



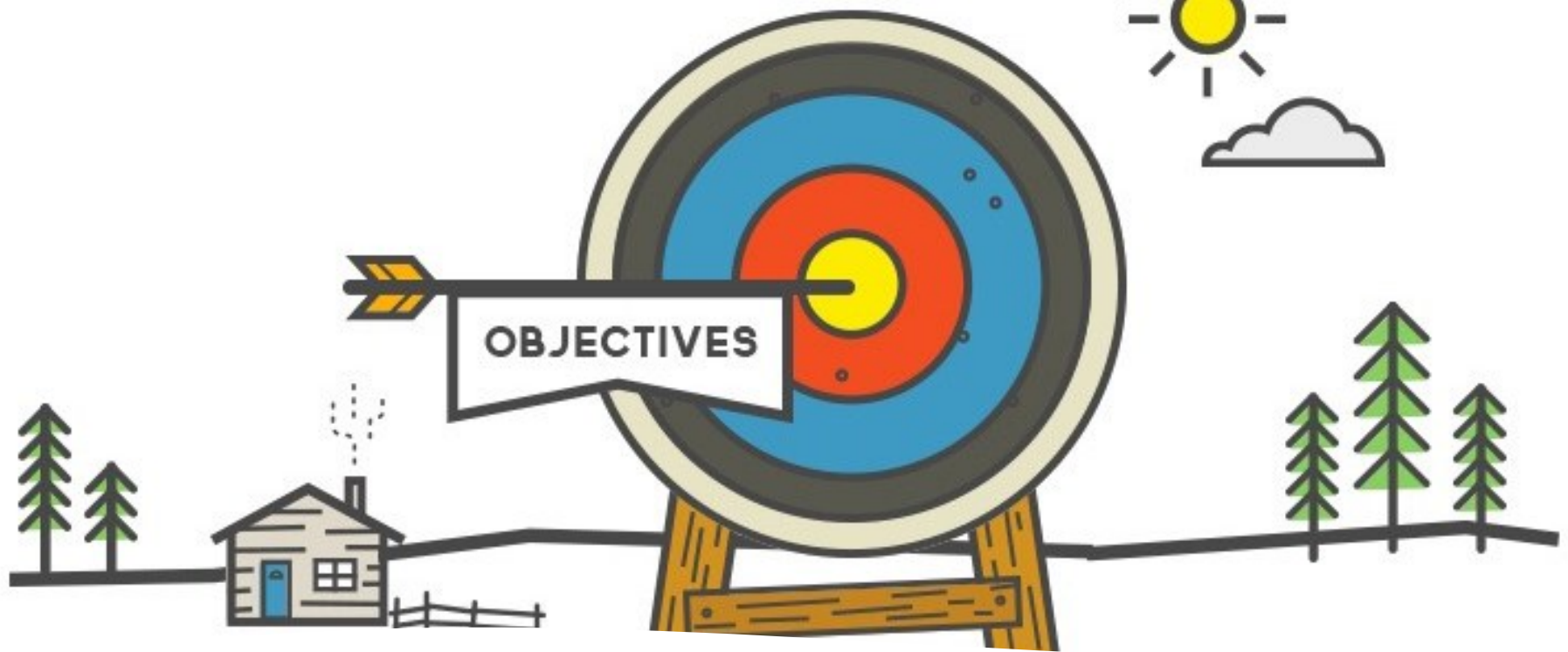
Lisbon School
of Economics
& Management
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NETWORK SCIENCE

Prof. Carlos J. Costa





Learning Goals

- Understand the context of network Science
- Explain main concepts and measurements
- Use mail tools
- Apply to specific context

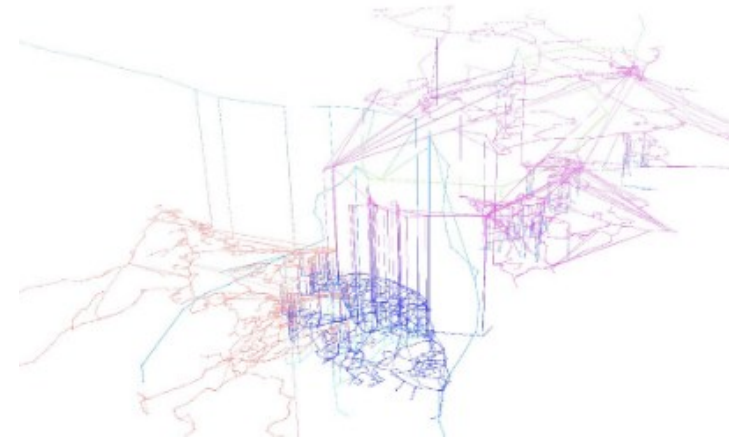
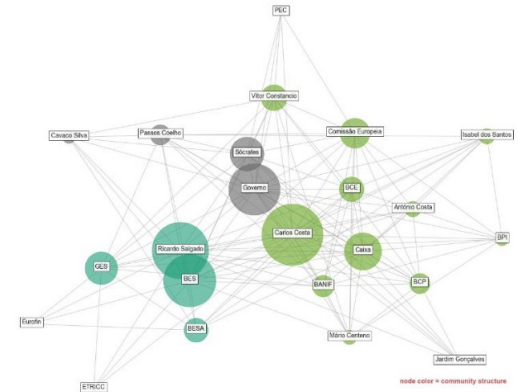
Agenda

- Complex Network
- Network Elements
- Measurements
- Node Degree
- Networks metrics
- Node metrics
- Tools
- Applications
- Challenges



Complex Network

- telecommunication networks
- computer networks
- biological networks
- cognitive and semantic networks
- social networks



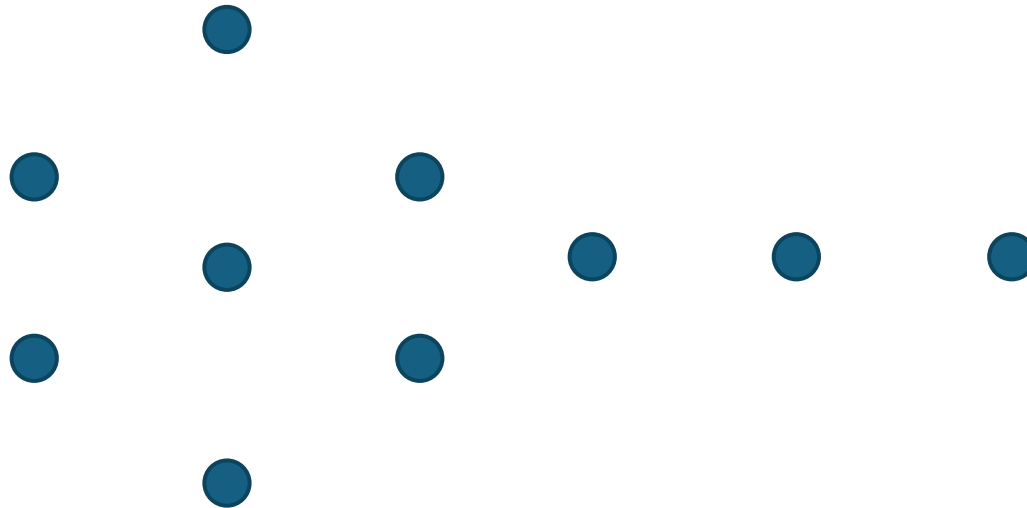
Network Elements

- "vertex" and "edge"
(Mathematics)
- "nodes" and "connections"
(or links) (Computer
Science)
- "actors" (or "agents") and
"relationships" (Sociology)
- "site" and "bond" (Physics)
- "dot" and "arcs" (or ties)



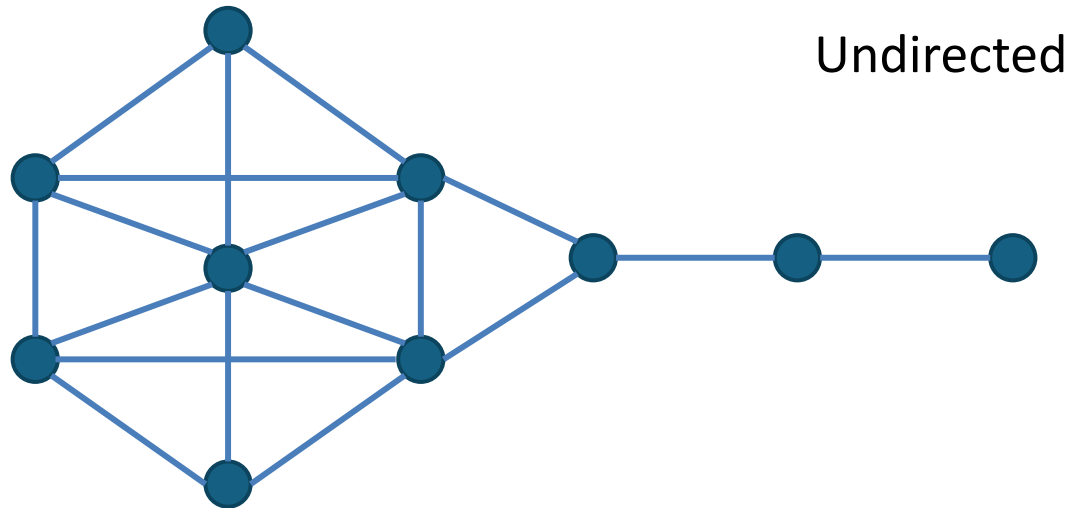
Network Elements

- Vertex, nodes and actors



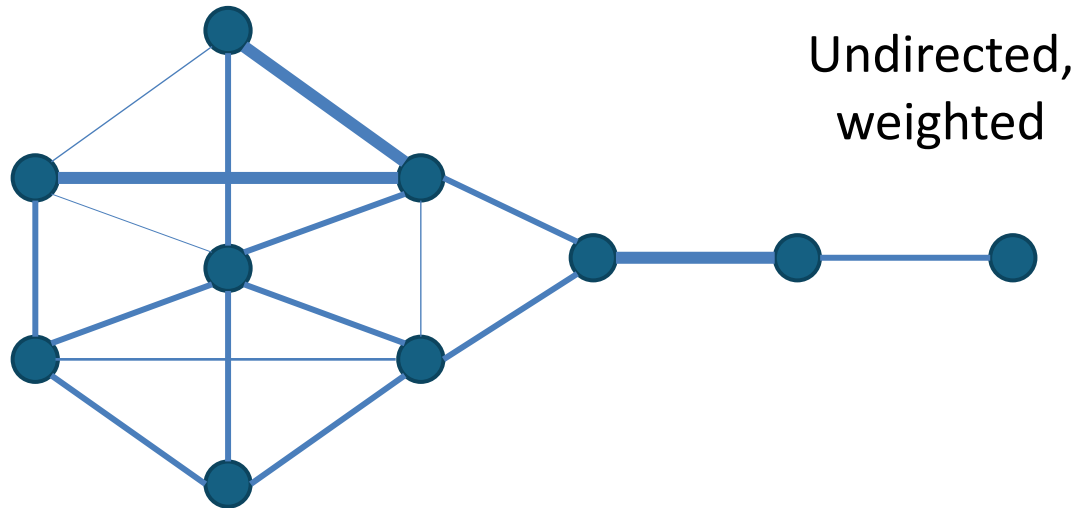
Network Elements

- Edges, arcs, links and relationships



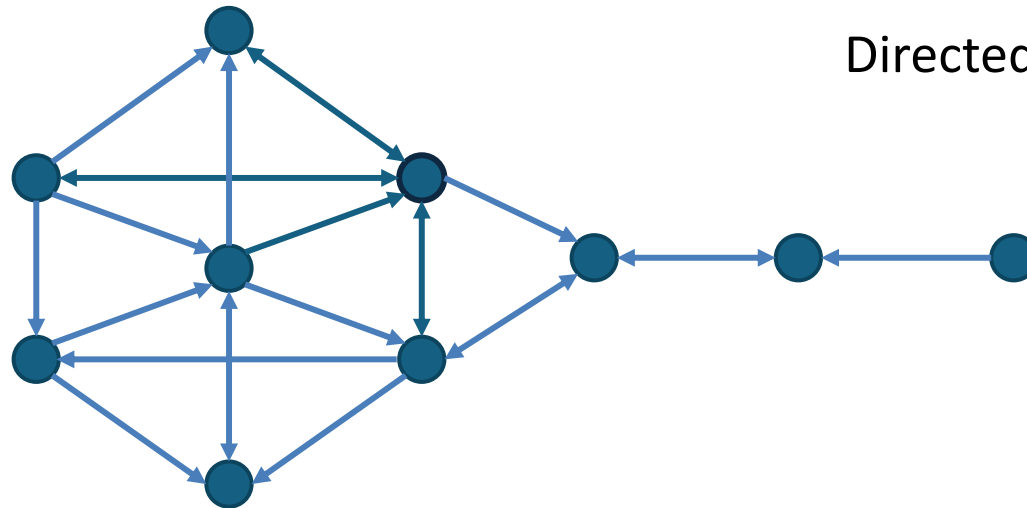
Network Elements

- Edges, arcs, links and relationships



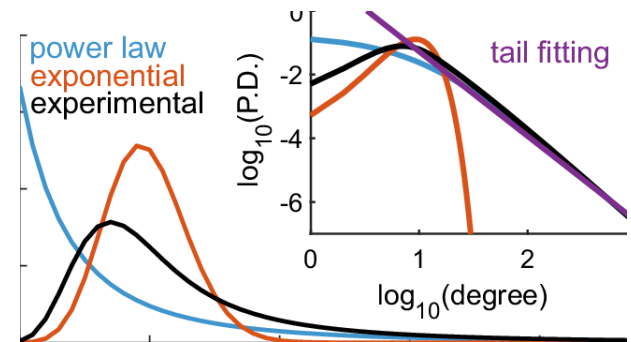
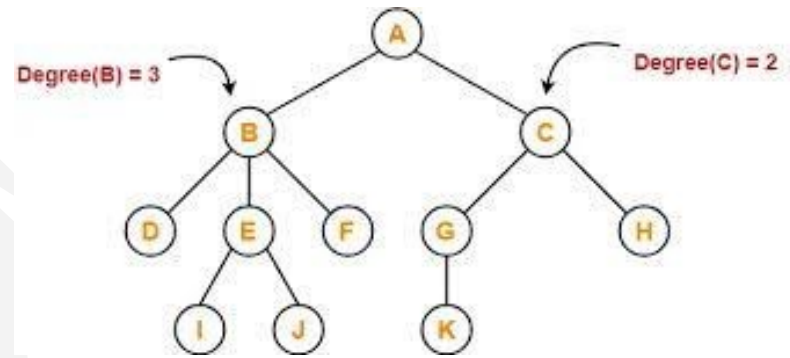
Network Elements

- Edges, arcs, links and relationships

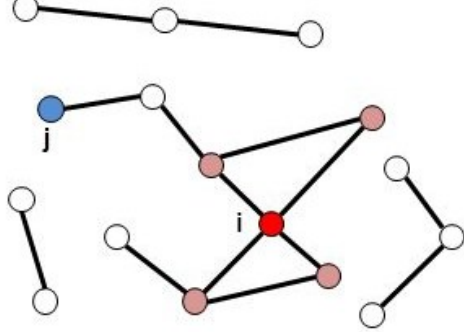


Node Degree

- number of connections it has to other nodes
- degree distribution is the probability distribution of these degrees over the whole network.



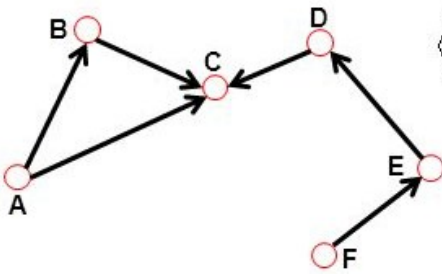
Undirected



$$\langle k \rangle \equiv \frac{1}{N} \sum_{i=1}^N k_i \quad \langle k \rangle \square \frac{2L}{N}$$

N – the number of nodes in the graph

Directed

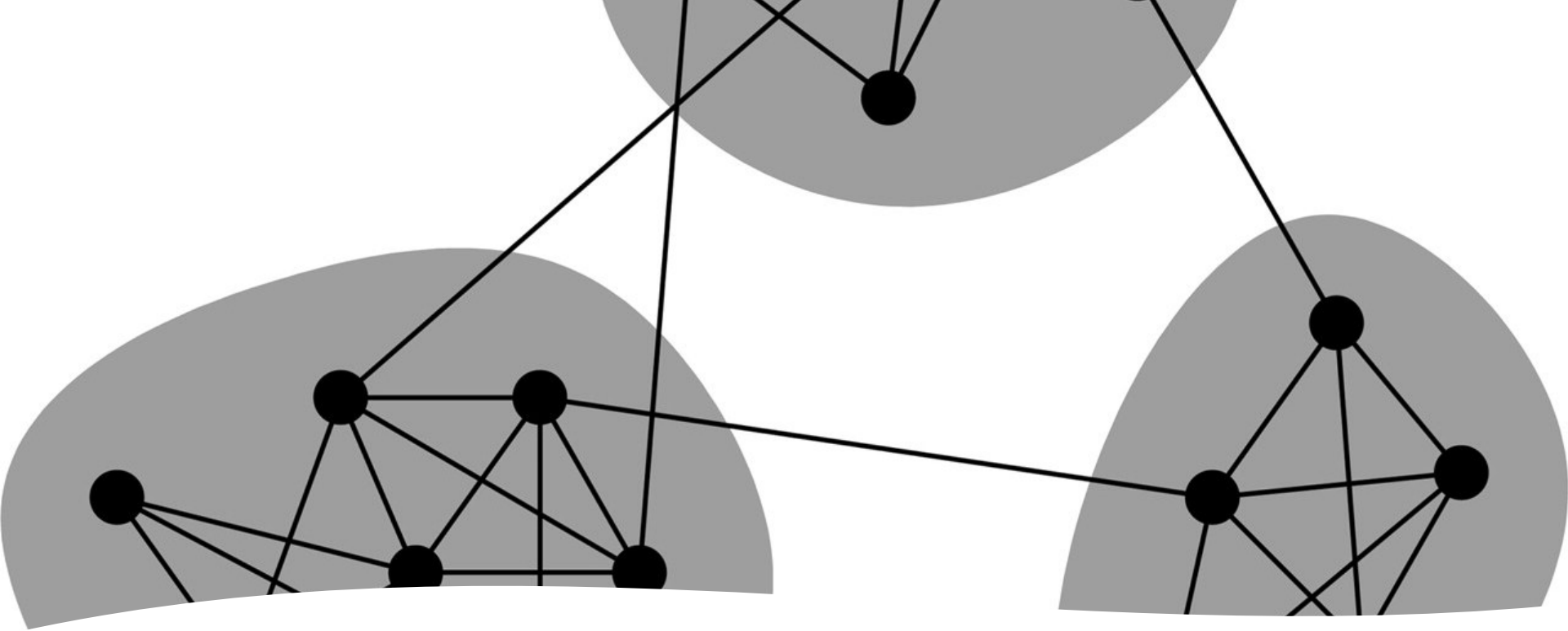


$$\langle k^{in} \rangle \equiv \frac{1}{N} \sum_{i=1}^N k_i^{in}, \quad \langle k^{out} \rangle \equiv \frac{1}{N} \sum_{i=1}^N k_i^{out}, \quad \langle k^{in} \rangle = \langle k^{out} \rangle$$

$$\langle k \rangle \square \frac{L}{N}$$

Network metrics

- Average Degree (average links per node)



Network metrics

Modularity

- is one measure of the structure of networks or graphs.
- It was designed to measure the strength of division of a network into modules (also called groups, clusters or communities).
- Networks with high modularity. have dense connections between the nodes within modules but sparse connections between nodes in different modules



assortative



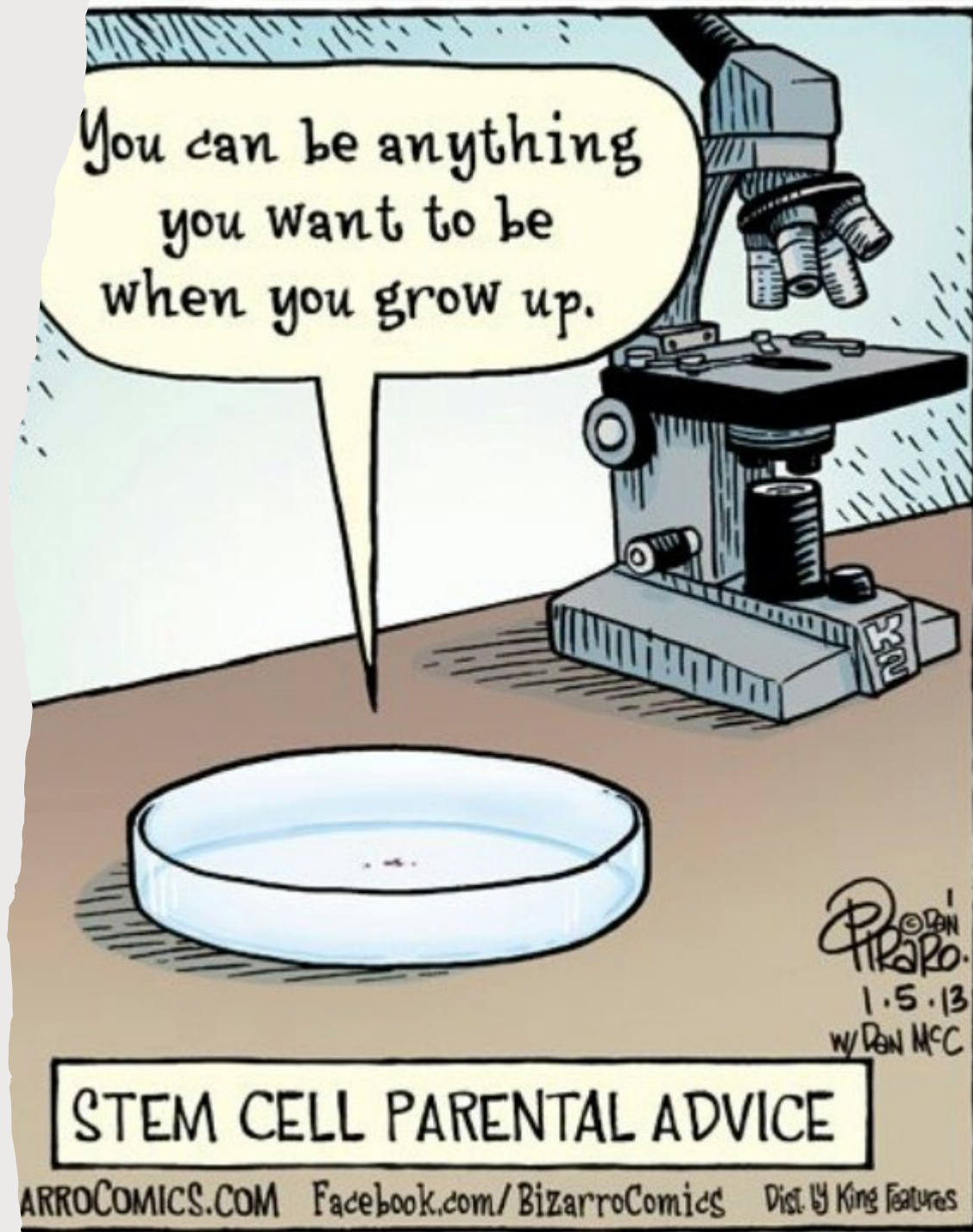
disassortative

Network metrics

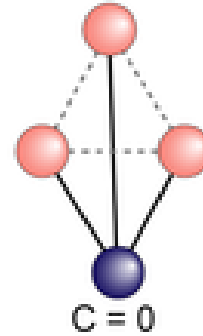
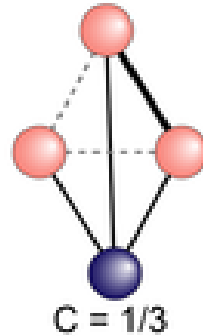
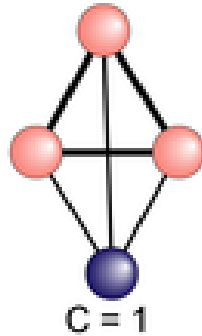
- Connected Components
- Social networks are highly assortative (homophily): high degree nodes connect to other high degree nodes
- technological are disassortative: high degree nodes connect to low degree nodes
- Assortative and disassortative mating

Node metrics

- Clustering Coefficient
- Centrality
- Closeness Centrality
- Betweenness Centrality
- Eigenvector Centrality



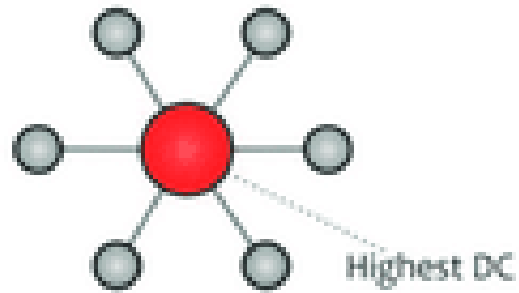
— Triangle Connection
— Actual Connection
... Possible Connection



Node metrics

a clustering coefficient is a measure of the degree to which nodes in a graph tend to cluster together

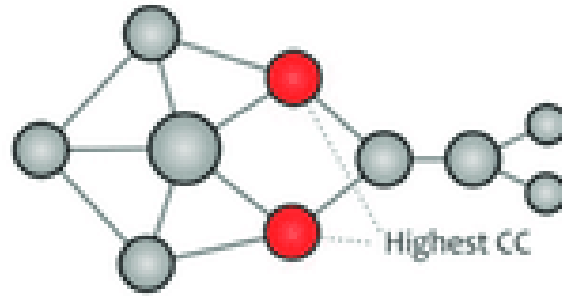
Degree centrality



Node metrics

Centrality refers to indicators which identify the most important vertices within a graph

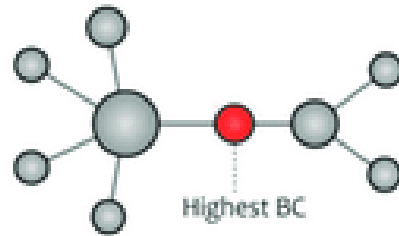
Closeness centrality



Node metrics

- In connected graphs there is a natural distance metric between all pairs of nodes, defined by the length of their shortest paths.
- The farness of a node is defined as the sum of its distances to all other nodes, and its closeness is defined as the reciprocal of the farness.
- Thus, the more central a node is the lower its total distance to all other nodes.

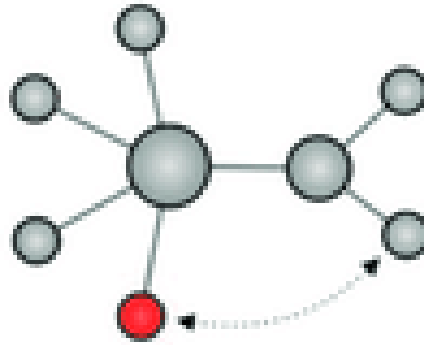
Betweenness centrality



Node metrics

- Betweenness centrality
- quantifies the number of times a node acts as a bridge along the shortest path between two other nodes.

Eigenvector centrality



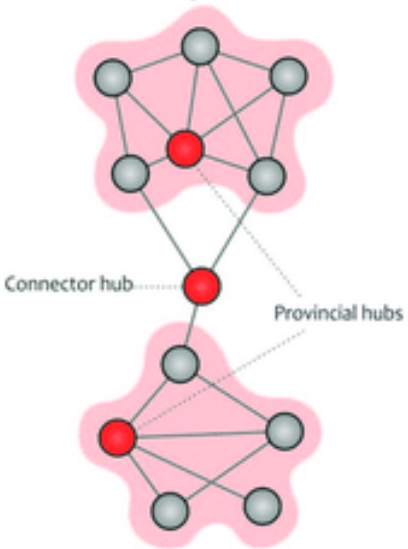
Node metrics

- Eigenvector centrality
- a node is connected to many nodes who themselves have high scores.

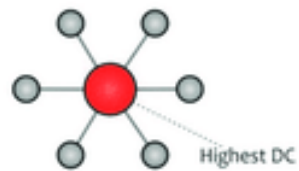
Node metrics

Centrality

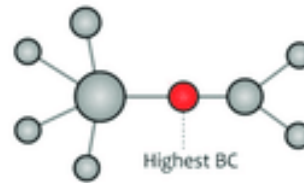
Centrality and hubs



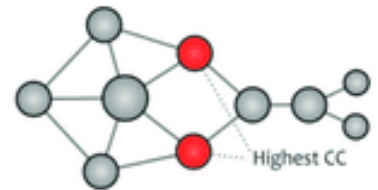
Degree centrality



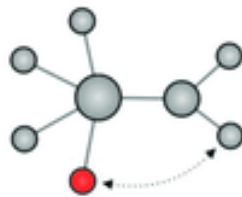
Betweenness centrality



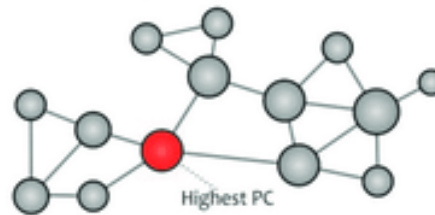
Closeness centrality



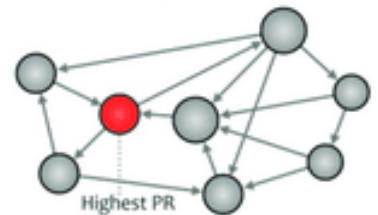
Eigenvector centrality



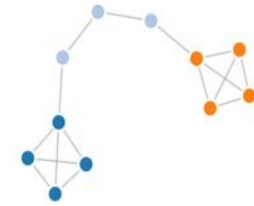
Participation coefficient



PageRank



Tools

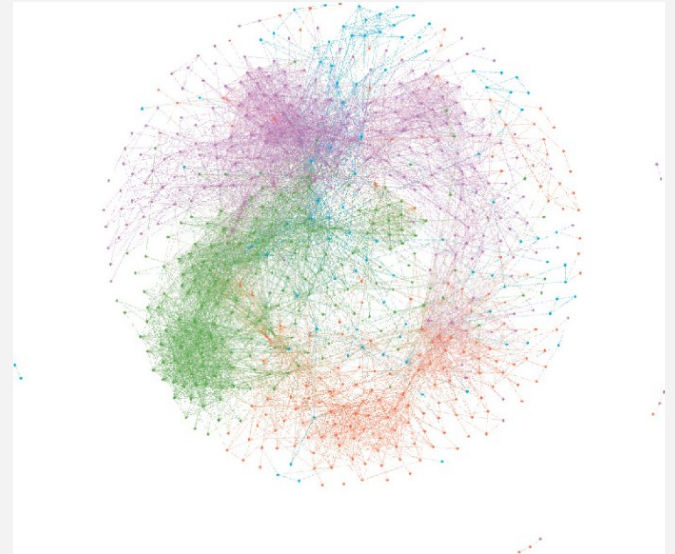


NetworkX



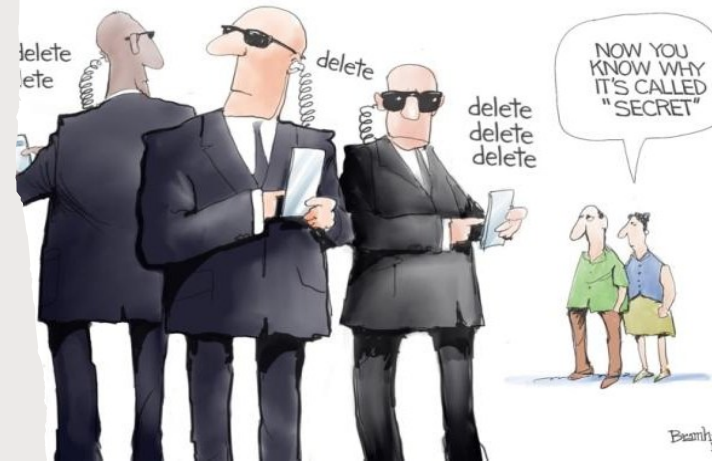
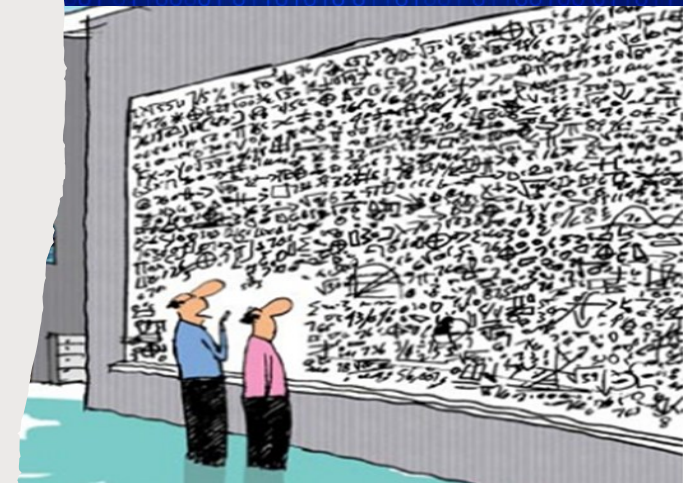
Applications

- Health and disease spread
- Capital participation
- Equity investment
- Internal communication
- Commercial relationship between enterprises



Challenges

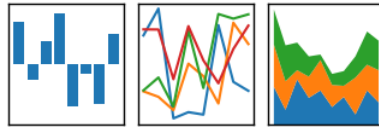
- Internal information
- Secrecy
- GDPR
- Conceptual Complexity
- Main value is obtained by integrate with other approaches
- ...



Python

pandas

$$y_{it} = \beta' x_{it} + \mu_i + \epsilon_{it}$$



matplotlib





Conclusions

- Complex Network
- Network Elements
- Measurements
- Node Degree
- Networks Overview
- Node Overview
- Tools
- Applications
- Challenges

References

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