Social Network Analysis: Introduction to the Course

Even Semester of Academic Year 2023-24

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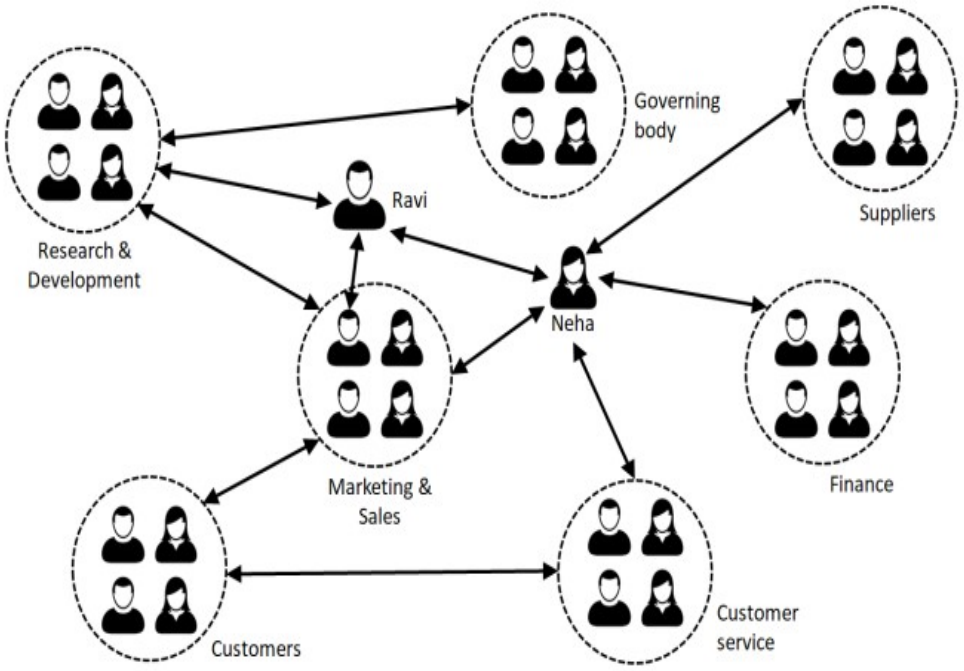
Slide Credits: Teaching Material on Social Network Analysis by Tanmoy Chakraborty, Wiley, 2021

Motivation, Syllabus, Teaching Scheme and Course Outcome

Books to refer

- Social Network Analysis by Tanmoy Chakraborty, Wiley (Slide credits to this book)
- Network Science by Barabasi, Cambridge University Press
- Slide Credits: Teaching Material on Social Network Analysis by Tanmoy Chakraborty, Wiley, 2021

What is Social Network Analysis?



Network:

An abstract representation of relations among entities

Social Network:

A simplified representation of the social structure characterized by actors and ties

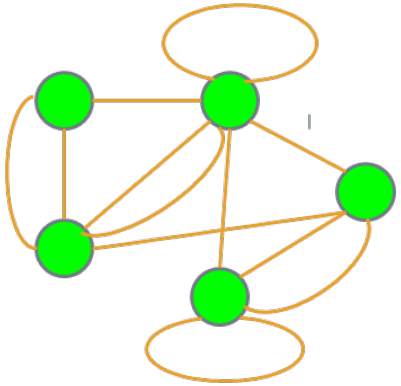
Social Network Analysis:

The application of networks and graph theory to analyze the relations present in a society

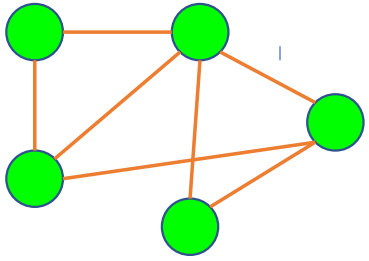
Network: Definition

- A network, also referred to as a *graph*, is defined as an ordered pair G(V, E), where V is a set of nodes (also referred to as vertices or entities), and E is a set of edges (also referred to as links or relations) joining the nodes.
- Depending on the nature of application, the above definition may be revised or augmented, as follows:
  - the nature of edges may vary – undirected (also called symmetric, or reversible) edges, directed (also called asymmetric, or irreversible) edges, or hyperedges, etc.
  - both the nodes and/or the links are associated with one or more attributes/features like weights, timestamps, textual features, etc.
- An edge in a graph may have same node as end nodes. Such edges of a graph are called self loops (or, simply, loops).
- A graph may have more than one edge joining a pair of nodes. Such edges are called parallel edges.

Network: Definition (contd…)

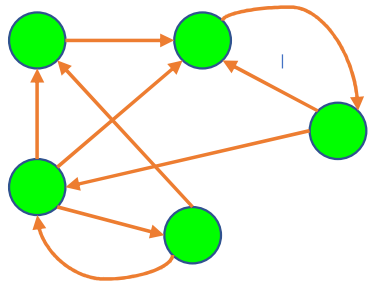


A graph with loops and parallel edges

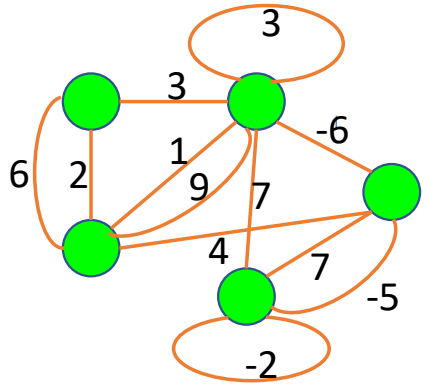


A simple graph

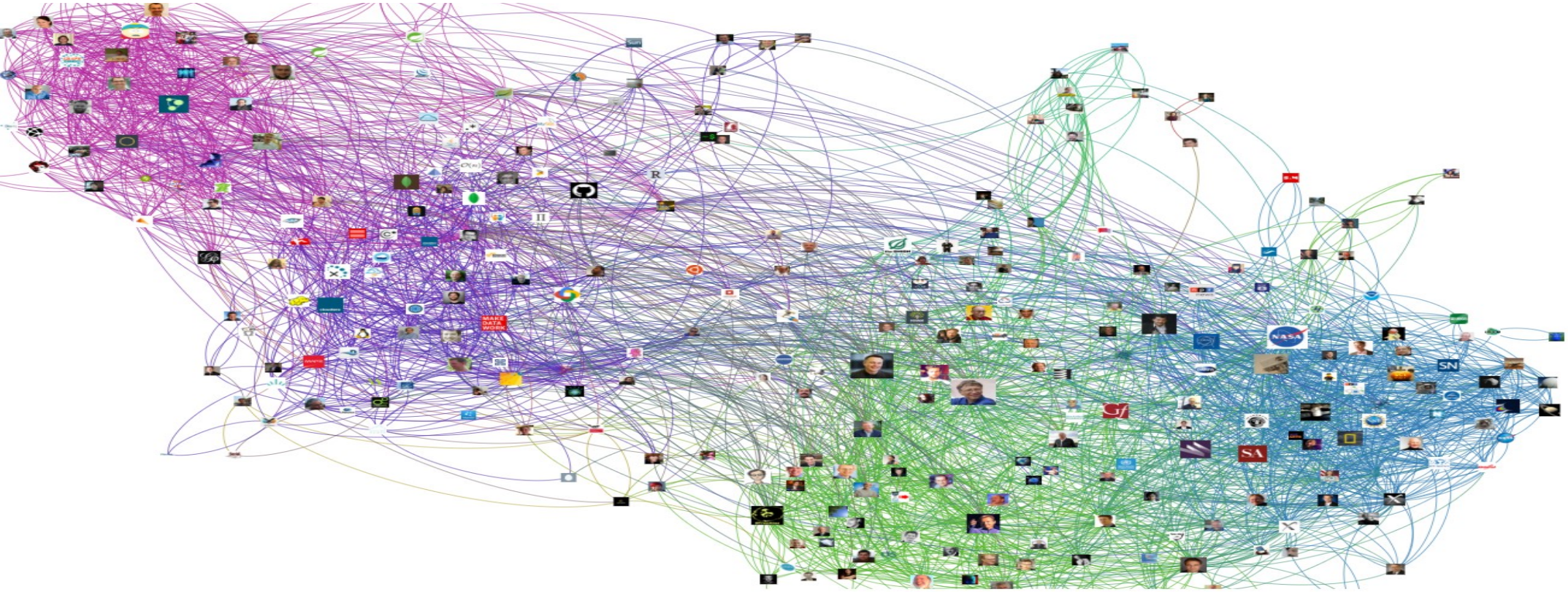
- A graph having neither self loops nor parallel edges are called a simple graph.
- A graph having directed edges (i.e. links having a direction) is called a directed graph. Directed edges are also referred to as arcs.
- A graph having no direction in its edges is called an undirected graph.
- A graph having weights associated with its edges are called a weighted graph. A weighted graph can be directed as well as undirected.
- A graph having its nodes and/or edges attributed with feature values is called an attributed graph.



A directed graph



A weighted graph



A sample of Twitter follower-followee network

(image source: http://allthingsgraphed.com/2014/11/02/twitter-friends-network/)

Social Network Analysis: Key Features

- **Required Knowledge Domains**

❑ Sociology ❑ Psychology ❑ Mathematics ❑ Statistics ❑ Computer Science

- **Study Benefits**

❑To know the way social interactions influence a network

❑To learn how the information flows inside a network

❑To characterize roles of the individuals in a network

❑To characterize communities inside a network

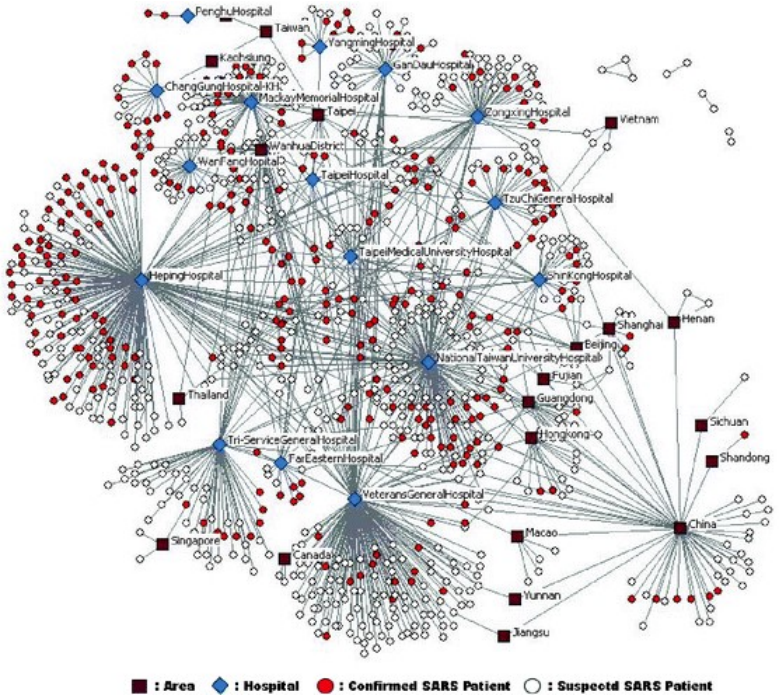
❑To characterize the evolution of a network

Key Application Areas

- Healthcare
  - Combating Epidemics
  - Mass Vaccination
- Social Media & E-Commerce
  - Friend & Follow Recommendation
  - Know Your Customers
  - Recommendation & viral marketing
- Web & Cyberspace
  - Search engine optimization
  - Malware detection
  - Spam detection
- Police & Military
  - Fighting cyber crimes
  - Fighting terrorism
  - Network-centric warfare
- Scientific Research & Academic Collaboration
  - Ranking scientific publications
  - Ranking scientific authors
  - Ranking publication venues
- Miscellaneous
  - Computer-supported collaborative learning
  - Complex project management

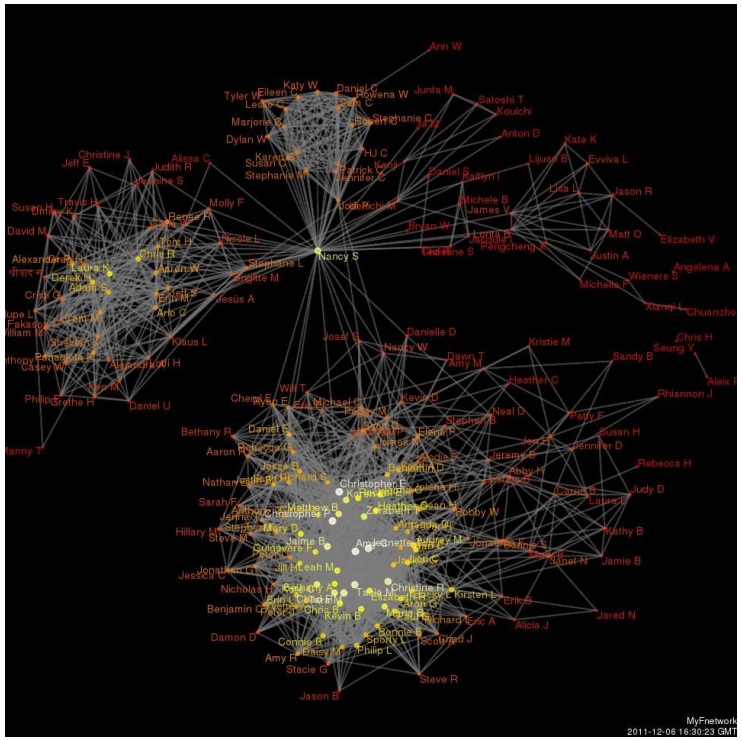
SNA Applications: Healthcare

- ❑ Modeling the spread of infectious diseases
- ❑ Contact tracing during epidemic outbreak to identify possible patients
- ❑ Identify and isolate super-spreaders
- ❑ Planning lockdown schedule
- ❑ Identify vulnerable population during vaccination
- ❑ Planning vaccination schedule, etc.



2003 SARS contact Network in Taiwan
https://doi.org/10.1007/978-1-4419-6892-0_15

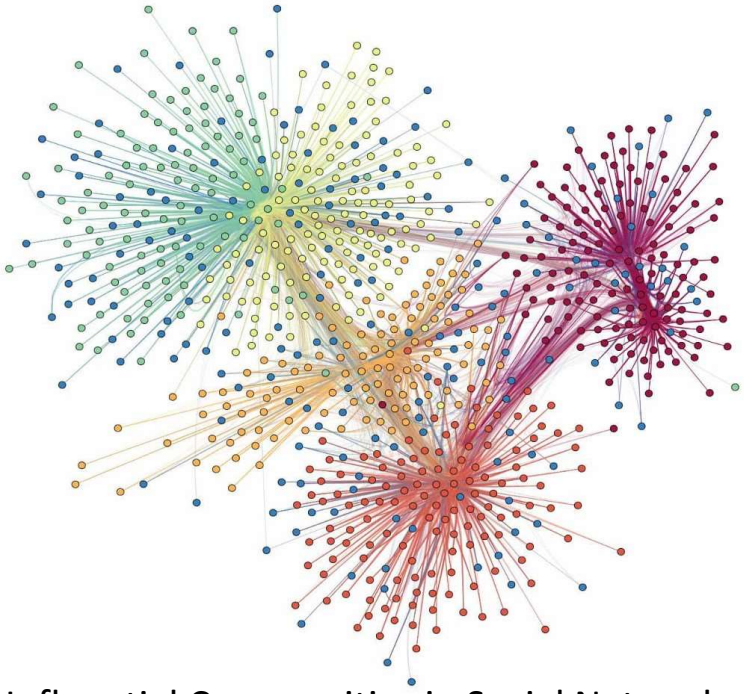
SNA Applications: Social Media



An Example Map of a Facebook Friendship Network
https://mathconceptions.wordpress.com/2012/01/16/application-snippet-friendship-and-influence-in-social-networks/

- ❑ Identifying friendship structures in online social media
- ❑ Recommending friends, and groups, or pages to follow
- ❑ Identifying information propagation patterns in social networks

SNA Applications: E-Commerce

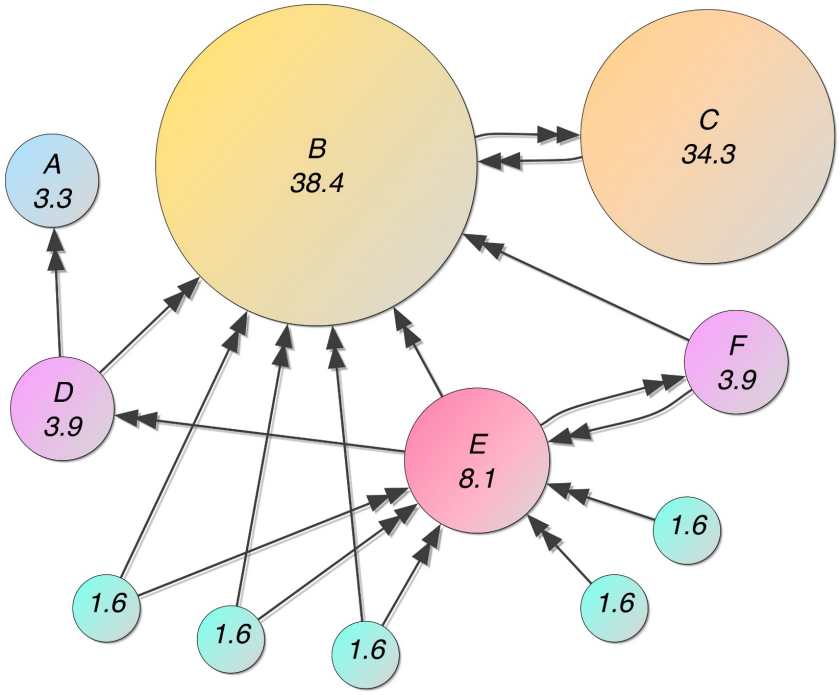


Influential Communities in Social Network

https://towardsdatascience.com/influential-communities-in-social-network-simplified-fe5050dbe5a4

- ❑ Customer profiling to Know the customers
- ❑ Product/Service recommendation based on customer profile
- ❑ Instigating viral marketing by pinpointing influential players
- ❑ “People like you buy”, “Frequently bought with this”, or “Frequently browsed”, “Trending” are common buzzwords

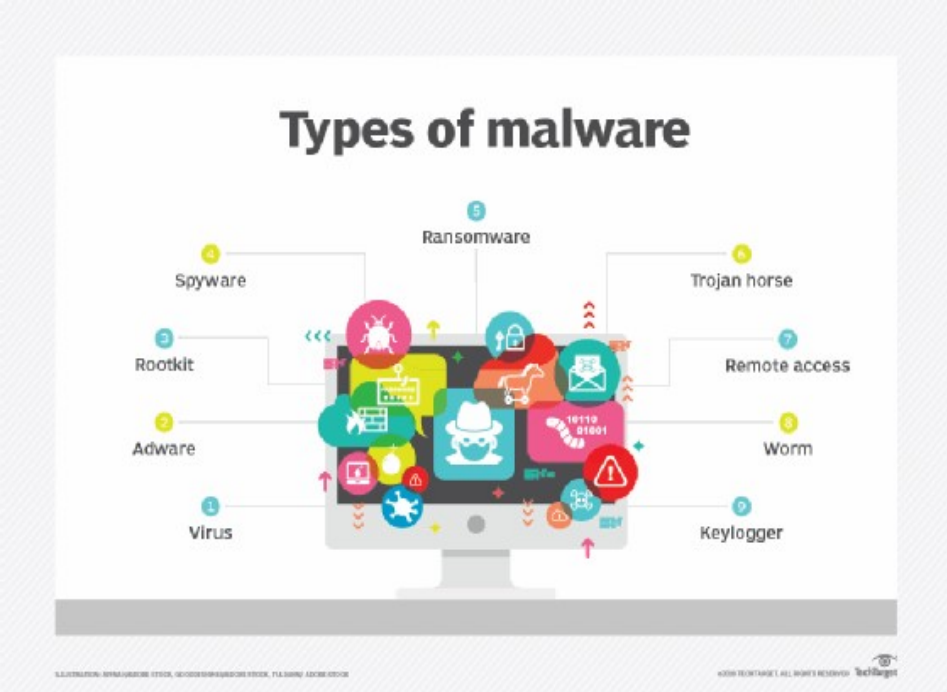
SNA Applications:
Web Search Optimization



Toy Example of Google's PageRank
https://en.wikipedia.org/wiki/PageRank

- ❑ Ranking the webpages based on hyperlinks
- ❑ Ordering of displayed pages based on ranks
- ❑ Displaying webpages based on user search profile

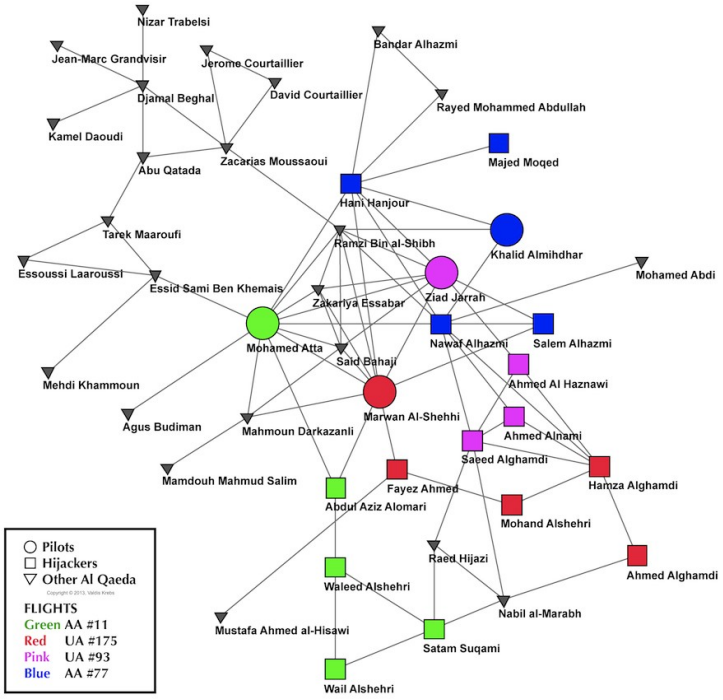
SNA Applications:
Malware & SPAM Detection



- ❑Modeling malwares using Graph representations
- ❑System call graphs, malware similarity network, etc. are typical examples
- ❑These graphs are large due to volume of networks
- ❑Malware detection through network analysis
- ❑SPAM detection

https://searchsecurity.techtarget.com/definition/malware

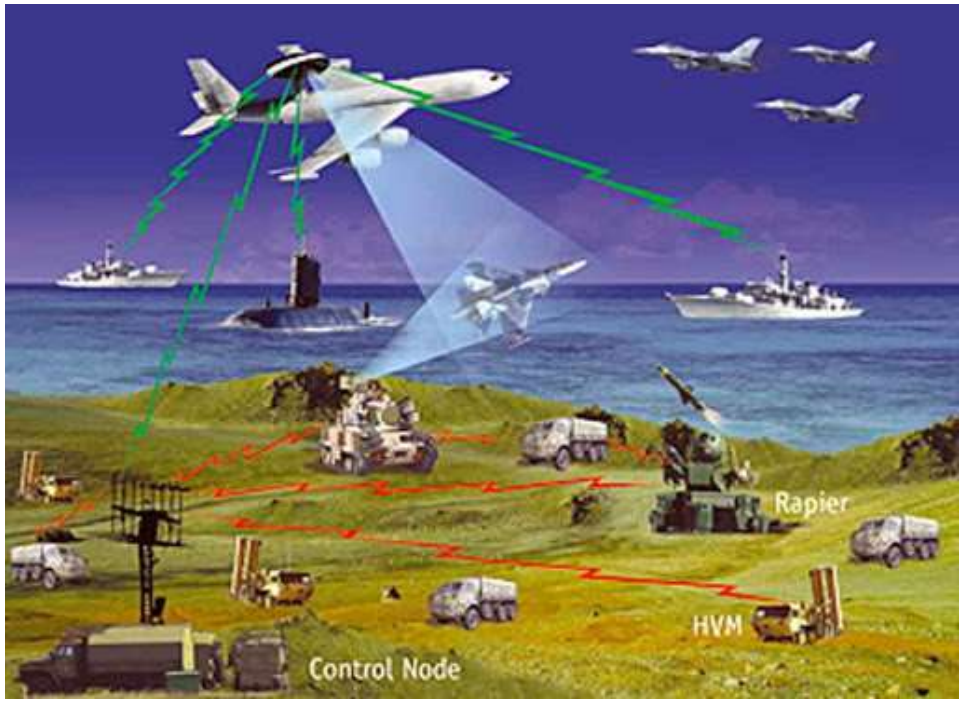
SNA Applications: Cybercrimes & Terrorism



9/11 Terrorist Network
http://www.orgnet.com/hijackers.html

- Online fraud, fake news propagation, cyber bullying/trolling, sharing pornographic materials, etc. rising with growth of social media
- Terrorists often use social media to communicate as well as to brainwash innocent people
- These people often span across countries and use untraceable communication devices
- Tracking cyber criminals in conventional methods are difficult due to user anonymity, fake accounts, lack of cyber laws, etc.
- Social network analysis techniques help nabbing these criminals

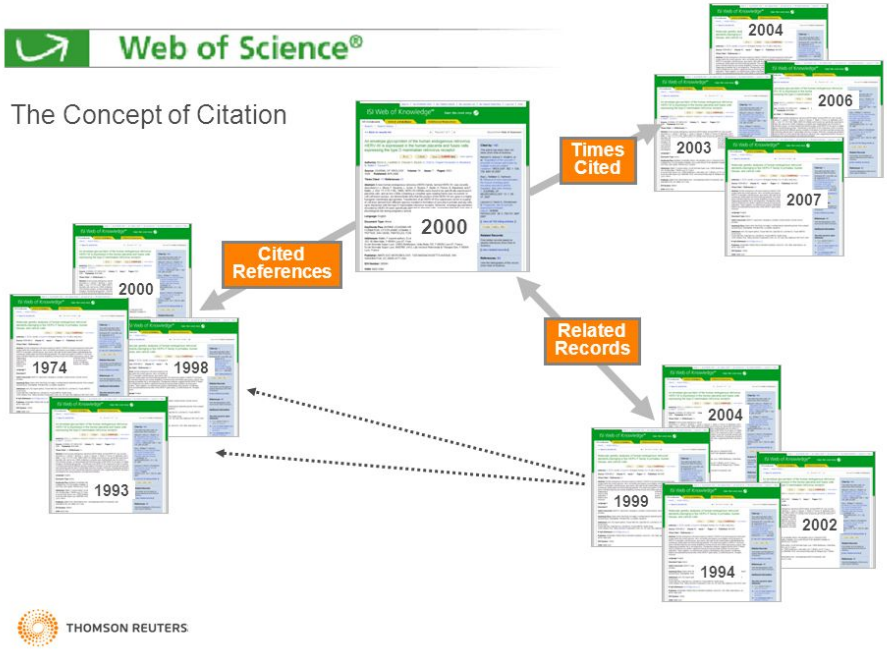
SNA Applications:
Network Centric Warfare



Network Centric Warfare
http://www.indiandefencereview.com/news/network-centric-warfare/

- Rising popularity of social network analysis influence the military doctrines
- Various military think-tanks proposed for network-centric warfare principle using social network analysis methods
- It is claimed that Saddam Hussein has been captured from his hideout exploiting network analysis techniques
- It is also claimed US Navy Seal Team Six assassinated Osama Bin Laden by tracking his secret hiding location in a similar manner

SNA Applications: Scientific Research & Academic Collaboration



- Scientific authors cite (refer) the works of other authors in their publications to authenticate their claims
- Finding the dynamics of these citations attracted social scientists
- Various networks of scholarly articles may be formed exploiting this relationship
  - Paper-paper citation network
  - Paper-paper co-citation network, etc.
- Various popular metrics are outcome of analysing these networks.
  - Publication related: H-index, i-10 index, g-index, etc.
  - Venue related: impact factor, CORE rank, etc.

https://library.bu.edu/citedreferences

SNA Applications: Scientific Research & Academic Collaboration

https://scholarlykitchen.sspnet.org/2017/04/07/updated-figures-scale-nature-researchers-use-scholarly-collaboration-networks/

- Scientific authors collaborate with one another to improve research quality
- Various scholar networks may be formed using these relationships
  - Author collaboration network
  - Author citation network
  - Author co-citation network, etc.
- Information retrieved from these networks may be used to measure authors' research quality

SNA Applications: Computer-supported Collaborative Learning

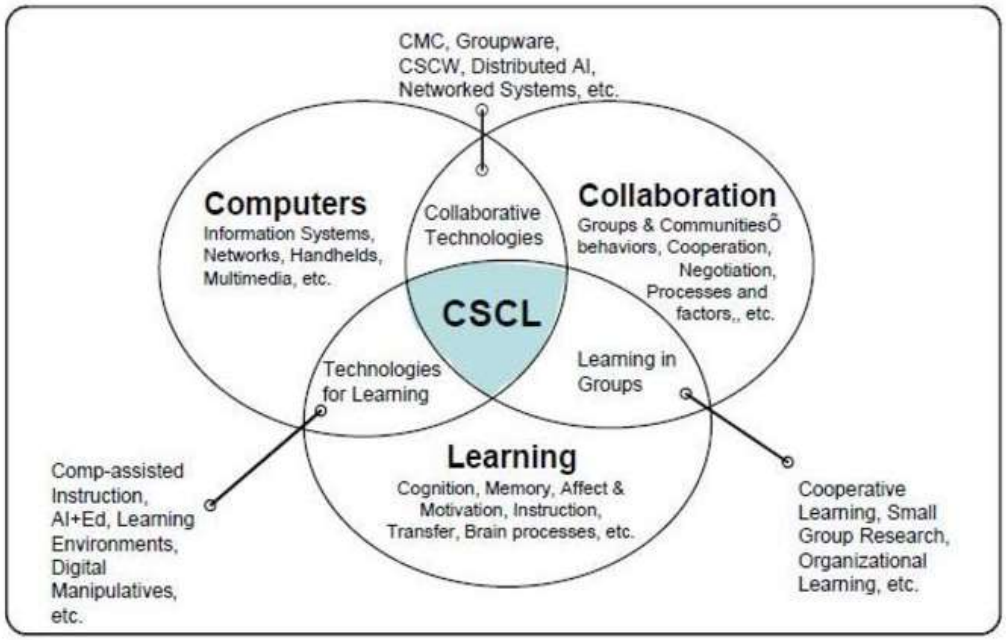
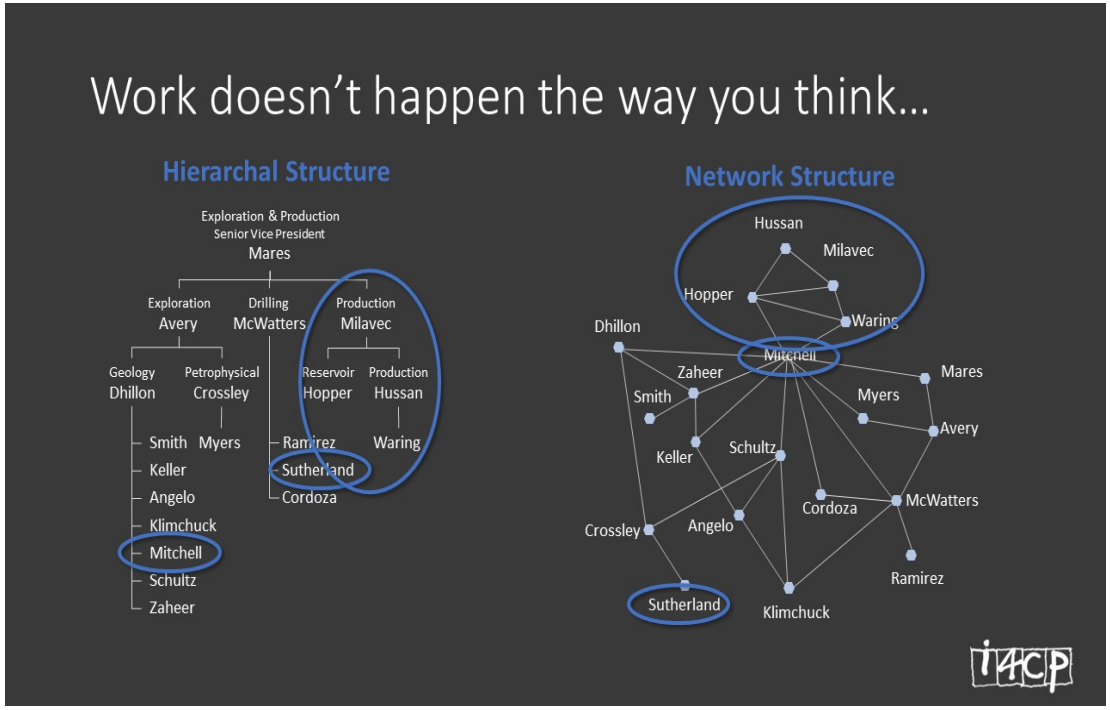


Figure 1: Multidisciplinary of CSCL

- Pedagogical process of observation where students learn progressively through active group interaction using ICT
- SNA techniques used to extract relationship between various actors (human and non-human) of CSCL
- Study insights are used to improve the students' learning outcome and user experience

https://www.semanticscholar.org/paper/The-Characteristics-of-the-Computer-Supported-a-on-Hashim-Ismail/42176e6bf76dd15a2c9874e6fa8696e153a3f554

SNA Applications:
Organizational Network Analysis

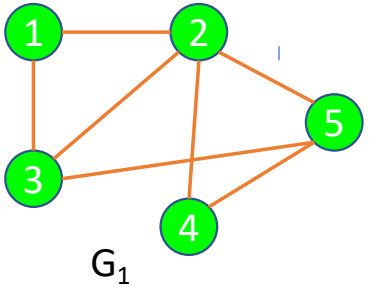


https://www.i4cp.com/productivity-blog/what-organizational-network-analysis-is-and-how-it-benefits-companies

- Classic (linear) organization charts do not effectively describe the real social network of an organization
- The informal networks, historically considered an annoying problem and an indicator of undisciplined attitude of workers, carry *huge potential if applied suitably*
- ONA provides information on how to improve performance in the organization
- ONA represents the complete set of real relationships between the players
  - who is in touch with whom
  - specific features of each player
  - Type and intensity of relationship, etc.

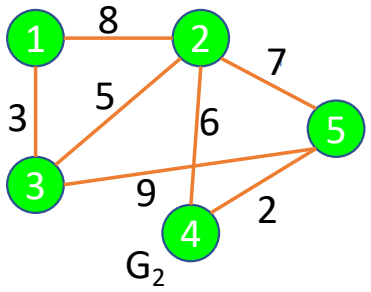
Network Representation: Adjacency Matrix

- An adjacency matrix $A = (a_{ij})$ for a graph $G(V, E)$ is a square matrix of dimension $|V| \times |V|$ such that each element a_{ij} of A indicates the existence of an edge between the node v_i and node v_j (also the weight of the corresponding edge in case of a weighted graph) in G.



G_1

$$A(G_1) = \begin{bmatrix} 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 \\ 0 & 1 & 1 & 1 & 0 \end{bmatrix}$$



G_2

$$A(G_2) = \begin{bmatrix} 0 & 8 & 3 & 0 & 0 \\ 8 & 0 & 5 & 6 & 7 \\ 3 & 5 & 0 & 0 & 9 \\ 0 & 6 & 0 & 0 & 2 \\ 0 & 7 & 9 & 2 & 0 \end{bmatrix}$$

Network Representation: Adjacency Matrix (Cont…)

advantages

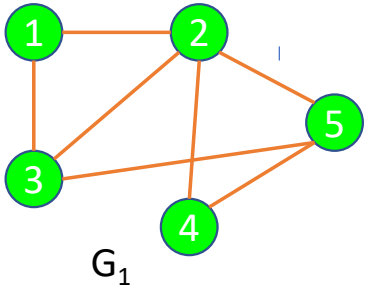
- Easy to implement and follow
- Addition, and removal of an edge require (1) time
- Query to an edge require (1) time

disadvantages

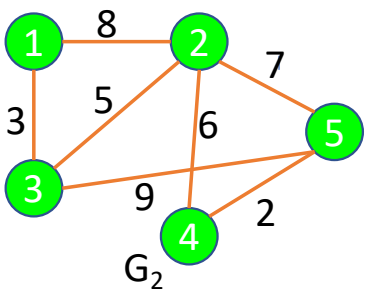
- Consumes $O(|V|^2)$ storage space, even if the graph is sparse
- Addition or removal of a node require $O(|V|^2)$ time

Network Representation: Adjacency List

- An adjacency list for a graph $G(V, E)$ is a collection of unordered lists such that each node correspond to a list from the collection that indicates the set of neighbours of the node. Every entry in an adjacency list A_i for node v_i in the graph is a node adjacent to node v_i



1	2	3		
2	1	3	4	5
3	1	2	5	
4	2	5		
5	2	3	4	



1	2,8	3,3		
2	1,8	3,5	4,6	5,7
3	1,3	2,5	5,9	
4	2,6	5,2		
5	2,7	3,9	4,2	

Network Representation: Adjacency List (Cont…)

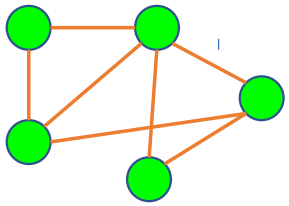
advantages

- Require $\Theta(|V|+|E|)$ space
- Insertion of vertex and edge require $\Theta(1)$ time
- Removal of vertex require $\Theta(|V|+|E|)$ time

disadvantages

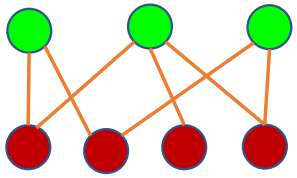
- Removal of edge require $\Theta(|E|)$ time
- Query to an edge require $\Theta(|E|)$ time

Network Types: Link-centric View
Unipartite Network



- Consists of a vertex set ***V*** and an edge set ***E***. There is no restriction on the formation of edges between nodes of the network
- Example: An organizational LAN, where nodes are the devices, and edges are the local area links.
- Used to model the situation when links can join any pair of nodes of the network

Network Types: Link-centric View
Bipartite Network

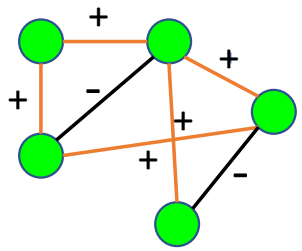


- Consists of a vertex set ***V*** that is divided into two sets ***V1*** and ***V2*** that are disjoint and independent. Each edge of the network connects a vertex in ***V1*** to another vertex in ***V2***

- Example: An e-commerce user-product network. One part consists of the users, the other part consists of the products, the links are based on the basis of who bought what.

- Generalization of Bipartite network is n-partite networks, where the vertex set is partitioned into n number of part, an edges join a node from one part with a node from another part.

Network Types: Link-centric View
Signed Networks

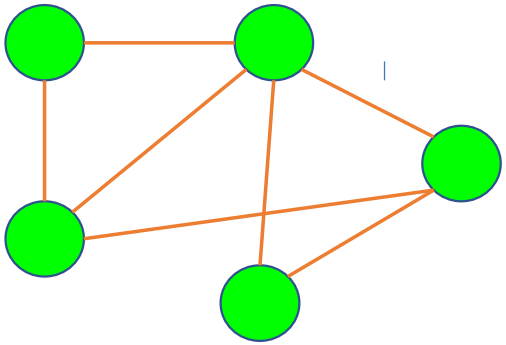


- Consists of a set of nodes ***V,*** a set of edges ***E***, and a function ***f : E → {+, −}*** that assigns each edge a positive or a negative sign

- Example: Consider a social media website that allows users to tag other users as friends or foes. The positive edges are friendship links and negative links are between foes.

- studied specifically in the context of balance and status theory which determines the stability or existence of certain types of structural patterns in a network.

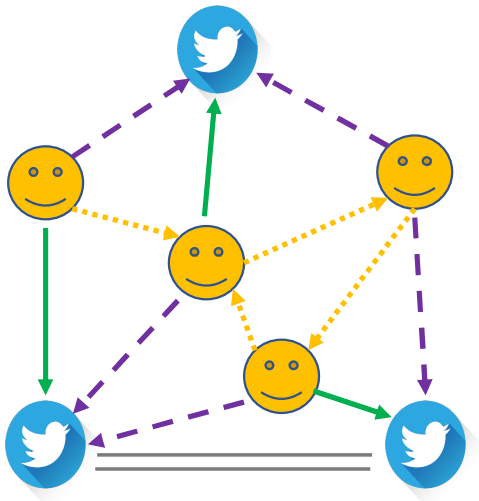
Network Types: Node and Link-centric View: Homogeneous Network



- Consists of a set of nodes V, all of which are of same type, and a set of edges ***E*** , all of which are of same type

- Example: Follower-Followee network of any kind.
  - Nodes are the users of the platform (all nodes are of same type),
  - Links are the follower-followee link between these nodes (all links are of same type)

Network Types: Node and Link-centric View: Heterogeneous Network



- Consists of a set of nodes $\boldsymbol{V}$ and a set of edges $\boldsymbol{E}$, and two associated mapping functions, $\boldsymbol{f_v}$ and $\boldsymbol{f_e}$, for nodes and edges, respectively. $\boldsymbol{f_v}$ maps a node to a node type and $\boldsymbol{f_e}$ maps an edge to an edge type

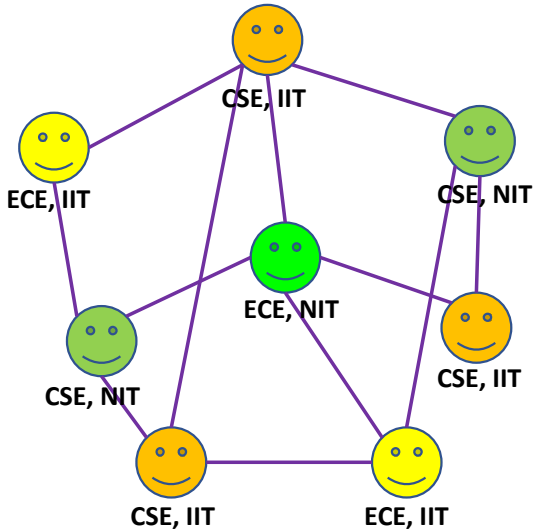
- Example: We consider a specific instance of Twitter network like the figure.
  - Two types of nodes:
    - Twitter Users
    - Tweet Posts
  - Four types of edges representing four types of relations between these nodes:
    - .Posted-by (User – Post: Directed links)
    - Followed-by (User – User: Directed links)
    - Similar (Post – Post: Undirected links)
    - Retweet (User – Post: Directed links)

Network Types: Node and Link-centric View: Attributed Network

- Consists of a set of nodes $\boldsymbol{V}$ and a set of edges $\boldsymbol{E}$, and two associated mapping functions, $\boldsymbol{f_v}$ and $\boldsymbol{f_e}$, for nodes and edges, respectively. $\boldsymbol{f_v}$ maps a node to a node attribute vector and and $\boldsymbol{f_e}$ maps an edge to an edge attribute vector

- Example: We consider a specific instance of Facebook network like the figure
  - Nodes are some Facebook users
  - Edges are given by Facebook friendship relationship between these users
  - Node attributes are the users' academic affiliations
  - There is no edge attribute in this network

- The example is a node-attributed network

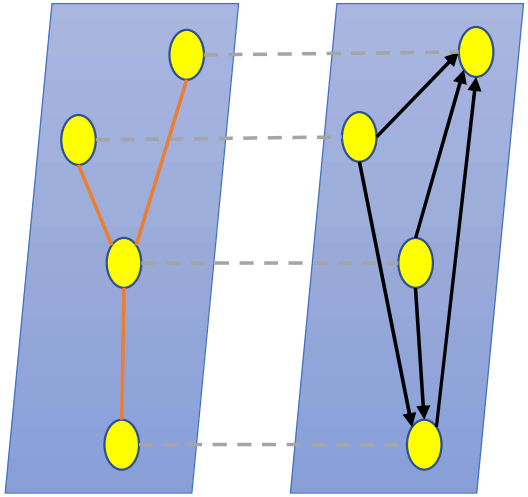


Network Types: Node and Link-centric View: Multidimensional Network

- A special type of multilayer network where each layer represents a particular type of relationship among nodes

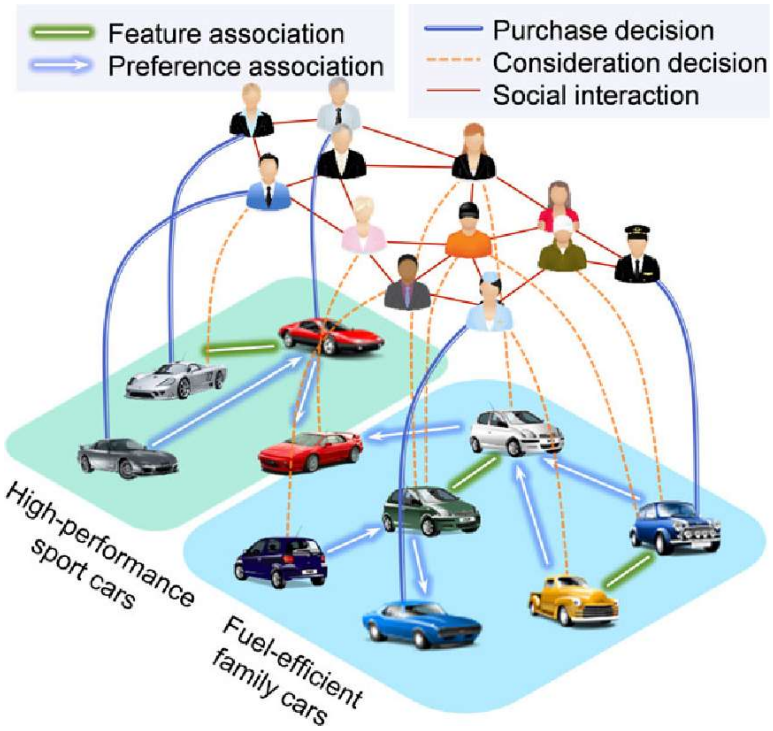
- Example 1: A special instance of Twitter network:
  - Nodes are Twitter users in both layer
  - Layer 1 edges: user – user similarity links (based on mutual interests) – Undirected links
  - Layer 2 edges: user – user follower-followee links – Directed links

- Note: In this example, each layer is node homogeneous.



Network Types: Node and Link-centric View: Multidimensional Network (Cont…)

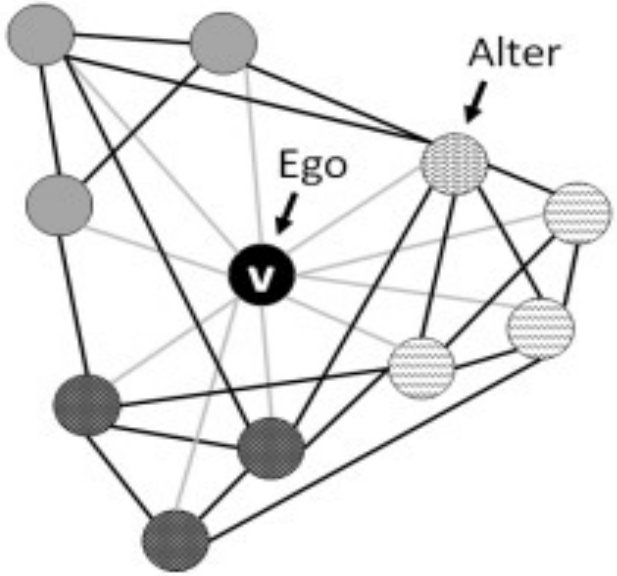
- Example 2: Customer – product relationships as a multidimensional complex network system
  - Layer 1: One type of nodes, one type of edges:
    - Nodes: Customers
    - Edges: Customer Social Interaction – Undirected links
  - Layer 2: Two types of nodes, two types of nodes
    - Nodes:
      - High performance Cars,
      - Fuel efficient cars
    - Edges:
      - Car feature association – Undirected links
      - Car preference association – Directed links
  - Inter-layer edges: two types of edges
    - Customer – Car: Purchase decision – Undirected links
    - Customer – Car: Consideration decision – Undirected links



https://www.semanticscholar.org/paper/Modeling-customer-preferences-using-network-in-Wang-Chen/539c7f0632041903521b8cbc42eabd27b8844673

Network Types: Local View: Ego-centric Network

- A network of the form G(V, E, u), that corresponds to a node u □ V, usually known as the 'ego', and consists of the node u as the central node, the nodes that are connected directly to the node u, usually known as the 'alters', and the induced subgraph for the same.

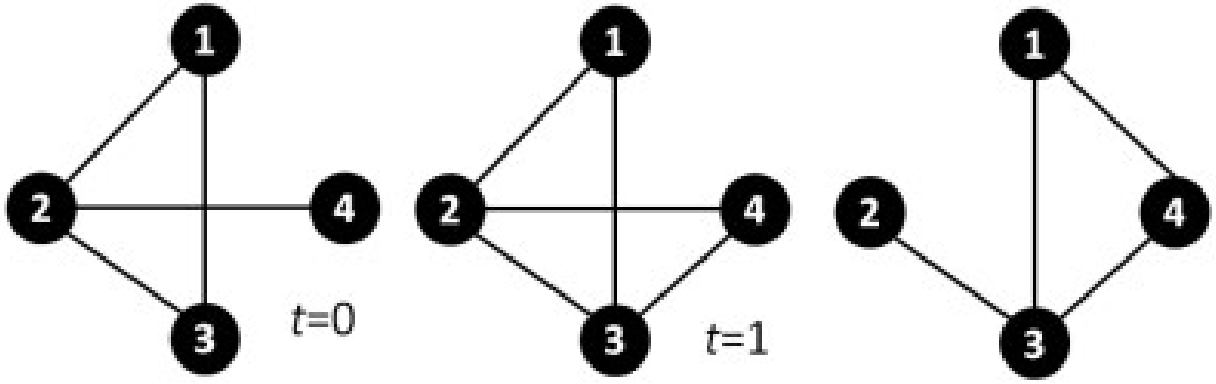


- Example: A subgraph of a Facebook Friendship Network:
  - Ego node corresponds to a user,
  - Alter nodes are his Facebook friends from different capacities and affiliations.

Network Types: Temporal View: Time-varying Network

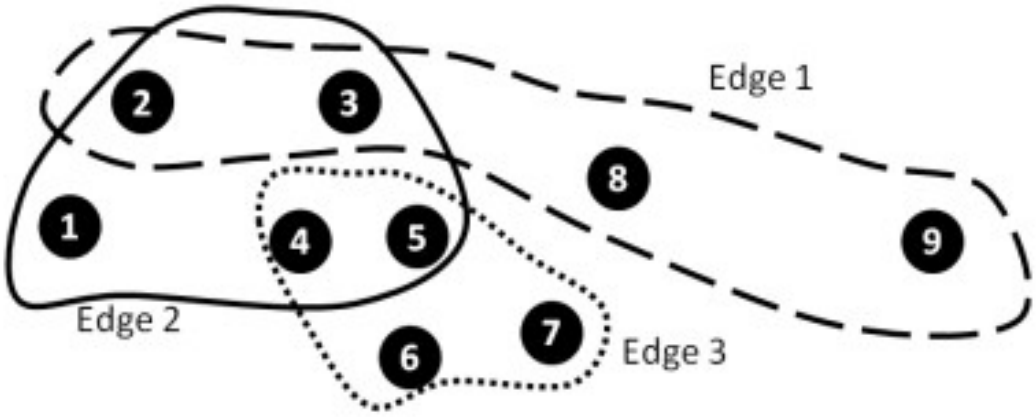
- Consists of a set of nodes $\boldsymbol{V}$ and a set of edges $\boldsymbol{E}$ where each edge $\boldsymbol{e_{i,j}} \in \boldsymbol{E}$ is represented by a three- tuple $\boldsymbol{e_{i,j} = \{v_i, v_j, t_{ij}\}}$. Here, $\boldsymbol{v_i}$ and $\boldsymbol{v_j}$ are two end-points, and $\boldsymbol{t_{ij}}$ indicates the persistence duration of the edge $\boldsymbol{e_{ij}}$

- Example: Person-to-person communication network over a span of time. The visible components are snapshots of the network at different time instances.



Network Types: Generalized View: Hypergraph

- Defined by a set of nodes ***V*** and a set of edge or hyperedges ***E***, where each hyperedge ***e*** connects multiple nodes of the hypergraph
- Example: A special representation of Coauthoship Network:
  - Nodes are authors
  - Papers are hyperedges connecting the coauthors of the paper



Popular Real-world Networks

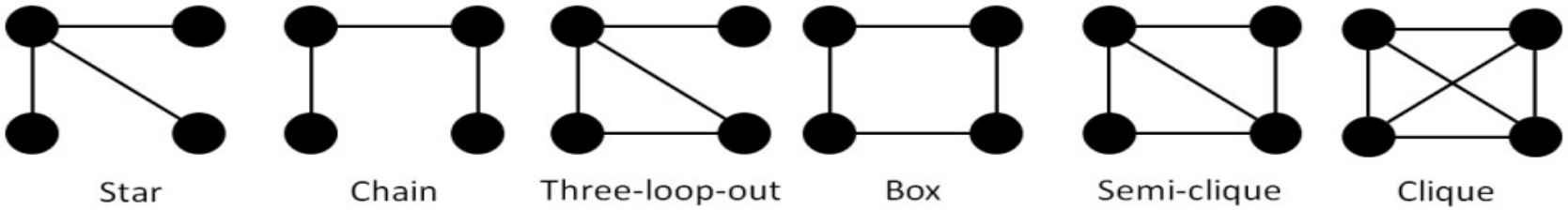
- Social Network
  - Telephone call network
  - Email message network
  - Film actor collaboration network
  - Academic co-authorship network
- Biological Network
  - Protein-protein interaction networks
  - Genetic regulatory networks
  - Neural networks
  - Metabolic networks
  - Food Web
  - Cell signalling networks
- Information Network
  - World Wide Web (WWW)
  - Citation network
- Technological Network
  - Electric power grids
  - Networks of airline routes
  - Network of Railway Routes
  - Electronic circuits
  - Delivery networks of post-office/Courier
  - The Internet
- Language Network
  - Network formed by using the persons speaking a particular language

Levels of Social Network Analysis: Microscopic Level

- We begin by analyzing how a pair of nodes interacts and gradually trace the interactions at the group level or subgraph level.
- ***Dyadic level*** ➔ Interaction patterns among two nodes
  - Examined properties: homophily, reciprocity, social equality, mutuality, etc.
  - Derived global statistics: assortativity, mixing coefficient, etc.
- ***Triadic level*** ➔ Interaction patterns among three nodes
  - Examined properties: triadic closure
  - Derived network properties: Clustering Coefficient, local bridges, etc.
- ***Ego-centric circles*** ➔ Interaction pattern between ego node with its alters

Levels of Social Network Analysis: Mesoscopic Level

- Mesoscopic analysis is an intermediary between microscopic and macroscopic analyses, which mostly deals with a subset of the entire population.
- ***Communities*** ➔ Formed due to frequent interactions among homogeneous nodes in a network
  - Within a community, the nodes exhibit a particular kind of dynamicity
  - Across communities, the dynamic behaviour differs
- ***Network Motifs*** ➔ Subgraphs that repeat themselves frequently within or across a network
  - Highly effective in capturing functional properties in a network



Undirected motifs with size 4 and their names

Levels of Social Network Analysis: Macroscopic Level

- At macroscopic level, we deal with the entire network as a whole and try to understand the micro-level dynamics by exploring the overall graph property.
- Features of Interest :
  - Connectedness,
  - Diameter or Average path length,
  - Degree Distribution,
  - Edge Density, etc.
- Example:
  - We find that the diameter of a network is too small ⇒ network may look like a star, or a clique
  - We further find that overall edge density is too high ⇒ network looks like a clique

Graph Visualization Tools

- Web-based tools
  - ***Pollinode:*** https://www.polinode.com (Non-open source application)
  - ***NodeGoat:*** https://nodegoat.net (Non-open source application)
  - ***Linkage:*** https://linkage.fr (Open source application)
  - ***EchoDemo:*** https://osome.iuni.iu.edu/demos/echo (Non-open source application)
  - ***Palladio:*** https://hdlab.stanford.edu/palladio (Open source application)
- Standalone tools
  - ***NDlib-Viz:*** https://ndlib.readthedocs.io/en/latest/viz/ndlib-viz.html (Open source application)
  - ***CytoScape:*** https://cytoscape.org (Open source application)
  - ***Gephi:*** https://gephi.org (Open source application)
  - ***Vizster:*** http://vis.stanford.edu/jheer/projects/vizster (Open source application)
  - ***SparklingGraph:*** https://sparkling-graph.github.io (Open source application)