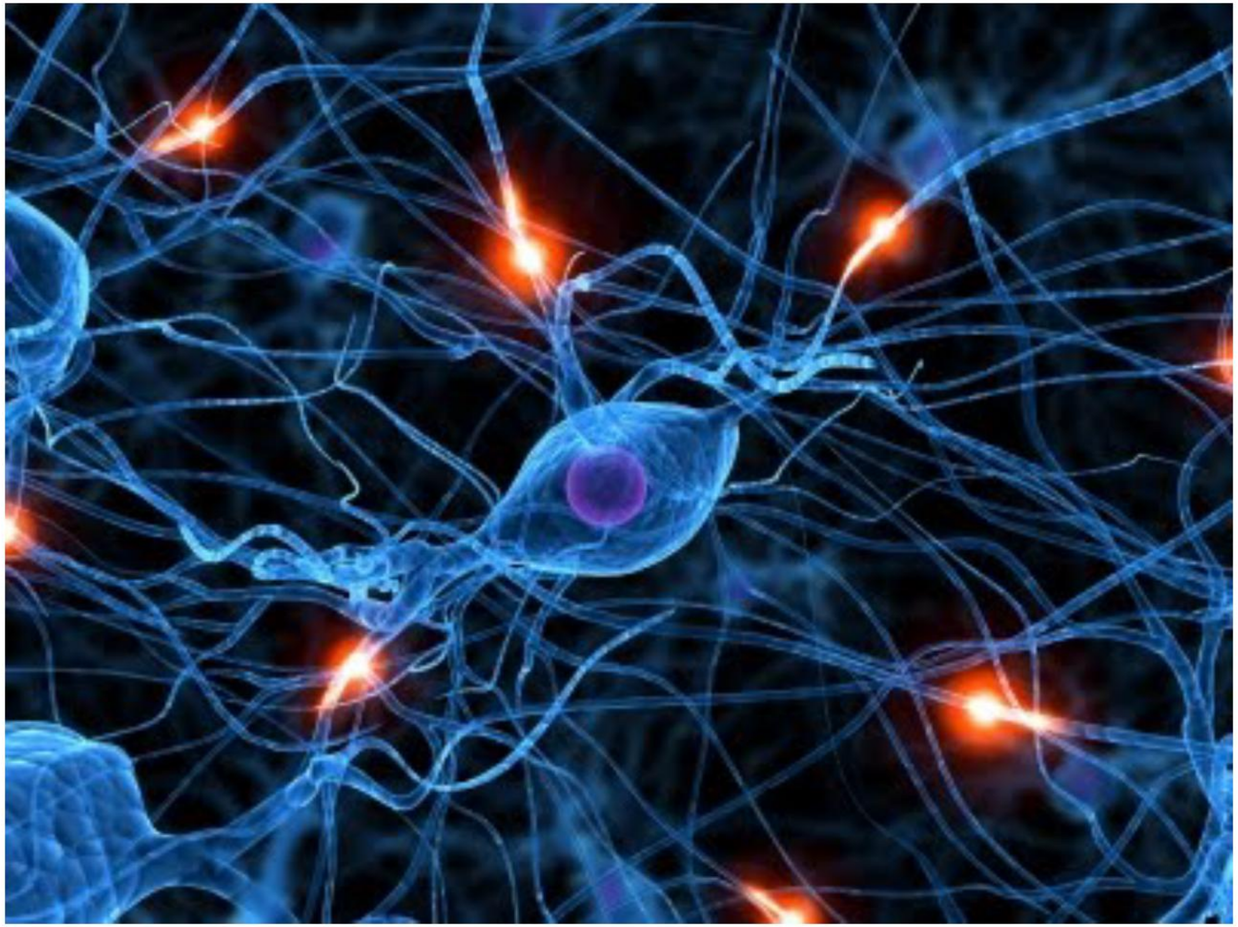
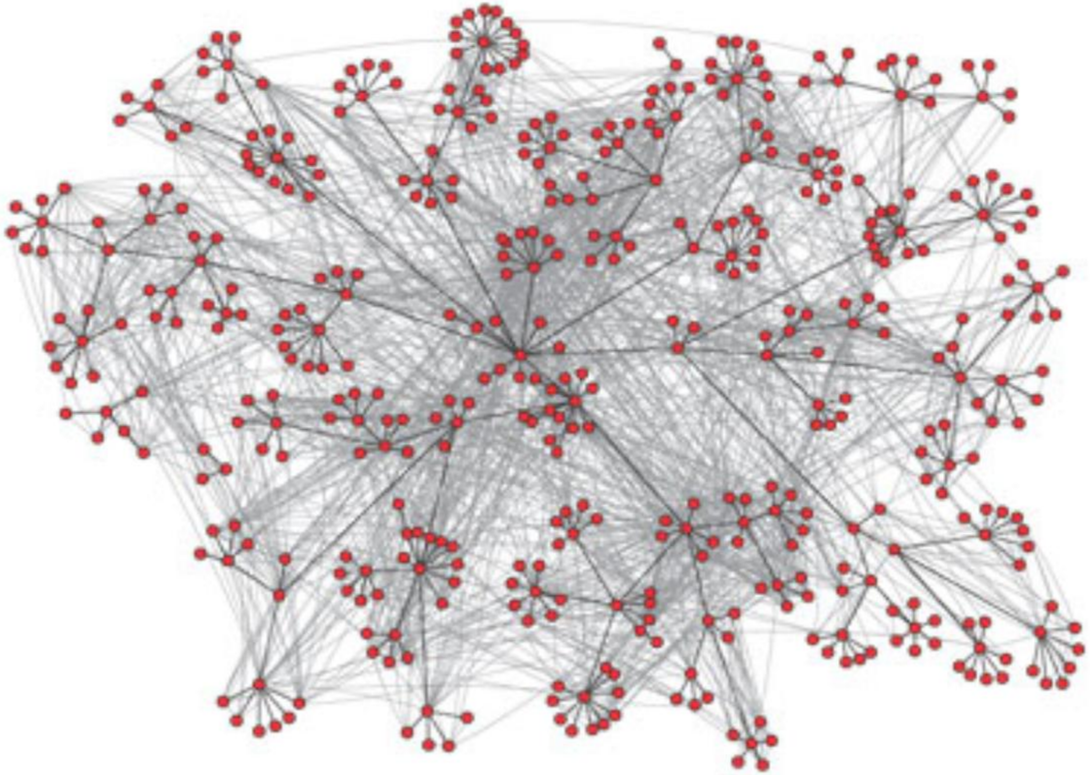
計算認知神經科學
腦神經網路特性

Network: brain



Human brain has between 10-100 billion neurons

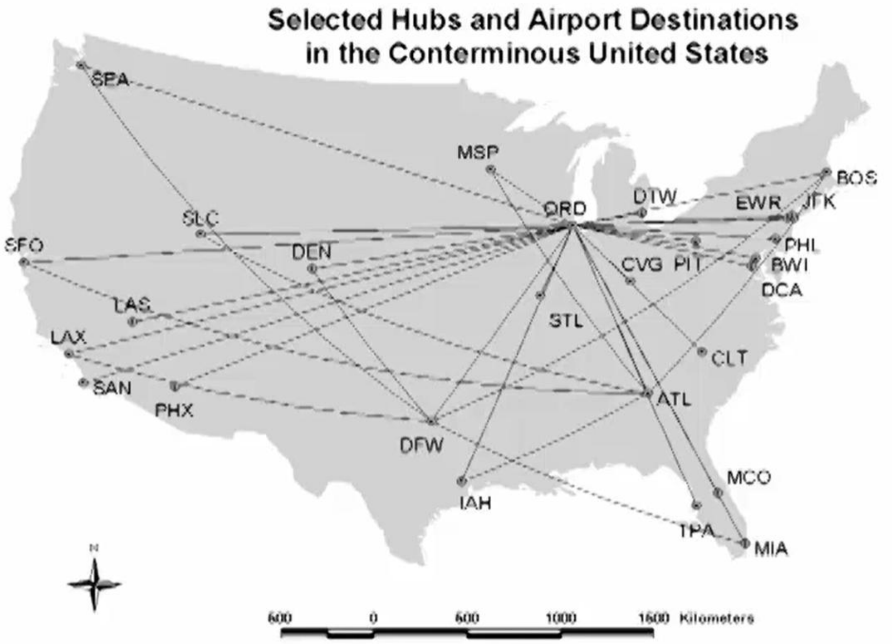
[Sporns, 2011]

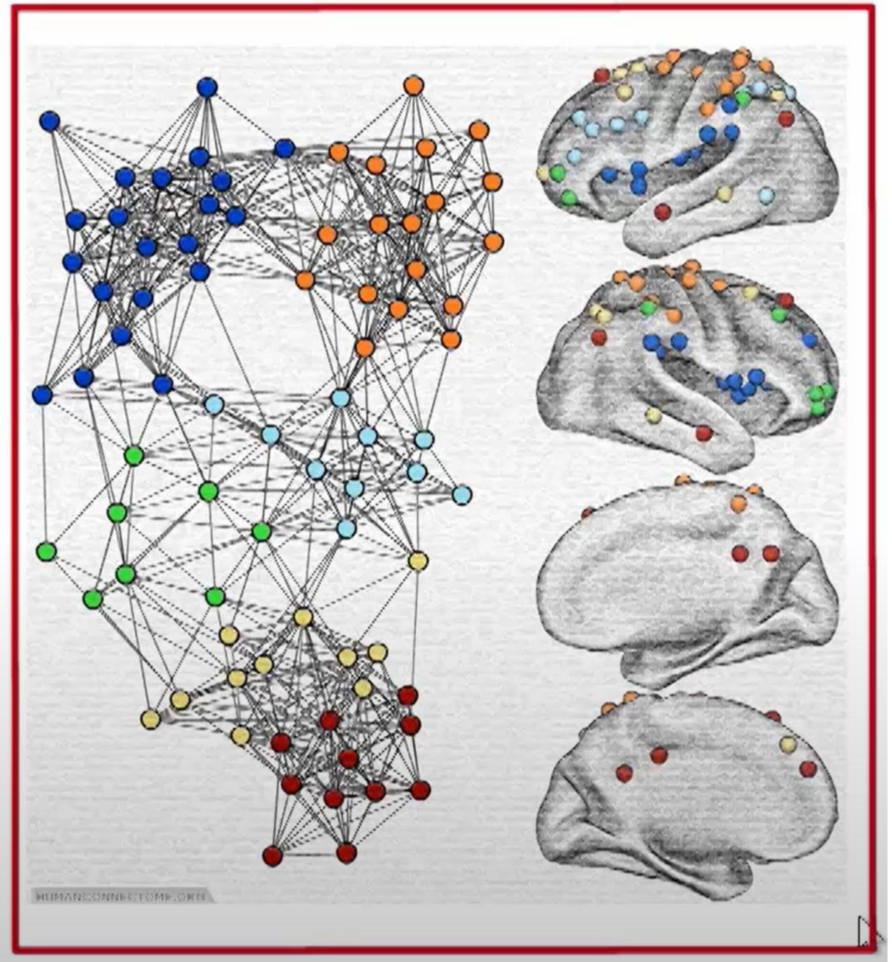


A network is a collection of objects where some pairs of objects are connected by links

What is the structure of the network?

Small world: Graph theory





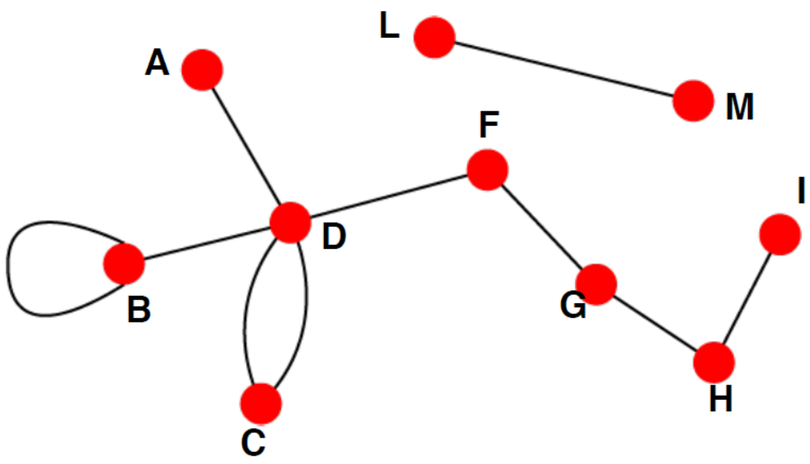
Vertices (Nodes)

Edge

Arc

Undirected

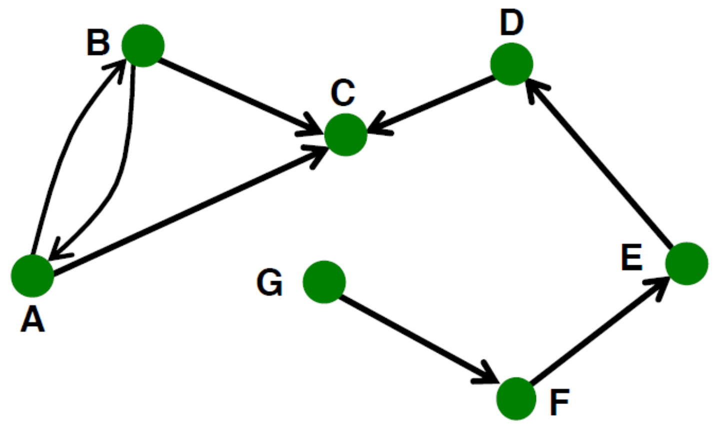
- **Links:** undirected (symmetrical, reciprocal)



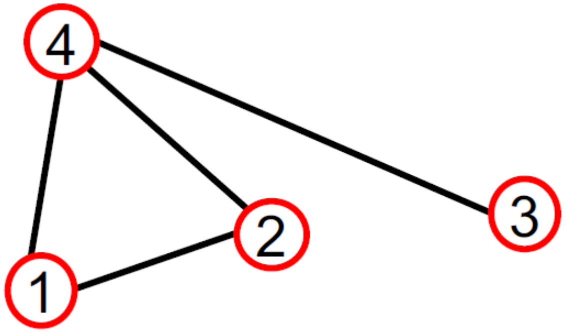
- **Examples:**
  - Collaborations
  - Friendship on Facebook

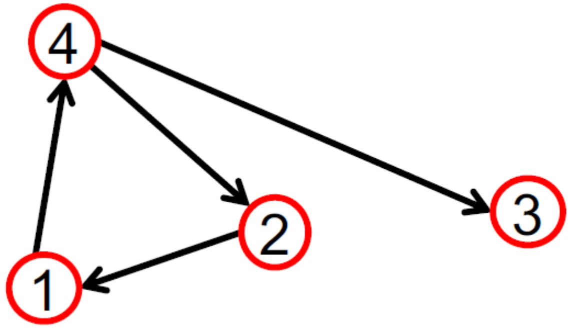
Directed

- **Links:** directed (arcs)



- **Examples:**
  - Phone calls
  - Following on Twitter





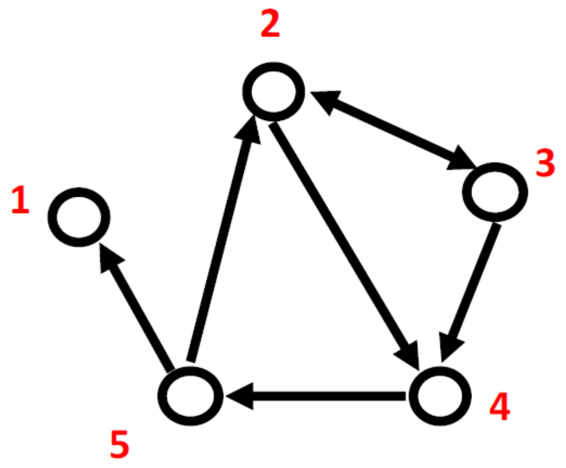
$A_{ij} = 1$ if there is a link from node ***i*** to node ***j***

$A_{ij} = 0$ otherwise

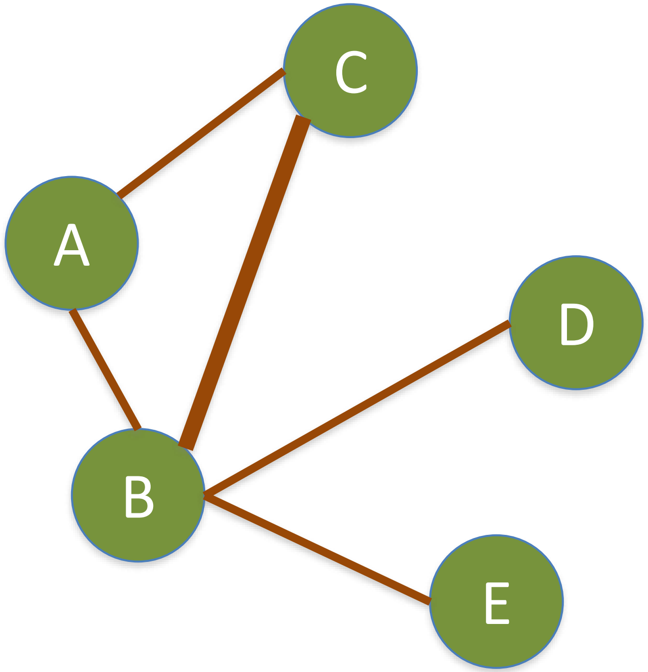
$$A = \begin{pmatrix} 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{pmatrix} \qquad A = \begin{pmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 \end{pmatrix}$$

Note that for a directed graph (right) the matrix is not symmetric.

- **Adjacency list:**
  - Easier to work with if network is
    - Large
    - Sparse
  - Allows us to quickly retrieve all neighbors of a given node
    - 1:
    - 2: 3, 4
    - 3: 2, 4
    - 4: 5
    - 5: 1, 2



Degree



A: 2
<u>B: 4</u>
C: 2
D:1
E: 1

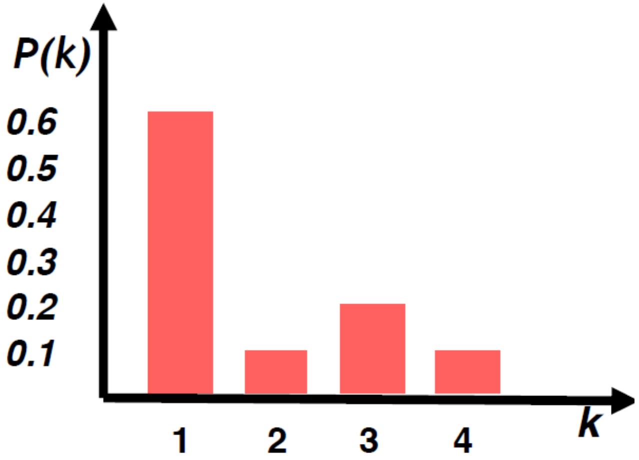
Source: https://www.youtube.com/watch?v=89mxOdwPfxA

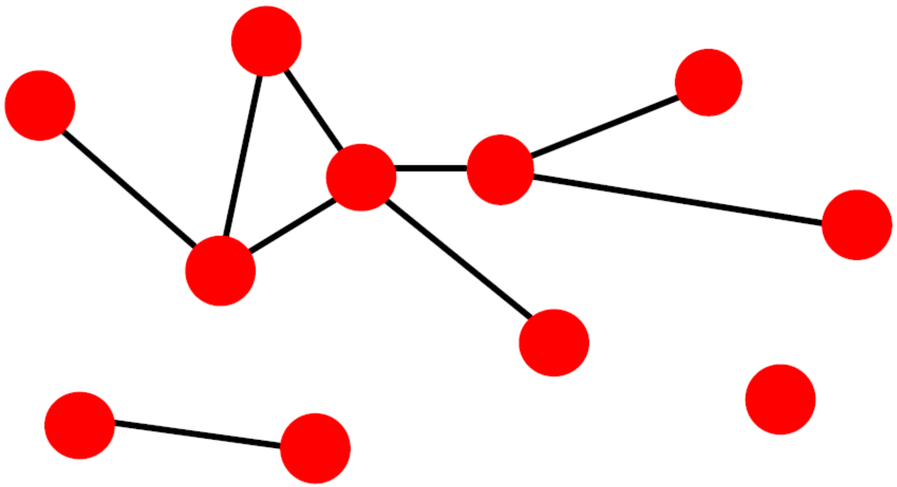
- **Degree distribution $P(k)$:** Probability that a randomly chosen node has degree k

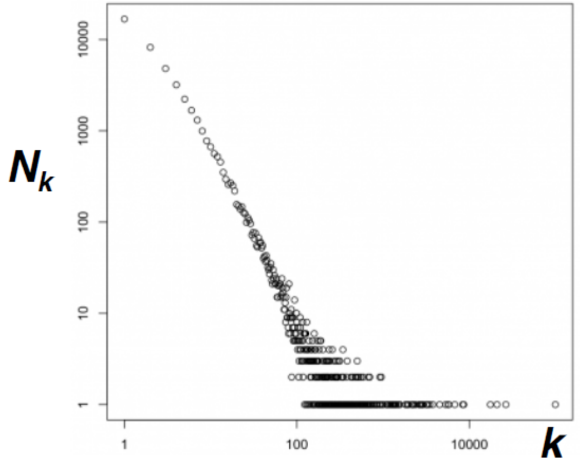
  N_k = # nodes with degree k

- Normalized histogram:

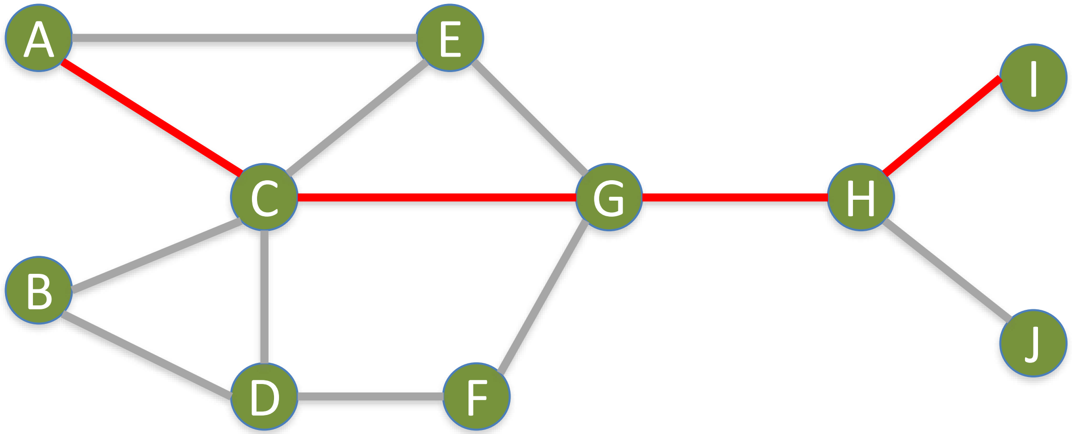
  $P(k) = N_k / N$ → plot



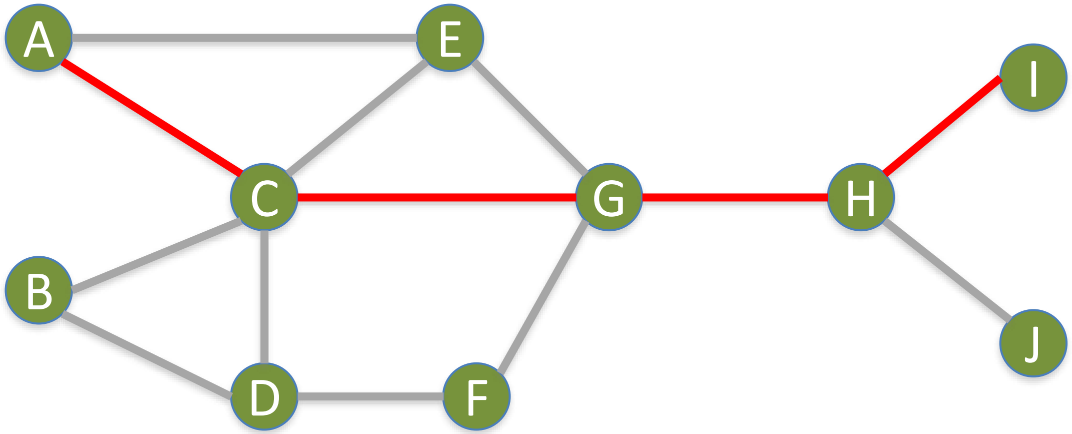




Diameter

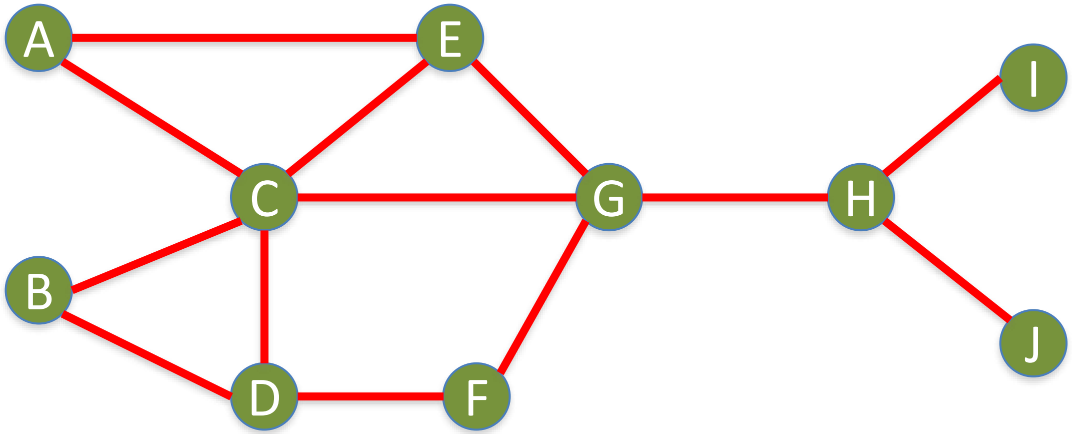


Diameter
Geodesic Path (Shortest Path)



A→ I : Diameter = 4

Which Node is Most Important?

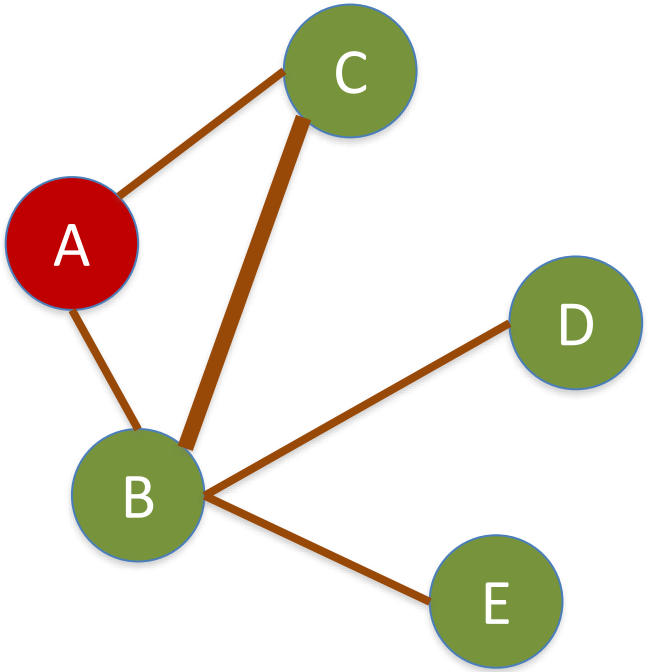


Betweenness centrality:

Connectivity

Number of shortest paths going through the actor

Betweenness Centrality



A:

B→C: 0/1 = 0

B→D: 0/1 = 0

B→E: 0/1 = 0

C→D: 0/1 = 0

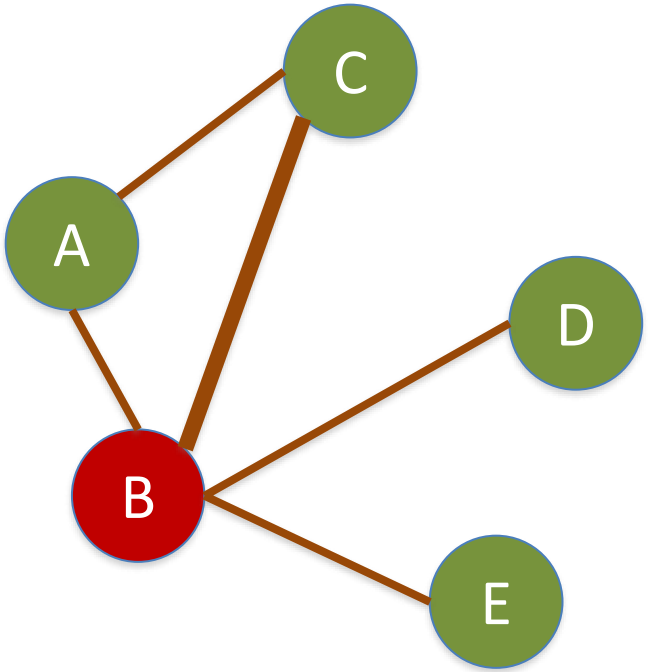
C→E: 0/1 = 0

D→E: 0/1 = 0

Total: 0

A: Betweenness Centrality = 0

Betweenness Centrality



B:

A→C: 0/1 = 0

A→D: 1/1 = 1

A→E: 1/1 = 1

C→D: 1/1 = 1

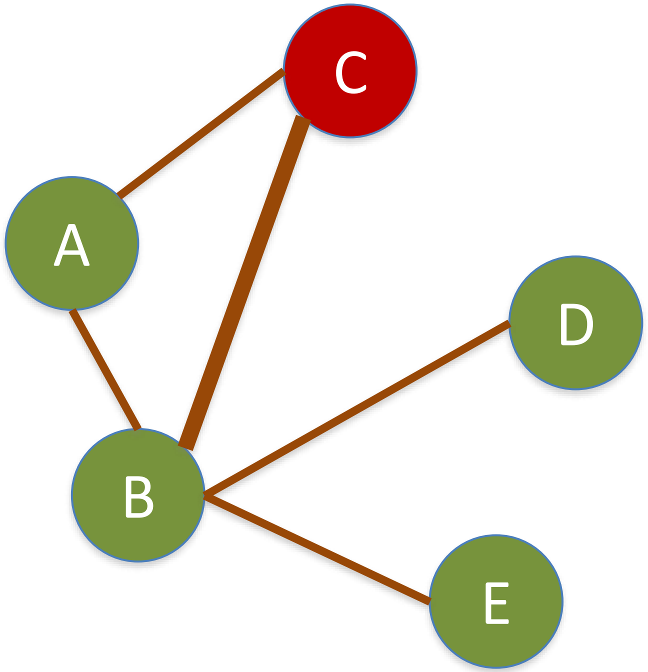
C→E: 1/1 = 1

D→E: 1/1 = 1

Total: 5

B: Betweenness Centrality = 5

Betweenness Centrality



C:

A→B: 0/1 = 0

A→D: 0/1 = 0

A→E: 0/1 = 0

B→D: 0/1 = 0

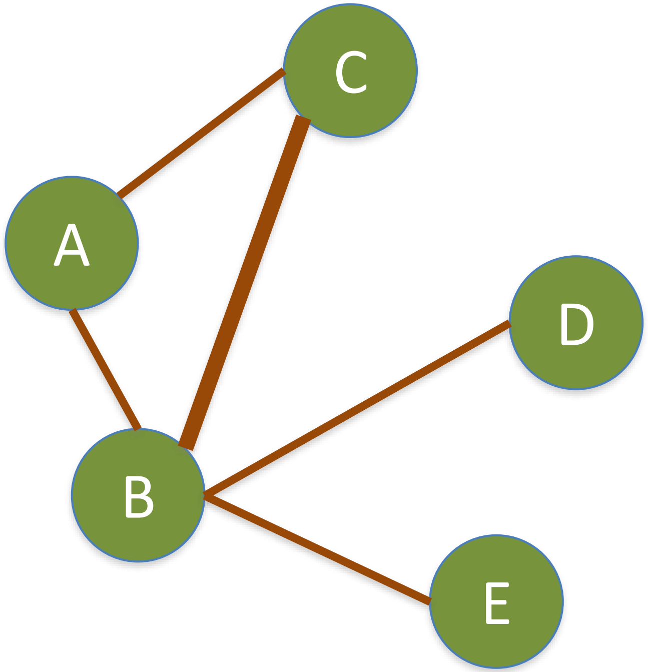
B→E: 0/1 = 0

D→E: 0/1 = 0

Total: 0

C: Betweenness Centrality = 0

Betweenness Centrality



A: 0

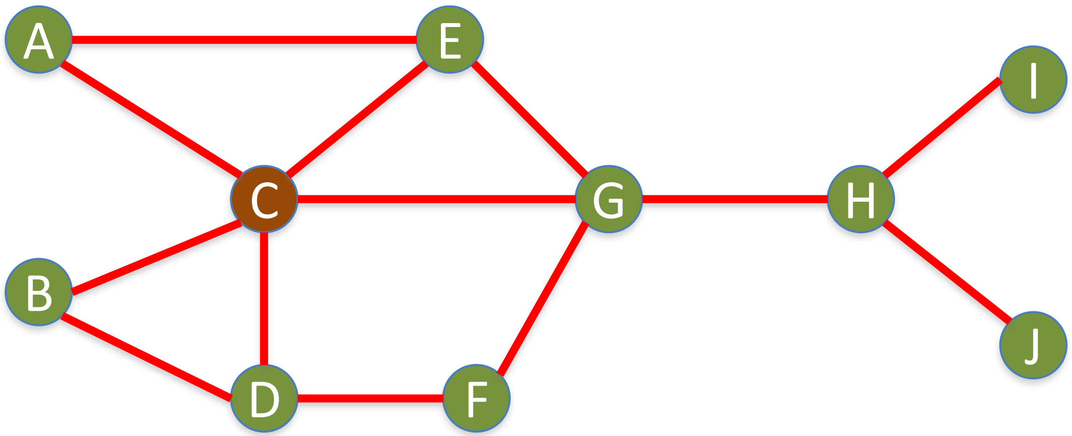
<u>B: 5</u>

C: 0

D: 0

E: 0

Closeness Centrality

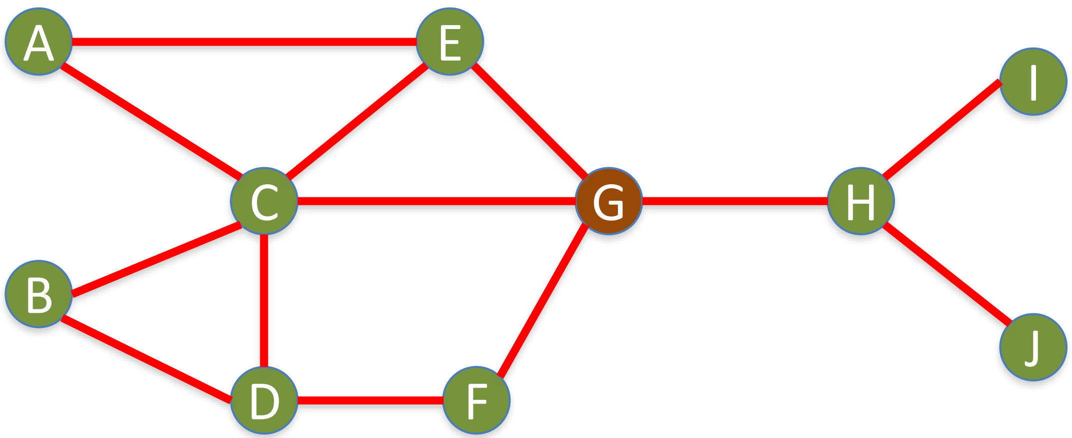


C→A: 1
C→B: 1
C→D: 1
C→E: 1
C→F: 2
C→G: 1
C→H: 2
C→I: 3
C→J: 3

Total=15

C: Closeness Centrality = 15/9 = 1.67

Closeness Centrality

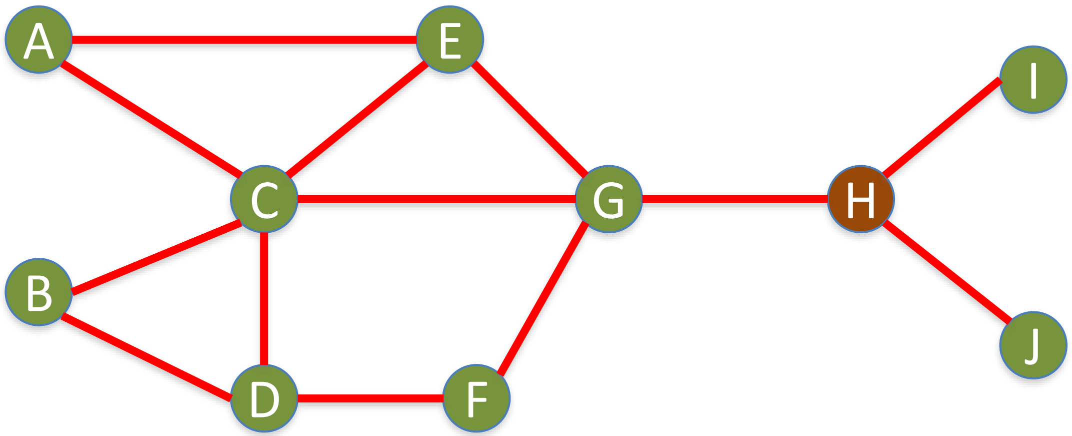


G→A: 2
G→B: 2
G→C: 1
G→D: 2
G→E: 1
G→F: 1
G→H: 1
G→I: 2
G→J: 2

Total=14

G: Closeness Centrality = 14/9 = 1.56

Closeness Centrality

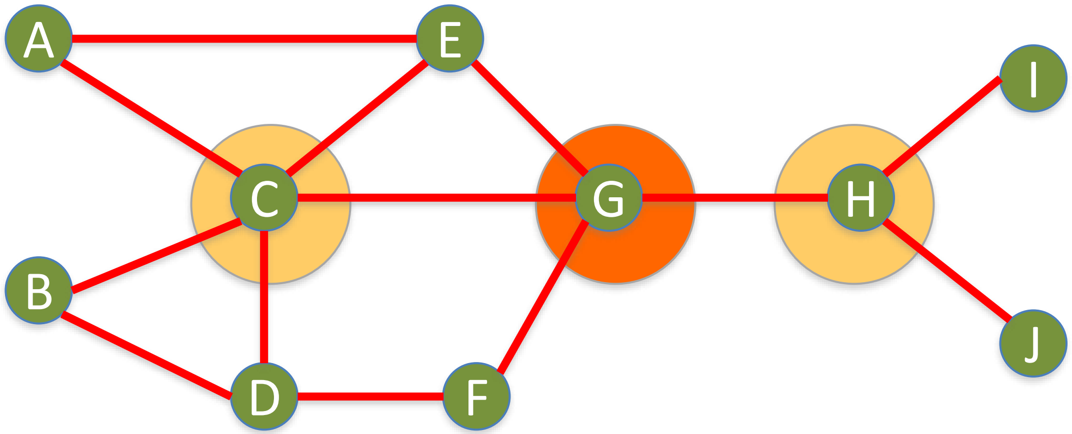


H→A: 3
H→B: 3
H→C: 2
H→D: 2
H→E: 2
H→F: 2
H→G: 1
H→I: 1
H→J: 1

Total=17

H: Closeness Centrality = 17/9 = 1.89

Closeness Centrality



<u>G: Closeness Centrality = 14/9 = 1.56</u> 1

C: Closeness Centrality = 15/9 = 1.67 2

H: Closeness Centrality = 17/9 = 1.89 3

Social Network Analysis (SNA)

importance of neighbors

Eigenvector centrality

Eigenvector Centrality: 基本概念為 degree centrality，跟越重要的 node 連，算分越高。

認識世界知名人物

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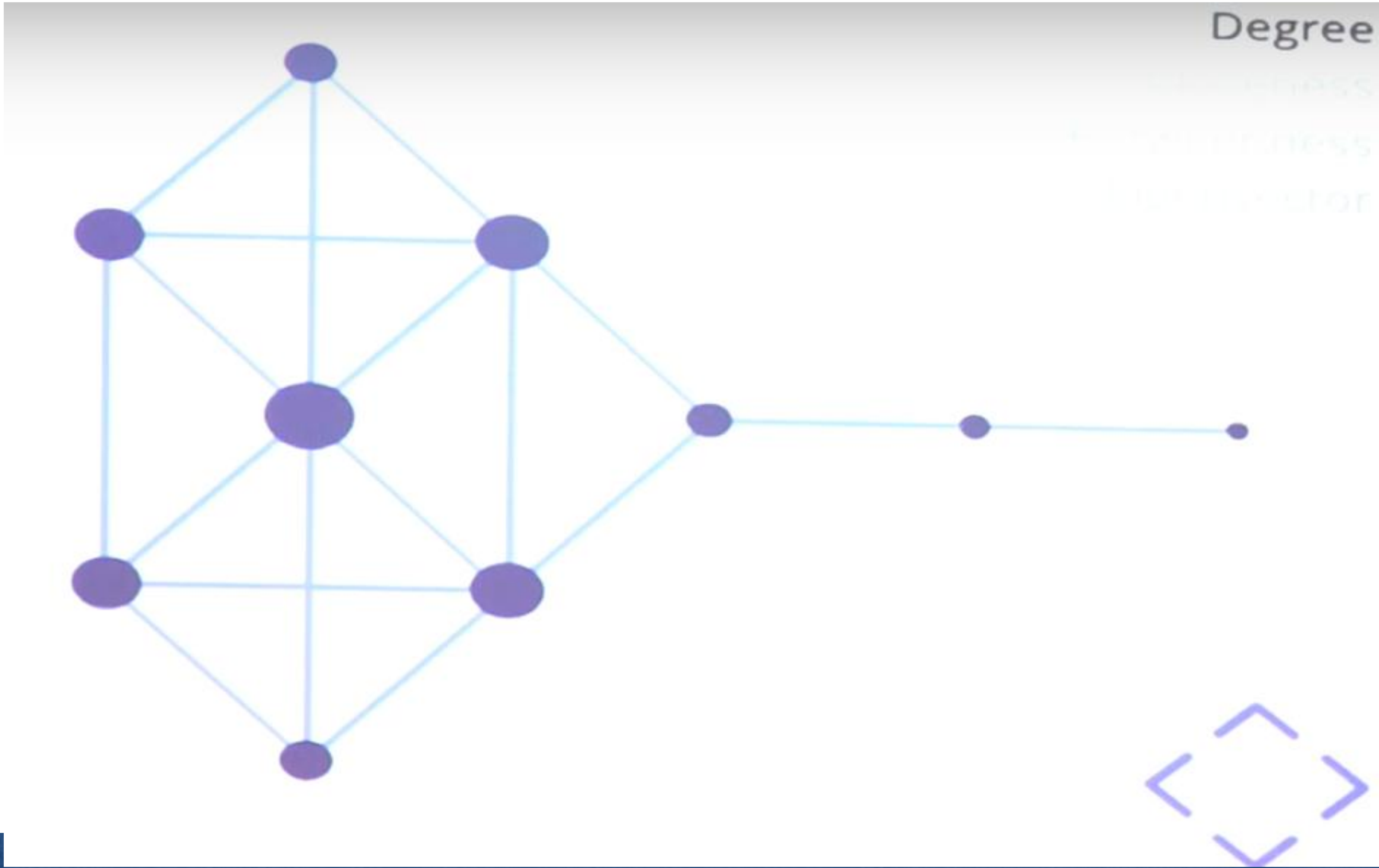
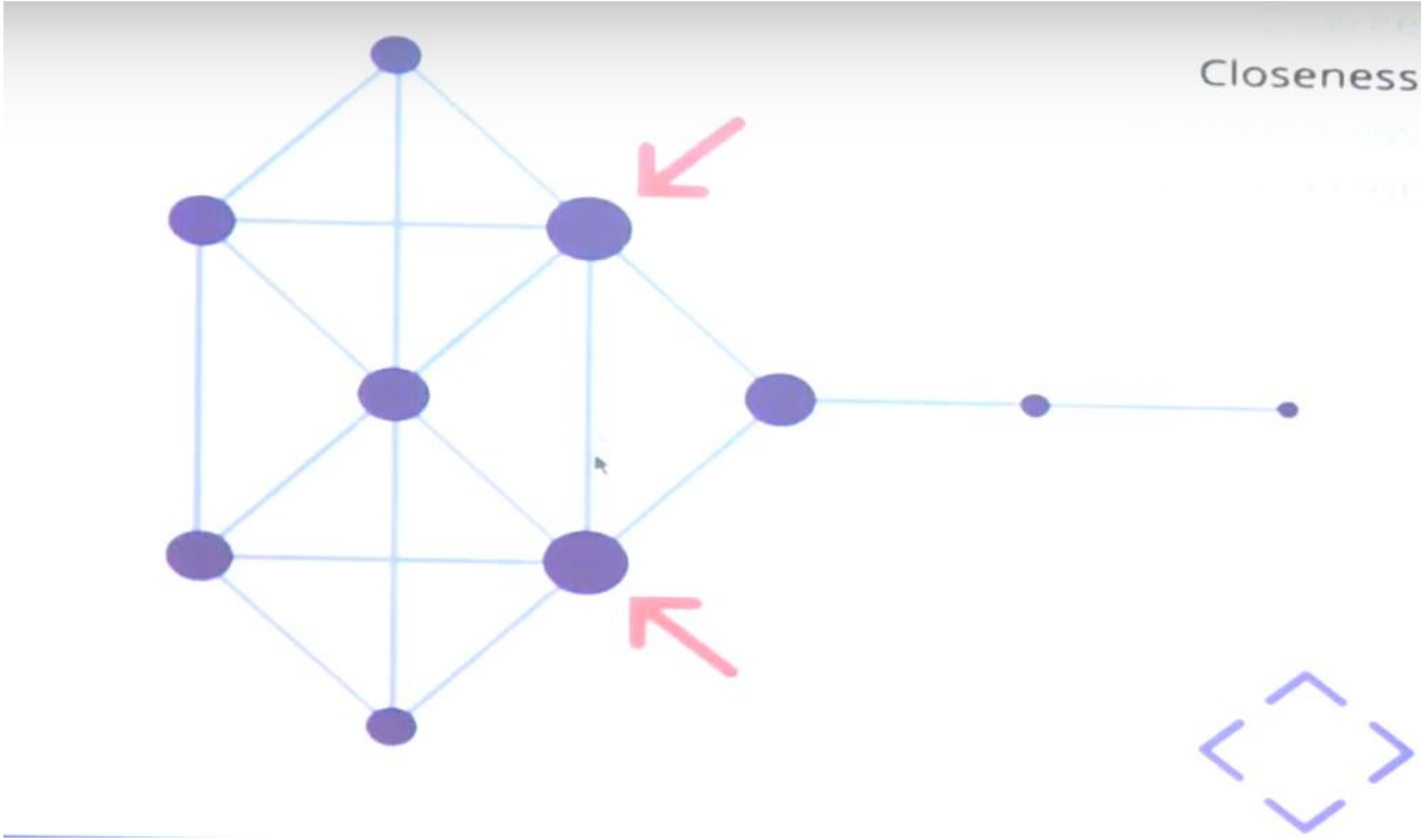
認識默默無名小生物

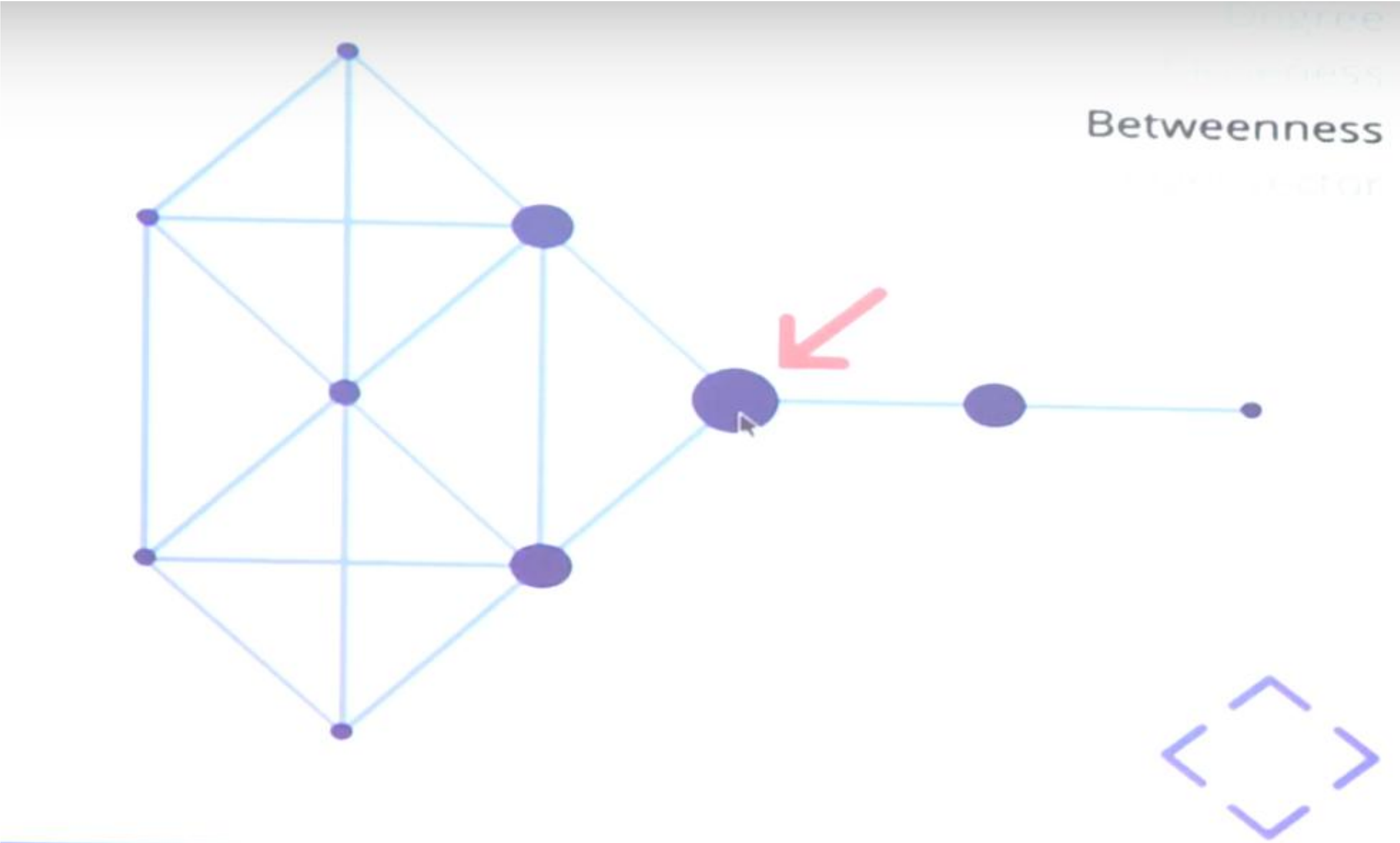
Degree



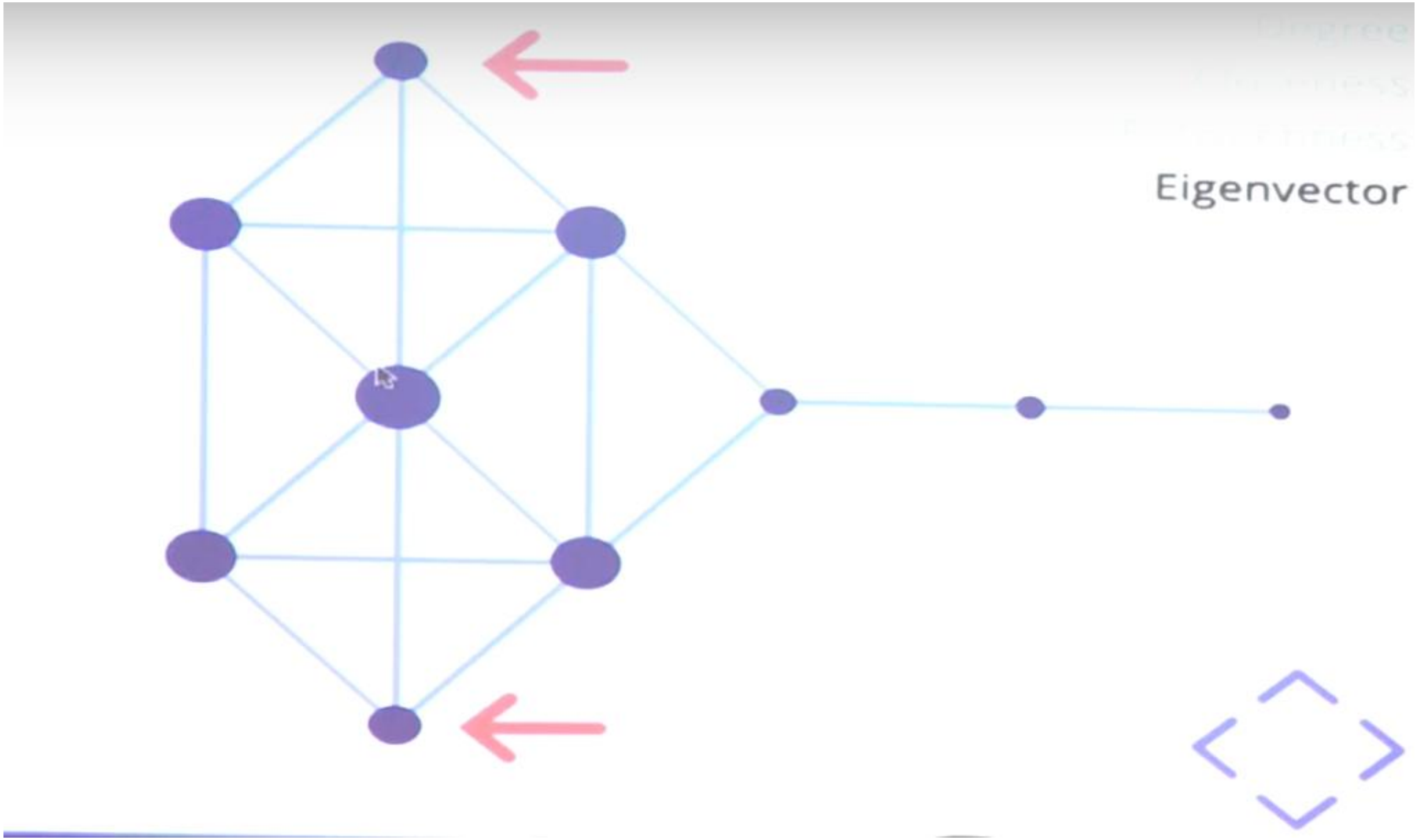
Closeness



Betwenness

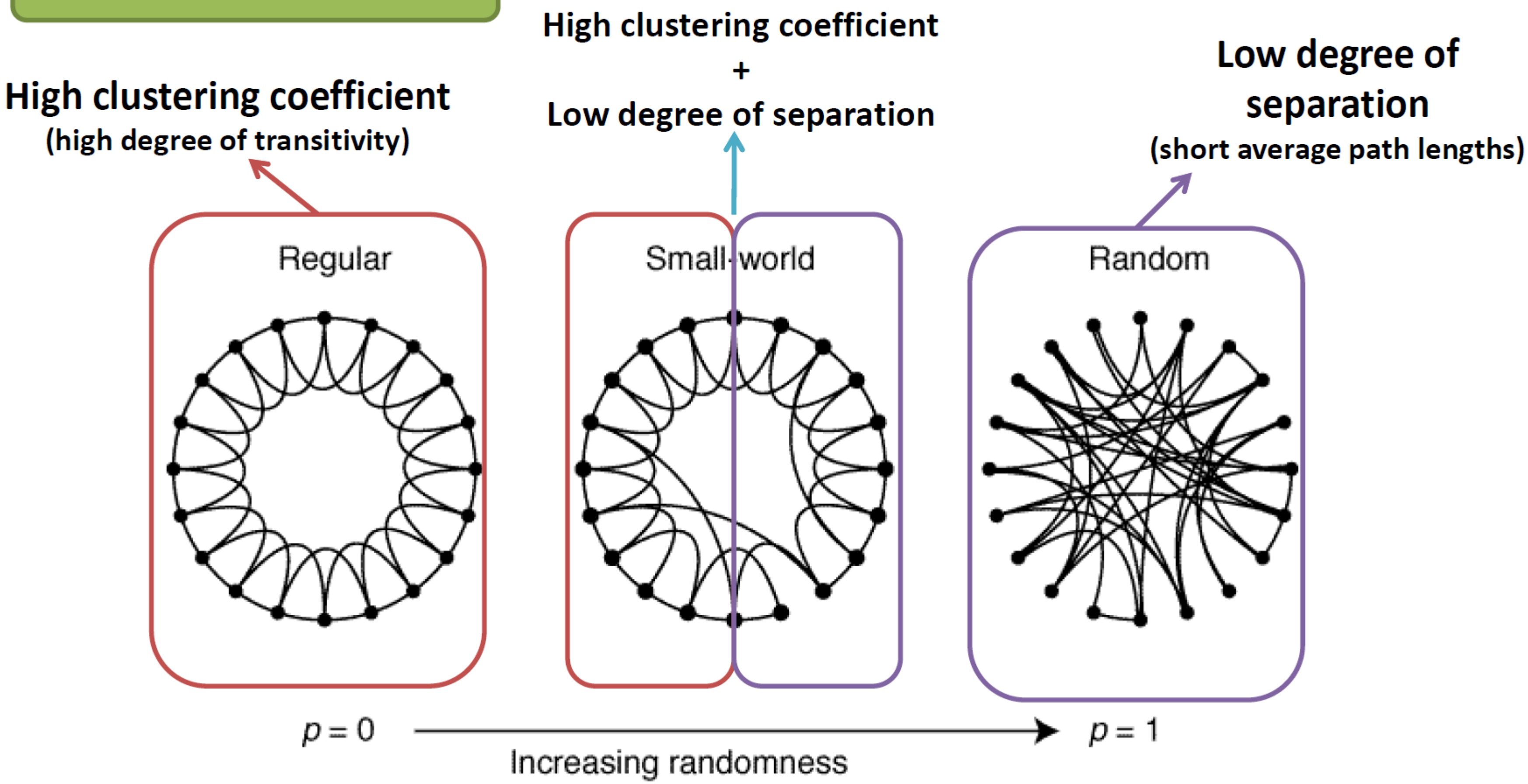


Eigenvector centrality



Real world network properties

1. Small-world effect

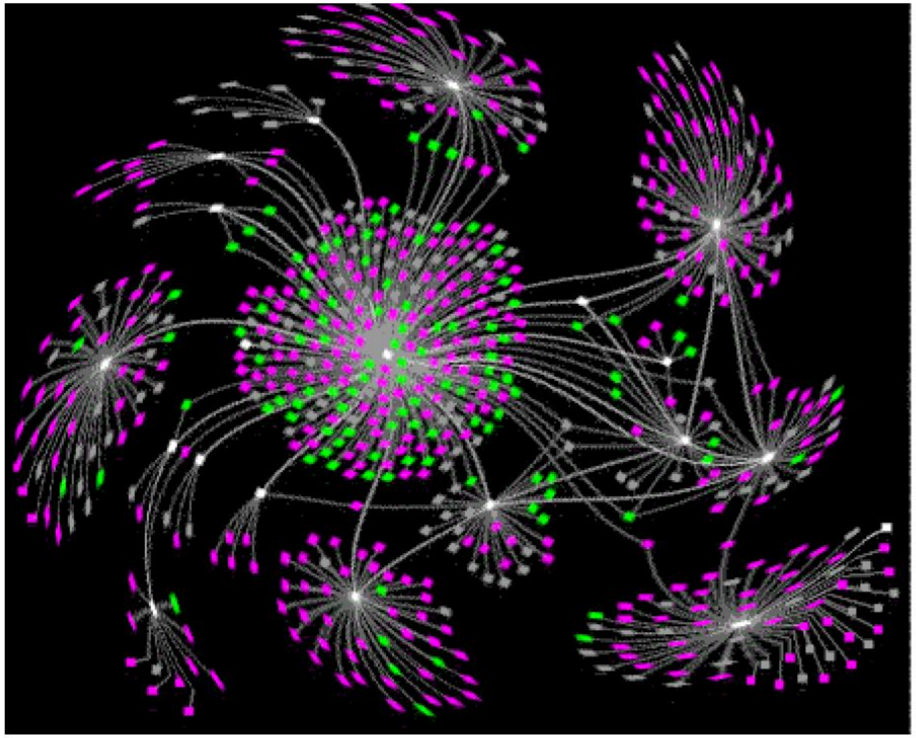


Real world network properties

3. Power-law degree distributions

Scale-free networks (Barabási and Albert, 1999)

❖ The mechanism of *"preferential attachment"* is easily explained by the fact that new nodes (e.g. individuals) entering the network tend to connect to well-connected nodes, which are often associated to central and prestigious positions (e.g. individuals with more status, popularity, knowledge, money etc.) in the network.



❖ These highly-connected nodes are known as **hubs**