Engineering Systems Doctoral Seminar

ESD.83 – Fall 2009

Class 11

Faculty: Chris Magee and Joe Sussman

Guest: Professor Maria Yang

Professor of Engineering Systems

and Mechanical Engineering

Session 11: Agenda

- Welcome and Overview of class 11 (5 min.)
- Dialogue with Professor Yang (55min)
- Break (10 min.)
- Discussion of other papers (led by Pearl Donohoo and Kaushik Sinha, 40 -50 min)
- Theme and topic integration (Magee)
  - Carryover from sessions 7 and 8 and today
  - Report from the Front
  - Structure, Function and Dynamics/History I
- Next Steps -preparation for week 12- (5 min.)

ES Observational Techniques- “structure” from class 7 & 8

- Need for extensive data analysis and experiment vs. observational study are key differentiating factors among observational techniques
- Case studies (N = 1)
  - Implications of a singular fact (“The World is Green”; “Engineering Design is Successful”?)
  - In-situ: Ethnographic study, surveys, interviews, document study, email studies, minutes, calendar analysis, quantitative and qualitative, etc.
  - Historical analysis: primary and secondary documents, interviews, quantitative and qualitative, etc.
- Medium N- as above but time limited
- High N (possibility of experiment)-

	Experiment (control of experimenter is necessary)	Observational Study
Highly sophisticated quantitative analysis –use reliable theories to examine new theory	Many examples in natural science and some in social science	Many examples in natural science but only beginning in social science
Little quantitative analysis before use of data	Examples are more common in certain natural and engineering sciences	Common in social science (but not modern natural science) significant qualitative analysis is often done

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Sophisticated apparatus design

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ES Opportunity

Anderson speculation

- Can we think of any higher level fundamentals in socio-technical (or engineering) systems?
- Price vs. aggregate demand. Is there a relationship to why an individual makes a purchase ?
- Price vs. supply-
- Other regularities at higher levels in systems with social and technical complexity?
- Small worlds?, Normal distributions, “fat-tail distributions” exponential growth, logistic curves?

RFTF

- Will “production” of engineers be necessary for solution of Global warming?
- Will production of more engineers be beneficial to solution of global warming?
- Assuming that a robust legal framework for carbon reduction (carbon tax for example) is agreed to, what will be the possible impact of more engineers involved in global warming?

Brief History of System Concepts

- Aristotle… the Holon and the Pan
- J. H. Lambert..(1728-1777) Defined systems as *a whole composed of parts in a purposeful way* Lambert also classified a great variety of natural and man-made systems and pointed to similarities
- Darwin (and earlier geologists) introduced a new stronger methodology for History of complex systems looking at relationships in types over time
- R. von Bartalanffy (1940's) and others proposed *General Systems Theory.* Cybernetics and Simon work were alternative formulations that were better received partly because they did not claim as much as GST
- Structure, Function and Dynamics (Long-term = history) are the "framing" concept areas that are identified from this long period of study.

Structure, Function and Dynamics of Selected Complex Systems

- What sub-fields in medicine/human biology represent S, F and H/D? How has human understanding in these sub-domains changed over time?
- Structure- anatomy, (research now at cellular and finer scales)
- Function- physiology (many sub-specialties and far more experimental detail known)
- Dynamics:
  - History- evolution (genes and now genomes and beyond understood)
  - Evo-Devo and control systems in biology
  - Real-time brain controlled feedback –e.g. throwing
- Mechanisms and models more richly described

The key concepts

- Function
  - What the system does = definition
  - Generic functions
- History/Dynamics
  - Feedback
  - Accumulation
  - Adaptation, Evolution and History
- Structure (architecture)
  - The nature of elements and their interactions
  - Decomposability
  - Hierarchy (non-symmetric relationships and levels)
- Concept integration- systems must be understood from all three of these perspectives simultaneously.

Generic functional analysis- Ropohl, Magee and de Weck etc.

Operand / Operation	Matter (M)	Energy (E)	Information (I)
Transform	blast furnace	Engines, Electric motors	Analytic engine, Calculator
Transport	Truck	Electrical Grid	Cables, Radio, Telephone and Internet
Store	Warehouse	Batteries, flywheels, Capacitors	Magnetic tape and disk, Book
Exchange	eBay Trading System	Energy Markets	World wide web, Wikipedia
Control	Health Care System	Atomic Energy Commission	Internet engineering task force

Function and "Advanced Methods"

- Functional analysis and functional decomposition are widely used in formal systems engineering
  - What the elements of the system do to support or achieve the overall system functions
- OPM (operation-process methodology)
  - Basis for generalization of function

Dynamics/History "Advanced Methods"

- Agent-based models (where agents can make contingent and heterogeneous decisions)
- Genetic algorithms (evolutionary algorithms)
- Historical methodology (Latent semantic analysis)
- Control Theory
- Systems Dynamics (stocks and flows)
- Evolutionary Dynamics
- **These methods are listed in the rough order of their application frequency in Engineering Systems Problems**

Dynamics/History thinking and Human Limitations

- How do we think about time?
- Time is a difficult area for clear thinking (visual can be limiting as can logical)
- Thinking dominated by the "present time" with the future and distant past very blurry.
- Feedback and stocks can be misread ("Beer Game")
- Exponentials are common in trends (accumulation effects) but linear is the 2^{nd} most usual mode of thinking about trends
- The most usual is "stationary".

Structure/architecture and "Advanced Methods"

- Network analysis
  - Based on graph theory (Euler started in 1776)
  - Operations research and flow
  - Social Networks
  - Has extensive publications and methods now being applied to "Engineering Systems Problems" but has suffered from ***multiple*** "two cultures" issues (Jesse and Kaushik)
- **Architecting** is the deliberate manipulation of **structure** to achieve desired system behavior and properties

Class 12 (from ESD 342) Lecture Outline

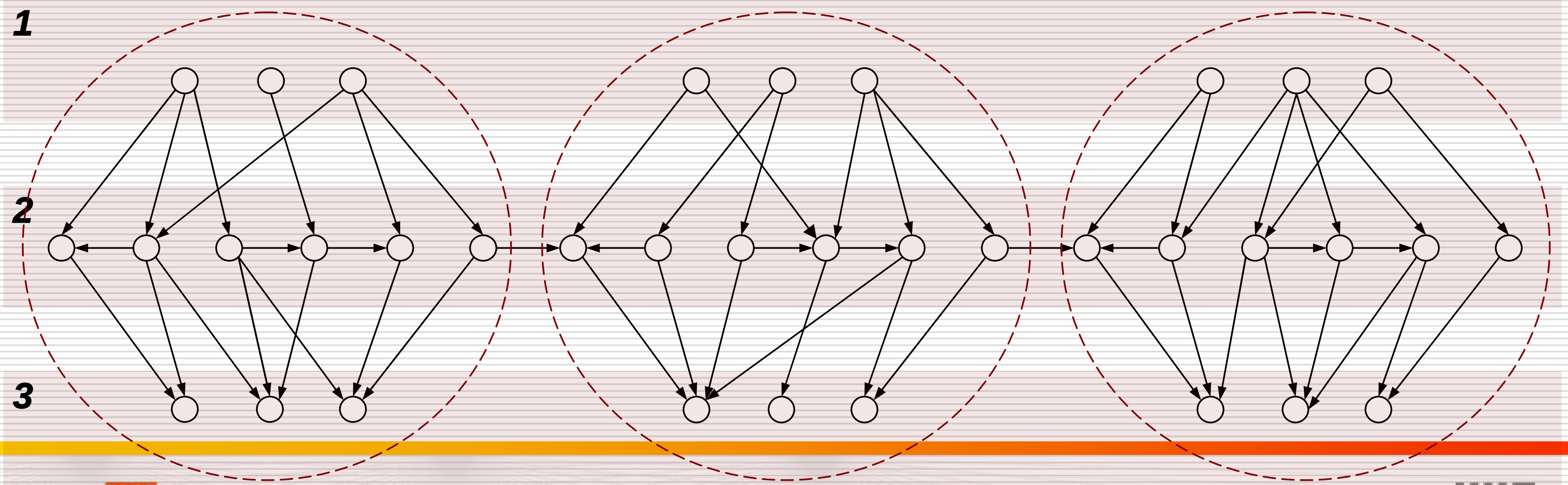
- Decomposition
  - Practical and theoretical importance
  - Link to modularity
  - Taxonomy and examples
  - Network-based Approaches to Quantitative Decomposition
    - Structural or cohesive decomposition
    - Functional decomposition
      - Roles, positions and hierarchy
      - Motifs and course graining
- Overview of modeling

Steps toward quantitative decomposition based upon network models

- Systems to be decomposed are represented as networks among elements that have relationships indicated by links
- "**Strategic" Question**: What characteristics do we use to decide upon decomposition?
- We first consider only simple networks with one kind of node and one kind of link but even in this "simple" case, we will see several strategic ways (at least three) to logically decompose the system with different meanings and different answers to the **tactical questions**
- How many subgroups (and what members)?
- How "perfect" is the proposed decomposition?

Two strategically different approaches for decomposition of a network

- First *quantitatively* pursued in Mo-Han Hsieh's thesis with application to decomposing the citation network of the Internet standards into meaningful subgroups but the basic ideas were developed by social network researchers 35 years ago
  - Cohesion to others in subgroup
  - Role similar to others in subgroup (hierarchy)

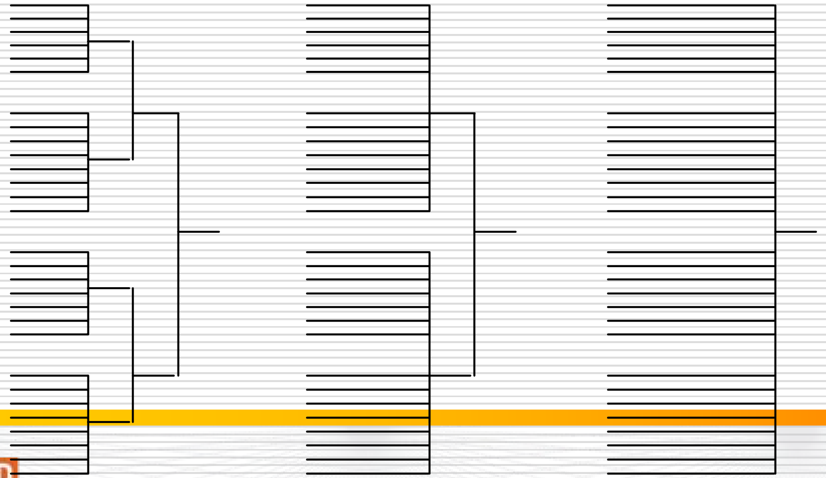


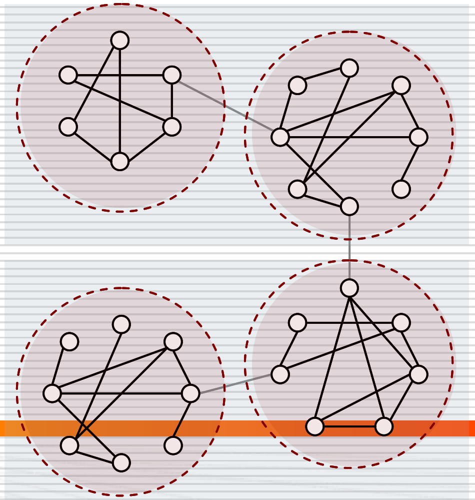
The tactical "answers: Algorithms for decomposition and decomposability metrics (tactics)

- *Cohesion*: Newman-Girvan algorithm and Newman "modularity" (and newly derived normalized decomposability metric)
- Role (position or hierarchy): Hsieh-Magee algorithm and decomposability metric for *structural* and *regular equivalence*
- All three concepts have been defined in the Social Network Literature
- Cohesive sub-groups are formed among nodes (agents) who have links among each other more often than with those in other sub-groups

Cohesive decomposition: The Newman-Girvan algorithm

- The algorithm
  1. Calculate the betweenness of all edges in the network.
  2. Remove the edge with the highest betweenness.
  3. Recalculate the betweenness of all remaining edges.
  4. Repeat from step 2 until no edges remain (Max Q is best).
- The community structure (i.e. dendrogram)
- "Modularity": Q *(To determine the best number of communities)*





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Engineering Systems Division

Newman Modularity Metric

- Basic idea
  - the sum of the fraction of intra-group edges minus the value that it would take if edges were placed at random.

$$Q = \sum_i \left(e_{ii} - a_i^2 \right)$$

- e_{ij} - the fraction of edges in the network that connect vertices in group *i* to those in group *j*,
- a_i - is the fraction of all edges that go out from vertices in group *i* or come in to vertices in group *i*
  - (i.e. $a_i = \sum_j e_{ij}$ or $a_i = \sum_i e_{ij}$) (Newman 2004).
- This metric is used by Newman and Girvan as a “stopping rule”- the correct number (and members) of subgroups maximizes Q (answering the first tactical question for this type of decomposition)

Cohesive Decomposability Metric

- Q cannot be used to compare how effective a decomposition is between different networks
  - To compare networks of different sizes, different numbers of sub-groups and different link densities, one needs a properly normalized metric
- Normalized Cohesive Decomposability Metric: Q_c
  - Let p be the number of sub-groups
  - Let n be the total number of edges of the network
  - For a connected network, the largest possible fraction of intra-group edges: $f=1-(p-1)/n$
  - We normalize the Newman modularity measure by f minus the value that it would take if edges were placed at random.

$$Q_n = \sum_i \left(e_{ii} - a_i^2\right) \Big/ \left(f - \sum_i a_i^2\right)$$

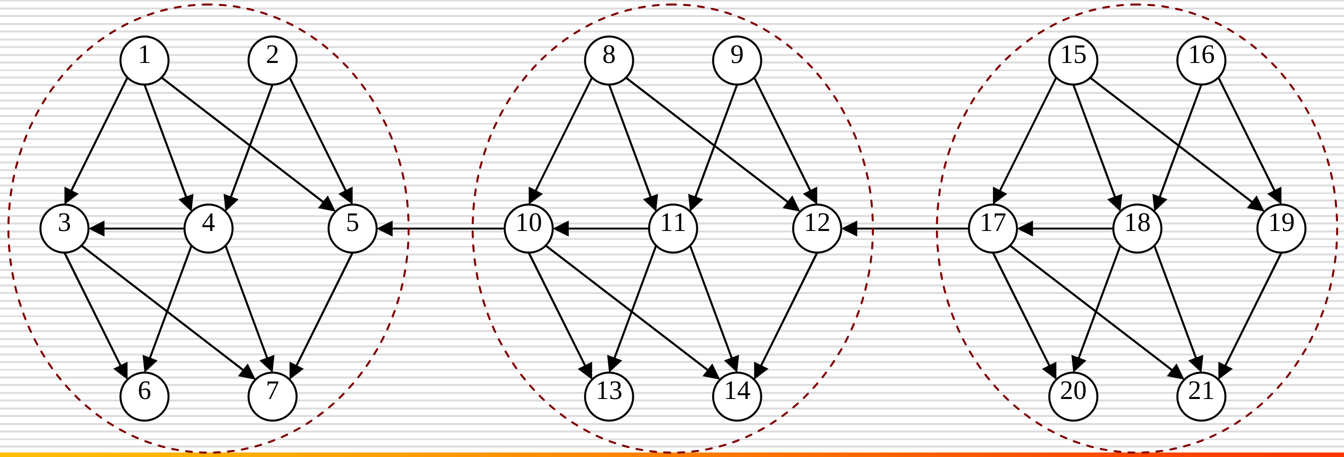
Cohesive Decomposability Metric: Example

$$e = \begin{bmatrix} 0.31 & 0.00 & 0.00 \\ 0.03 & 0.31 & 0.00 \\ 0.00 & 0.03 & 0.31 \end{bmatrix} \quad a = \begin{bmatrix} 0.31 \\ 0.34 \\ 0.34 \end{bmatrix}$$

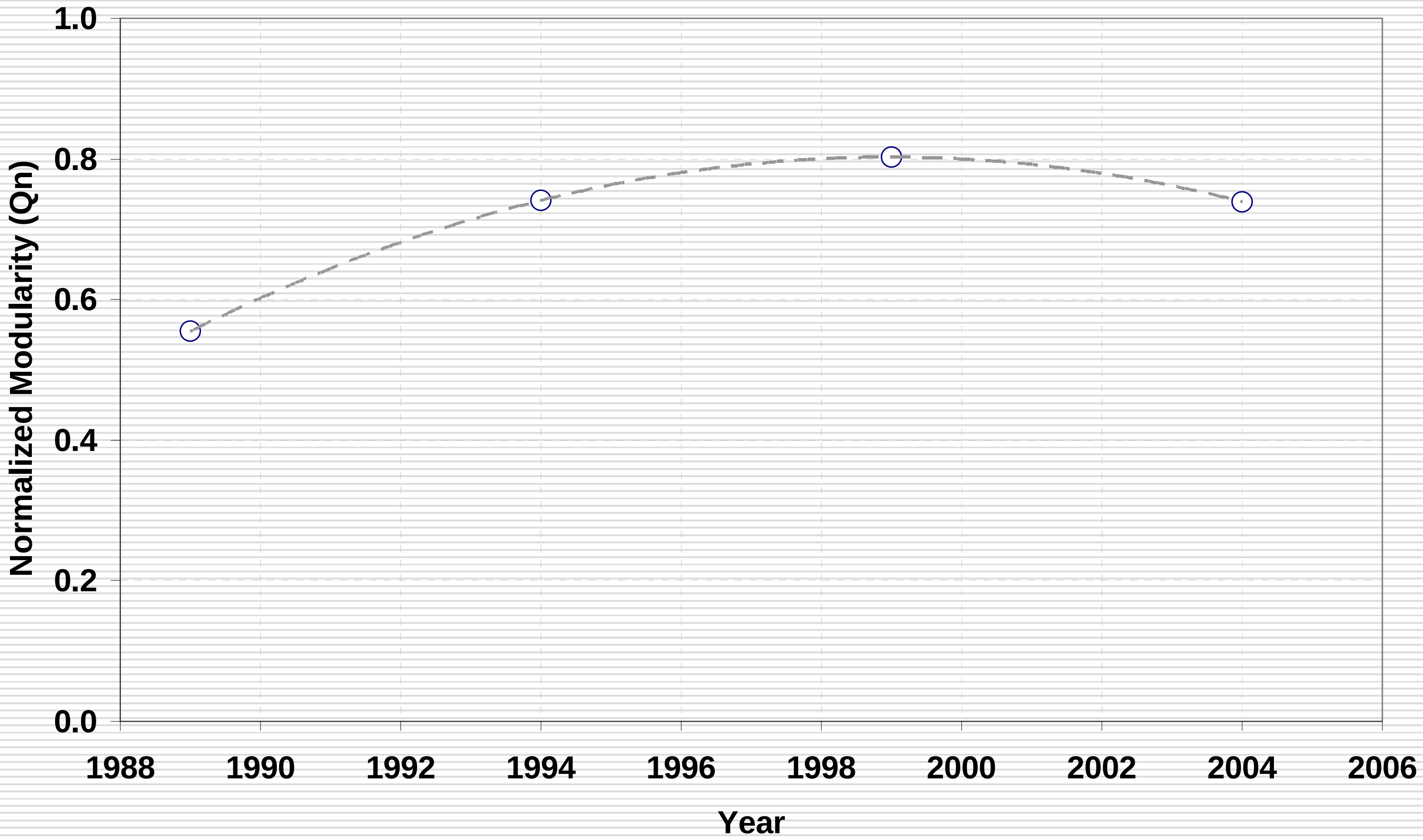
$$f = 1-(p-1)/n$$
$$= 1-(3-1)/35 = 0.93$$

$$Q = \sum_i \left(e_{ii} - a_i^2\right) = (0.31 - 0.31^2) + (0.31 - 0.34^2) + (0.31 - 0.34^2) = 0.60$$

$$Q_n = Q/(f - \sum_i a_i^2) = 0.60/\left[0.93 - (0.31^2 + 0.34^2 + 0.34^2)\right] = 1.00$$



Cohesive Decomposability Metric Example – Internet Standards



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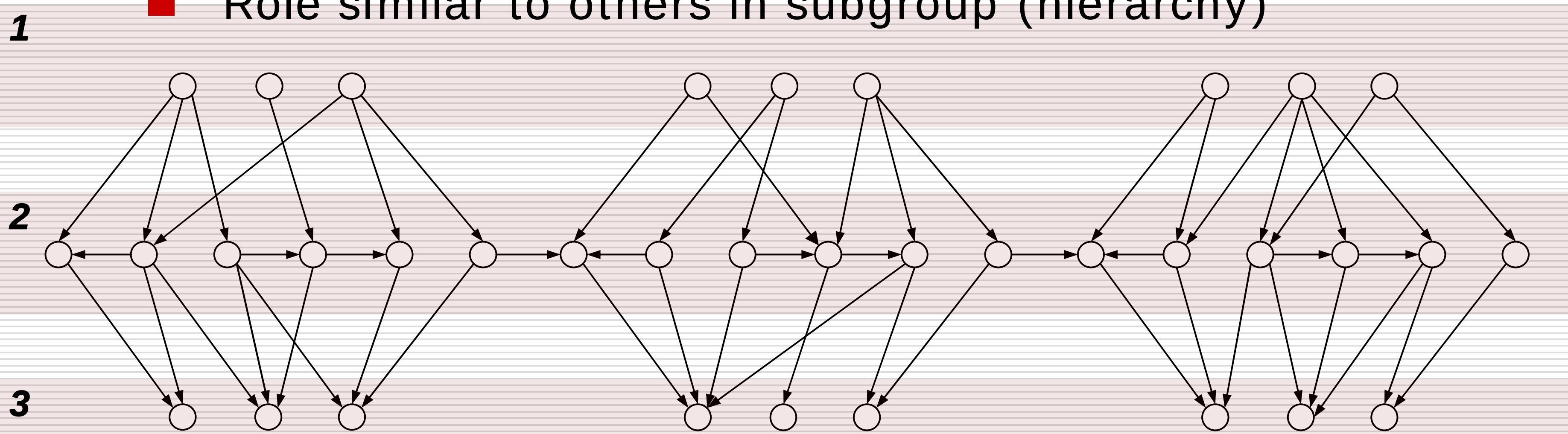


Decomposition by Role: The algorithm

- The *algorithms* (and the decomposability metrics) for structural and regular equivalence are very similar:
- Transform *n* by *n* adjacency matrix into a *n* by *n* Similarity matrix by use of the definitions of structural (and regular) equivalence
- View *n* by *n* Similarity matrix as *n* nodes in *n* dimensional space
- Apply K means algorithm to find *k* sub-groups of nodes that best match (are most similar to) each other
- Use comparison to **random network changes** to arrive at best number and members of sub-groups (answers first tactical question for this strategic approach to decomposition)

Hsieh-Magee (Normalized) Decomposability for Structural and REGE Equivalence

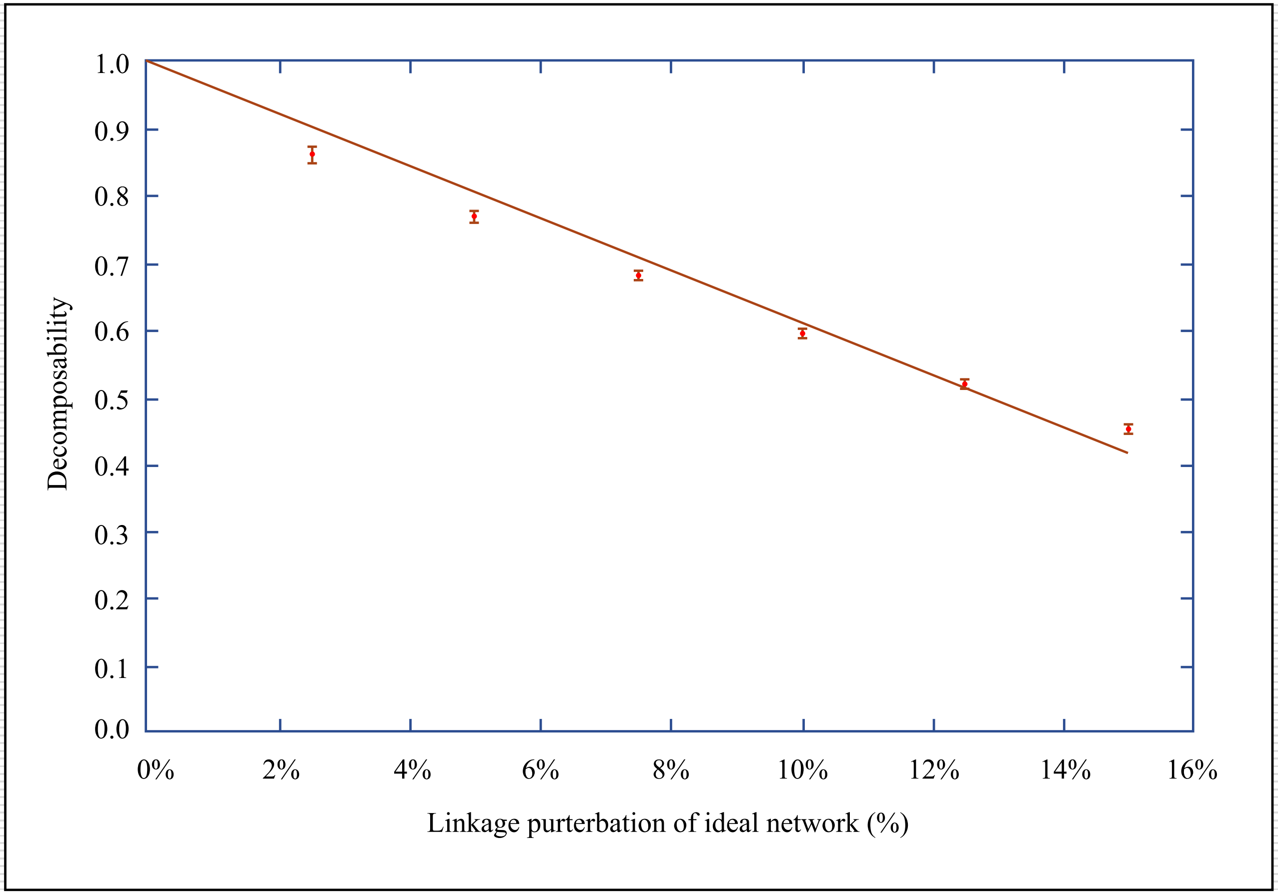
- Transform *n by n* Adjacency matrix into *n by n* Similarity matrix (using the definition of structural or REGE equivalence)
- The sum of the inter-cluster point-to-centroid distances

$$D_k = \sum_{i=1}^{k} \sum_{j \in S_i} \left\| \mathbf{x}_j - \mathbf{c}_i \right\|^2$$

  - $\mathbf{x}_j$ - the *n* dimensional coordinate of node *j*
  - S_i $(i=1,2,\ldots,k)$ - the sub-group and
  - $\mathbf{c}_i$ - the centroid or mean point of all of the data points x_j in cluster S_i.

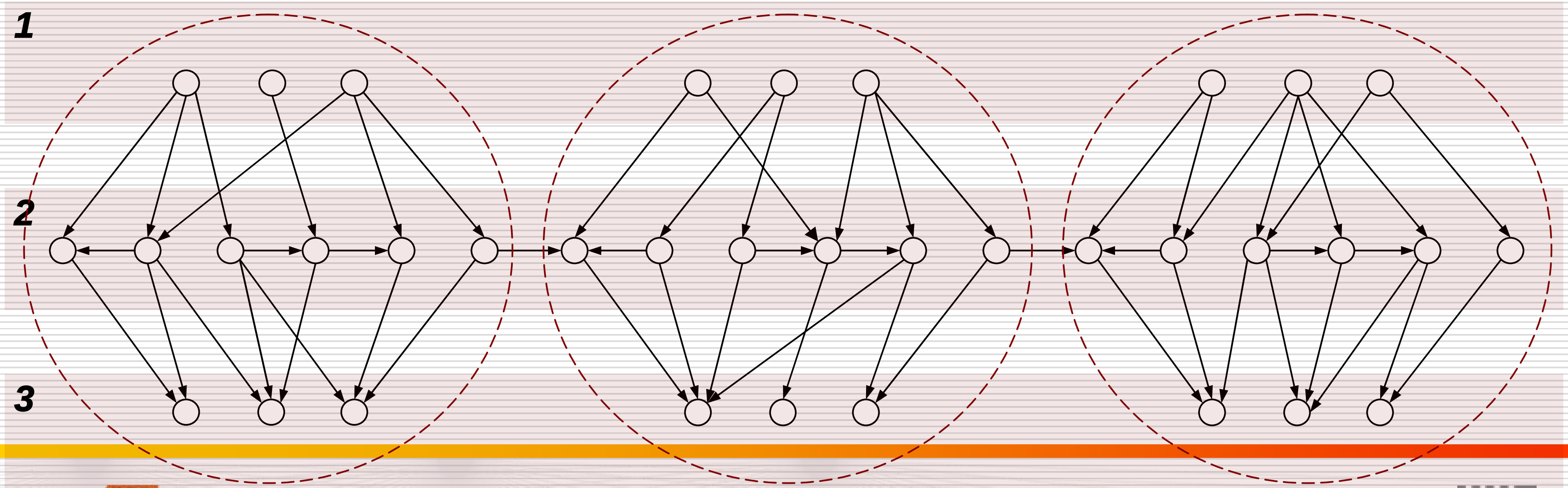
$$Q = 1 - \frac{D_k - D_{ideal}}{D_{\max(n,k)} - D_{ideal}} = 1 - \frac{D_k}{D_{\max(n,k)}}$$

Magee-Hsieh Decomposability for Structural Equivalence Example – Decomposability vs. Linkage Perturbation



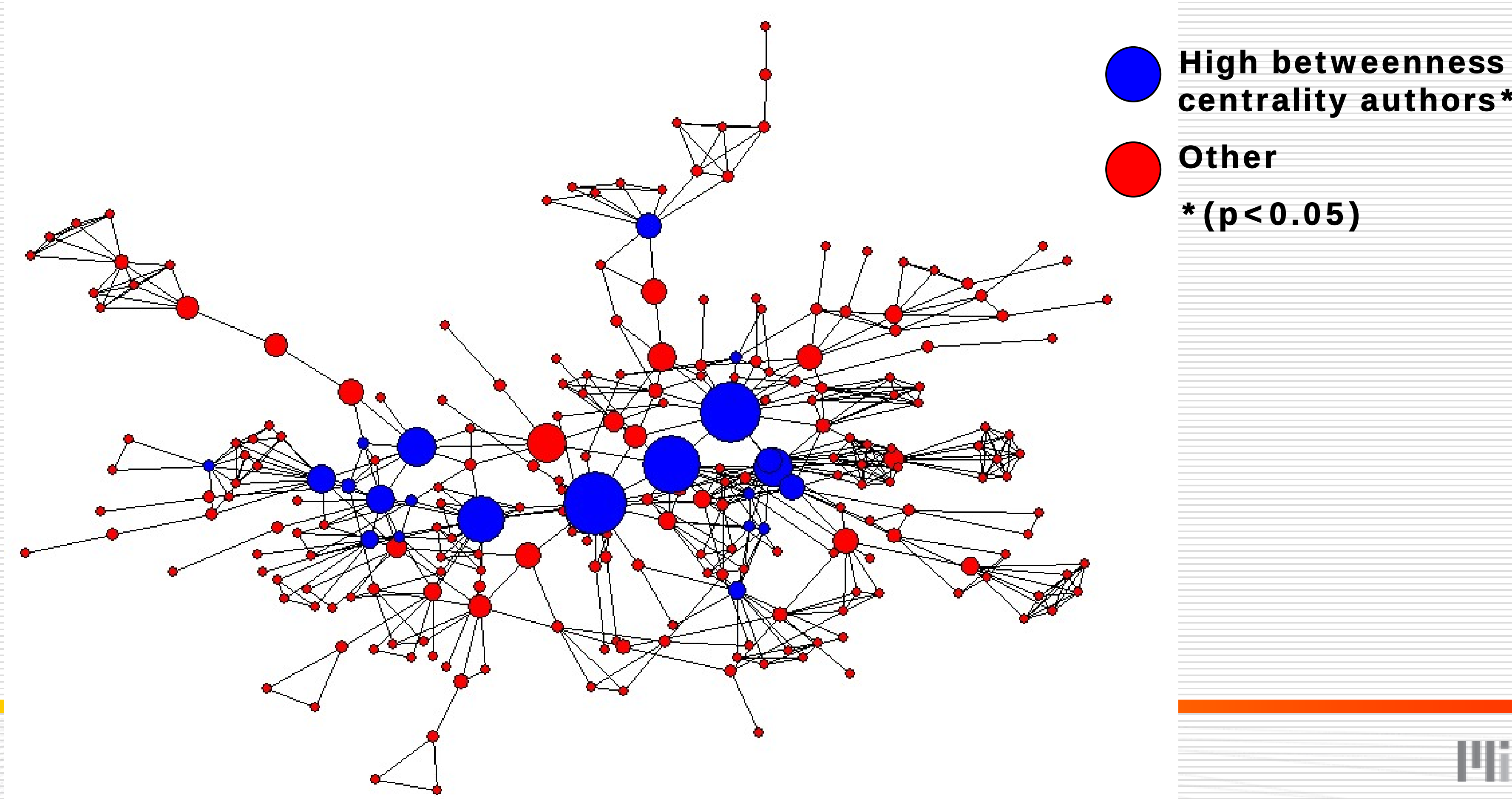
Two methods for decomposition of a network

- Application to the citation network of the Internet standards into meaningful subgroups
  - Cohesion to others in subgroup
  - Role similar to others in subgroup



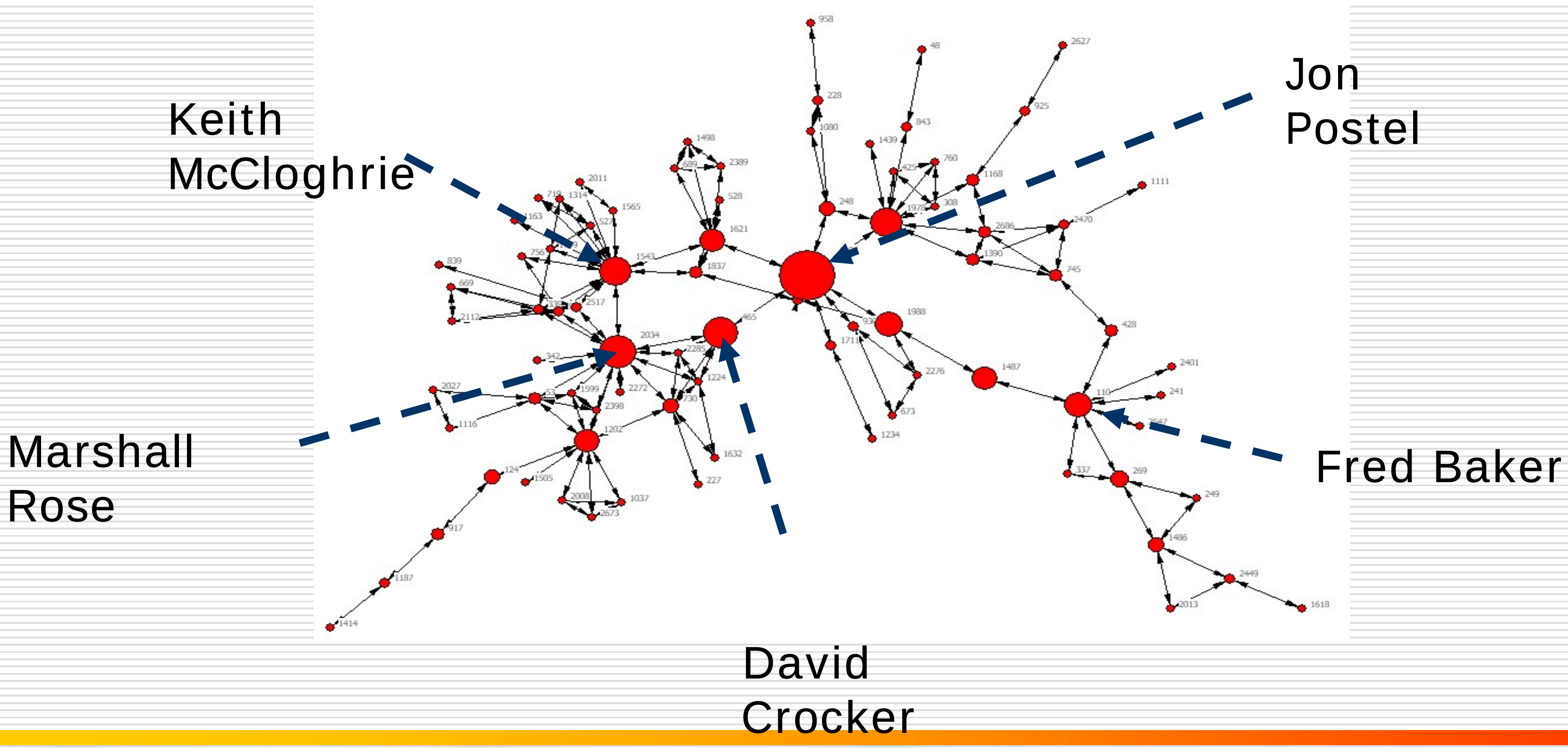
Application of the Methods to the Standards Research (II) – IETF Coauthor Network (07/1994)

- Decomposing the network into 2 roles



Example of social network of the Internet society: Coauthor network of the IETF standards (07/1994)

- Multidimensional scaling of geodesic distances



The key concepts

- Function
  - What the system does = definition
  - Generic functions
  - Flexibility and other lifecycle properties
- History/Dynamics
  - Feedback
  - Accumulation
  - Adaptation, Evolution and History
- Structure (architecture)
  - The nature of elements and their interactions
  - Decomposability
  - Hierarchy (non-symmetric relationships and levels)
- Concept integration- In session 13,we will discuss an example where all three concepts (SFD) will play key roles

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