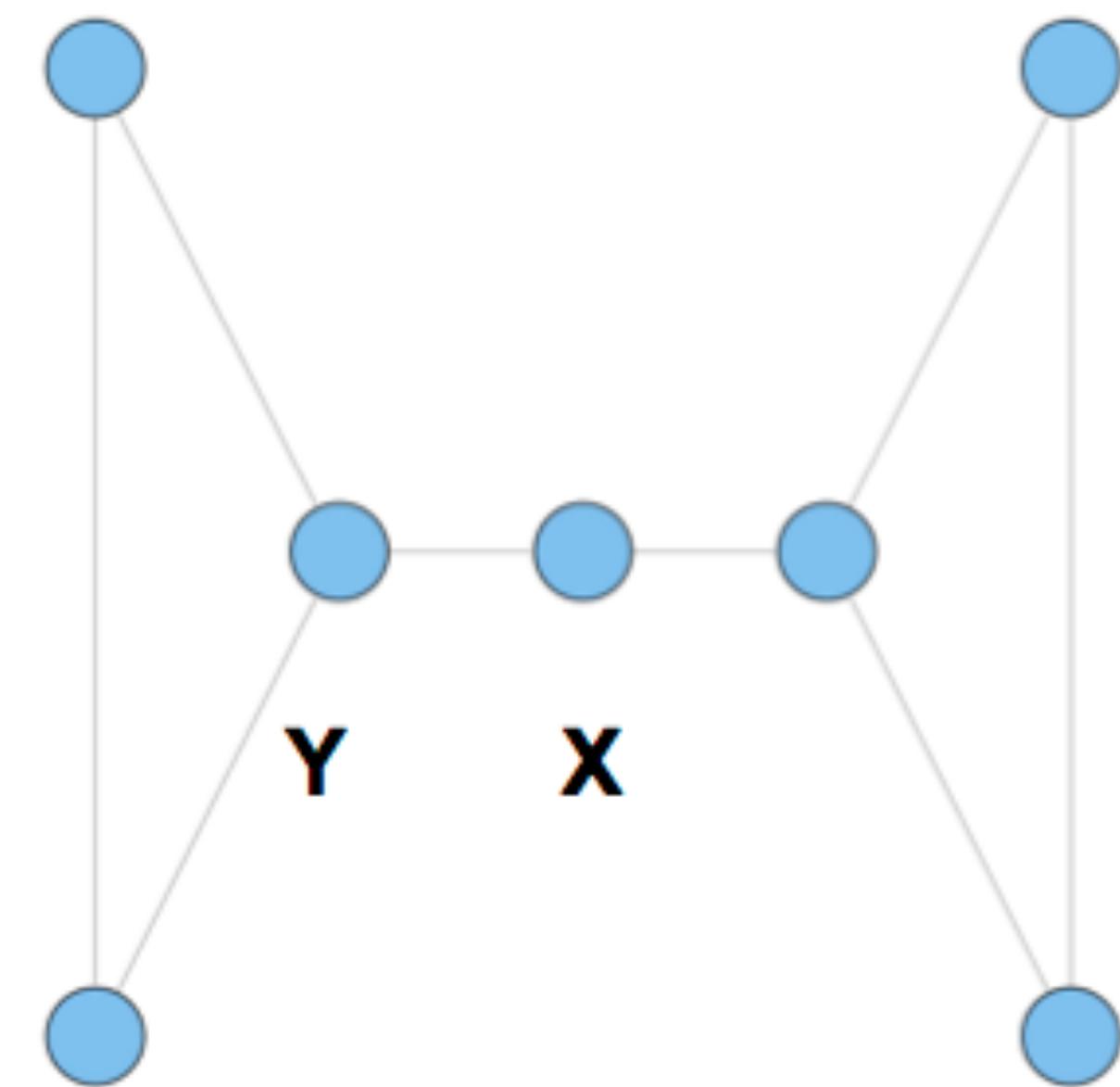
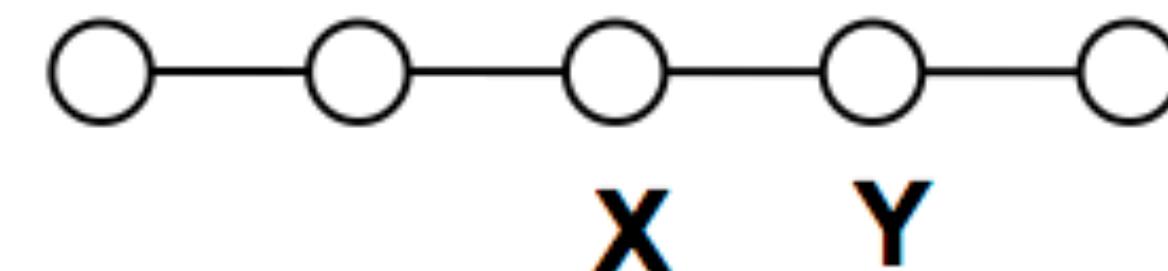
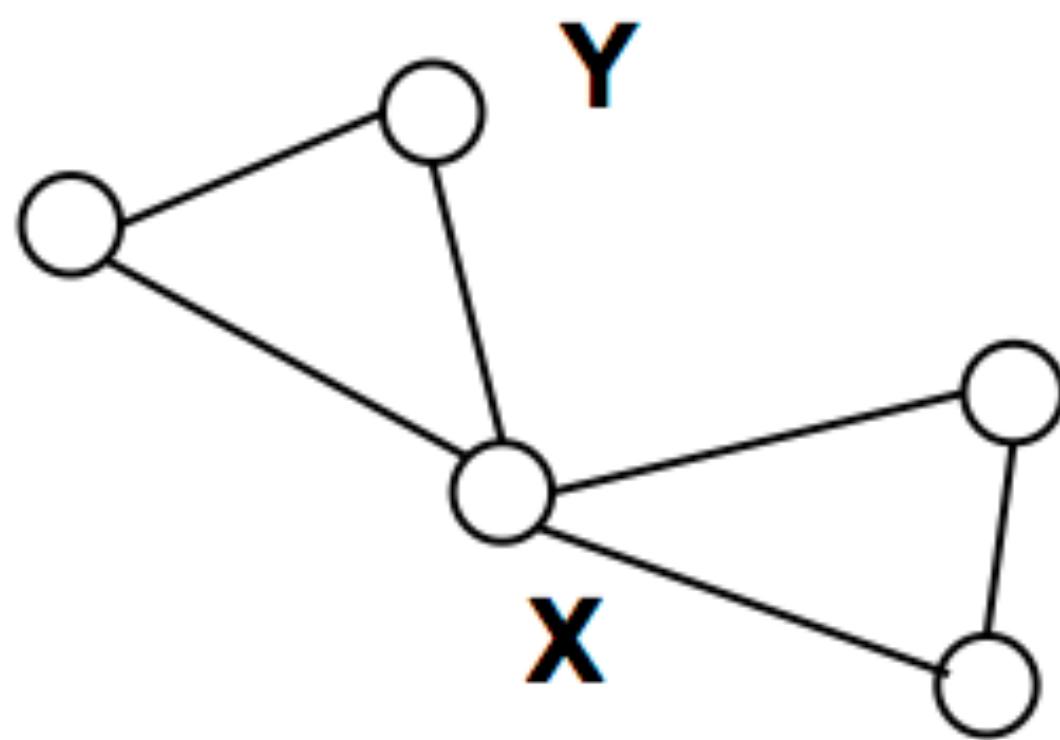
normalized

$$C_D(i) = \frac{\tilde{C}_D(i)}{N - 1}$$



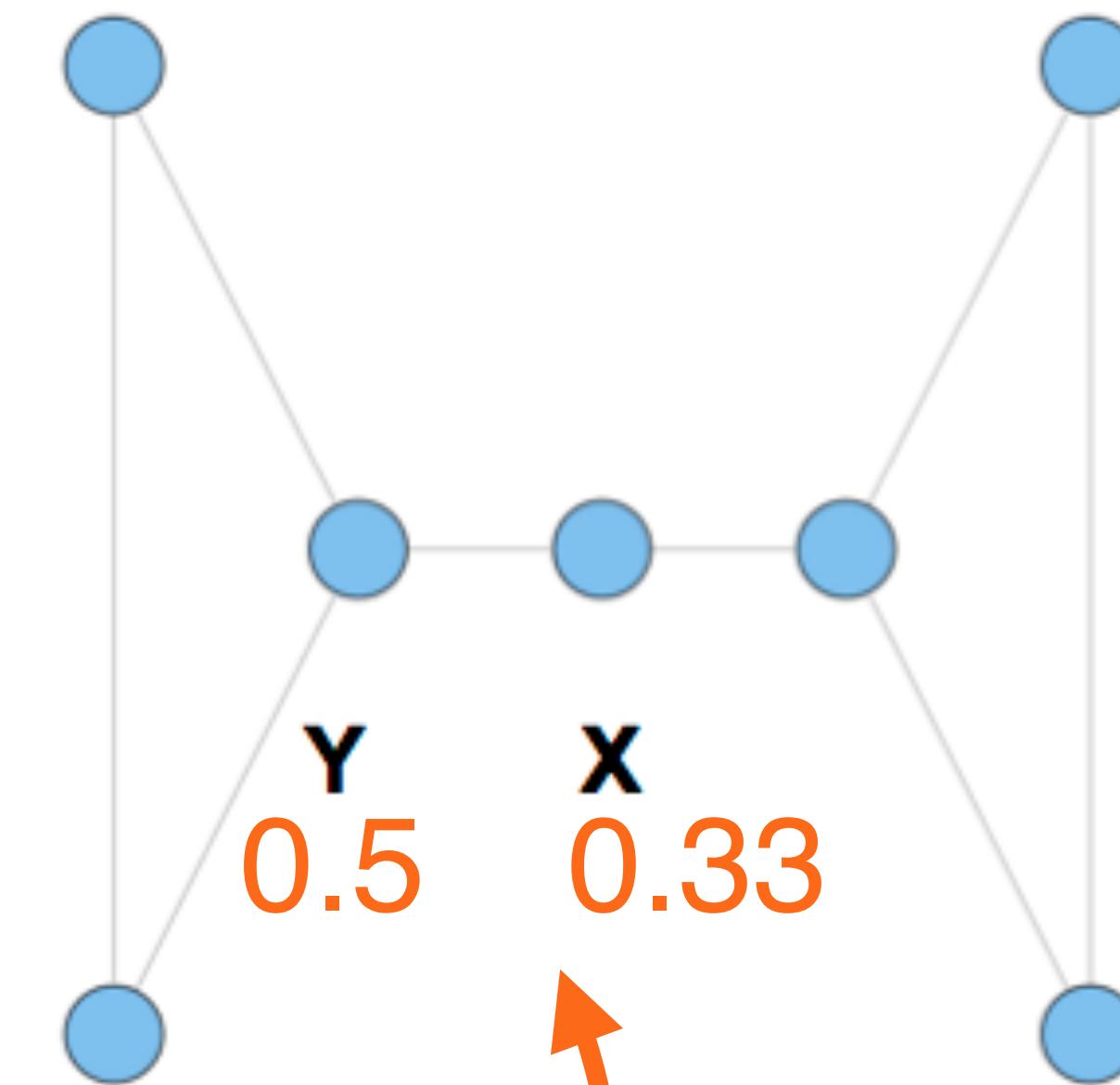
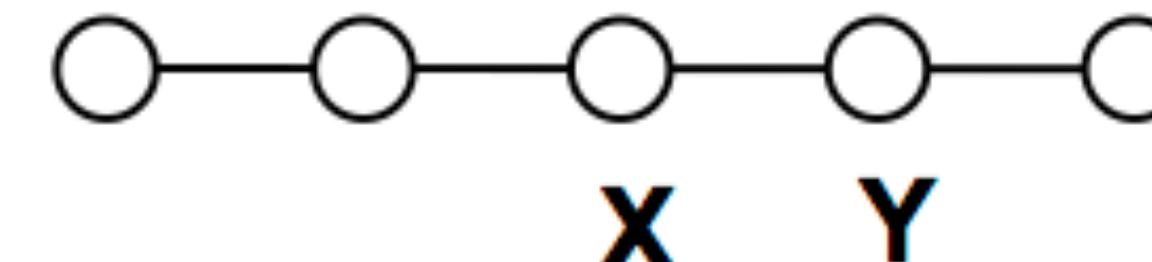
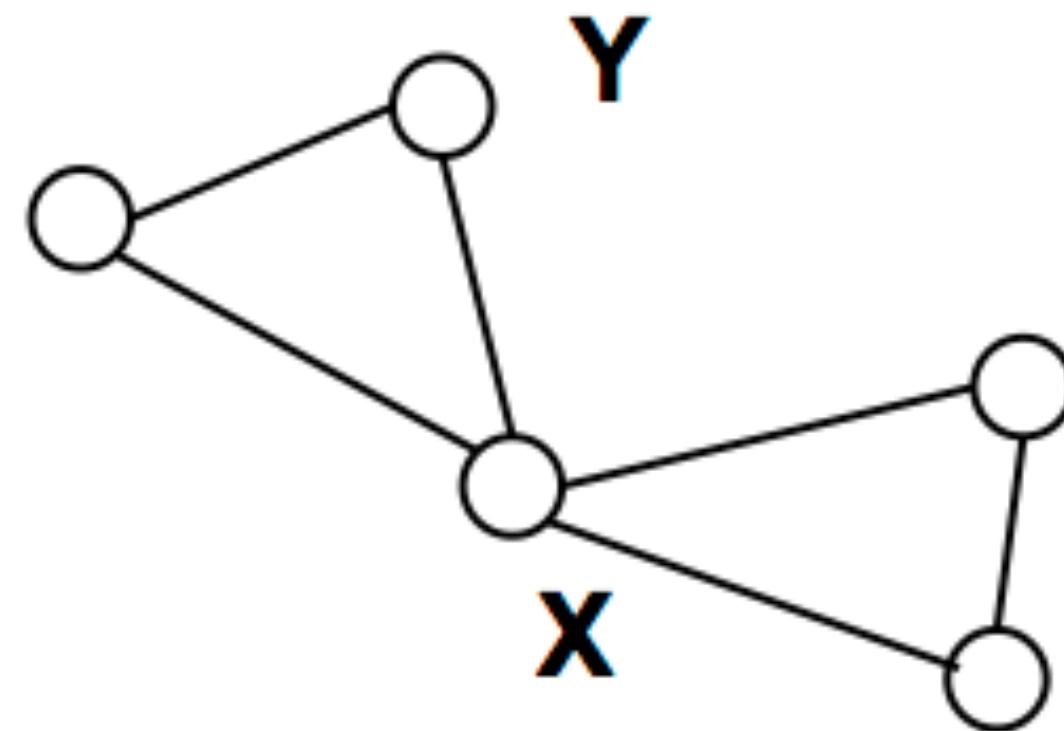
Degree is not everything

Who is more important: X or Y?



Degree is not everything

Who is more important: X or Y?



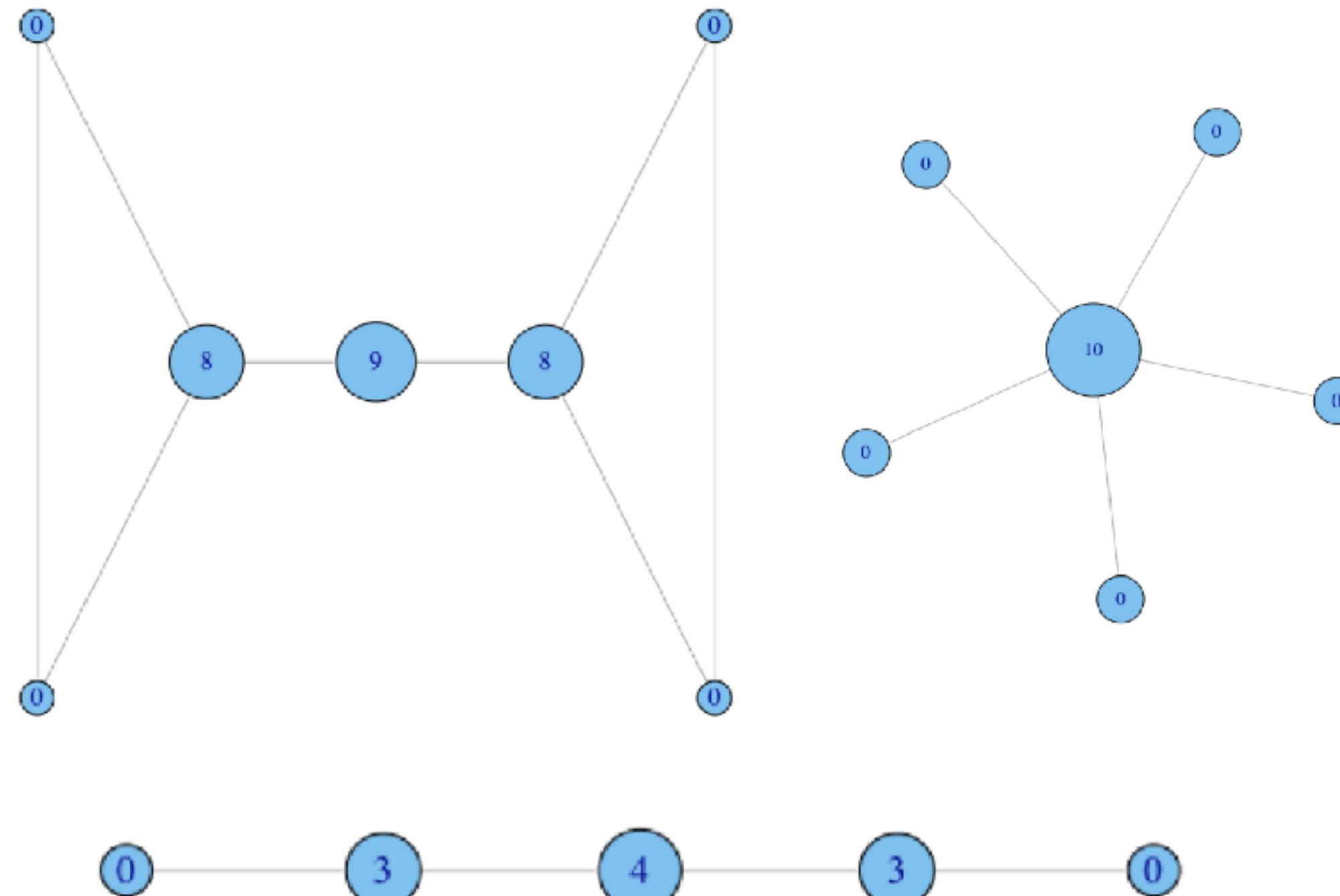
If we care about the ability to broker between groups, or to ~~catch~~ information originating anywhere, degree centrality can **fail**

Betweenness centrality C_B captures being part of shortest paths

$$\tilde{C}_B(i) = \sum_{i \neq j \neq k} \frac{\sigma_{jk}(i)}{\sigma_{jk}}$$

$\sigma_{jk}(i) \leftarrow$ Number of shortest paths between j and k that go through i

$\sigma_{jk} \leftarrow$ Number of all shortest paths between j and k

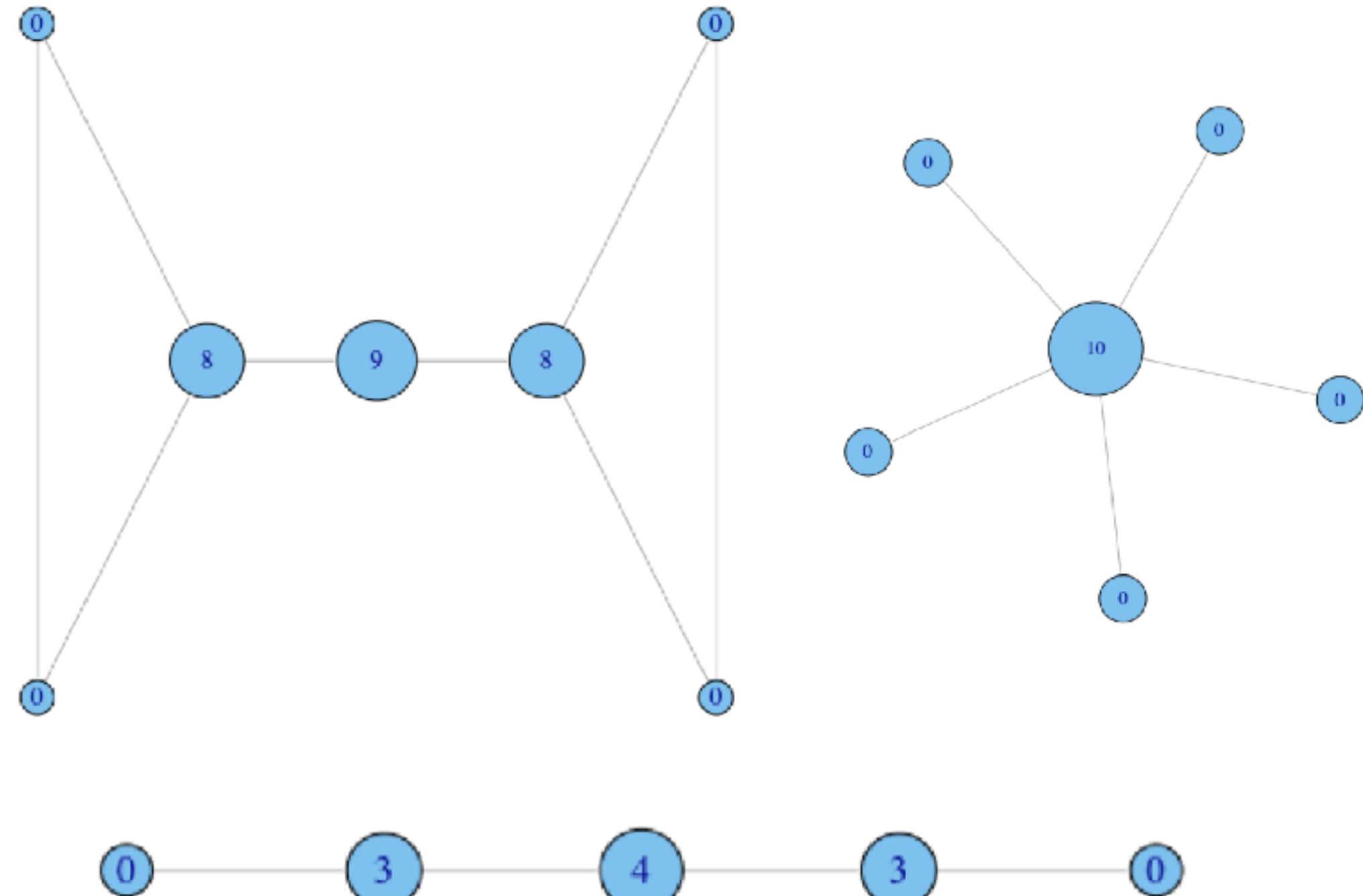


Betweenness centrality C_B captures being part of shortest paths

$$\tilde{C}_B(i) = \sum_{i \neq j \neq k} \frac{\sigma_{jk}(i)}{\sigma_{jk}} \leftarrow$$

Number of shortest paths between j and k
that go through i

$\sigma_{jk} \leftarrow$ Number of all shortest paths between j and k

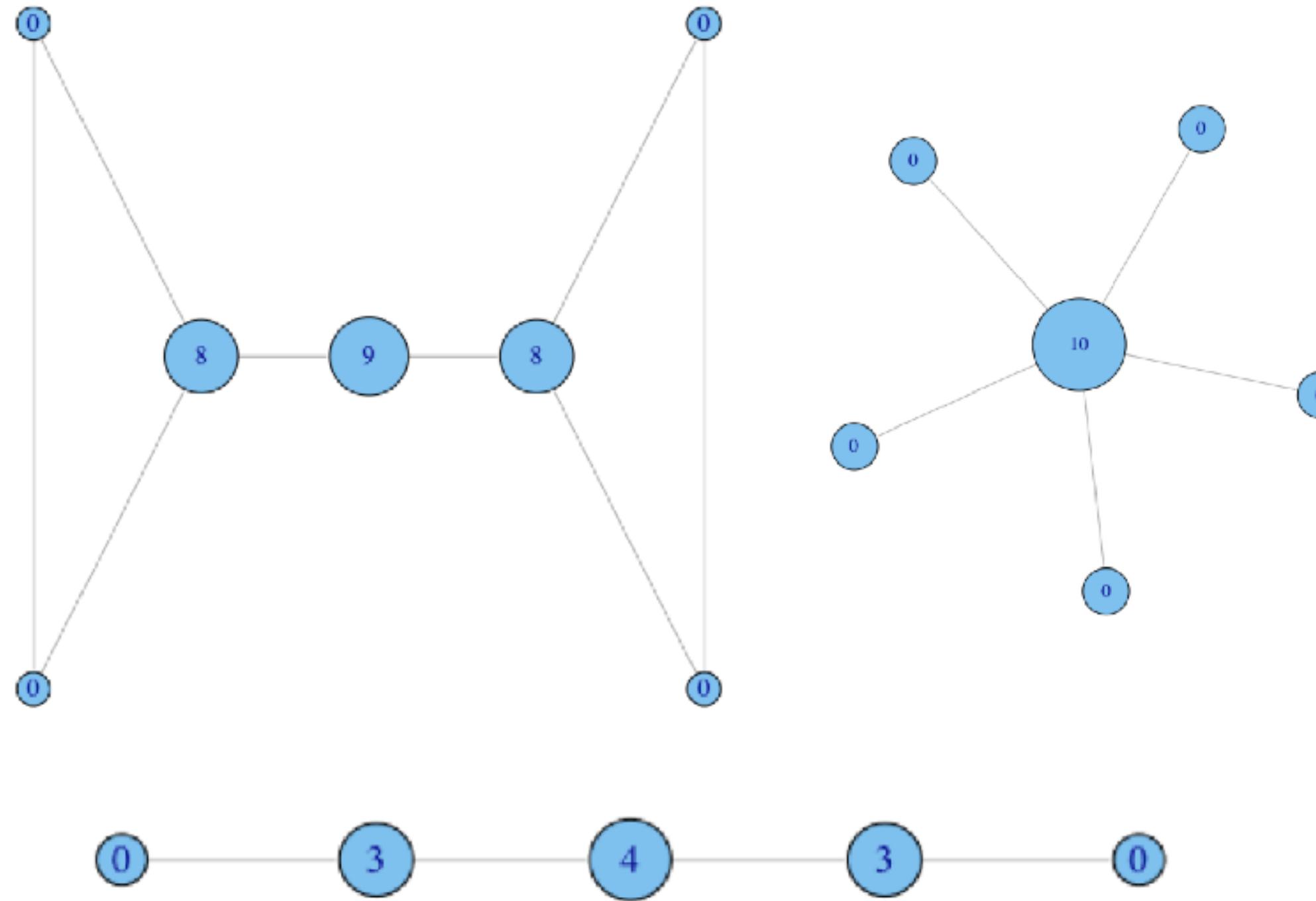


normalized

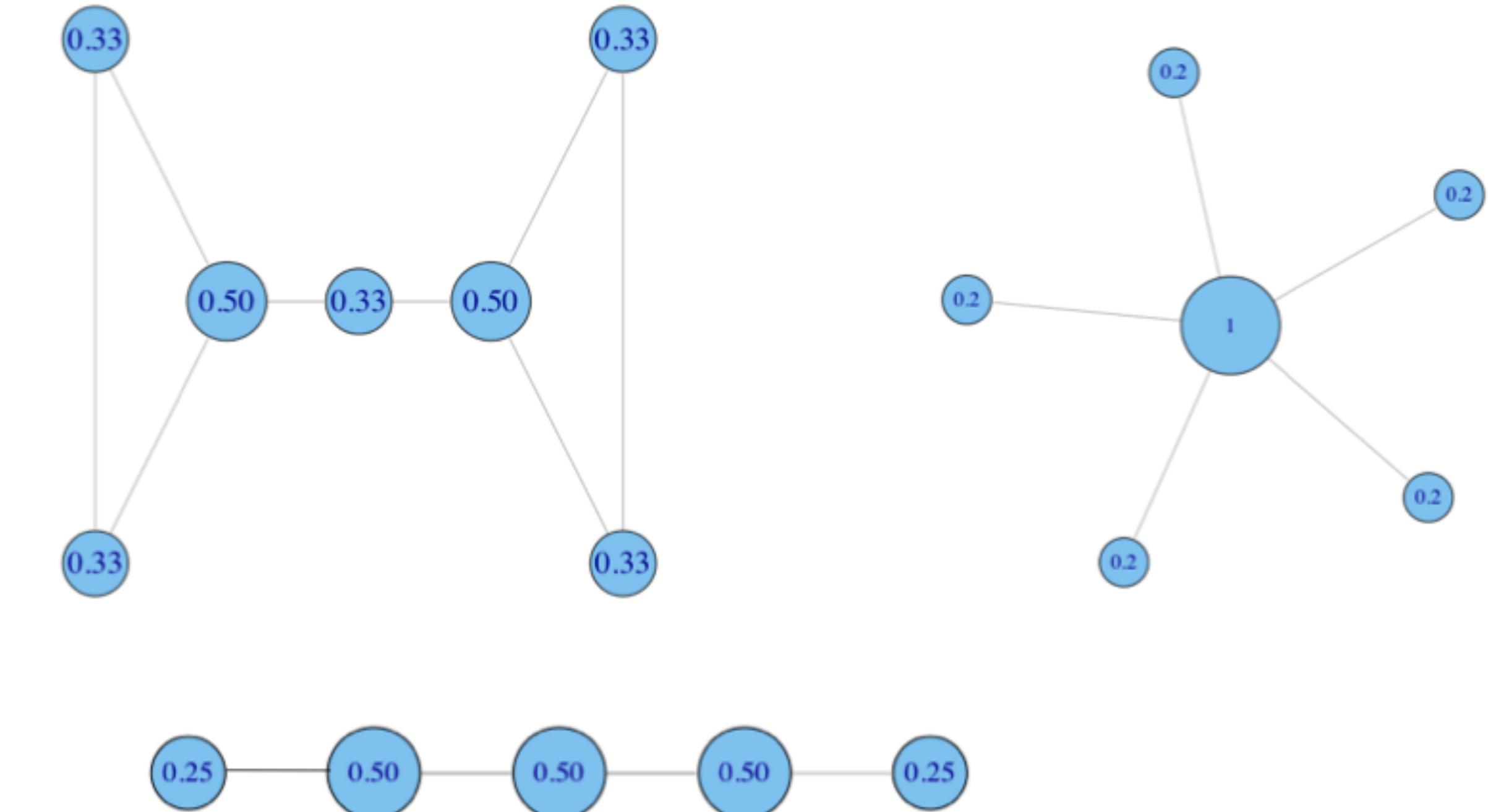
$$C_B(i) = \frac{\tilde{C}_B(i)}{(N-1)(N-2)/2}$$

Betweenness centrality C_B captures being part of shortest paths

Betweenness centrality

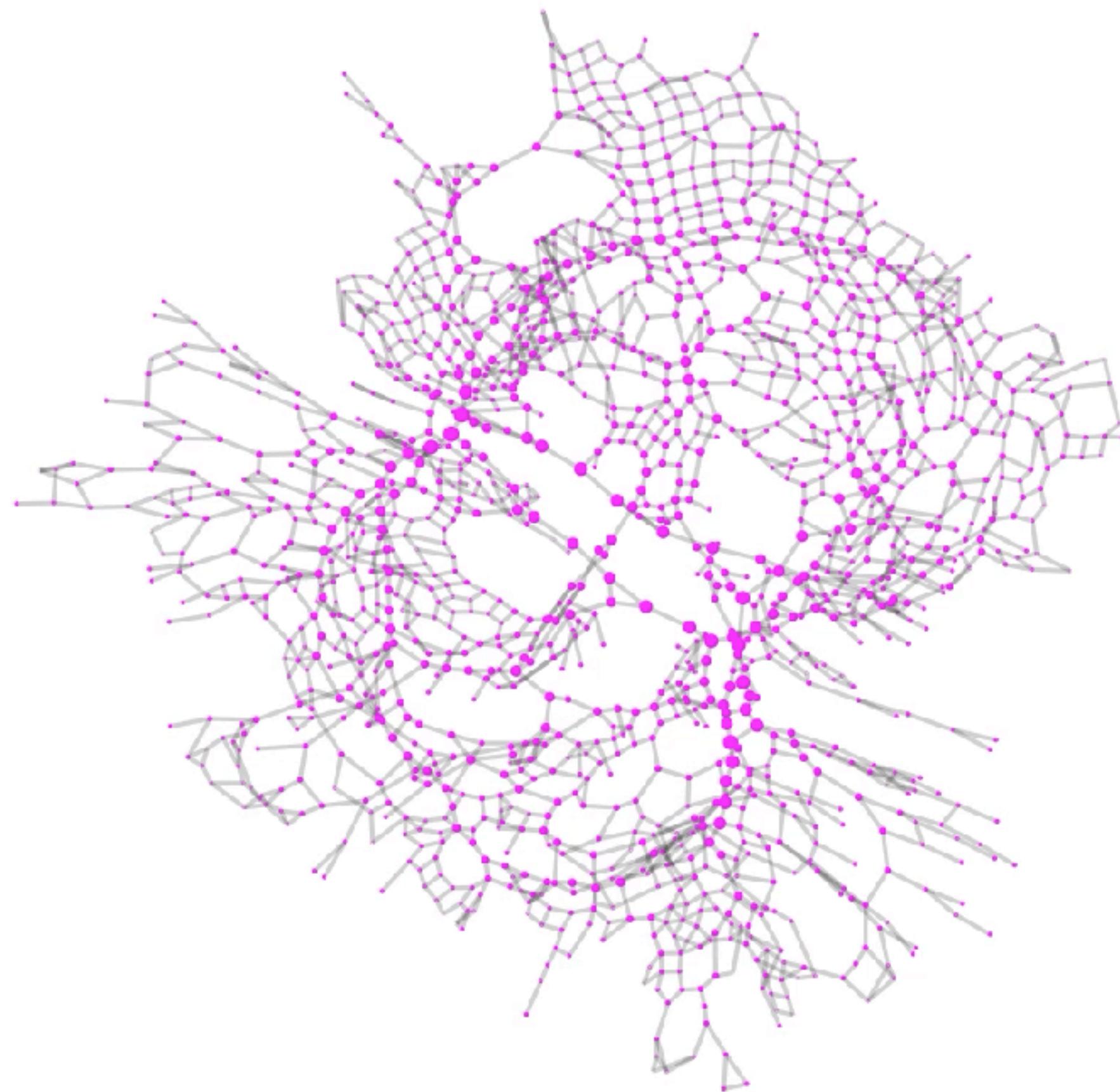


Degree centrality



Betweenness centrality identifies bottlenecks in transport networks

Budapest attack tolerance



Fraction of intersections removed: 0.0%
Connected Components: 1



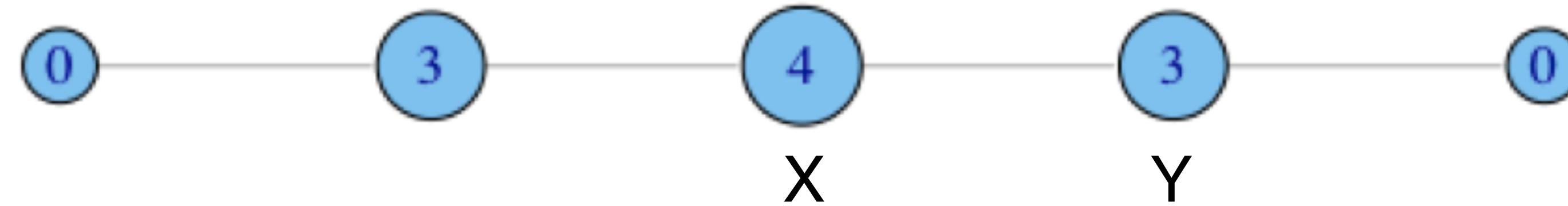
Video by Luis Guillermo Natera Orozco

Betweenness centrality identifies missing gaps in bicycle networks



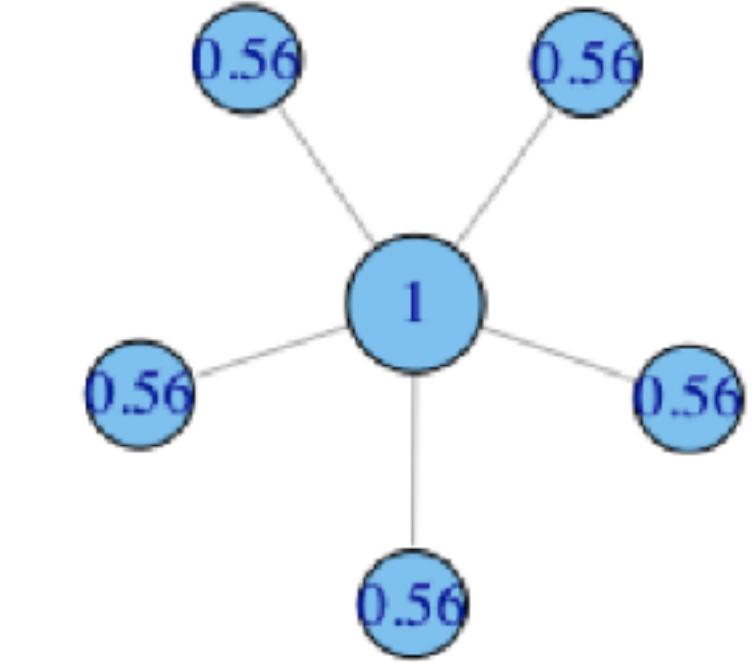
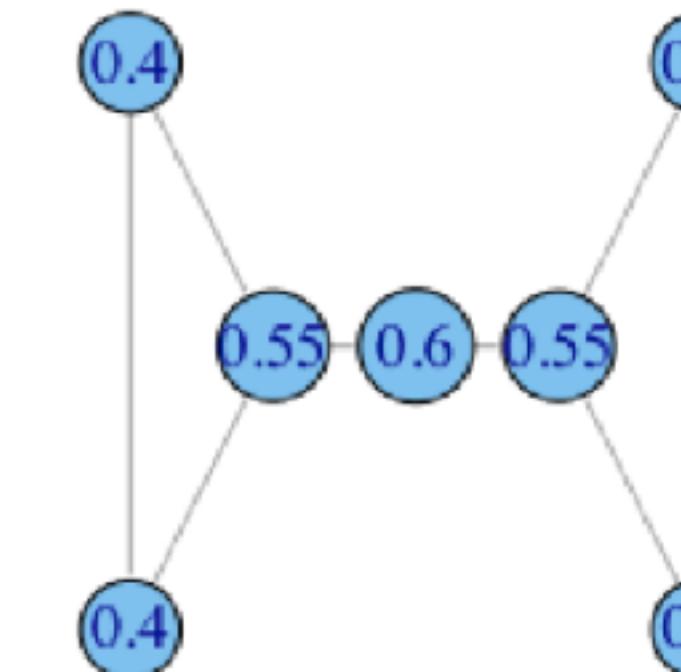
Betweenness is not everything

X and Y do not differ much for betweenness



but X is closer to other nodes than Y

Closeness centrality C_C captures being close to all other nodes



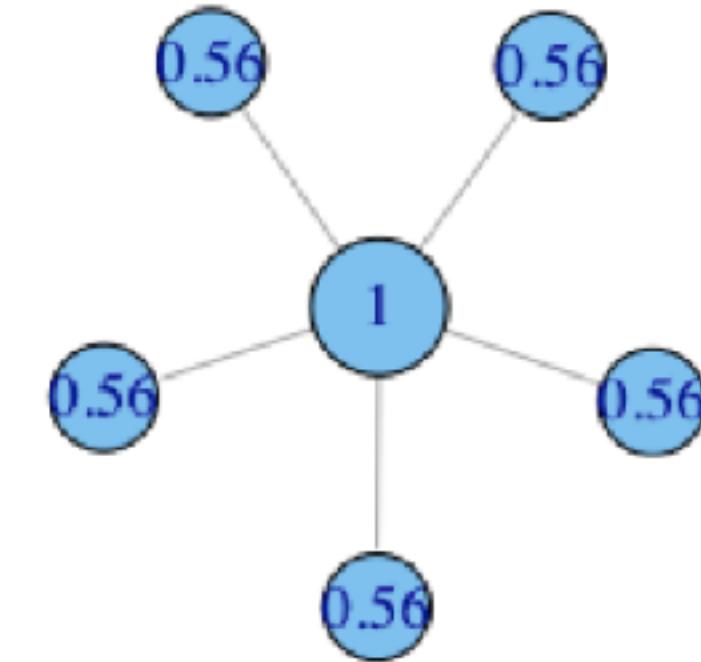
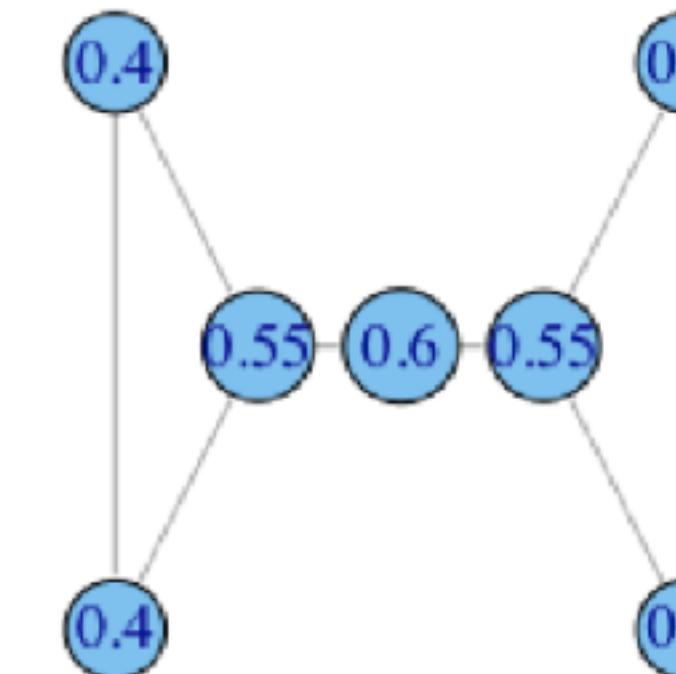
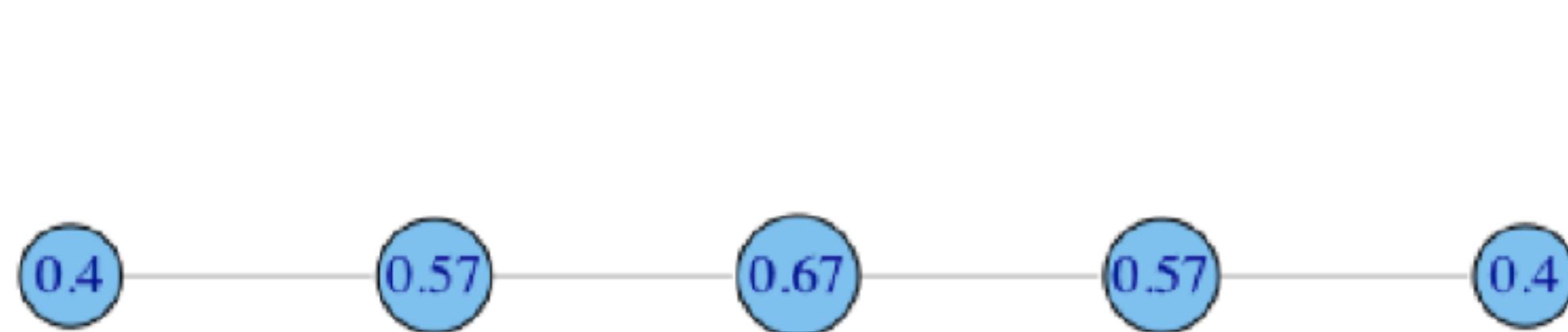
$$\tilde{C}_C(i) = \frac{1}{\sum_{j=1}^N d(i,j)}$$

unnormalized

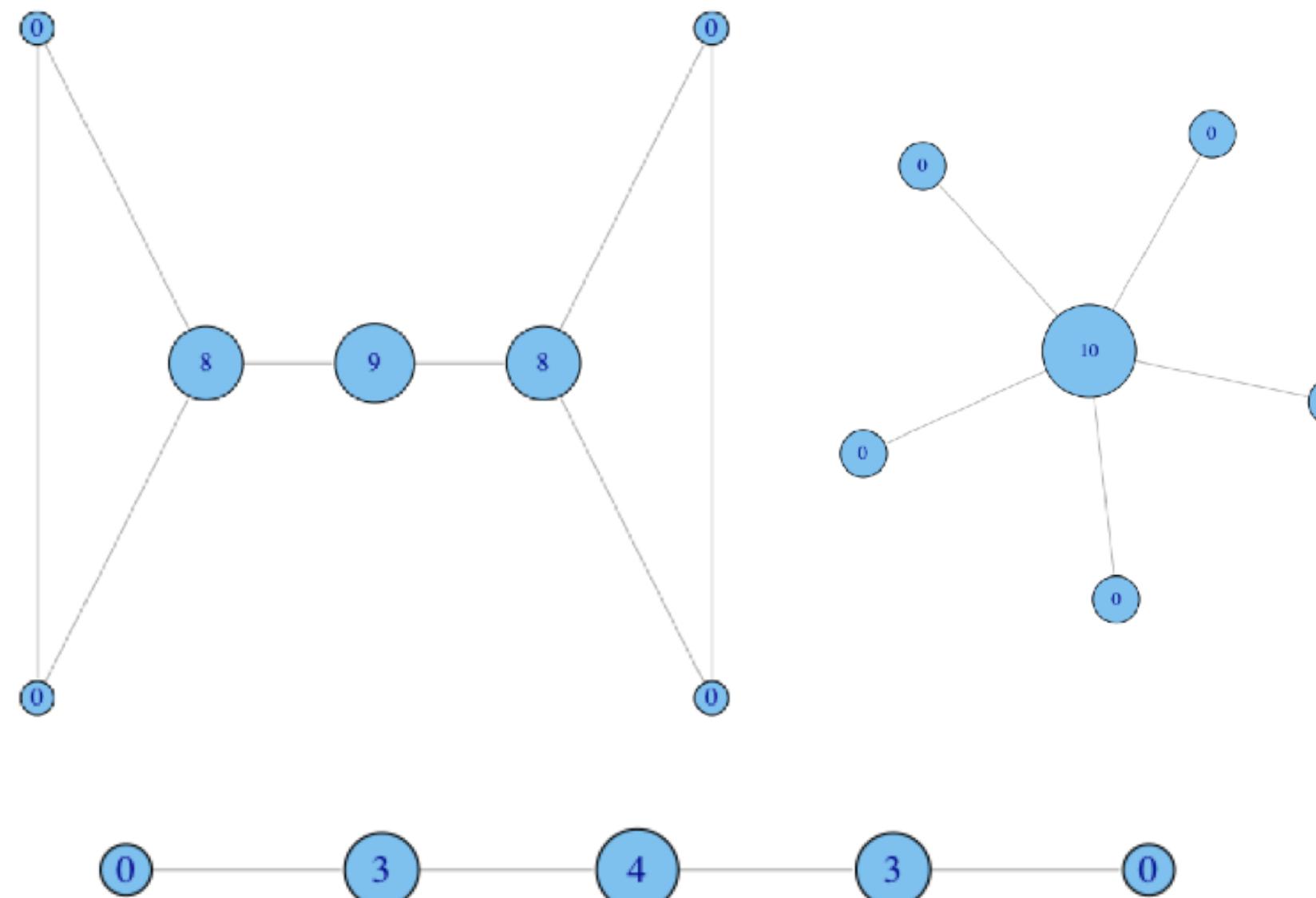
$$C_C(i) = (N - 1) \tilde{C}_C(i)$$

normalized

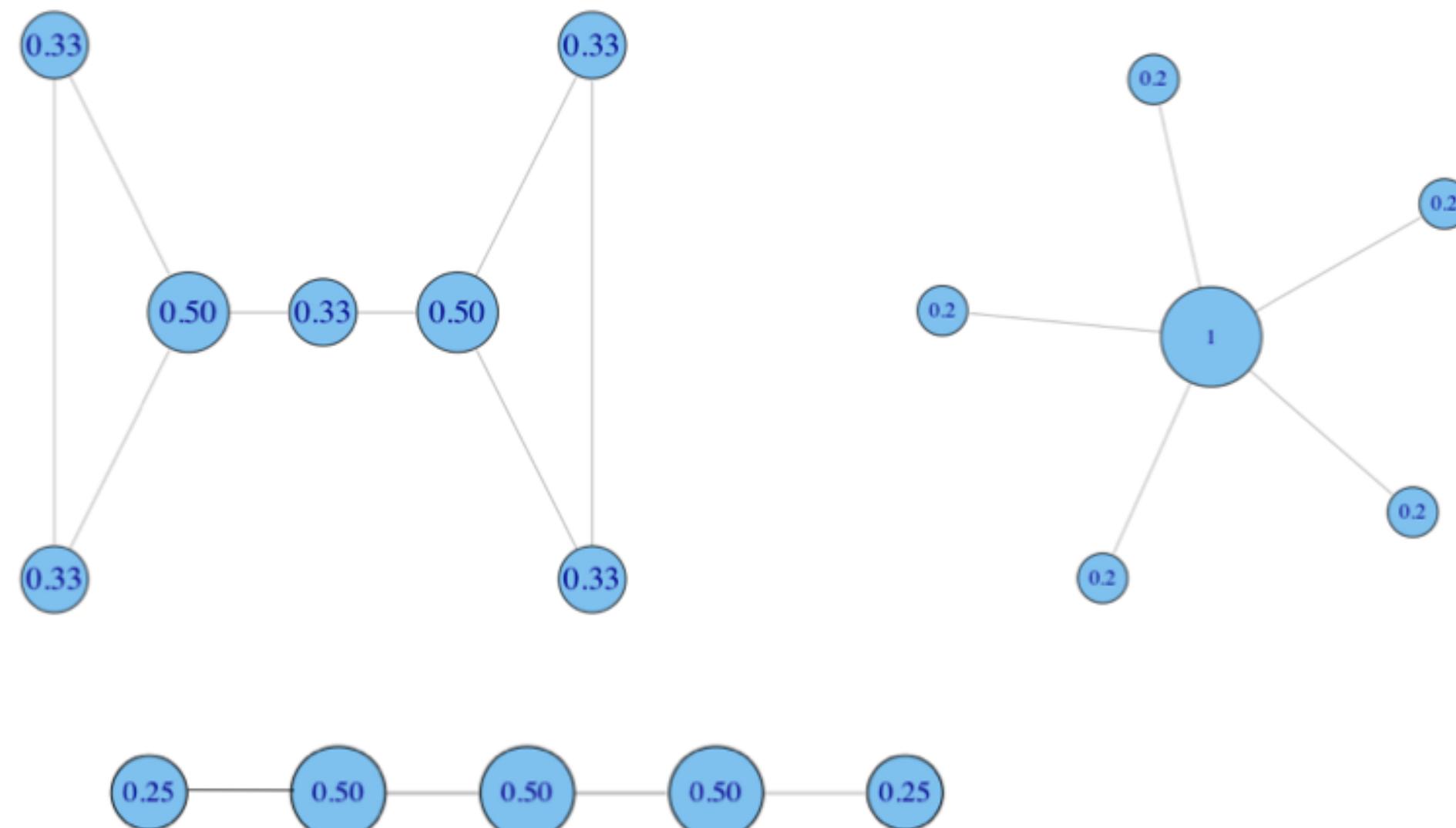
Closeness centrality C_C captures being close to all other nodes



Betweenness centrality

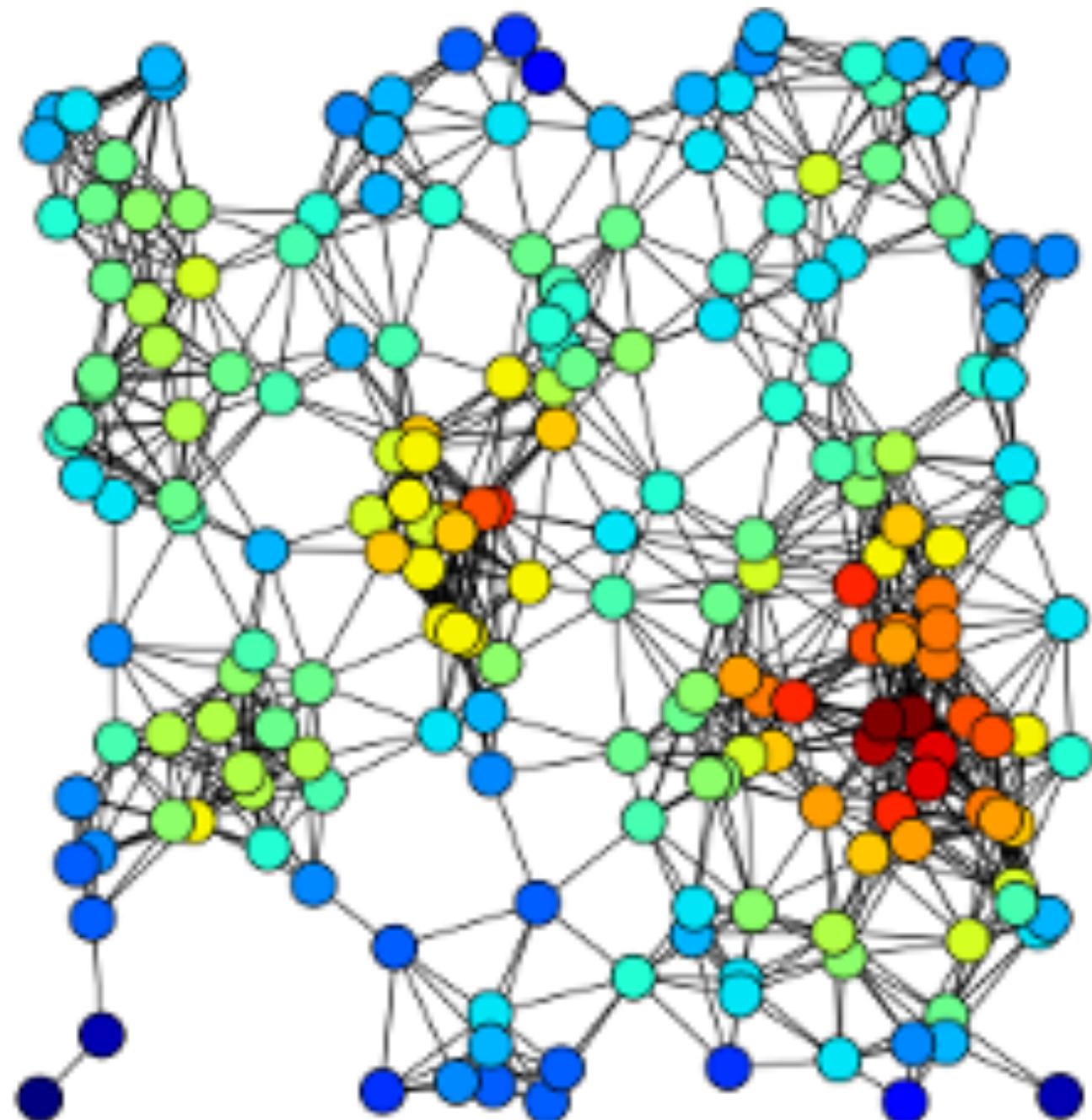


Degree centrality

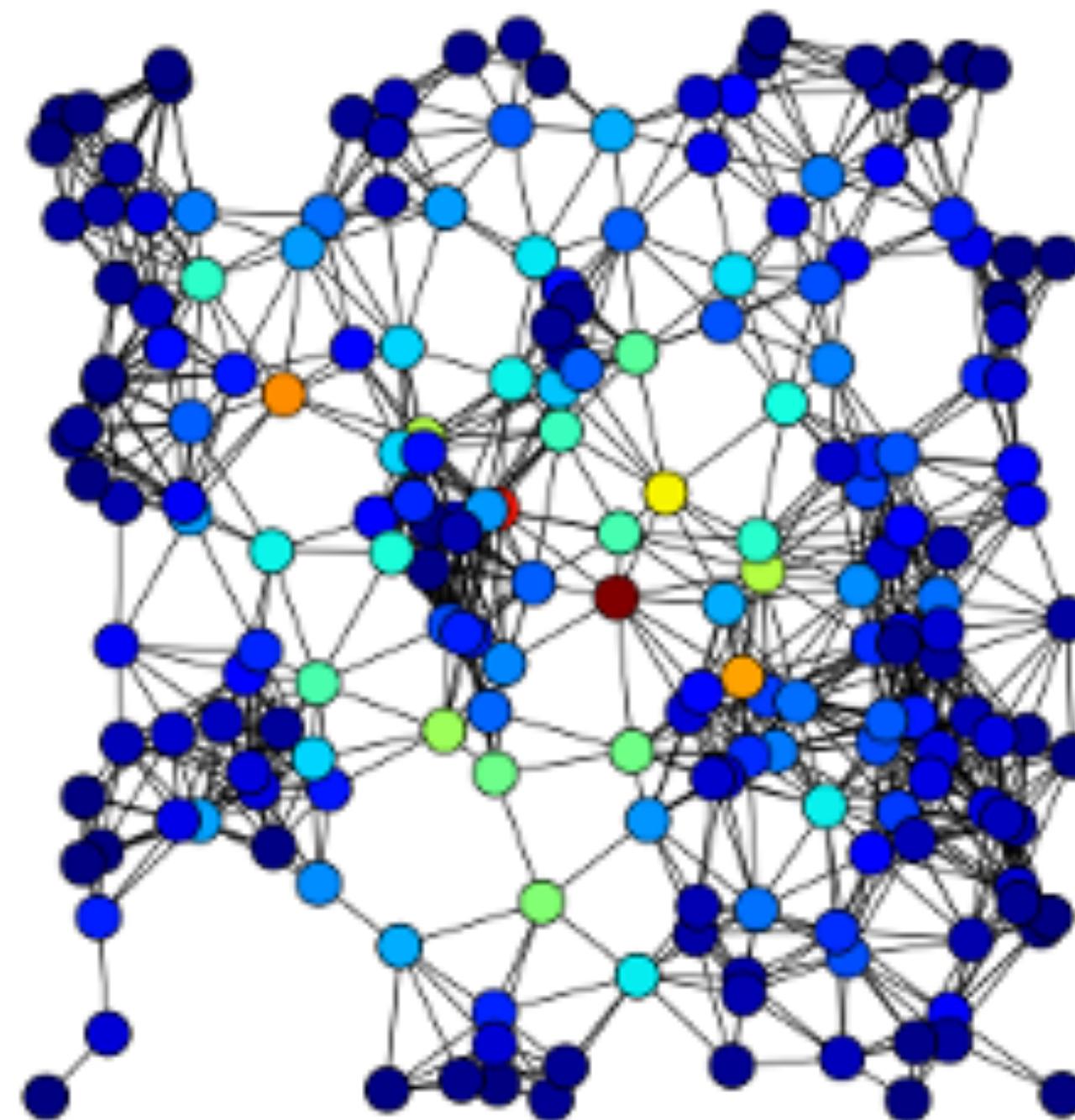


Which node is important? Depends on our definition of importance

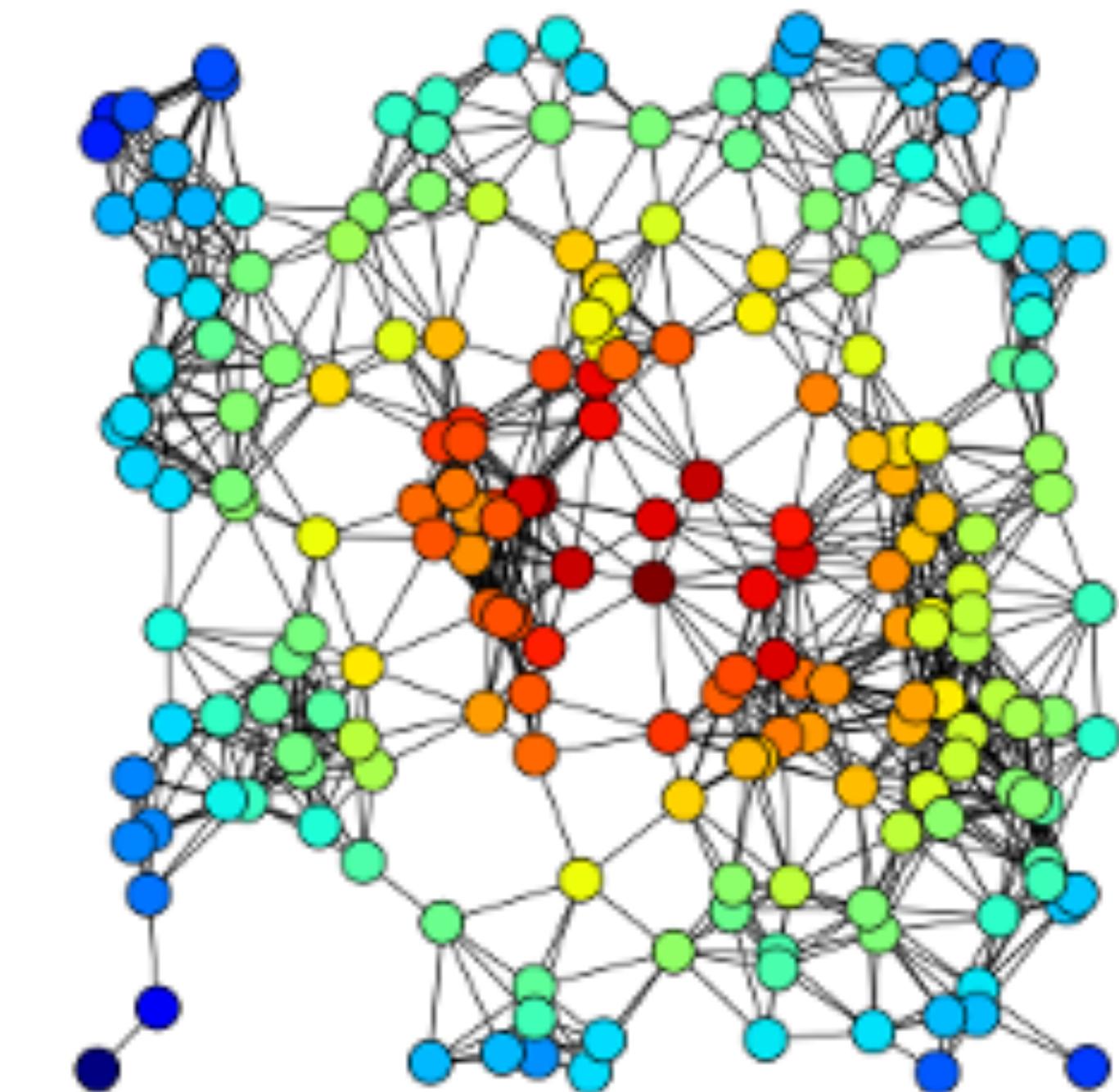
Degree



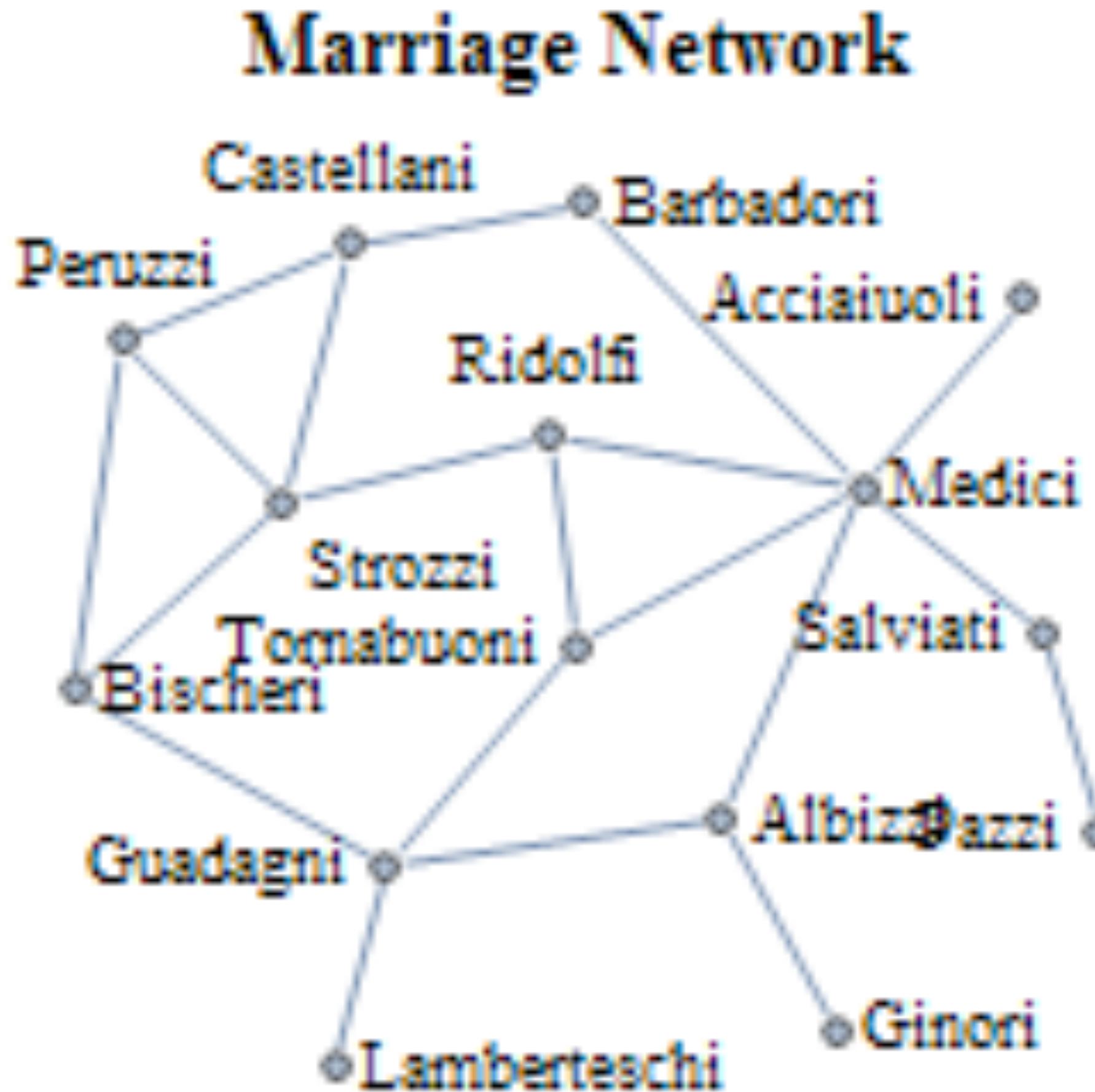
Betweenness



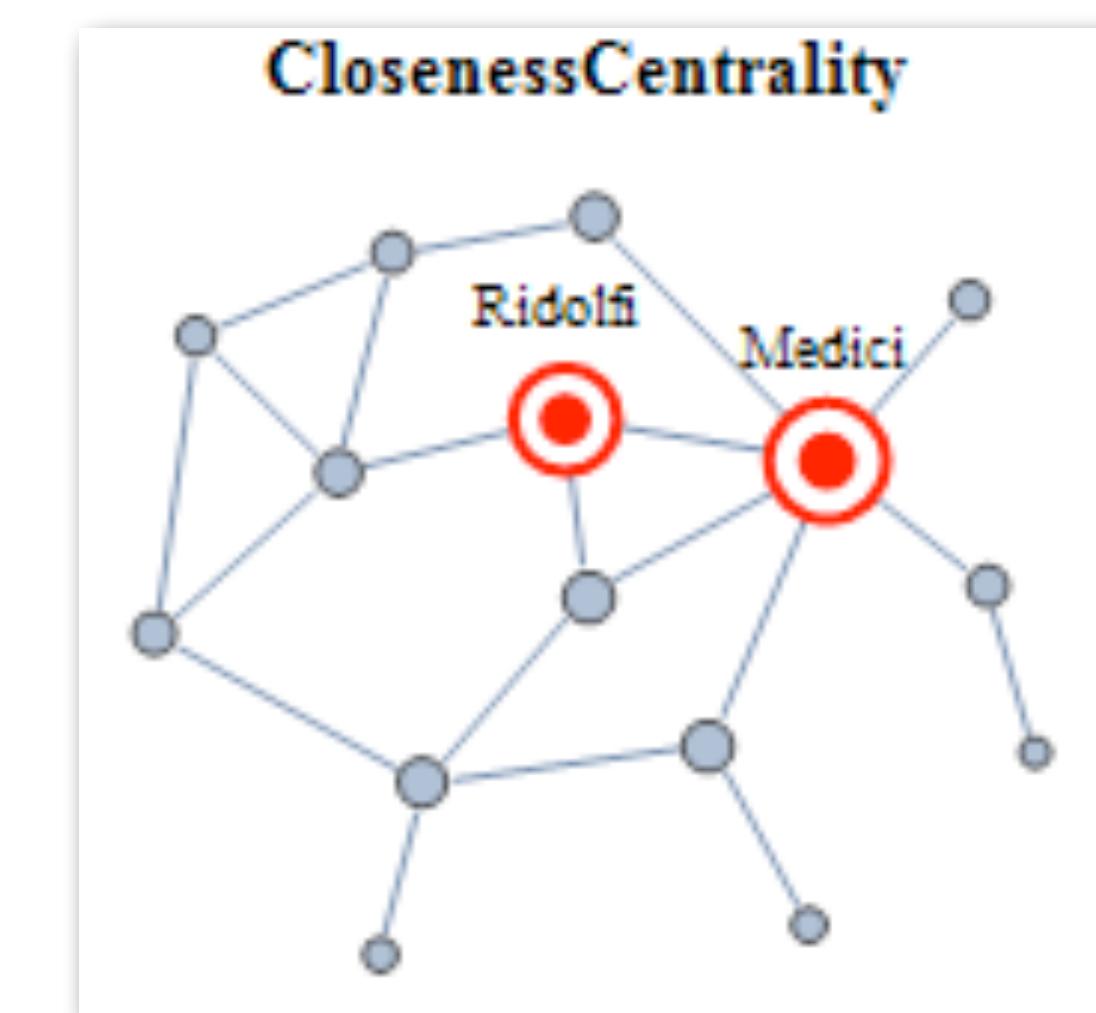
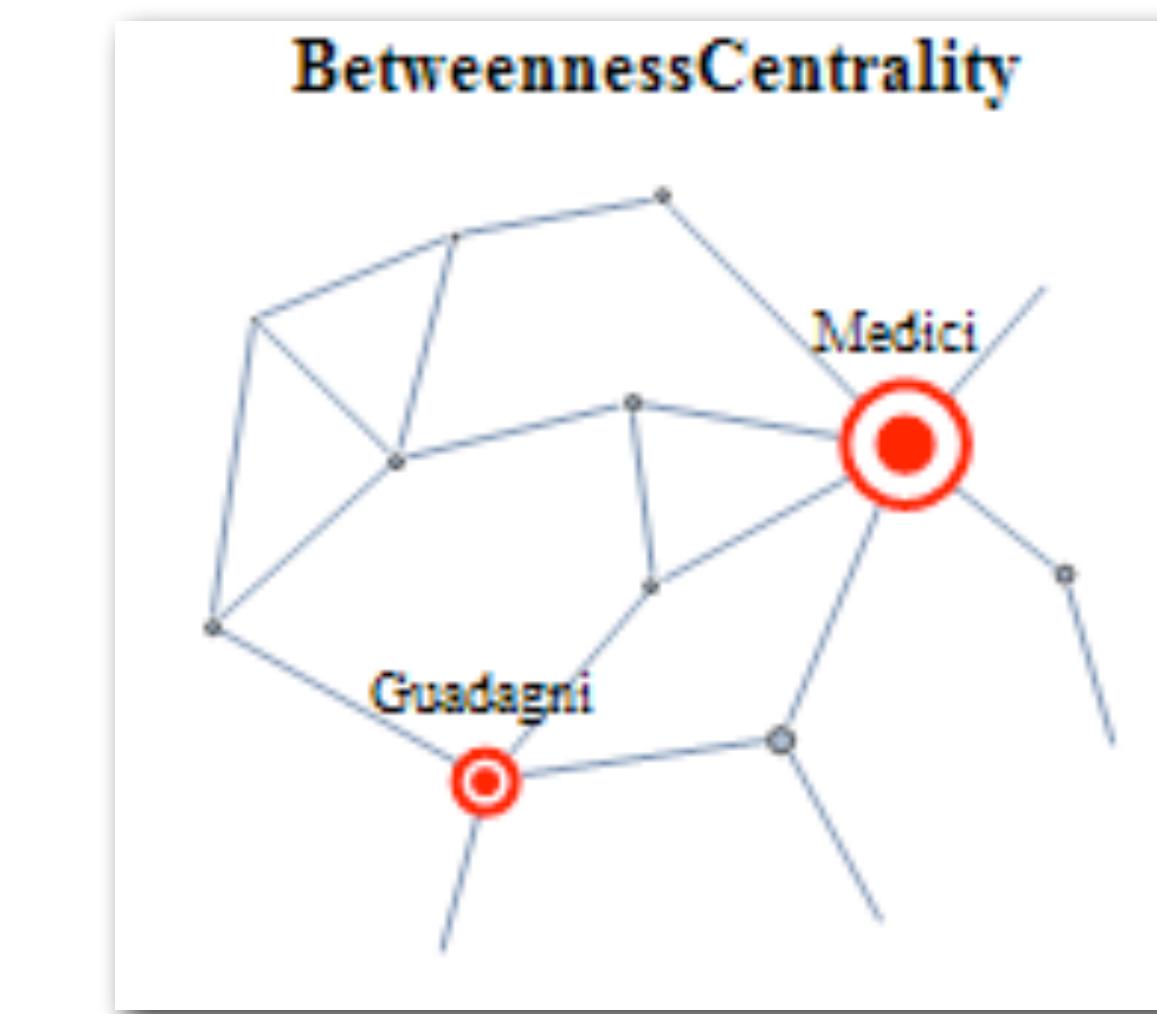
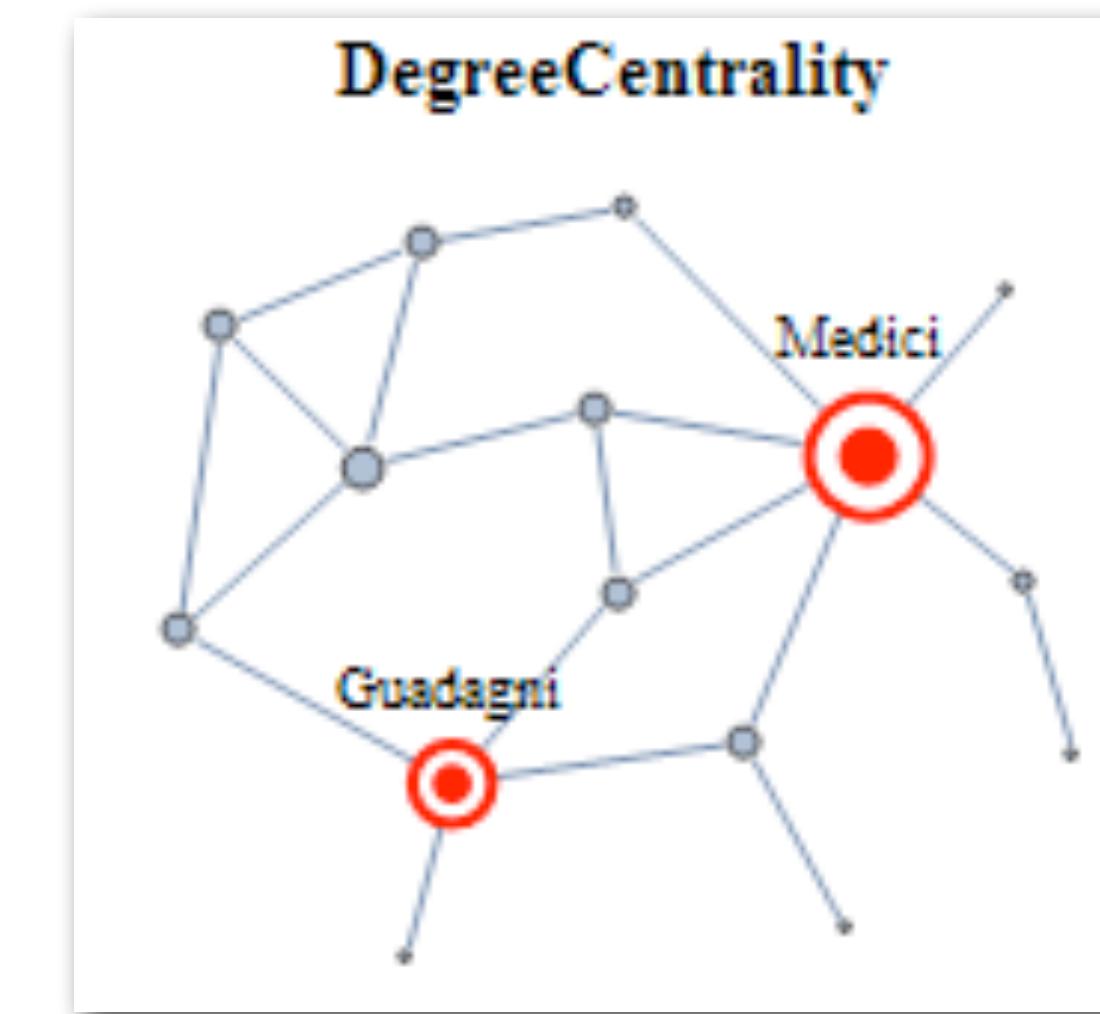
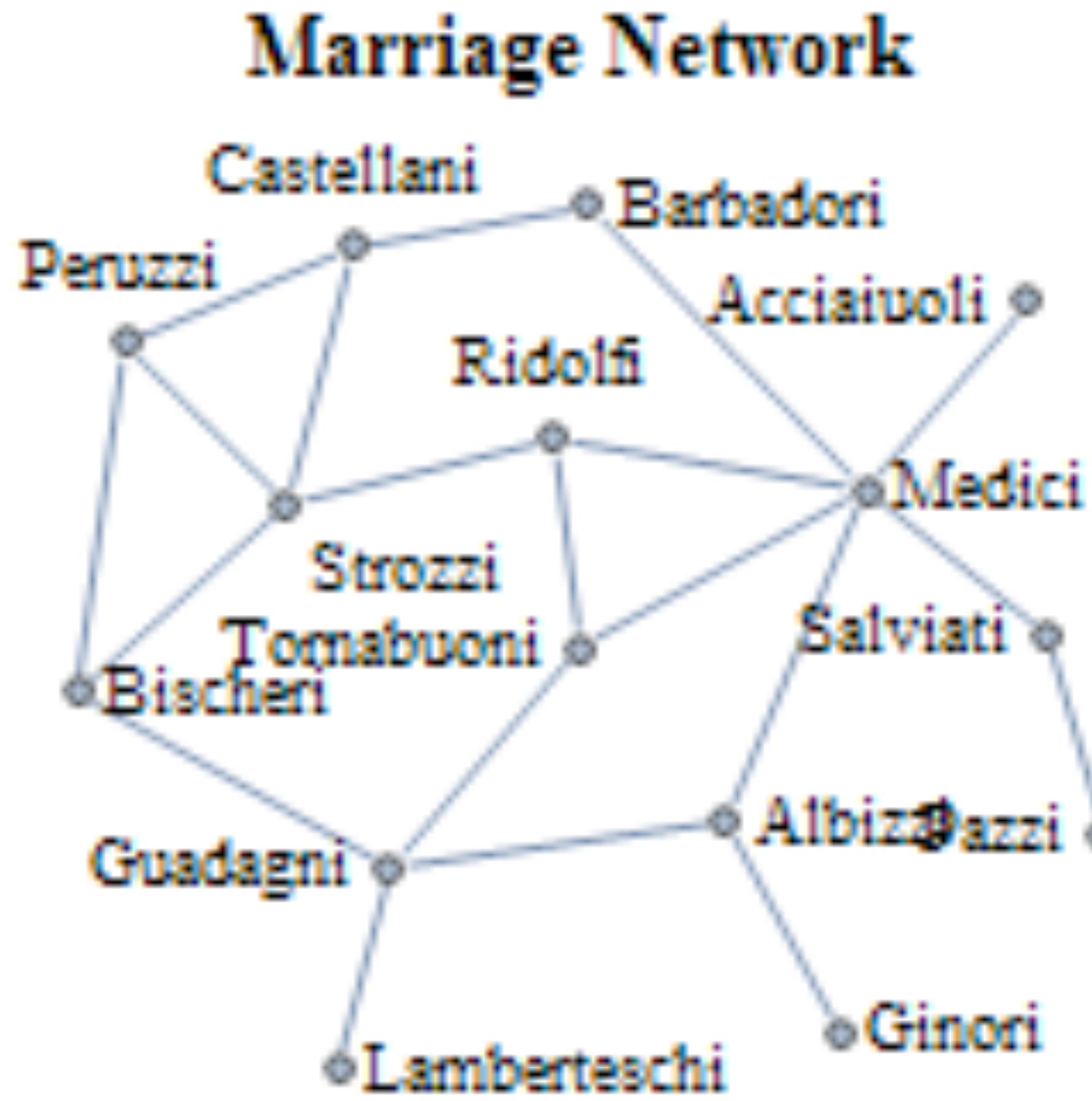
Closeness



Influence of florentine families can be analyzed with centralities

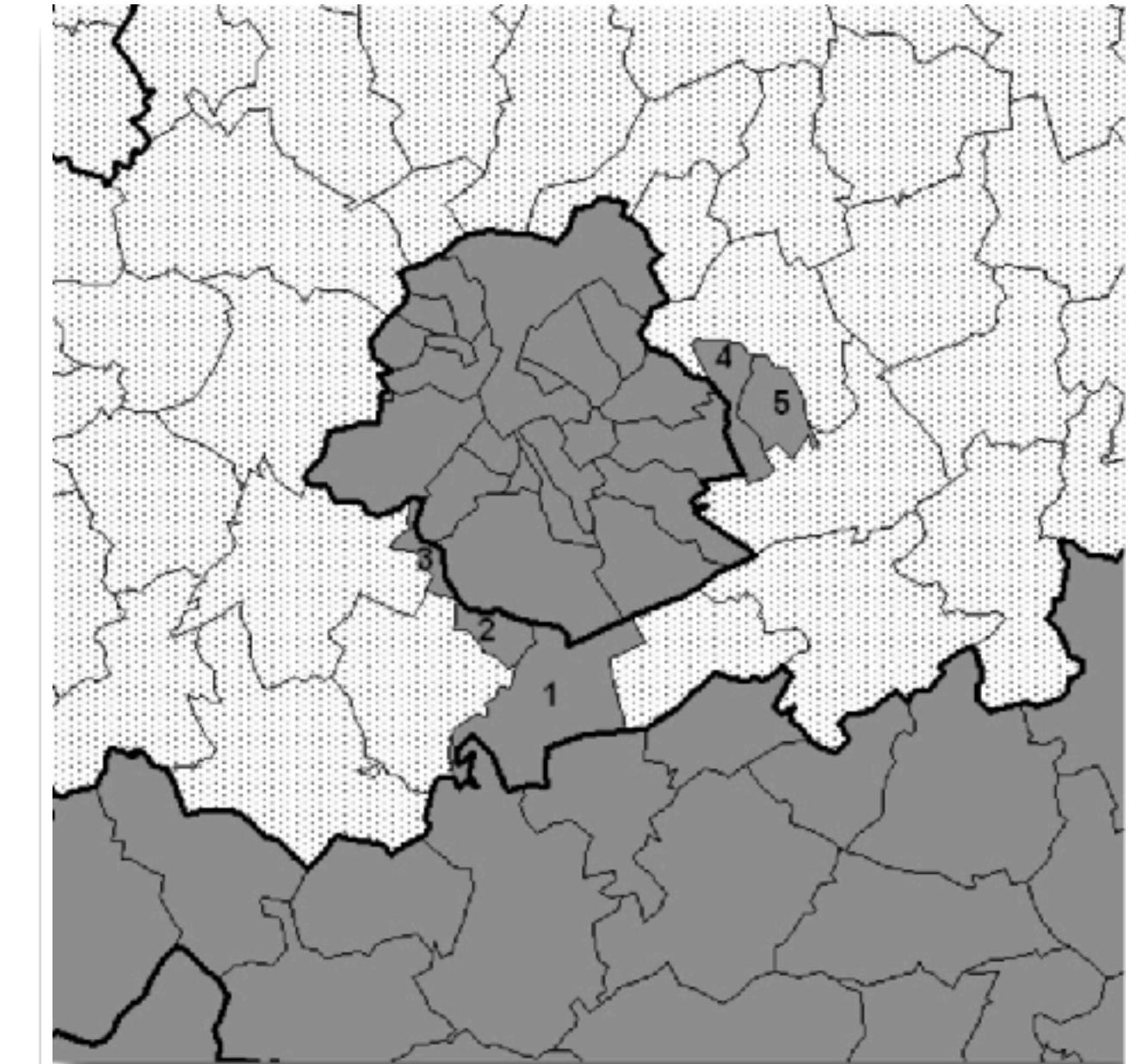
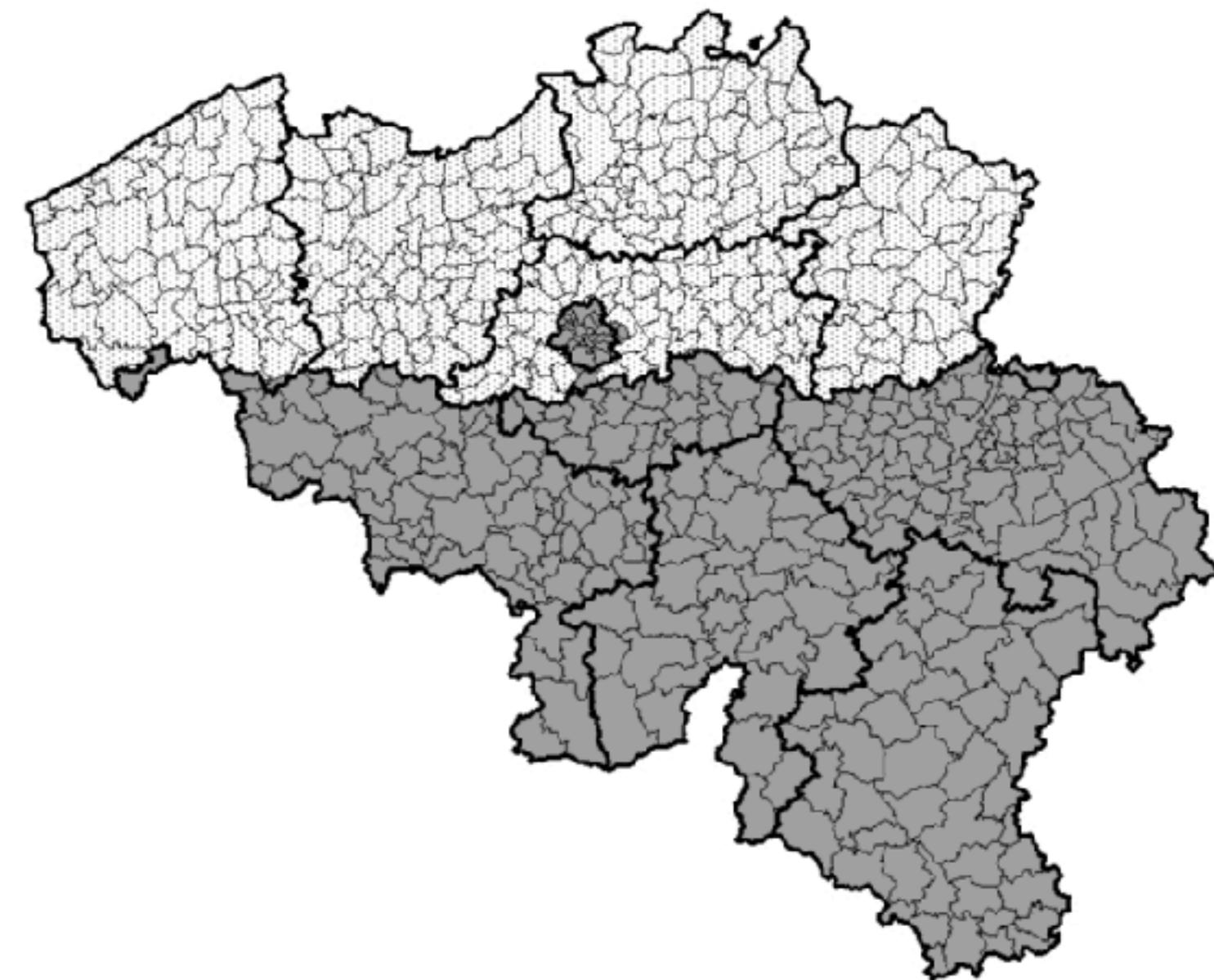
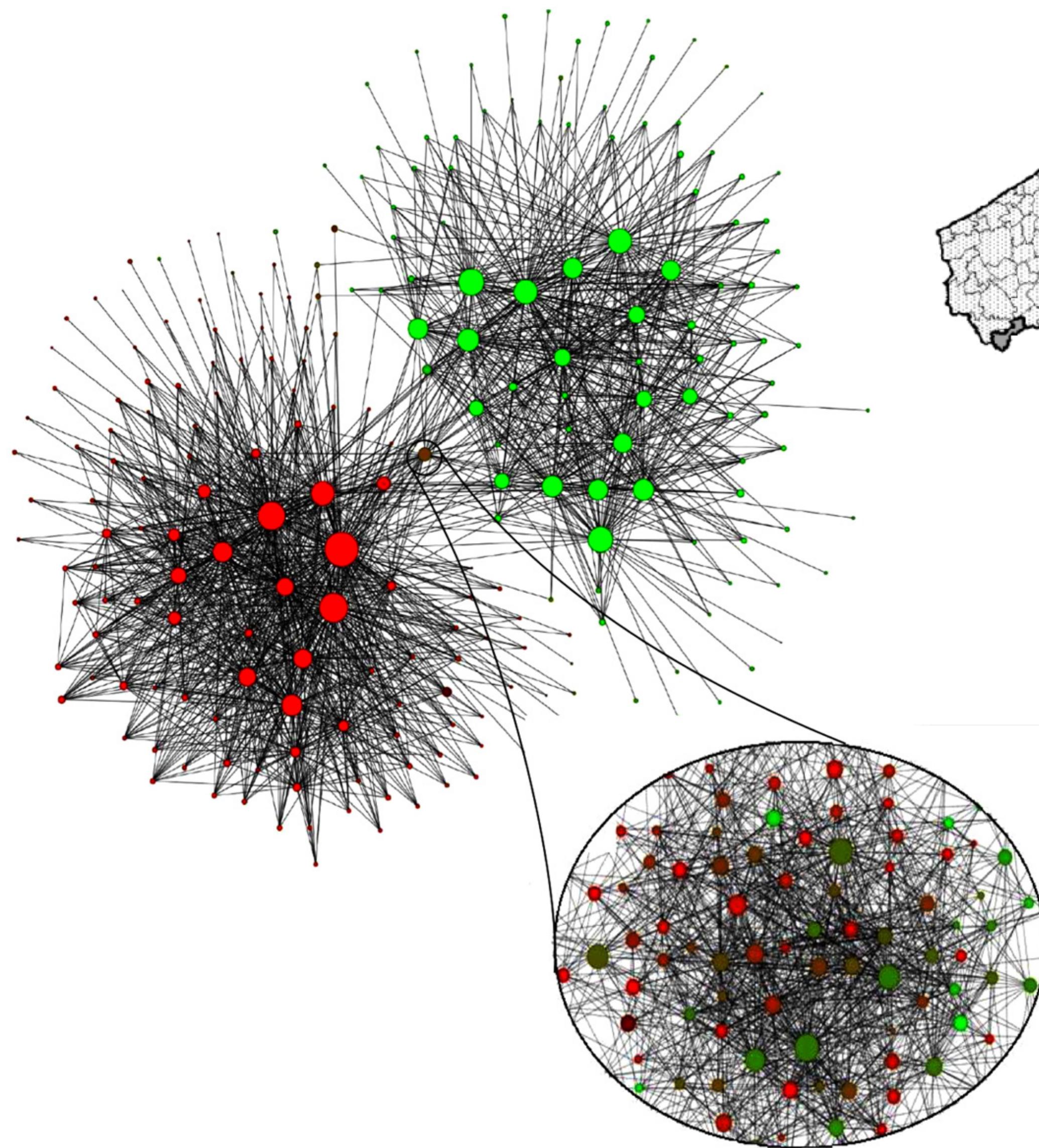


Influence of florentine families can be analyzed with centralities

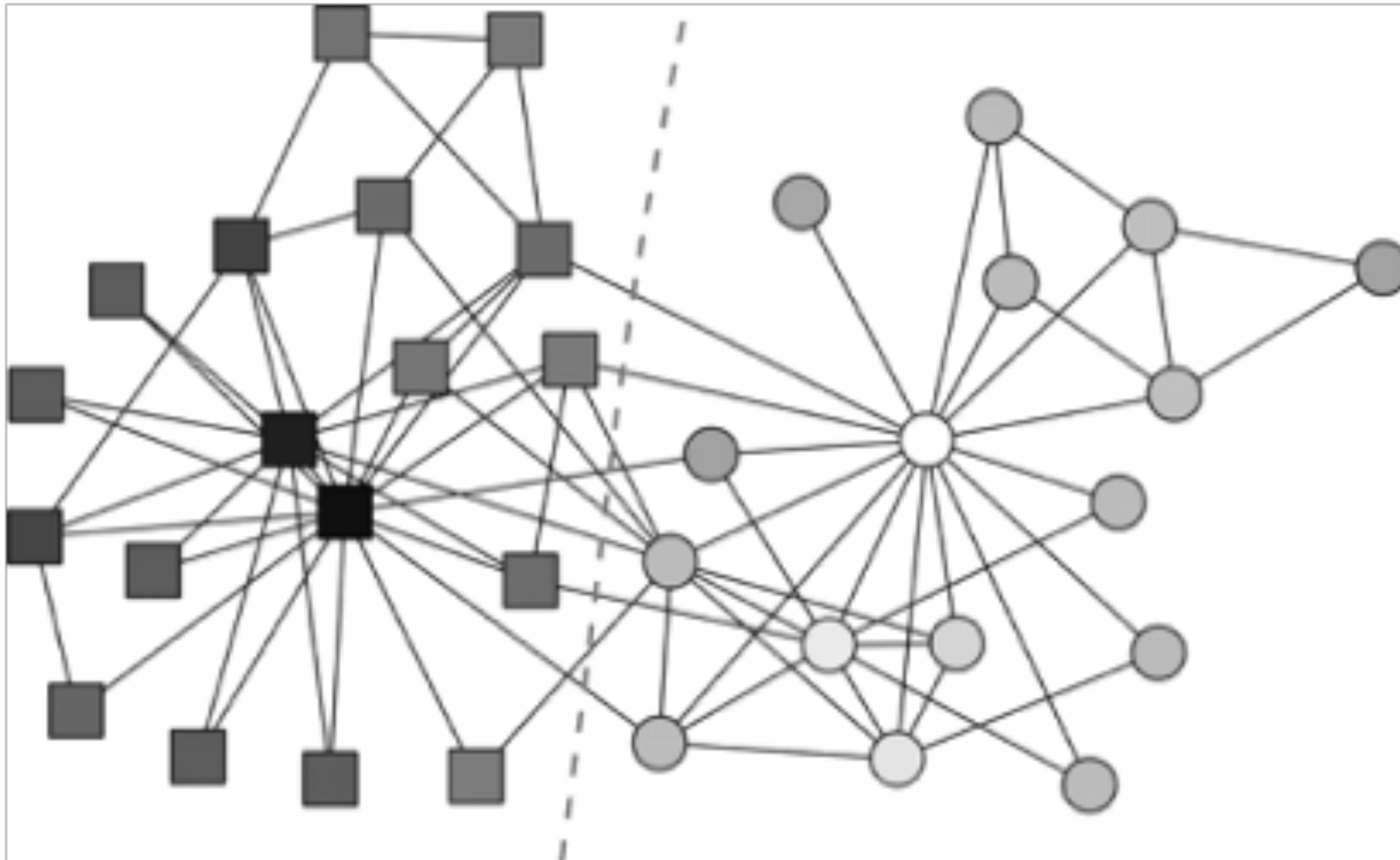


Community detection

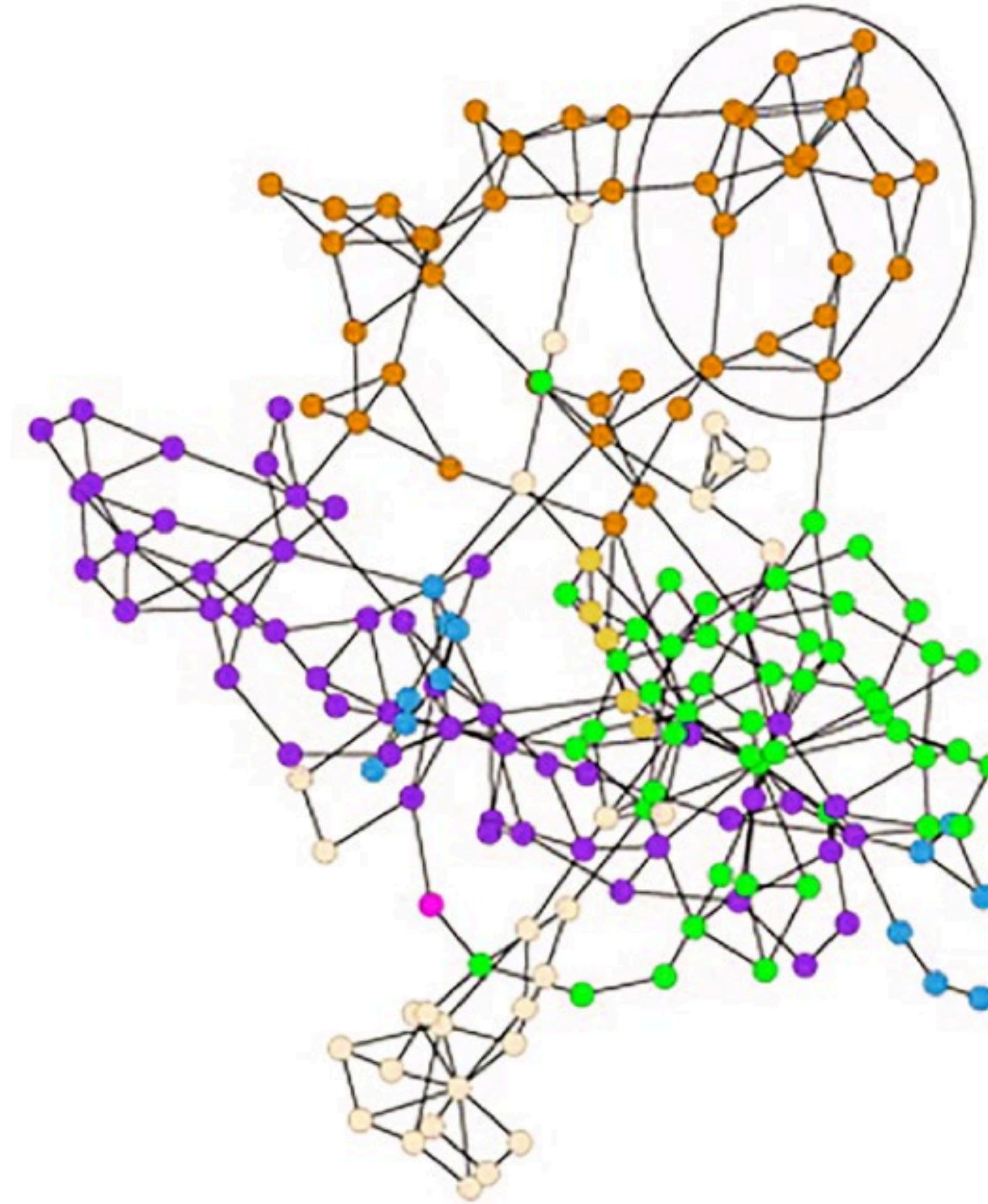
Communities are sets of nodes with many links to each other



The Zachary Karate Club is a benchmark for community detection

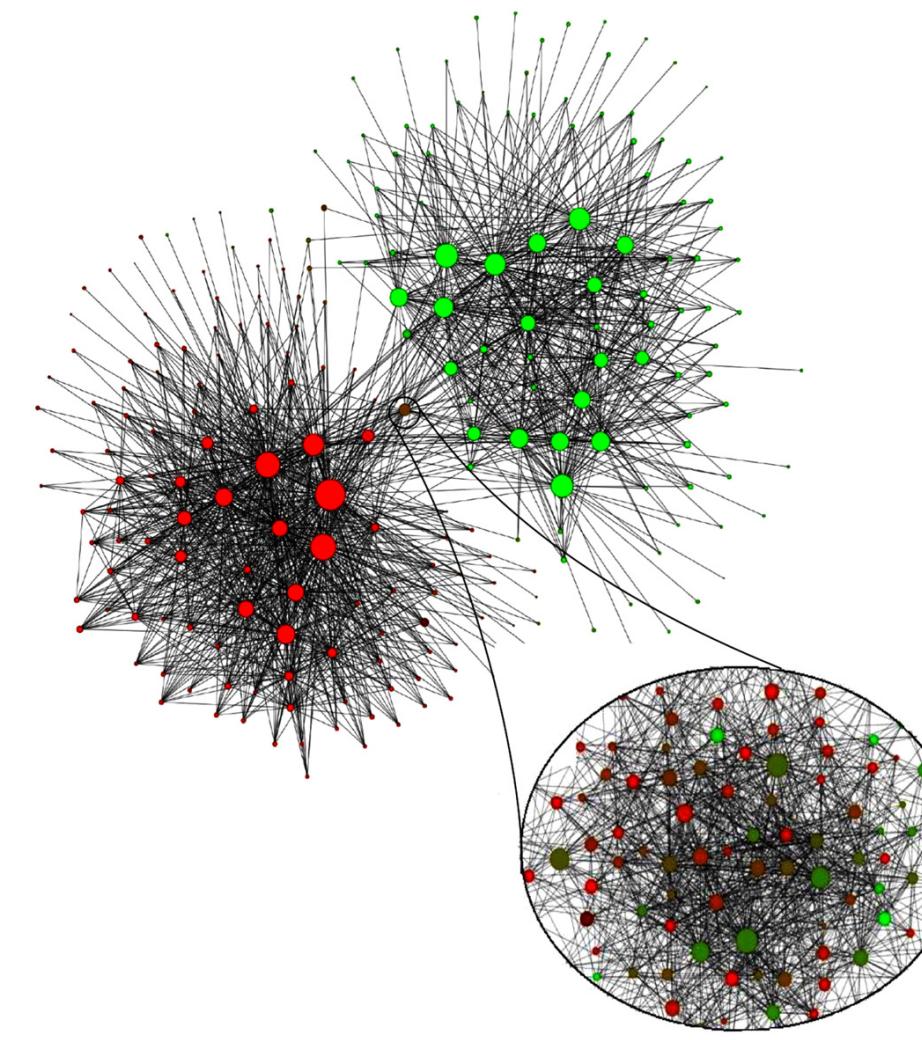
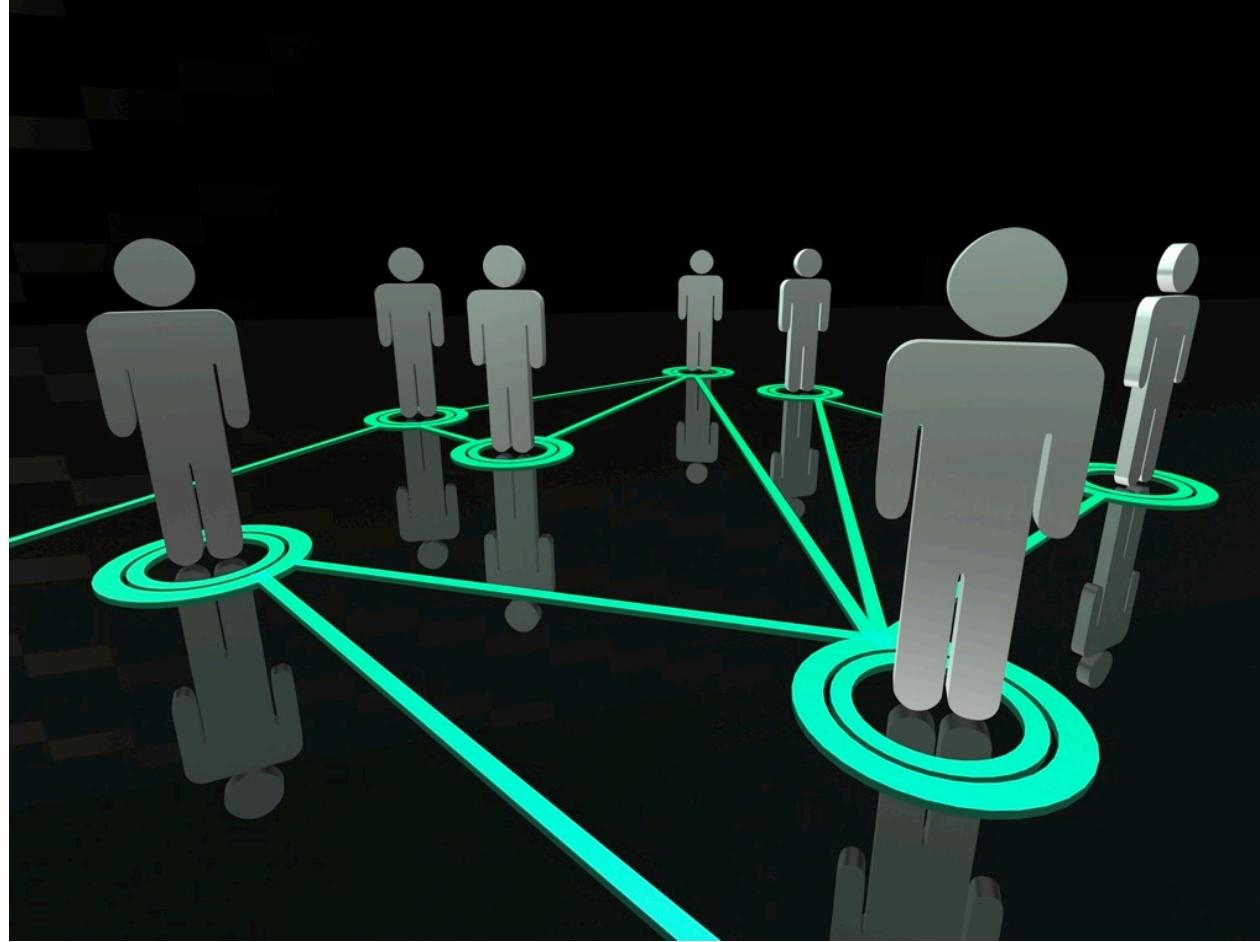


Here, communities are groups of molecules with more patterns of reactions with each other than with others



Ravasz, E., Somera, A. L., Mongru, D. A., Oltvai, Z. N., & Barabási, A. L. (2002). Hierarchical organization of modularity in metabolic networks. *Science*, 297(5586), 1551-1555.

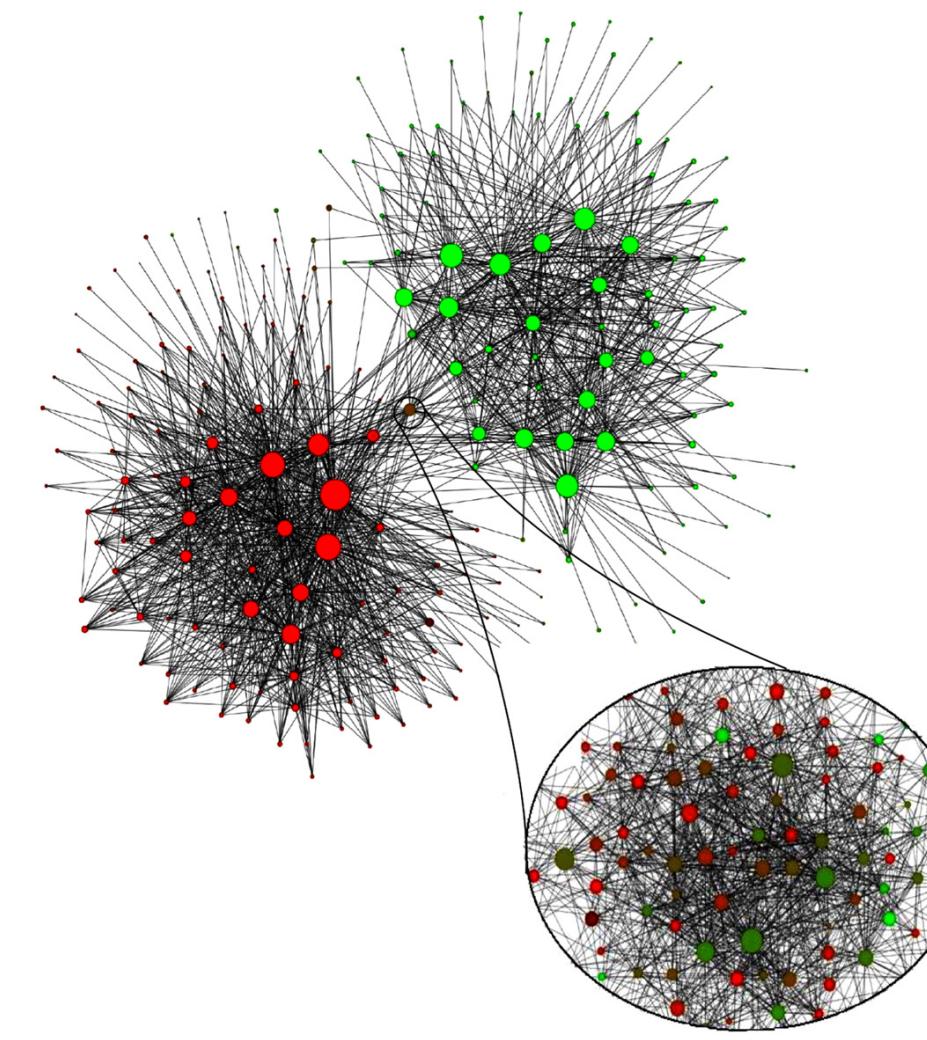
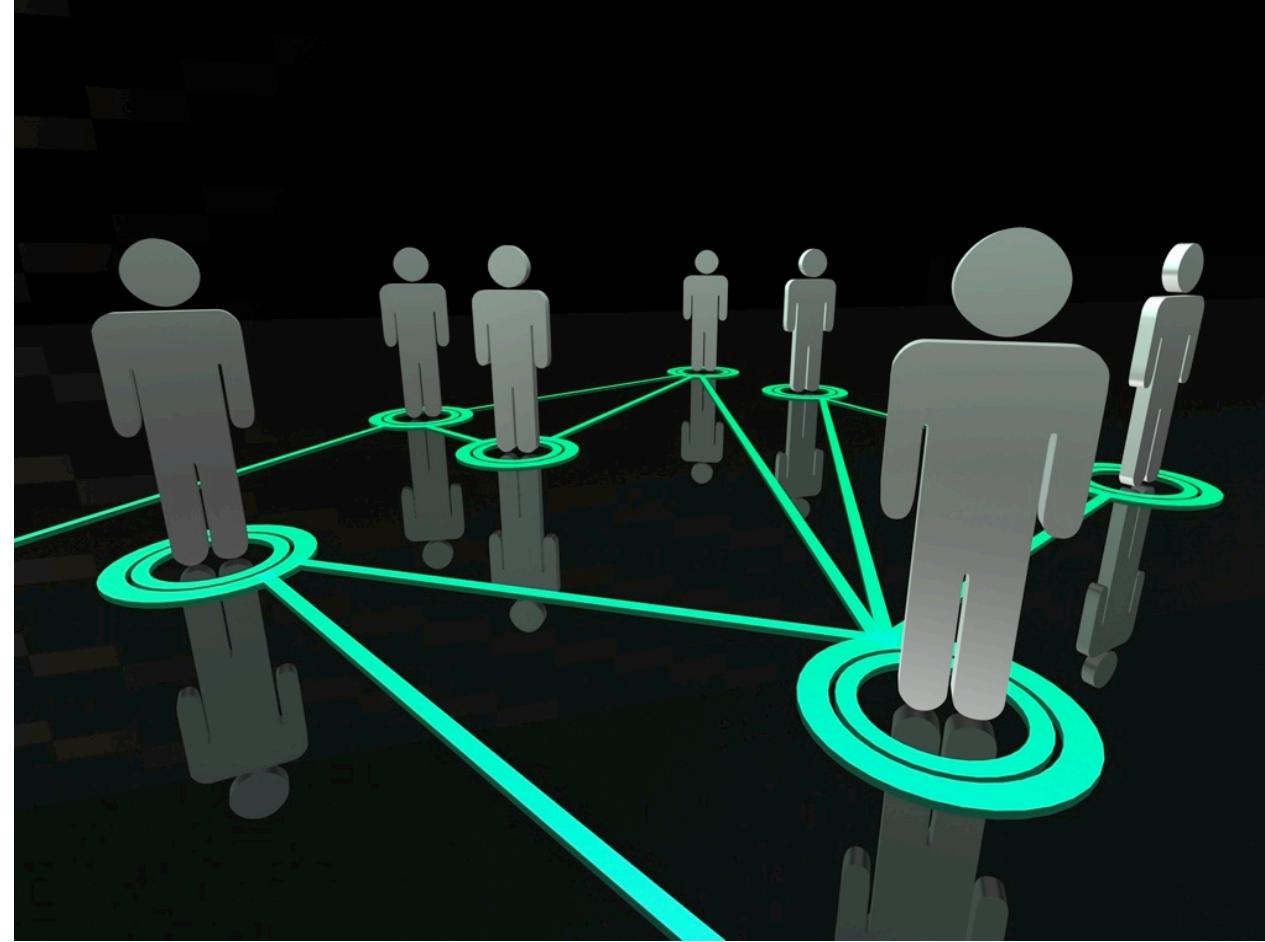
The study of communities focuses on the mesoscopic scale



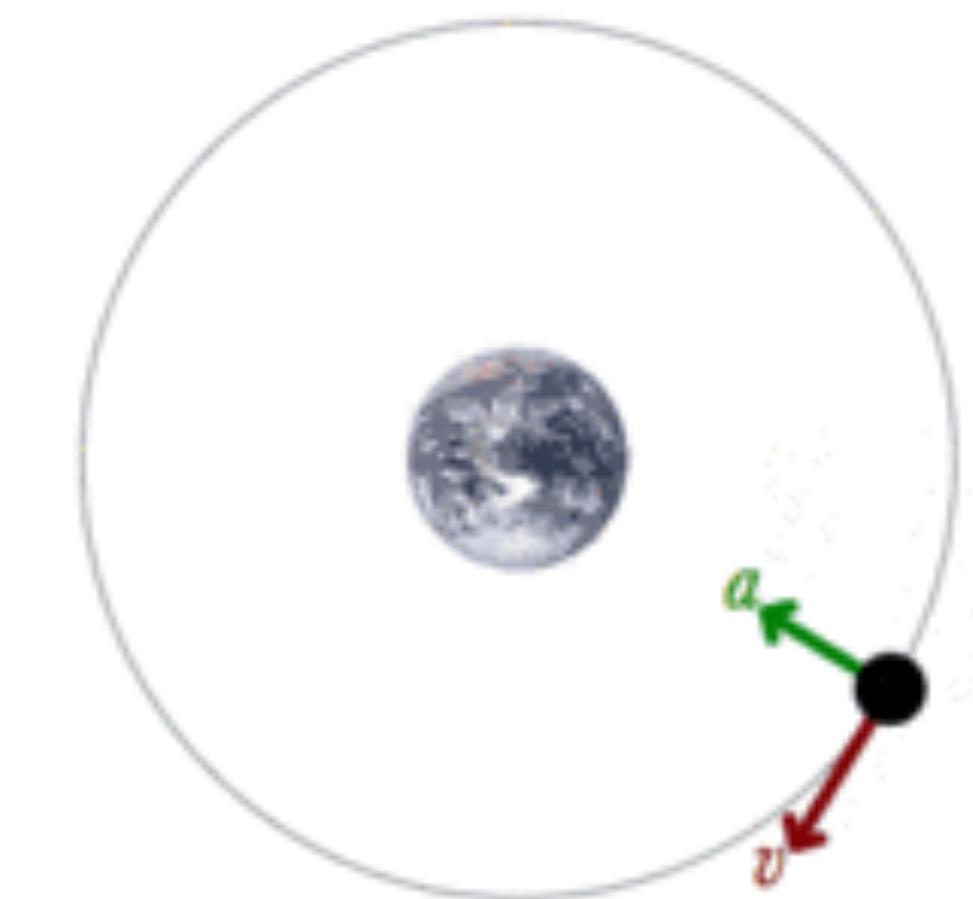
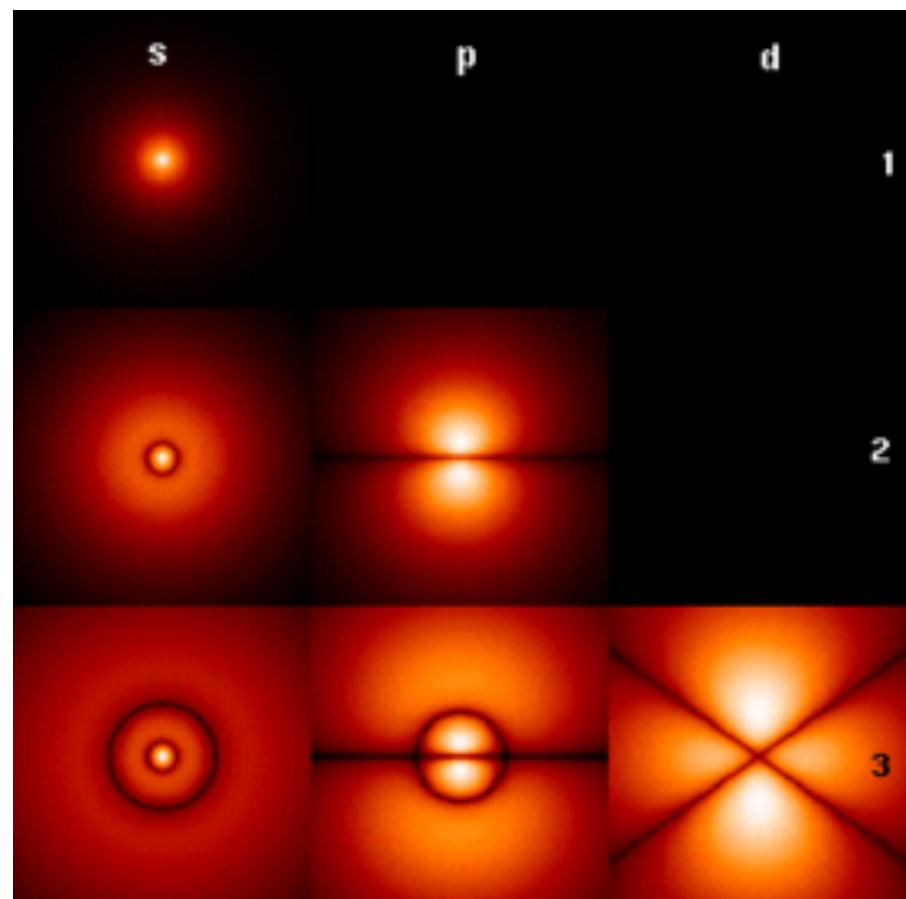
← →

Microscopic Mesoscopic Macroscopic

The study of communities focuses on the mesoscopic scale



↔ Microscopic Mesoscopic Macroscopic →



Community detection has a long history

- **1927:** The sociologists Stuart Rice used the similarity of voting patterns to identify communities in small political bodies [8].
- **1949:** Duncan R Luce and Albert D Perry used complete subgraphs to model cliques of individuals [9].
- **1950:** George Homans showed that social groups can be revealed by rearranging the rows and the columns of the adjacency matrix [3] ([Figure 9.3](#)).
- **1955:** Robert Weiss and Eugene Jacobson identified work groups within a government agency by removing the connectors, individuals that are linked to different groups [10].
- **1970s:** The need to minimize the communication time between processors on a chip has fueled an extensive literature on graph partitioning (Box 9.x) [11], leading to the Kernighan-Lin algorithm [12].
- **1973:** Mark Granovetter explored the role of communities on an individual's ability to find a job [13].

Community detection relies on some hypotheses

H1 (Fundamental Hypothesis)

A network's community structure is uniquely encoded in its wiring diagram

$$A = \begin{pmatrix} 0 & 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Community detection relies on some hypotheses

H1 (Fundamental Hypothesis)

A network's community structure is uniquely encoded in its wiring diagram

H2 (Connectedness Hypothesis)

A community corresponds to a connected subgraph

Community detection relies on some hypotheses

H1 (Fundamental Hypothesis)

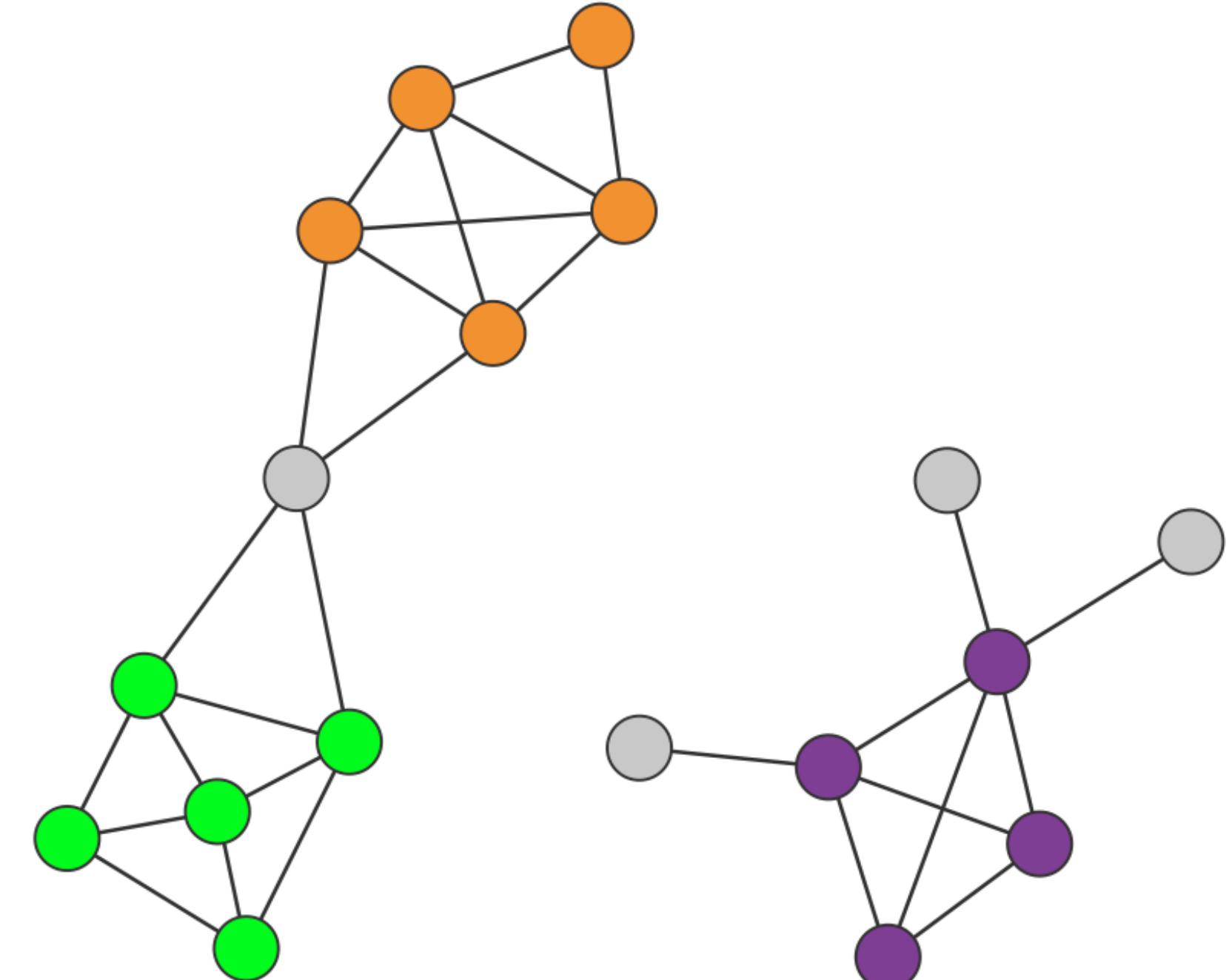
A network's community structure is uniquely encoded in its wiring diagram

H2 (Connectedness Hypothesis)

A community corresponds to a connected subgraph

H3 (Density Hypothesis)

Communities are locally dense subgraphs



Community detection relies on some hypotheses

H1 (Fundamental Hypothesis)

A network's community structure is uniquely encoded in its wiring diagram

H2 (Connectedness Hypothesis)

A community corresponds to a connected subgraph

H3 (Density Hypothesis)

Communities are locally dense subgraphs

H4 (Random Hypothesis)

Randomly wired networks are not expected to have a community structure

The random hypothesis leads to the measure of **modularity M**, which compares structure to a random model

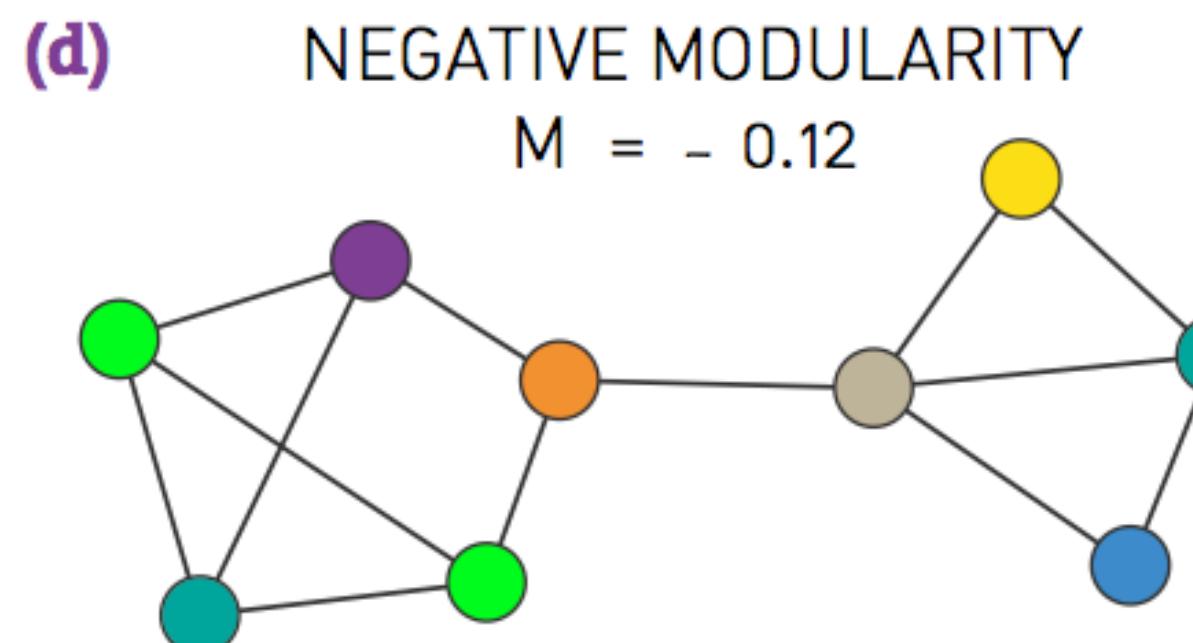
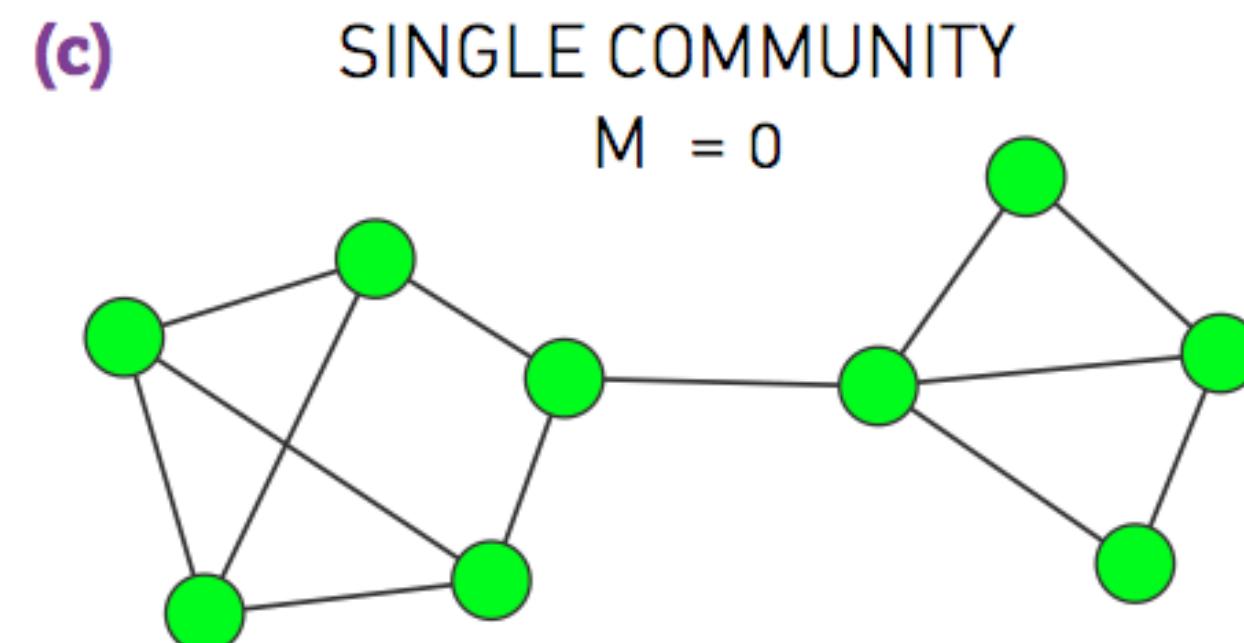
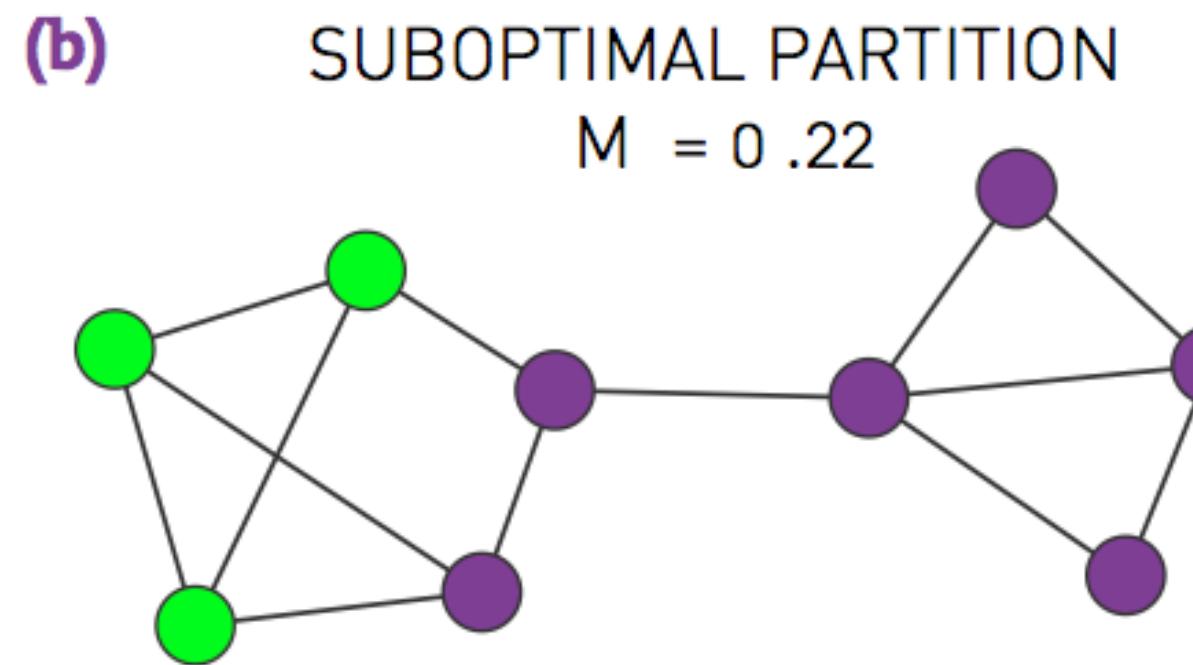
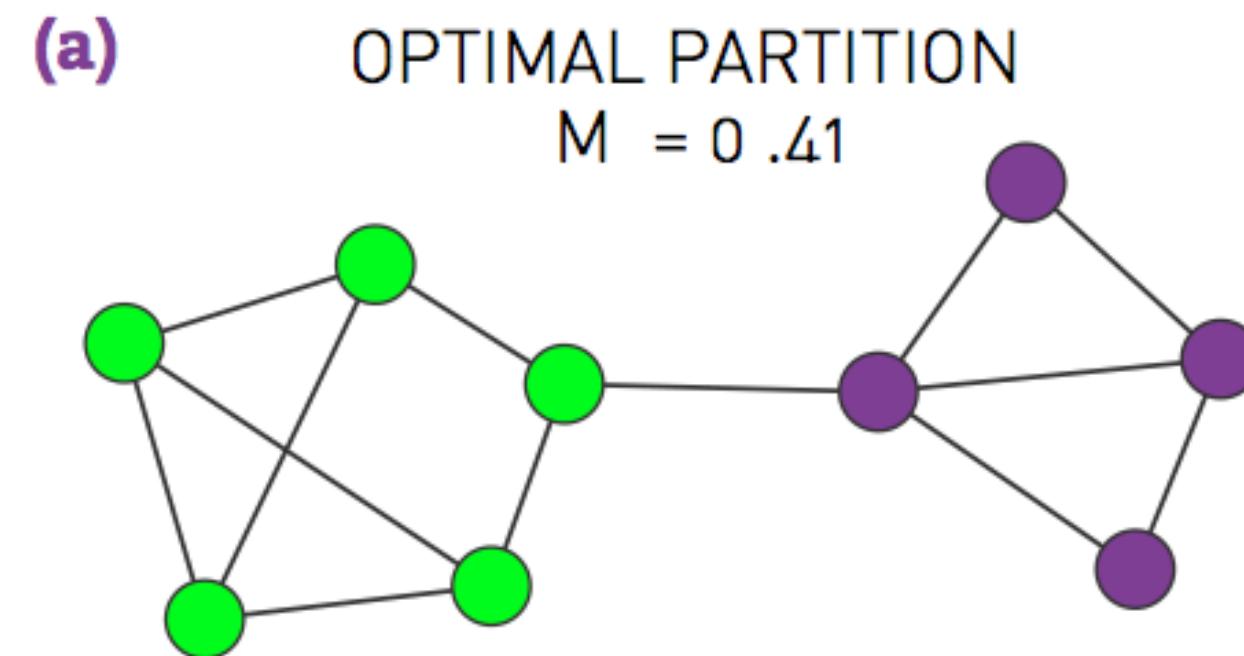
H5 (Maximal Modularity Hypothesis)

The partition with maximum modularity M for a given network offers the optimal community structure

The random hypothesis leads to the measure of **modularity M**, which compares structure to a random model

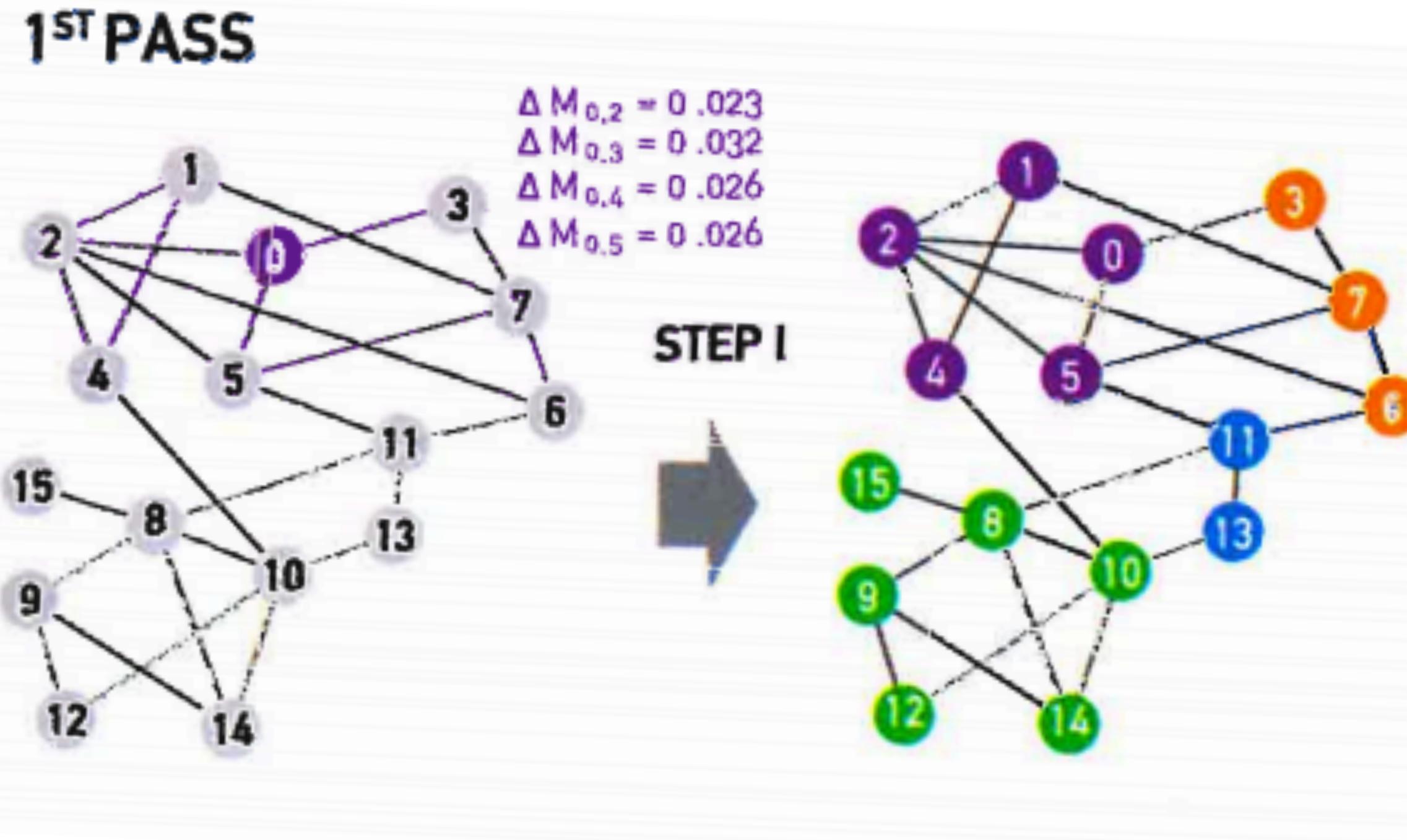
H5 (Maximal Modularity Hypothesis)

The partition with maximum modularity M for a given network offers the optimal community structure



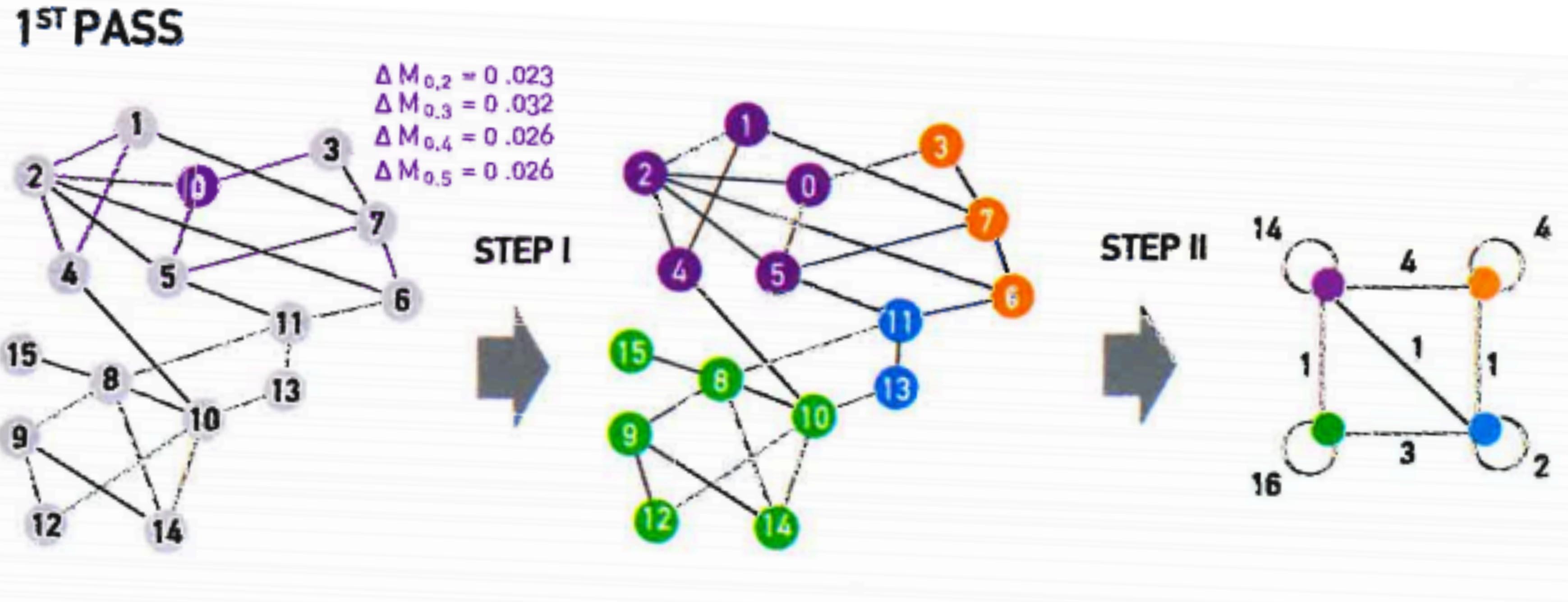
Goal: Find the partition that maximizes M

The Louvain method implements modularity maximization



STEP I: Optimize modularity by local changes.
Which of its neighbors should a node join?

The Louvain method implements modularity maximization

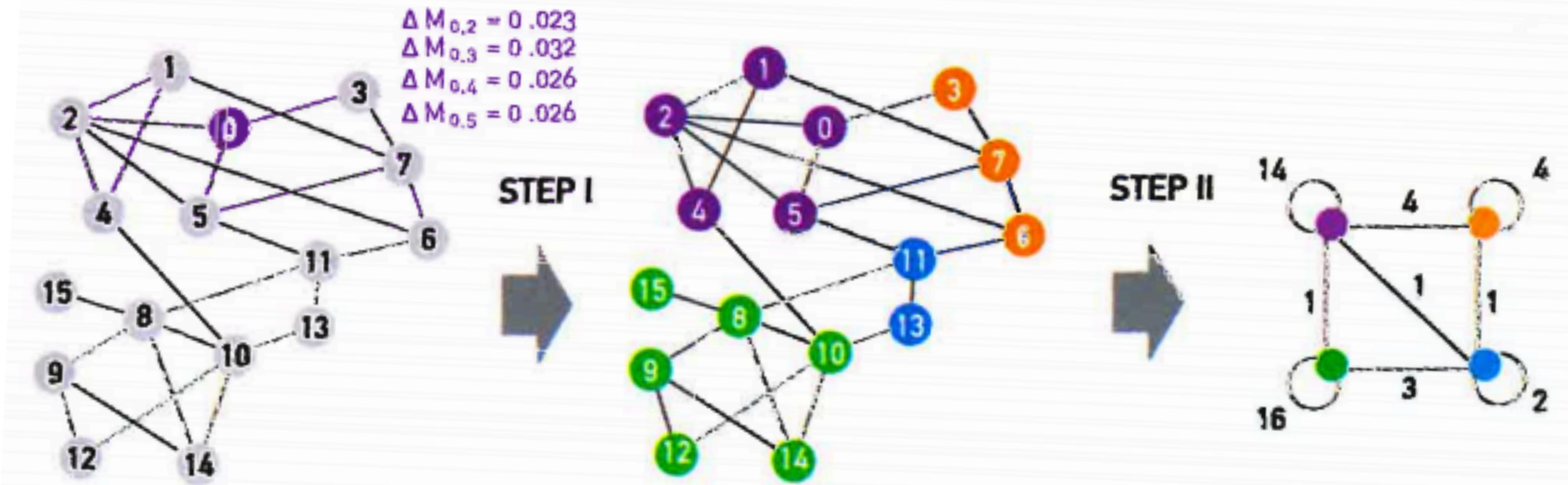


STEP I: Optimize modularity by local changes.
Which of its neighbors should a node join?

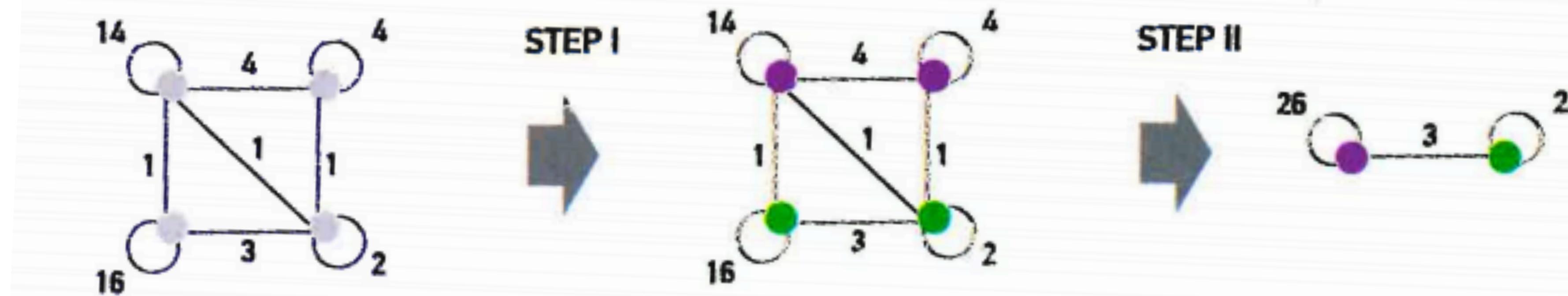
STEP II: Aggregate the communities into single nodes. Weights are number of links.

The Louvain method implements modularity maximization

1ST PASS



2ND PASS

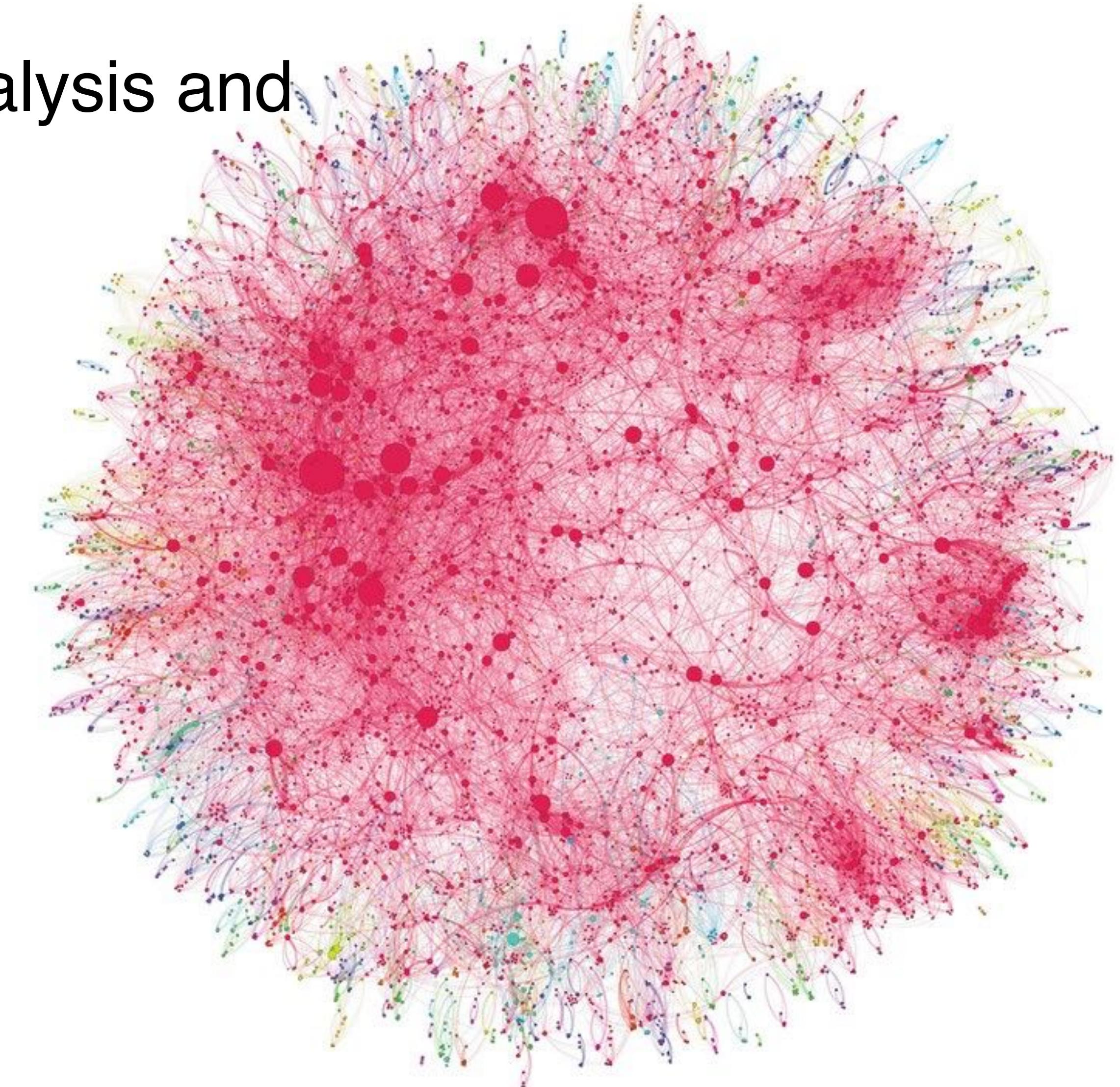


Next we are learning to use Gephi - the "Photoshop for networks"

Gephi is an open-source network analysis and visualization software written in Java



gephi.org



<https://www.flickr.com/photos/speedoflife/8240814593/>

Next we are learning to use Gephi - the "Photoshop for networks"

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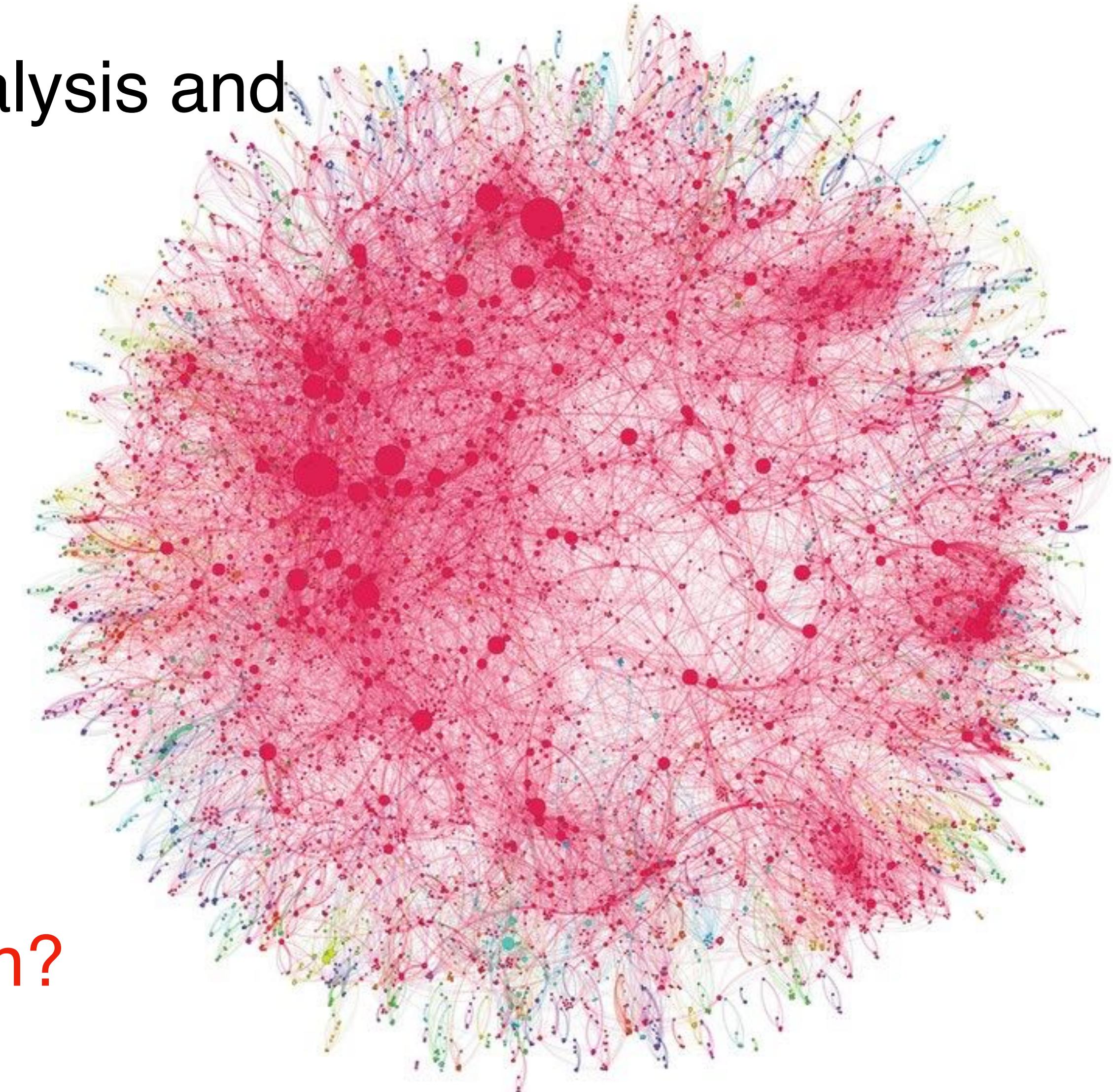


gephi.org

Nice vector-image rendering
Many layouts
Quick black box network analysis

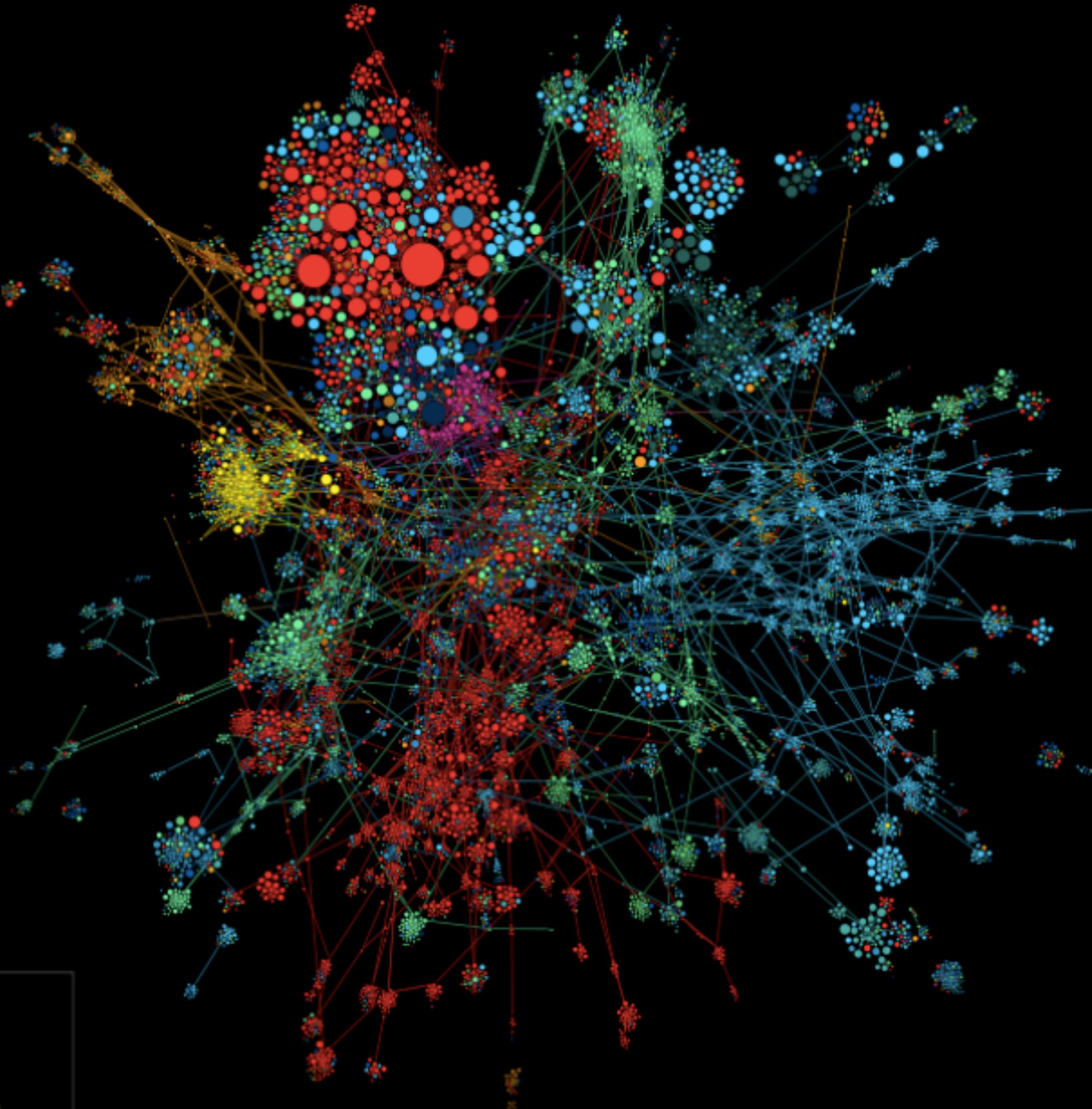


Not maintained anymore - yes again?
No UNDO!



<https://www.flickr.com/photos/speedoflife/8240814593/>

Art Network



Spain	Austria	Central America	Japan	Africa
UK	Switzerland	Canada	Other Asia	South America
France	Italy	United States		Oceania
Germany	Other Europe			

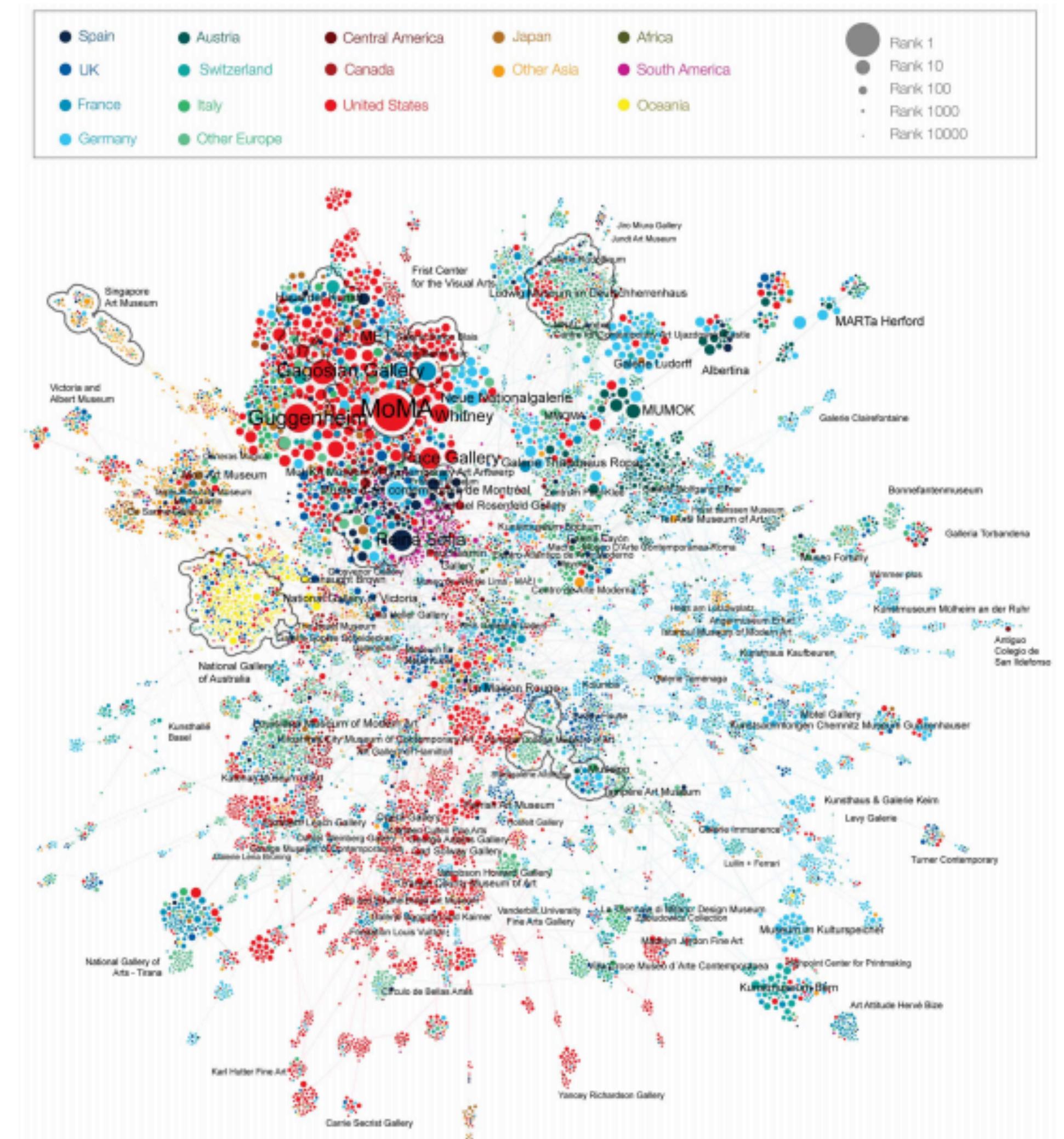


Fig. 1. Coexhibition network. Force-directed layout of the order $\tau = \infty$ coexhibition network, whose nodes are institutions (galleries, museums). Node size is proportional to each institution's eigenvector centrality. Nodes are connected if they both exhibited the same artist, with link weights being equal to the number of artists' coexhibitions. Node colors encode the region in which institutions are located. Links are of the same colors as their end nodes, or gray when end nodes have different colors. For

visualization purposes, we only show the 12,238 nodes corresponding to institutions with more than 10 exhibits; we pruned the links by keeping the most statistically significant links (20) (supplementary text S2.2). We implemented community detection on the pruned network (21), identifying 122 communities (supplementary text S2.3). We highlighted five of them, the full community breakdown being shown in fig. S3. We also show the names of the most prestigious institution for each community.

Downloaded from <http://science.scienmag.org/> on November 21, 2018

[http://science.scienmag.org/
content/362/6416/825/tab-pdf](http://science.scienmag.org/content/362/6416/825/tab-pdf)

Gephi

NetworkX is the most used Python package for network analysis



Open source, easy to install

Many measures, algorithms, generators

Flexible: nodes can be anything, links can hold any attributes



Data structures can be confusing

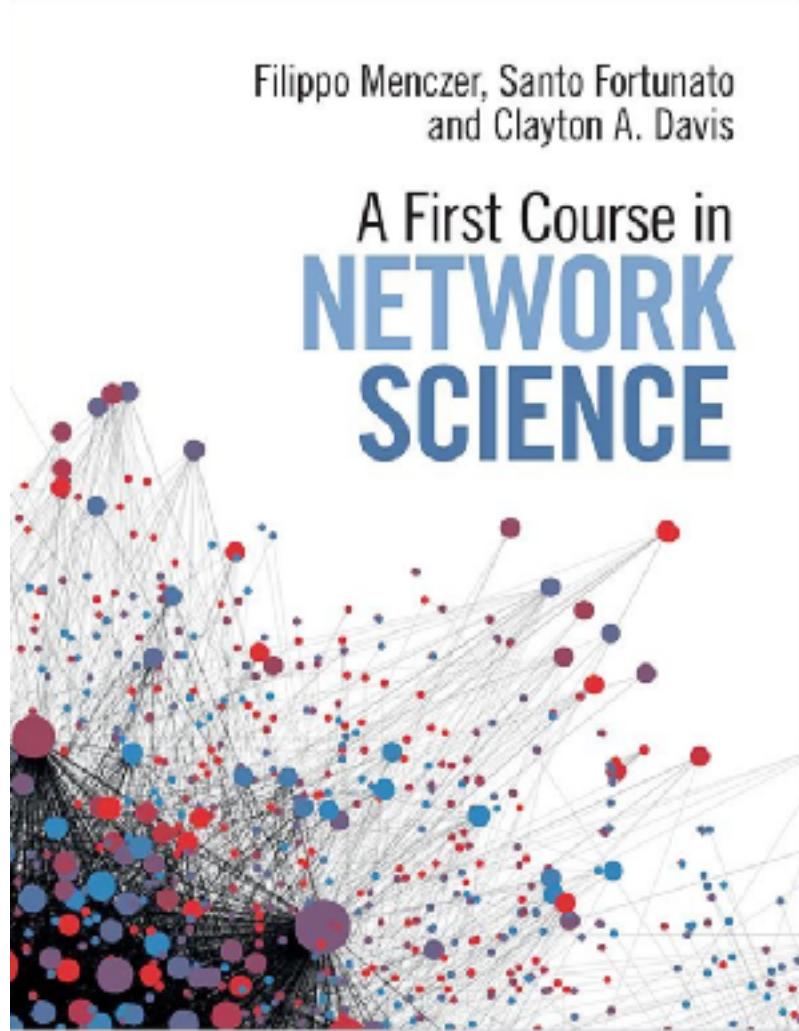
Relatively slow

There are many other alternatives with pros and cons

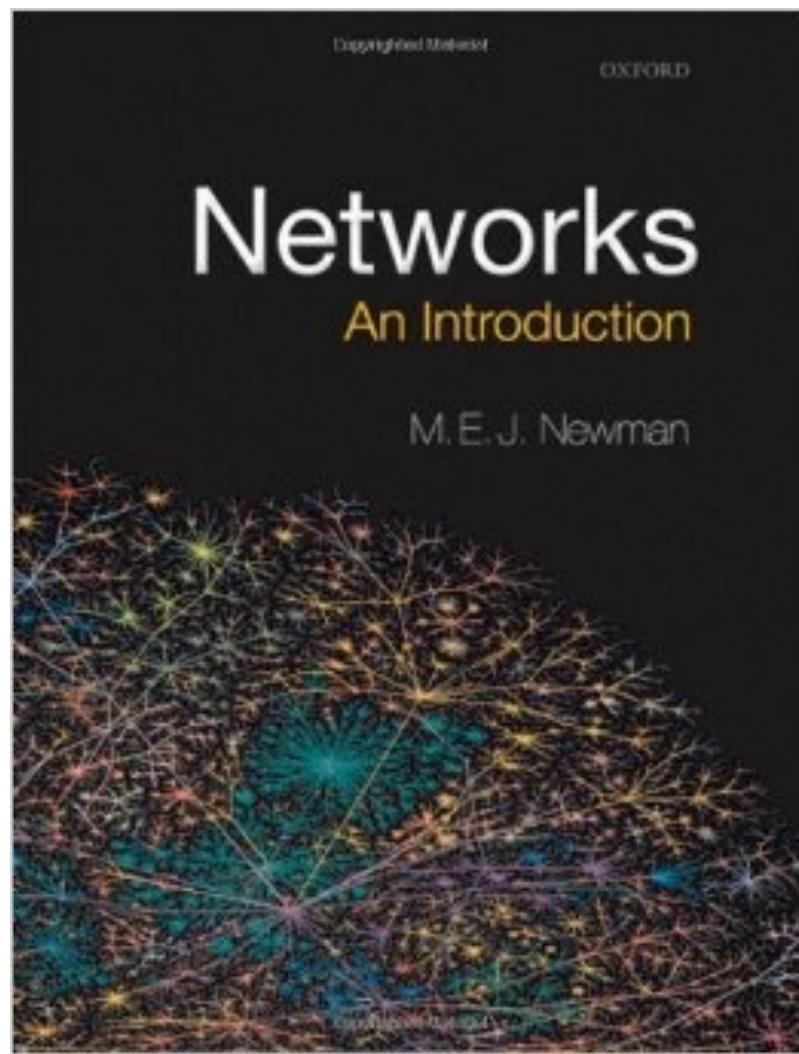


Jupyter

Sources and further materials for today's class



F. Menczer, S. Fortunato, C.A. Davis
A first course in Network Science
Cambridge University Press (2020)



M.E.J. Newman.
Networks: An Introduction.
Oxford University Press (2010)