Network Complexity, Control, and Cooperation

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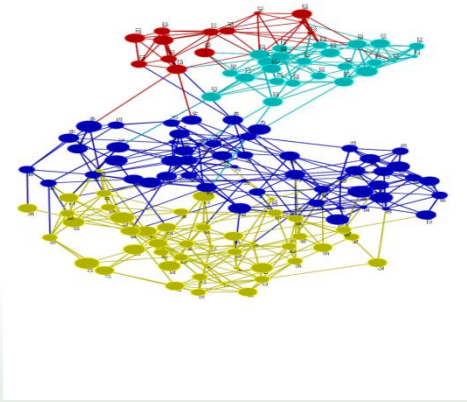
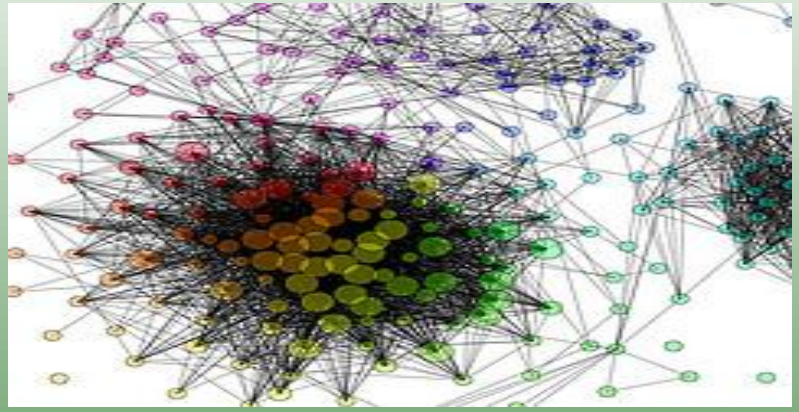
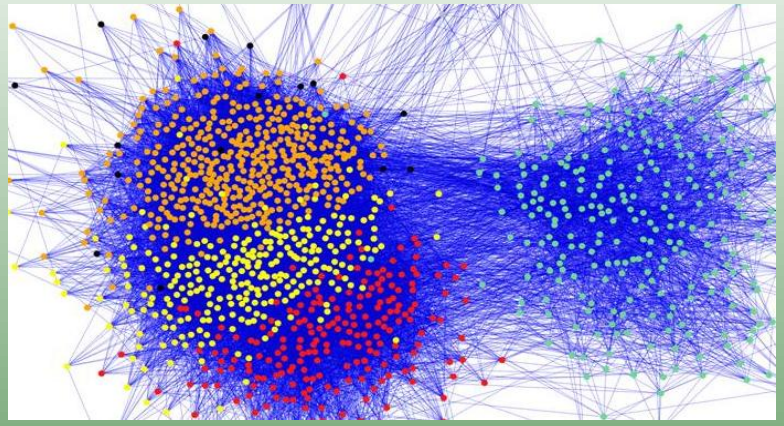
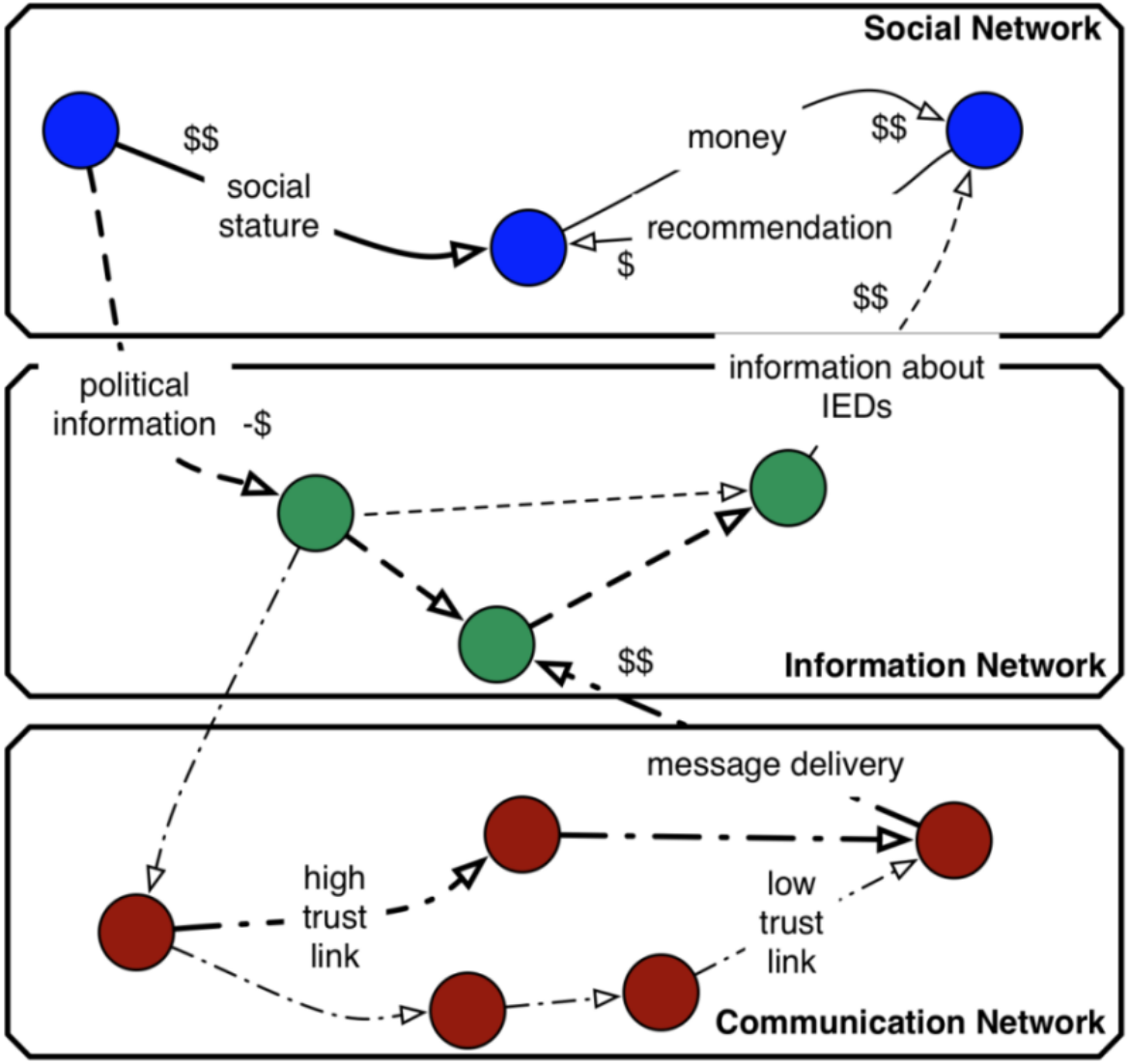






Outline

- Philosophy
- Complexity
- Control
- Cooperation
- Examples



links carry both utility ($$) and risk (high risk = low trust)

New Philosophy for Applied Mathematics: Using Network Models to Embrace the Complexity

- Wicked Applications in Information and Social Sciences.
- Human-based Utility Functions/Metrics (non-linear)/Control Mechanisms
- New Structural Use of Geometry
- Higher Dimensional Data/Discrete Analytic Algorithms
- More Simulations/Games
- Measure real worth to the mission (of the organization or system) through cooperation
- Modeling that EMBRACES THE COMPLEXITY!!!

Observations

1) Understanding networks comes from merging graph theory measures with **cooperative** game theory using human-based metrics in a **complexity**-based modeling framework.

2) The framework embraces the **complexity** of networks through the measurement and use of diversity, specialization, energy, cooperation, and information to enhance performance.

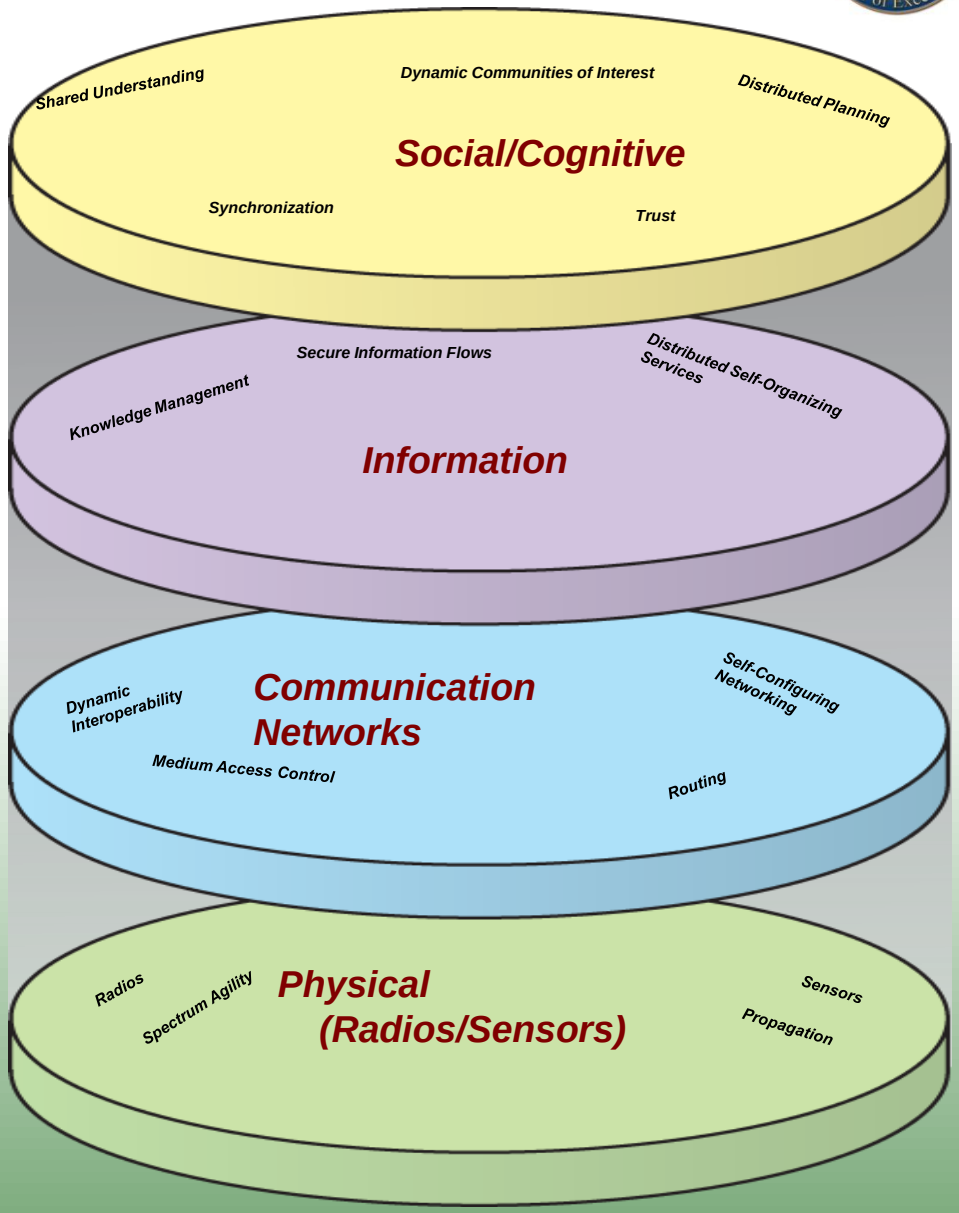
3) **Complexity** as a global network metric includes network purpose, architecture, structure and process.

4) Information and energy resonance provide a way of viewing the exchange between networks to enable network **control**.

5) Effective influencing of networks is not done directly by control mechanisms using domination because they can be absorbed by the network's dynamics or lost in friction. The influence should be delicate and indirect (**cooperative**) by matching the network in **complexity**. Network **control** often does not go to the most powerful but to the most subtle and flexible.

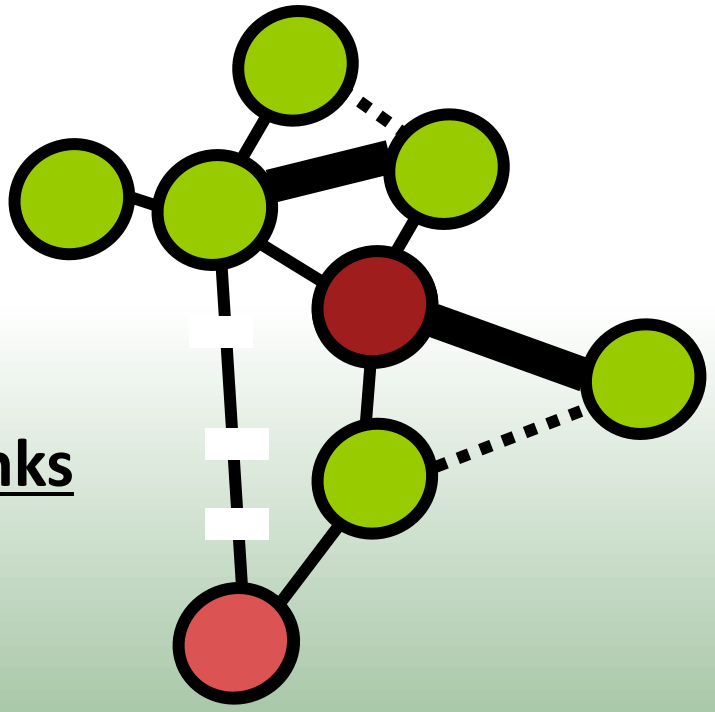
Layer Framework still valid

- Model, analyze, predict, & control the behavior of networks
- Understand linkages & interactions among network domains
- Enable humans to exploit information for timely, effective decision making
- Design robust networks that align with human cognitive capabilities



Mission-Oriented Network Context

- **Network Nodes represent an organization**
  - Social and cognitive
  - Collaborative and distributed
  - Human & agent
- **Information**
  - Carried over the links
  - Required at the nodes
- **Sensitivity of Network's Communication and Influence Links**
  - Formal & informal
  - Intact or broken
  - Bandwidth limited



Complexity
(as a metric or utility function)

Purpose (flow, grow, decide, perform, manage), Architecture (random, scaled), Entropy (information, energy), Structure, Process (dynamics, specialization, diversity), Attributes (data mining, underlying distribution), Dimensionality

Structure: Density, Spread (diameter/size), Balance (reciprocity, transitivity, clusters, silos), Variance (centralities), Centralizations, Black swans

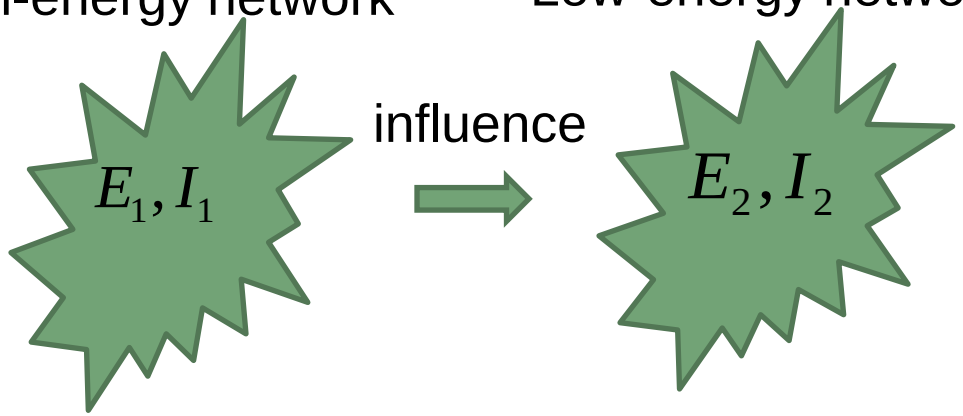
Normalized, non-linear, dynamic, local, global, <u>subgroup</u>

CONTROL ISSUES

B. West's *Universal Principle* in Network Science

High-energy network

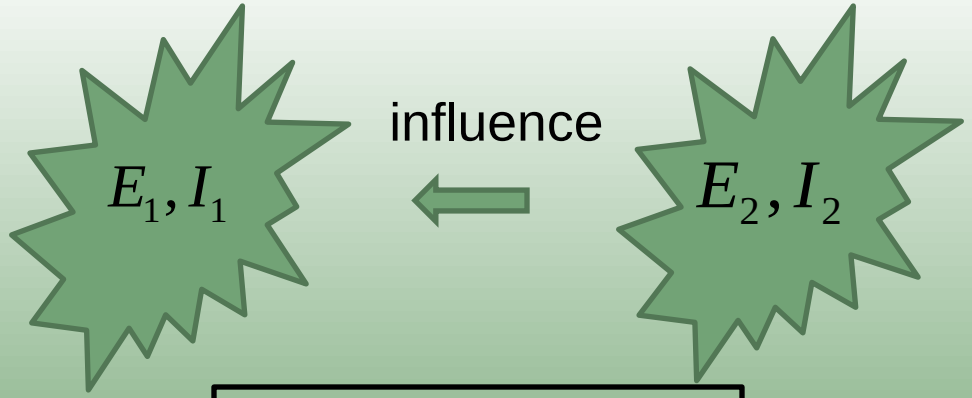
Low-energy network



Energy-dominated process

Low-information network

High-information network



Information-dominated process

$$E_1 > E_2;\ I_1 < I_2$$

Control Results

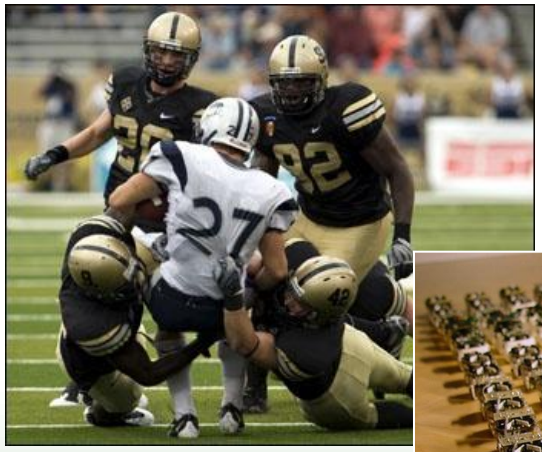
- Information resonance enables the viewing of the information exchange or **control** between **complex** networks.

- **Control** of a complex network is not best done by direct force by authority, such action would be absorbed by the network's dynamics. To be effective the influence should be delicate (**cooperative**) and indirect (through negotiation)and it must match the network in **complexity**.

- The interaction between **complex** clusters can be very weak and still the dynamics of the perturbed cluster can inherit the dynamics of perturbing cluster.

Cooperation

Successful Organizations consist of teams known for their trust and autonomy… the teams may involve people, computers, robots, sensors, vehicles.



Motivating Questions

Cooperation is complex and can provide control!

What makes one behavior more cooperative than another?

Can we determine why agents cooperate?

What behaviors indicate a player is trustworthy?

How and why should you decide who to trust?

Can a cooperative autonomous system be as effective as a centrally controlled system?

Existing Frameworks for Cooperation

von Neumann's Cooperative Game Theory

- Agents work together for a common payoff
- Mathematical theory for dividing payoff among the participants ("Shapley value")

Problem 1: *no concept of "team"*

- Agents participate only for selfish reasons
- Not applicable to most cooperative systems

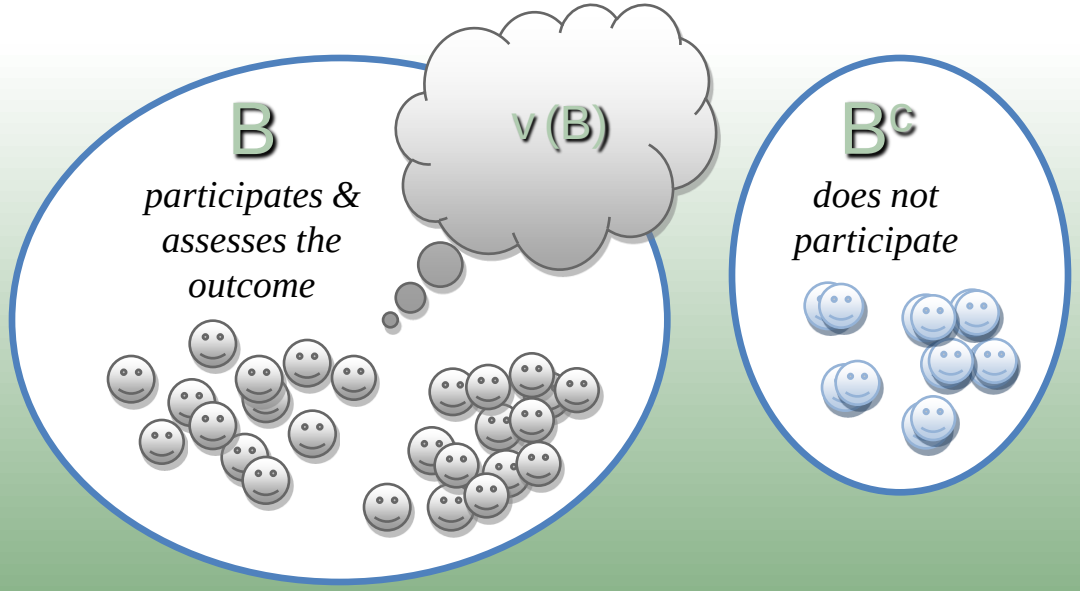
Problem 2: *in practice, even selfish human behavior doesn't follow the laws of economics*

- Prisoner's Dilemma

Cooperative Game Theory

- A **cooperative game** is a set of players T with an **outcome** for each subset $B \subset T$ and a **payoff (utility) function** for each outcome

- Associates a value $v(B)$ to the outcome when B participates

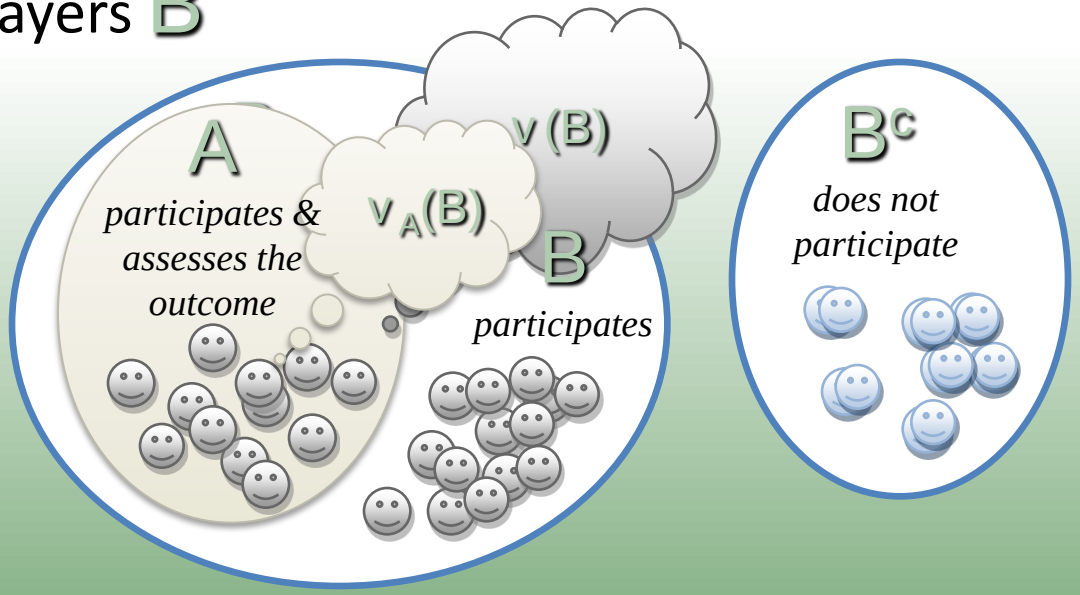


Subset Team Games

a new framework for studying cooperation

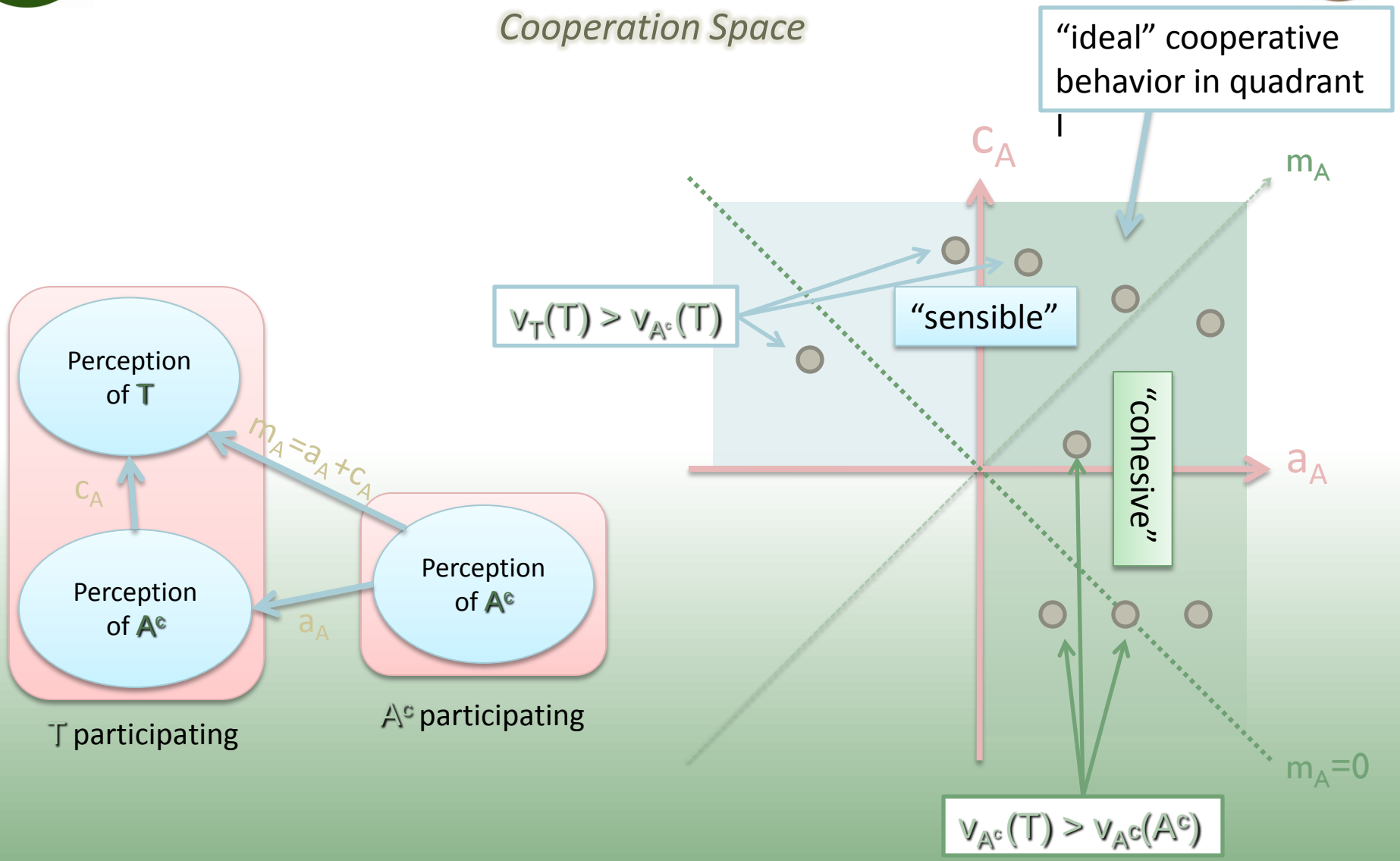
DEFINITION: A **subset team game** is a set of players T with an **outcome** for each subset $B \subset T$ and a **utility function** ***for each outcome and each subset*** $A \subset B$.

- Associates a value $v_A(B)$ to each subset A of participating players B



Measuring Player Contributions

Cooperation Space



Using the Framework

Practical aspects

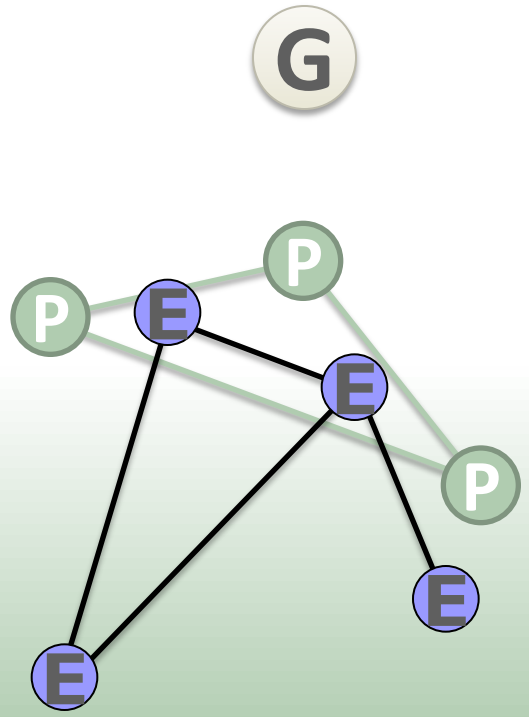
1. Decide on "value" or "utility" function $v_A(B)$
   - Should make sense for individuals **and** for *subsets* of players

2. Compute $v_T(T)$, $v_{A^c}(A^c)$, and $v_{A^c}(T)$
   - Must consider two outcomes: with all of T participating, and with only A^c participating

3. Use metrics to either
   - assess cooperative nature of the team
   - adjust behavior of players based on these metrics

Example: Pursuit-Evasion Games

Using cooperation metrics to analyze and alter behavior



- What is a **Pursuit-Evasion Game**?
  - Typically two teams with opposing goals
  - Endless variations: “cops and Robbers”, football, playground tag, etc.
- Why use PEGs to study cooperation?
  - ***Good metrics*** are easy to find
  - ***Simple*** to state, simulate, and study, yet ***complex*** behaviors emerge
  - ***Applications*** to unmanned vehicles, human-robot teaming, and network science

.Pursuit-Evasion Games

Preliminary results and observations

- Many metrics to work with
  - Number of opponents captured
  - Sum of distances to nearest opponents
  - Distance from goal
  - Time to first capture

- Observations
  - Altruistic players: slow-moving, but see and communicate over long distances
  - Selfish players: quick, relying on communications from other players

Pursuit-Evasion Games

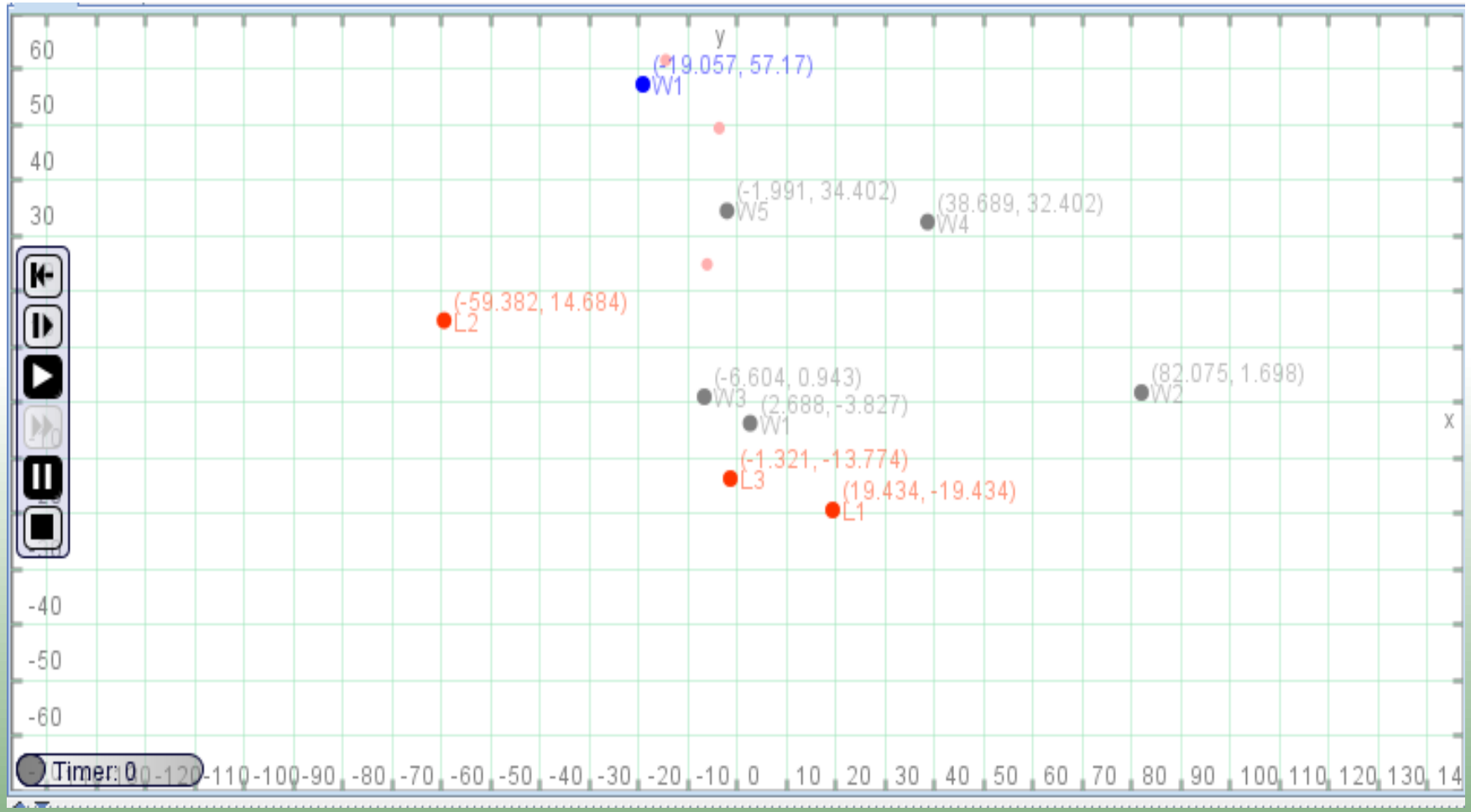
Altruism & Selfish Cooperation (back to West' Control issue)

Altruistic Case:
- slow
- large sensor & comm networks
- High Information

Selfish Case
- fast
- may not have information
- High Energy

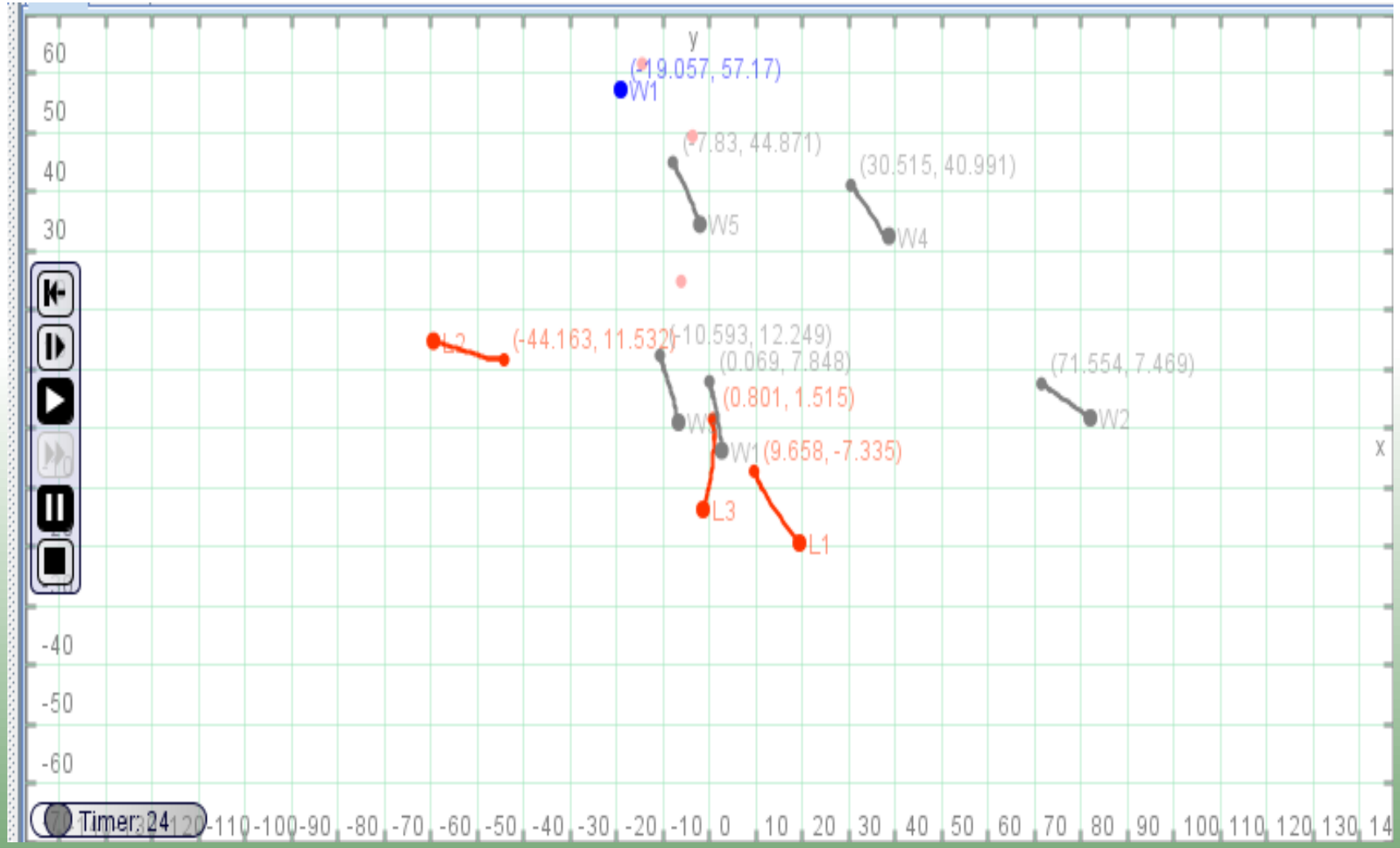
Quest for the Elixir of Life (Initial State)

3 Lions (Speed 6.5, Sensor Range 20, Comm Range 50 ,Quadrant Search Mode) and 5 Wildebeests (Speed 5, Sensor Range 20, Comm Range 50 in Straight to water mode)



Stage 1: Time = 24

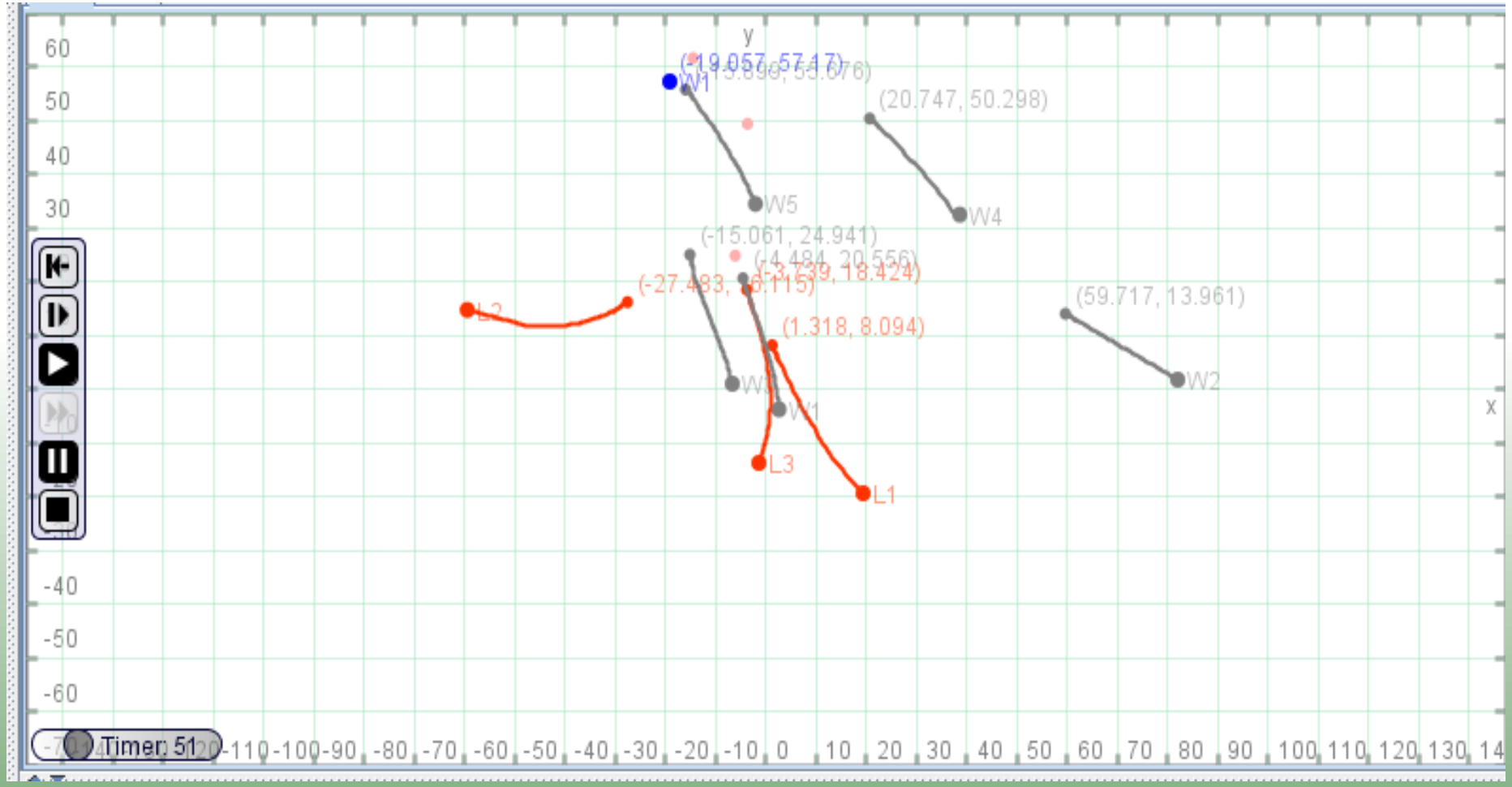
Lions 1 and 3 attempt to capture Wildebeest 1. Lion 2 changes course to move toward Wildebeest 3. Lion 2 and 3 are in comms range, therefore Lion 2 knows where to move to capture Wildebeest 3 although Lion 2 can not sense Wildebeest 3.



Stage 2: Time = 51

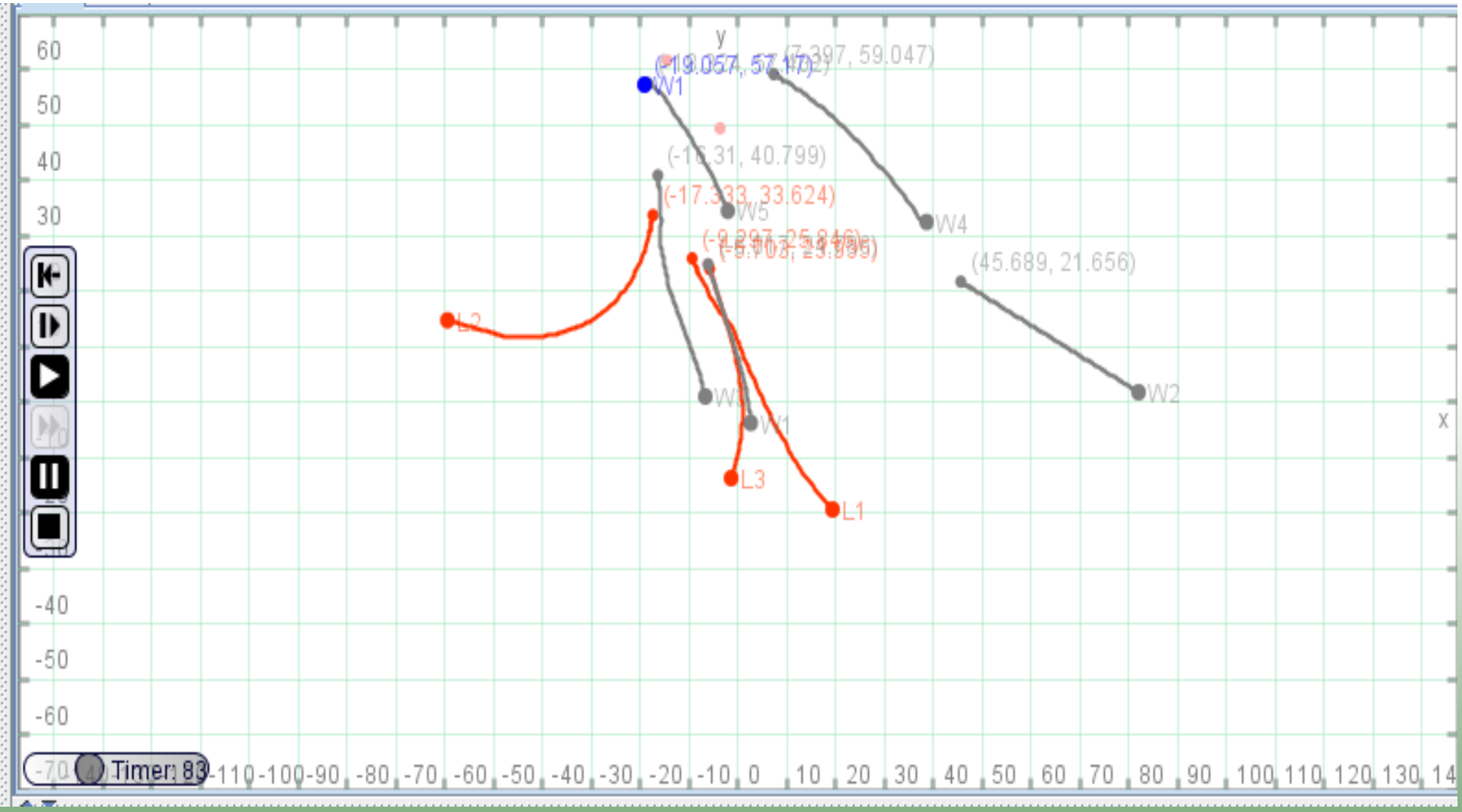
Lion 3 will capture Wildebeest 1. Lion 1 continues on path towards Wildebeest 1.

Lion 2 can now sense Wildebeest 3 and attempts to capture. Wildebeest 5 will reach the watering hole safely.



Stage 3: Time = 83

Lion 1 attempts to assist Lion 2 in capturing Wildebeast 3. Currently both lions can only sense that one wildebeast so Wildebest 2 is undetected.

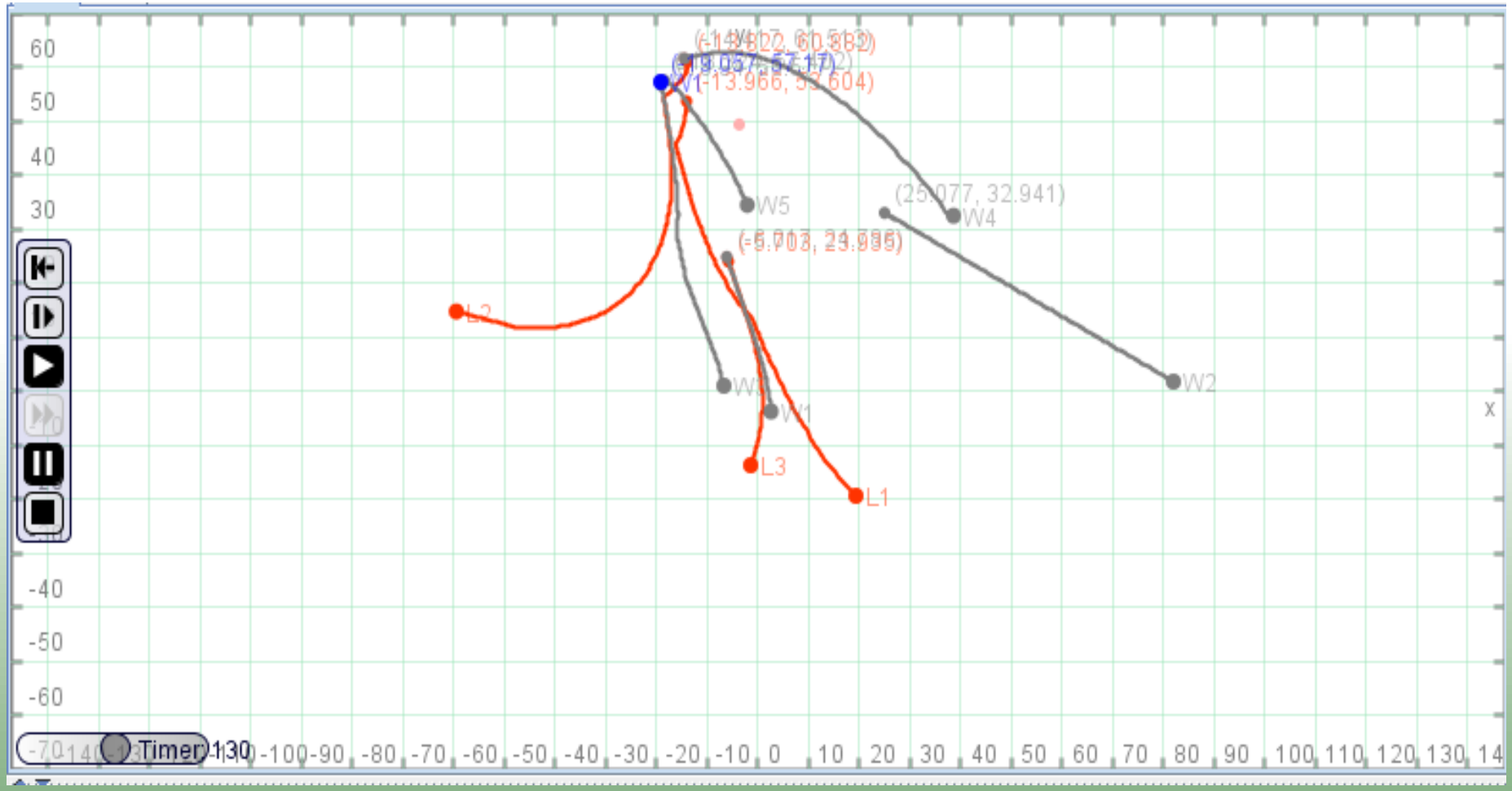


Stage 4: Time = 113

Wildebeast 3 will reach the watering hole safely after being pursued by both Lion 2 and Lion 1. Wildebeast 2 is still undetected.

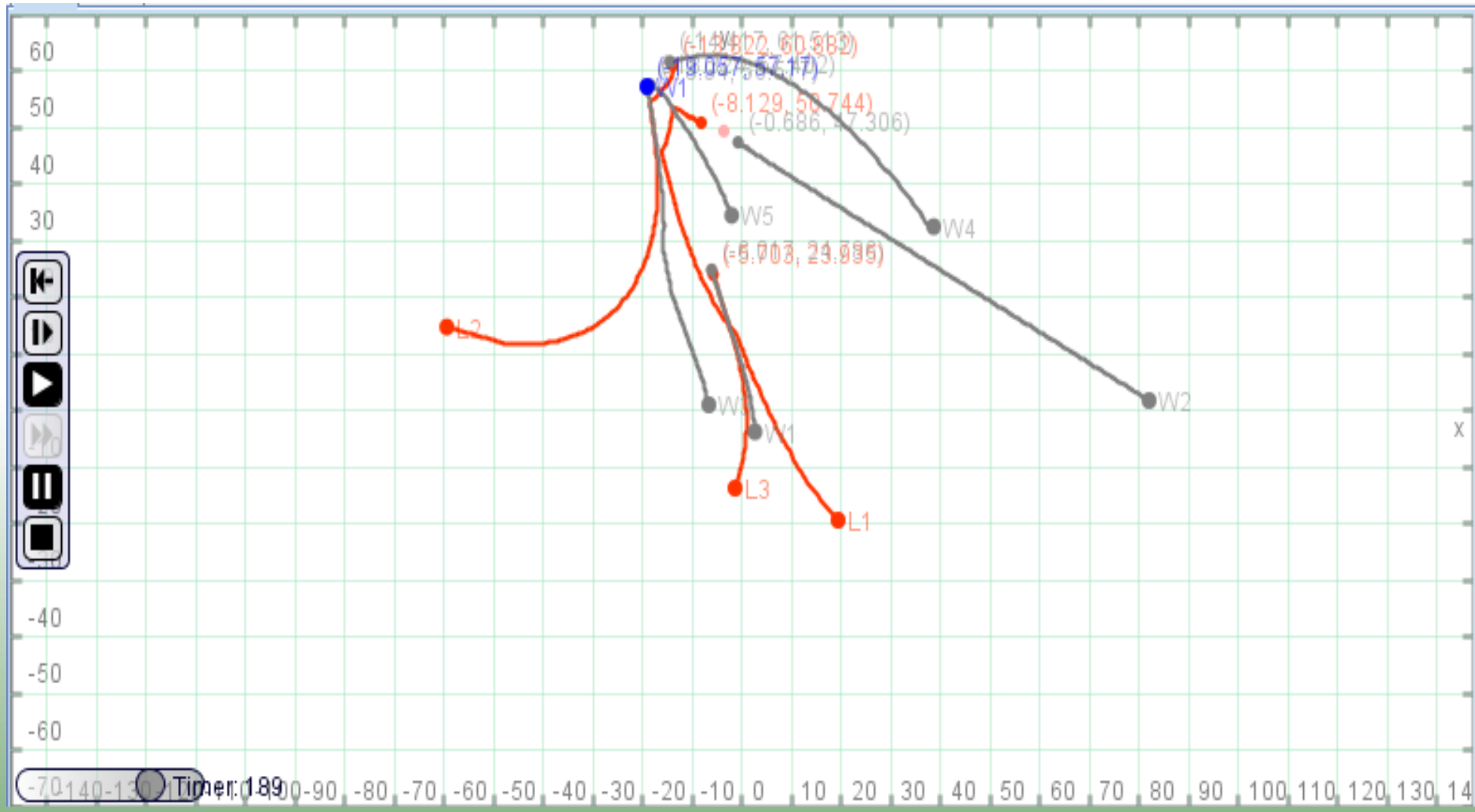
Stage 5: Time = 130

Lion 2, after unsuccessfully chasing Wildebeast 3, waits by the watering hole, then senses Wildebeast 4 and captures it. Lion 1 now has no one to communicate with and nothing that it senses and will wait by the watering hole. Wildebeast 2 still undetected.



Stage 6: Time = 189

Once Wildebeast 2 comes into sensor range for Lion 1, Lion 1 easily pursues and captures.



Summary of Quest for the Elixir of Life

W5 reached at 56 seconds.

W1 captured at 59 seconds by Lion 3.

W3 reached at 115 seconds.

W4 captured at 129 seconds by Lion 2.

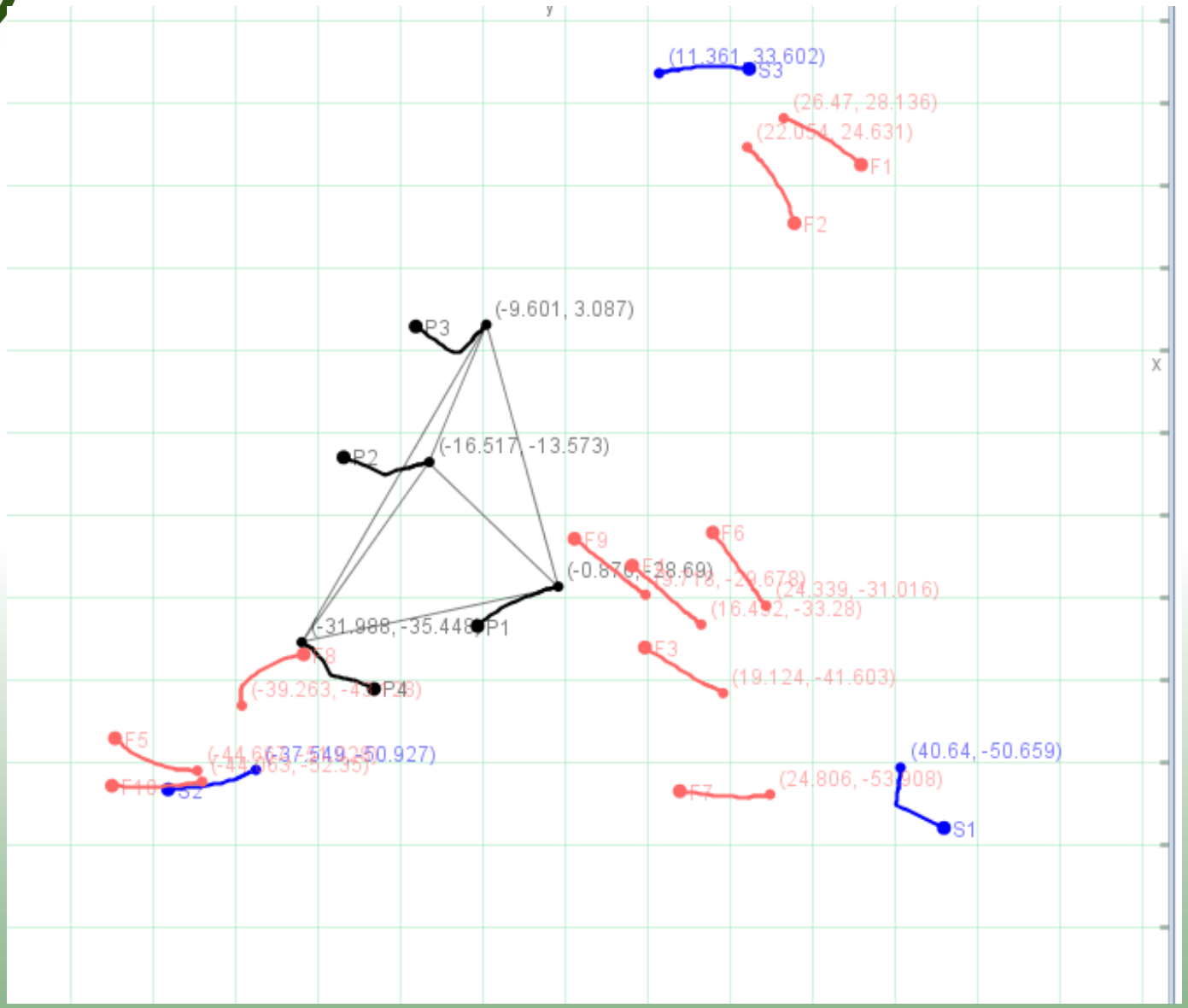
W2 captured at 196 seconds by Lion 1.

Cooperation: L2 and L3 share wildebeest location information to enable cooperation.

L1 and L3 and then L1 and L2 unnecessarily chase the same wildebeest

Searching: L2 is search mode when has no information.

3-species pursuer-evader



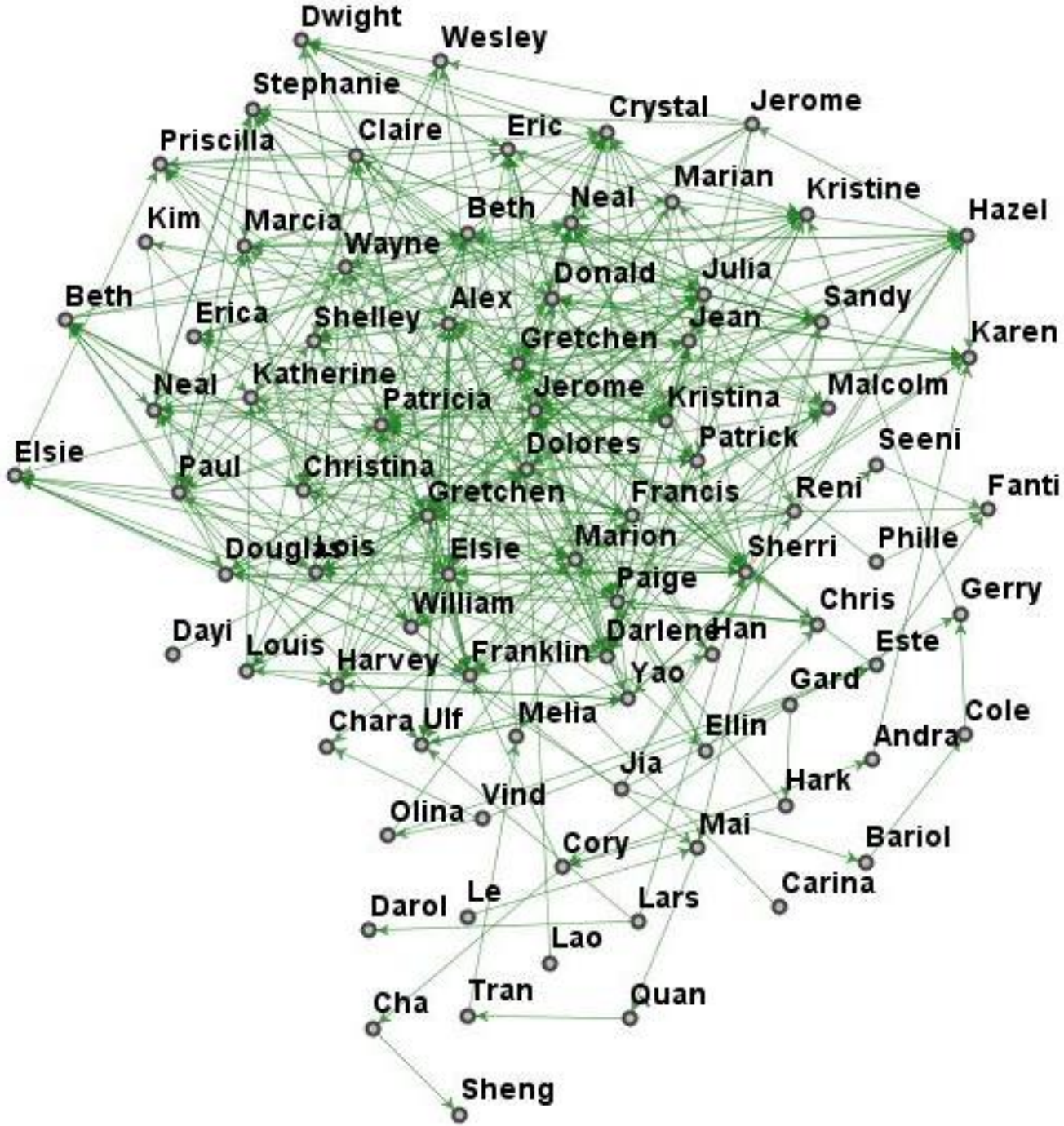
Seals

Penguins

Fish

Interdisciplinary Contest in Modeling

- 1337 three-undergraduate teams worked for 4 days in Feb 2012 to solve a criminal conspiracy network problem
- 83 people in the company (8 known conspirators, 7 known non-conspirators
- 400-600 messages
- 15 topics (3 conspiratorial topics)


Dwight
Wesley
Stephanie
Crystal
Jerome
Priscilla
Claire
Eric
Marian
Kristine
Hazel
Kim
Marcia
Beth
Neal
Wayne
Donald
Julia
Beth
Alex
Sandy
Erica
Shelley
Jean
Karen
Gretchen
Neal
Katherine
Jerome
Kristina
Malcolm
Patricia
Dolores
Patrick
Seeni
Elsie
Paul
Christina
Gretchen
Francis
Reni
Fanti
Marion
Phille
Douglas
Lois
Elsie
Sherri
Paige
Gerry
Chris
William
Dayi
Louis
Harvey
Franklin
Darlene
Han
Este
Yao
Gard
Chara
Ulf
Melia
Ellin
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Andra
Jia
Hark
Vind
Olina
Mai
Bariol
Cory
Carina
Darol
Le
Lars
Lao
Cha
Tran
Quan
Sheng

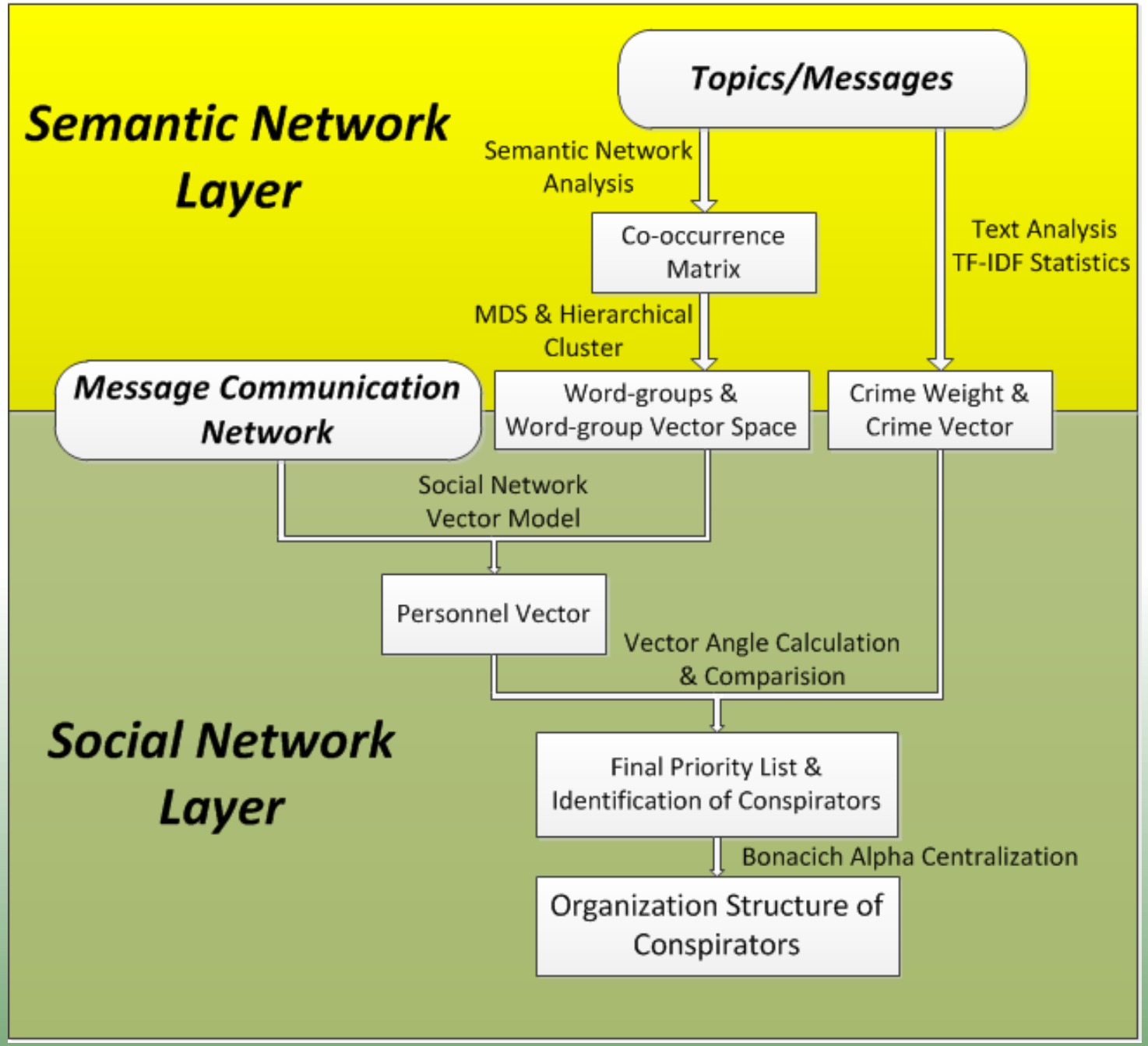
Requirements

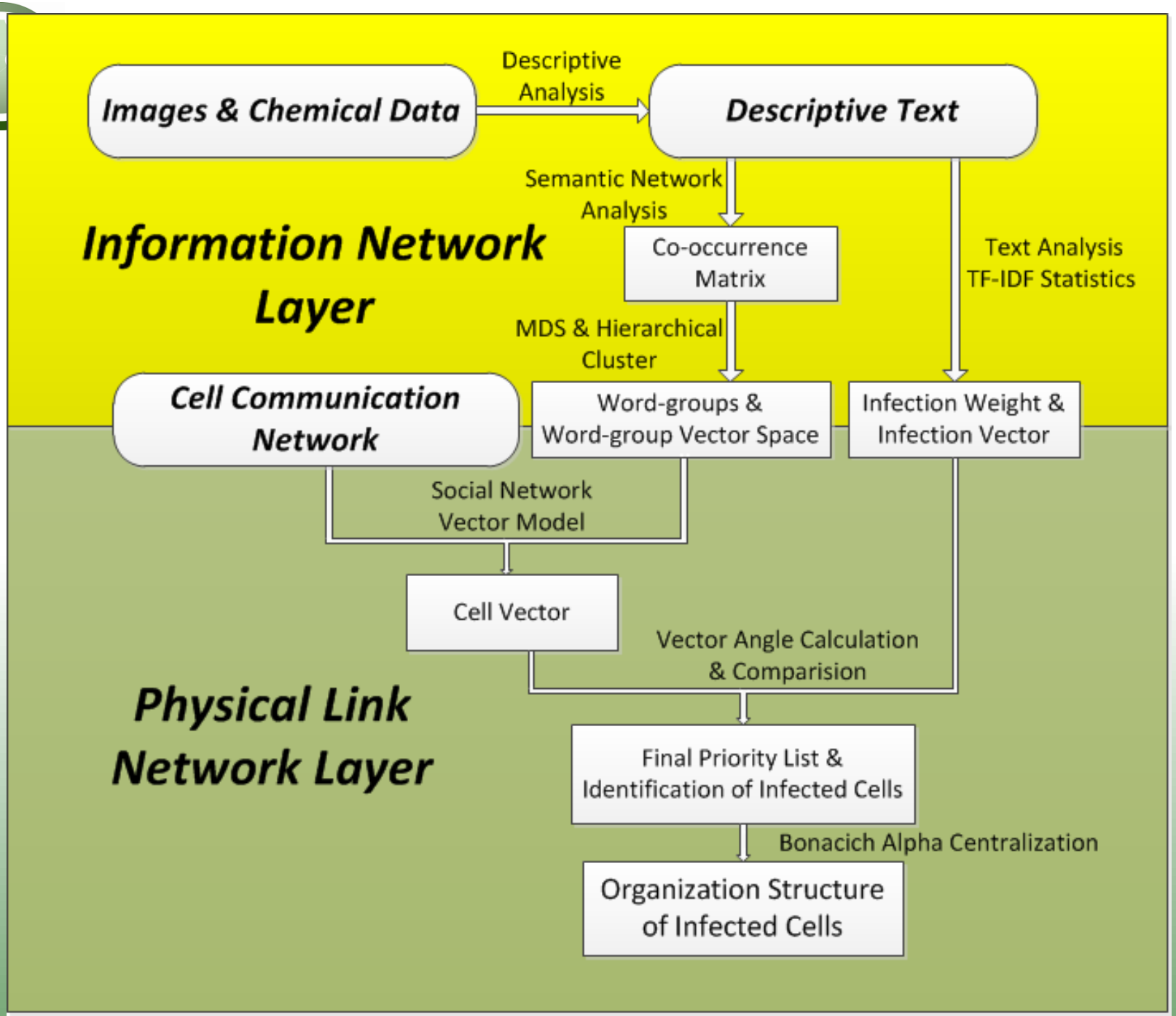
Requirement 1: Build a model to prioritize the 83 nodes by likelihood of being part of the conspiracy and explain your model and metrics. Are any senior managers of the company involved in the conspiracy.

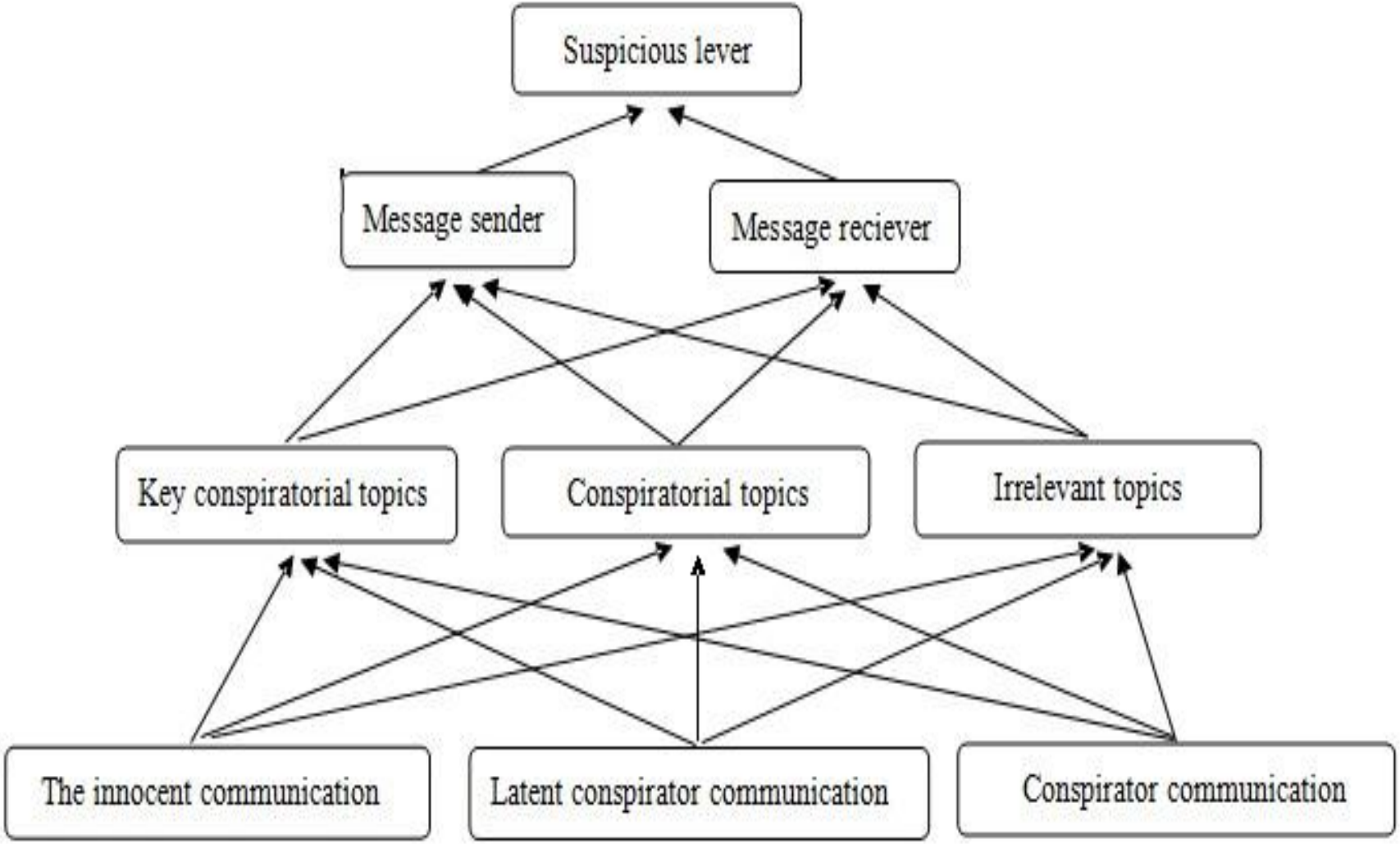
Requirement 2: New information comes to light that Topic 1 is also connected to the conspiracy and that Chris is one of the conspirators --- redo!

Requirement 3: Explain how semantic and text analyses of the message traffic, if you could obtain the original messages, could help develop even better models.

Requirement 4: Explain the network modeling techniques you developed and how they can be used to identify, prioritize, and categorize nodes in a network database of any type, not just crime and message data


Semantic Network Layer
Topics/Messages
Semantic Network Analysis
Co-occurrence Matrix
Text Analysis TF-IDF Statistics
MDS & Hierarchical Cluster
Message Communication Network
Word-groups & Word-group Vector Space
Crime Weight & Crime Vector
Social Network Vector Model
Personnel Vector
Vector Angle Calculation & Comparision
Social Network Layer
Final Priority List & Identification of Conspirators
Bonacich Alpha Centralization
Organization Structure of Conspirators


Images & Chemical Data
Descriptive Analysis
Descriptive Text
Semantic Network Analysis
Information Network Layer
Co-occurrence Matrix
Text Analysis TF-IDF Statistics
MDS & Hierarchical Cluster
Cell Communication Network
Word-groups & Word-group Vector Space
Infection Weight & Infection Vector
Social Network Vector Model
Cell Vector
Vector Angle Calculation & Comparision
Physical Link Network Layer
Final Priority List & Identification of Infected Cells
Bonacich Alpha Centralization
Organization Structure of Infected Cells


Suspicious lever
Message sender
Message reciever
Key conspiratorial topics
Conspiratorial topics
Irrelevant topics
The innocent communication
Latent conspirator communication
Conspirator communication

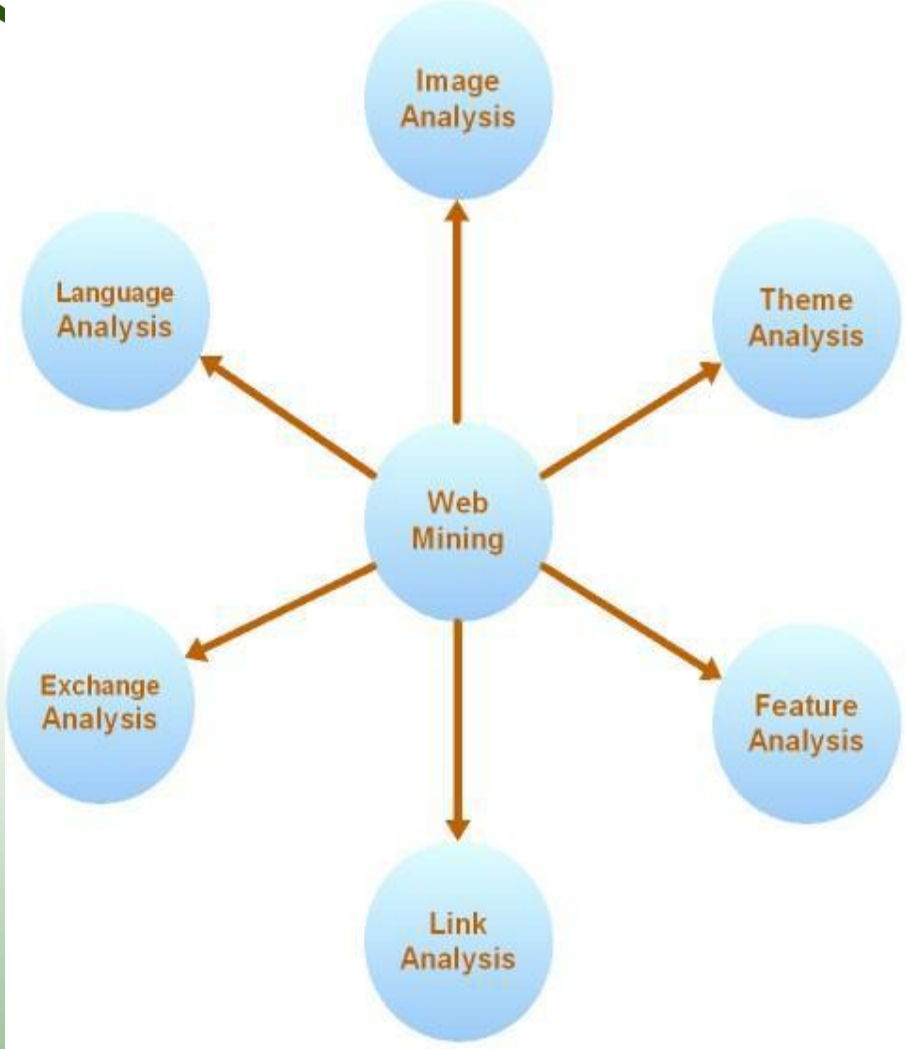
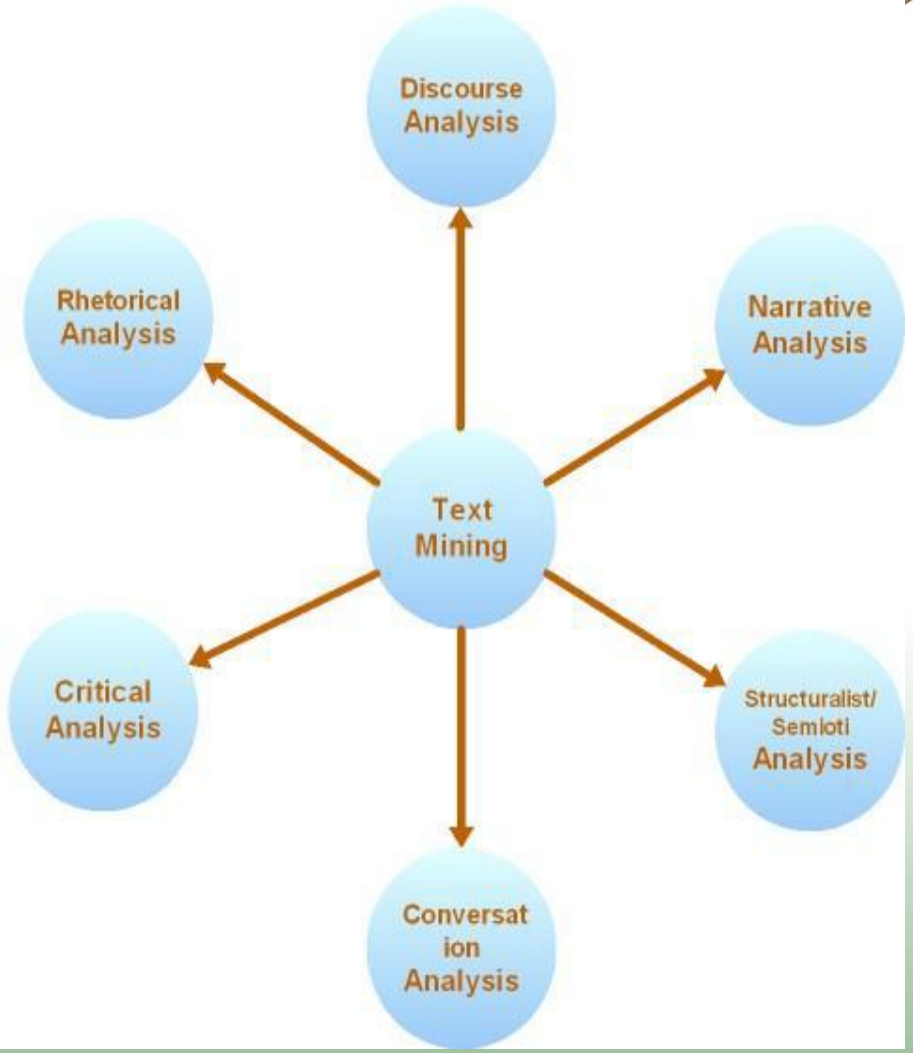
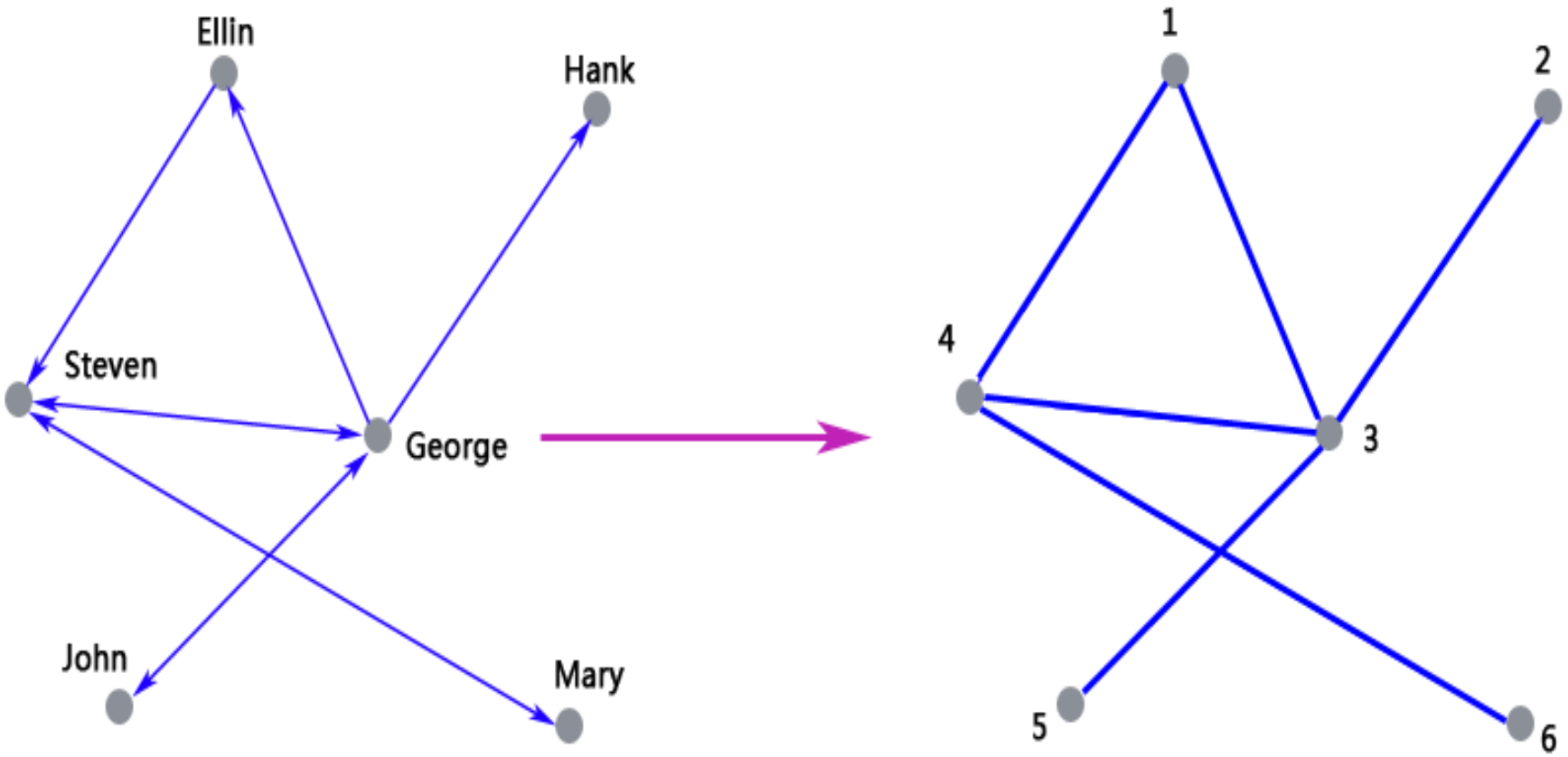
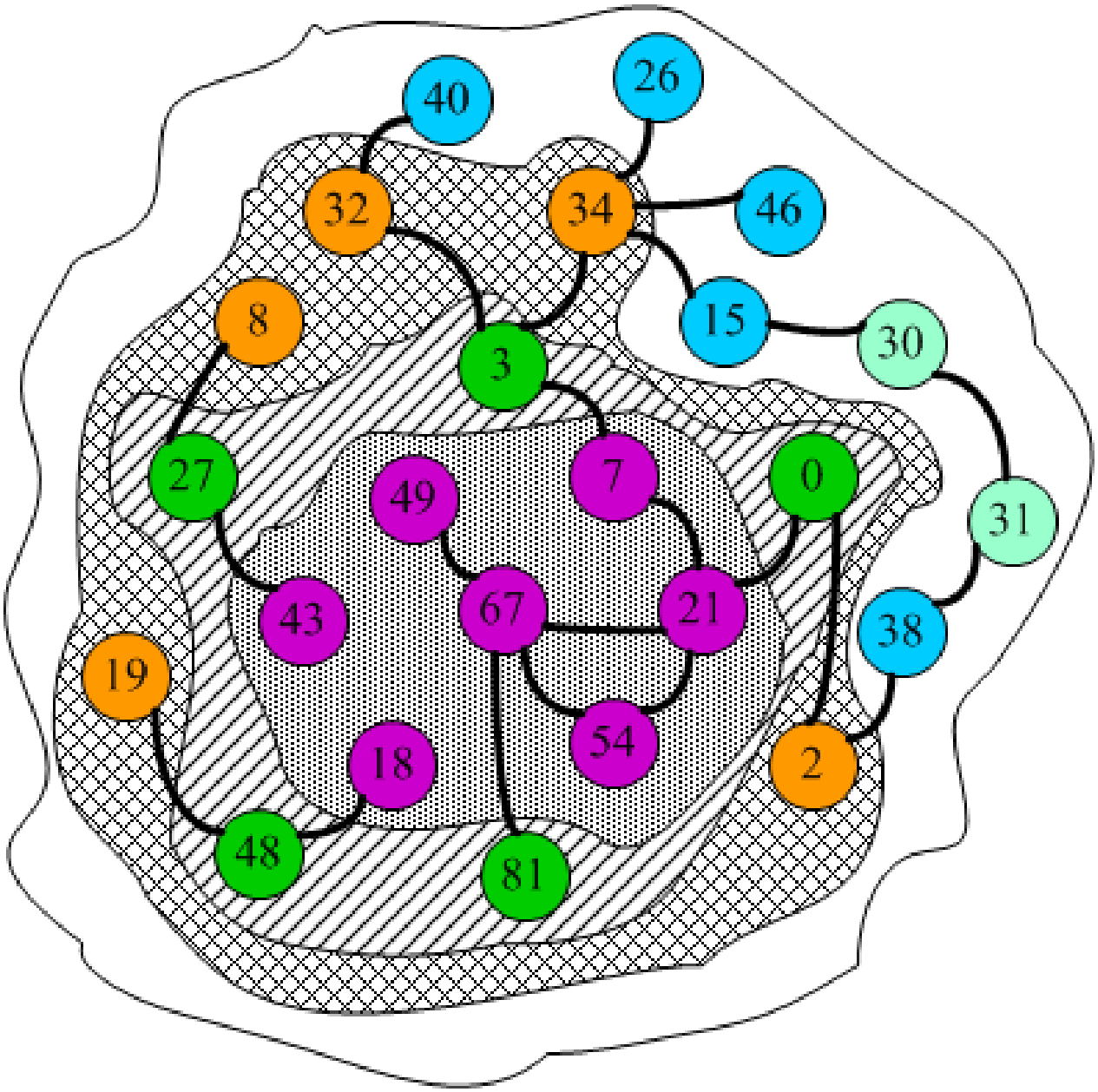


Image Analysis
Language Analysis
Theme Analysis
Web Mining
Exchange Analysis
Feature Analysis
Link Analysis


Discourse Analysis
Rhetorical Analysis
Narrative Analysis
Text Mining
Critical Analysis
Structuralist/ Semioti Analysis
Conversat ion Analysis

Local structure

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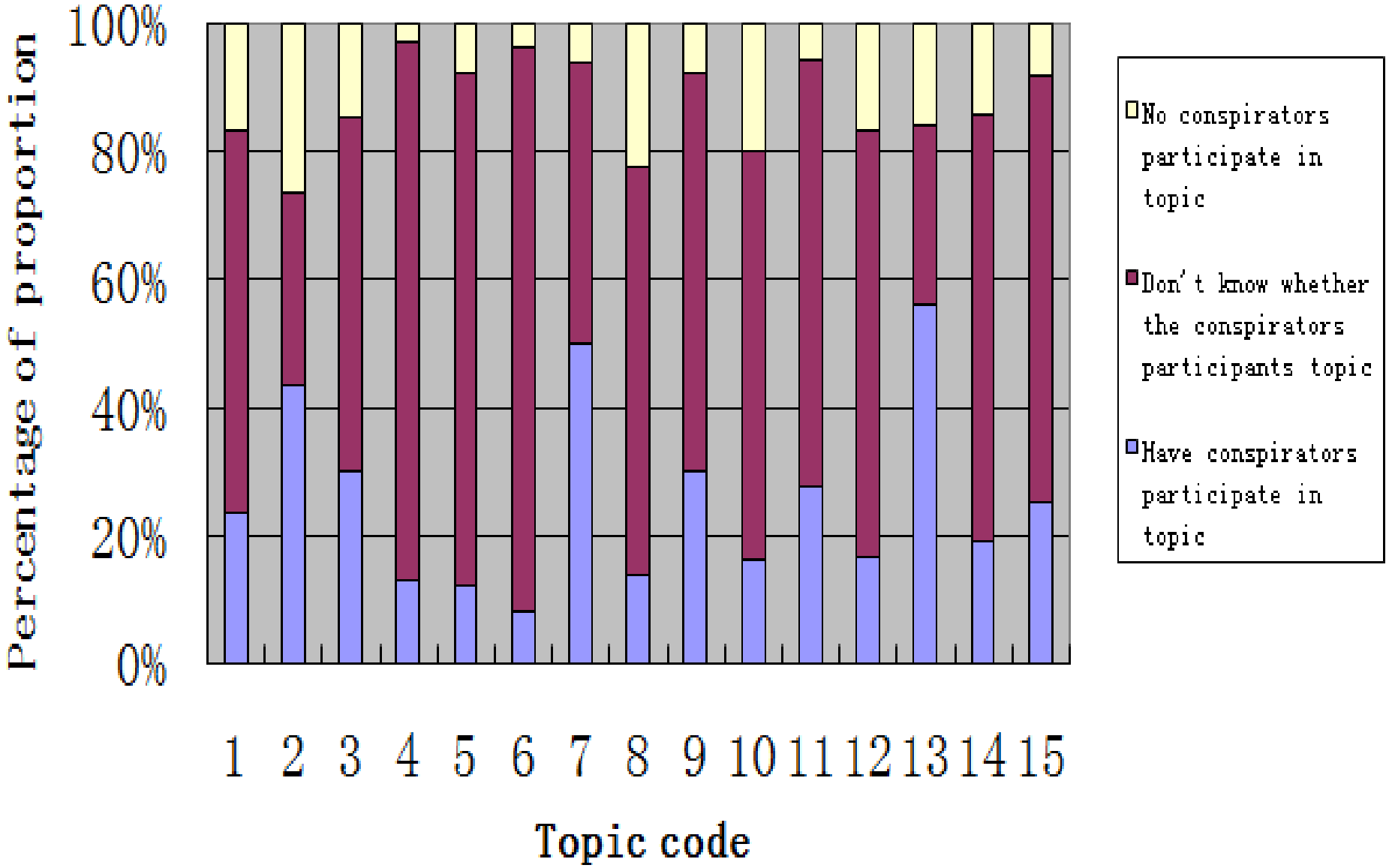
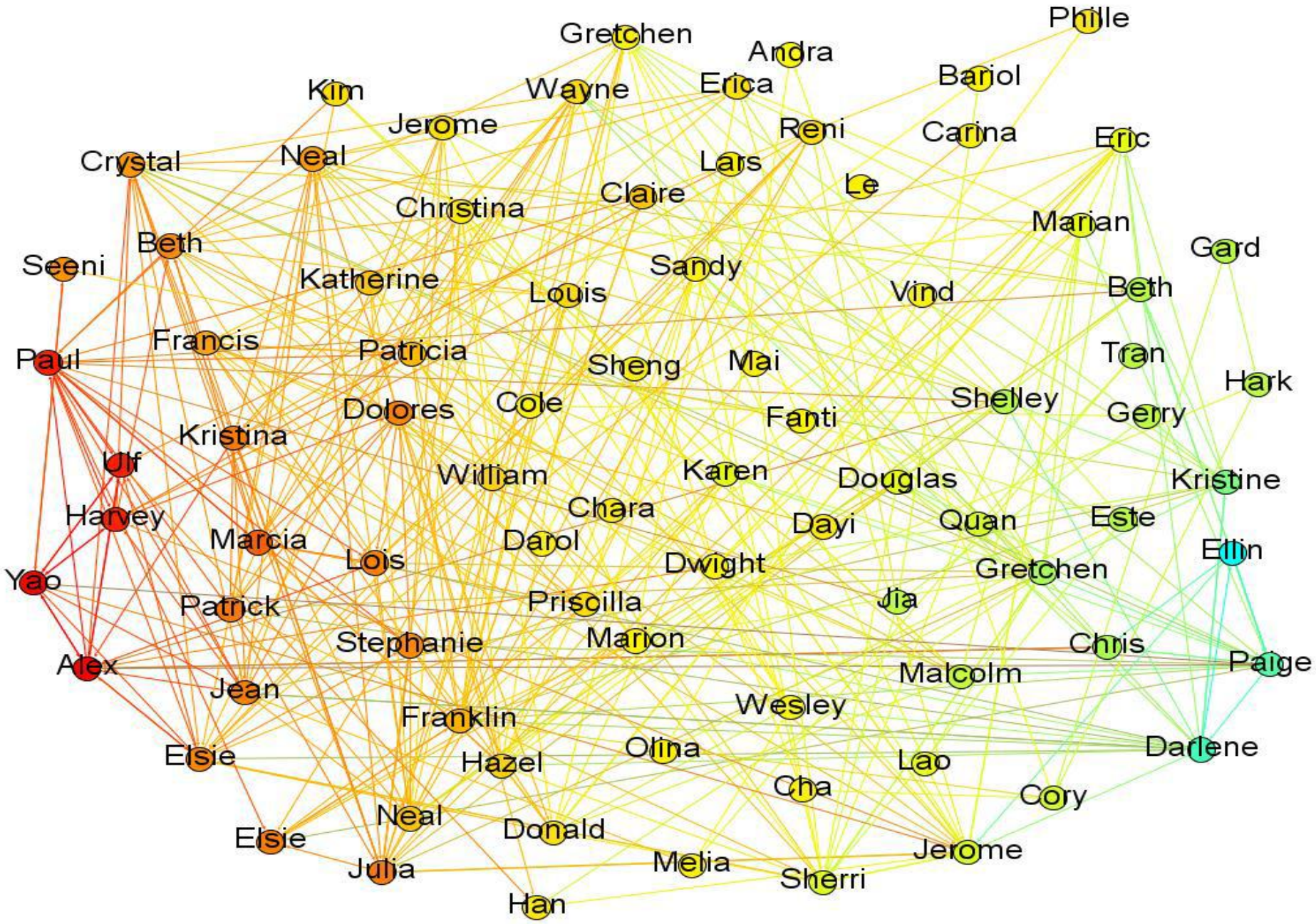

Percentage of proportion
100%
80%
60%
40%
20%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Topic code
No conspirators participate in topic
Don't know whether the conspirators participants topic
Have conspirators participate in topic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Ulf
William
Karen
Douglas
Kristine
Harvey
Chara
Dayi
Quan
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Dwight
Gretchen
Yao
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Jia
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Marion
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Alex
Paige
Malcolm
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Franklin
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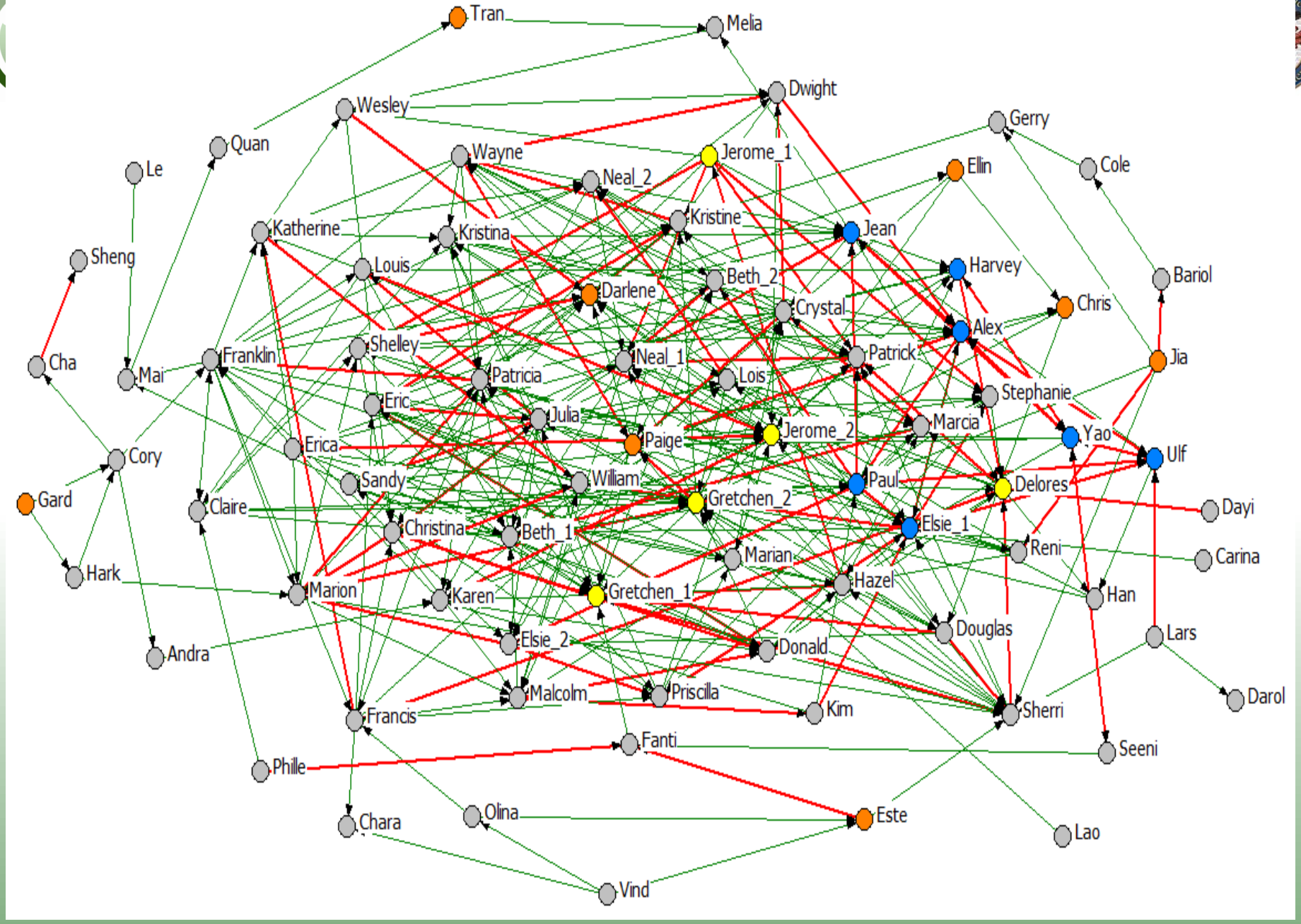
Melia
Sherri
Han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Crystal
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Franklin
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Patrick
Jia
Mai
Patricia
Lois
Stephanie
Eric
Julia
Marcia
Jerome_2
Yao
Erica
Paige
Cory
Ulf
Sandy
William
Paul
Delores
Gard
Claire
Gretchen_2
Dayi
Christina
Beth_1
Elsie_1
Reni
Marian
Carina
Hark
Hazel
Marion
Karen
Gretchen_1
Han
Douglas
Lars
Andra
Elsie_2
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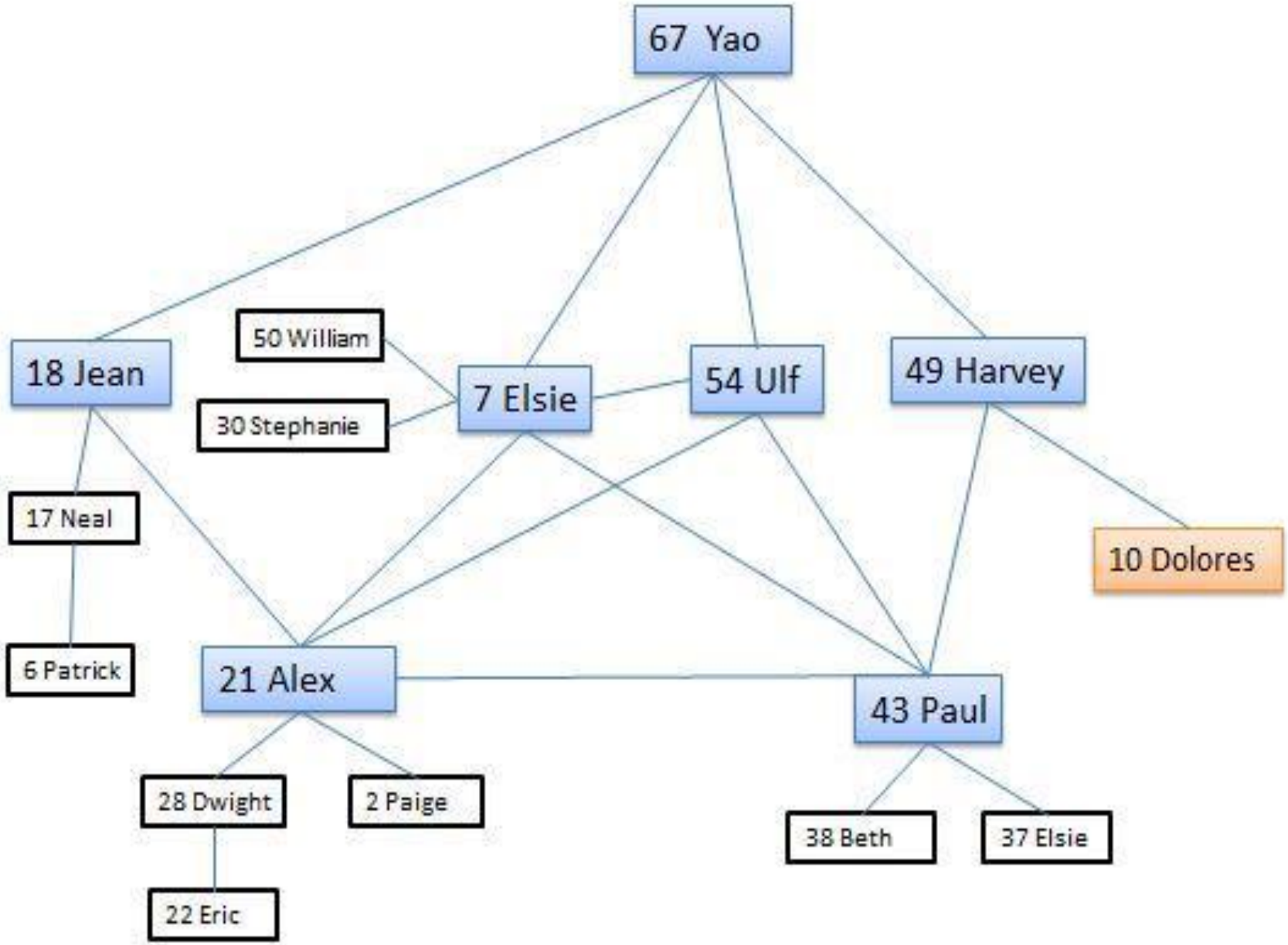
Fanti
Seeni
Phille
Olina
Este
Chara
Lao
Vind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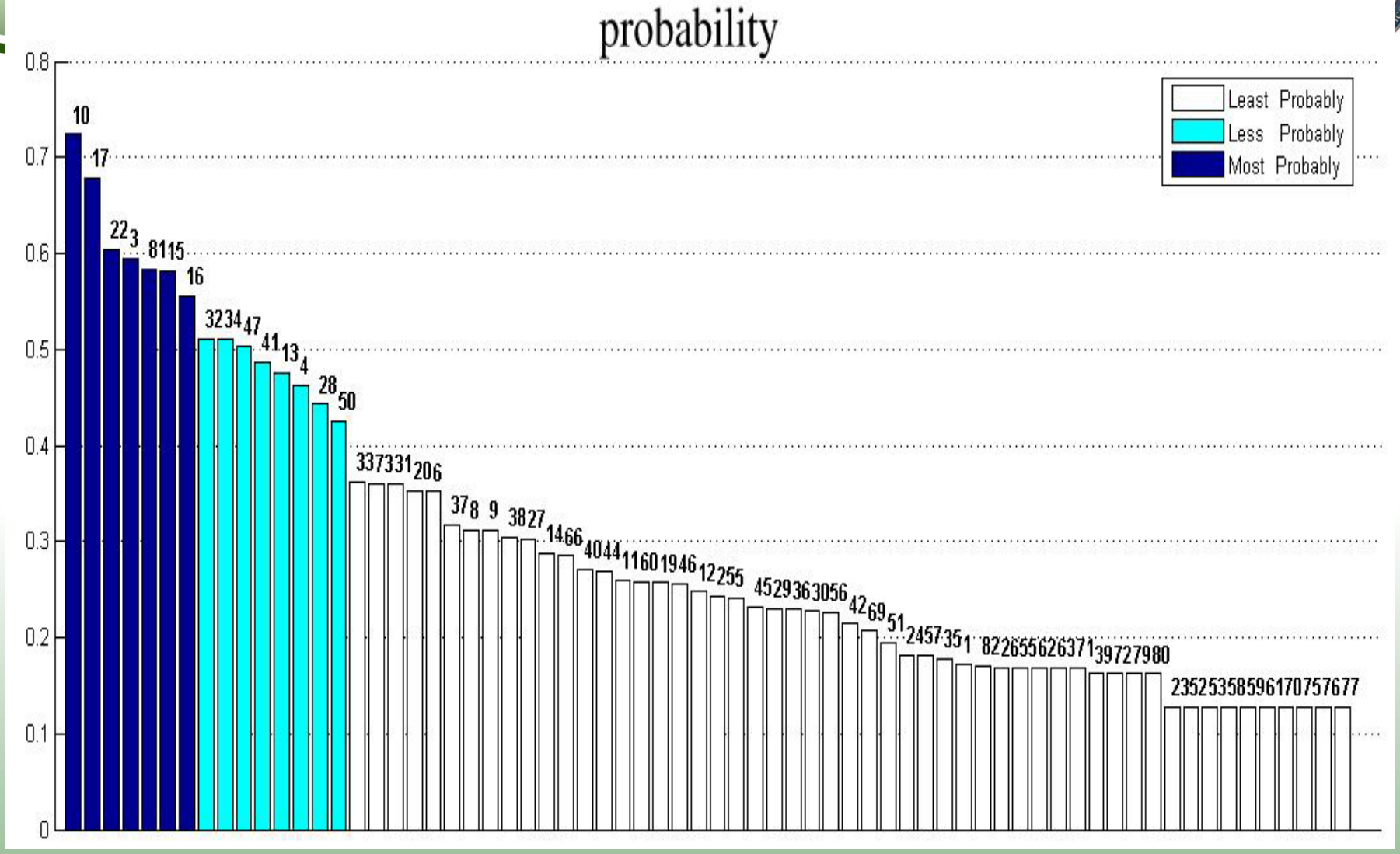
50 William
30 Stephanie
7 Elsie
54 Ulf
49 Harvey
17 Neal
10 Dolores
6 Patrick
21 Alex
43 Paul
28 Dwight
2 Paige
38 Beth
37 Elsie
22 Eric


probability
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Least Probably
Less Probably
Most Probably
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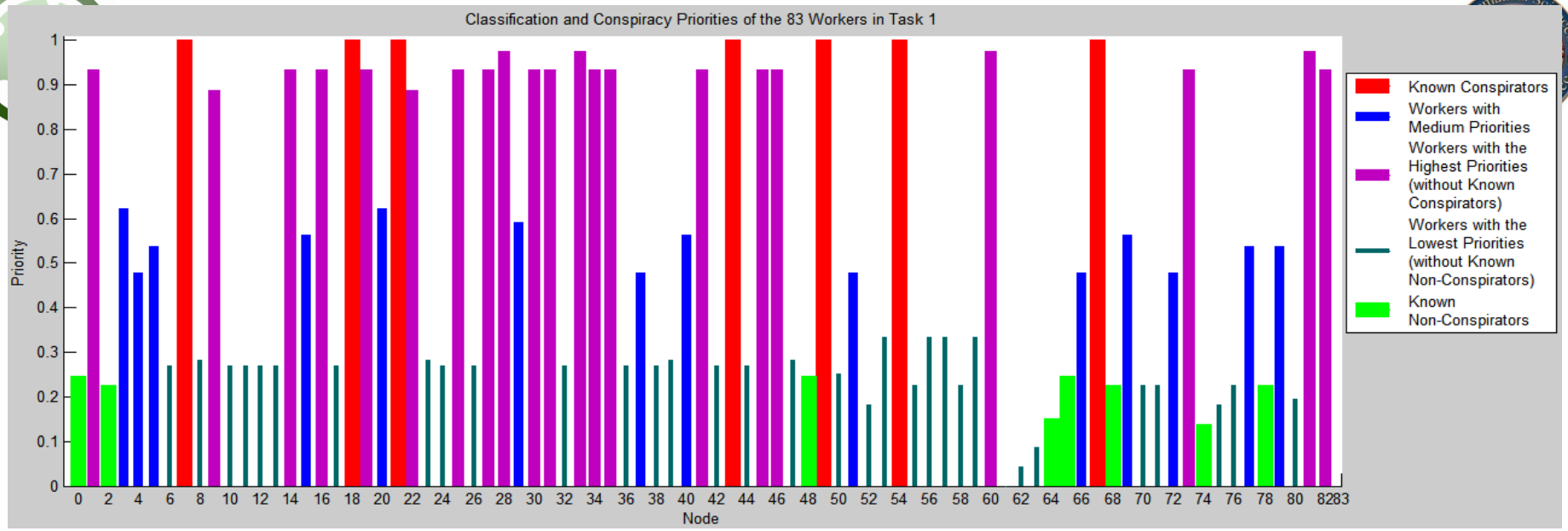
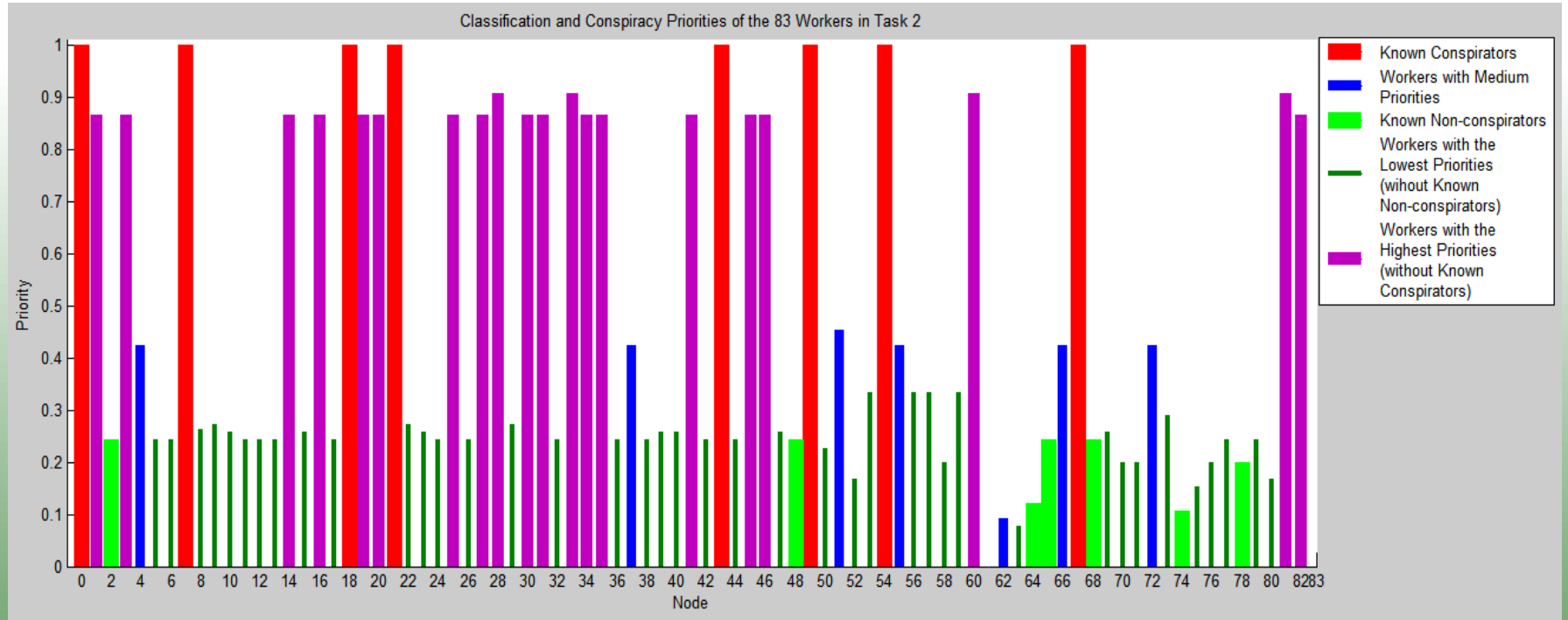
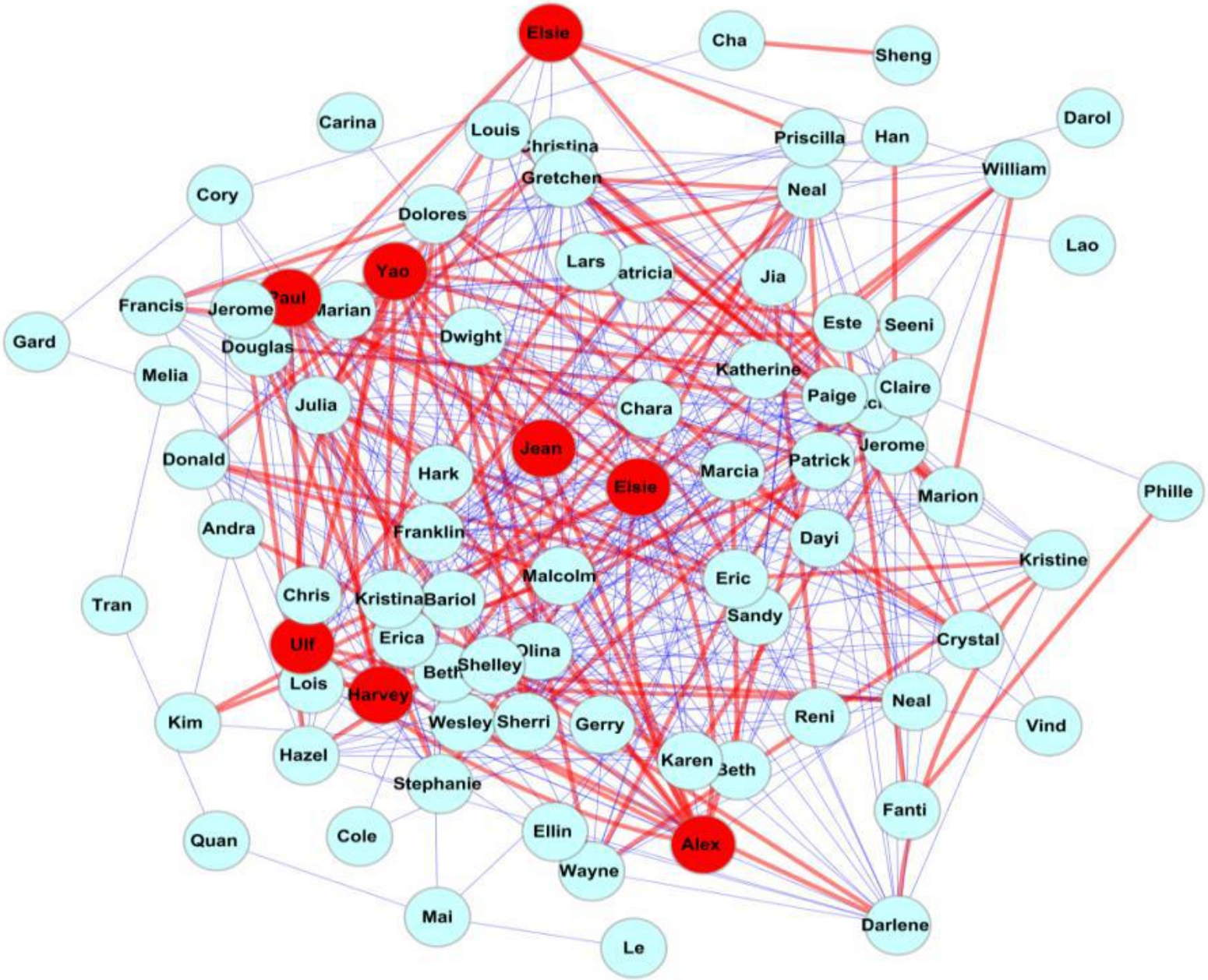
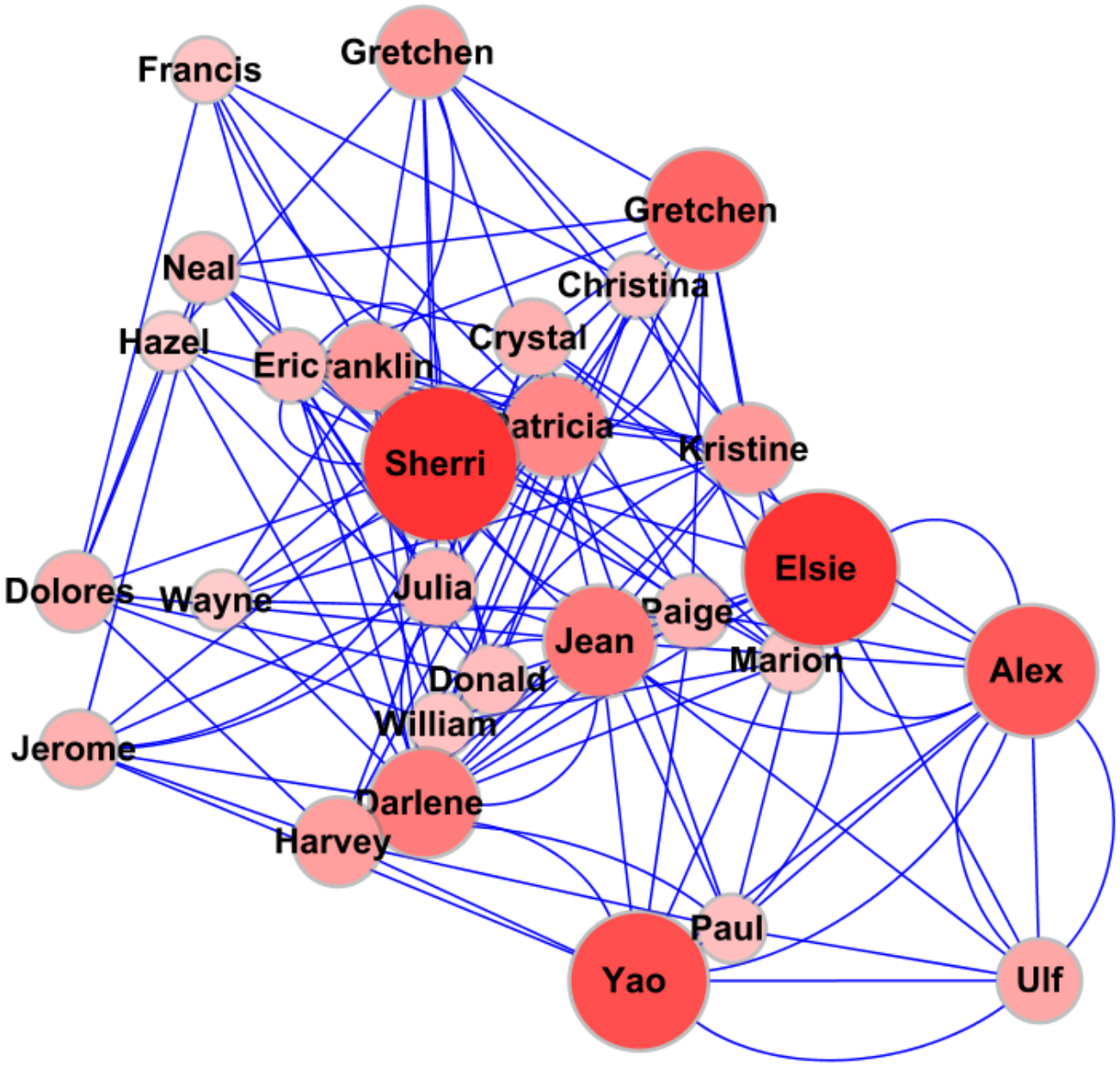

Classification and Conspiracy Priorities of the 83 Workers in Task 1
Priority
Node
Known Conspirators
Workers with Medium Priorities
Workers with the Highest Priorities (without Known Conspirators)
Workers with the Lowest Priorities (without Known Non-Conspirators)
Known Non-Conspirators


Classification and Conspiracy Priorities of the 83 Workers in Task 2
Priority
Node
Known Conspirators
Workers with Medium Priorities
Known Non-conspirators
Workers with the Lowest Priorities (wihout Known Non-conspirators)
Workers with the Highest Priorities (without Known Conspirators)


Elsie
Cha
Sheng
Carina
Louis
Christina
Priscilla
Han
Darol
William
Gretchen
Neal
Cory
Dolores
Lao
Lars
Yao
Patricia
Jia
Francis
Jerome
Paul
Marian
Este
Seeni
Gard
Douglas
Dwight
Melia
Katherine
Claire
Paige
Julia
Chara
Jean
Jerome
Donald
Hark
Marcia
Patrick
Elsie
Marion
Phille
Andra
Franklin
Dayi
Kristine
Malcolm
Eric
Tran
Chris
Kristina
Bariol
Sandy
Crystal
Ulf
Erica
Olina
Shelley
Beth
Lois
Harvey
Neal
Kim
Wesley
Sherri
Gerry
Reni
Vind
Hazel
Karen
Beth
Stephanie
Fanti
Quan
Cole
Ellin
Alex
Wayne
Mai
Darlene
Le


Francis
Gretchen
Gretchen
Neal
Christina
Hazel
Crystal
Eric
anklin
atricia
Sherri
Kristine
Elsie
Dolores
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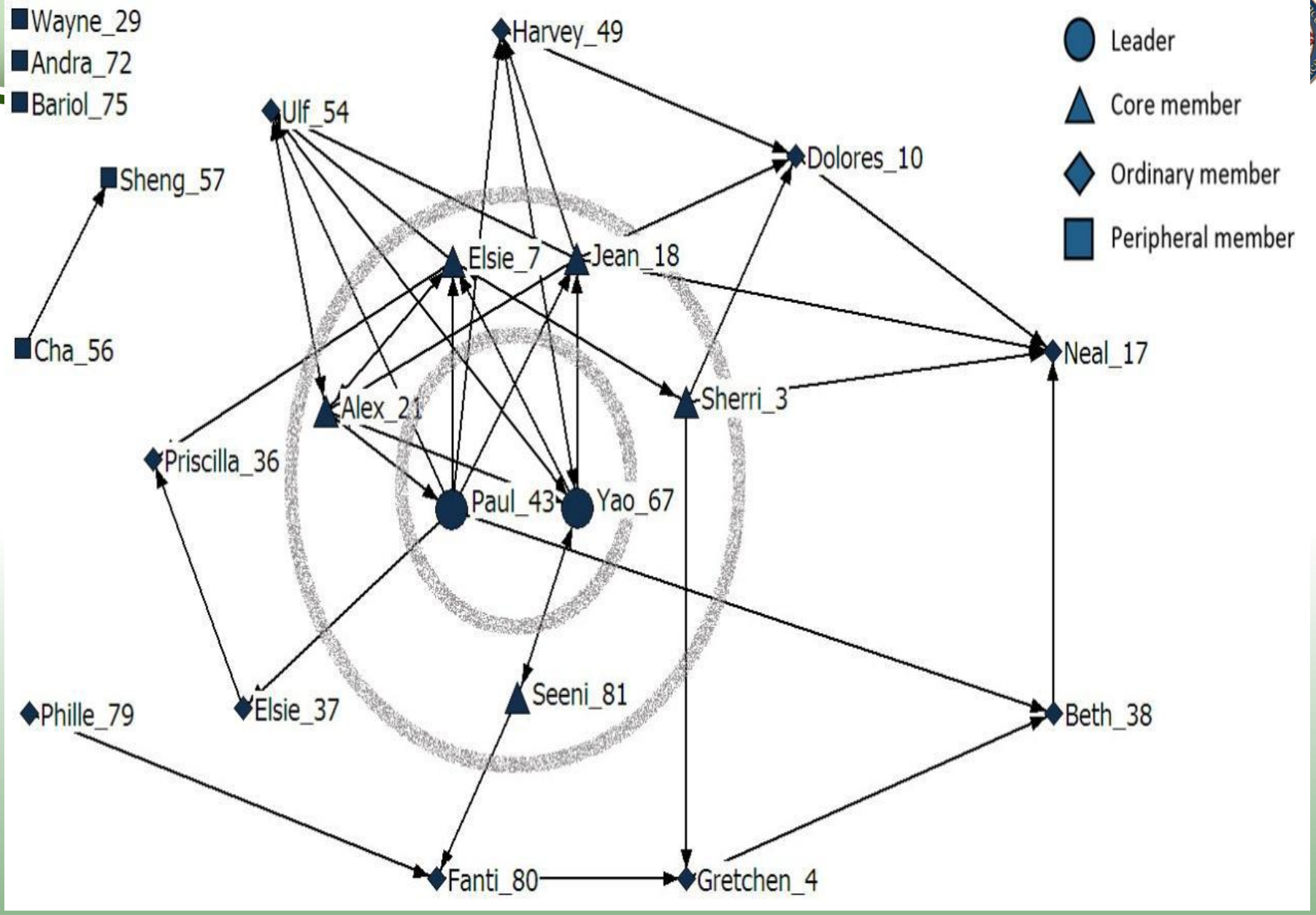
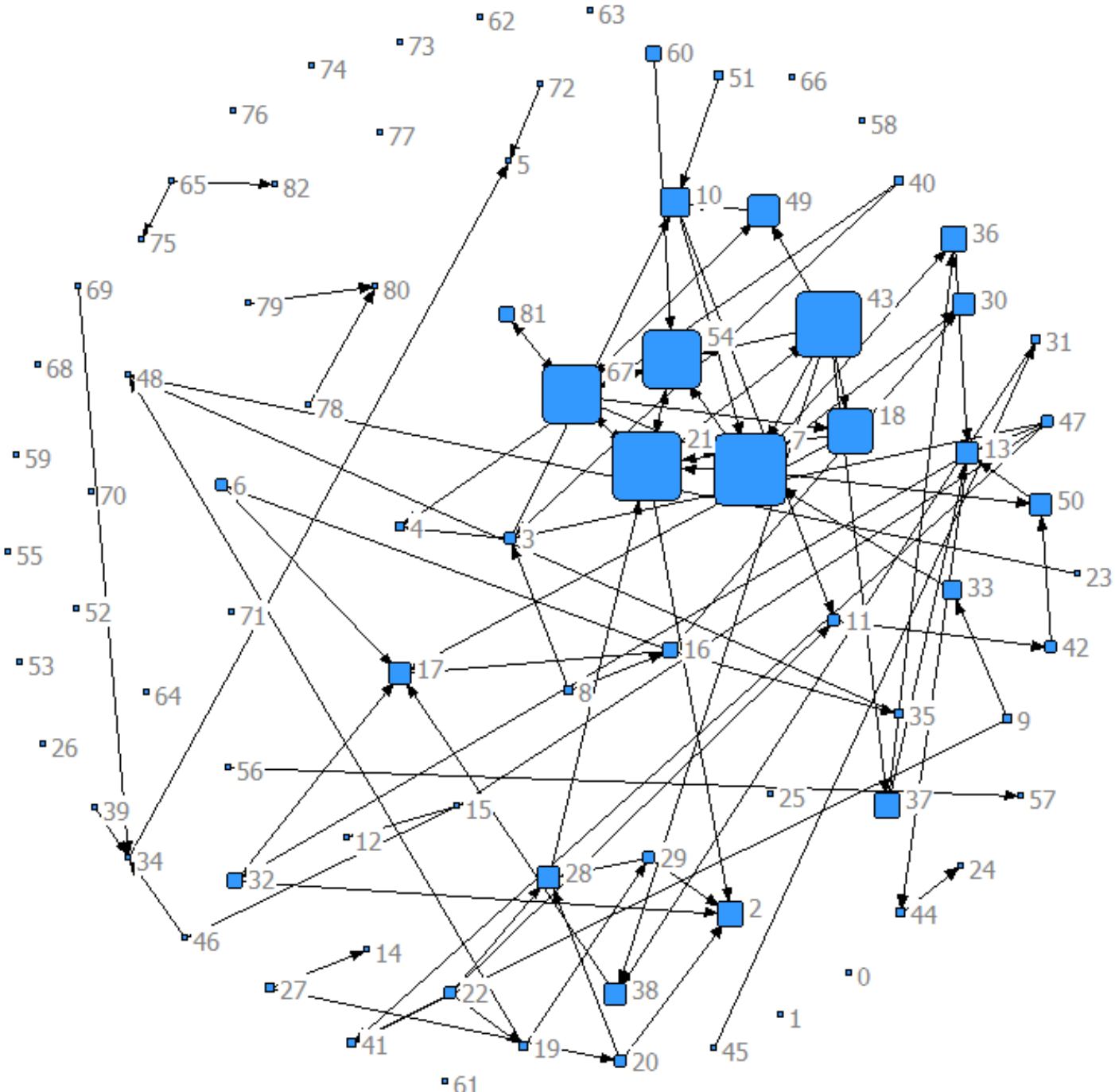
Julia
Paige
Jean
Marion
Alex
Donald
William
Jerome
Darlene
Harvey
Paul
Yao
Ulf


Wayne_29
Andra_72
Bariol_75
Harvey_49
Leader
Core member
Ordinary member
Peripheral member
Ulf_54
Dolores_10
Sheng_57
Elsie_7
Jean_18
Cha_56
Neal_17
Sherri_3
Alex_21
Priscilla_36
Paul_43
Yao_67
Seeni_81
Phille_79
Elsie_37
Beth_38
Fanti_80
Gretchen_4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ICM (Feb 2013)
(next year's problem will be another one involving network science)

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- and the Management Sciences
- The Society for Industrial and Applied Mathematics
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- ???