



# Dynamic Network Analysis: Automap/ORA/Dynet

Annual Tools/Computational Approaches/Methods Conference

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*USAF Behavioral Influences Analysis (BIA) Center*

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Center for Computational Analysis of Social and Organizational Systems

[www.casos.cs.cmu.edu/](http://www.casos.cs.cmu.edu/)



# Introduction to CASOS

- Center for Computational Analysis of Social and Organizational Systems (CASOS)
- Carnegie Mellon University, Pittsburgh, PA, USA
- School of Computer Science
- Director: Kathleen M. Carley
- ~30 staff, researchers & Ph.D. students
  
- Interdisciplinary research lab:
  - computer science
  - social network & text analysis
  - organization theory
- Computational & social network techniques combined
  - to develop a better understanding of the fundamental principles of organizing, coordinating, managing and destabilizing systems of intelligent adaptive agents (human and artificial) engaged in real tasks at the team, organizational or social level.*
  
- Overt- & covert-organization research for government sponsors
- Network analysis & simulation tools
- Annual summer institute





# Goal

## *Develop a basic understanding of Dynamic Network Analysis (DNA):*

- Its Worldview
- What it can be used for
- Basic terminology and measures
- Analysis and interpretation
- Available software tools



# Gameplan

## *Part I:*

- Introduction to various concepts of DNA & CASOS tools

## *Part II:*

- Operationalize the techniques using CASOS tools:  
Raw data to simulation



# Worldview



# Worldview

- It's not about the demographics, it's about the relationships!
- Relationships can be represented as a network, therefore we can quantify them!
- Since we can quantify relationships, we can measure, analyze, manage and simulate!
- Social Network Analysis (SNA) is about:
  - person-to-person networks
  - Single network
  - Static
  - Individual relation exists or not
  - Ideas since 1930's/1960's
- Dynamic Network Analysis (DNA) is about:
  - Entity-to-entity relationships
  - Multiple networks
  - Changing
  - Individual relation can be probabilistic
  - Ideas since 2000's



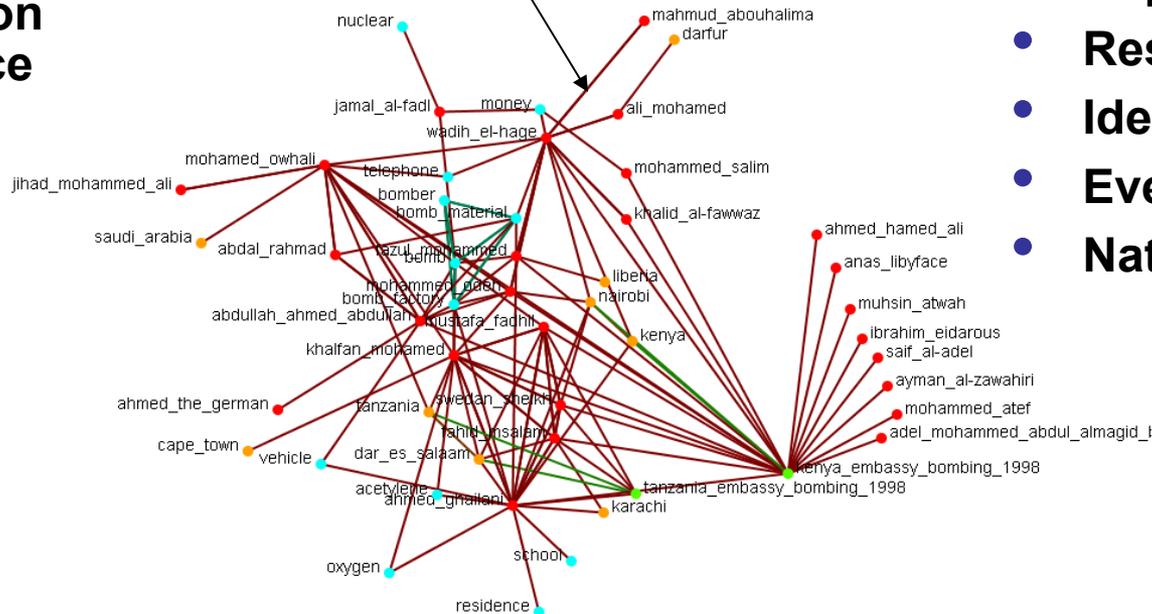
# What is a network?

## Ties Between Nodes (links)

- Who do you like or respect?
- Transfer of resources
- Authority lines
- Association or affiliation
- Alliance
- Substitution
- Precedence
- Proximity

## Nodes

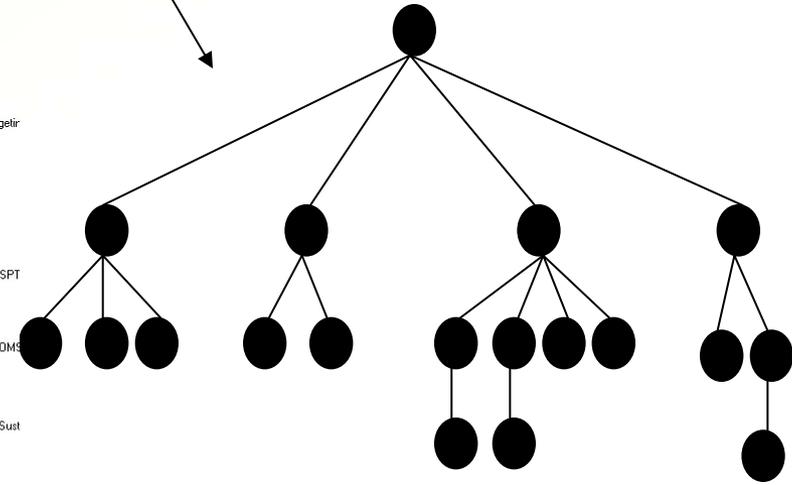
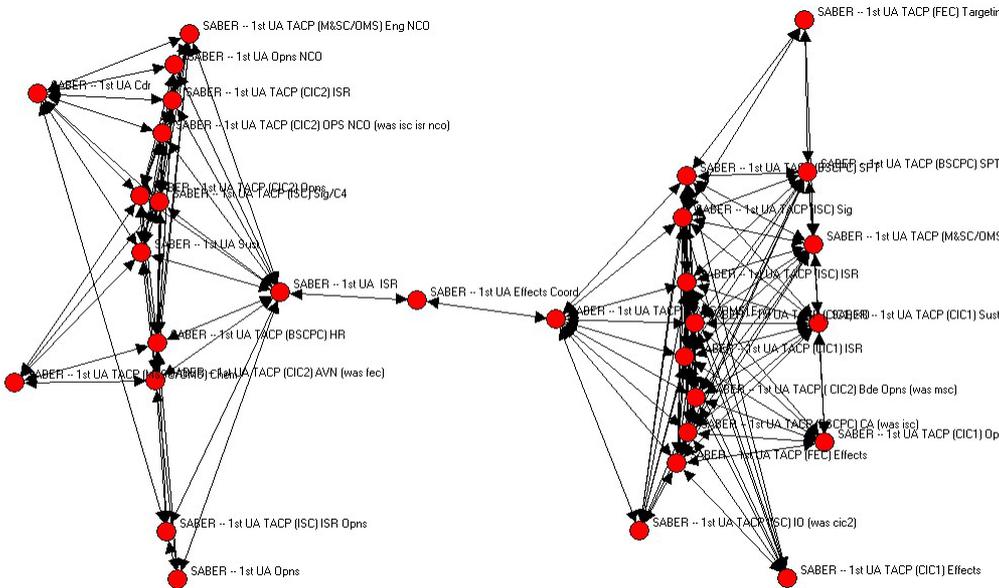
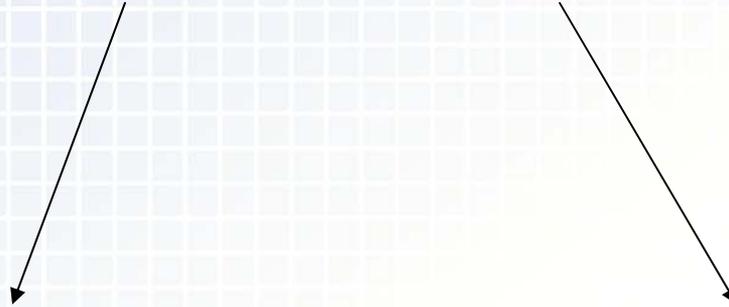
- People
- Units of action
- Coalition partners
- Departments
- Resources
- Ideas or Skills
- Events
- Nation-states



**Networks are ubiquitous**



# Informal and Formal Structure



*Each person is embedded in many networks*



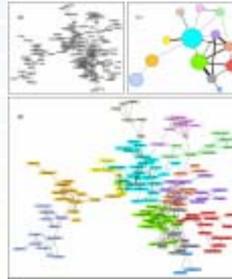


# Illustrative Networks

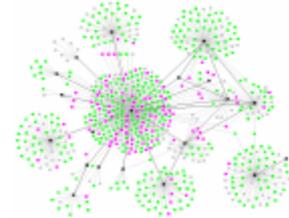
High School Dating



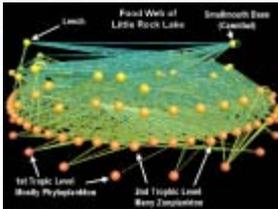
Physicist Collaborations



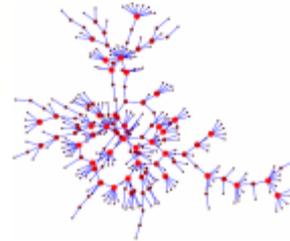
Contagion of TB



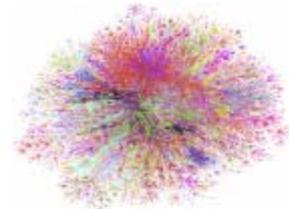
Fresh Water Food Web



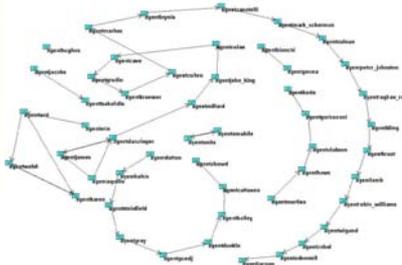
Sexual Contacts



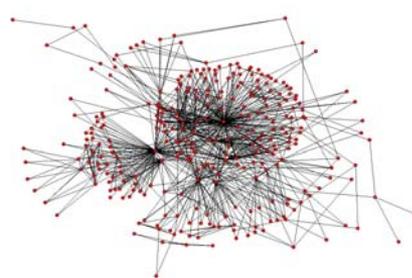
The Internet



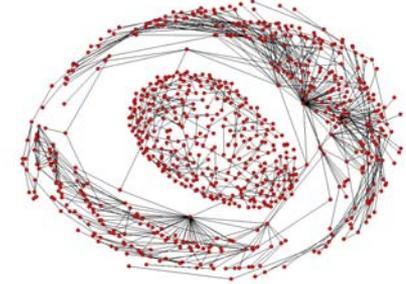
Topic Network (Email)



Email Profile

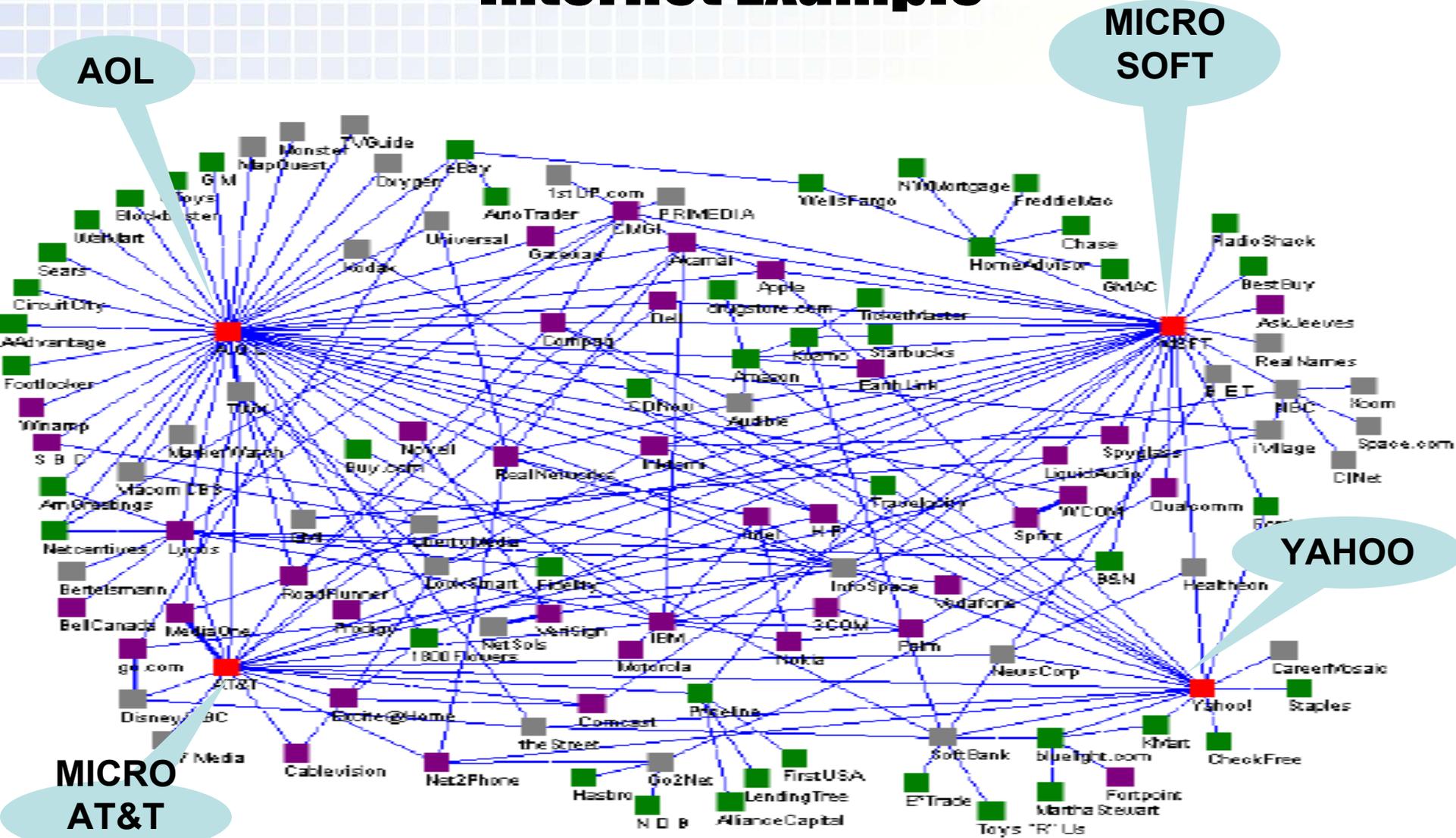


al Qaida 2004



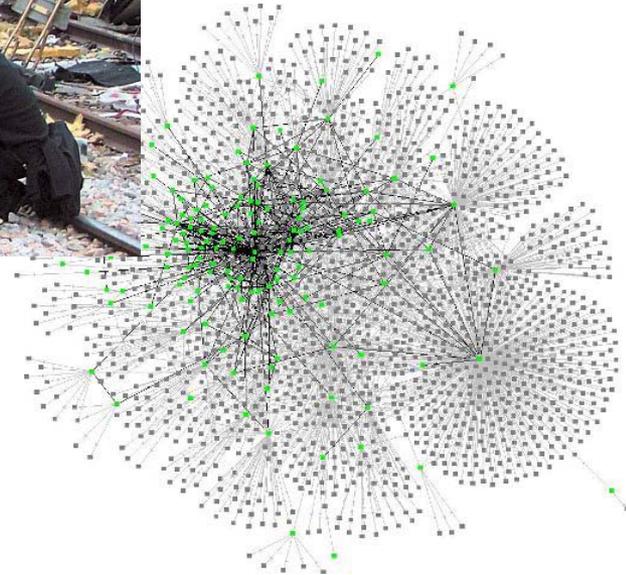
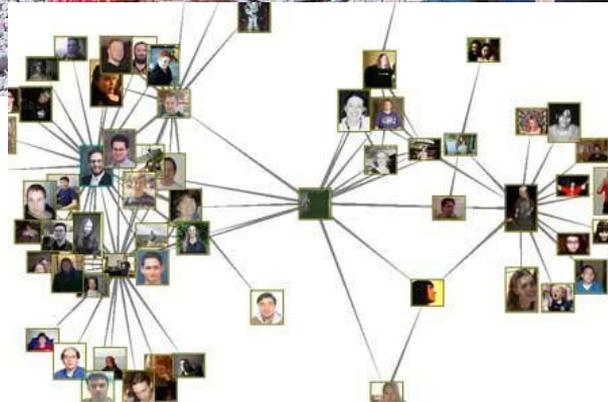
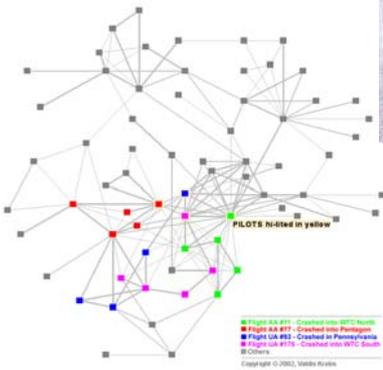
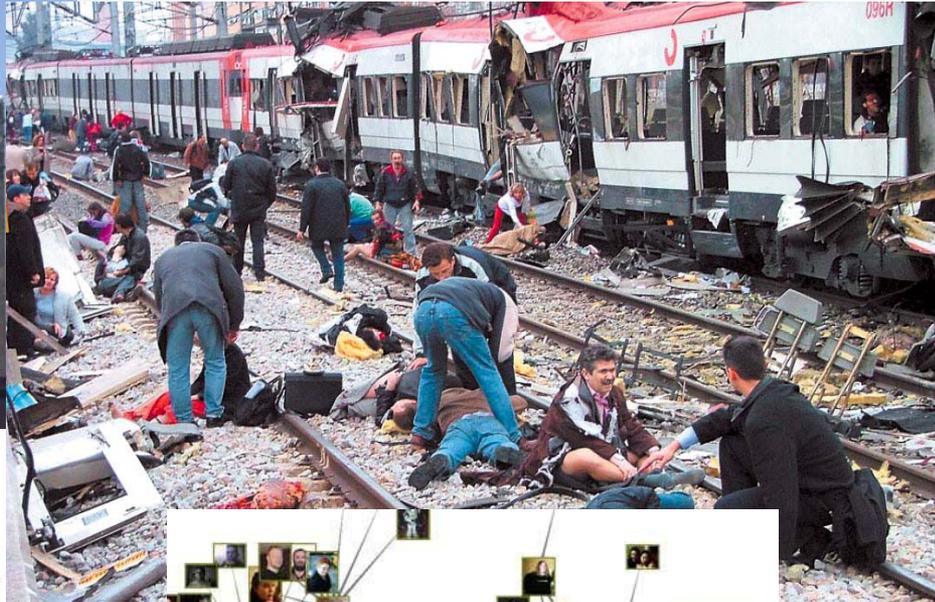


# Internet Example





# Why are these networks Important?





# Dynamic Network Analysis in Practice

Commander's Choice (in the news)      Model Choice

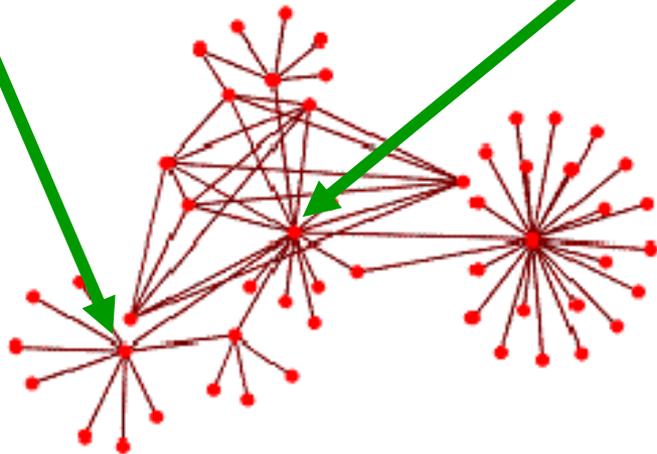


Figure 1: Notional: Terrorist network before isolation of critical actor. Fragmentation: 0 – This is a single unified organization. Diffusion: 0.93 – Messages and resources passed from actor to actor can move quickly.

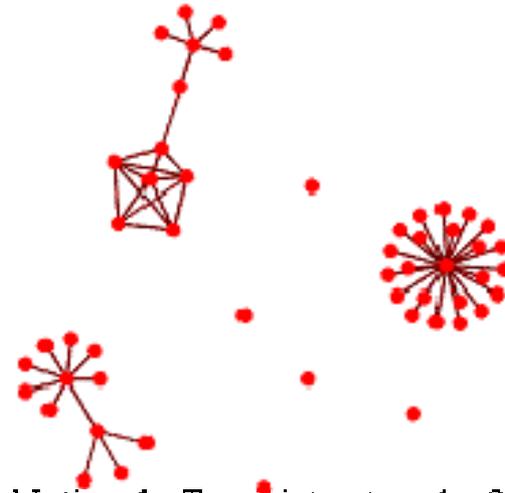
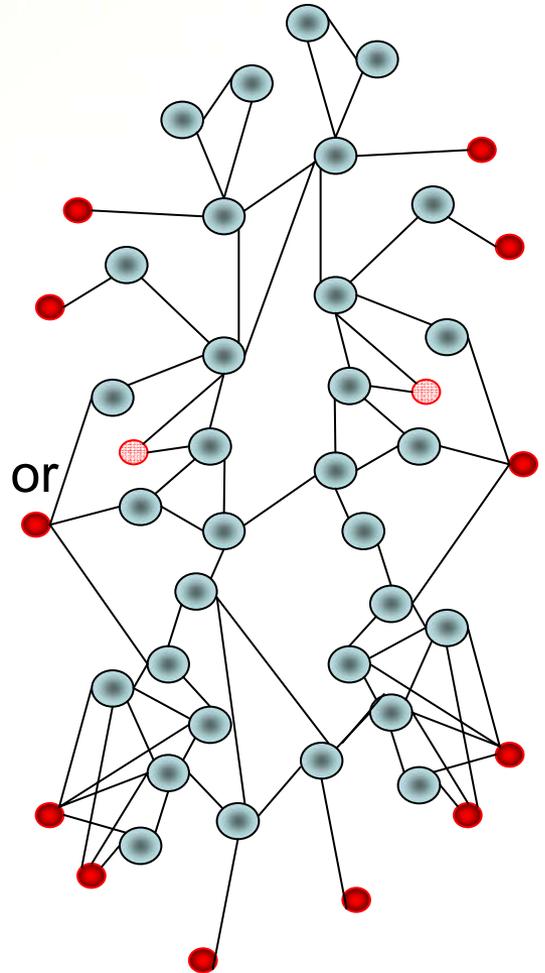


Figure 2: Notional: Terrorist network after isolation of critical actor. Fragmentation: 0.71 – Now there are many isolated sub-groups. Diffusion: 0.26 – Messages or resources are passed from actor move slower.



# Analyst Questions

- Who to target (vulnerabilities)
  - What groups or individuals stand out
- How to influence
  - Are there important connections
- What is the “health” of the organization
- Where might there be missing data
- How different are two groups – or two sources – or the same group at two different times
- What is the immediate effect of an intervention
  - On Diffusion, Performance, Leadership
- What is the near term effect
  - Can the network heal?
  - Who might step in?





# Connect & *Dis-Connect* the Dots!

	Degree	Betweenness	Closeness
1	0.417 Mohamed Atta	0.334 Nawaf Alhazm	0.571 Mohamed Atta
2	0.389 Marwan Al-Shehhi	0.318 Mohamed Atta	0.537 Nawaf Alhazmi
3	0.278 Hani Hanjour	0.227 Hani Hanjour	0.507 Hani Hanjour
4	0.278 Nawaf Alhazmi	0.158 Marwan Al-Shehhi	0.500 Marwan Al-Shehhi

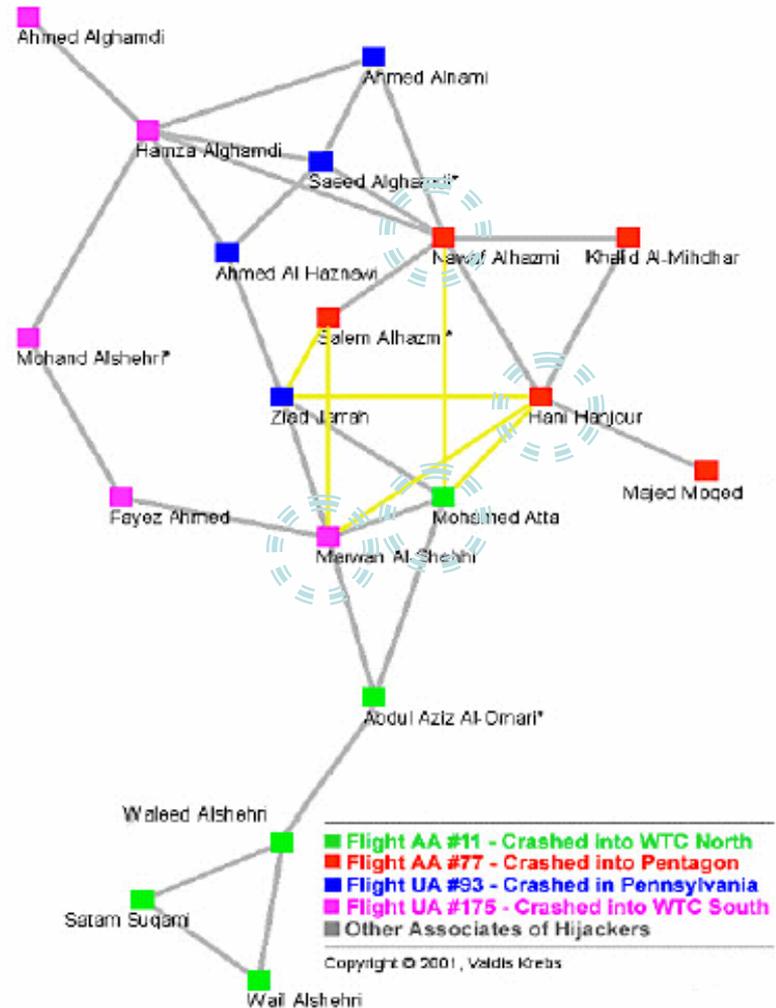


Figure 3 Trusted Prior Contacts + Meeting Ties [shortcuts]

## Standard Social Network Measures



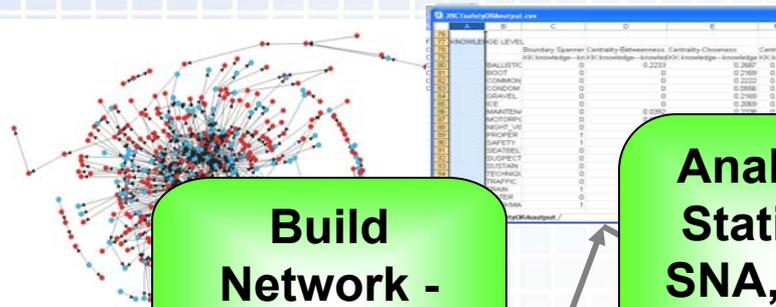


# So – why is this hard?

- The Network
  - Vast quantities of data
  - Multi-mode – people, events, etc.
  - Multi-plex – many connections e.g. financial and authority
- The Information
  - Intentional misinformation – e.g., aliases
  - Inaccurate information – e.g., typos
  - Out-of-date information
  - Incomplete information
- Dynamic
  - Learning
  - Recruitment
  - Attrition
  - ...



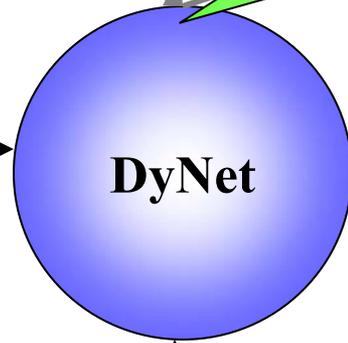
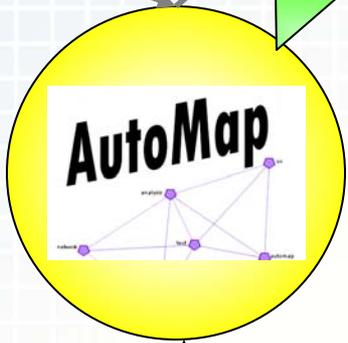
Texts



Build Network - Text Mining

Analyze - Statistics SNA, DNA, Link Analysis

Assess Change, What if Analysis - Multi-agent DNA



**Meta-Network**

Entity	Category	Role	Location	Time	Source	Target	Weight	Score
Entity 1	Category 1	Role 1	Location 1	Time 1	Source 1	Target 1	Weight 1	Score 1
Entity 2	Category 2	Role 2	Location 2	Time 2	Source 2	Target 2	Weight 2	Score 2

**DyNetML**

Unified Database(s)



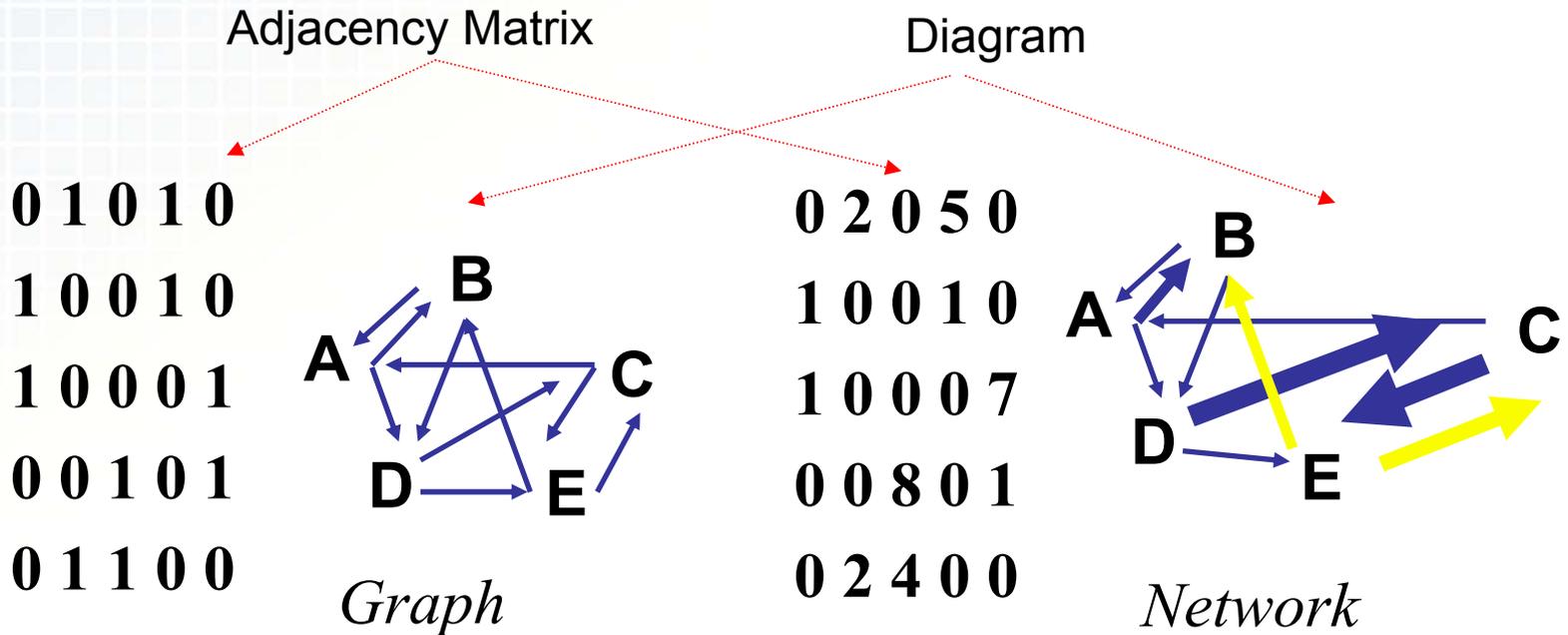


# Basic terminology and measures



# Network Analysis

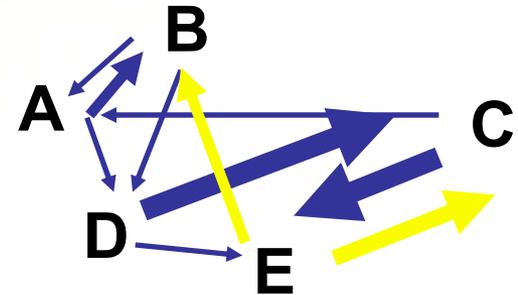
- Derives from graph theory
- Set of measures on graphs or networks
- Graph - binary matrix
- Network - weighted matrix





# Key Graph Theoretic Concepts

- Directed –versus- undirected
  - Directed – commands
  - Undirected – works with
- Strength
  - Frequency of interaction
  - Distance
- Adjacency
  - Equivalent matrix
- Walk; length
  - Unrestricted; number of ties
- Path
  - Do not repeat a node
- Trail
  - Do not repeat a tie
- Distance
  - Shortest path (geodesic)



0 2 0 5 0

1 0 0 1 0

1 0 0 0 7

0 0 8 0 1

0 2 4 0 0



# Terminology

- Degree – total number of edges/ nodes ego is connected to
- In Degree – total number of nodes that send edge to ego
- Out Degree – total number of nodes that receive edge from ego

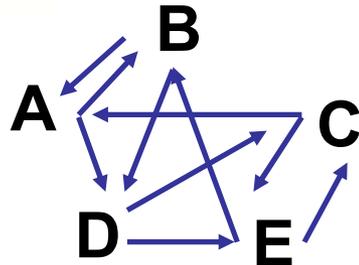
0 1 0 1 0

1 0 0 1 0

1 0 0 0 1

0 0 1 0 1

0 1 1 0 0



N In Out Total

A 2 2 4

B 2 2 4

C 2 2 4

D 2 2 4

E 2 2 4



# Network Measures – Analysis Levels

- Network (complete graph) level
  - E.g., density
  - Is it easier to disrupt a cellular or hierarchical structure?
  - Use: Characterizing topology, comparing groups, high level change
- Dyadic level
  - E.g., frequency
  - Is there are pattern that money launderers follow?
  - Use: Locating trails
- Node level
  - E.g., centralities
  - Who has the power?
  - Use: Identifying key actors, events, resources ...



# Simple SNA Measures

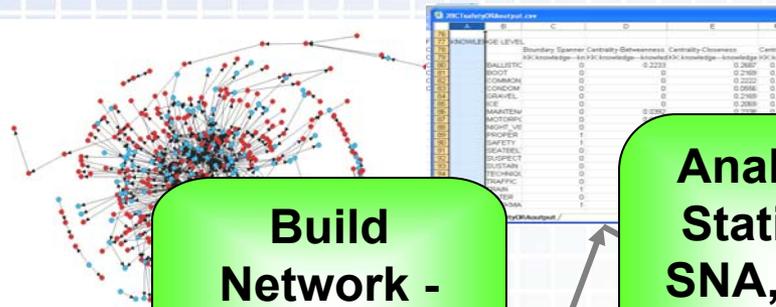
Measure	Definition	Meaning	Usage
Degree Centrality	Node with the most connections	In the know	Identifying sources for intel; Reducing information flow
Betweenness	Node in the most best paths Needs symmetric data	Connects groups	Typically has political influence, but may be too constrained to act
Eigenvector centrality	Node most connected to other highly connected nodes	Strong social capital	Identifying those who can mobilize others
Closeness	Node that is closest to all other nodes	Rapid access to all information	Identifying sources to acquire/transmit information
Betweenness - Centrality	High in betweenness but not degree centrality	Connects disconnected groups	Go-between; Reduction in activity by disconnecting groups



# Analysis and Interpretation



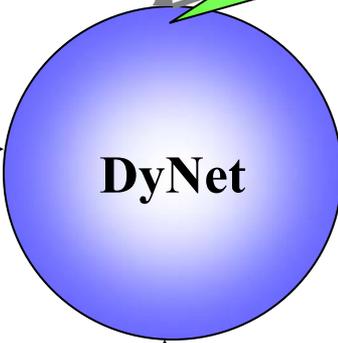
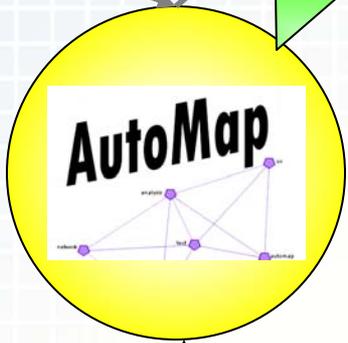
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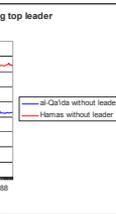


Meta-Network

Node ID	Node Name	Node Type	Node Role	Node Status	Node Location	Node Contact	Node Description	Node Notes
1	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...
6	...	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...	...
10	...	...	...	...	...	...	...	...

DyNetML

Unified Database(s)

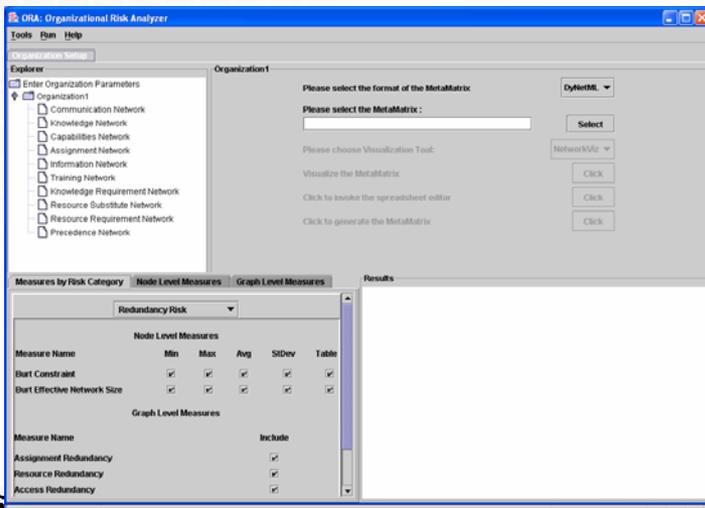




# ORA: From networks to information



ORA: a DNA statistical analysis tool for locating patterns and identifying vulnerabilities



- Organized by function not measure
  - E.g., Intelligence Report
  - Management Report
- Import/Export tools
- Linkage to mysql
- Visualization components
- Batch, web, thick-client
- Can handle large  $10^6$  networks quickly



# Critical Actors

## What Nodes Matter?

Degree & Eigenvector	Betweenness	Closeness
0.417 Mohamed Atta	0.334 Nawaf Alhazm	0.571 Mohamed Atta
In the know power	Connects groups	Rapid access

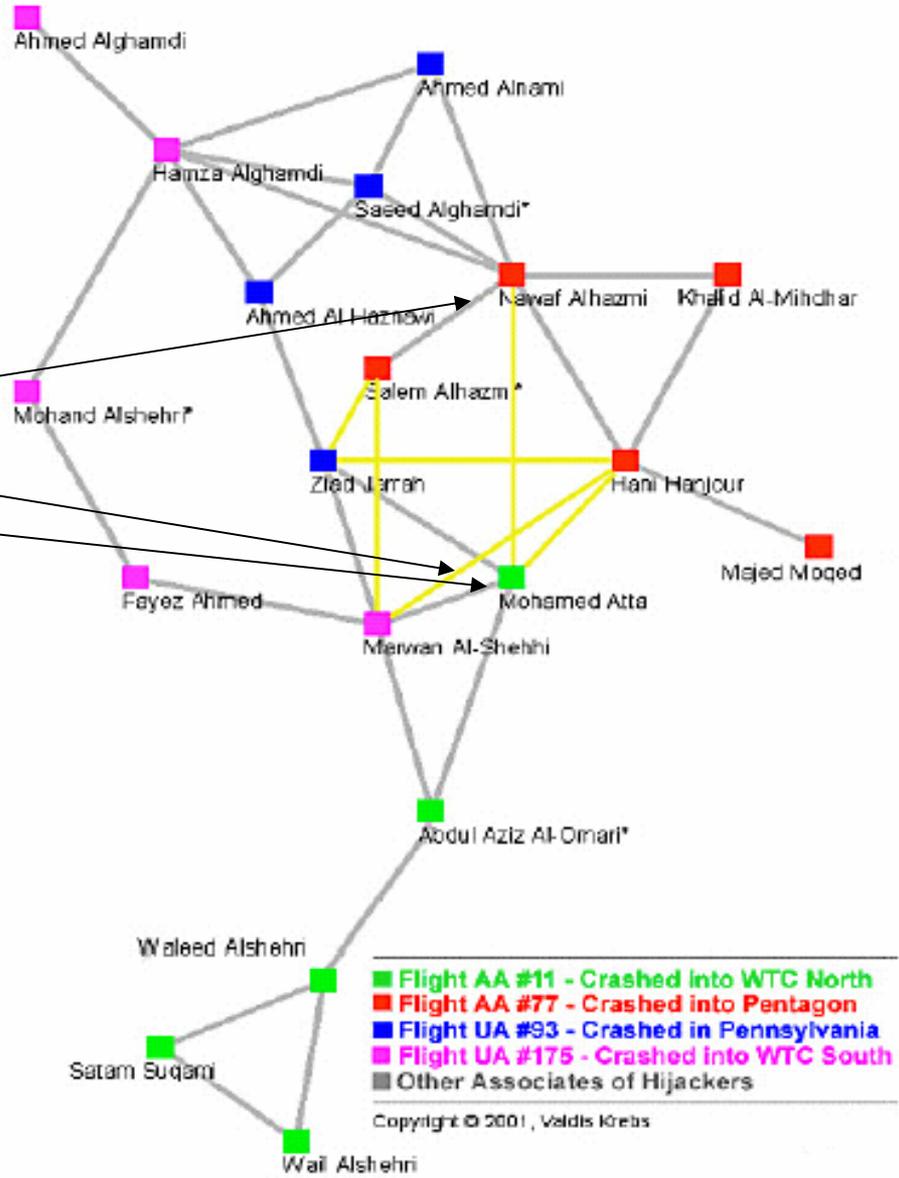


Figure 3 Trusted Prior Contacts + Meeting Ties [shortcuts]

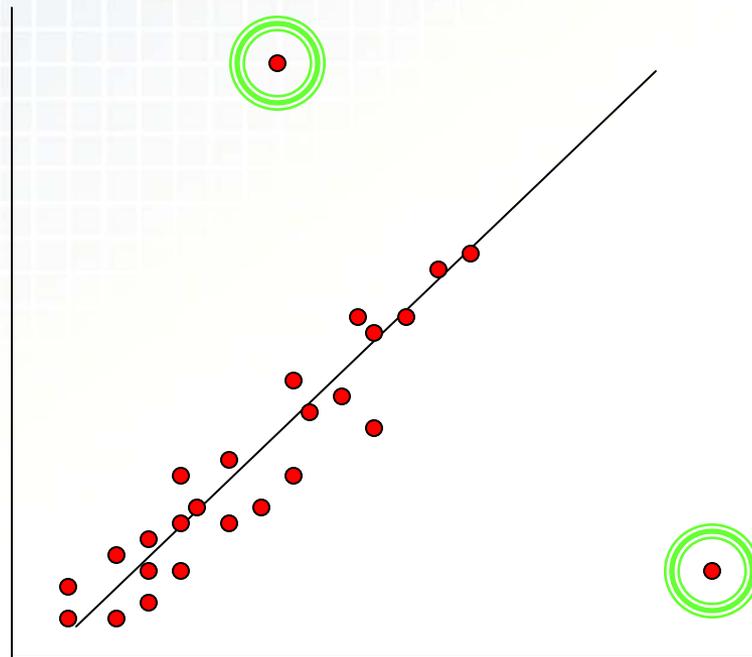




# *Issue: Centrality Measures are highly correlated* **Moving Beyond Single Measures**

Betweenness

A Bridge!



Degree

Sink? Or Source?





# Criticality is NOT just about people

- Communication
  - Centralities
    - Degree – most connected
    - Betweenness – most paths
- Expertise
  - Exclusivities
    - Knowledge – expertise
    - Task – special experience
    - Resource – unique
- Role
  - Loads and demands
    - Cognitive demand – emergent leader
    - Workload

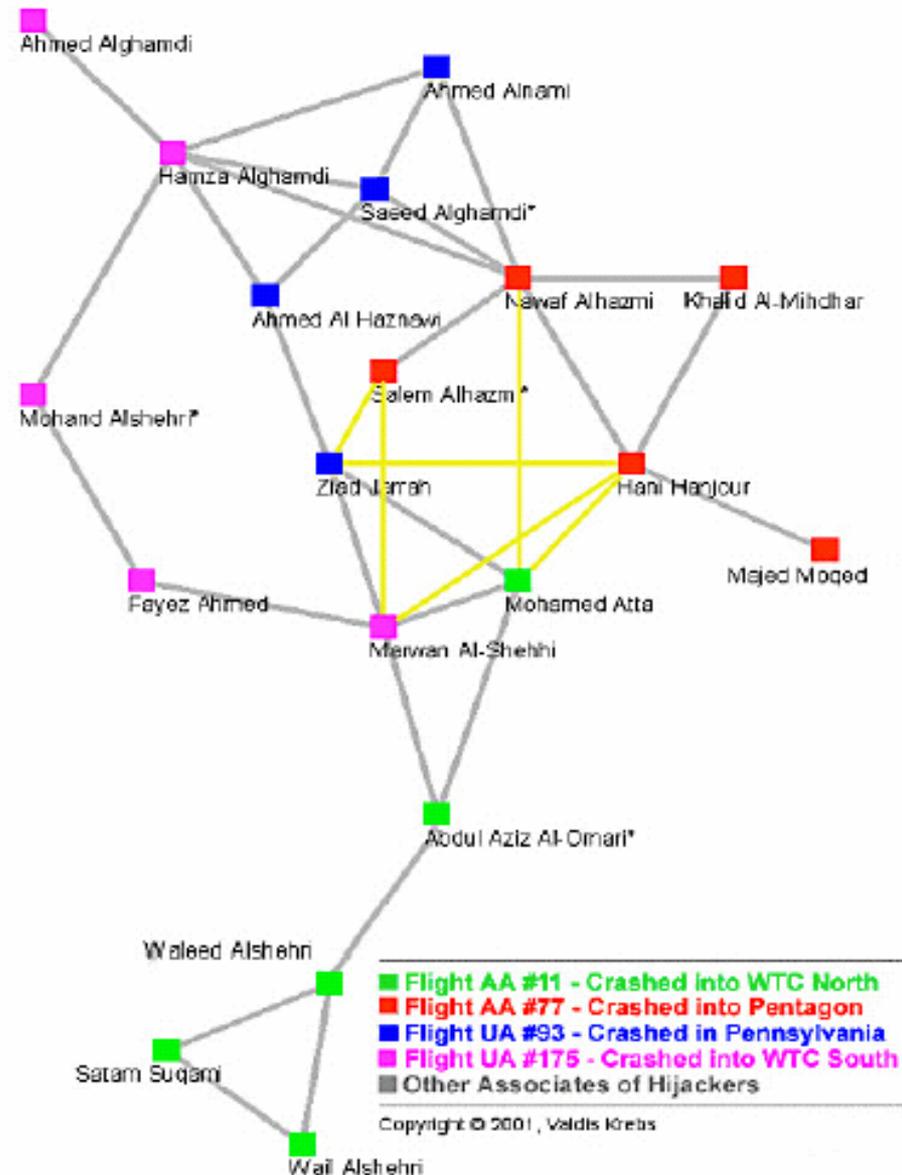


Figure 3 Trusted Prior Contacts + Meeting Ties [shortcuts]

**Even a little information beyond the who helps**

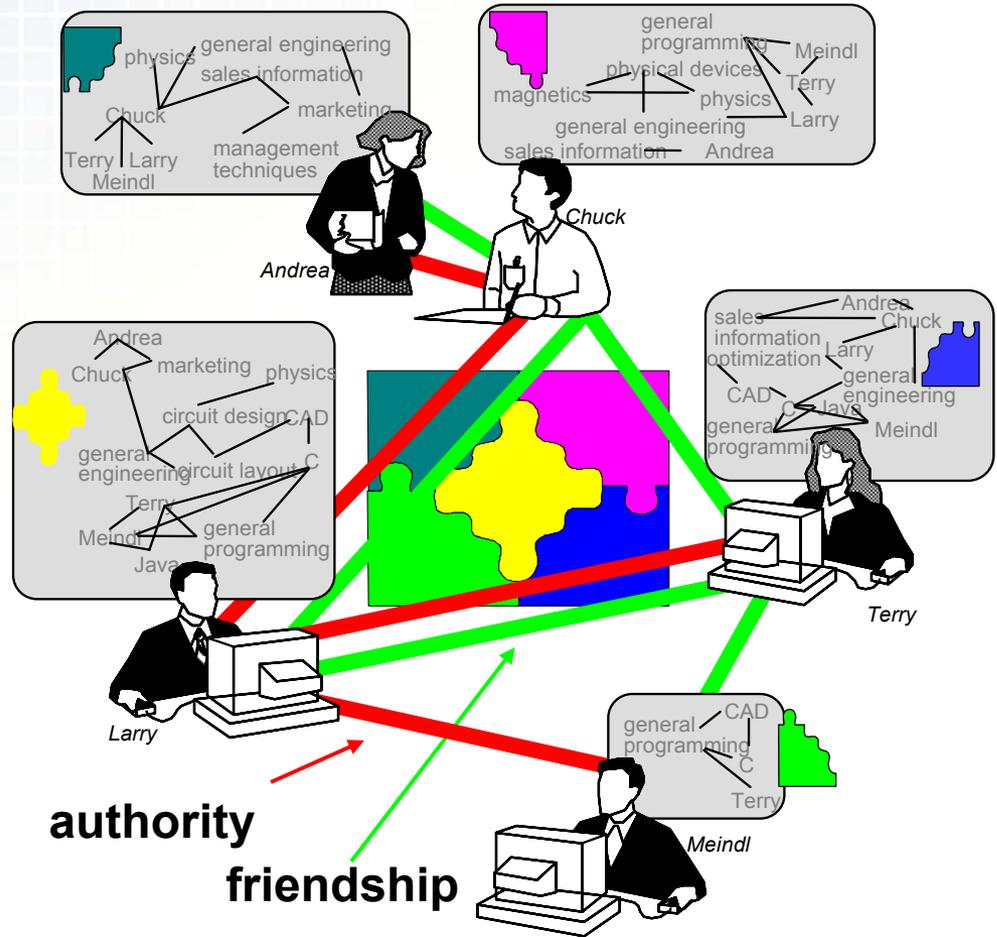


# Networks Interlink

- **Social networks**
  - Who to whom
- **Information networks**
  - What to what
- **Knowledge networks**
  - Who to what

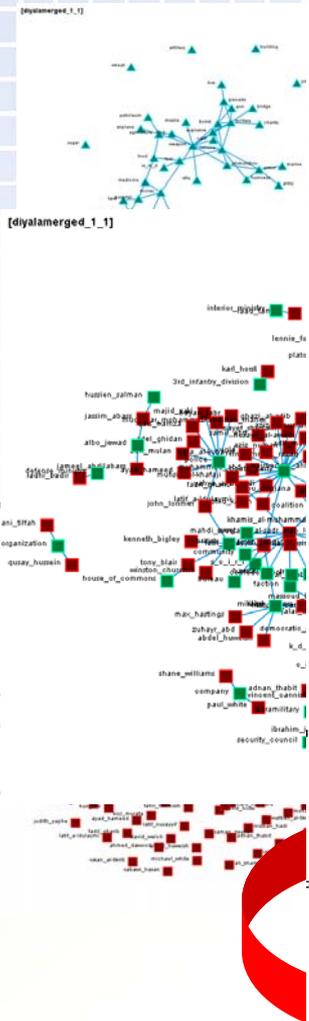
*These can be inter-linked at either the individual, group, or corporate level.*

*These can be inter-linked in terms of words, specific pieces of information, or general bodies of knowledge.*

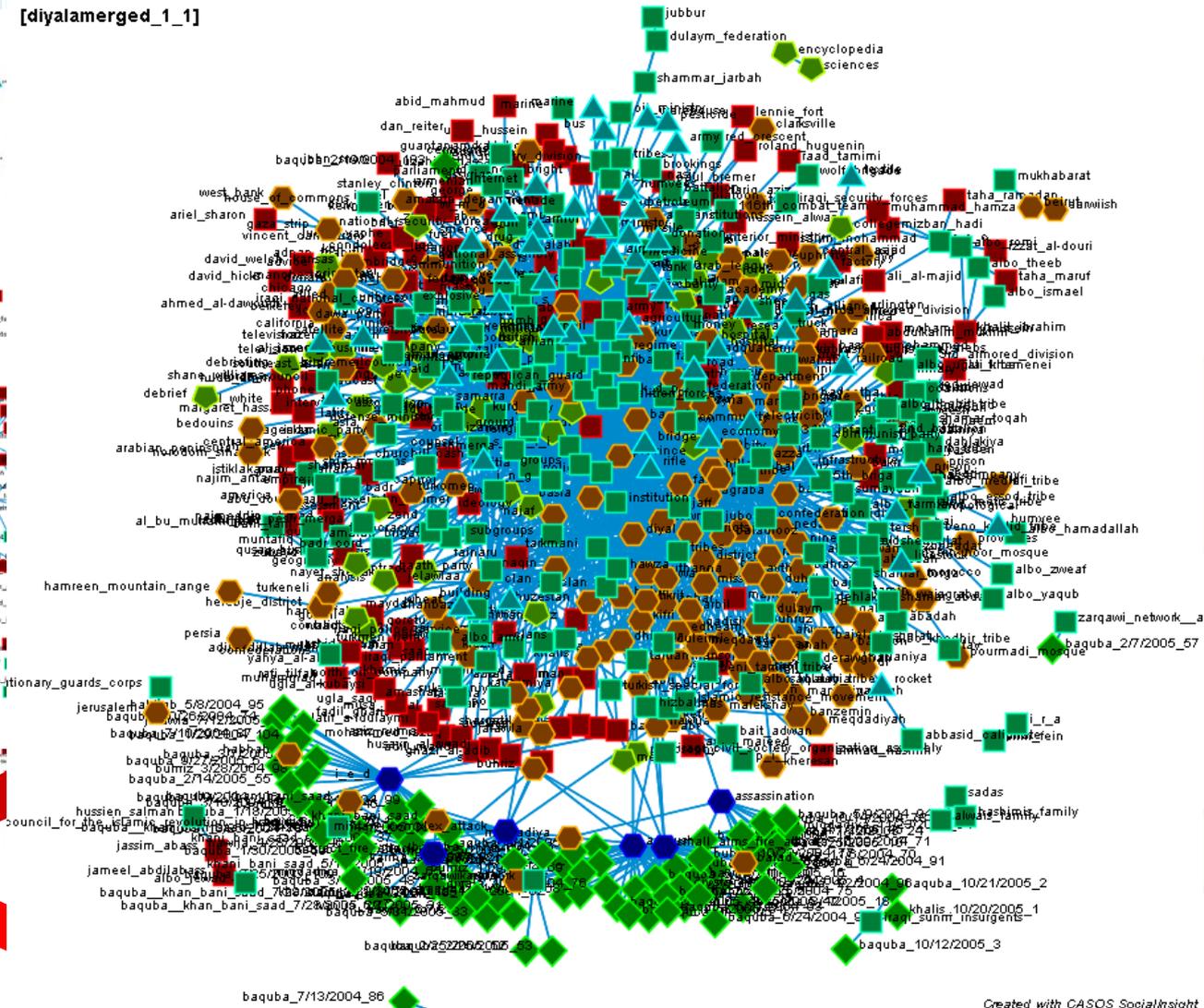




# Network to Meta-Networks



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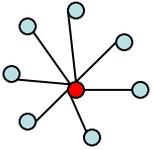
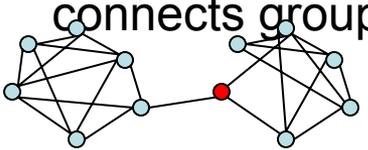
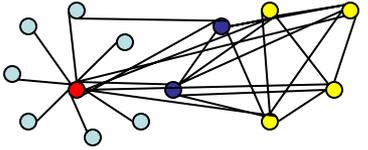
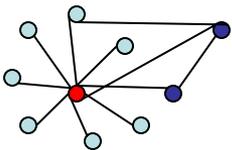
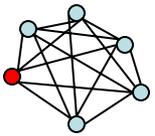
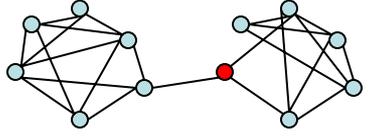
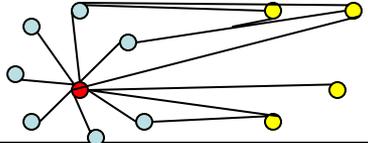
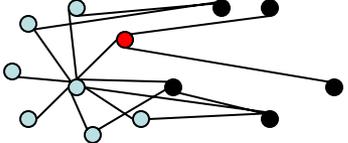


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# Individuals Who Stand Out

<p>Degree Centrality in the know</p> 	<p>High Betweenness and not Degree</p> <p>connects groups</p> 	<p>Cognitive Demand</p> <p>emergent leader</p> 	<p>Task exclusivity critical ability</p> 
<p>Eigenvector central core</p> 	<p>Betweenness many paths</p> 	<p>Resource exclusivity</p> <p>Mobilize resources</p> 	<p>Knowledge exclusivity</p> <p>Mobilize info</p> 



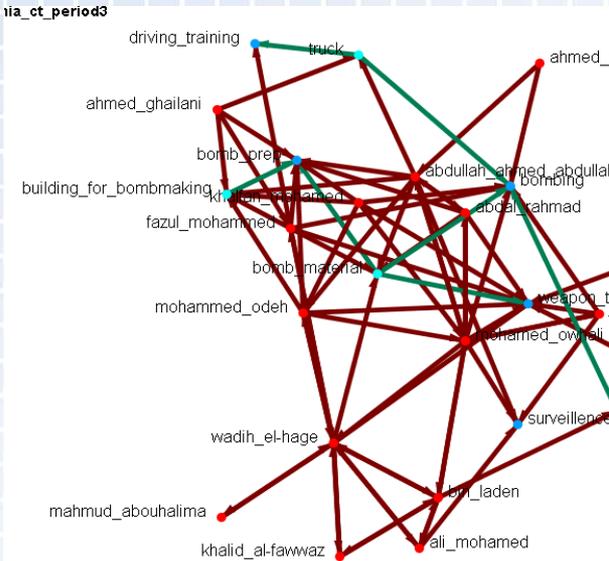
# Getting Results on Key Actors Using ORA

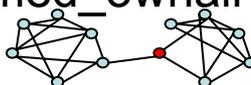
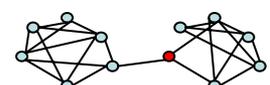
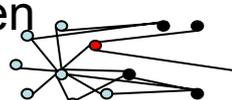
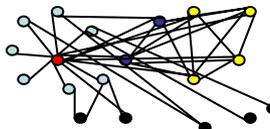
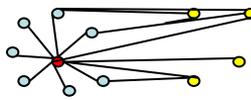
- Key Entity Report
  - Selected measures for key nodes – interesting from an info gathering or group disruption perspective
- Management Report
  - Selected measures for key nodes – interesting from an organizational design or vulnerability perspective
- All Measures
  - All measures for all nodes
- User defined
  - Use measures manager to get only the measures you want for all nodes
- Saving data
  - Save as csv and put in excel and process
  - Save as DyNetML for future visualization and analysis
  - Save as txt for integrating in word reports



# Key Entity Report: Who's Key?

## ORA: Key Entity Report - Who



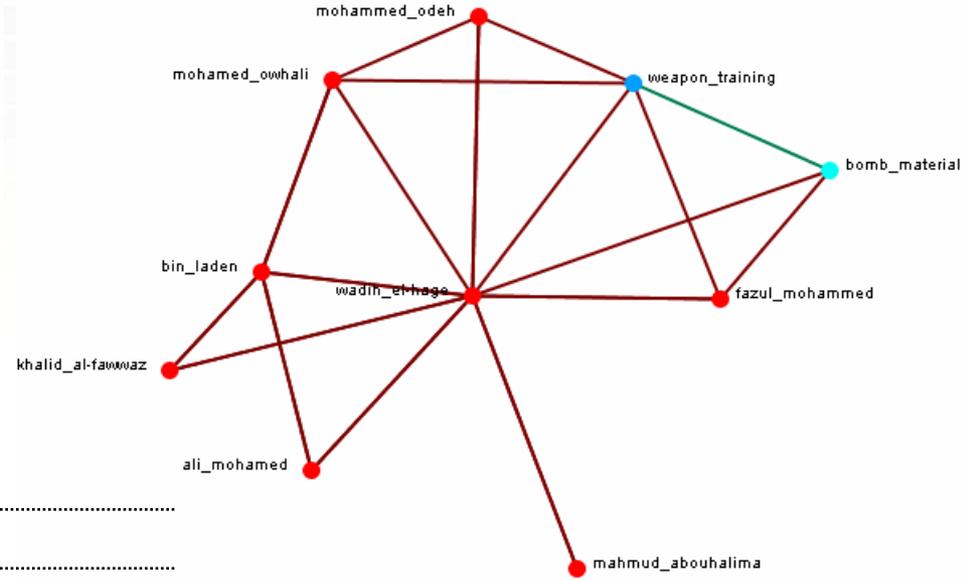
<p>Metric Node Graphic</p>	<p>HighBetweenness low Degree Connects groups mohamed_owhali</p> 	<p>Task Exclusivity Critical role fazuul_mohammed</p> 
<p>Degree Centrality In the Know wadih_el-hage</p> 	<p>Betweenness Power wadih_el-hage</p> 	<p>Expertise Exclusivity Critical expertise bin-laden</p> 
<p>Eigenvector Centrality Central core mohamed_owhali</p> 	<p>Cognitive Demand Emergent leader fazuul_mohammed</p> 	<p>Resource Mobilization Critical access abdullah</p> 



**ORA:  
Sphere of  
Influence**

# How to Influence

Node Type	Size	Percent
agent	8	+50%
knowledge	2	+50%
location	2	+3%
resource	1	+25%
task	1	+20%



powered by ORA, CASOS Center @ CMU

**Most similar other –  
jamal al-fadil**

Name	Value
alias	wadh_hage
hostility_level	1
joined_al_qaeda	1989
left_al_qaeda	1998
nationality	lebanese
nationality_relation	hostile
nyi	prosecutor
source_date	2006-05-10
suspected_terrorist	yes





# Are Two Critical Actors Linked? Path Finder

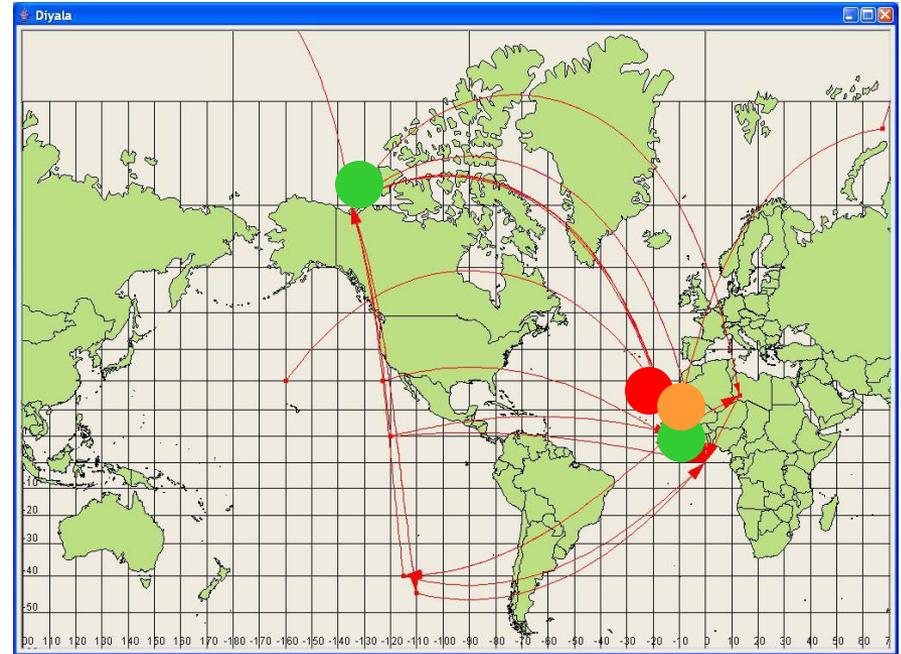
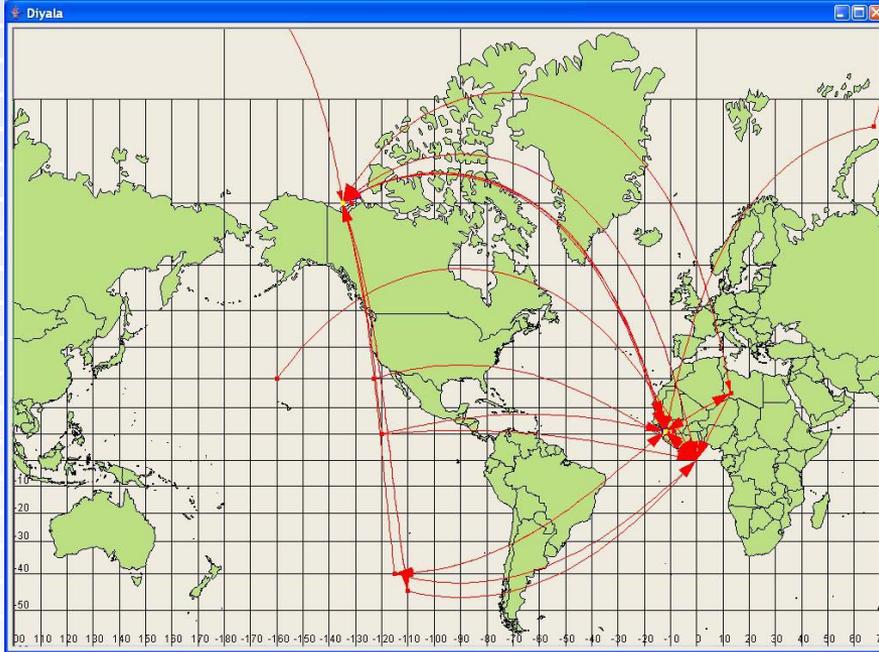
, tariq\_al-fadli

mohammed\_atta /



# Geo-Spatial Criticality

Networks can be viewed on maps!



Network Metrics can be shown as node size:

- Event
- Resource
- Location
- Agent
- Organization

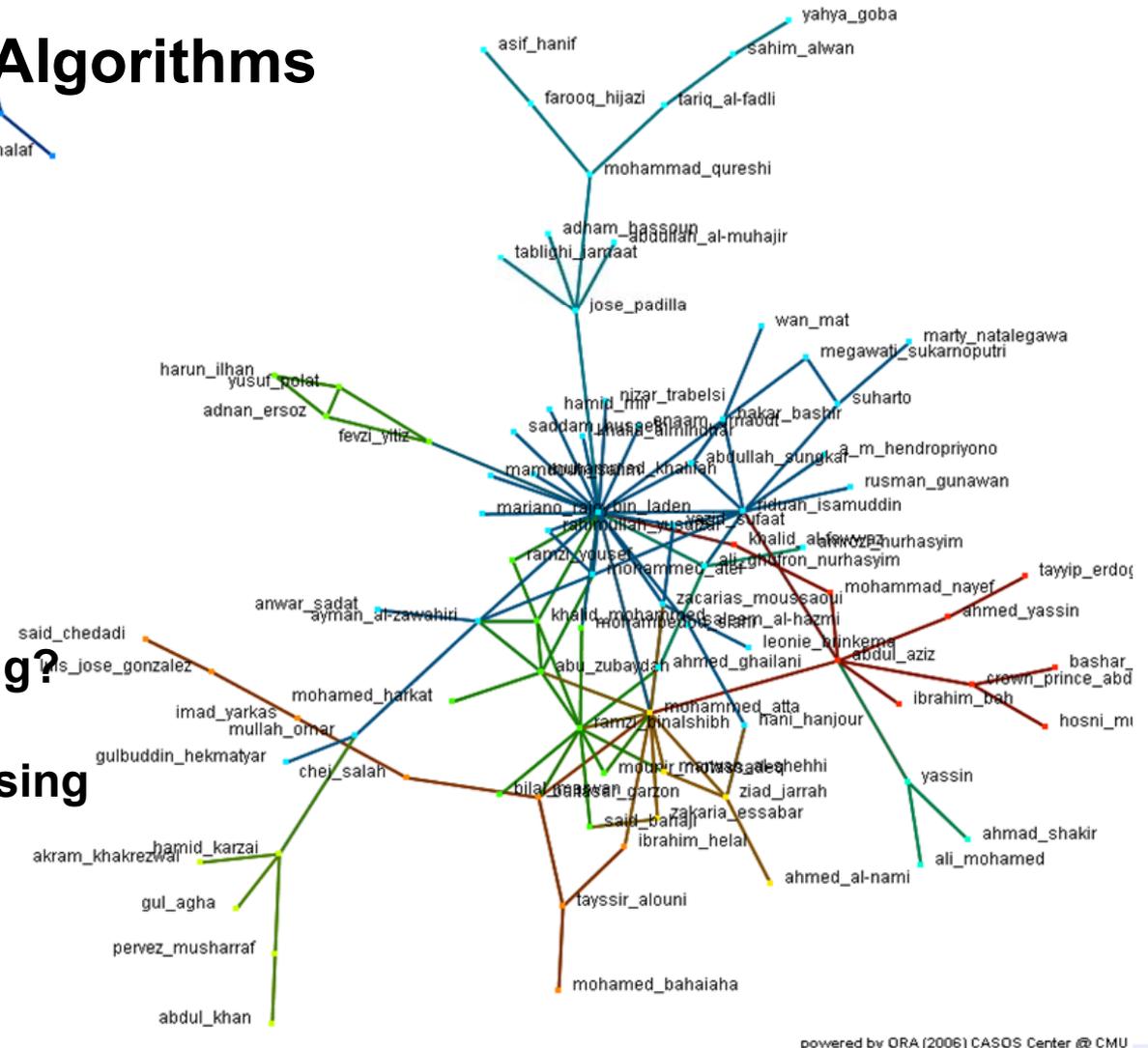




# Are there sub-groups?

## Multiple Grouping Algorithms

- Newman
- Concor
- Cliques
- H-FOG
- K-FOG



- How is the group changing?
- How might it change?
- Where might there be missing data?







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