Engineering Systems Doctoral Seminar

ESD.83 – Fall 2011

Session 8

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TA: Rebecca Kaarina Saari
Guest: Professor Marta Gonzalez

Massachusetts Institute of Technology
Engineering Systems Division

Session 8: Agenda

- Welcome and Overview of class 8 (5 min.)
- Dialogue with Professor Gonzalez (55min)
- Break (10 min.)
- Discussion of other papers (30-40 mins)
- Theme and topic integration (Magee)
  - Network Models in differing domains
  - Modeling as a guide to experiment and practice
  - Domain knowledge vs. modeling knowledge
  - Practice and Research
- Next Steps -preparation for week 9: Historical Roots Presentations- (5 min.)

Network models and metaphors

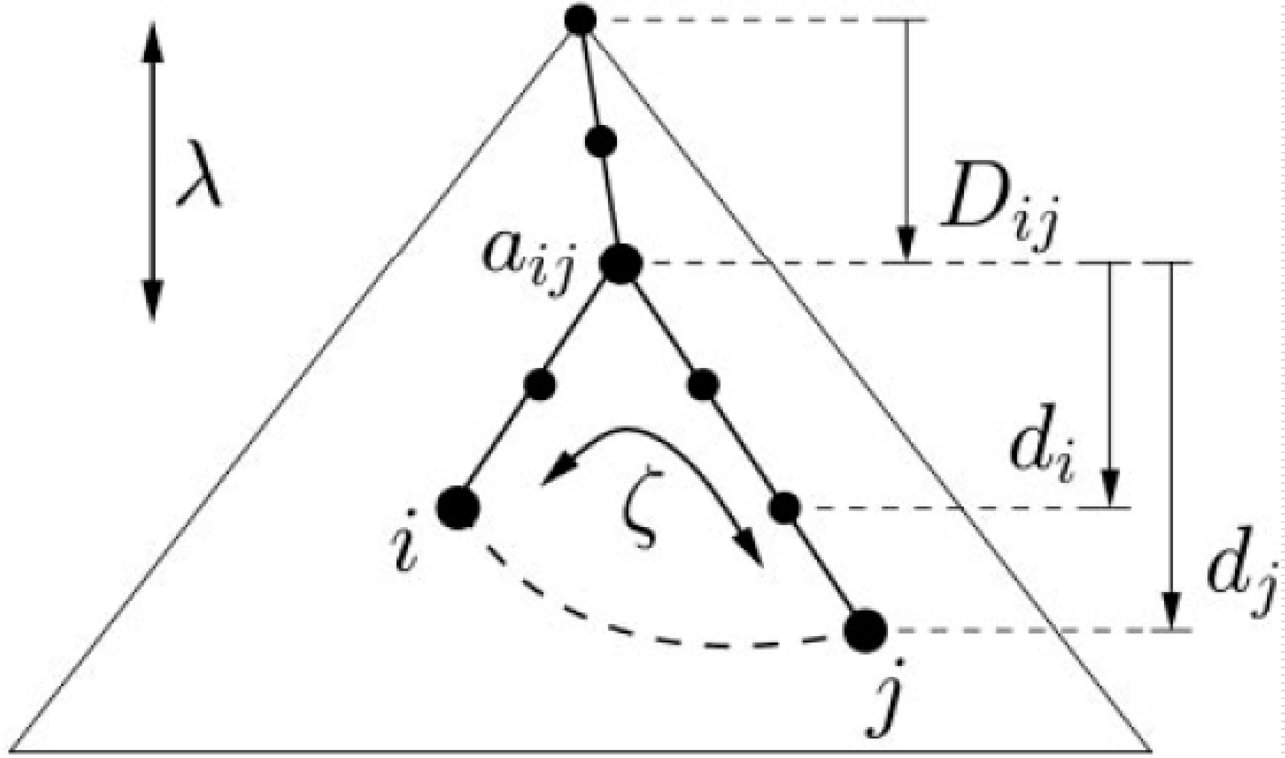
- Two relatively different network modeling approaches applied to quite distinct domains
  - Dodds, Watts and Sabel – organizational structure and communication
  - Gastner and Newman- distribution

Dodds, Watts and Sabel Organizational Modeling for Communication Robustness

- The questions being addressed are:
  - Topologies (architectures) of total organization
  - Choice of topology for robust problem solving
- ***In order to develop a diverse set of organizational structures*** relative to communication, DWS develop an ***organizational structure generator***
  - Starts with **hierarchy with L levels** and branching ratio b (the formal organization)
  - m additional links are added ("informal organization" -***actually*** the method they use to develop diverse organizational structures- ***generalized hierarchies***)

Dodds, Watts and Sabel Organizational Model for Communication Robustness

- The organizational structure generator
  - The questions being addressed are:
    - Topologies (architectures) of total organization
    - Choice of topology for robust problem solving
  - Starts with **hierarchy with L levels** and branching ratio b (the formal organization)
  - Randomly **adds m weighted links**
  - Probability of two nodes being linked, P(i,j) depends on depth of lowest common ancestor and also their own depths



Definingk ey parameters

Courtesy of National Academy of Sciences, U.S.A. Used with permission. Source: Dodds, P. S., D. J. Watts, and C. F. Sabel. "Information Exchange and the Robustness of Organizational Networks." *Proc. Natl. Acad. Sci.* 100, no. 21 (2003): 12516-21. (c) National Academy of Sciences, U.S.A.

Dodds, Watts and Sabel Network Organizational Model for Communication Robustness

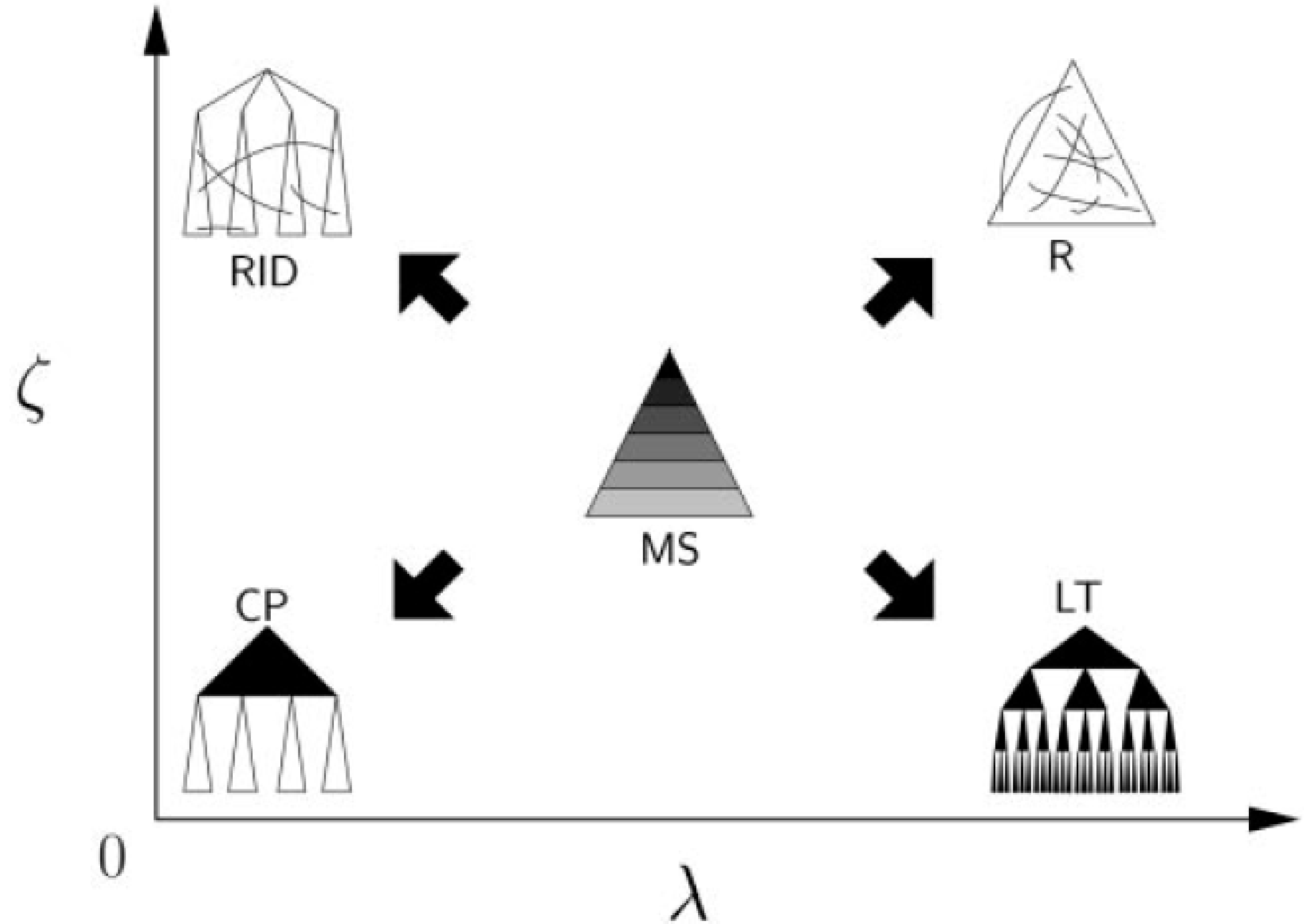
- The ***organizational structural generator***
  - Starts with **hierarchy with L levels** and branching ratio b
  - Randomly **adds m weighted** links
  - Probability of two nodes being linked, P(i,j) depends on depth of lowest common ancestor and also their own depths
  - Organizational distance

$$x_{ij} = (d_i^2 + d_j^2 - 2)^{\frac{1}{2}}$$

  - Overall

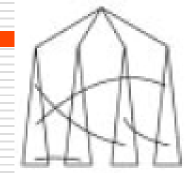
$$P(i,j) \propto e^{\frac{-D_{ij}}{\lambda}} e^{\frac{-x_{ij}}{\zeta}}$$

  - Where $\lambda \; and \; \zeta$ are adjustable parameters allowing different organization structures to be generated by their network model. Varying **these parameters** leads to


RID
R
MS
CP
LT
ζ
0
λ

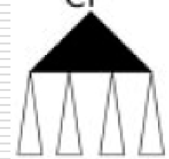
Organization Categories from the DWS Model

- **RID** (Random Interdivisional) high ζ and low λ



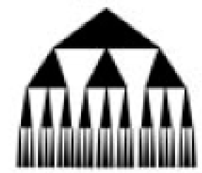
Links are allocated **exclusively** between node that have as their lowest common superior the "top node". Links between random levels as homophily is unimportant

- **CP** (Core Periphery) low ζ and low λ



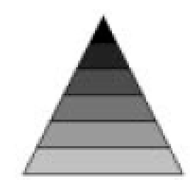
Links are added **primarily** between subordinates of the top node alone

- **LT** (Local Team) low ζ and high λ



Links are added **exclusively** between pairs of nodes that share the same immediate superior

- **MS** (Multiscale) intermediate ζ and λ



Connectivity at all levels but the density of connections is **greater the higher** one goes in the hierarchy

- R (Random) the extra m links are added to the hierarchy randomly (not shown)

Processes Used in the Organization Model Study in DWS

- The study basically models ***information exchange*** with a stated purpose to study distributed **"Problem Solving"** (decision-making?). Model assumptions:
  - Information passing based on local + "pseudo-global" knowledge (higher nodes know less and less about more)
  - The task environment is characterized by a rate of information exchange, μ and variable amounts of ***problem decomposability*** weighted by the social distance, x_{ij} and the "decomposability" parameter ξ with the weight, S, related to distance and ξ as

$$S = e^{-\frac{x_{ij}}{\xi}}$$

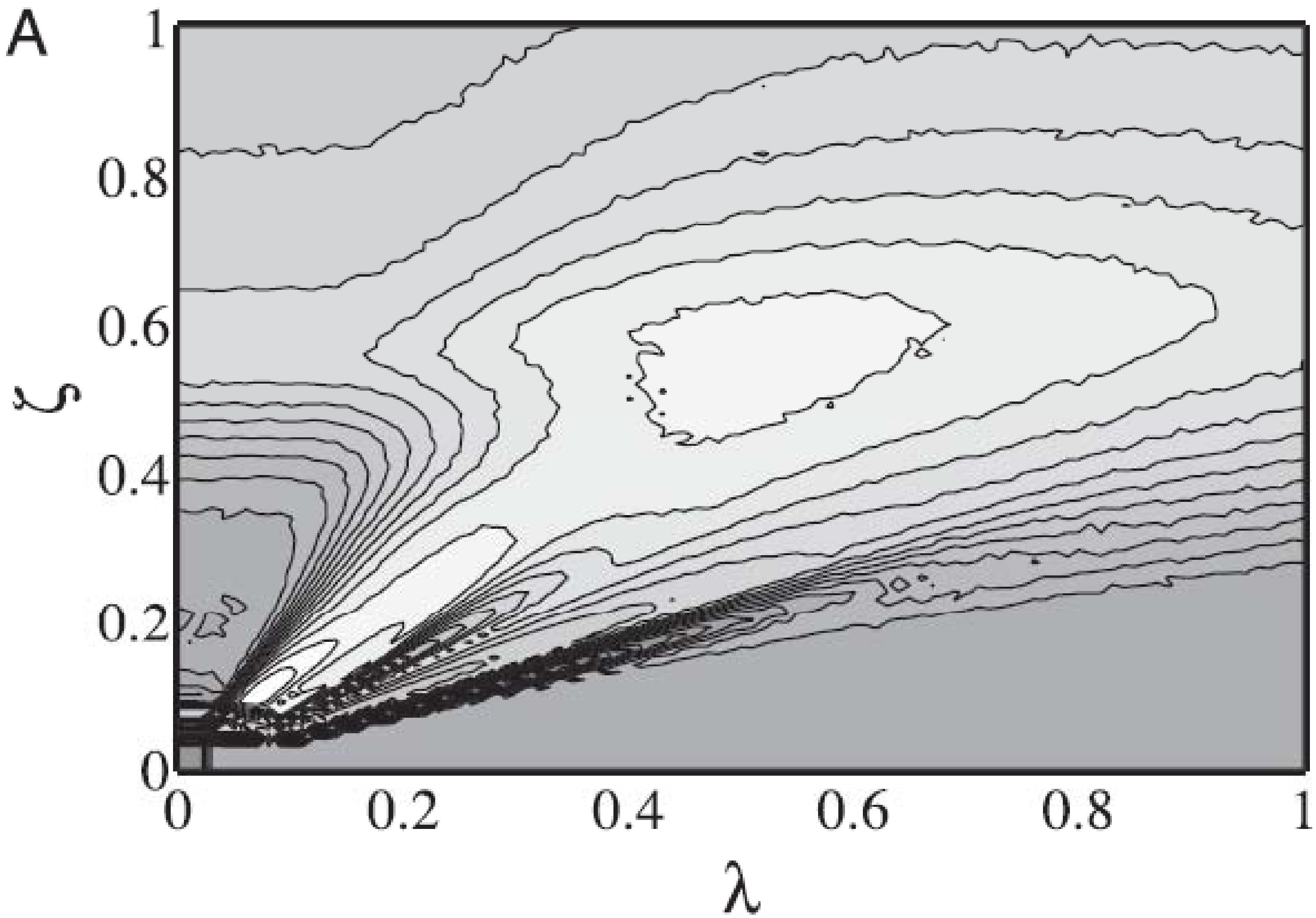
As ξ becomes large, problems that are **not dependent** on organizational distance become important in the organization. This is a useful modeling device

Properties of the Organizational Models studied by DWS

- Robustness
  - Congestion robustness: the capacity to protect individual nodes from congestion (overload).
  - Connectivity robustness:
  - Ultrarobustness:

Properties of the Organizational Models studied by DWS

- Robustness
  - Congestion robustness: the capacity to protect individual nodes from congestion (overload). **This is accomplished by the structure giving the minimum of the maximum congestion centrality**
  - Connectivity robustness:
  - Ultrarobustness:
- Results



Congestion metric over the ζ λ plane

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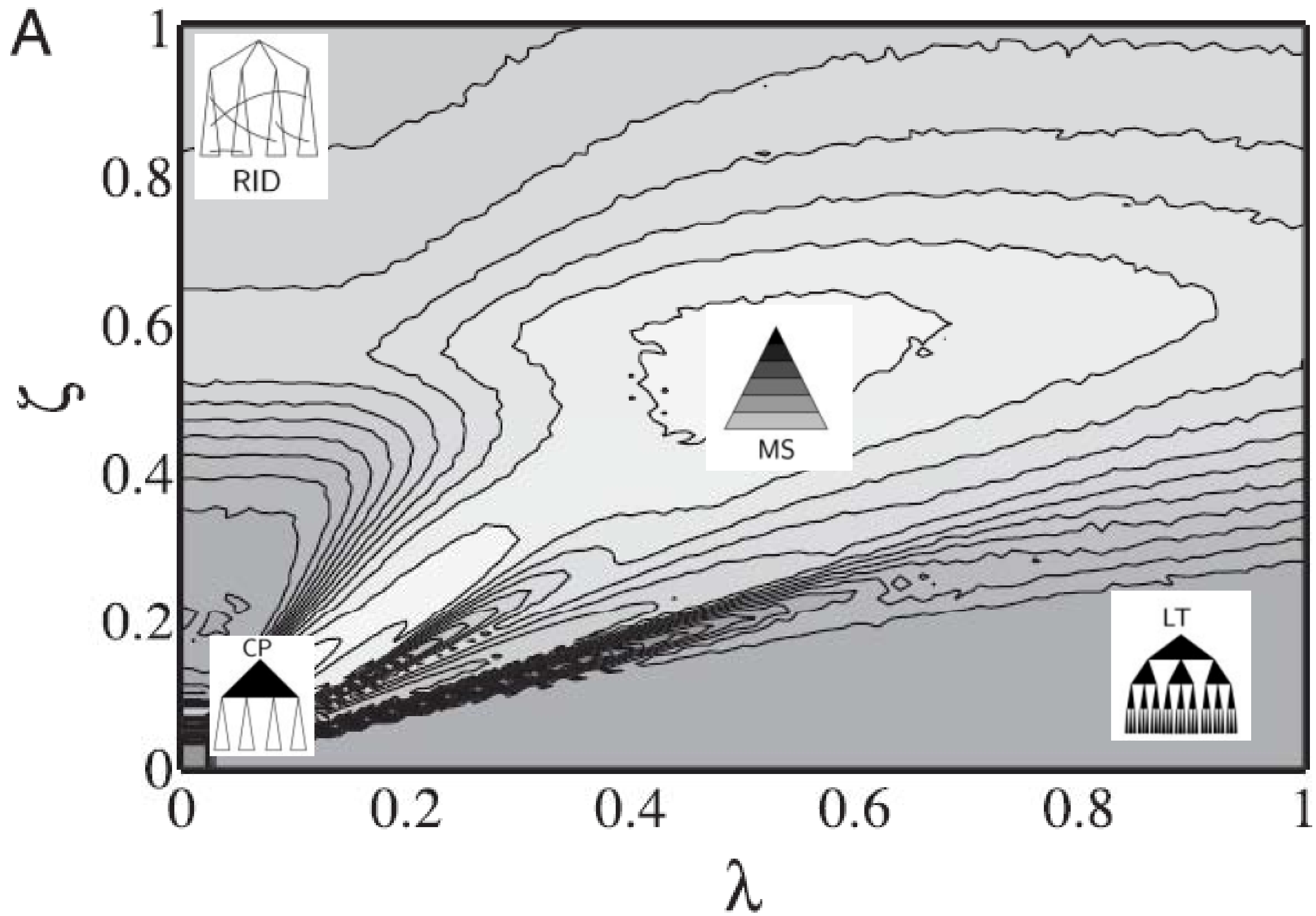
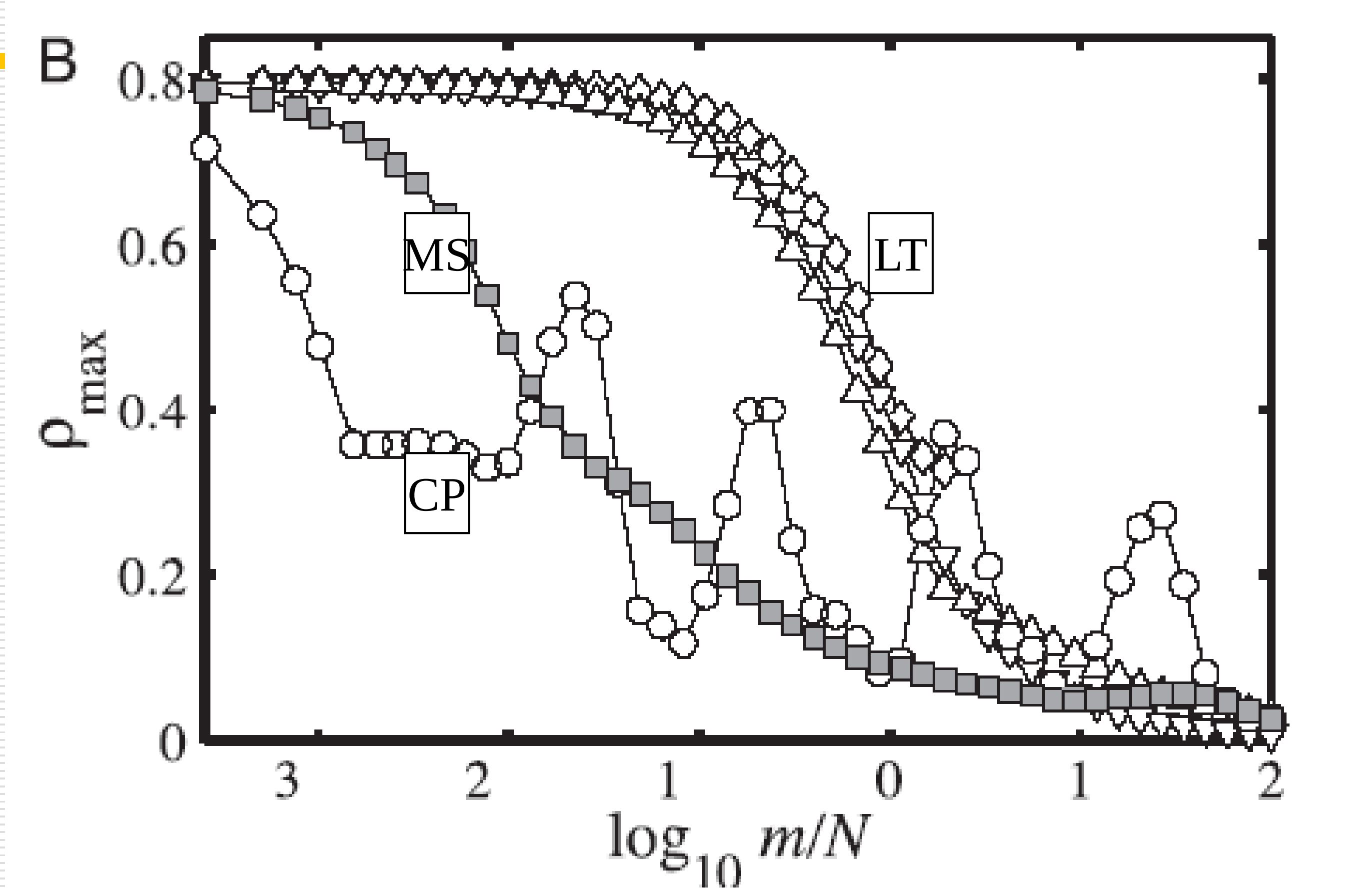


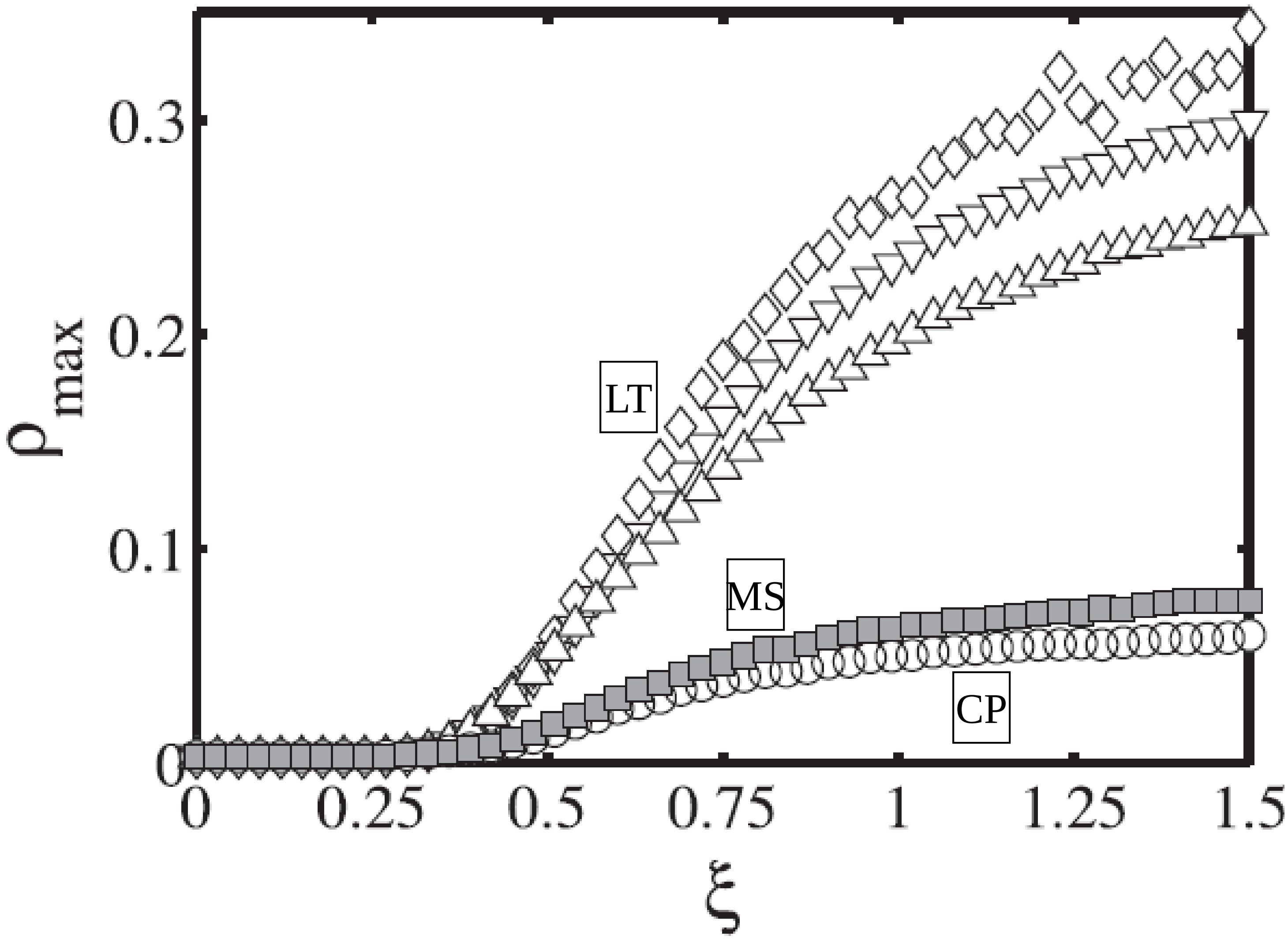
Congestion metric over the ζ λ plane



Congestion metric as links are added

Properties of the Organizational Models studied by DWS

- Robustness
  - Congestion robustness: the capacity to protect individual nodes from congestion (overload).
    - Better structure results in **Minimal congestion centrality and this is shown for MS (only CP is competitive but *not as reliable*)**



Congestion centrality with **decreasing** task decomposability, ξ

Properties of the Organizational Models studied by DWS

- Robustness
  - Congestion robustness: the capacity to protect individual nodes from congestion (overload).
    - Better structure results in Minimal congestion centrality and this is shown for MS (only CP is competitive but *not as reliable*)
    - **All structures are OK with decomposable tasks** (excepting the pure hierarchy?) **but MS and CP are best when larger scale interactions are significant.**

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- Robustness
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    - Minimal congestion centrality is better structure and this is shown for MS (only CP is competitive but not as reliable)
    - All structures are OK with decomposable tasks but MS and CP are best when larger scale interactions are key.
    - **Maximum uncongested size is for MS (CP again second)**

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  - Congestion robustness: the capacity to protect individual nodes from congestion (overload).
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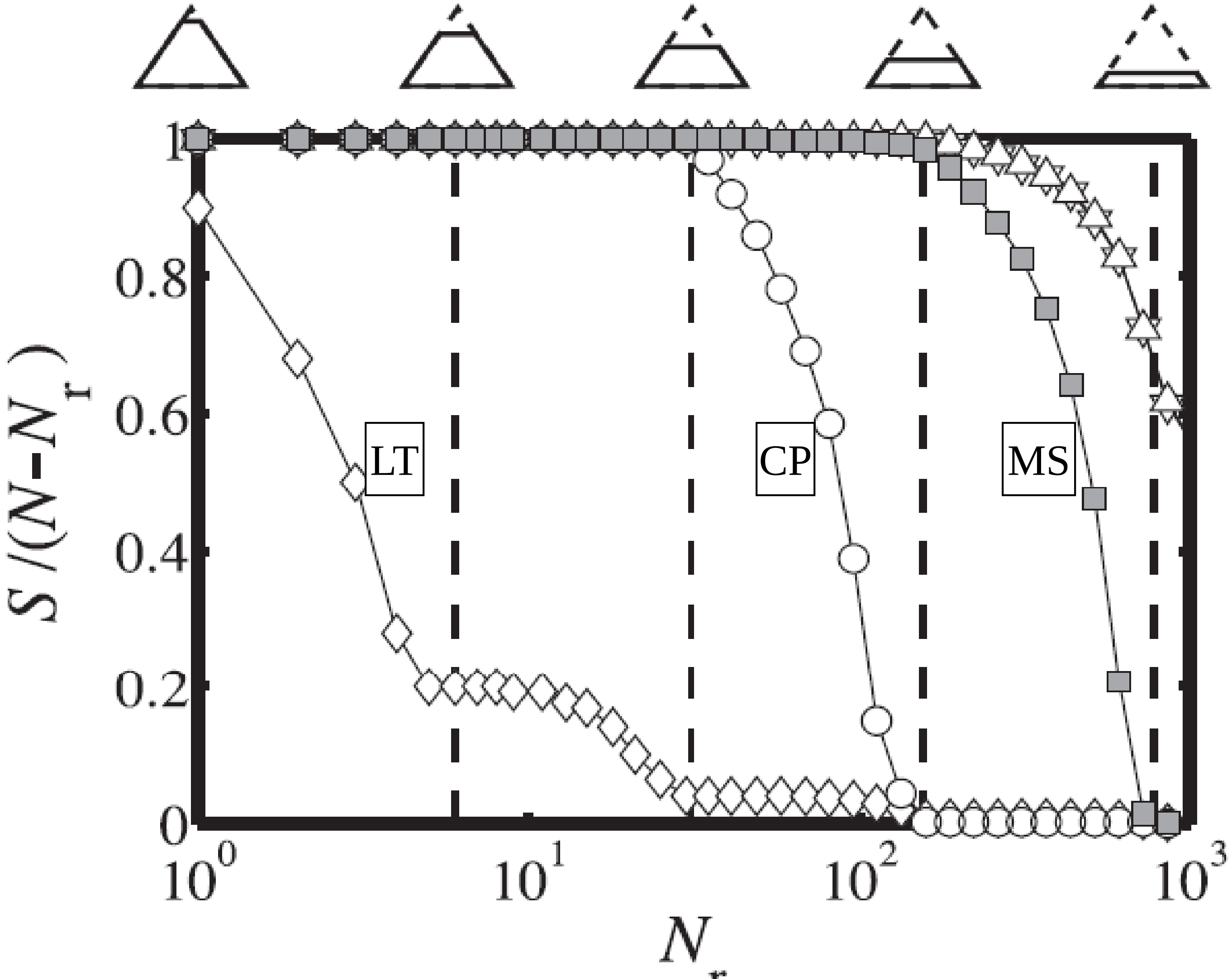
    - All structures are OK with decomposable tasks but MS and CP are best when larger scale interactions are key.
    - Maximum uncongested size is for MS
  - Connectivity robustness: The capacity to remain connected even when individual failures do occur.



Connectivity robustness (largest cluster size) after top-down targeted removal of N nodes

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    - Maximum uncongested size is for MS
  - Connectivity robustness: The capacity to remain connected even when individual failures do occur.
    - **Random best for targeted attack but MS as good until 4 of the 6 hierarchy levels are removed (LT and CP are significantly worse)**

Properties of the Organizational Models studied by DWS

- Robustness
  - Congestion robustness: the capacity to protect individual nodes from congestion (overload).
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    - All structures are OK with decomposable tasks but MS and CP are best when larger scale interactions are key.
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  - **Ultrarobustness**: A simultaneous capacity to exhibit superior Congestion and Connectivity robustness

Properties of the Organizational Models studied by DWS

- Robustness
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    - Maximum uncongested size is for **MS**
  - Connectivity robustness: The capacity to remain connected even when individual failures do occur.
    - Random best for targeted attack but **MS** as good
  - **Ultrarobustness**: A simultaneous capacity to exhibit superior Congestion and Connectivity robustness—clearly **MS** fits this definition by their measures and simulation

Ultra robustness

- Dodds, Watts and Sabel argue that one of their 5 structures is Ultrarobust.
  - The "Multiscale" Structure has superior (or at least near best) robustness and reliability to a variety of failure modes
    - Congestion
    - Node Failure
    - Link disconnection
- Reactions ?
- If one compares the difficulty of forming different kinds of links leading to MS, LT, CP etc. (costs or tradeoffs with other processes or properties), would MS still be always superior?

Ultra robustness II

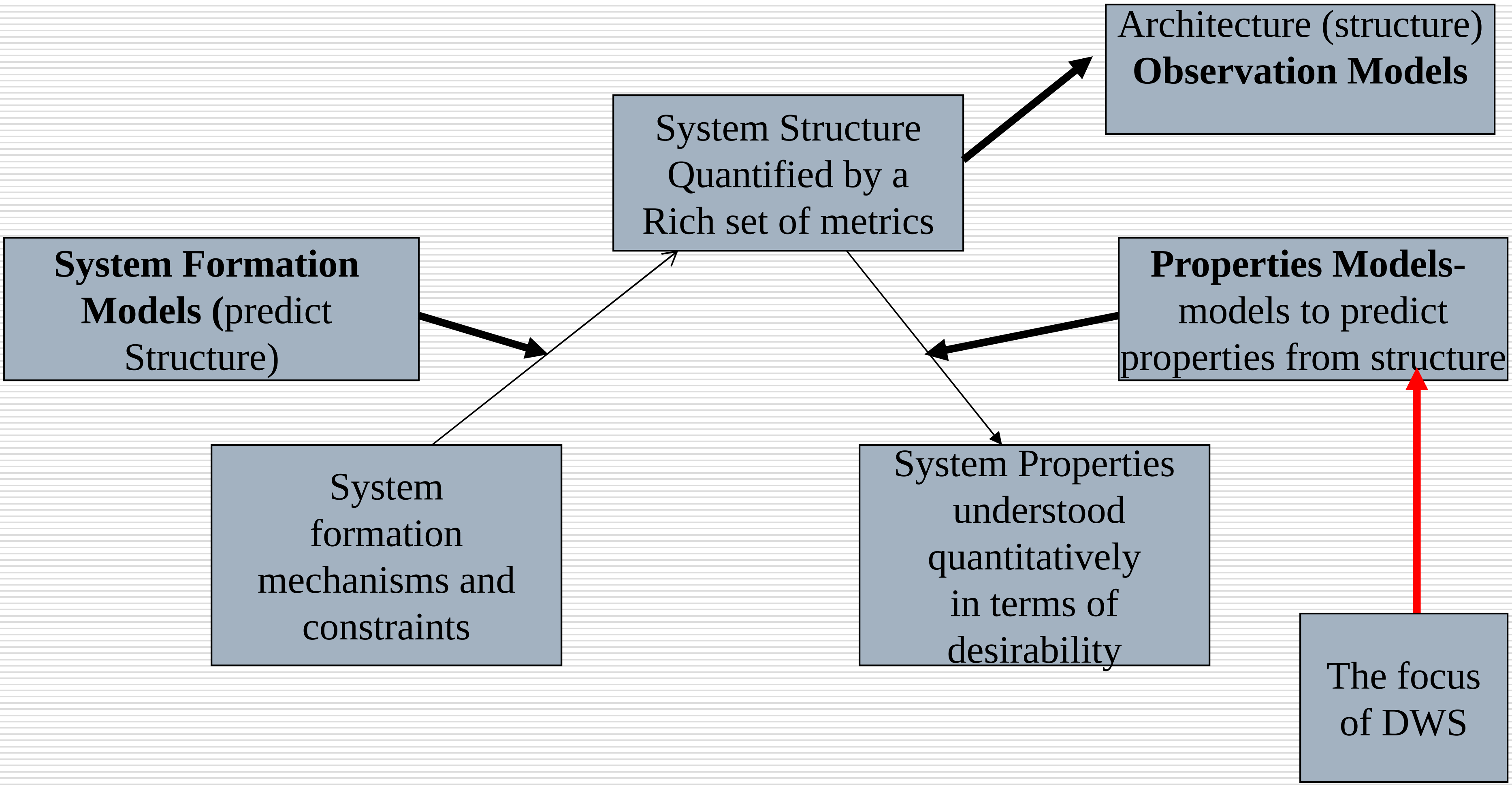
- Dodds, Watts and Sabel argue that one of their 5 structure is Ultrarobust.
  - The "Multiscale" Structure has superior (or at least near best) robustness and reliability to a variety of failure modes
    - Congestion
    - Node Failure
    - Link disconnection
- Reactions and link cost tradeoff.

- **How do we assess the DWS work?**

Assessment of Network model by DWS

- The model is not about the mechanism of formation of organizations but only about the structure-property relationship. It does not add to our knowledge of formation constraints or models of this kind

Schematic of Engineering System Model Types within a Framework



Assessment of Network model by DWS II

- The model is not about the mechanism of formation of organizations but only about the structure-property relationship. It does not add to our knowledge of formation constraints or models of this kind

- The random weighted additions to a hierarchy was a creative device to simulate different kinds of organizations (5 broad types but continuous variation among the types is possible with tuning of ζ and λ
- They also introduce a way to simulate the interdependence of tasks (local decomposability)
- Although they only modeled communication, this is relatively important in a number of other properties and thus can argued to be fundamental
- The paper **does not** introduce totally new fundamental insights about organizational design. What is its potential practical significance?

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Practice Assessment of DWS Paper

- The paper is really only about trying to derive a "structure-property" relationship and does not cover realistic structure formation. They do not consider the organizational structure generator as a model of structure formation nor should anyone else.
- The paper combines ideas from sociology and OR (as well as statistical physics) which is an approach Watts pursues and I applaud
- There are two issues to consider when assessing whether this model may have practical relevance:
  - Do real organizations have to deal with (a non-significant number of) problems whose solution requires participation by actors at large organizational distances (problems which are not locally decomposable) ?
  - How would one realistically arrive at the hybrid structures that DWS identify as best in dealing with such problems?
- I will consider these issues largely from my practical experience

Organizational Problem Decomposition

- In large functionally oriented firms, typical major organizations would include (for large firms 7 or so levels) sub-hierarchies for the following functions.

Manu-facturing	Sales & Marketing	Product Develop	Finance	HR	etc

- What problems might exist that require input across large organizational distances ?
- What are some possible solutions?

Organizational Problem Decomposition II

- In large functionally oriented firms, typical major organizations would include (for large firms 7 or so level) sub- hierarchies for the following functions.

Manu-facturing	Sales & Marketing	Product Develop	Finance	HR	etc

- One solution is to organize by sectors, markets, location etc. to become essentially smaller. In small firms, the functional organizations (and thus organizational distance through the hierarchy) would be smaller.
- However, if large firms can be decomposed to a set of non-interacting small firms then they will generally be more successful breaking themselves up. Pure conglomerates really do not work. However, one can still strive to organize to minimize the "large-organizational-distance" problems and this is what is often implicitly if not explicitly considered in most attempts at reorganization.

Possible Organizational Solutions to non-decomposable problems I

- Have highest levels totally absorb knowledge below them in hierarchy
- Become a small firm or a group of small firms
- Result: Loss of efficiencies of scale and reason for existence of large firms
- Re-organize so the nasty problems come into more closely related organizational entities.
- Result: some success but also *organizational cyclic instability*
- Flatten the organization and rely on "Local Teams"
- Result: manager-coordination overload, how does one person with 15 direct reports know that all 210 relations among his or her reports are being maintained? Multiple levels at this branching ratio do not work.

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Possible Organizational Solutions to non-decomposable problems III

- Some widely used approaches in large firms
- *Co-location* (for example of personnel or finance people with unit management) as a means to strengthen communication while maintaining organizational reporting through functional hierarchy.
- *Cohort* strengthening at large organizational distance ("old" IBM, Japan, military, others)
- Training for and *rewarding cross-organizational knowledge* and contacts (Japan)
- Matrix Management, co-location and rewards structure balancing can work but takes significant coordination efforts
- Importantly, the DWS paper shows that whatever approaches are taken, they should be a little stronger as one goes up the hierarchy and a little stronger with shorter organizational distances (**MS is best).** Many of the widely used approaches are actually stronger at lower levels.

Possible Future Research and Applications of Organizational Network Models

1. Observation of Collaborative Problem Solving in Large Organizations
   - Is task decomposability observable and different in different organizations?
   - What communication paths are actually followed in problem solving of non-locally-decomposable problems in selected J/G and US firms?

2. Observation of Social Networks within organizational hierarchies
   - Identification of important characteristics that determine such networks (age, hiring group, educational institution, neighborhood, functional specialty, co-workers, etc.)
   - Possible role/utility in organizational architecture and effectiveness
   - Management rules and practices that affect these social networks including rewards and incentives

Possible Future Research and Applications of Organizational Network Models b.

- 3. Modeling of the cost of lateral links
  - based upon effort to forge, impact on "Unity of Command" and accountability
  - Trade-offs with communication and problem-solving at different levels of task decomposability
- 4. Simulation of knowledge-capture and learning processes
  - Accountability for local and global learning
  - Observations in a variety of global and local organizations
- 5. Formal vs. informal lateral links
  - How well do "idealized" matrix organizations compare (robustness simulation) to the ideal organizational types depicted by DWS?
  - How well do specific matrix organizations compare (actual observations as the basis for simulation comparison) to the ideal organizations depicted by DWS?

Possible Future Research and Applications of Organizational Network Models c.

- 6. Observe link formation costs in various existing firms
- 7. Extend the model to simulate decision-making with different decision-making structures (Sah and Stiglitz)
- 8. Extend the model (or build a new one) to simulate **flexibility**
  - Changes in problem-solving intensity
  - Changes in task decomposability
  - Changes in knowledge needed to survive
  - Changes in leadership style needed
- 9. Extend the model to allow the communications to be between intelligent agents (use of ABM)
  - Give agents known **social cognition** patterns from cognitive psychology such as "Machiavellian intelligence", cooperative intelligence, etc.

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Overview Assessment of DWS Paper III

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- The paper combines ideas from sociology and OR (as well as statistical physics) which is an approach Watts pursues and I applaud
- The paper gives some practically useful direction to organizational changes.
- The structure generator and the problem decomposability approaches suggest a number of potentially fruitful future research directions (where actual observations of organizations are also pursued).

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  - Network Models in differing domains
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Network models and metaphors

- Two relatively different network modeling approaches applied to quite distinct domains
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Spatial distribution networks

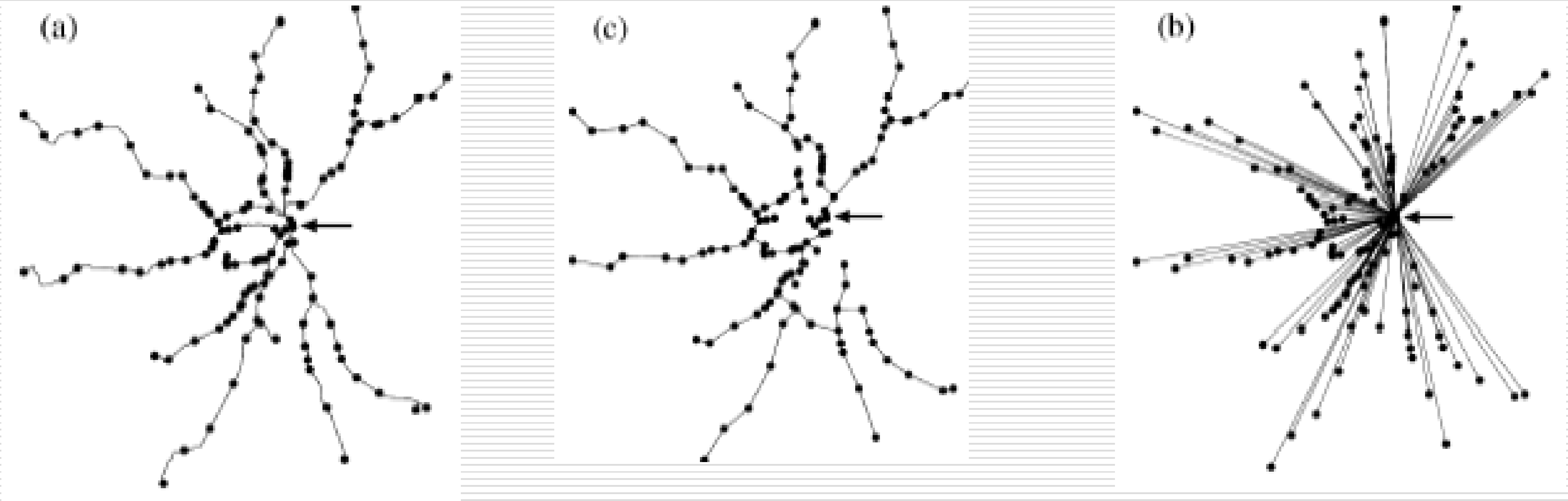
The model developed was for the case where the distribution system has a “root node” which is the **sole source or sink** for the items

- Examples where this is OK?
- Limitations

- Additional Design factors considered
  - Additional node locations (constraint)
  - Total link length (minimize to minimize cost)
  - Shortest path length between two nodes (minimize to minimize transport time)
- Tradeoffs in last two factors is the design/architecting problem
  - Look at ideal solutions for each criteria
  - Examine how real networks compare on the tradeoffs
  - Build growth model to derive pattern and look for consistency.

Spatial distribution networks

- For actual example system (a), minimum total edge length including paths to the root node is given by a Minimum Spanning Tree (c) while obtaining shortest paths to the root node is optimized by a star graph (b)



From Gastner, M. T., and M. E. J. Newman. "Shape and Efficiency in Spatial Distribution Networks." *J. Stat. Mech.* (2006): P01015. (Fig. 1) Courtesy the Institute of Physics. Used with permission.

Spatial distribution networks c

- From transportation research, a route factor is $q = \frac{1}{n}\sum_{i=1}^{n}\frac{l_{i0}}{d_{i0}}$, with *l* the shortest actual path length and and d is the shortest Euclidean distance and ***is equal to 1 for a star graph***

-

network	n	route factor actual	route factor MST	edge length (km) actual	edge length (km) MST	edge length (km) star
sewer system	23 922	1.59	2.93	498	421	102 998
gas (WA)	226	1.13	1.82	5 578	4 374	245 034
gas (IL)	490	1.48	2.42	6 547	4 009	59 595

From Gastner, M. T., and M. E. J. Newman. "Shape and Efficiency in Spatial Distribution Networks." *J. Stat. Mech.* (2006): P01015. (Table 1) Courtesy the Institute of Physics. Used with permission.

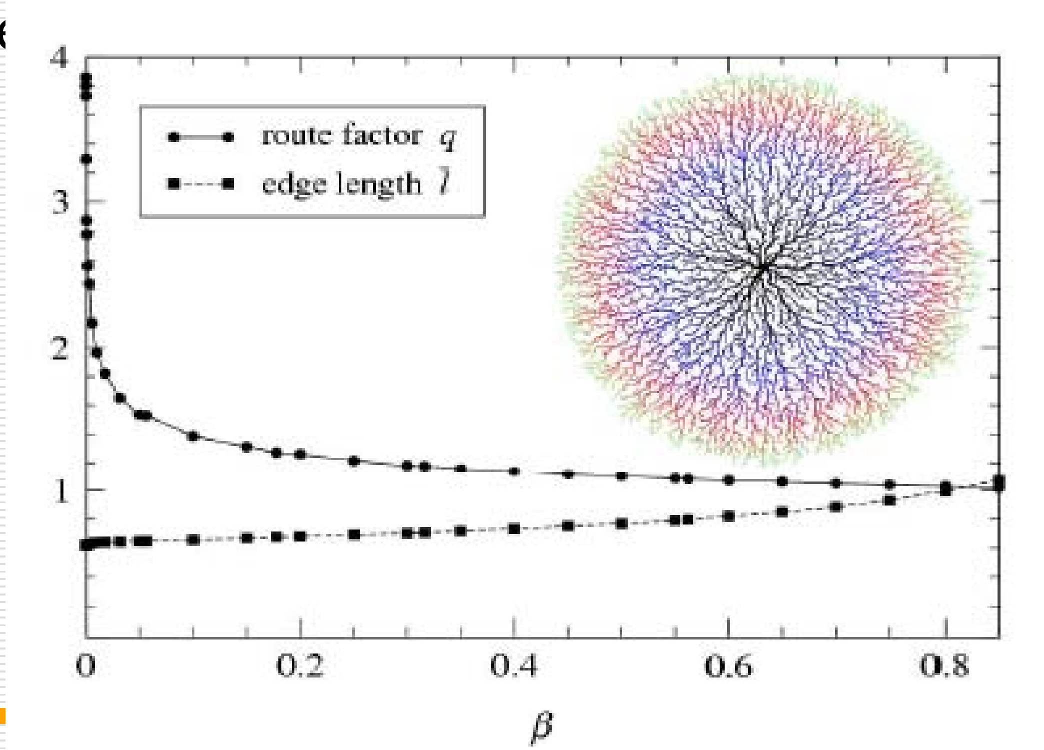
- The systems favor minimum edge length but have route factors considerably superior to MST optimums indicating *effective tradeoff in the two criteria.*
- A simple growth model is used to explain this result

Spatial distribution networks d

- The growth model assumes that the systems evolve from the root node by adding new (but ... es using a greedy optimization criterion that adds unconnected node, i, to an already connected node, j with the weighting factor give

$$w'_{ij} = d_{ij} + \beta l_{j0}.$$

- Simulations using these



From Gastner, M. T., and M. E. J. Newman. "Shape and Efficiency in Spatial Distribution Networks." *J. Stat. Mech.* (2006): P01015. (Fig. 3) Courtesy the Institute of Physics. Used with permission.

showing small tradeoffs in total link length give β large improvements in path length

Spatial distribution networks e

- What is **missing** from these studies of spatial distribution networks from your perspective? What ***future research*** do these studies suggest?
- Consideration of other network properties
  - Shipment capacity
  - Link capacities (and scaling/cost effects for key links)
  - Node capacities and roles (joints vs. ***transfer/routers***)
  - ***Flexibility for growth*** (new nodes as well as new connections of existing nodes)
  - Robustness to node or link breakdowns
- Development of more broadly applicable models
  - More than one source/sink node
- Development of other rules/protocols for growth that achieve the key properties well
- Consideration of top-down vs. evolved systems

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