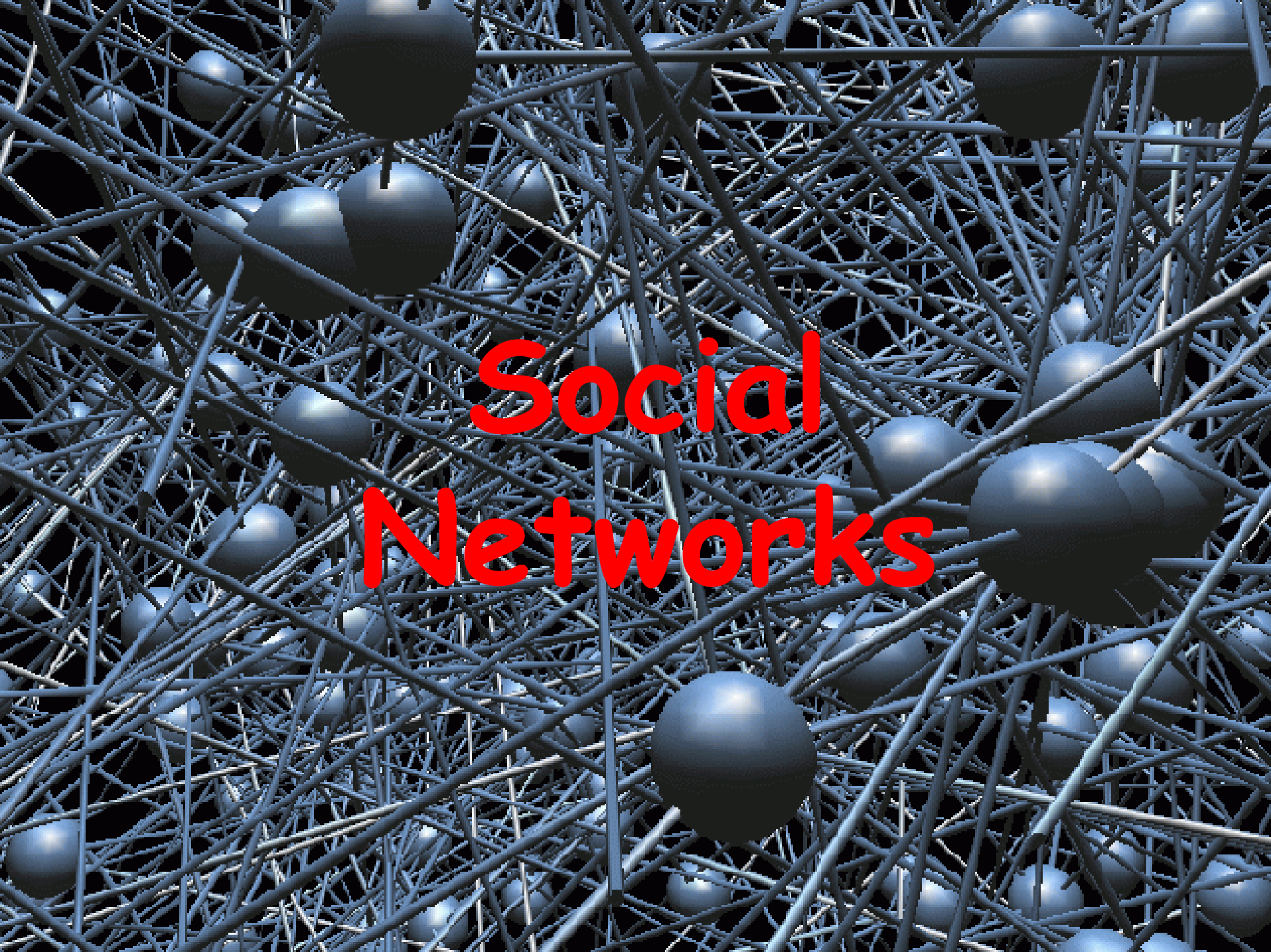

Social
Networks

| TIME | SCHEDULE | |
|---|---|---|
| 7:30-8:00 | Registration & breakfast social | |
| 8:00-8:15 | **Welcome.** *Nick Athanassiou (organizer)* | |
| 8:15-9:30 | **Basic Concepts.** *Steve Borgatti* | |
| 9:30-9:37 | MINI-BREAK | |
| 9:37-10:53:20 | **Survey of Network Research.** *Dan Brass* | |
| 10:53:21-11:00 | MINI-BREAK | |
| 11:00-12:15 | **Designing Network Research.** *Julie Hite & Dan Brass* | |
| 12:15-1:30 | LUNCH | |
| 1:30-2:15 | **Data Collection.** *David Krackhardt* | |
| 2:15-3:00 | **Analyzing Network Data.** *Steve Borgatti* | **Publishing Network Research**. *Panel discussion.* |
| 3:00-3:15 | BREAK | |
| 3:15-4:30 | **Analyzing Network Data** *Steve & David* | **Sharing Network Research in Progress.** *Roundtables* |
| 4:30-5:00 | **Integration.** *Nick Athanassiou and friends* | |

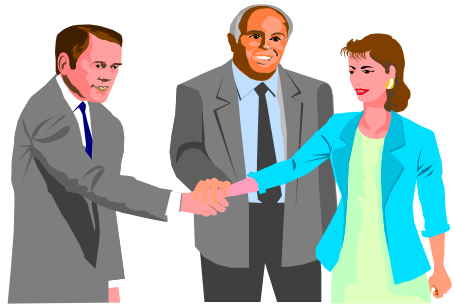
Handouts available at
www.analytictech.com/aomnetwork

# Basic Social Network Concepts

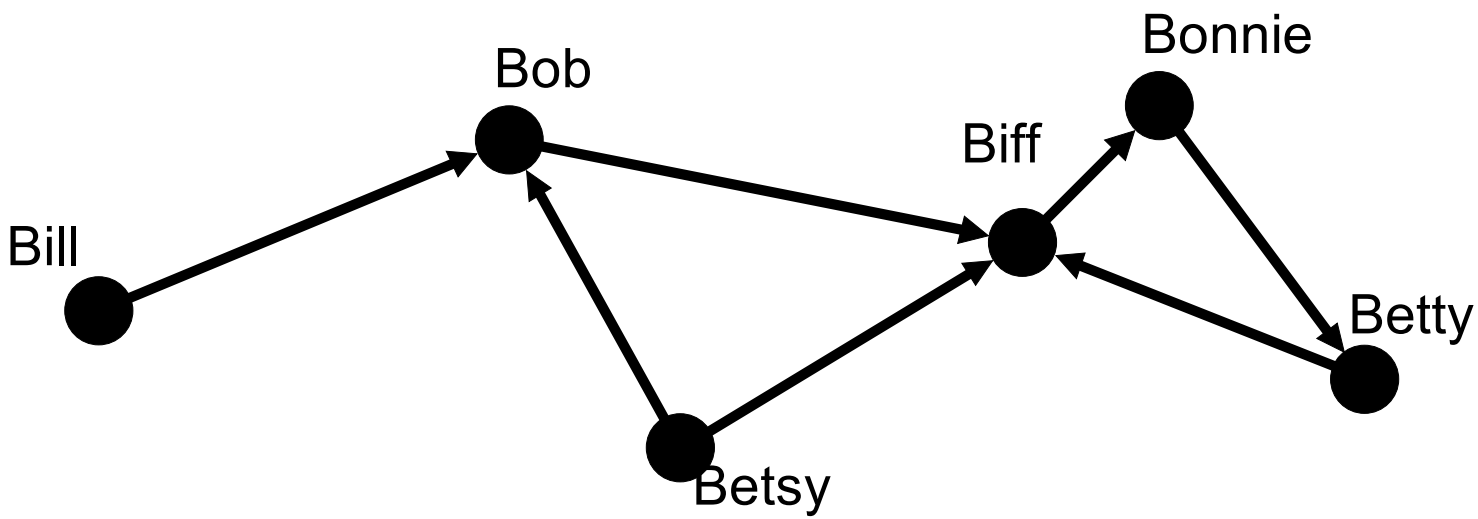
Steve Borgatti, Boston College
www.analytictech.com/borgatti
borgatts@bc.edu

**AoM PDW @ Denver**
**August, 2002**

# What is a Network?



- A set of dyadic ties, all of the same type, among a set of actors
- Actors can be persons, organizations …
- A tie is an instance of a social relation



# Relations Among Persons

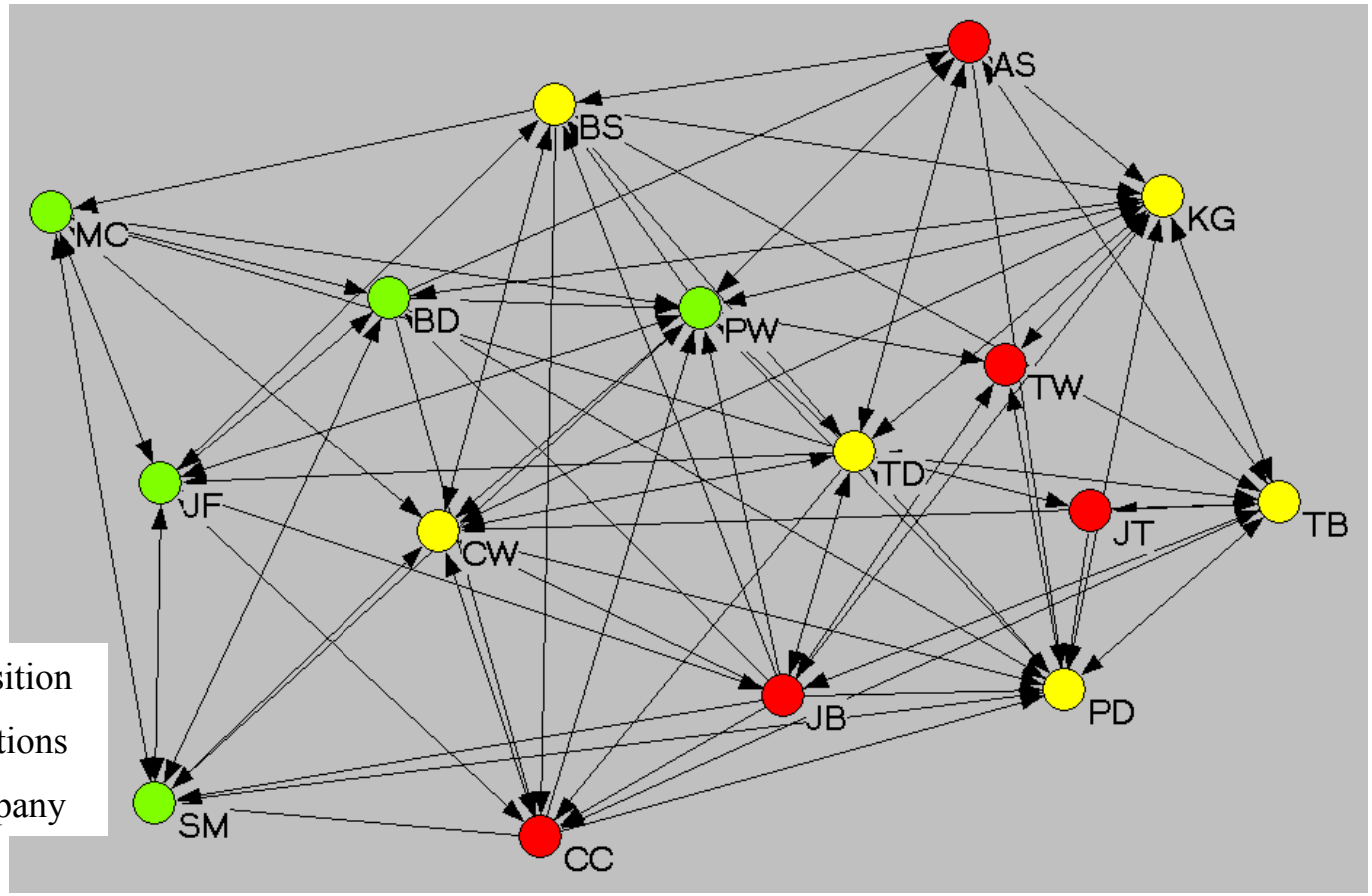
- Kinship
  - mother of, wife of
- Other role-based
  - boss of, teacher of
  - friend of
- Cognitive/perceptual
  - knows
  - aware of what they know
- Affective
  - likes, trusts
- Interactions
  - give advice, talks to, fights with
  - sex / drugs with
- Affiliations
  - belong to same clubs
  - is physically near

Note: Content matters!
Each relation yields a different structure & has different effects

# Simple Answers

Who you ask for answers to straightforward questions.

HR Dept
of Large
Health Care
Organization

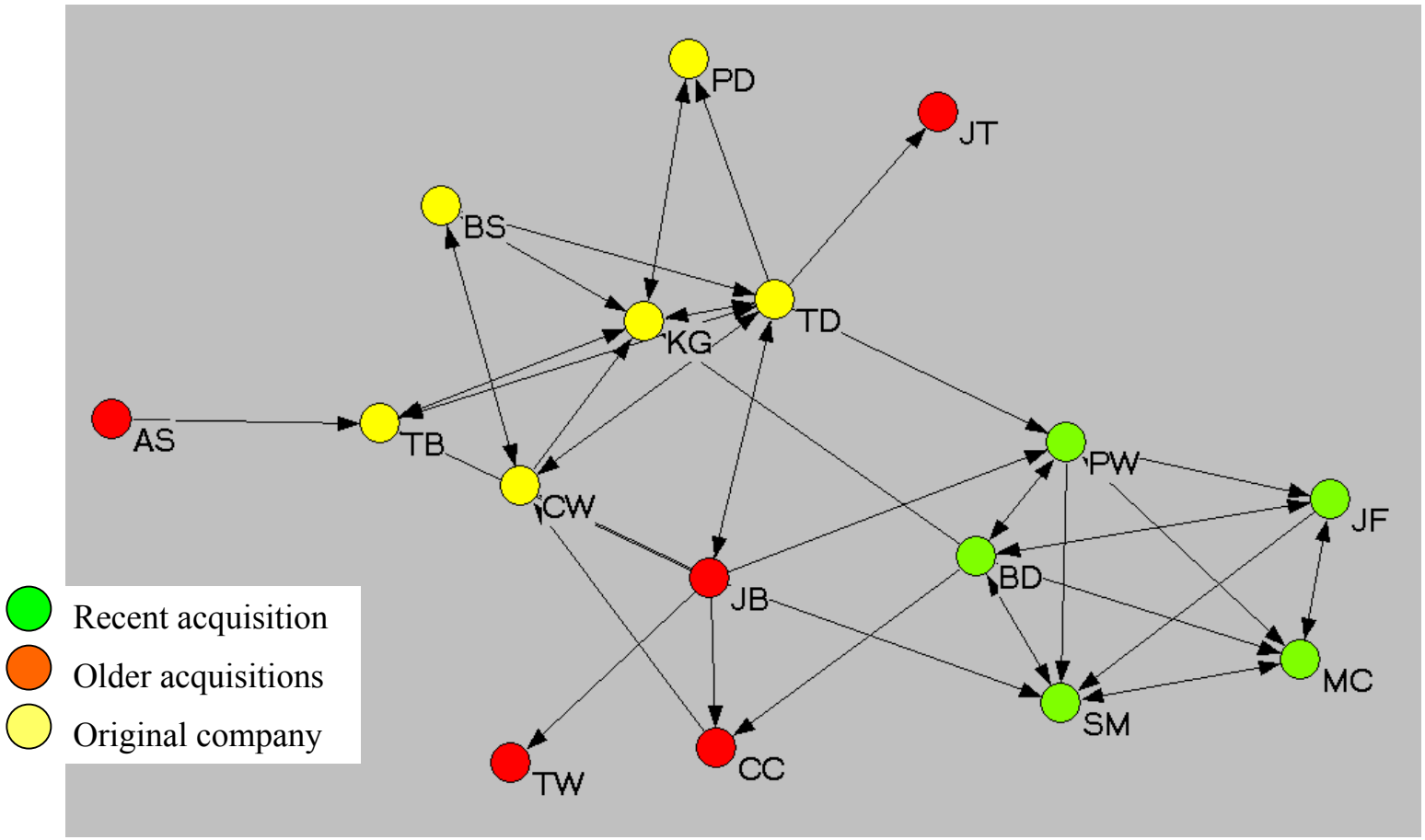



Recent acquisition
Older acquisitions
Original company

Data drawn from Cross, Borgatti & Parker 2001.

# Problem Reformulation

Who you see to help you think through issues

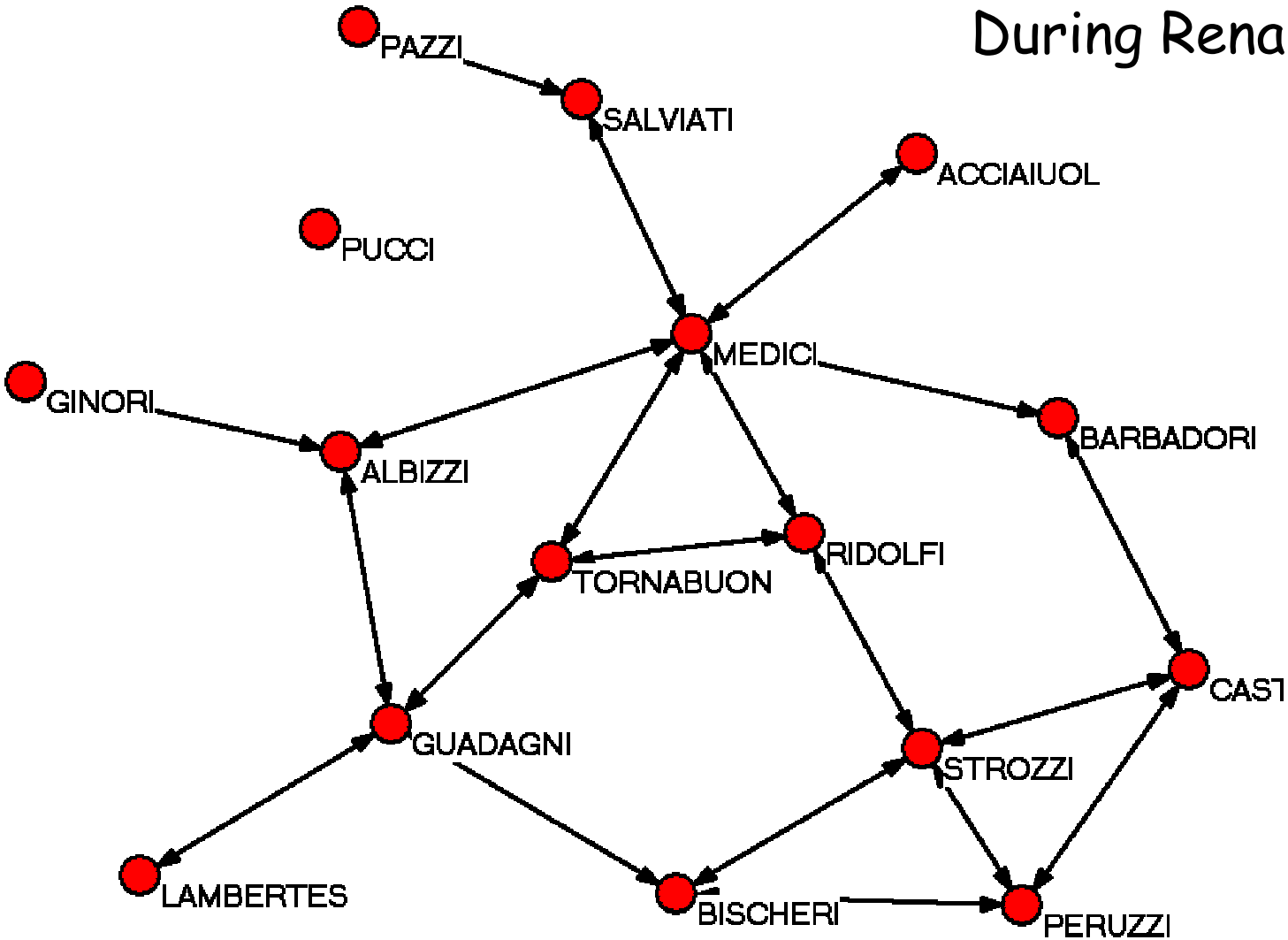



Data drawn from Cross, Borgatti & Parker 2001.

**Example of a Network**

# Marriage Ties Among Florentine Families

During Renaissance times

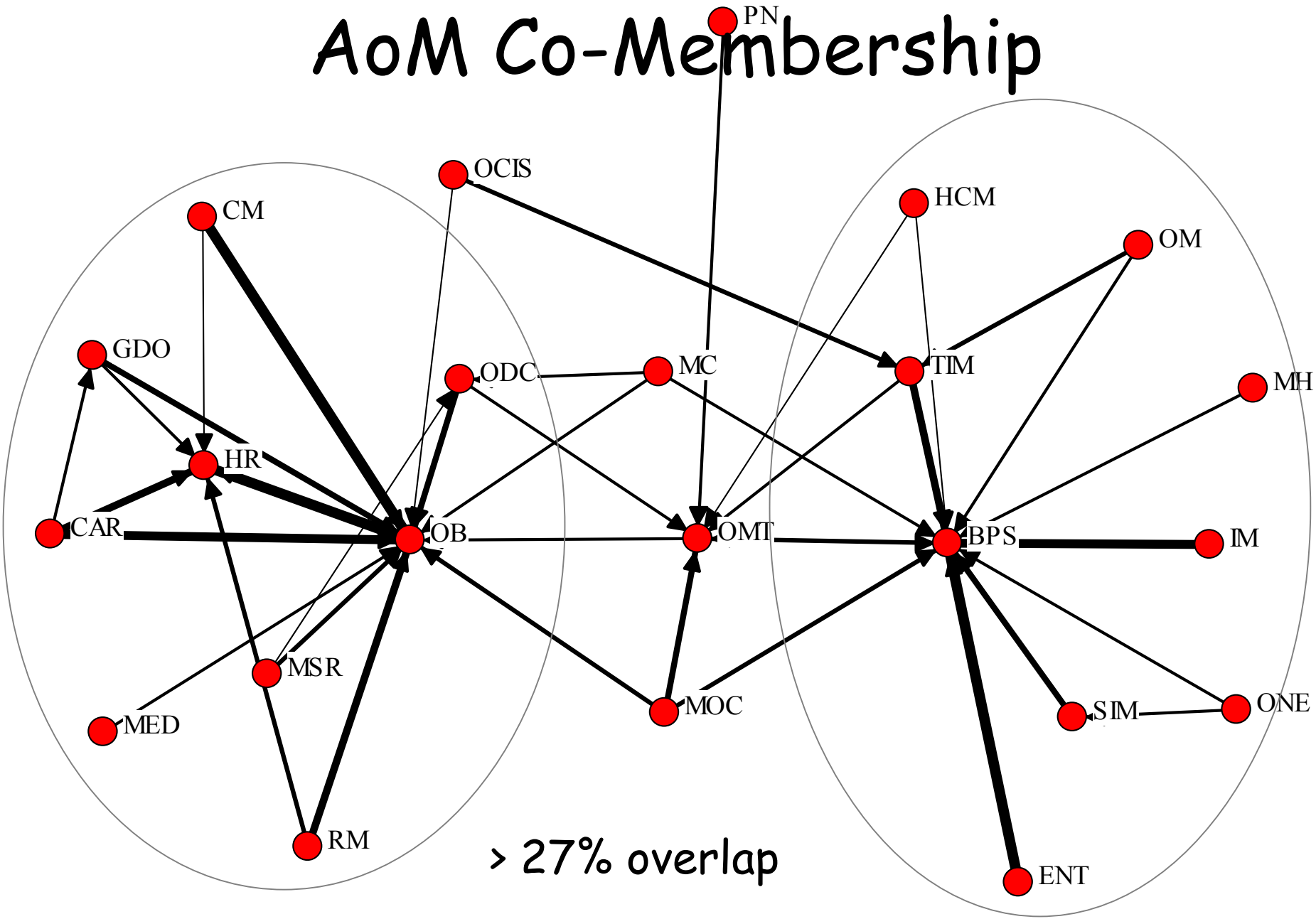



Data compiled by John Padgett

# Relations Among Organizations

- As corporate entities
  - Buy from / sell to, leases to, outsources to
  - Owns shares of, subsidiary of
  - Joint ventures, cooperate sales agreements, alliances
  - Regulates
- Via their members
  - Personnel flows
  - Interlocking directorates
  - Personal friendships
  - Co-memberships

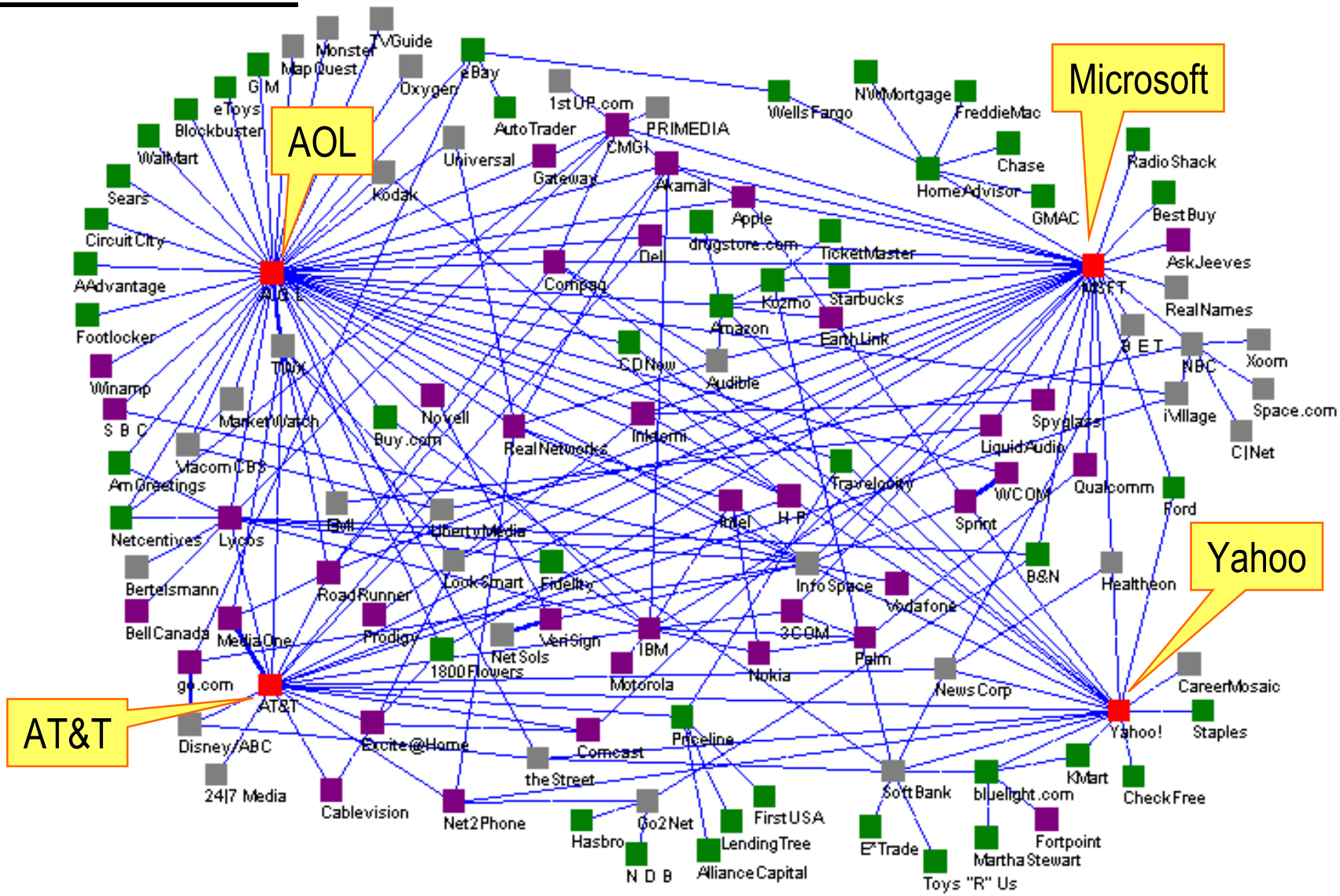
# AoM Co-Membership




> 27% overlap

**Example of a Network**

# Internet Alliances

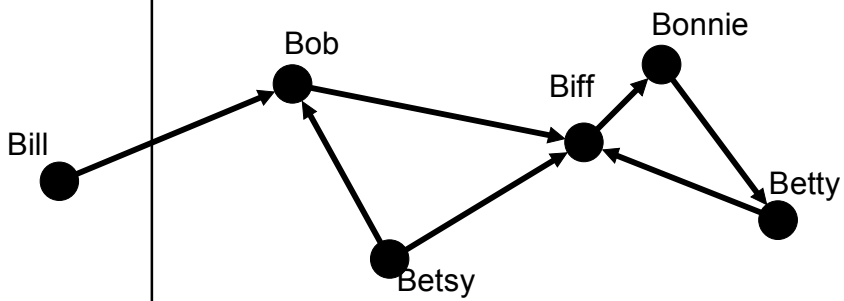
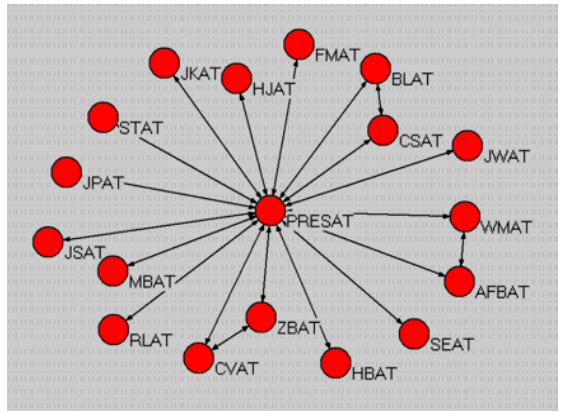
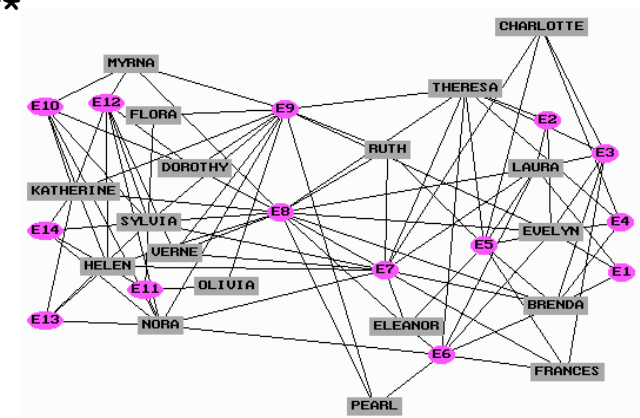
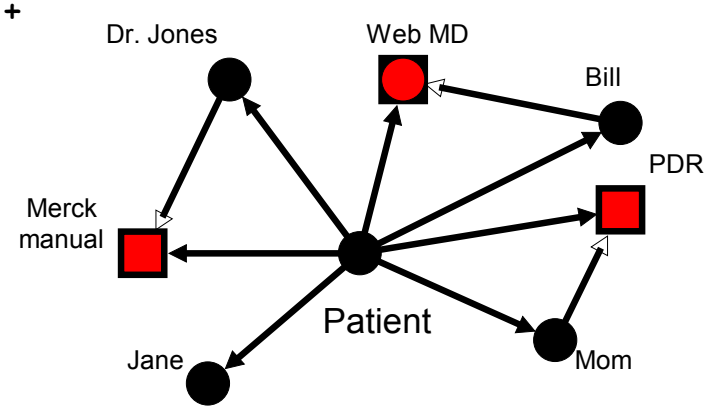



***Consumer Internet***

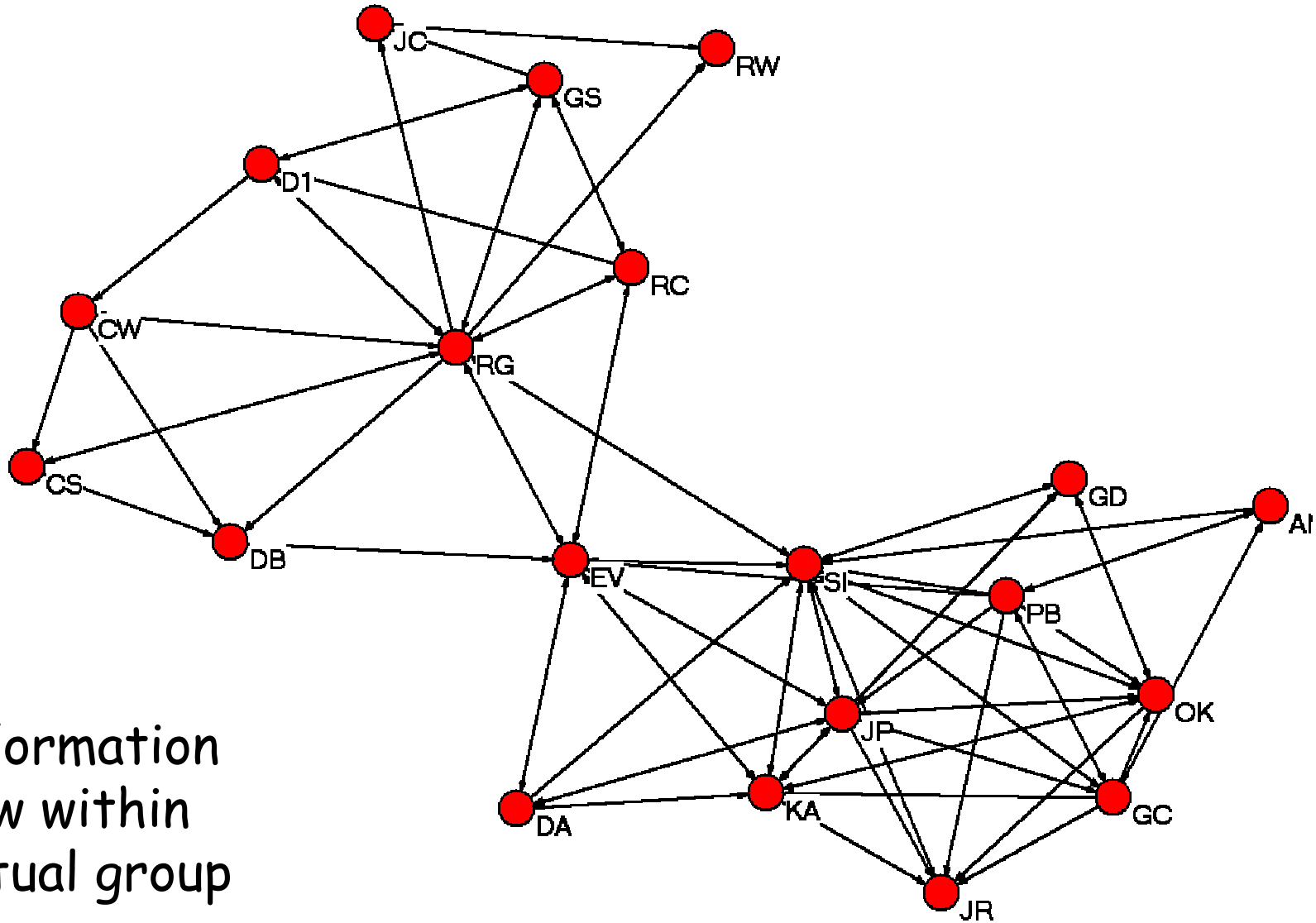


http://www.orgnet.com/netindustry.html

# Kinds of Network Data

| | Complete | Ego |
|---|---|---|
| 1-mode | ++++   | ++++   |
| 2-mode | **   | +   |

# 1-mode complete network

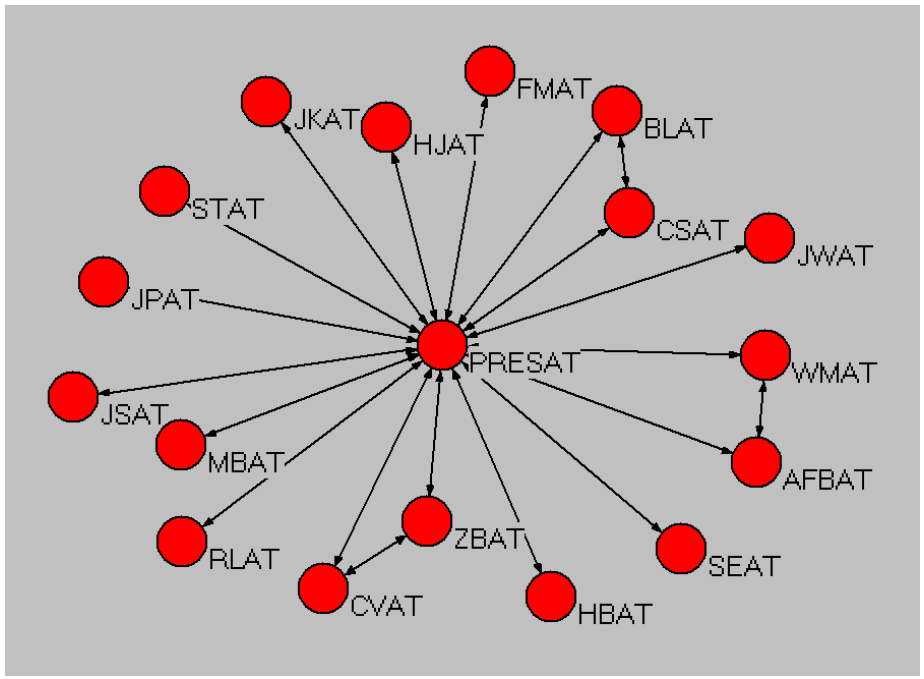



Information flow within virtual group

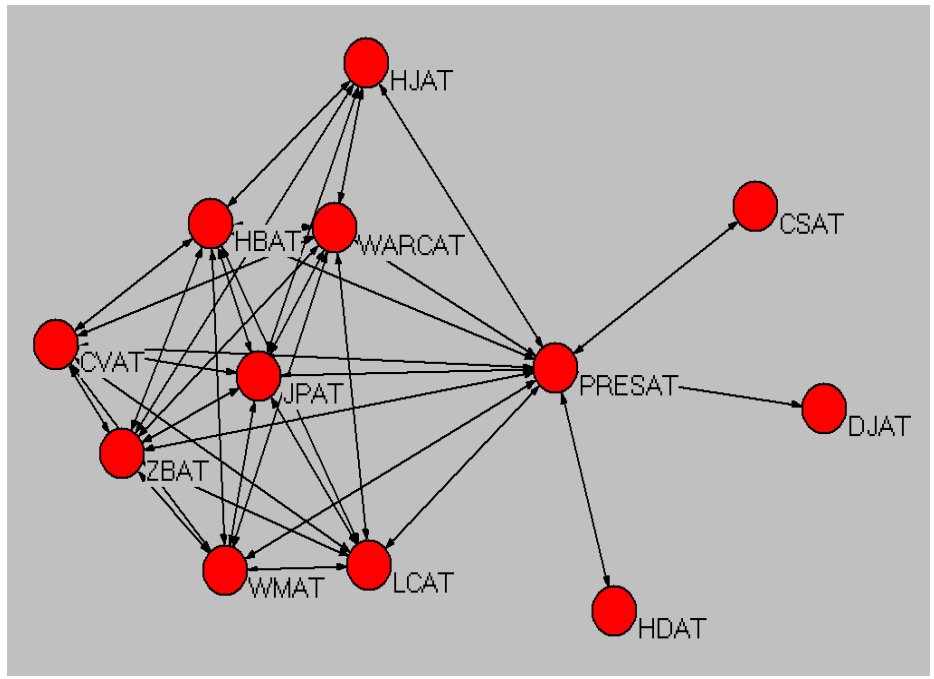
Data collected by Cross

# 1-mode ego network

## Carter Administration meetings



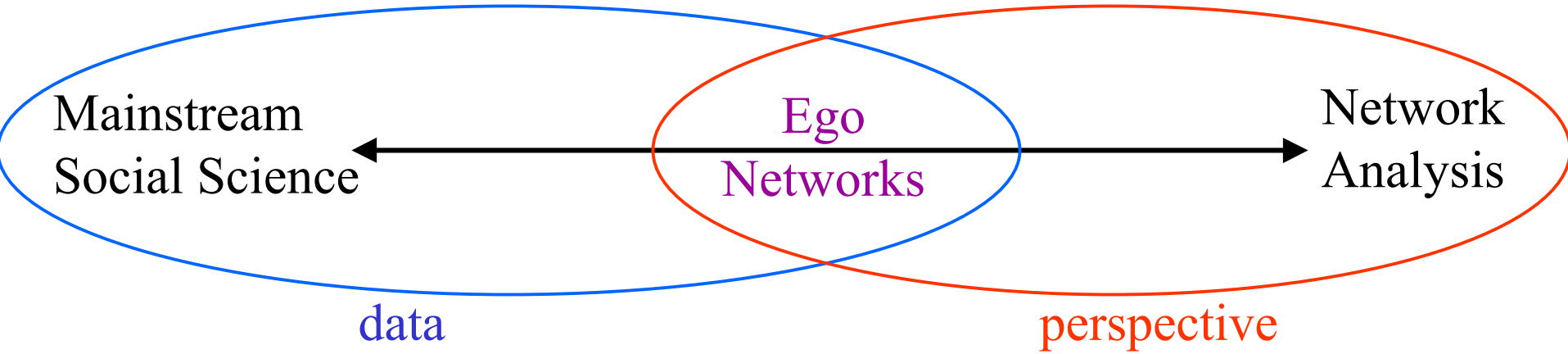

Year 1




Year 4

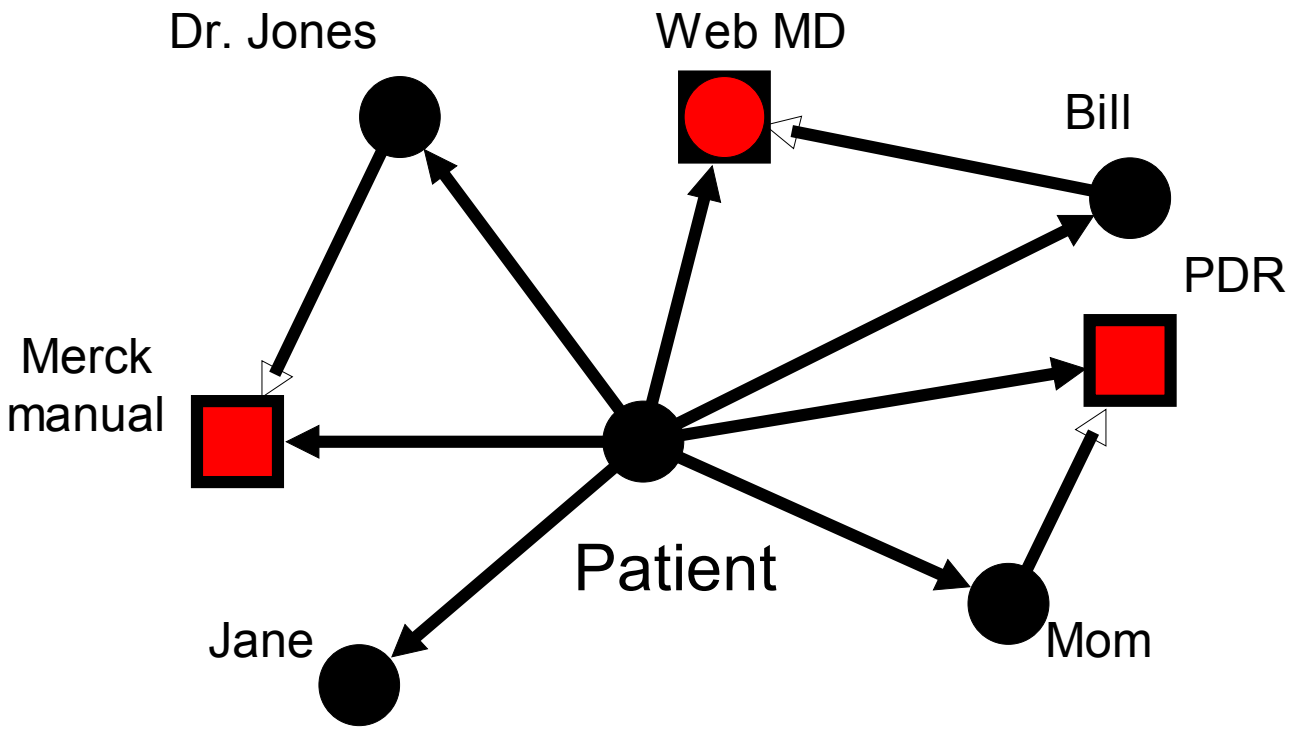
Data courtesy of Michael Link

# Ego Network Analysis

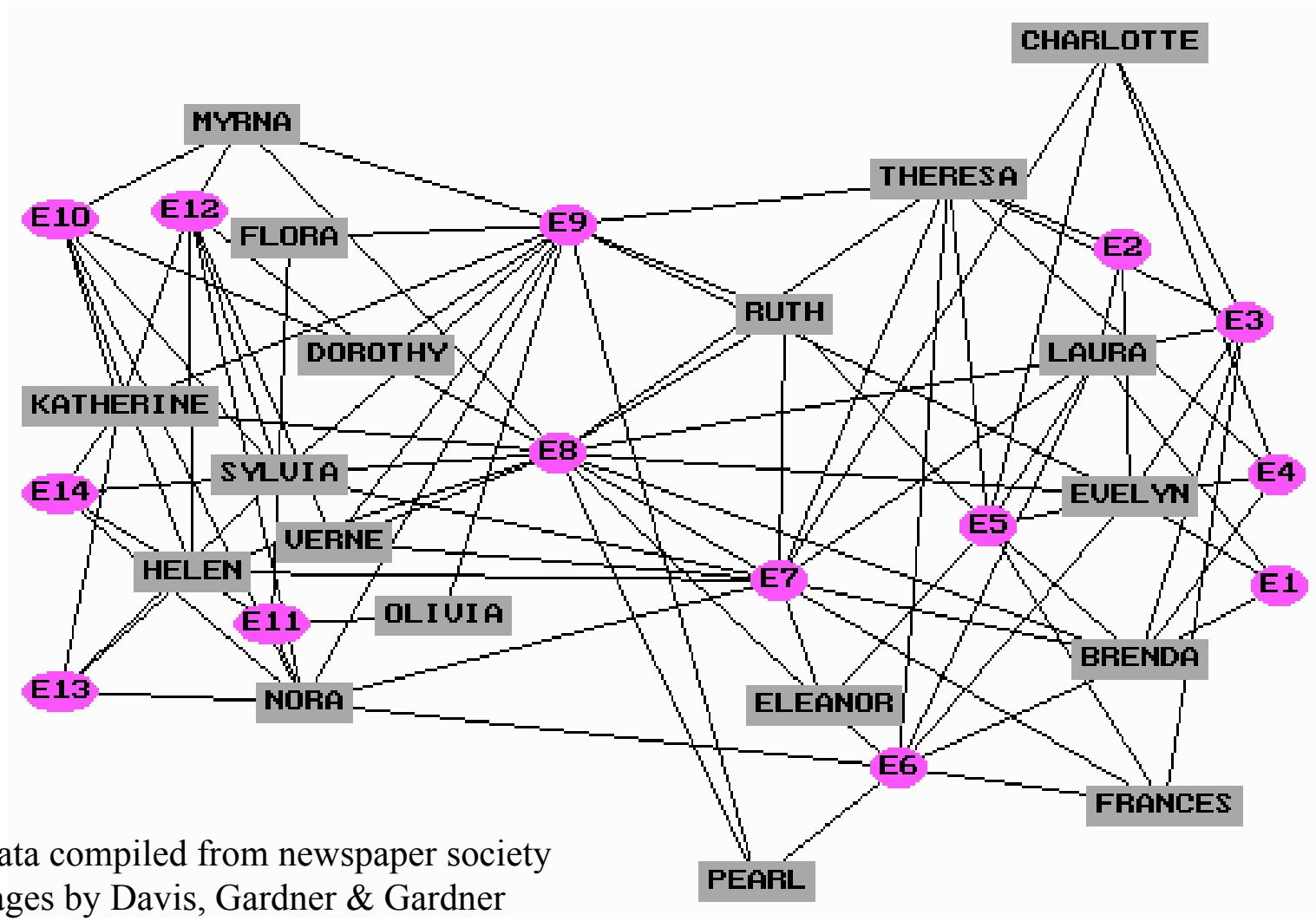



- Combine the perspective of network analysis with the data of mainstream social science
- No computer programs available

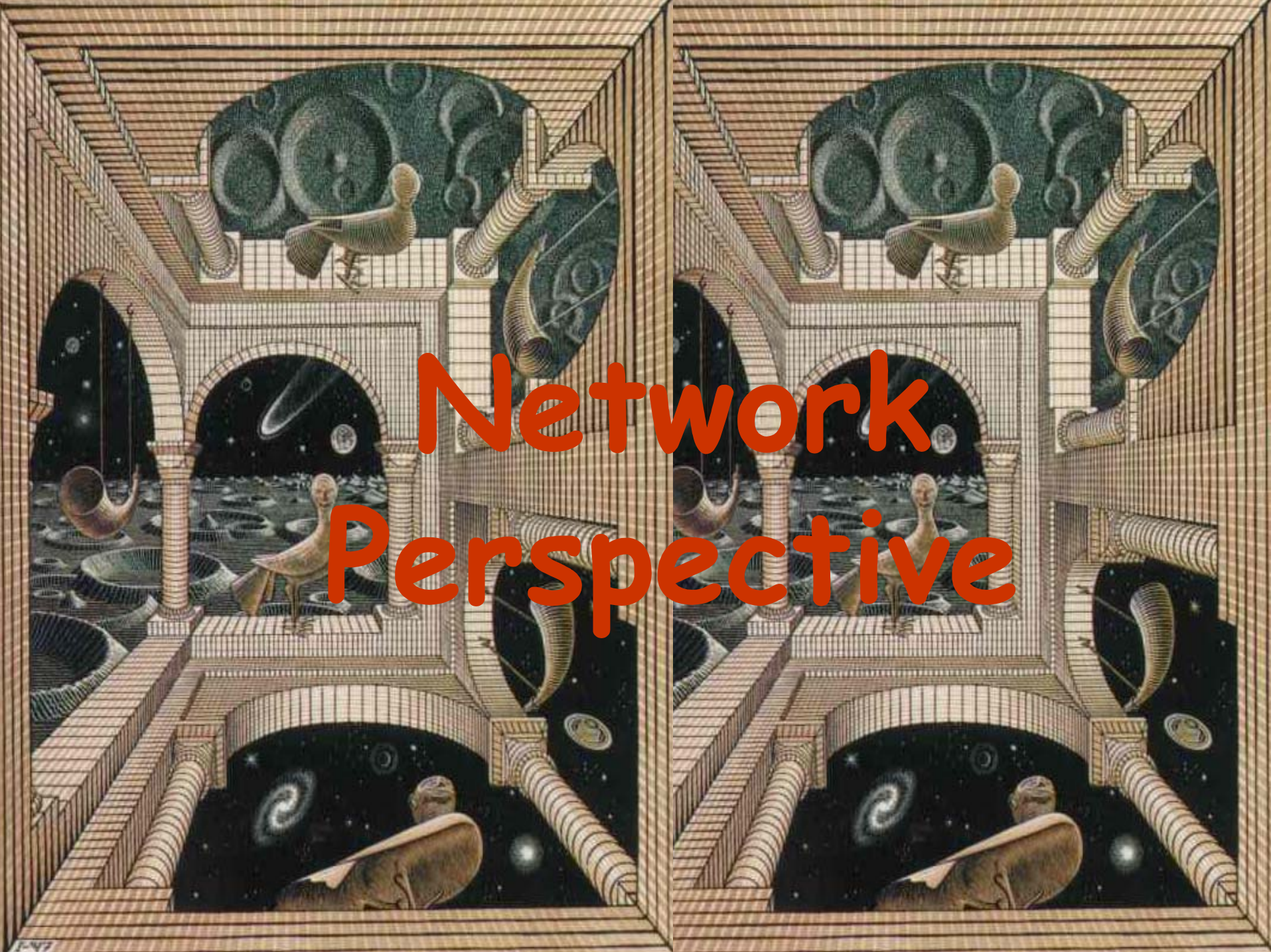
# 2-mode Ego Network



# 2-mode complete network




Data compiled from newspaper society pages by Davis, Gardner & Gardner

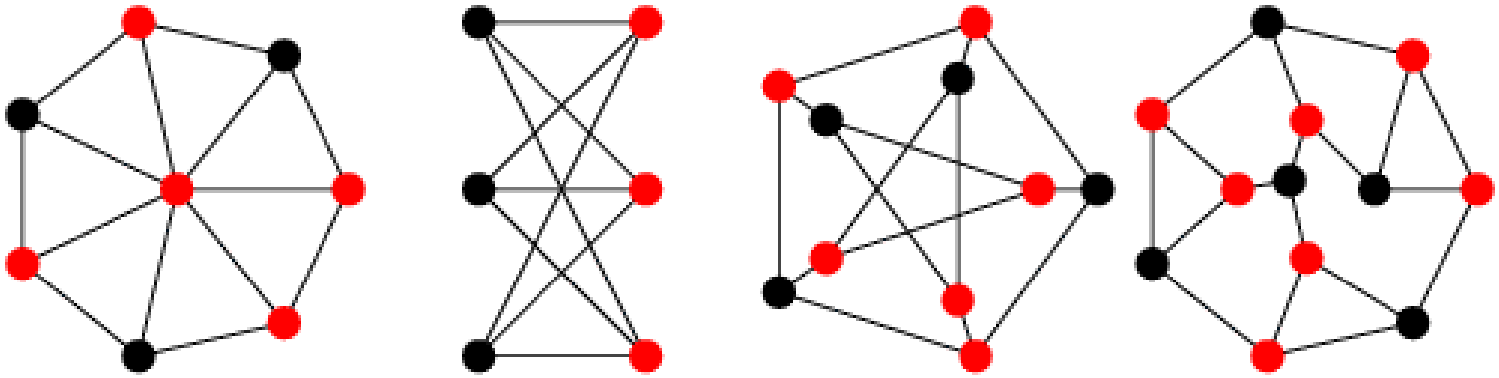

Network
Perspective

# The Network Perspective

- Relations vs. Attributes
  - Individual characteristics only half the story
  - People influence each other, ideas & materials flow
  - Predicting adoption of innovation
  - Interdependence vs atomistic essentialism
- Structure vs. Composition
  - It's not just the elements of a system, but how they are put together
  - non-reductionist, holistic, systemic

# The Network Perspective

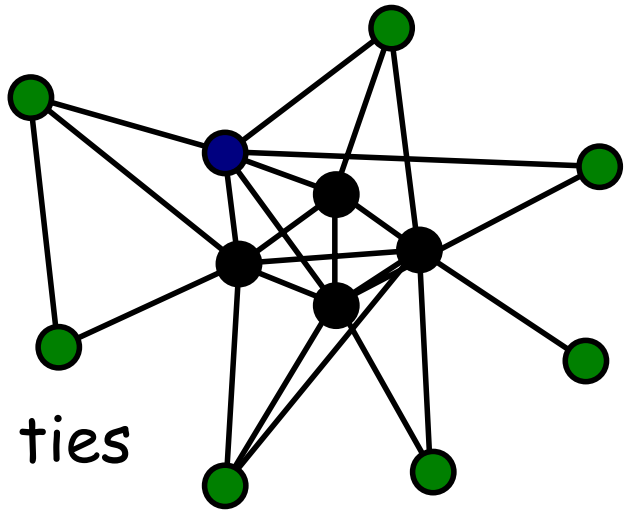
- Emergence vs. Design
  - groups (e.g., communities vs. departments)
  - roles
- Structuralism vs individualism
  - structure -> group performance
  - position -> opportunities & constraints
  - Faith that social capital trumps human capital
  - more research on consequences of network structure & position than causes
  - Preference for direction of causality
    - position -> personality, not the reverse

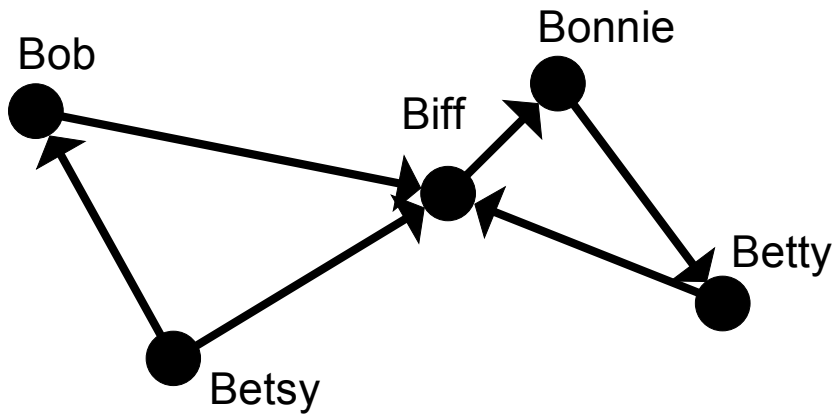


# Graph Theoretic Concepts

# Directed vs undirected ties

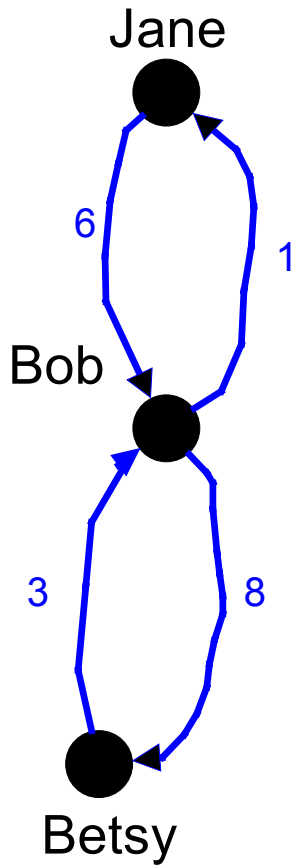
- Undirected relations
  - Attended meeting with
  - Communicates daily with
- Directed relations
  - Lent money to
- Logically vs empirically directed ties
  - Empirically, even un-directed relations can be non-symmetric due to measurement error





# Strength of Tie

- We can attach values to ties, representing quantitative attributes
  - Strength of relationship
  - Information capacity of tie
  - Rates of flow or traffic across tie
  - Distances between nodes
  - Probabilities of passing on information
  - Frequency of interaction



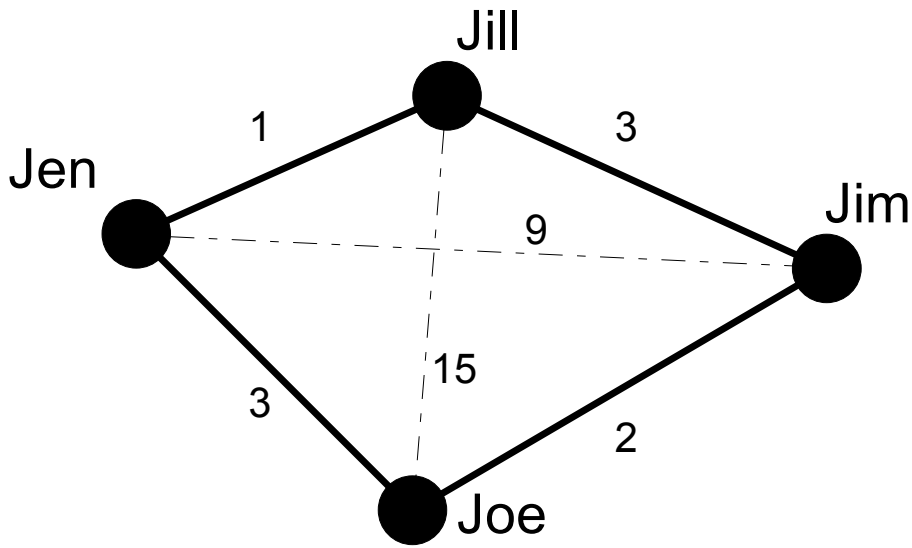
# Adjacency Matrices

Friendship

| | Jim | Jill | Jen | Joe |
|---|---|---|---|---|
| Jim | - | 1 | 0 | 1 |
| Jill | 1 | - | 1 | 0 |
| Jen | 0 | 1 | - | 1 |
| Joe | 1 | 0 | 1 | - |

Proximity

| | Jim | Jill | Jen | Joe |
|---|---|---|---|---|
| Jim | - | 3 | 9 | 2 |
| Jill | 3 | - | 1 | 15 |
| Jen | 9 | 1 | - | 3 |
| Joe | 2 | 15 | 3 | - |



# Data Formats

Dl n = 5
Format = fullmatrix
Labels embedded
Data:

| | billy | john | jill | mary |
|---|---|---|---|---|
| billy | 0 | 1 | 0 | 0 |
| john | 1 | 0 | 1 | 0 |
| jill | 0 | 0 | 0 | 1 |
| mary | 1 | 0 | 1 | 0 |

(Values optional)

Dl n = 5
Format = nodelist
Labels embedded
Data:
Billy jill john jim jane
Jill billy bob bertha
Dick jane
Jim bob billy brenda

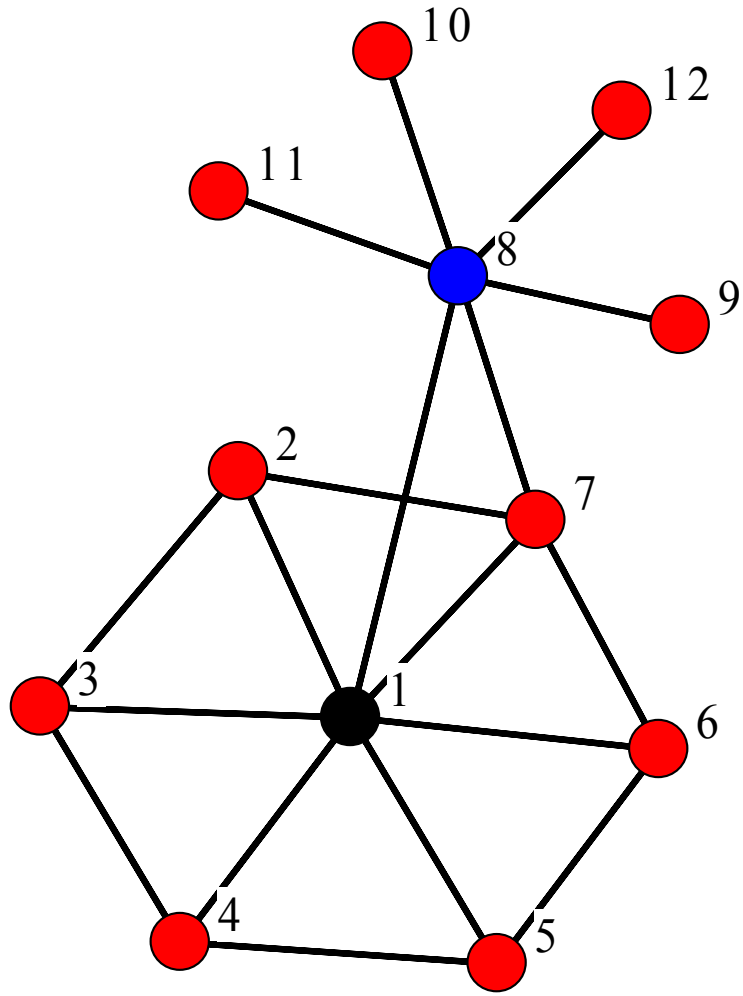
(No values possible)

Dl n = 5
Format = edgelist
Labels embedded
Data:
Billy jill
Billy john 6.3
Dick jane
Jim bob 2.5

(Values optional – assigned 1 if omitted)

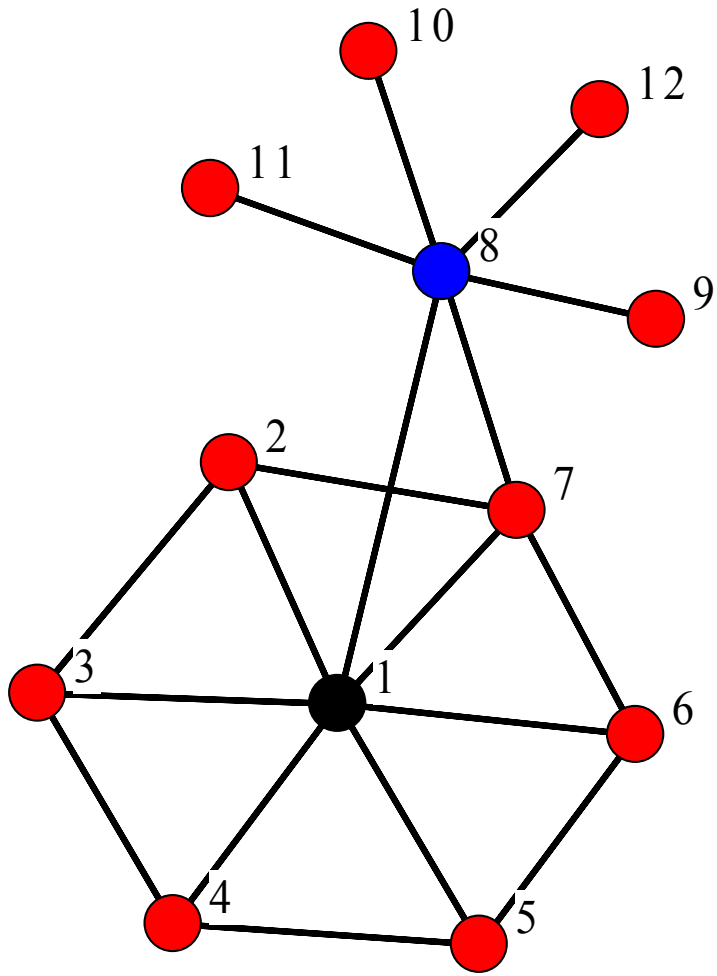
# Walks, Trails, Paths

- Path: can't repeat node
  - 1-2-3-4-5-6-7-8
  - Not 7-1-2-3-7-4
- Trail: can't repeat line
  - 1-2-3-1-7-8
  - Not 7-1-2-7-1-4
- Walk: unrestricted
  - 1-2-3-1-2-7-1-7-1



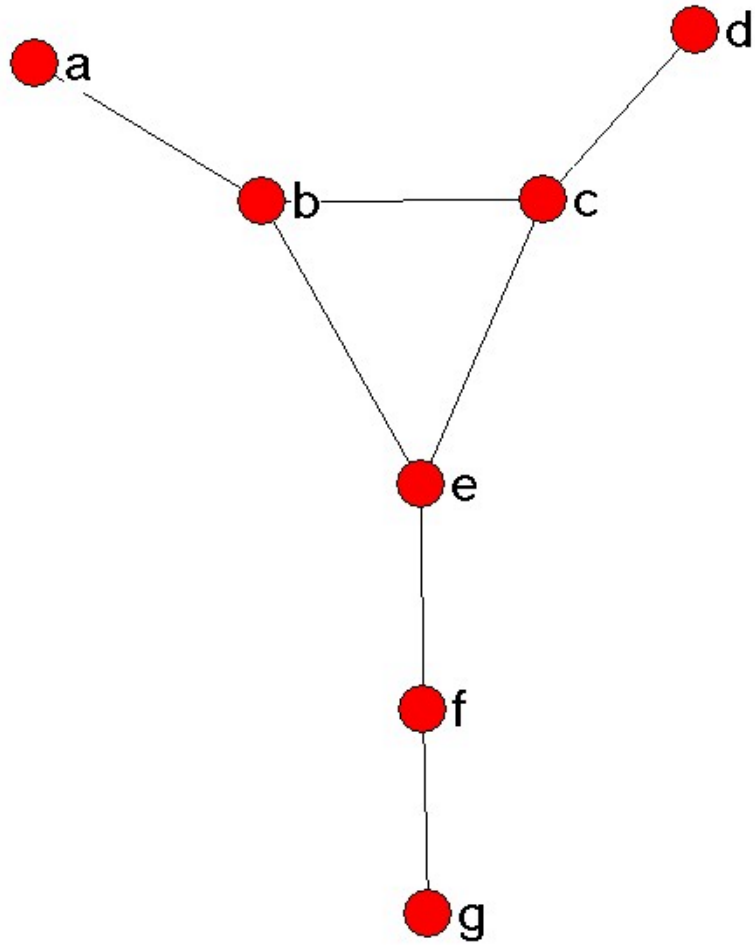
# Length & Distance

- Length of a path is number of links
- Distance between two nodes is length of shortest path (aka geodesic)



# Geodesic Distance Matrix

| | a | b | c | d | e | f | g |
|---|---|---|---|---|---|---|---|
| a | 0 | 1 | 2 | 3 | 2 | 3 | 4 |
| b | 1 | 0 | 1 | 2 | 1 | 2 | 3 |
| c | 2 | 1 | 0 | 1 | 1 | 2 | 3 |
| d | 3 | 2 | 1 | 0 | 2 | 3 | 4 |
| e | 2 | 1 | 1 | 2 | 0 | 1 | 2 |
| f | 3 | 2 | 2 | 3 | 1 | 0 | 1 |
| g | 4 | 3 | 3 | 4 | 2 | 1 | 0 |



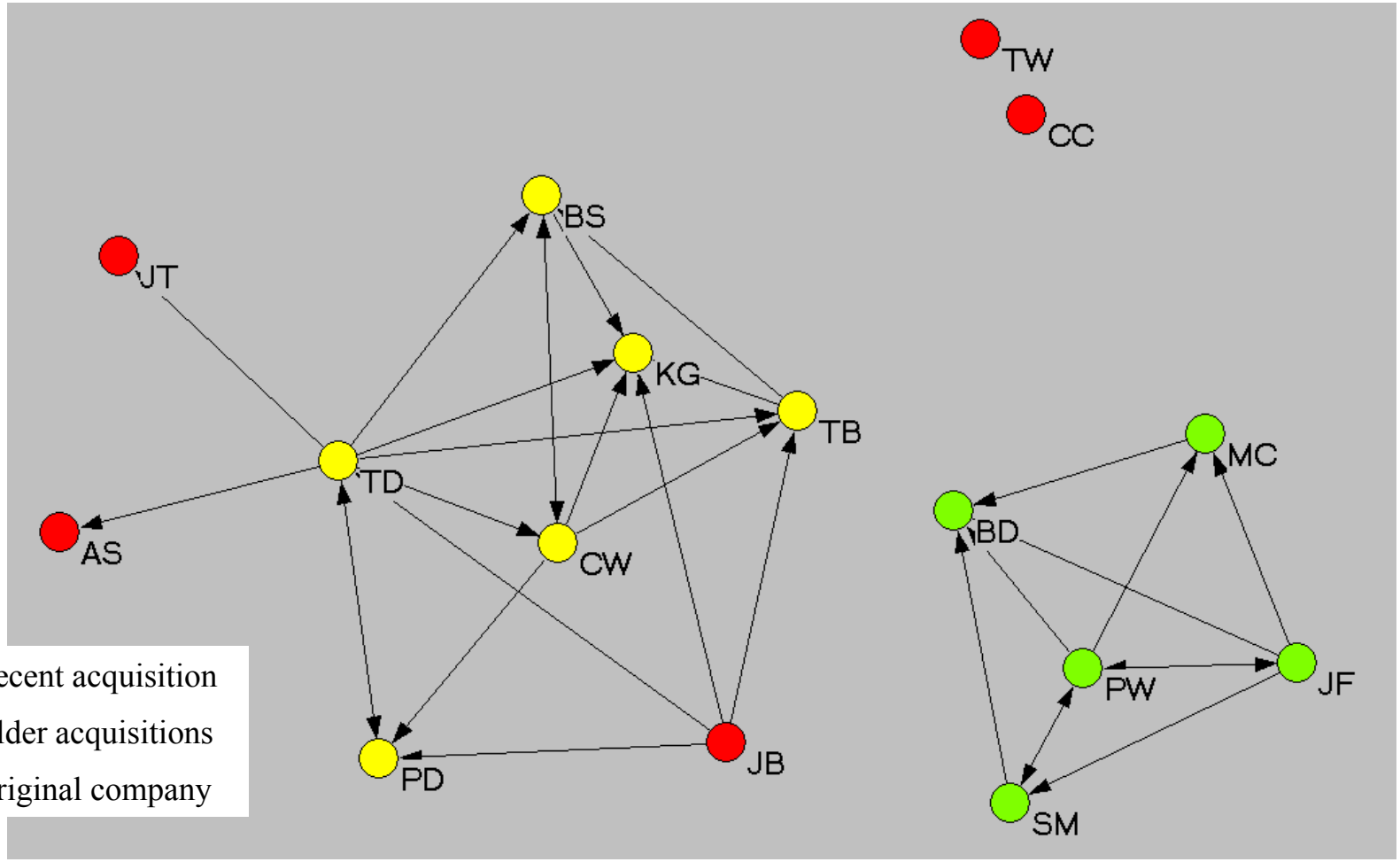
# Components

- Maximal sets of nodes in which every node can reach every other by some path (no matter how long)
- A connected graph has just one component

Relations form different networks. Components don't.

# A network with 4 components

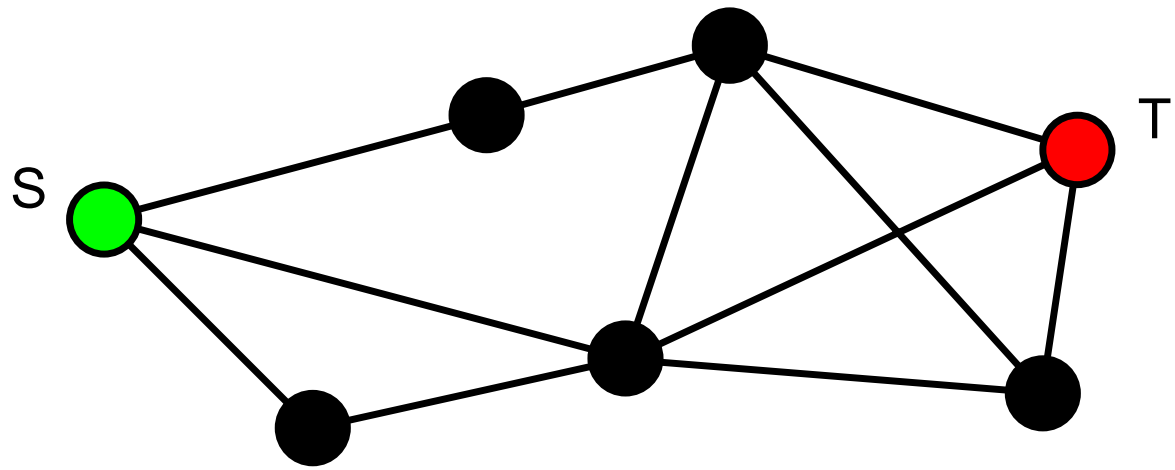
Who you go to so that you can say 'I ran it by ____, and she says ...'




Data drawn from Cross, Borgatti & Parker 2001.

# Independent Paths

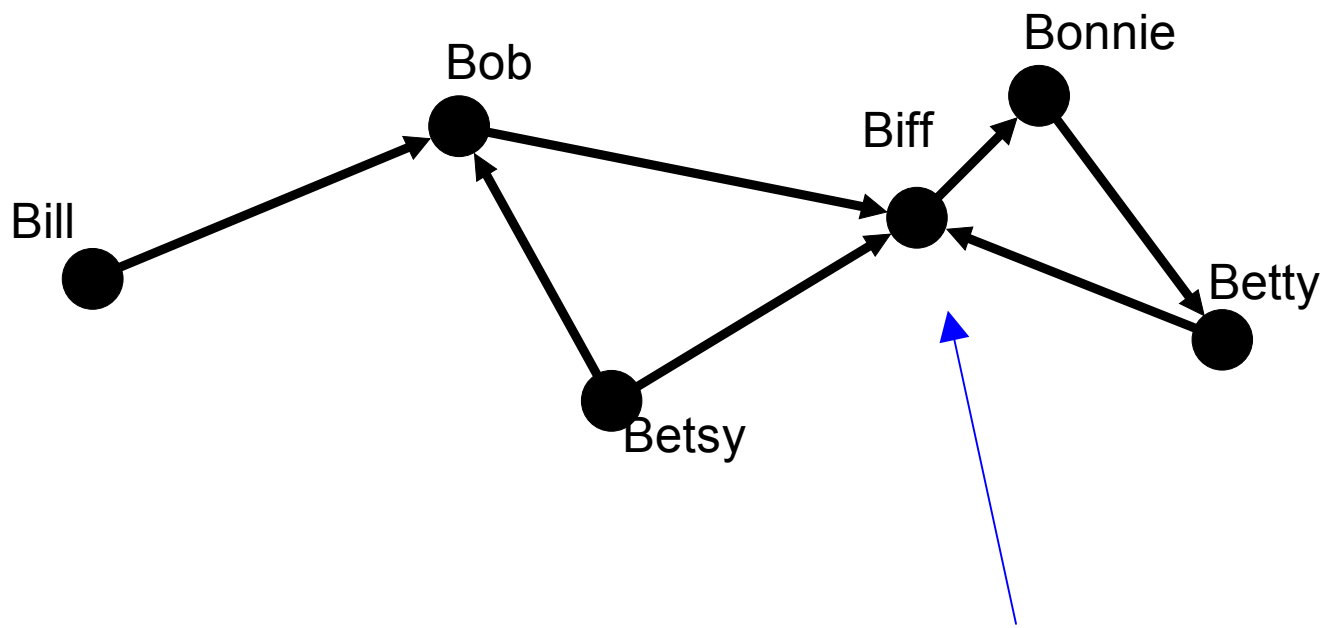
- A set of paths is node-independent if they share no nodes (except beginning and end)
  - They are line-independent if they share no lines




- 2 node-independent paths from S to T
- 3 line-independent paths from S to T

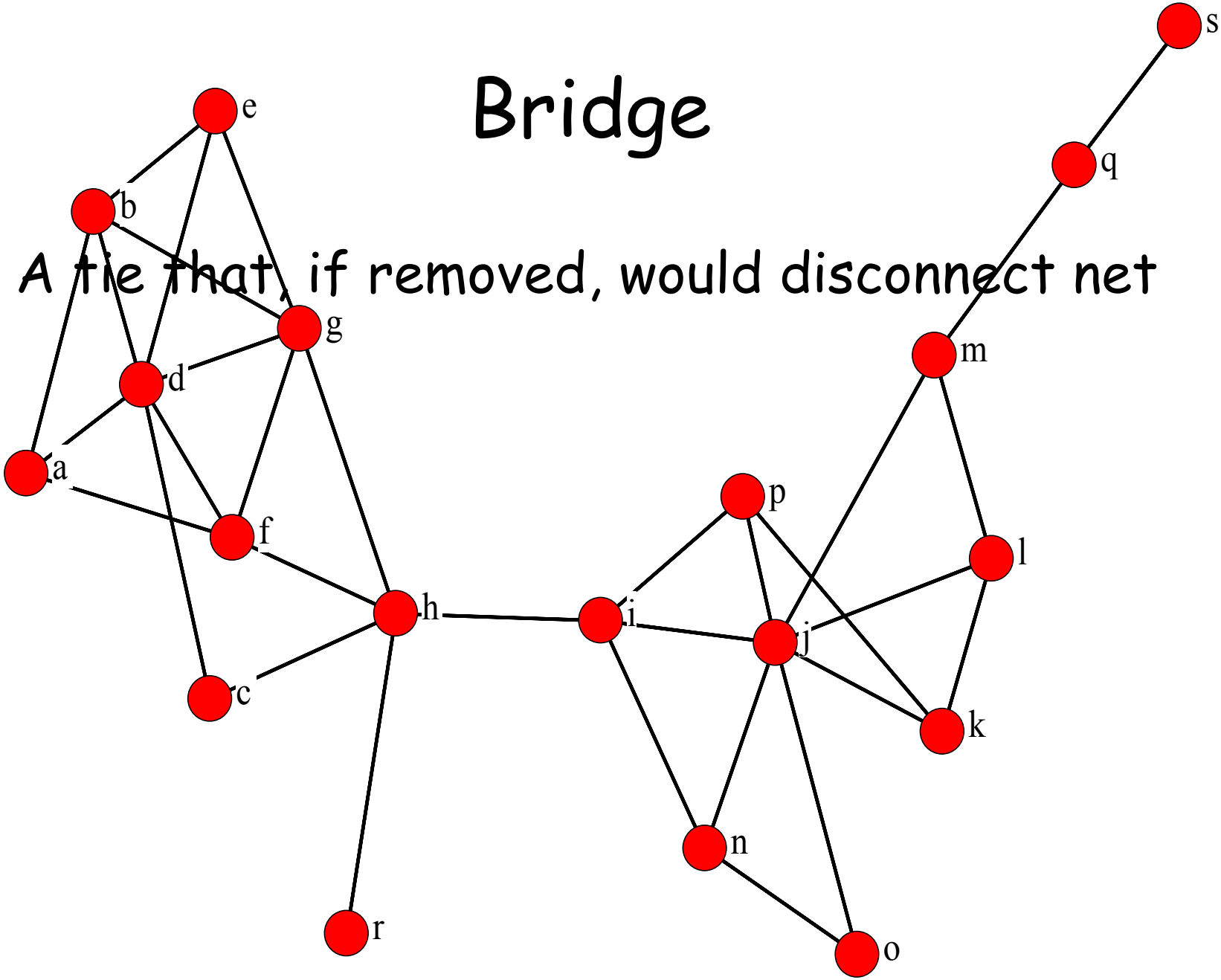
# Cutpoints

- Nodes which, if deleted, would disconnect net



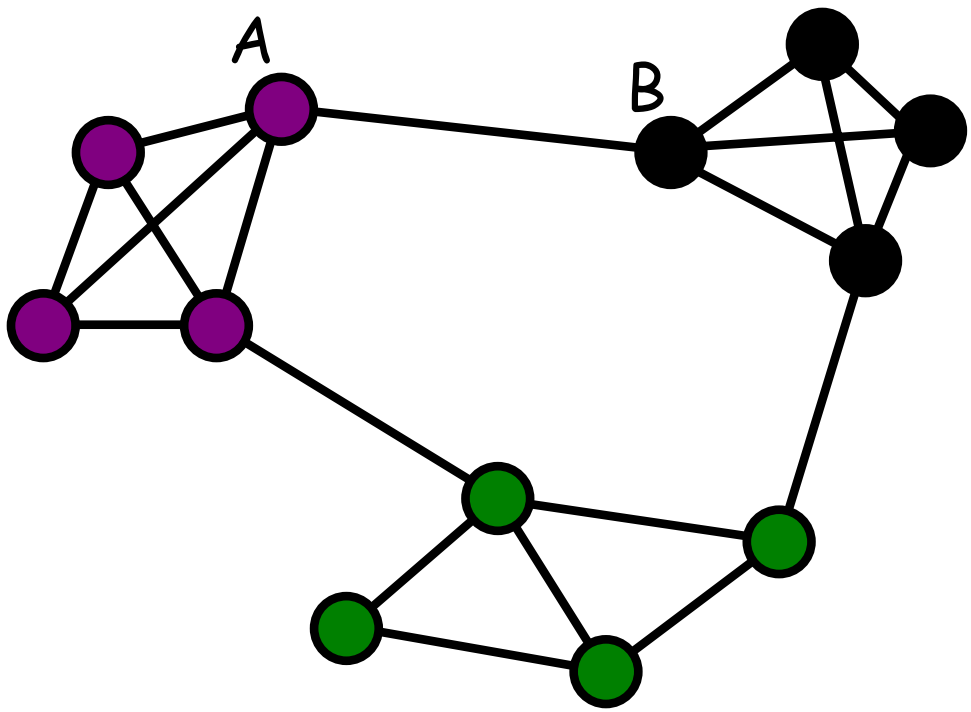
# Bridge

- A tie that, if removed, would disconnect net



# Local Bridge of Degree K

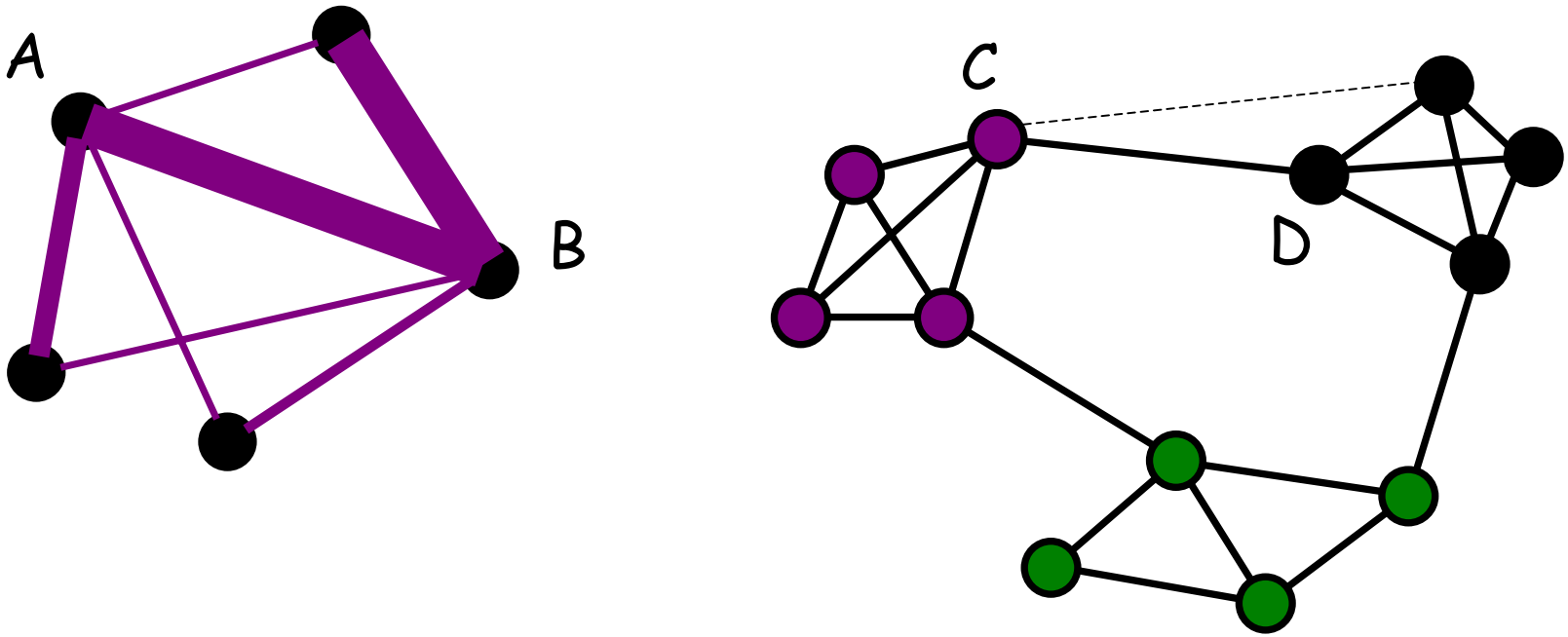
- A tie that connects nodes that would otherwise be at least k steps apart



# Granovetter's SWT Theory

- Strong ties create transitivity
  - Two nodes connected by a strong tie will have mutual acquaintances (ties to same 3rd parties)
- Ties that are part of transitive triples cannot be bridges or local bridges
- Therefore, only weak ties can be bridges
  - Hence the value of weak ties
- Strong ties embedded in tight homophilous clusters, weak ties connect to diversity
  - Weak ties a source of novel information

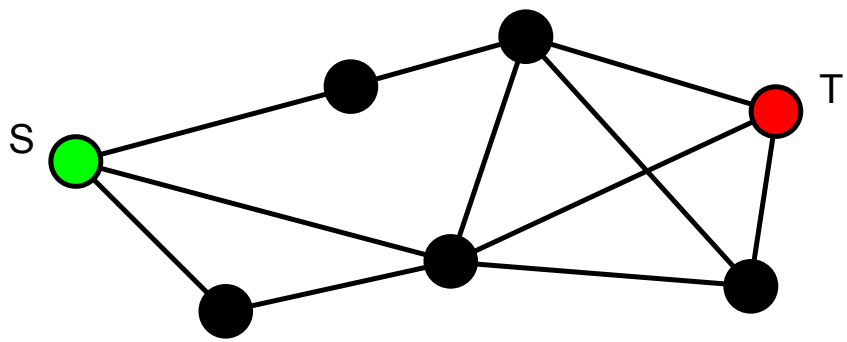
# Granovetter Transitivity



# Network Cohesion

# Connectivity

- Line connectivity $\lambda$ is the minimum number of lines that must be removed to disconnect network
- Node connectivity $\kappa$ is minimum number of nodes that must be removed to disconnect network



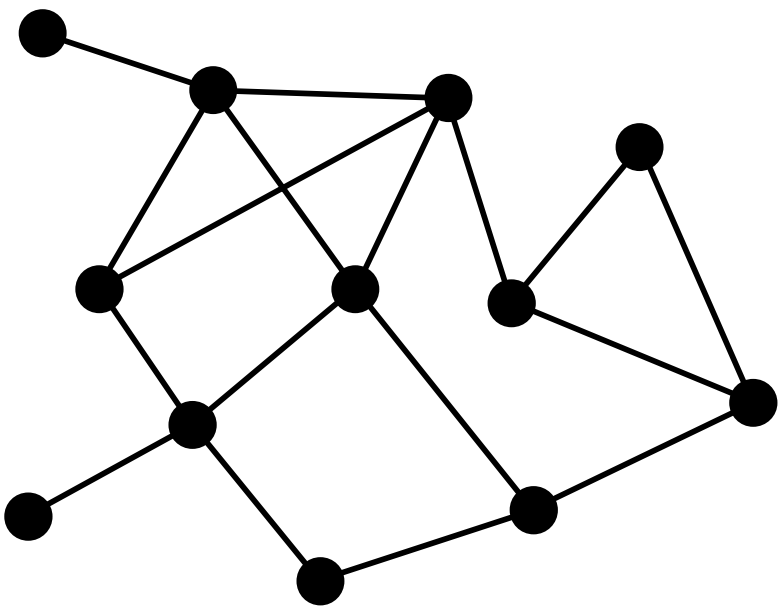
# Fragmentation

- Proportion of pairs of nodes that are unreachable from each other

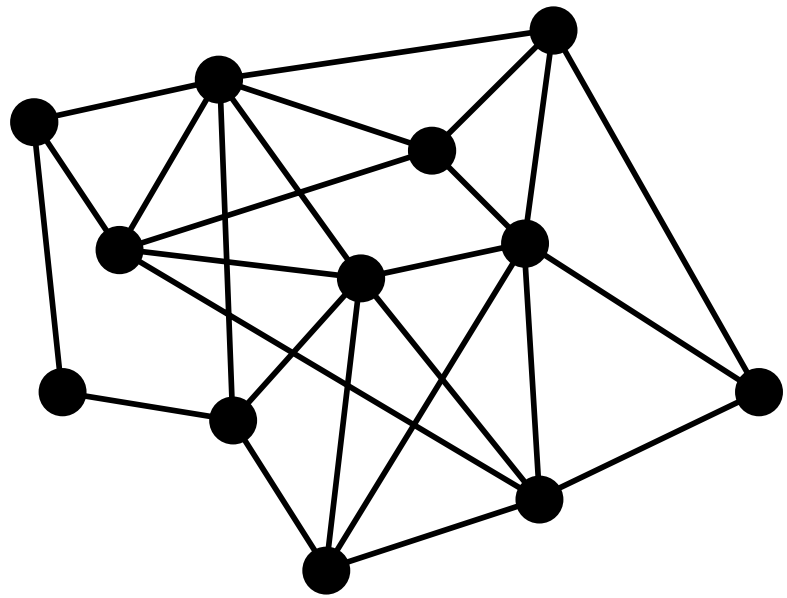
$$F = 1 - \frac{\sum_k s_k (s_k - 1)}{n(n-1)}$$

# Density

- Number of ties, expressed as percentage of the number of ordered/unordered pairs

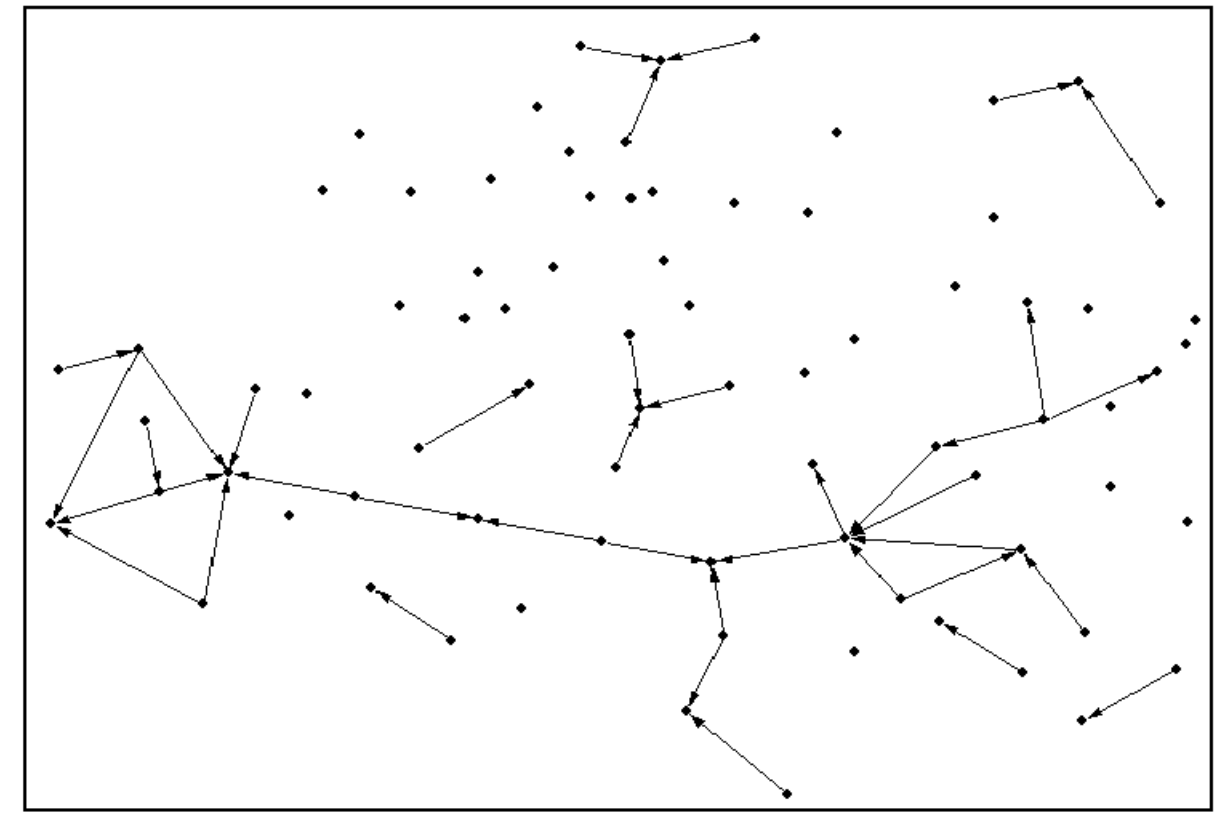


Low Density (25%)
Avg. Dist. = 2.27



High Density (39%)
Avg. Dist. = 1.76

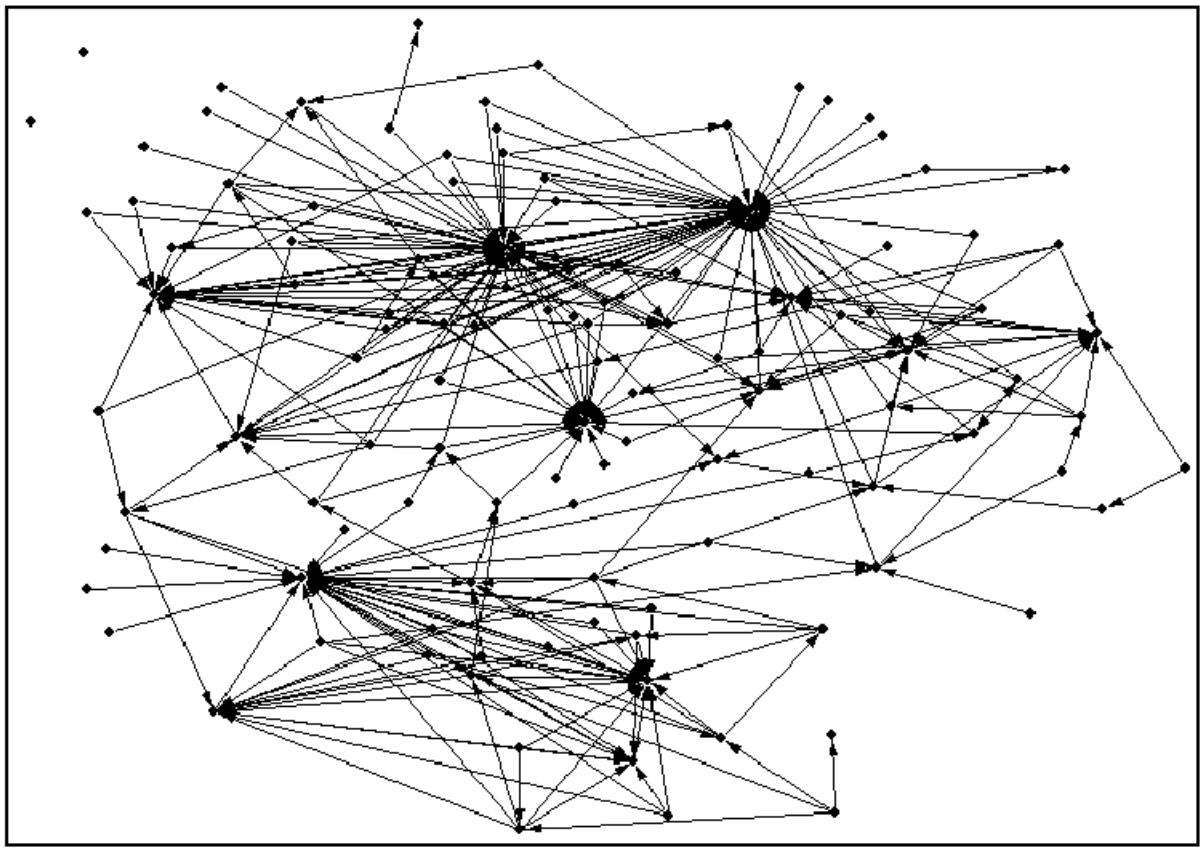
# Help With the Rice Harvest



Village 1

Data from Entwistle et al

# Help With the Rice Harvest



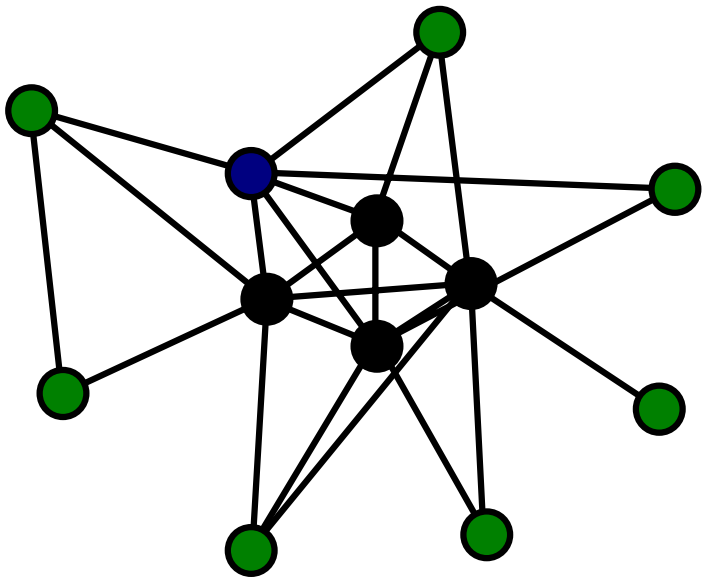
Village 2

Which village is more likely to survive?

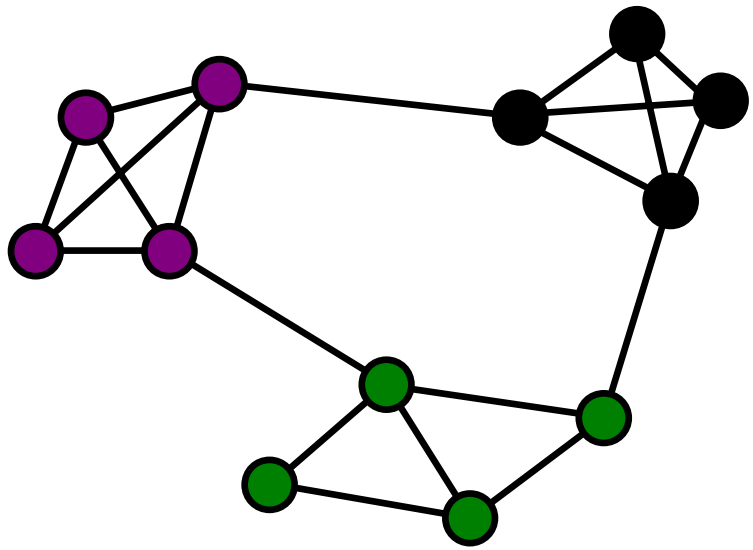
Data from Entwistle et al

# Average Distance

- Average distance between all pairs of nodes



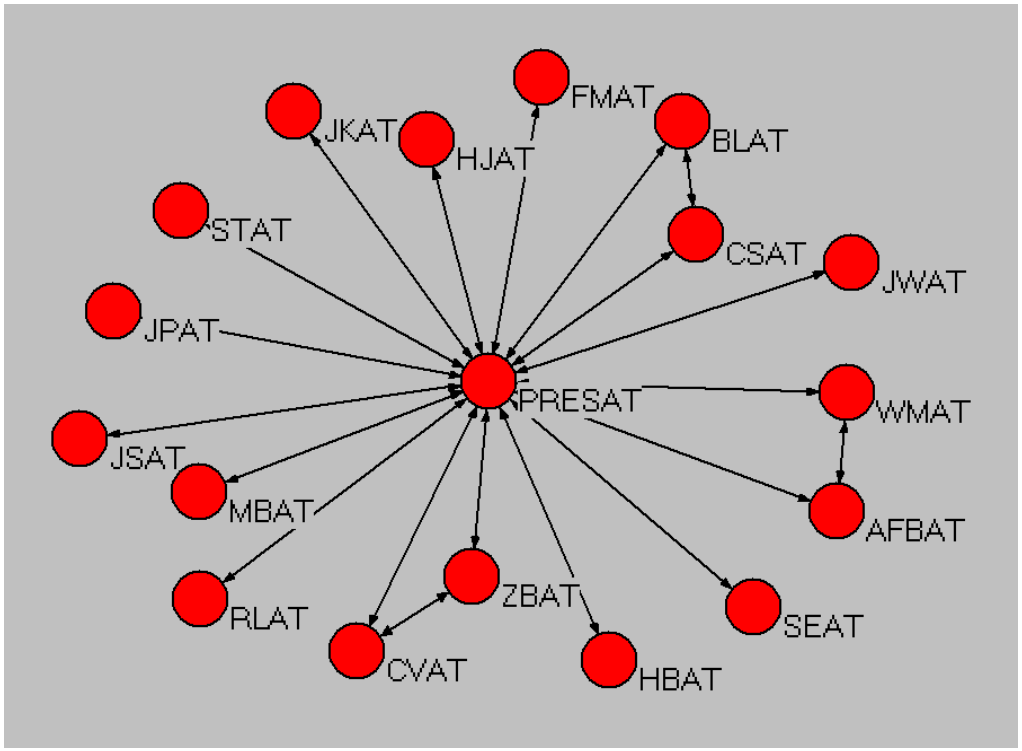
Core/Periphery
c/p fit = 0.97, avg. dist. = 1.9



Clique structure
c/p fit = 0.33, avg. dist. = 2.4

# Centralization

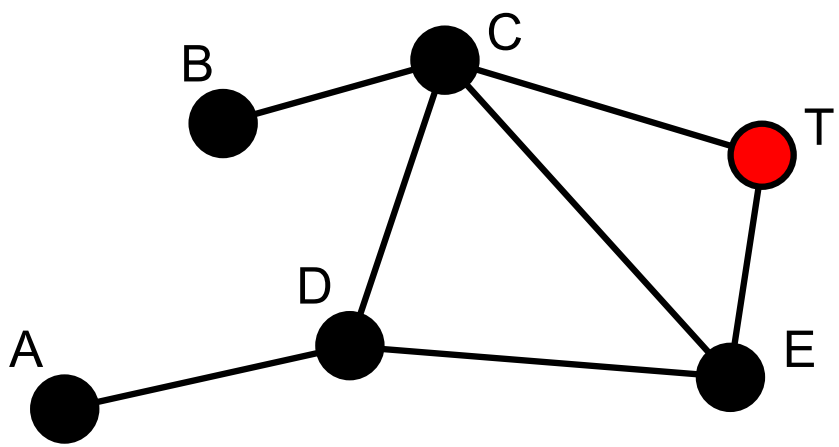
- Degree to which network revolves around a single node




Carter admin.
Year 1

# Transitivity

- Proportion of triples with 3 ties as a proportion of triples with 2 or more ties
  - Aka the clustering coefficient

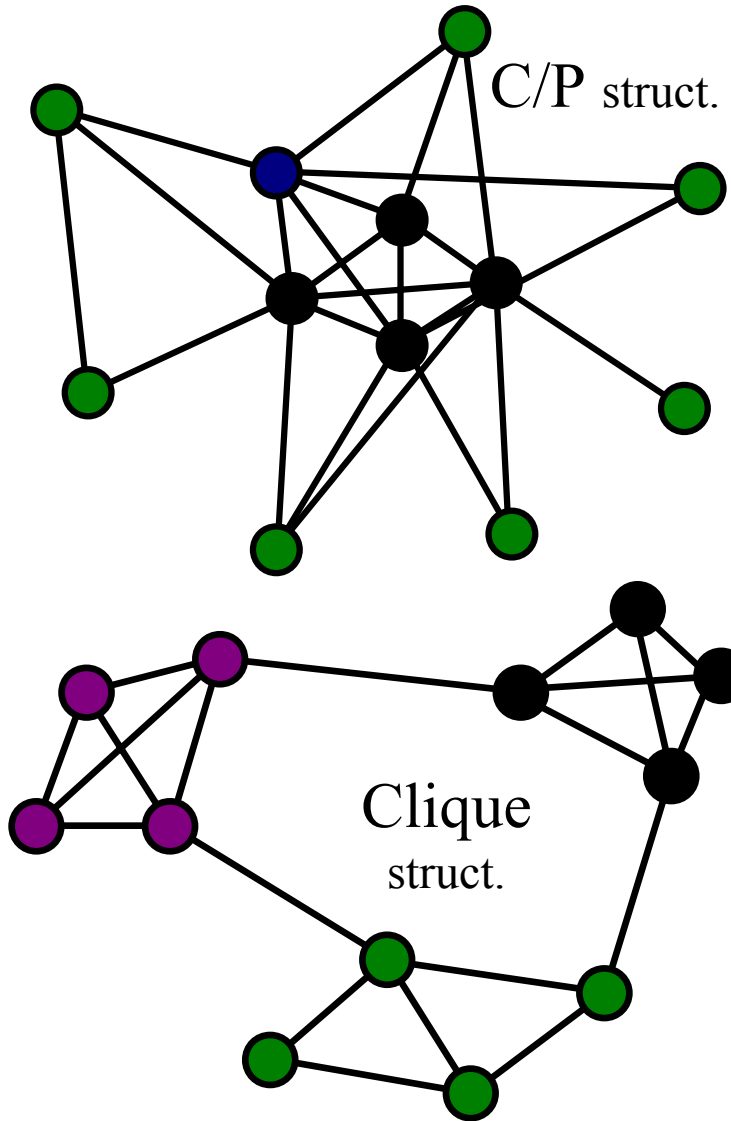



cc = 2/6 = 33%

{C,T,E} is a transitive triple, but {B,C,D} is not

# Core/Periphery Structures

- Does the network consist of a single group (a core) together with hangers-on (a periphery), or
- are there multiple subgroups, each with their own peripheries?



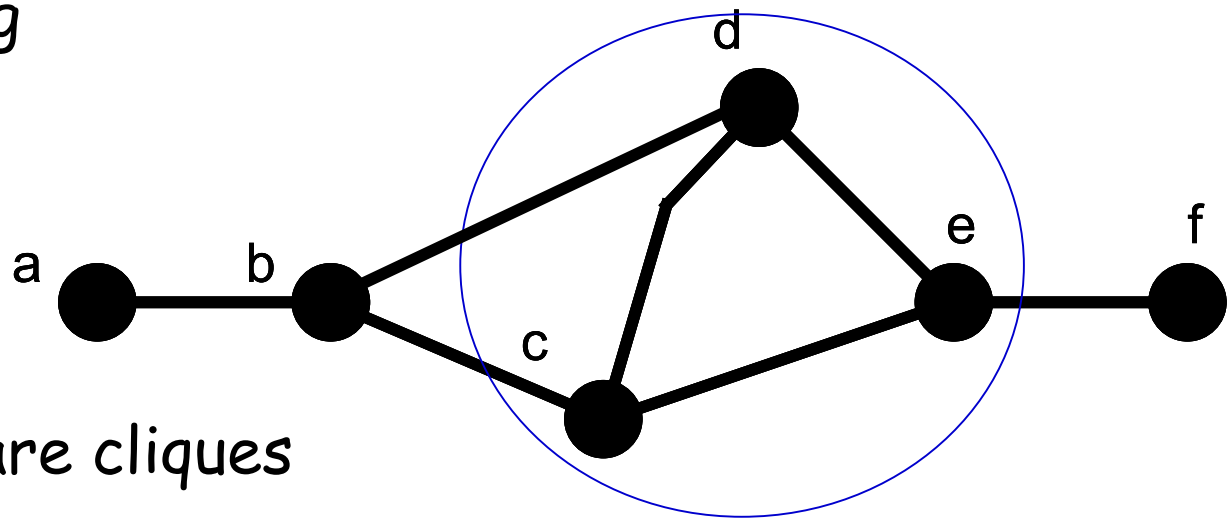
# Subgroup Cohesion

# Graph-Theoretic Concepts

- Structural definitions of groups
  - Clique
  - N-clique, n-clan, n-club
  - K-core, K-plexes
  - Ls-set, Lambda sets
  - Factions

# Clique

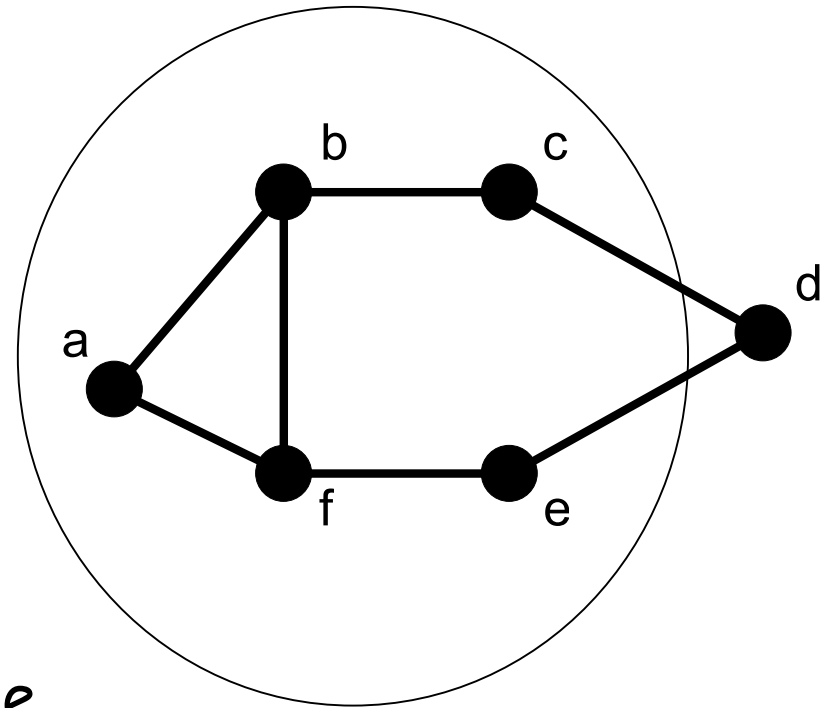
- Maximal set of actors in which every actors is connected to every other
- Properties
  - Maximum density (1.0)
  - Minimum distances (avg = 1)
  - overlapping




{c,d,e} & {b,c,d} are cliques

# N-Clique

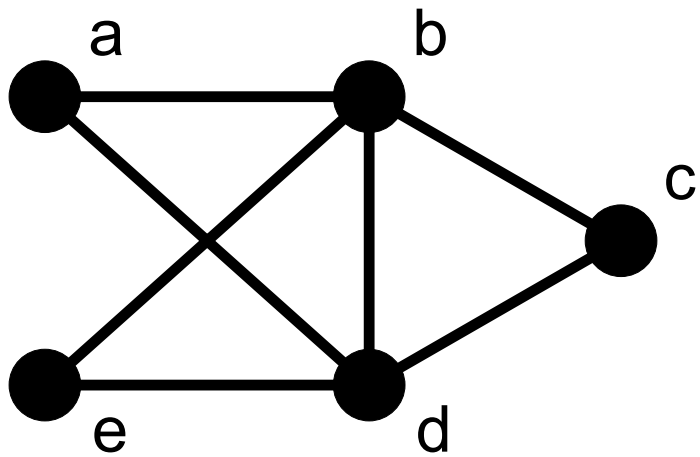
- A set of nodes that are within distance n of each other
- Relaxes distance aspect of clique concept
  - 1-clique is just a clique




{a,b,c,e,f} is a 2-clique

# K-Plex

- A set of n nodes in which every node has a tie to at least n-k others in the set
  - In a 1-plex, every node is connected to all but one others in the set – i.e., is a clique




{a,b,d,e} is a 2-plex: each node tied to 4-2 others in set.

Is {a,b,c,d,e} a 2-plex?

# Factions

- A set of mutually exclusive groups of actors such that density of ties within group is greater than density of ties between groups

| | a | b | c | d | e | f | g |
|---|---|---|---|---|---|---|---|
| a | - | 1 | 1 | 0 | 0 | 1 | 0 |
| b | 1 | - | 1 | 1 | 0 | 0 | 1 |
| c | 0 | 1 | - | 1 | 1 | 0 | 0 |
| d | 1 | 0 | 1 | - | 0 | 0 | 0 |
| e | 0 | 0 | 0 | 0 | - | 1 | 1 |
| f | 0 | 0 | 0 | 0 | 1 | - | 1 |
| g | 0 | 1 | 0 | 0 | 1 | 0 | - |

Density within group: 14/18 = .78
Density between groups: 4/24 = .17

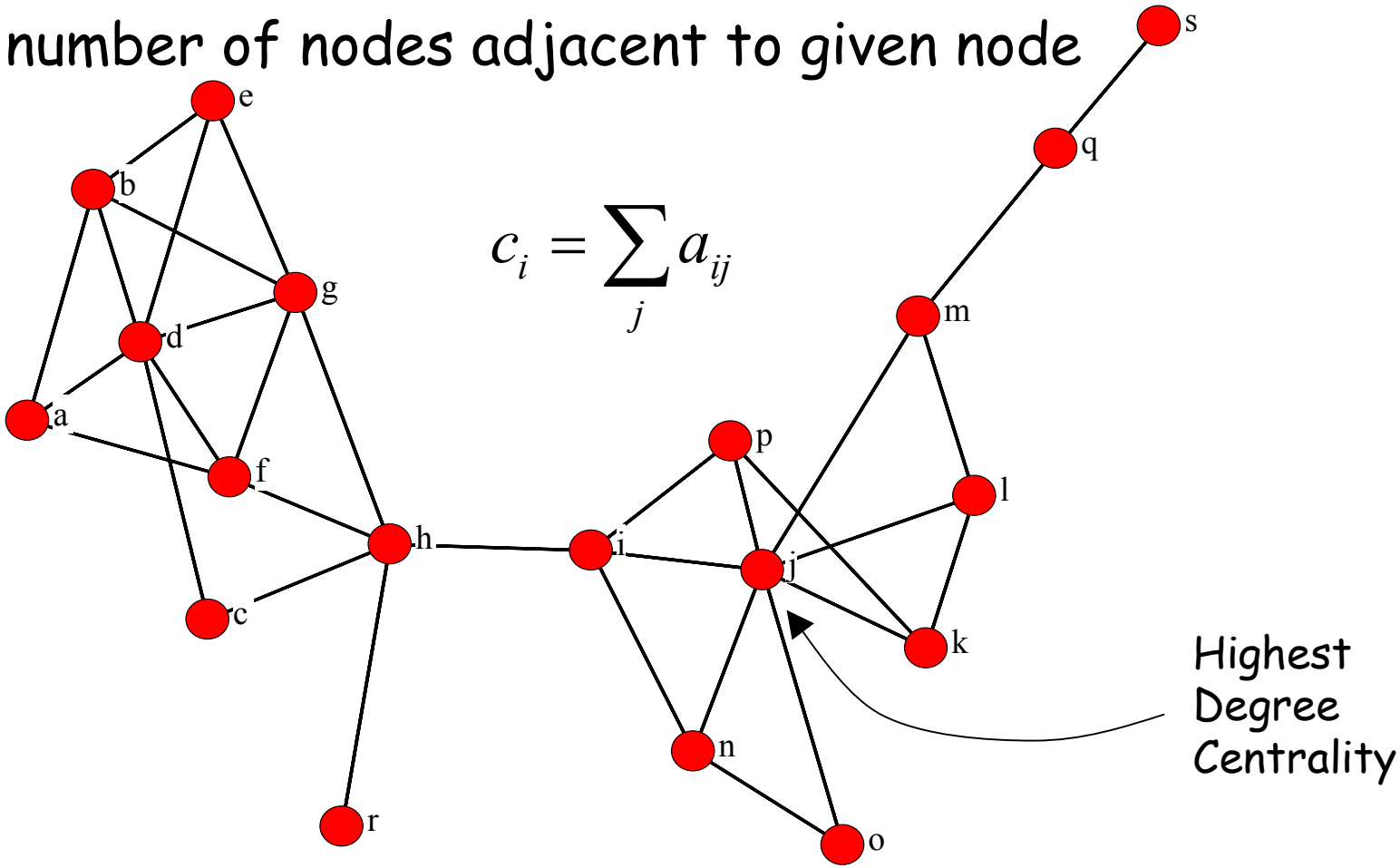
# Individual Cohesion

# Centrality

- Path-based
  - Degree
  - Closeness
  - Betweenness
  - Flow betweenness
  - Redundancy/constraint
- Walk-based
  - Eigenvector
  - Bonacich Power
  - Katz
  - Hubbell

# Degree Centrality

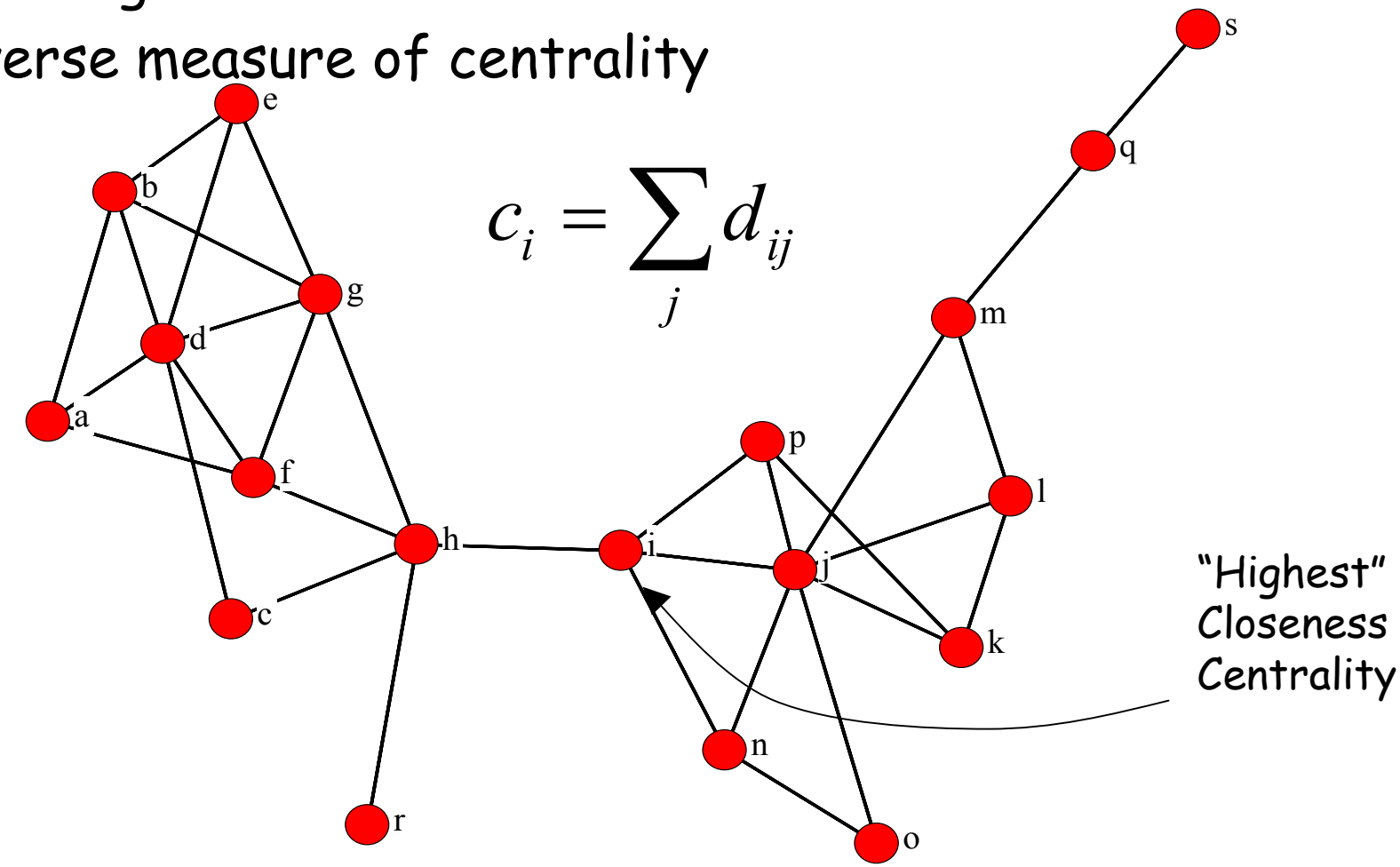
- The number of nodes adjacent to given node



# Closeness Centrality

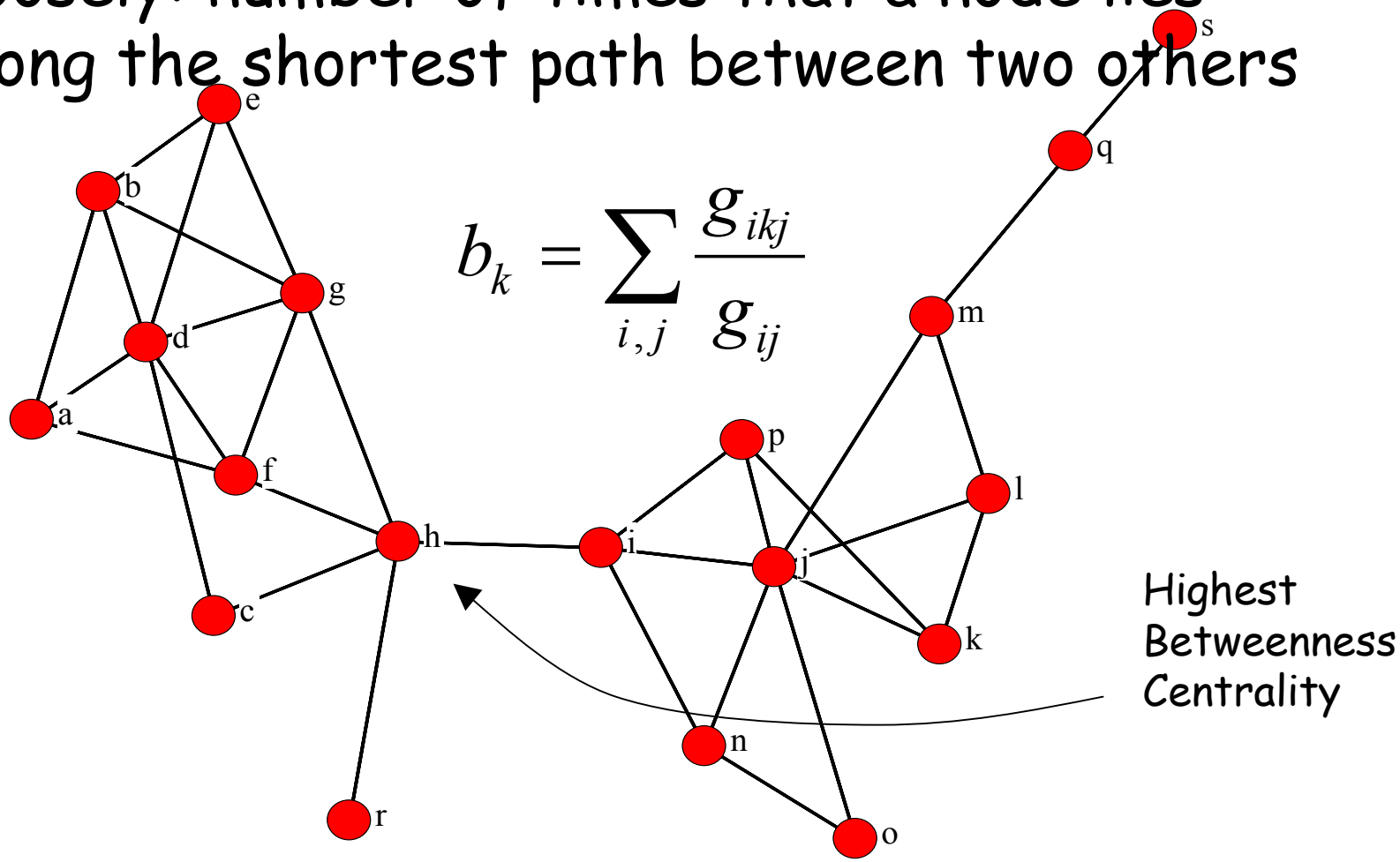
- Sum of geodesic distances to all other nodes
- Inverse measure of centrality

$$c_i = \sum_j d_{ij}$$



# Betweenness Centrality

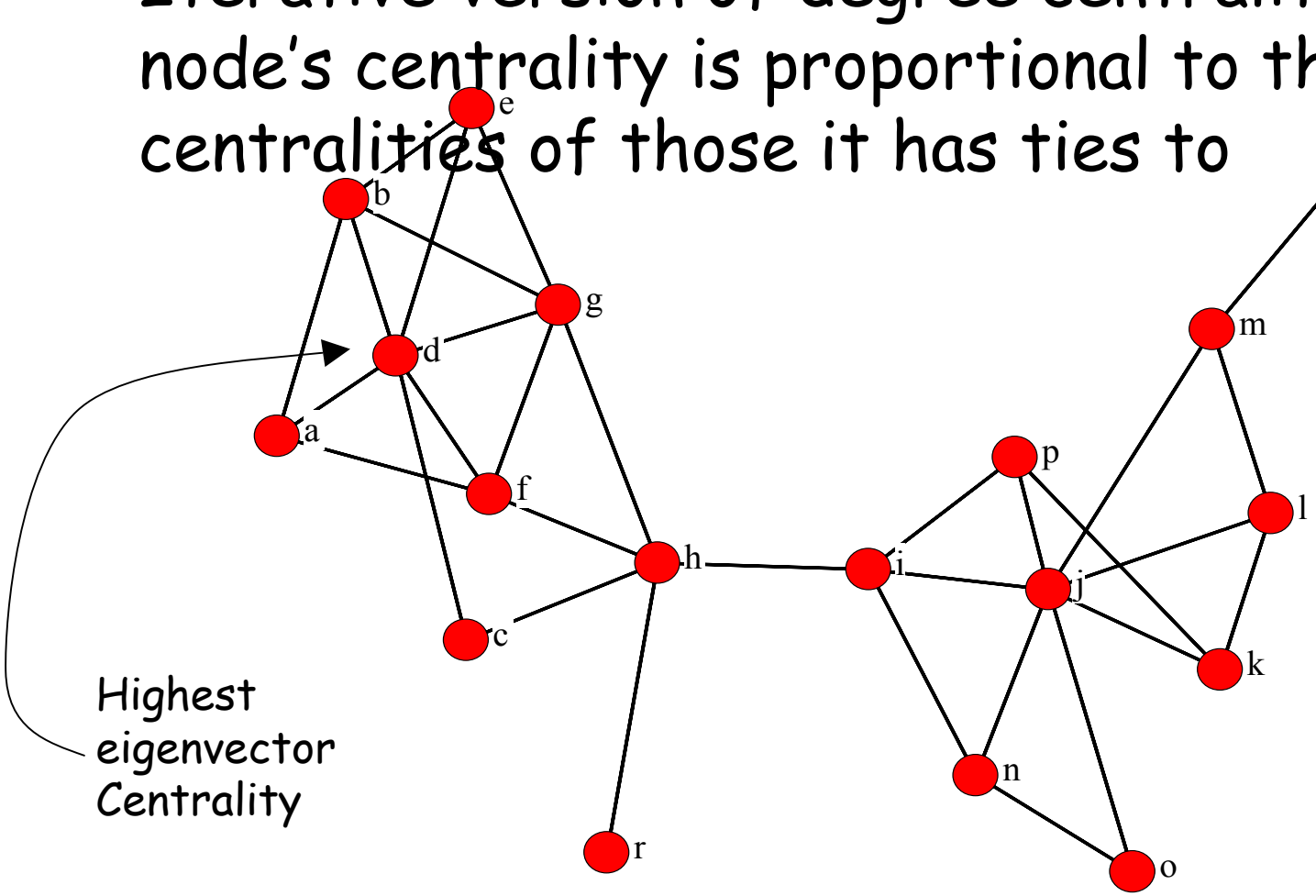
- Loosely: number of times that a node lies along the shortest path between two others




$$b_k = \sum_{i,j} \frac{g_{ikj}}{g_{ij}}$$

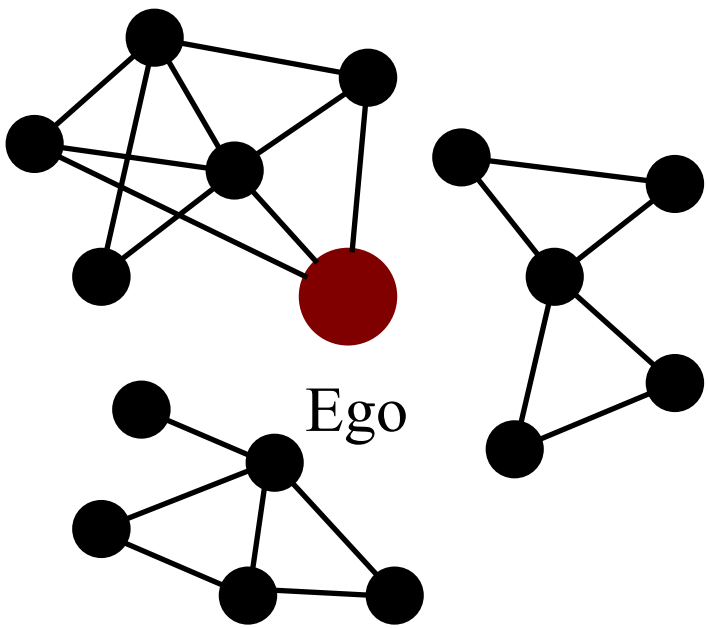
# Eigenvector Centrality

- Iterative version of degree centrality: a node's centrality is proportional to the sum of centralities of those it has ties to

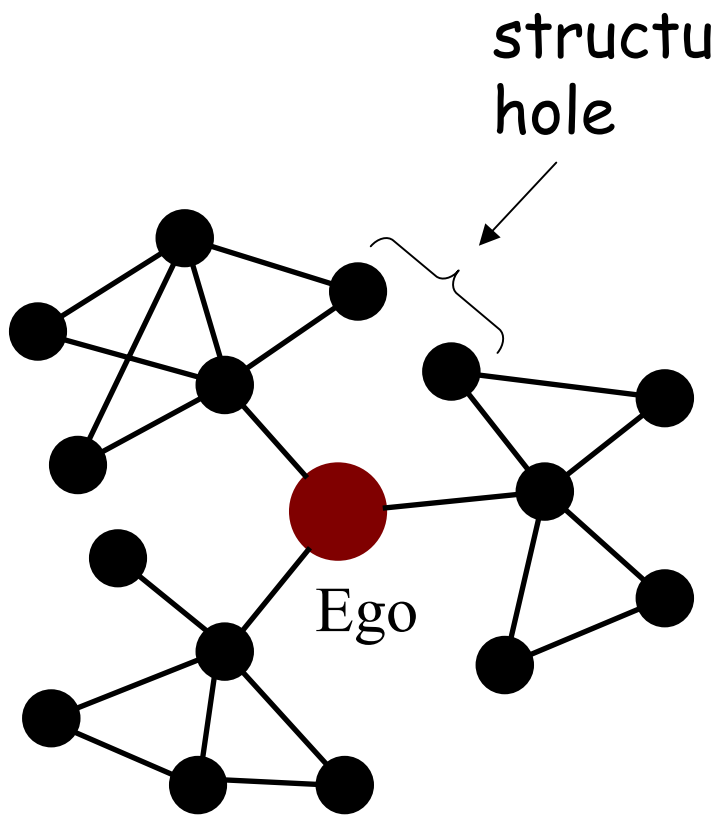


# Structural Holes

- "cheap" betweenness

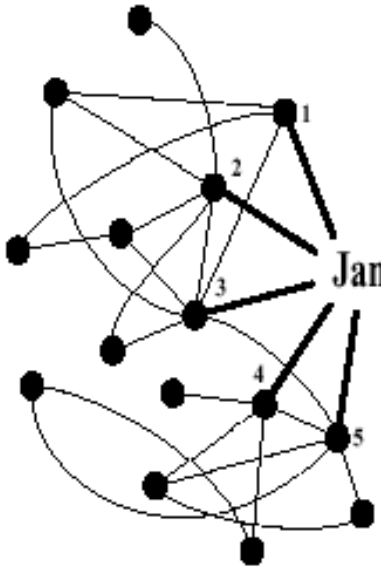



Few structural holes



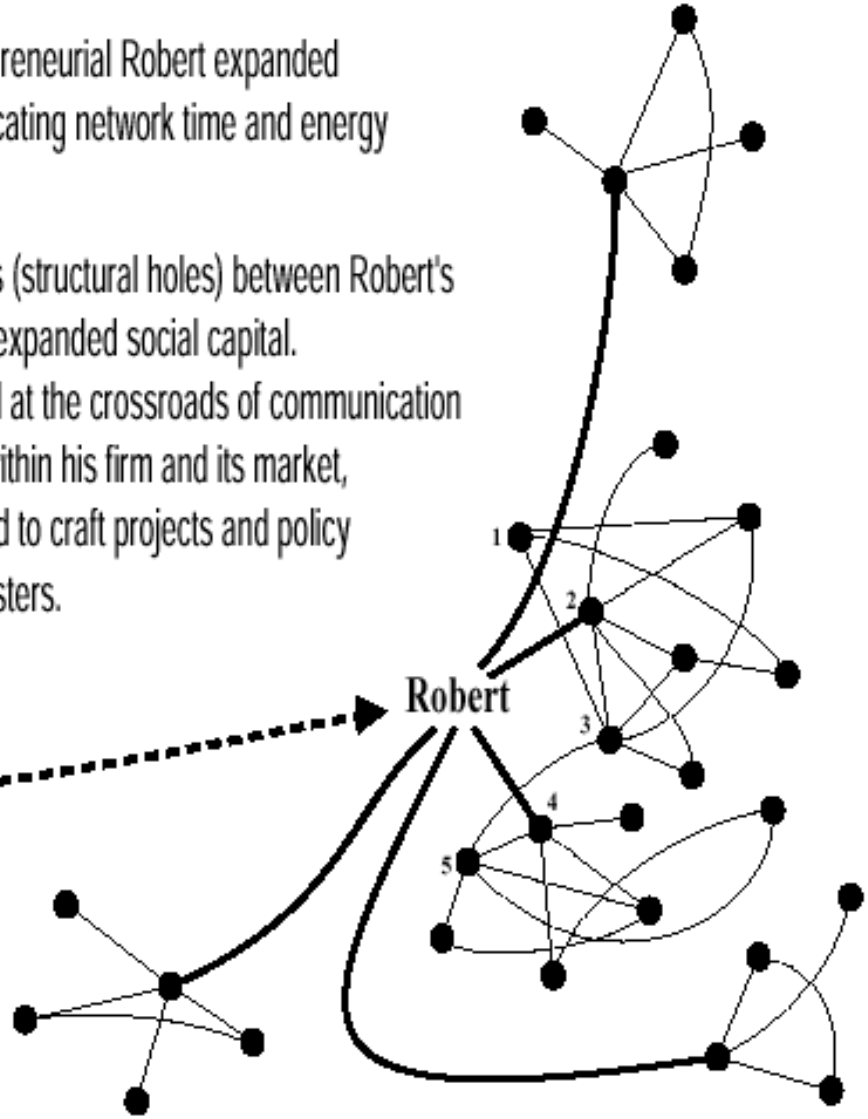

Many structural holes:
- power, info, freedom

# Structural Holes




Robert took over James' job. Entrepreneurial Robert expanded the social capital of the job by reallocating network time and energy to more diverse contacts.

It is the weak connections (structural holes) between Robert's contacts that provide his expanded social capital. Robert is more positioned at the crossroads of communication between social clusters within his firm and its market, and so is better positioned to craft projects and policy that add value across clusters.

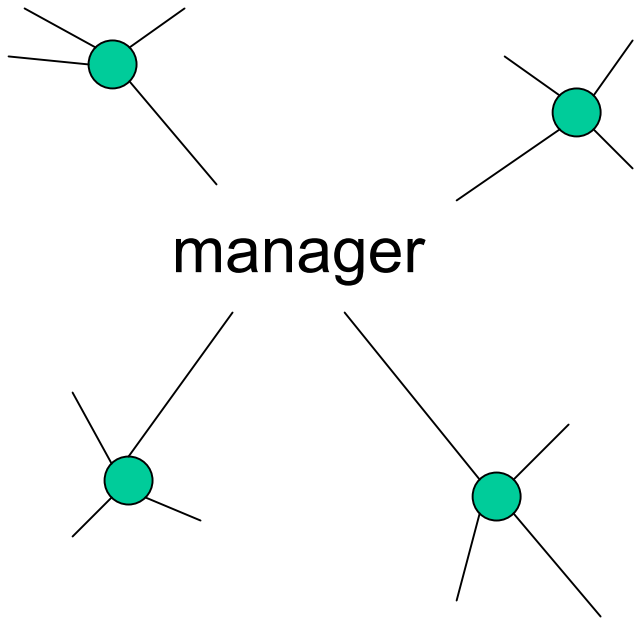



Research shows that people like Robert, better positioned for entrepreneurial opportunity, are the key to integrating across functions and across the people of increasingly diverse backgrounds in today's flatter organizations. In research comparisons between managers like James and Robert, it is the people like Robert who get promoted faster, earn higher compensation, receive better performance evaluations, and perform more successfully on teams.

Slide from Ron Burt

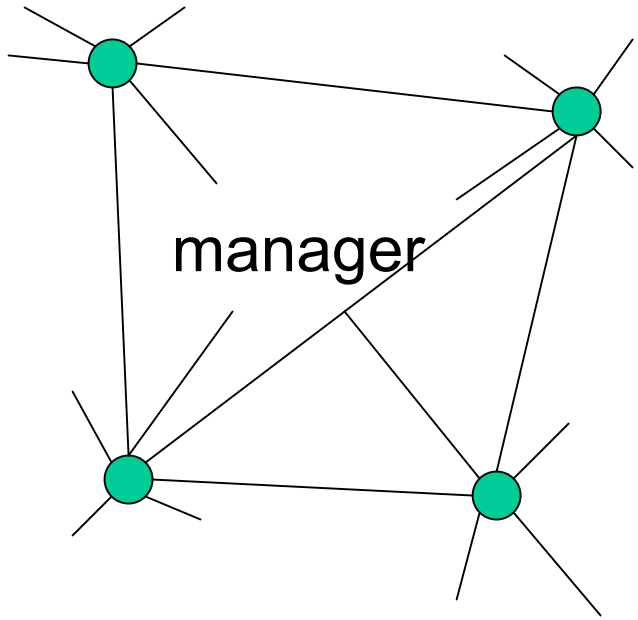
# Entrepreneurial Network

- sparse, flat structure
- independent relations, sustained by manager
- structural holes, low redundancy provides info & control benefits
- associated with successful managers



# Support Network

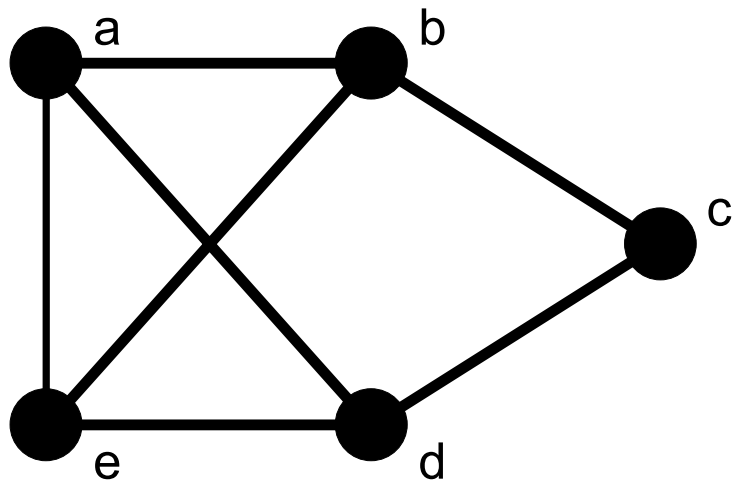
- dense, flat structure
- interdependent relations sustained by each other for manager
- few holes, high redundancy creates social support
- associated with unsuccessful managers



# Structural Similarity

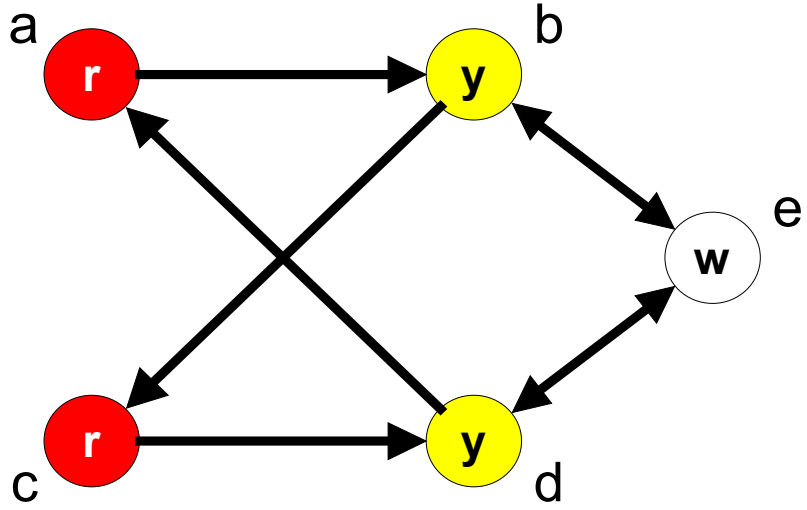
# Network Neighborhoods

- An actor's neighborhood is the set of actors they are connected to
- For directed networks:
  - In-neighborhood
    - Actors sending ties to focal actor
  - Out-neighborhood
    - Set of actors receiving ties from focal actor



# Structural Equivalence

- Actors are structurally equivalent to the extent they have the same in-neighborhoods and out-neighborhoods




Structurally equivalent nodes are colored the same

# Structural Equivalence

- Structurally indistinguishable
  - Same degree, centrality, belong to same number of cliques, etc.
  - Only the label on the node can distinguish it from those equiv to it.
  - Perfectly substitutable: same contacts, resources
- Face the same social environment
  - Similar forces affecting them

# Structural Equivalence

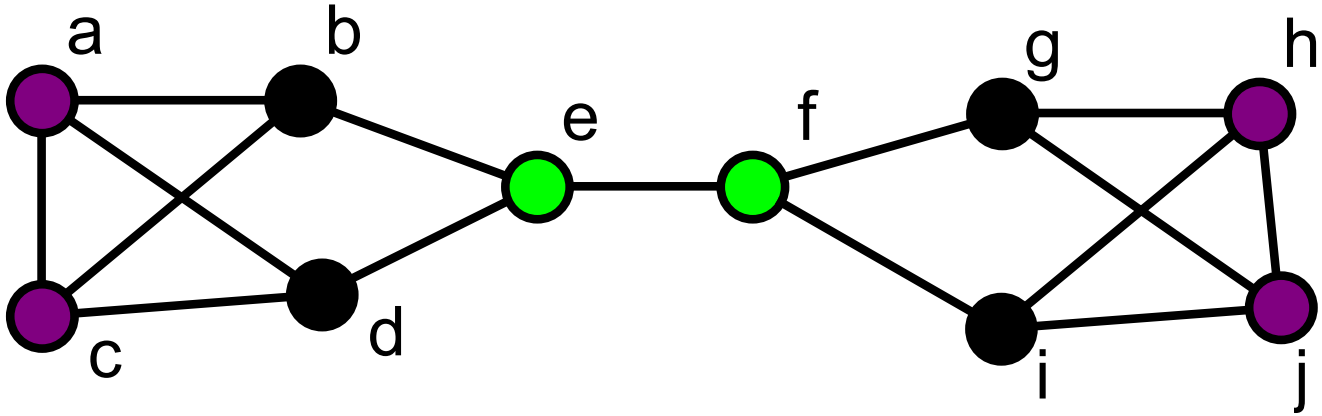
- Captures notions like niche
- Location or position
  - You are your friends

# BlockModeling

| | a | b | c | d | e | f | g | h | i | j |
|---|---|---|---|---|---|---|---|---|---|---|
| a | | | | 1 | 1 | 1 | | | | |
| b | | | | 1 | 1 | 1 | | | | |
| c | | | | 1 | 1 | 1 | | | | |
| d | 1 | 1 | 1 | | | | 1 | 1 | 1 | 1 |
| e | 1 | 1 | 1 | | | | | 1 | 1 | 1 |
| f | 1 | 1 | 1 | | | | 1 | 1 | 1 | 1 |
| g | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| h | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| i | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| j | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

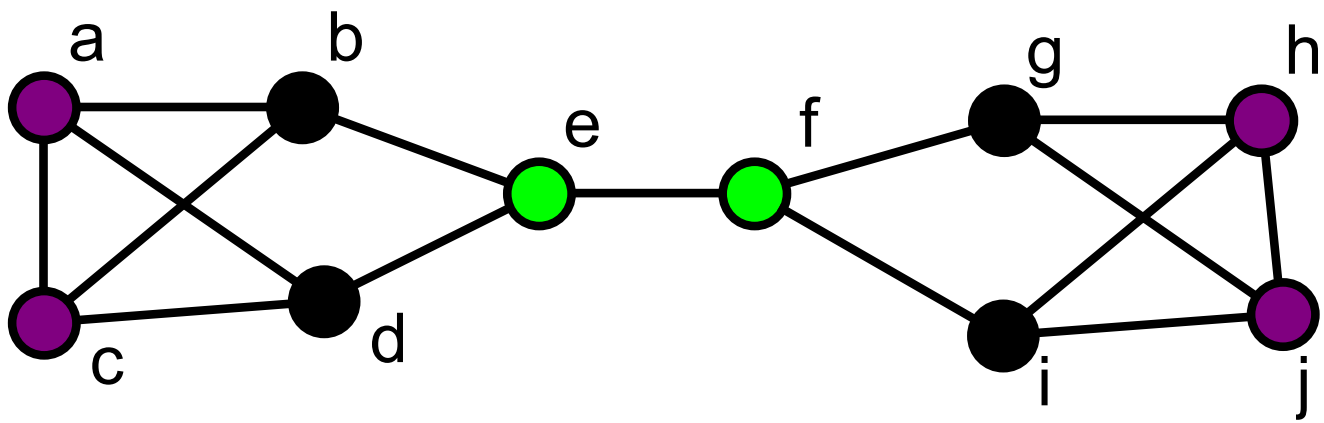
# Regular Equivalence

- B and D are structurally equivalent but what B and G?
  - E on left has mirror-image counterpart F
- Structural equivalence is to equality what regular equivalence is analogy



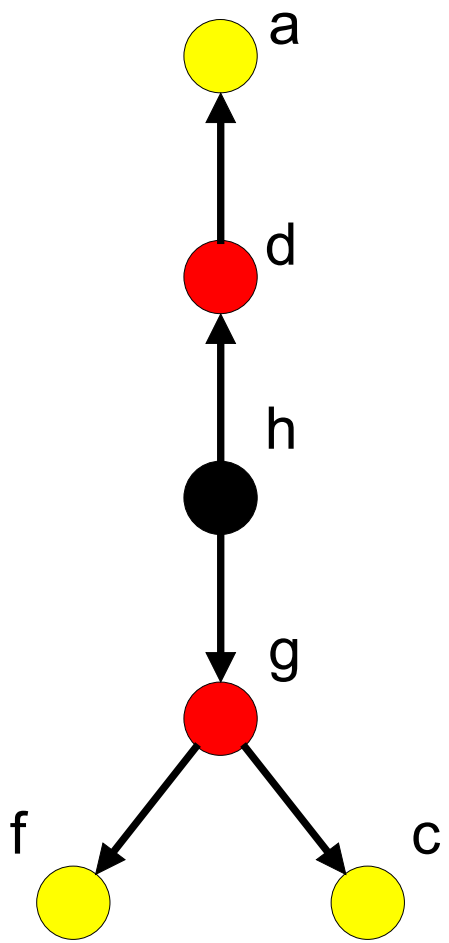
# Regular Equivalence

- Two actors are regularly equivalent if they are connected to equivalent others
  - Not necessarily same others
  - Not necessarily in same quantity



# Technical Definition

- If two actors u and v are regularly equivalent, this implies that
  - For any third party i that u → i, there exists an actor j that v → j and j is regularly equivalent to i
  - For any third party i that i → u, there exists an actor j that j → v and j is regularly equivalent to i



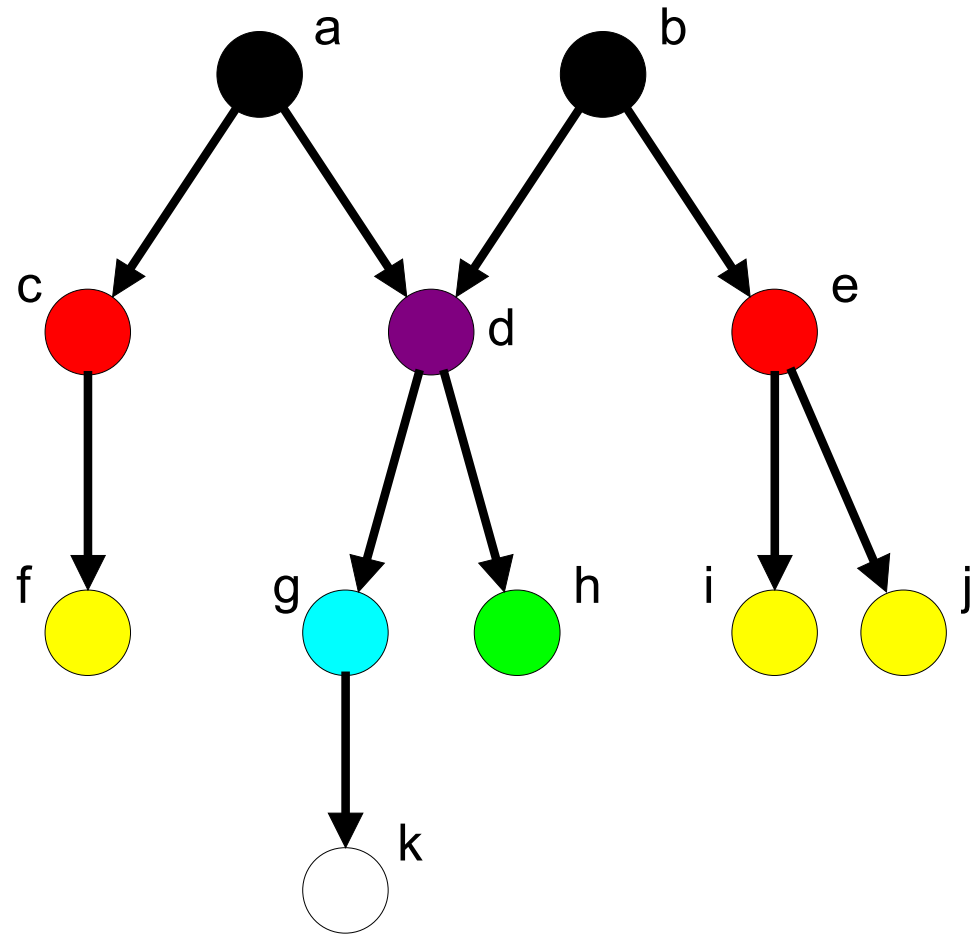
# Regular Equivalence

- Captures notion of role counterpart
  - Two doctors equivalent because they have same kinds of relations with same kinds of others, such giving advice to patients, giving orders to nurses, receiving products from vendors, etc.
  - Works when when roles are emergent – unnamed
- Captures position in hierarchies well

# Blockmodel View

| | a | b | c | d | e | f | g | h | i | j |
|---|---|---|---|---|---|---|---|---|---|---|
| a | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| b | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| c | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| d | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| e | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| f | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| g | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| h | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 |
| i | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 |
| j | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 |

# Hierarchical Position



# Categorizing SN Concepts

| | Whole network | Subsets | Individual actors |
|---|---|---|---|
| Connection | <u>Cohesion</u><br>Density;<br>avg dist;<br>centralization | <u>Groups</u><br>Cliques;<br>n-clique;<br>k-plex | <u>Centrality</u><br>Degree;<br>closeness;<br>betweenness;<br>Struct holes |
| Similarity | | Structural & regular equiv classes | |

# Social Capital

- Group level concept: cohesion
  - pattern of ties among members of a group confers competitive advantage
    - immigrant groups, organizations, countries
- Individual level concept: centrality
  - benefits of being well connected
    - material aid
    - information (broadly defined)
    - fun, companionship, emotional support, love ...

# To Learn More …

- Workshop web site:
  - www.analytictech.com/aomnetwork
- INSNA web site:
  - www.heinz.cmu.edu/project/INSNA
- Contact me via email:
  - borgatts@bc.edu
- Papers on-line:
  - www.analytictech.com/borgatti/paperson.htm