# How can we analyze social networks?

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## A look back

<table>
<thead>
<tr>
<th>Week</th>
<th>Date</th>
<th>Title, Links</th>
<th>Comments and Links</th>
</tr>
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<tbody>
<tr>
<td>Week 3</td>
<td>19.3.</td>
<td>Network Theory and Terminology (slides, HA 1.1)</td>
<td>In this class, we will discuss network theory fundamentals, including concepts such as diameter, distance, clustering coefficient and others. We will also discuss different types of networks, such as scale-free networks, random networks etc. Readings: Graph structure in the Web, A. Broder and R. Kumar and P. Maghoul and P. Raghavan and S. Rajagopalan and R. Sita and A. Tomkins and J. Wiener Computer Networks 33 309–320 (2000) [Web link, Alternative Link] Optional: The Structure and Function of Complex Networks, M.E.J. Newman, SIAM Review 45 167–256 (2003) [Web link]</td>
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<tr>
<td>Week 4</td>
<td>26.3.</td>
<td>Tutorials: Python &amp; Octave (Python tutorial, Octave tutorial, NetworkX slides by Derek Greene)</td>
<td>In this class, we will discuss network theory fundamentals, including concepts such as diameter, distance, clustering coefficient and others. We will also discuss different types of networks, such as scale-free networks, random networks etc. Readings: An Experimental Study of the Small World Problem, J. Travers and S. Milgram Socionetw 32 425-443 (1969) [Protected Access] Optional: The Strength of Weak Ties, M.S. Granovetter The American Journal of Sociology 78 1360–1380 (1973) [Protected Access] Optional: Worldwide Buzz: Planetary-Scale Views on an Instant-Messaging Network, J. Leskovec and E. Horvitz MSR-TR-2006-186. Microsoft Research, June 2007. [Web link, the most recent and comprehensive study on the subject]</td>
</tr>
</tbody>
</table>

Markus Strohmaier

2013
A Small World

- **Target person:**
  - A Boston stockbroker

- **Three starting populations**
  - 100 “Nebraska stockholders”
  - 96 “Nebraska random”
  - 100 “Boston random”

Random Networks

- Page 44/ff, Watts 2003, random graphs

Random graph: a network of nodes connected by links in a purely random fashion.

Analogy of Stuart Kaufmann: Throw a boxload of buttons
Today

Agenda:

How can we analyze social networks?

A selection of concepts from Social Network Analysis

- Sociometry, adjacency lists and matrices
- Affiliation networks
- KNC Plots
- Prominence
- Cliques, clans and clubs

Sociometry as a precursor of (social) network analysis

[Wasserman Faust 1994]

- Jacob L. Moreno, 1889 - 1974
- Psychiatrist

- born in Bukarest, grew up in Vienna, lived in the US
- Worked for Austrian Government

- Driving research motivation (in the 1930’s and 1940’s):
  - Exploring the advantages of picturing interpersonal interactions using sociograms, for sets with many actors
Sociometry
[Wassermann and Faust 1994]

• Sociometry is the study of positive and negative relations, such as liking/disliking and friends/enemies among a set of people.

Can you give an example of web formats that capture such relationships?


• A social network data set consisting of people and measured affective relations between people is often referred to as sociometric.

• Relational data is often presented in two-way matrices termed sociomatrices.

Table 3.1. Sociomatrices for the six actors and three relations of Figure 3.2

<table>
<thead>
<tr>
<th>Actors</th>
<th>Allison</th>
<th>Drew</th>
<th>Elliot</th>
<th>Keith</th>
<th>Ross</th>
<th>Sarah</th>
</tr>
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<tr>
<td>Friendship at Beginning of Year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allison</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
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</tr>
<tr>
<td>Drew</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Elliot</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Keith</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Ross</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sarah</td>
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<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Friendship at End of Year</td>
<td>Solid lines</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allison</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
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</tr>
<tr>
<td>Elliot</td>
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<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Keith</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Ross</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sarah</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Lines Near</td>
<td></td>
<td></td>
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<td></td>
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<td>Allison</td>
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<td>0</td>
<td>0</td>
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<td>1</td>
</tr>
<tr>
<td>Drew</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>Elliot</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Keith</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
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<td>1</td>
</tr>
<tr>
<td>Ross</td>
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<td>0</td>
<td>1</td>
<td>1</td>
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</tr>
<tr>
<td>Sarah</td>
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<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Fundamental Concepts in SNA
[Wassermann and Faust 1994]

• Actor
  – Social entities
  – Def: Discrete individual, corporate or collective social units
  – Examples: people, departments, agencies

• Relational Tie
  – Social ties
  – Examples: Evaluation of one person by another, transfer of resources, association, behavioral interaction, formal relations, biological relationships

• Dyad
  – Emphasizes on a tie between two actors
  – Def: A dyad consists of two actors and a tie between them
  – An inherent property between two actors (not pertaining to a single one)
  – Analysis focuses on dyadic properties
  – Example: Reciprocity, trust

Which networks would not qualify as social networks?

Fundamental Concepts in SNA
[Wassermann and Faust 1994]

• Triad
  – Def: A subgroup of three actors and the possible ties among them
  – Transitivity
    • If actor i “likes” j, and j “likes” k, then i also “likes” k
  – Balance
    • If actor i and j like each other, they should be similar in their evaluation of some k
    • If actor i and j dislike each other, they should evaluate k differently

Example 1: Transitivity
Example 2: Balance
Example 3: Balance
Fundamental Concepts in SNA
[Wassermann and Faust 1994]

• Definition of a Social Network
  – Consists of a finite set or sets of actors and the relation or relations defined on them
  – Focuses on relational information rather than attributes of actors

One and Two Mode Networks
[Wasserman Faust 1994]

• The mode of a network is the number of sets of entities on which structural variables are measured

• The number of modes refers to the number of distinct kinds of social entities in a network

• One-mode networks study just a single set of actors

• Two mode networks focus on two sets of actors, or on one set of actors and one set of events
Two Mode Networks

- Example:
- Two types of nodes

![Diagram of Two Mode Networks]

Can you give examples of two mode networks?

Reminder: Social Networks Examples
Affiliation Networks

- Affiliation networks are two-mode networks
  - Nodes of one type "affiliate" with nodes of the other type (only!)
- Affiliation networks consist of subsets of actors, rather than simply pairs of actors
- Connections among members of one of the modes are based on linkages established through the second
- Affiliation networks allow to study the dual perspectives of the actors and the events

![Bipartite and Complete Bipartite Graphs](image)

Is this an Affiliation Network? Why/Why not?

![Friendship network of children in a US school](image)

FIG. 8 Friendship network of children in a US school. Friendships are determined by asking the participants, and hence are directed, since A may say that B is their friend but not vice versa. Vertices are color coded according to race, as marked, and the split from left to right in this figure is clearly primarily along lines of race. The split from top to bottom is between middle school and high school, i.e., between younger and older children. Picture courtesy of James Moody.

[Newman 2003]
Examples of Affiliation Networks on the Web

- Facebook.com users and groups/networks
- XING.com users and groups
- Del.icio.us users and URLs
- Bibsonomy.org users and literature
- Netflix customers and movies
- Amazon customers and books
- Scientific network of authors and articles
- etc

Representing Affiliation Networks As Two Mode Sociomatrices
[Wasserman Faust 1994]

General form:

\[
\begin{pmatrix}
0 & A \\
A' & 0
\end{pmatrix}
\]

Fig. 8.3. Sociomatrix for the bipartite graph of six children and three parties
Two Mode Networks and One Mode Networks

- **Folding** is the process of transforming two mode networks into one mode networks
  - Also referred to as $T, \perp$ projections [Latapy et al 2006]
- Each two mode network can be folded into 2 one mode networks

![Diagram showing folding of two mode networks into one mode networks]

**Transforming Two Mode Networks into One Mode Networks**

[Wasserman Faust 1994]

- Two one mode (or co-affiliation) networks
  (folded from the children/party affiliation network)

![Diagram showing transformation of children/party affiliation network]

<table>
<thead>
<tr>
<th>$M_P$</th>
<th>$M_{PC}$</th>
<th>$M_{PC}^t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_1$</td>
<td>2 0 1 1 2 1</td>
<td></td>
</tr>
<tr>
<td>$n_2$</td>
<td>0 1 1 0 1 1</td>
<td></td>
</tr>
<tr>
<td>$n_3$</td>
<td>1 1 2 1 2 1</td>
<td></td>
</tr>
<tr>
<td>$n_4$</td>
<td>1 0 1 1 1 0</td>
<td></td>
</tr>
<tr>
<td>$n_5$</td>
<td>2 1 2 1 3 2</td>
<td></td>
</tr>
<tr>
<td>$n_6$</td>
<td>1 1 1 0 2 2</td>
<td></td>
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</tbody>
</table>

Fig. 8.5. Actor co-membership matrix for the six children

<table>
<thead>
<tr>
<th>$M_P$</th>
<th>$M_{PC}$</th>
<th>$M_{PC}^t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_1$</td>
<td>3 2 2</td>
<td></td>
</tr>
<tr>
<td>$m_2$</td>
<td>2 4 2</td>
<td></td>
</tr>
<tr>
<td>$m_3$</td>
<td>2 2 4</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 8.6. Event overlap matrix for the three parties

[Images taken from Wasserman Faust 1994]
Transforming Two Mode Networks into One Mode Networks
[Wasserman Faust 1994]

\[ M_p = M_{PC} * M_{PC}' \]

C...Children
P...Party

<table>
<thead>
<tr>
<th>Allison</th>
<th>Drew</th>
<th>Eliot</th>
<th>Keith</th>
<th>Ross</th>
<th>Sarah</th>
</tr>
</thead>
<tbody>
<tr>
<td>Party 1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Party 2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Party 3</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

\[
\begin{array}{ccc}
\text{Party 1} & \text{Party 2} & \text{Party 3} \\
\hline
\text{Allison} & 1 & 0 & 1 \\
\text{Drew} & 0 & 1 & 0 \\
\text{Eliot} & 0 & 1 & 1 \\
\text{Keith} & 0 & 0 & 1 \\
\text{Ross} & 1 & 1 & 1 \\
\text{Sarah} & 1 & 1 & 0 \\
\end{array}
\]

Output:
Weighted regular graph

Set theoretic interpretation (P1, P2)

Bi-partite representation (entire bipartite graph)

Vector interpretation (P1, P2)
Set-theoretic/Vector-based Measures of Similarity


Similarity between P1 & P2:

Raw measure (or Simple matching coefficient, result of folding)

\[ |X \cap Y| \] = 2

(does not take into account sizes of X or Y)

Binary Approaches (incl. Normalization)

Dice's coefficient (D)

\[ 2 \frac{|X \cap Y|}{|X| + |Y|} = 2 \frac{2}{3+4} = \frac{4}{7} \]

Jaccard’s coefficient (J)

\[ \frac{|X \cap Y|}{|X \cup Y|} = \frac{2}{5} \]

Cosine coefficient (C)

\[ \frac{|X \cap Y|}{\sqrt{|X| \cdot |Y|}} = 2/(3^{1/2} \times 4^{1/2}) = \sim 0.577 \]

Overlap coefficient (O)

\[ \frac{|X \cap Y|}{\min(|X|, |Y|)} = \frac{2}{3} \]

All the left (except the raw measure) are normalized similarity measures:
1. For \( S = D, J, C, O \), \( S(X,Y) = S(Y,X) \) and \( S(X; Y) = 1 \) iff \( X = Y \).
2. For \( S = D, J, C, O \), \( 0 \leq S(X,Y) \leq 1 \)


cf. http://www.dcs.gla.ac.uk/Keith/Chapter.3/Ch.3.html

counting measure | . | gives the size of the set.

Real-valued Vectors

Binäre Vektoren\(^1\)  Vektoren mit reellen Werten\(^2\)

\[ |x| = \sqrt{\sum_{i=1}^{n} x_i^2} \]

\[ \bar{x} \cdot \bar{y} = \sum_{i=1}^{n} x_i y_i \]

| \[ |X \cap Y| \] | \[ \sum_{k=1}^{n} (\text{weight}_{sk})(\text{weight}_{sk}) \] |
|---------------|---------------------------------|
| Raw Measure   | \[ 2 \frac{|X \cap Y|}{|X| + |Y|} \] | \[ 2 \frac{2}{3+4} \text{ (weight}_{sk} \cdot \text{weight}_{sk}) \] |
| Dice-Coefficient | \[ \frac{|X \cap Y|}{|X| + |Y|} \] | \[ \frac{2}{3} \text{ (weight}_{sk} \cdot \text{weight}_{sk}) \] |
| Jaccard-Coefficient | \[ \frac{|X \cap Y|}{|X \cup Y|} \] | \[ \frac{2}{5} \text{ (weight}_{sk} \cdot \text{weight}_{sk}) \] |
| Cosine-Coefficient | \[ \frac{|X \cap Y|}{\sqrt{|X| \times |Y|}} \] | \[ \frac{2}{3} \text{ (weight}_{sk} \cdot \text{weight}_{sk}) \] |
| Overlap-Coefficient | \[ \frac{|X \cap Y|}{\min(|X|, |Y|)} \] | \[ \min(\sum_{k=1}^{n} \text{weight}_{sk} \cdot \sum_{k=1}^{n} \text{weight}_{sk}) \] |

\( n \)

(C) Karin Haenelt

(Manning/Schütze, 2000, 300/301)

(Ferber, 2003)
The k-neighborhood graph, $G_k$

Given bipartite graph $B$, users on left, interests on right

Connect two users if they share at least $k$ interests in common

$G_1$
The \( k \)-neighborhood graph, \( G_k \)

Given bipartite graph \( B \), users on left, interests on right

Connect two users if they share at least \( k \) interests in common

Connect two users if they share at least \( k \) interests in common
Illustration k=1

Illustration k=2
Illustration k=3

Illustration k=4
Illustration k=5

The KNC-plot

The k-neighbor connectivity plot

- How many connected components does $G_k$ have?
- What is the size of the largest component?

Answers the question:

how many shared interests are meaningful?

- Communities, Cuts
Analysis

Four graphs:

- LiveJournal
  - Blogging site, users can specify interests
- Y! query logs (interests = queries)
  - Queries issued for Yahoo! Search (Try it at www.yahoo.com)
- Content match (users = web pages, interests = ads)
  - Ads shown on web pages
- Flickr photo tags (users = photos, interests = tags)

All data anonymized, sanitized, downsamplled

- Graphs have 100s of thousands to a million users

Examples

- Largest component
- Number of components

At k=5, all connected.
At k=6, interesting!

Content match
Web pages = “users”
Ads = “interests”

At k=6, nobody connected

Flickr
Photos = “users”
Tags = “interests”
Let's take a step back!

The Web Graph is Flat

Book tip
„Flatland: A romance of many dimensions“
Edwin A. Abbott 1838-1926 (1884)
http://www.geom.uiuc.edu/~banchoff/Flatland/

How can we infer information about the $n^{th} + 1$ dimension?

E.g. popularity, trust, prestige, importance, …

Dr Quantum - Flatland
http://www.youtube.com/watch?v=BWyTxCsIXE4
http://www.flatlandthefilm.com/
Inhabitants of Flatland

Tradesman

Men (The hero in this novel is A. Square)

Woman

Priests

Book tip
„Flatland: A romance of many dimensions“
Edwin A. Abbott 1838-1926 (1884)
http://www.geom.uiuc.edu/~banchoff/Flatland/

What kind of information can we infer from a „flat“ social graph?
Centrality and Prestige
[Wasserman Faust 1994]

Which actors are the most important or the most prominent in a given social network?

What kind of measures could we use to answer this (or similar questions)?

What are the implications of directed/undirected social graphs on calculating prominence?

⇒ In directed graphs, we can use Centrality and Prestige
⇒ In undirected graphs, we can only use Centrality

Prominence
[Wasserman Faust 1994]

We will consider an actor to be prominent if the ties of the actor make the actor particularly visible to the other actors in the network.
Actor Centrality  
[Wasserman Faust 1994]

Prominent actors are those that are extensively involved in relationships with other actors.

This involvement makes them more visible to the others

No focus on directionality -> what is emphasized is that the actor is involved

A central actor is one that is involved in many ties.  
[cf. Degree of nodes]

Actor Prestige  
[Wasserman Faust 1994]

A prestigious actor is an actor who is the object of extensive ties, thus focusing solely on the actor as a recipient.

[cf. indegree of nodes]

Only quantifiable for directed social graphs.

Also known as status, rank, popularity
Different Types of Centrality in Undirected Social Graphs
[Wasserman Faust 1994, Scripps et al 2007]

Degree Centrality
- Actor Degree Centrality: $\overline{CD}(n_i) = \sum_j I[(i,j) \in E]$  
  Where $I$ is a 0=1 indicator function.

Closeness Centrality
- Actor Closeness Centrality:
  - Based on how close an actor is to all the other actors in the set of actors
  - Closeness is the reciprocal of the sum of all the geodesic (shortest) distances from a given node to all others
  - Nodes with a small CC score are closer to the center of the network while those with higher scores are closer to the edge.

Betweenness Centrality
- Actor Betweenness Centrality:
  - An actor is central if it lies between other actors on their geodesics
  - The central actor must be between many of the actors via their geodesics

$\Rightarrow$ All three can be normalized to a value between 0 and 1 by dividing it with its max. value

Centrality and Prestige in Undirected Social Graphs
[Wasserman Faust 1994]

Actor = closeness
= betweenness centrality:
n1>n2,n3,n4,n5,n6,n7

Actor centrality = Betweenness centrality = Closeness centrality:
n1=n2=n3=n4=n5=n6 =n7

Betweeness centrality:
n1>n2,n3>n4,n5>n6,n7

Fig. 5.1. Three illustrative networks for the study of centrality and prestige
Examples and Simulation:
file:///M:/mydocs/courses/SS2012/707.000%20Web%20Science%20and%20Web%20Technology/measure/measure.html

How can we identify groups and subgroups in a social graph?
Cliqués, Subgroups

[Wasserman Faust 1994]

Definition of a Clique

• A clique in a graph is a maximal complete subgraph of three or more nodes.

Remark:

• Restriction to at least three nodes ensures that dyads are not considered to be cliques
• Definition allows cliques to overlap

Informally:

• A collection of actors in which each actor is adjacent to the other members of the clique

What cliques can you identify in the following graph?

Fig. 7.1. A graph and its cliques

Subgroups

[Wasserman Faust 1994]

Cliqués are very strict measures

• Absence of a single tie results in the subgroup not being a clique
• Within a clique, all actors are theoretically identical (no internal differentiation)
• Cliqués are seldom useful in the analysis of actual social network data because definition is overly strict

⇒ So how can the notion of cliques be extended to make the resulting subgroups more substantively and theoretically interesting?

⇒ Subgroups based on reachability and diameter
n cliques
[Wasserman Faust 1994]

N-cliques require that the **geodesic distances** among members of a subgroup are **small** by defining a **cutoff value** \( n \) as the maximum length of geodesics connecting pairs of actors within the cohesive subgroup.

An n-clique is a maximal **complete** subgraph in which the largest geodesic distance between any two nodes is no greater than \( n \).

Which 2-cliques can you identify in the following graph?

Fig. 7.2. Graph illustrating n-cliques, n-clans, and n-clubs

n clans
[Wasserman Faust 1994]

An n-clan is an **n-clique** in which the geodesic distance between all nodes in the subgraph is no greater than \( n \) for paths **within** the subgraph.

N-clans in a graph are **those n-cliques** that have diameter less than or equal to \( n \) (within the graph).

\( \Rightarrow \) All n-clans are n-cliques.

Why is \{1,2,3,4\} not a 2-clan?

Why is \{1,2,3,4,5\} not a 2-clan?

Fig. 7.2. Graph illustrating n-cliques, n-clans, and n-clubs

Which 2-clans can you identify in the following graph?
n clubs
[Wasserman Faust 1994]

An n-club is defined as a maximal subgraph of diameter n.

A subgraph in which the distance between all nodes within the subgraph is less than or equal to n

And no nodes can be added that also have geodesic distance n or less from all members of the subgraph

⇒ All n-clubs are contained within n-cliques.
⇒ All n-clans are also n-clubs
⇒ Not all n-clubs are n-clans

Subgroups in Co-Affiliation Networks
Borgatti 1997

• The obvious next step would be to try to identify these subgroups in co-affiliation networks.
  – For example, we can search for cliques, n-cliques, n-clans, n-clubs.

• Unfortunately, these methods are not well suited for analysing a bipartite graph.
  – In fact, bipartite graphs contain no cliques
  – In contrast, bipartite graphs contain too many 2-cliques and 2-clans.
  – One of the problems is that, in the bipartite graph, all nodes of the same type are necessarily two links distant.

⇒ we need to consider special types of subgraphs which are more appropriate for two-mode data.
Bicliques
[Borgatti 1997]

A biclique is a maximal complete bipartite subgraph of a given bipartite graph.

Reasonable to insist on bicliques of the form $K_{m,n}$ where $m$ and $n$ are greater than 2

- Why? Each of the two modes should form (after folding) interesting structures (triads or greater)

Subgroups in Co-Affiliation Networks
[Borgatti 1997]

- Clearly, we can define extensions of n-cliques, n-clubs and n-clans to n-bicliques, n-biclubs and n-biclans.
- But, the extensions would in many senses be unnatural since n would need to be odd.

- Next week we will discuss a way to analyze subgroups in affiliation networks: Galois Lattices
Home Assignment 1.2

- Online Today

- In case of any questions, do not hesitate to post to the newsgroup tu-graz.lv.web-science

Any questions?

See you next week!