Systems Thinking for Design

Session 8

INDIAN INSTITUTE OF INFORMATION TECHNOLOGY,
DESIGN AND MANUFACTURING,
KANCHEEPURAM

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Session outline: Diagnosis using Properties of Complex Networks

Introduction to complex networks

Properties of complex networks

Introduction

- We have already seen how one could use the in-, out- and total-degree to understand the nature of the network and classify the key elements

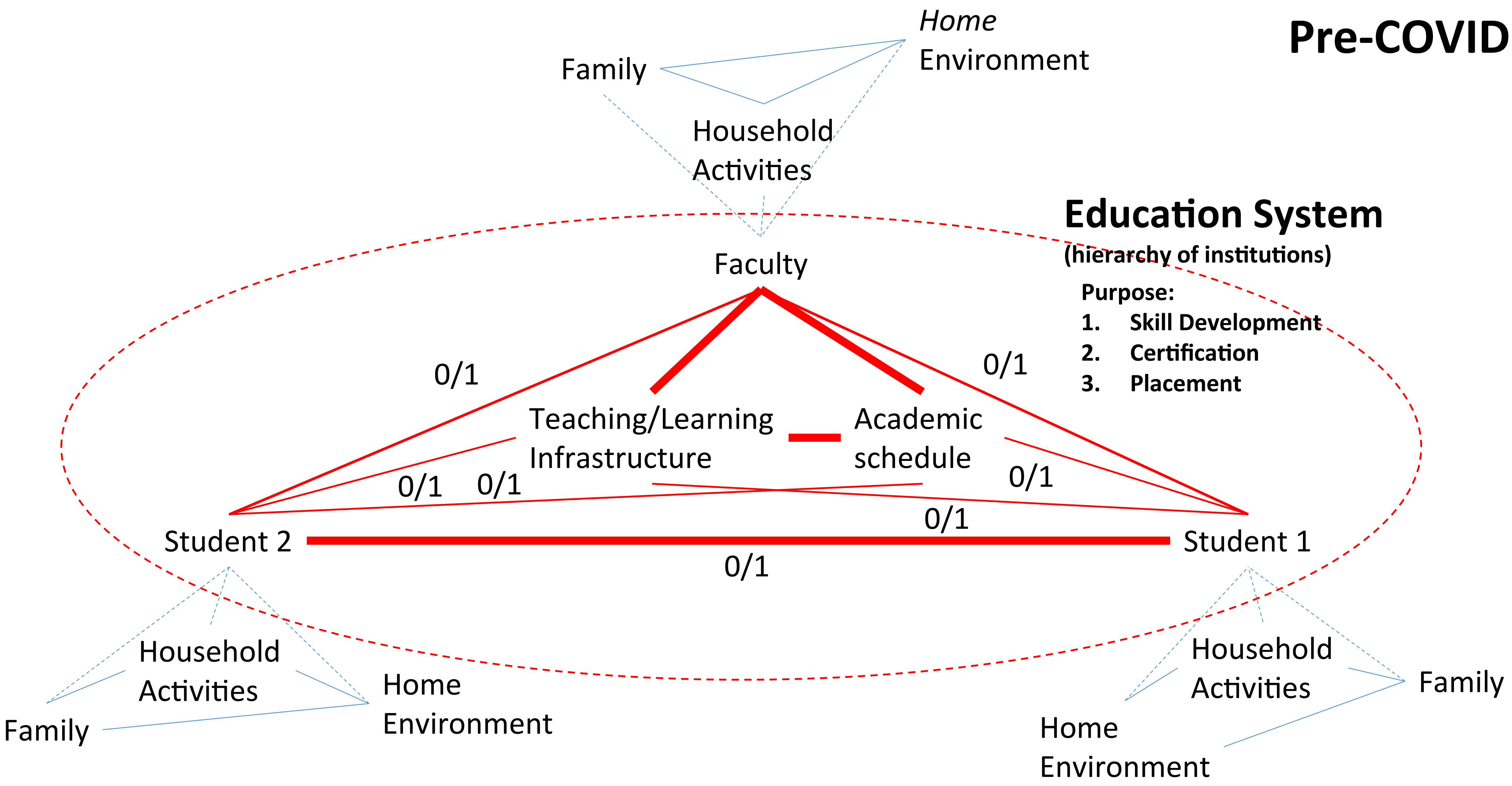
- In this session we will see how one could use other properties of complex networks to understand the problem situation

- We will analyze the discovery matrix (of the problem situation) to extract
  - Cores
  - Clusters
  - Centrality of nodes

What is a network perspective?

- A network perspective is about looking at the
  - Real world as elements (nodes) and relationships (edges/arcs)
  - With no clear ‘boundary’ (or the difference between inside and outside)

Pre-COVID

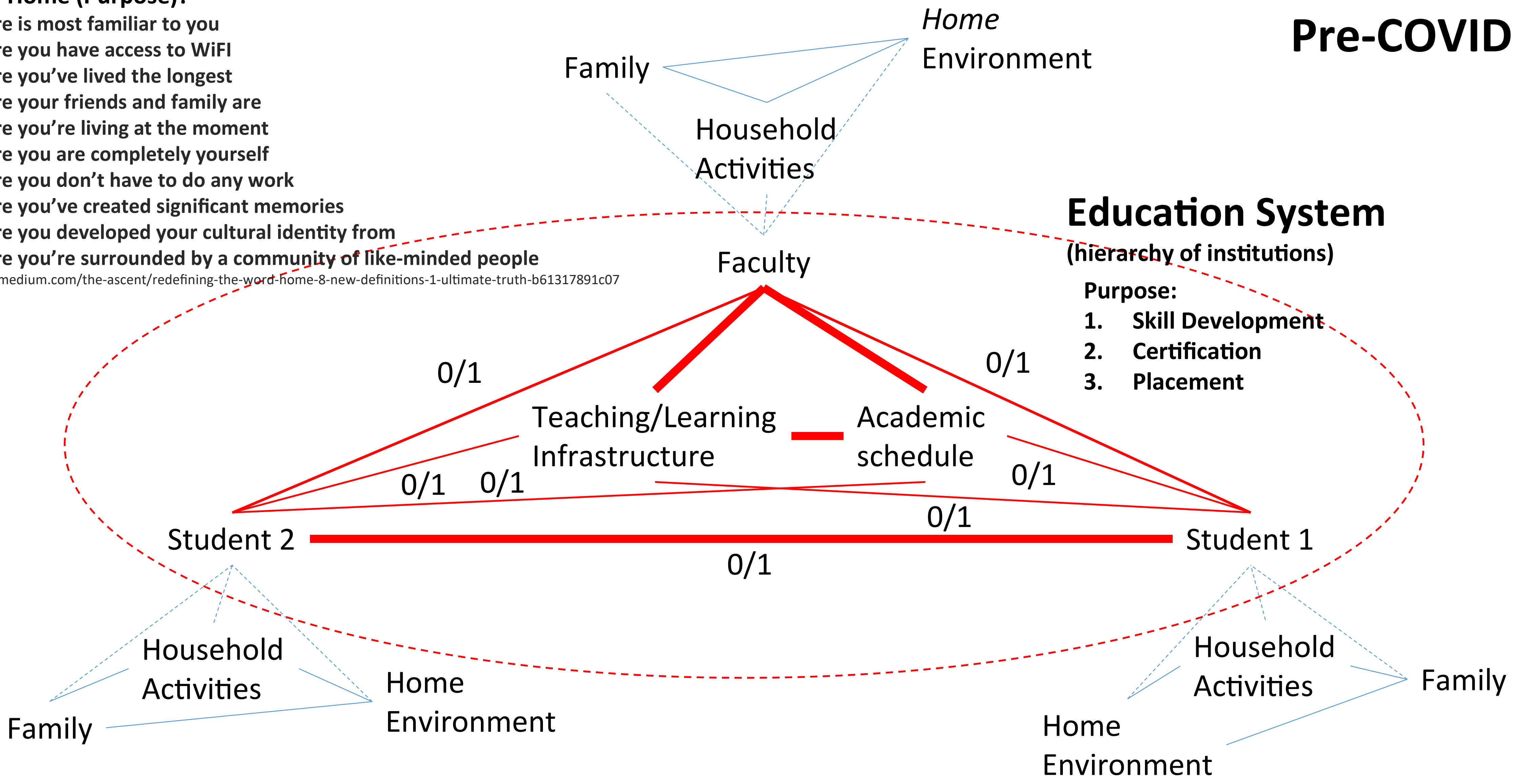

Home
Environment
Family
Household
Activities
Education System
(hierarchy of institutions)
Purpose:
1. Skill Development
2. Certification
3. Placement
Faculty
0/1
0/1
Teaching/Learning
Infrastructure
Academic
schedule
0/1
0/1
0/1
0/1
Student 2
Student 1
0/1
Household
Activities
Family
Home
Environment
Household
Activities
Family
Home
Environment

What is a Home (Purpose)?

1. Where is most familiar to you
2. Where you have access to WiFI
3. Where you've lived the longest
4. Where your friends and family are
5. Where you're living at the moment
6. Where you are completely yourself
7. Where you don't have to do any work
8. Where you've created significant memories
9. Where you developed your cultural identity from
10. Where you're surrounded by a community of like-minded people

Source: https://medium.com/the-ascent/redefining-the-word-home-8-new-definitions-1-ultimate-truth-b61317891c07

Pre-COVID

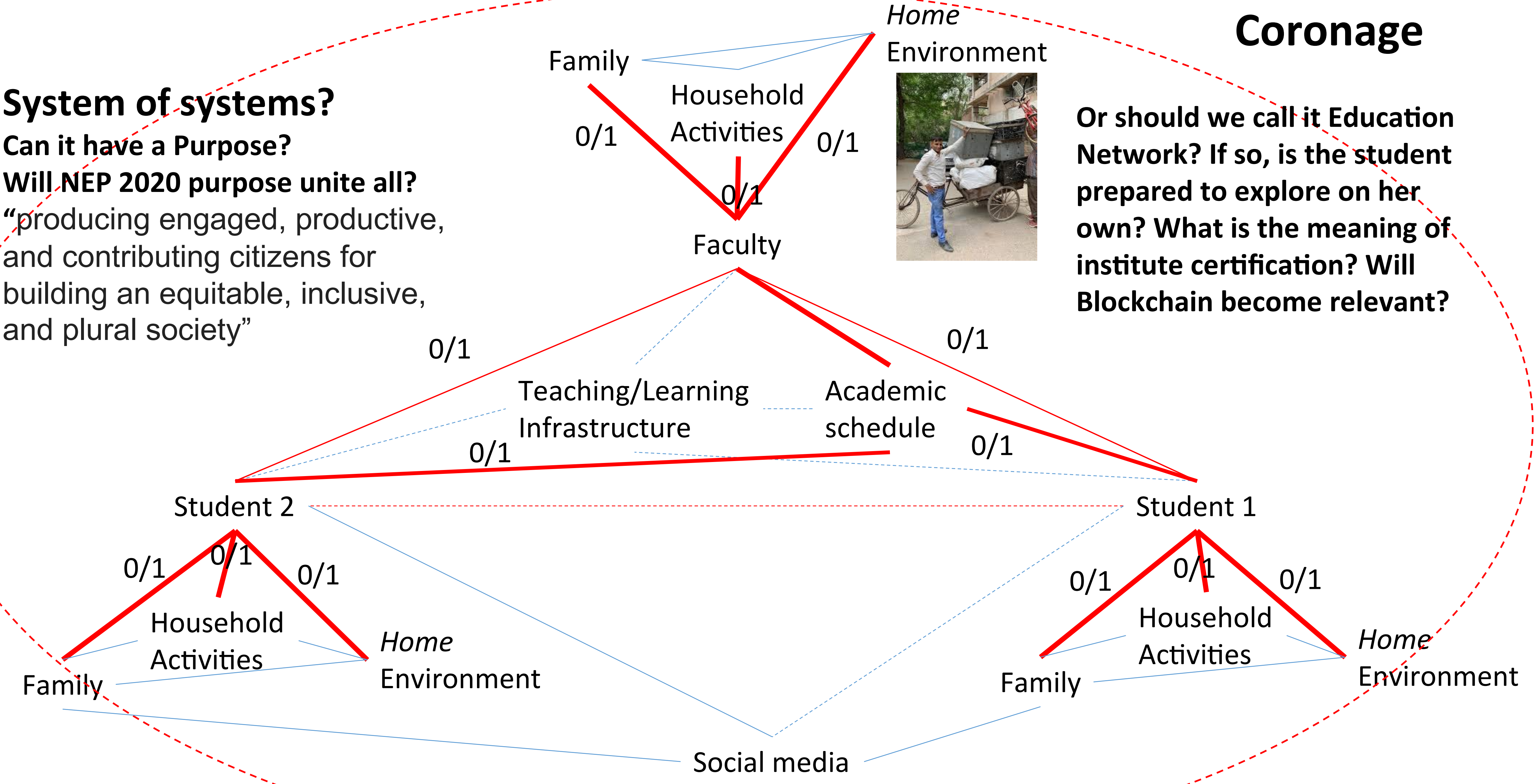


Coronage

System of systems?

Can it have a Purpose?
Will NEP 2020 purpose unite all?
“producing engaged, productive, and contributing citizens for building an equitable, inclusive, and plural society”

Or should we call it Education Network? If so, is the student prepared to explore on her own? What is the meaning of institute certification? Will Blockchain become relevant?



Complex networks in the real-world (1/5)

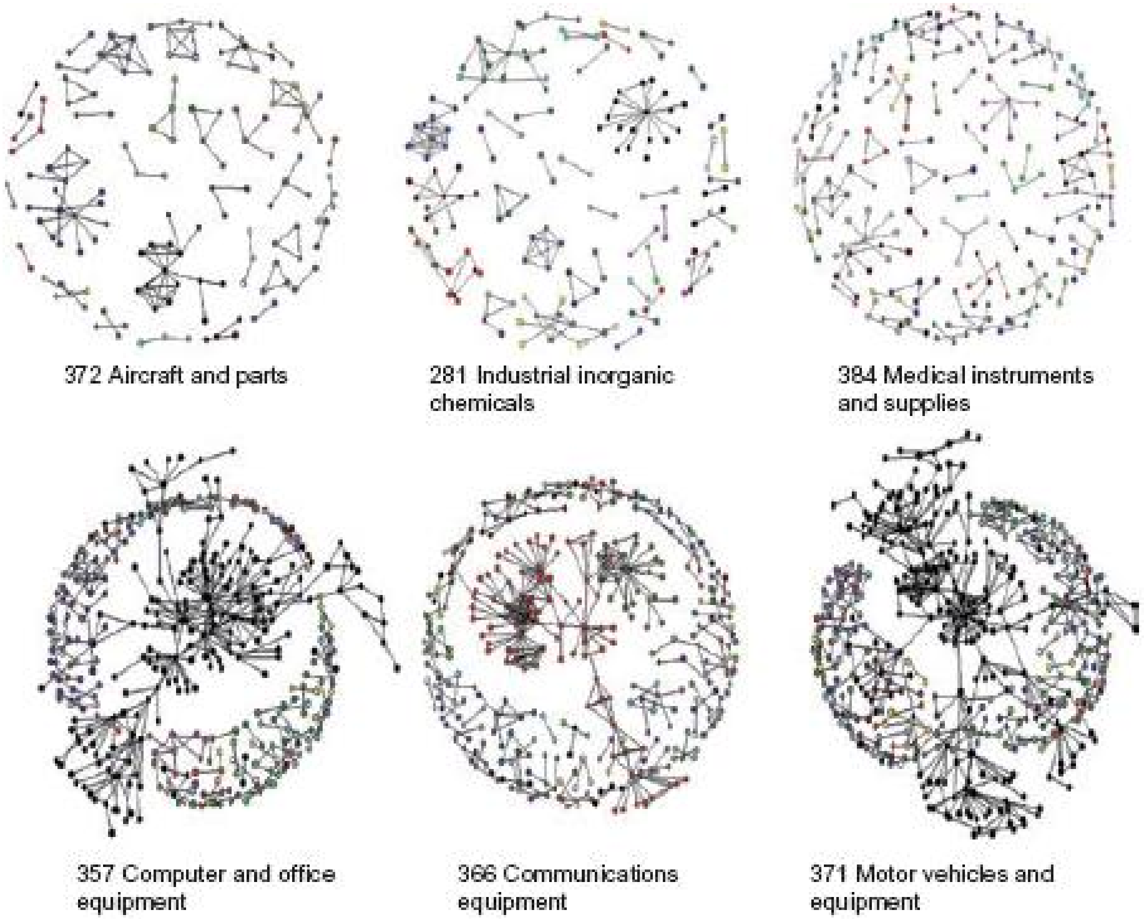
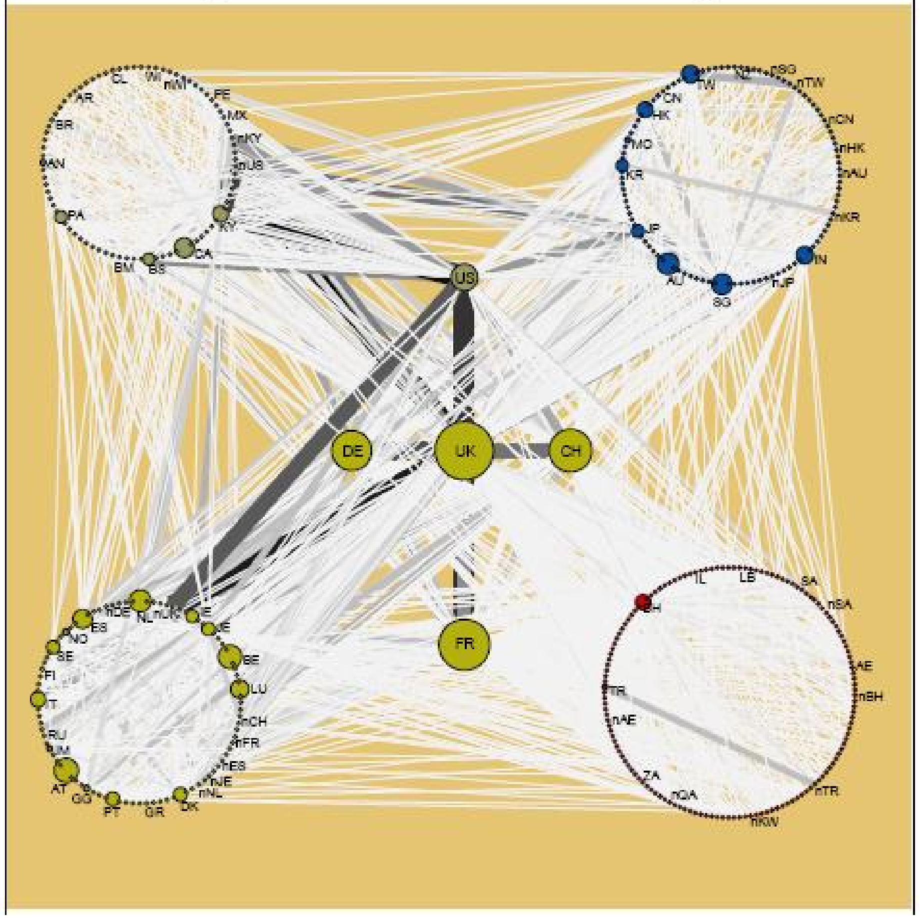


Figure 2. Nine industry alliance networks—graphical visualizations

Strategic Alliance Networks in different industries

Complex networks in real-world (2/5)

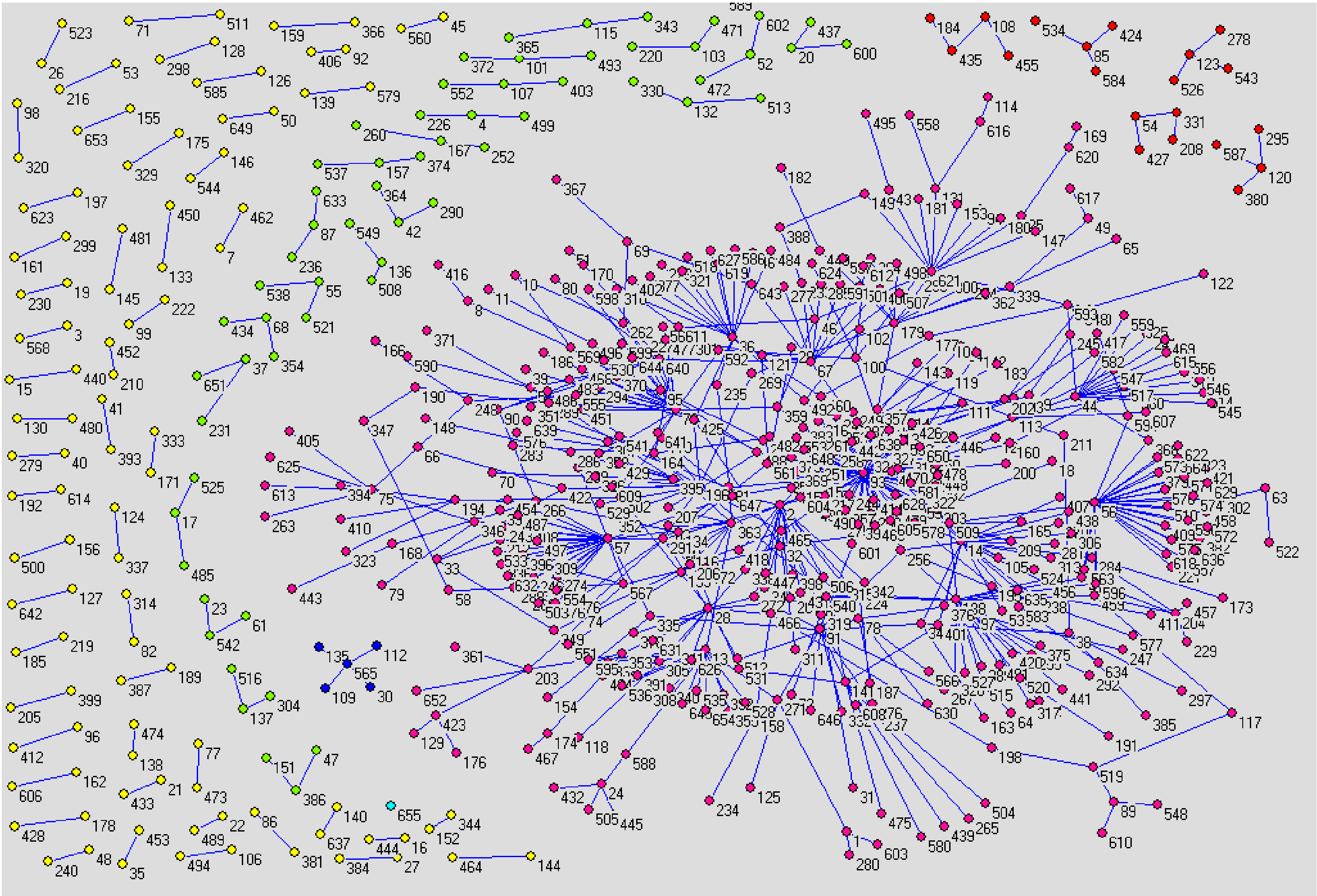
Global and regional hubs in the international banking network



The graph shows the linkages between 212 banking centres and their linkages with 212 non-banks.

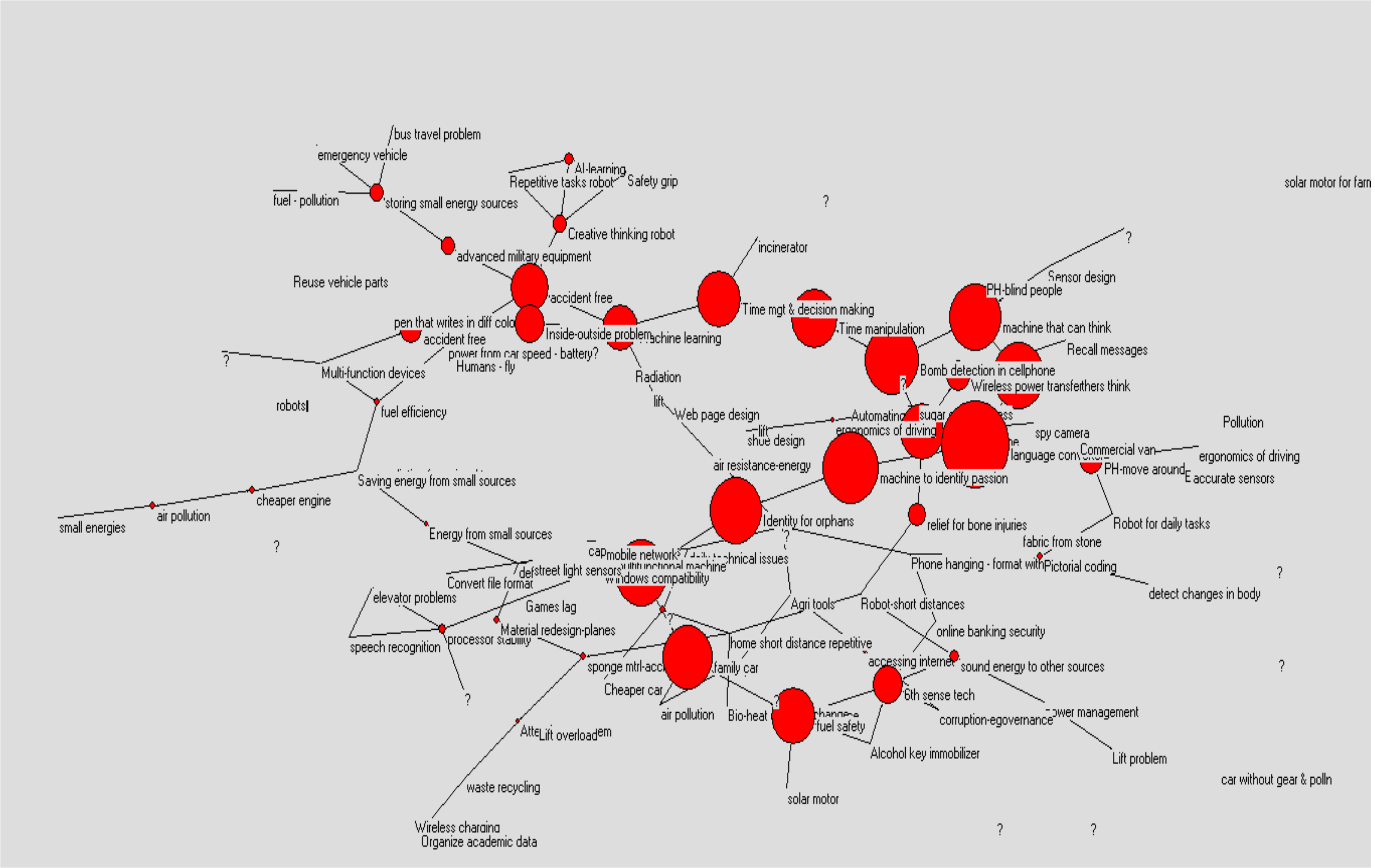
Each location is represented by a node. The color of the nodes represents the continent (red for Africa and the Middle East, green for the Americas, blue for Asia-Pacific and mustard for Europe).

Complex networks in the real-world (3/5)



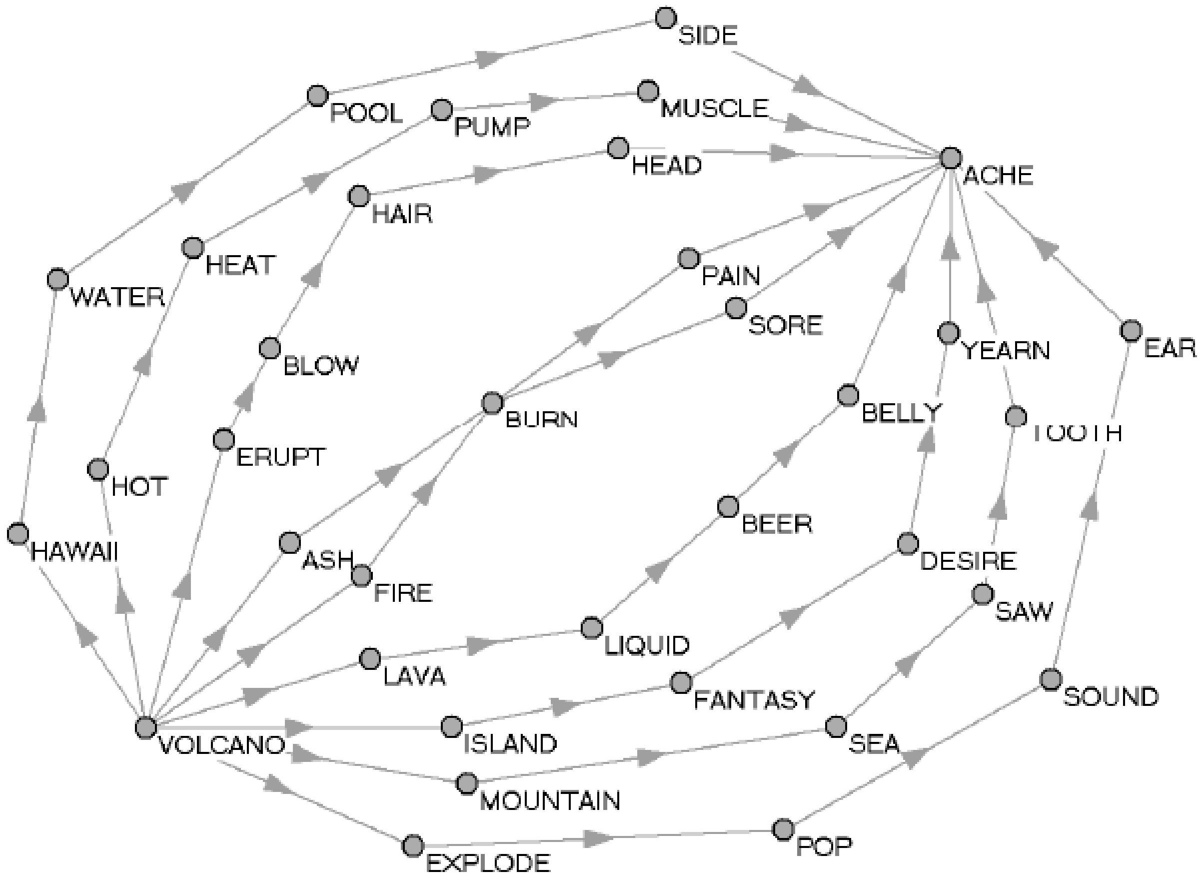
IT supplier contracts in Global Banking

Complex networks in the real-world (4/5)



Potential areas of collaboration among ideas of students

Complex networks in the real-world (5/5)



Part of the semantic network formed by free association.

Each directed edge illustrates an association between a cue and a response.

A sample of associative directed paths from VOLCANO to ACHE is shown (the shortest path length is four)

Session outline: Diagnosis using Properties of Complex Networks

Introduction to complex networks

Properties of complex networks

Concepts of complex networks

Question	Local metrics	Global metrics
How many different influences does an entity receive? How many other entities does it influence?	degree, in-degree, out-degree	degree distribution
Do some nodes in a network play an important role in connecting the whole network?	Centrality	degree distribution
How tightly are the entities (nodes) grouped together (by edges)?	clique, n-clique, k-core	clustering coefficient
How long does communication between nodes take?	shortest-path length	Diameter (maximum path length between nodes)

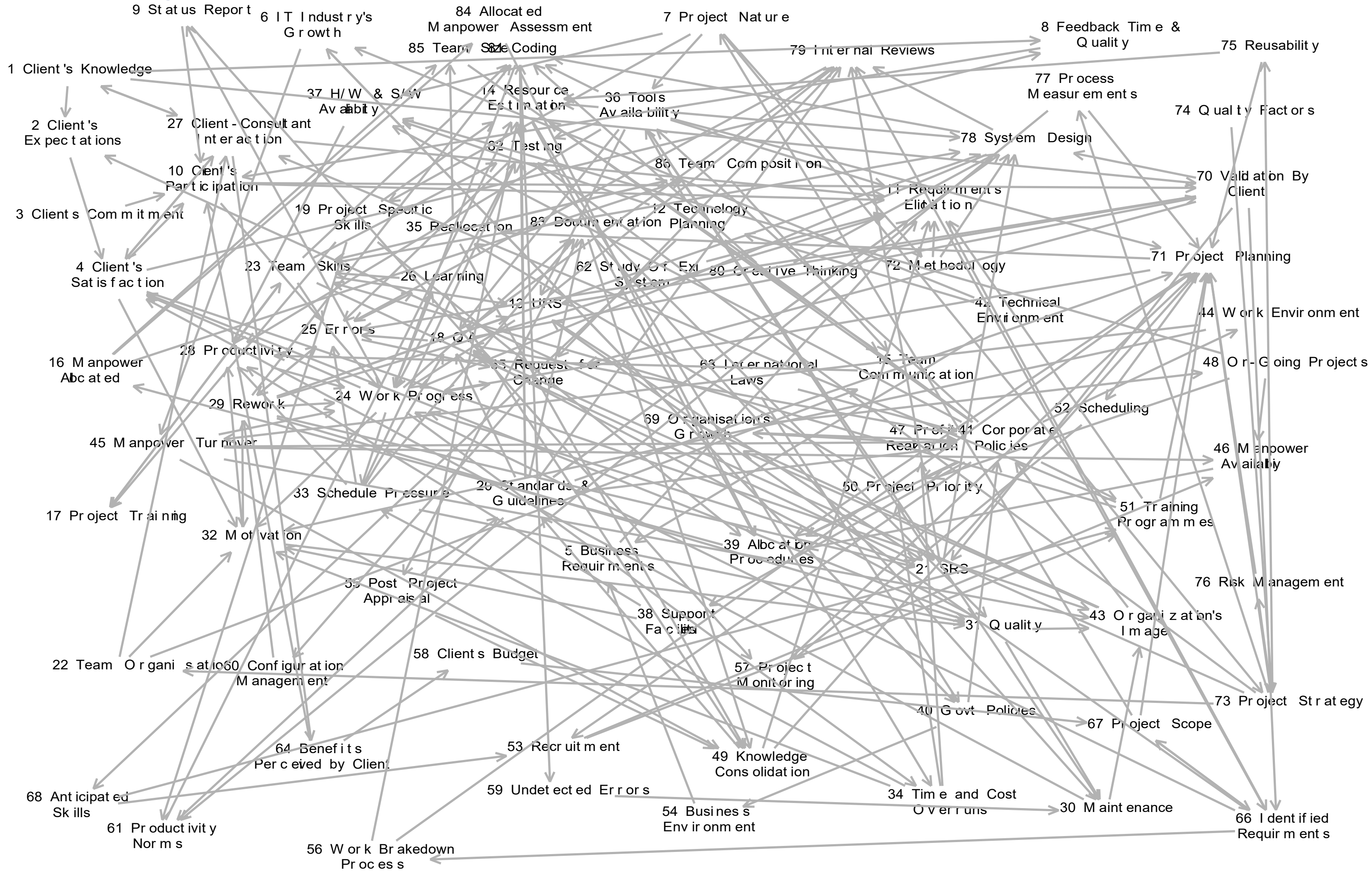
Network analysis tools

- For scholarly research tools like *UCINet*, *Pajek*, *ORA*, the *statnet* suite of packages in *R*, and *GUESS* are popular.

- Examples of business oriented social network tools include *InFlow*, *Keyhubs*, *NetMiner*, *Sentinel Visualizer* .

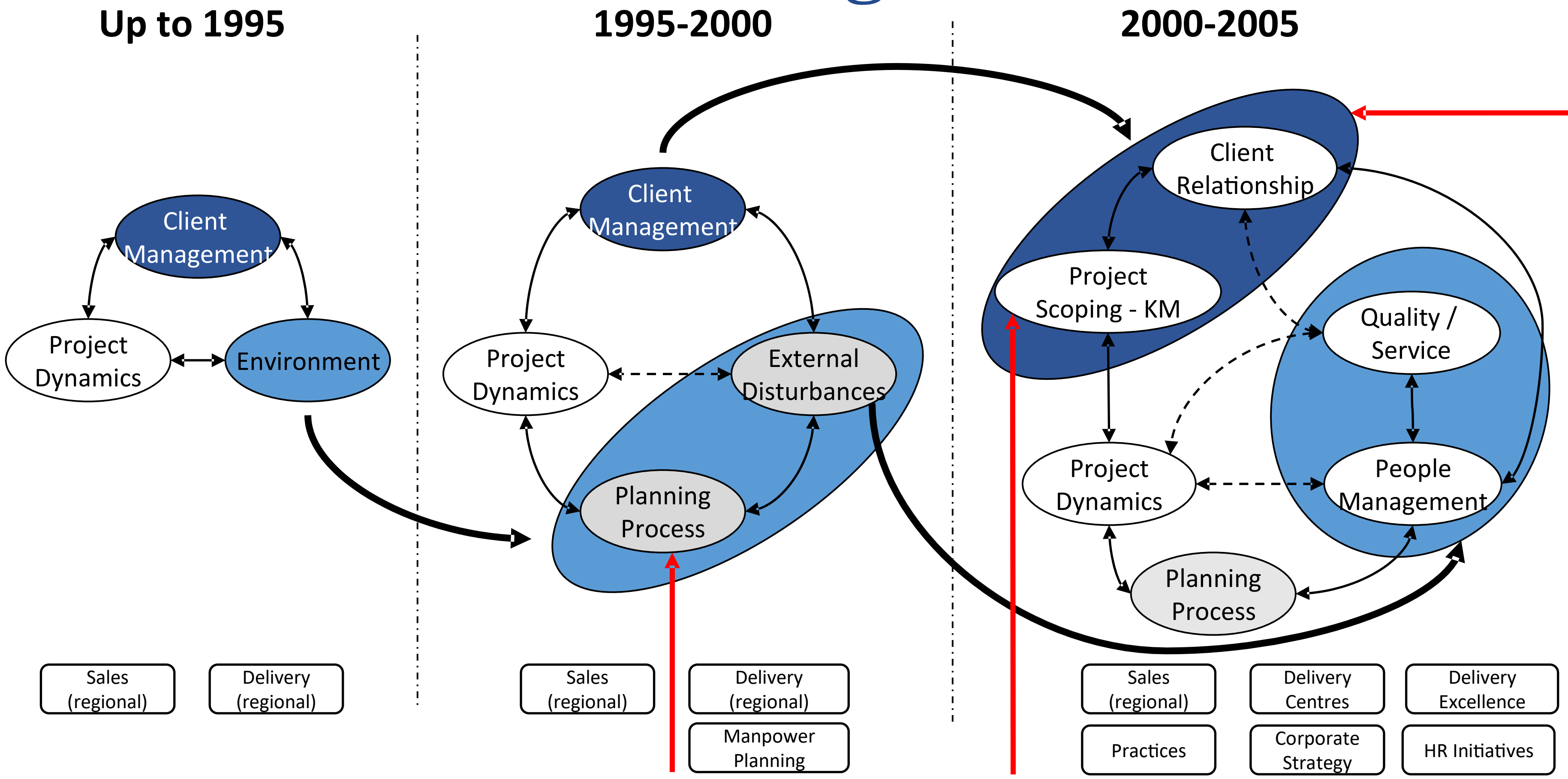
- http://www.insna.org/

Example: A large number of factors are involved in complex projects / products



Study by Prof.Sudhir V at TCS

Example: Patterns can be extracted from systems models – evolution of a global IT services company

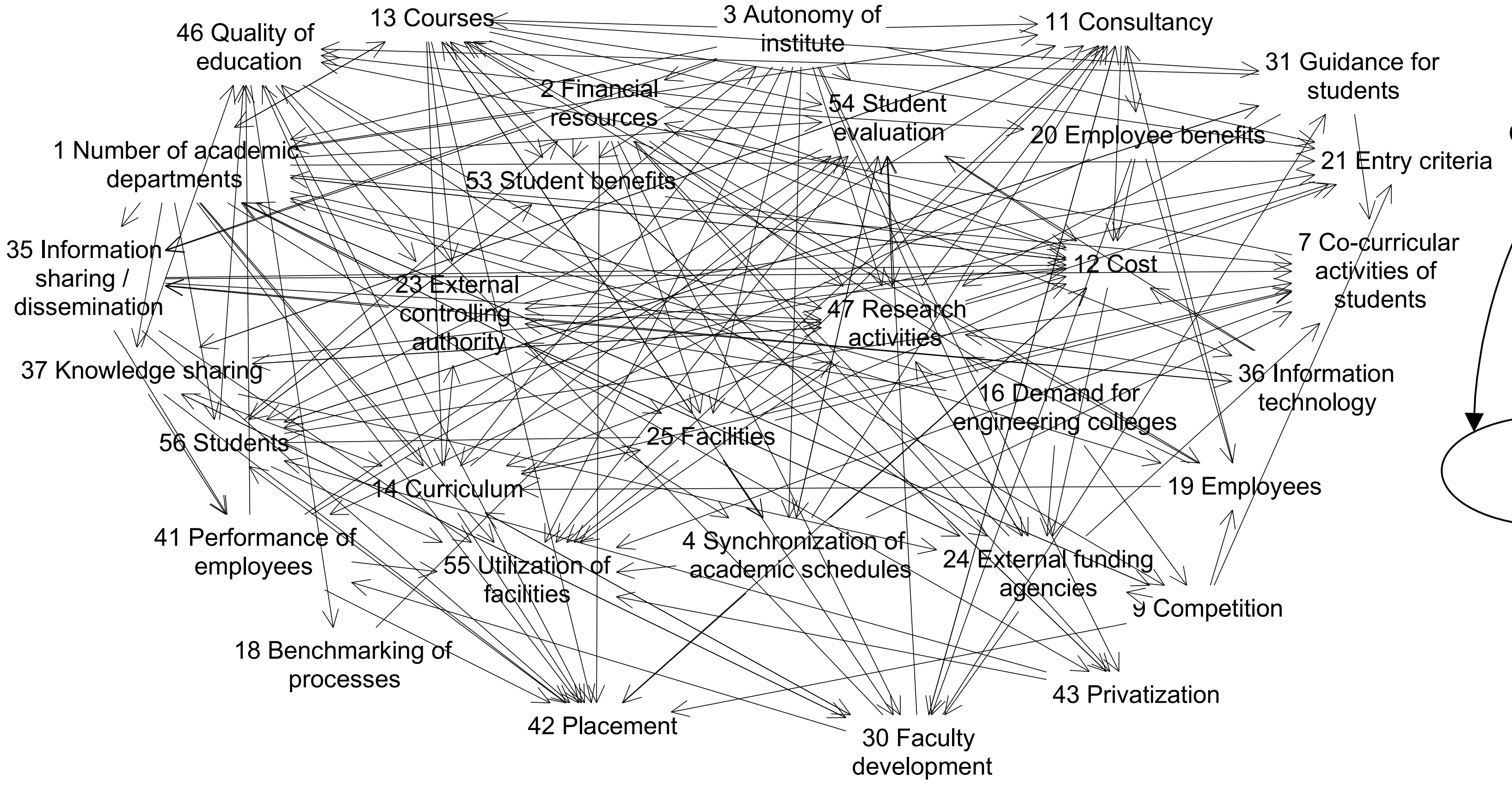


Importance of **Service Design and Innovation** … distinctive patterns & attractors

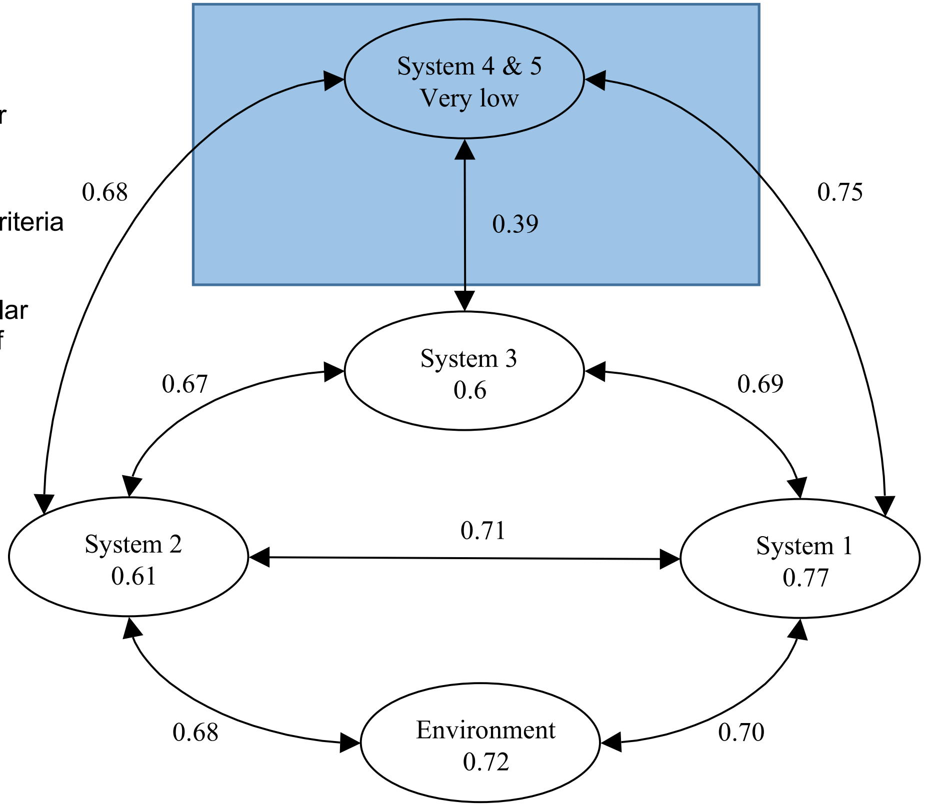
SE for Program Planning

SE for Requirements Mgt and Business-IT Alignment (Arch)

View of an Engineering College



Weak Strategic Capability



Different types of networks

- Random … Erdos & Renyi
- Scale free (power law) … Albert, Barabasi
- Small world (six degrees) … Watts

Random graphs (1/4)

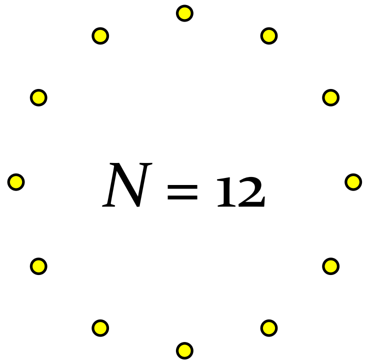
Erdős and Renyi (1959)

N nodes

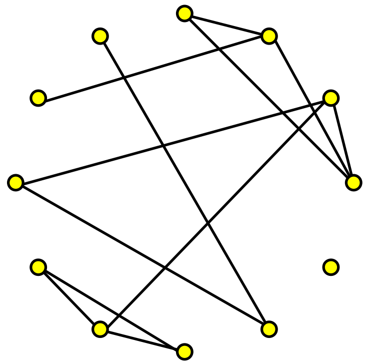
A pair of nodes has probability *p* of being connected

Average degree, $k \approx pN$

$p = 0.0\ ;\ k = 0$

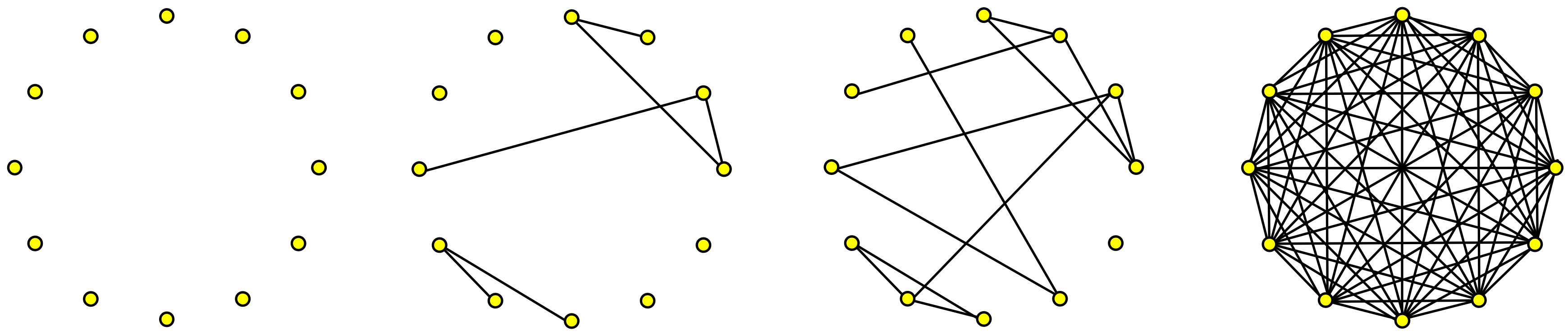


$p = 0.09\ ;\ k = 1$



Random Graphs (2/4)

What interesting things can be said for different values of p or k ?



$p = 0.0$; $k = 0$	$p = 0.045$; $k = 0.5$	$p = 0.09$; $k = 1$	$p = 1.0$; $k \approx ½N^2$

Size of largest component

1	5	11	12

Diameter of largest component

0	4	7	1

Average path length between nodes

0.0	2.0	4.2	1.0

Random graphs (3/4)

If $k < 1$:

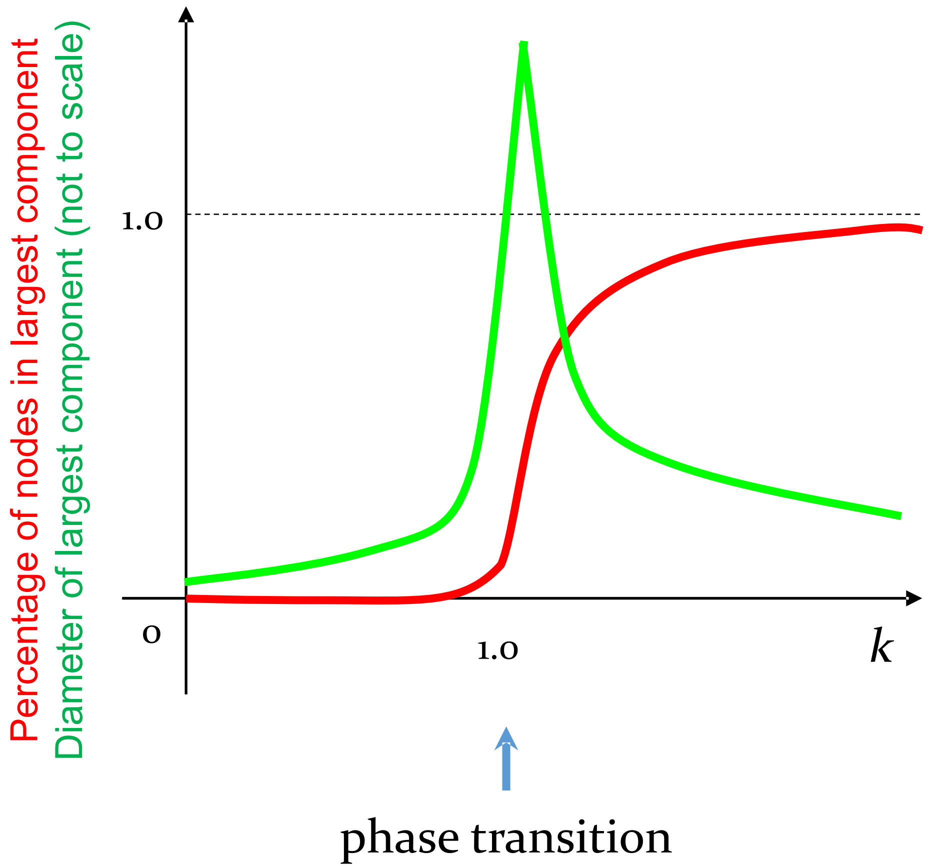
- small, isolated clusters
- small diameters
- short path lengths

At k = 1:

- a *giant component* appears
- diameter peaks
- path lengths are high

For k > 1:

- almost all nodes connected
- diameter shrinks
- path lengths shorten



Random graphs (4/4)

What does this mean?

If connections between people can be modeled as a random graph, then…

- Because the average person easily knows more than one person ($k >> 1$),
- **We live in a "small world" where within a few links, we are connected to anyone in the world**
- Erdős and Renyi showed that average path length between connected nodes is

$$\frac{\ln N}{\ln k}$$

Six degrees of separation (1/2)

Milgram (1967)

The experiment:

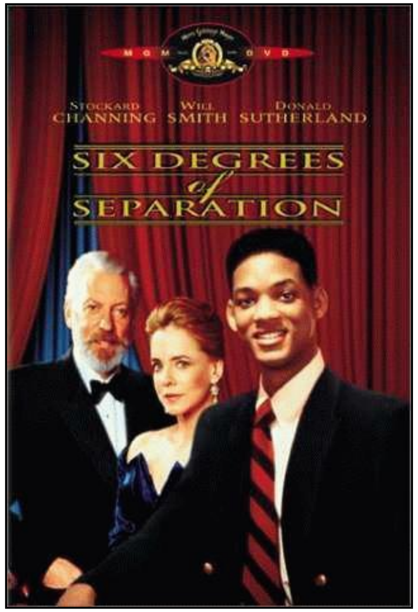
Random people from Nebraska were to send a letter (via intermediaries) to a stock broker in Boston.

Could only send to someone with whom they were related on a first-name basis.

Among the letters that found the target, the average number of links was six.

Stanley Milgram (1933-1984)

Six degrees of separation (2/2)



John Guare wrote a play called *Six Degrees of Separation,* based on this concept.

"Everybody on this planet is separated by only six other people. Six degrees of separation. Between us and everybody else on this planet. The president of the United States. A gondolier in Venice… It's not just the big names. It's anyone. A native in a rain forest. A Tierra del Fuegan. An Eskimo. I am bound to everyone on this planet by a trail of six people…"

Small-world networks (1/5)

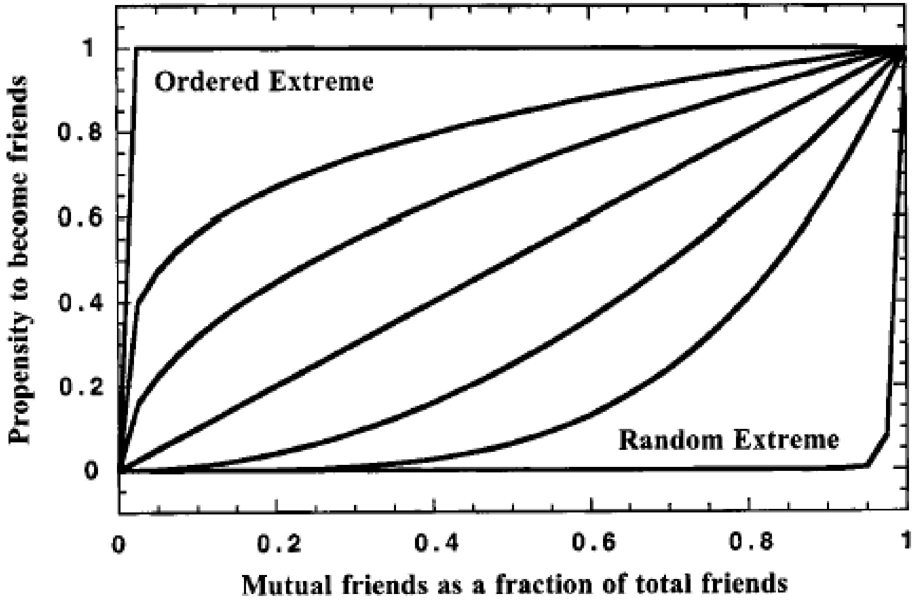
Watts (1999)

The people you know aren't randomly chosen.

People tend to get to know those who are two links away (Rapoport, 1957).

The real world exhibits a lot of *clustering*.

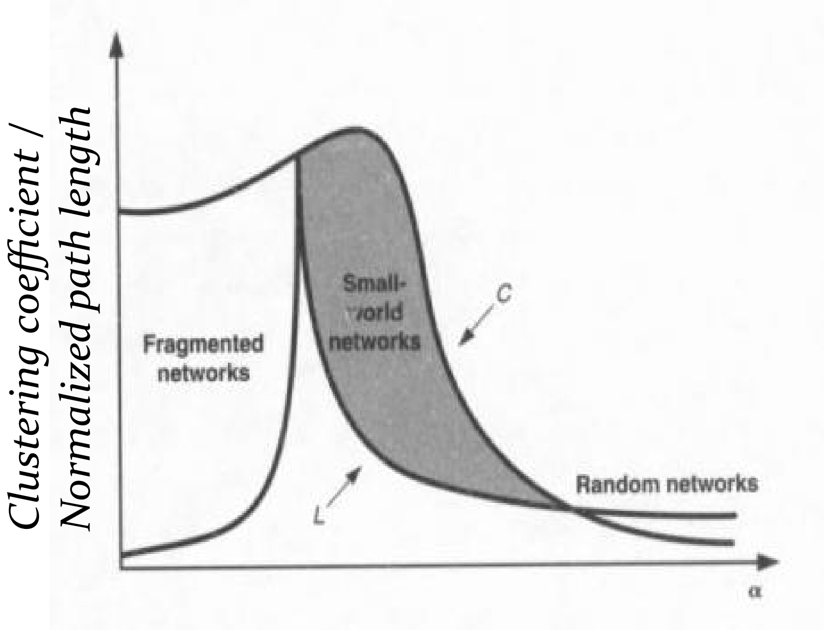
Small-world networks, alpha model (2/5)



Probability of linkage as a function of number of mutual friends (α is 0 in upper left, 1 in diagonal, and ∞ in bottom right curves.)

α model: Add edges to nodes, as in random graphs, but make links more likely when two nodes have a common friend.

Small-world networks, alpha model (3/5)

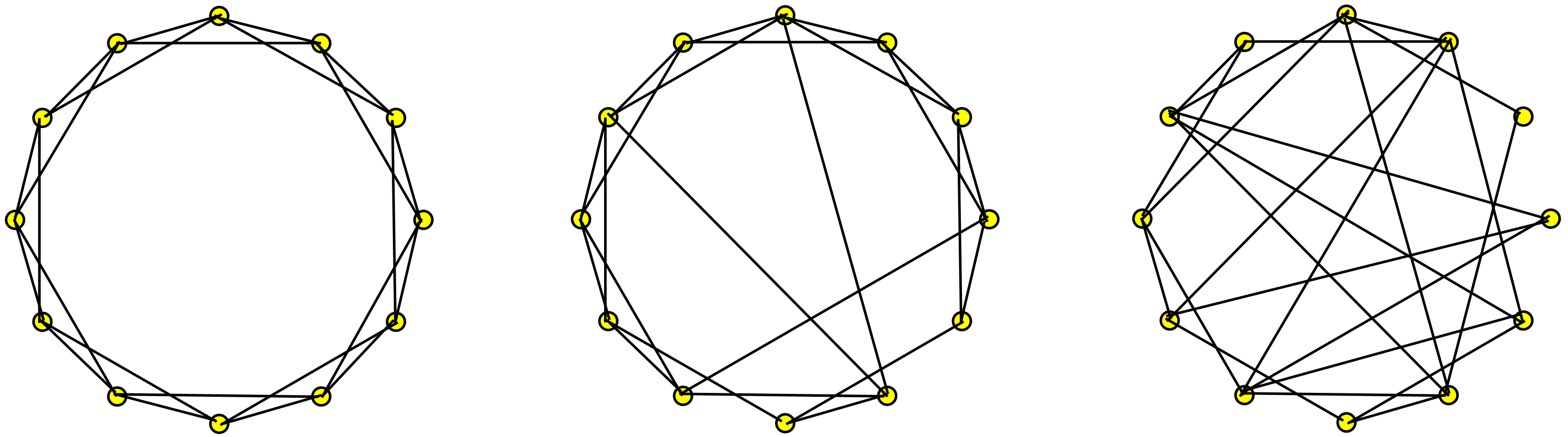


Clustering coefficient (C) and average path length (L) plotted against α

For a range of α values:

- The world is small (average path length is short), and
- Groups tend to form (high clustering coefficient).

Small-world networks, beta model (4/5)



$\beta = 0$

People know their neighbors.

Clustered, but not a “small world”

$\beta = 0.125$

People know their neighbors, and a few distant people.

Clustered and “small world”

$\beta = 1$

People know others at random.

Not clustered, but “small world”

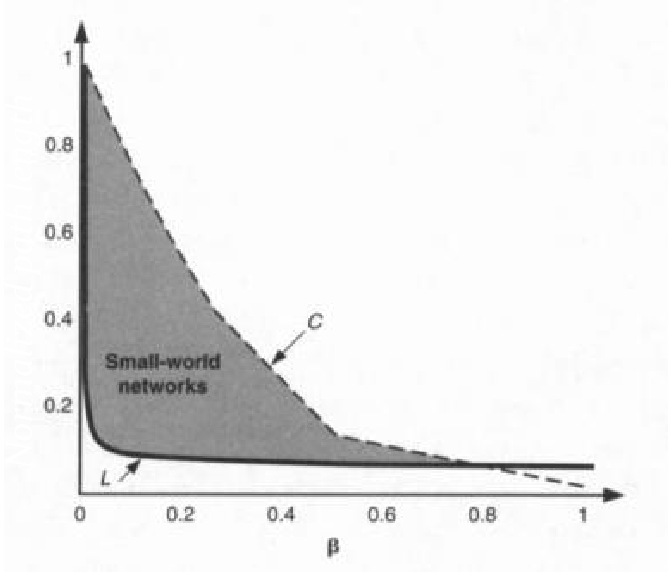
Small-world networks, beta model (5/5)

First five random links reduce the average path length of the network by half, regardless of *N*!

Both α and β models reproduce short-path results of random graphs, but also allow for clustering.

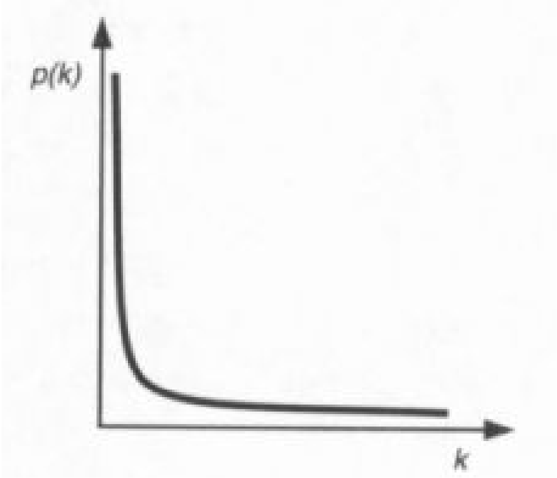
Small-world phenomena occur at threshold between order and chaos.

Clustering coefficient /



Clustering coefficient (C) and average path length (L) plotted against β

Scale-free networks (1/3)



Typical shape of a power-law distribution.

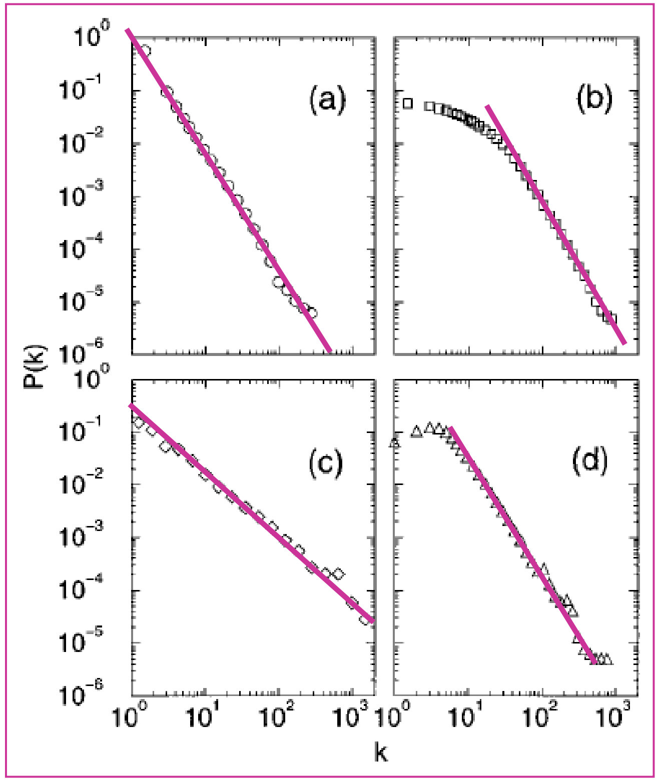
What's the degree (number of edges) distribution over a graph, for real-world graphs?

Many real-world networks exhibit a *power-law* distribution.

Scale-free networks (2/3)

Power-law distributions are straight lines in log-log space.

Pareto's* Law: Wealth distribution follows a power law.



Power laws in real networks:
(a) WWW hyperlinks
(b) co-starring in movies
(c) co-authorship of physicists
(d) co-authorship of neuroscientists

Scale-free networks (3/3)

“The rich get richer!”

Power-law distribution of node distribution arises if

- Number of nodes grow;
- Edges are added in proportion to the number of edges a node already has.

What is your network?

Reflect on today's session and post your comments.