# Organizational Networks:
# Information Exchange and Robustness

Last updated: 2018/03/23, 19:15:27

Complex Networks | @networksvox
CSYS/MATH 303, Spring, 2018

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## Outline





## Overview

### The basic idea/problem/motivation/history:

- Organizations as information exchange entities.
- Catastrophe recovery.
- Solving ambiguous, ill-defined problems.
- Robustness as 'optimal' design feature.

### A model of organizational networks:

- Network construction algorithm.
- Task specification.
- Message routing algorithm.

### Results:

- Performance measures.



## February, 1997:

### Aisin (eye-sheen), maker of brake valve parts for Toyota, burns to ground. [4]

- 4 hours supply ("just in time").
- 14,000 cars per day → 0 cars per day.
- 6 months before new machines would arrive.
- Recovered in 5 days.

- Case study performed by Nishiguchi and Beaudet [4]
  "Fractal Design: Self-organizing Links in Supply Chain"
  in "Knowledge Creation: A New Source of Value"

# February, 1997:



## Some details:

- 36 suppliers, 150 subcontractors
- 50 supply lines
- Sewing machine maker with no experience in car parts spent about 500 man hours refitting a milling machine to produce 40 valves a day.
- Recovery depended on horizontal links which arguably provided:
  1. robustness
  2. searchability





# Some things fall apart:










# Rebirth:






# Motivation

## Recovery from catastrophe involves solving problems that are:

- Unanticipated,
- Unprecedented,
- Ambiguous (nothing is obvious),
- Distributed (knowledge/people/resources),
- Limited by existing resources,
- Critical for survival.

## Frame:

- Collective solving of ambiguous problems





# Motivation

## Ambiguity:

- Question much less answer is not well understood.
- Back and forth search process rephrases question.
- Leads to iterative process of query reformulation.
- Ambiguous tasks are inherently not decomposable.
- How do individuals collectively work on an ambiguous organization-scale problem?
- How do we define ambiguity?

# Let's modelify:

## Modeling ambiguous problems is hard...

- Model response instead...
- Individuals need novel information and must communicate with others outside of their usual contacts.
- Creative search is intrinsically inefficient.

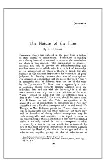
## Focus on robustness:

1. Avoidance of individual failures.
2. Survival of organization even when failures do occur.



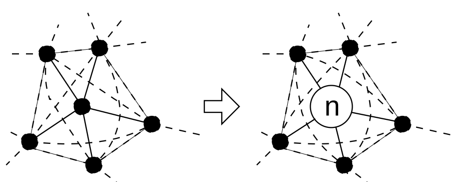


## Why organizations exist:



"The Nature of the Firm"
Ronald H. Coase,
Economica, **New Series, 4**, 386–405, 1937. [1]

- Notion of Transaction Costs.
- More efficient for individuals to cooperate outside of the market.




- Coase had a solid career.





# Real organizations—Extremes

## Hierarchy:

- Maximum efficiency,
- Suited to static environment,
- Brittle.

## Market:

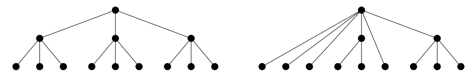
- Resilient,
- Suited to rapidly changing environment,
- Requires costless or low cost interactions.





# Organizations as efficient hierarchies

- Economics: Organizations ≡ Hierarchies.
- e.g., Radner (1993) [5], Van Zandt (1998) [7]
- Hierarchies performing associative operations:

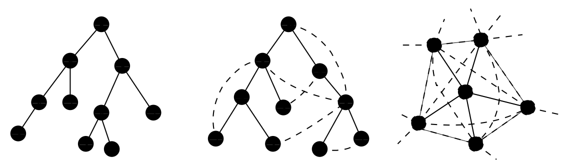






# Real organizations...

## But real, complex organizations are in the middle...



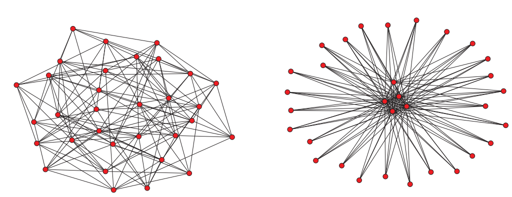
"Heterarchy"
David Stark,
The Biology of Business: Decoding the Natural Laws of the Enterprise., **New Series, 4**, 153–, 1999. [6]





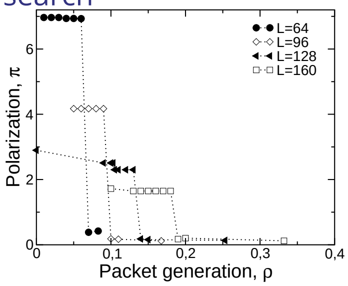
## Optimal network topologies for local search

"Optimal network topologies for local search with congestion"
Guimerà et al.,
Phys. Rev. Lett., **89**, 248701, 2002. [3]



- Parallel search and congestion.
- Queueing and network collapse.
- Exploration of random search mechanisms.

## Optimal network topologies for local search




- Betweenness: $\beta$.
- Polarization:

$$\pi = \frac{\max \beta}{\langle \beta \rangle} - 1.$$

- $L$ = number of links.

- Goal: minimize average search time.
- Few searches ⇒ hub-and-spoke network.
- Many searches ⇒ decentralized network.
- Phase transition?





## Desirable organizational qualities:

1. Low cost (requiring few links).
2. Scalability.
3. Ease of construction—existence is plausible.
4. Searchability.
5. 'Ultra-robustness':
   - I Congestion robustness
     (Resilience to failure due to information exchange);
   - II Connectivity robustness
     (Recoverability in the event of failure).





## Searchability

### Small world problem:

- Can individuals pass a message to a target individual using only personal connections?
- Yes, large scale networks searchable if nodes have identities.
- "Identity and Search in Social Networks," Watts, Dodds, & Newman, 2002. [8]





"Information exchange and the robustness of organizational networks"
Dodds, Watts, and Sabel,
Proc. Natl. Acad. Sci., **100**, 12516–12521, 2003. [2]

- Edited by Harrison White

### Formal organizational structure:

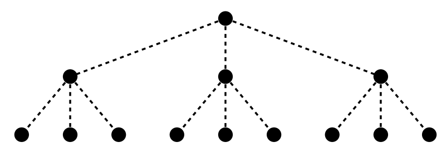
- Underlying hierarchy:
  - branching ratio $b$
  - depth $L$
  - $N = (b^L - 1)/(b - 1)$ nodes
  - $N - 1$ links
- Additional informal ties:
  - Choose $m$ links according to a two parameter probability distribution
  - $0 \leq m \leq (N-1)(N-2)/2$





## Model—underlying hierarchy

### Model—formal structure:



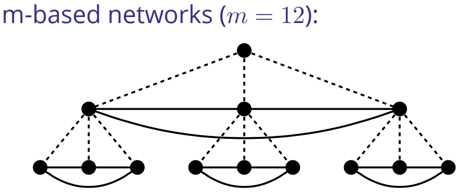
$$b = 3, \quad L = 3, \quad N = 13$$





## Model—addition of links

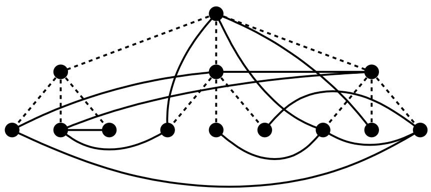
### Team-based networks ($m = 12$):



# Model—addition of links



Random networks $(m = 12)$:





# Model—addition of links

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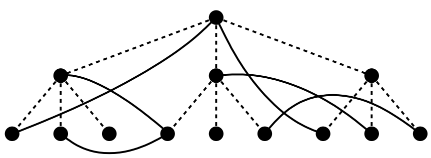
Random interdivisional networks $(m = 6)$:





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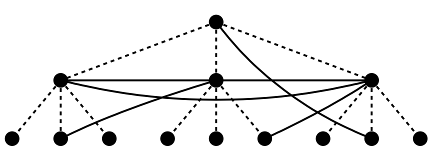
Core-periphery networks $(m = 6)$:





# Model—addition of links

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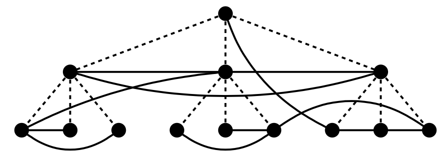
Multiscale networks $(m = 12)$:





# Model—construction

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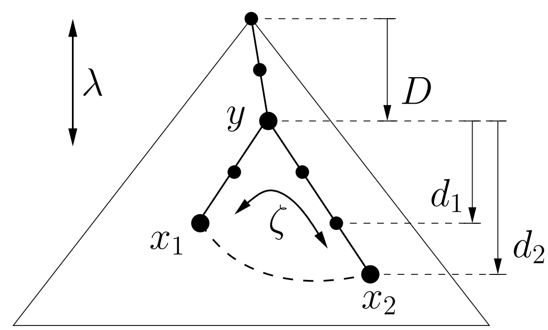




# Model—construction

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- Link addition probability:

$$P(D, d_1, d_2) \propto e^{-D/\lambda} e^{-f(d_1,d_2)/\zeta}$$

- First choose $(D, d_1, d_2)$.
- Randomly choose $(y, x_1, x_2)$ given $(D, d_1, d_2)$.
- Choose links without replacement.

# Model—construction





## Requirements for $f(d_1, d_2)$:

1. $f \geq 0$ for $d_1 + d_2 \geq 2$
2. $f$ increases monotonically with $d_1$, $d_2$.
3. $f(d_1, d_2) = f(d_2, d_1)$.
4. $f$ is maximized when $d_1 = d_2$.

## Simple function satisfying 1–4:

$$f(d_1, d_2) = (d_1^2 + d_2^2 - 2)^{1/2}$$

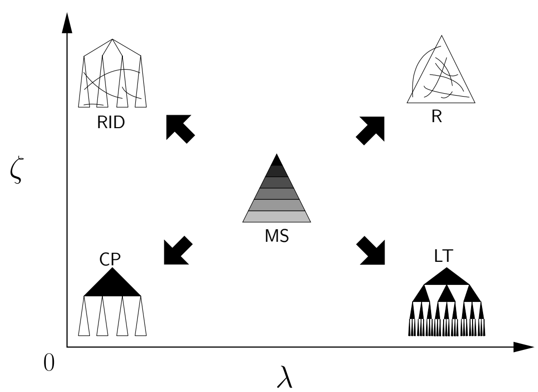
$$\Rightarrow P(y, x_1, x_2) \propto e^{-D/\lambda} e^{-(d_1^2+d_2^2-2)^{1/2}/\zeta}$$



# Model—limiting cases










# Message passing pattern





- Each of $T$ time steps, each node generates a message with probability $\mu$.
- Recipient of message chosen based on distance from sender.
- $$P(\text{recipient at distance } d) \propto e^{-d/\xi}.$$

1. $\xi$ = measure of uncertainty;
2. $\xi = 0$: local message passing;
3. $\xi = \infty$: random message passing.

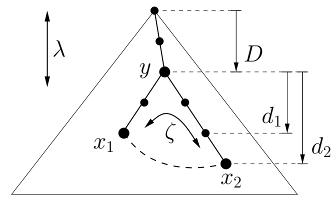


# Message passing pattern:





## Distance $d_{12}$ between two nodes $x_1$ and $x_2$:




$$d_{12} = \max(d_1, d_2) = 3$$

- Measure unchanged with presence of informal ties.



# Message passing pattern





## Simple message routing algorithm:

- Look ahead one step: always choose neighbor closest to recipient node.
- Pseudo-global knowledge:
  1. Nodes understand hierarchy.
  2. Nodes know only local informal ties.



# Message passing pattern





## Interpretations:

1. Sender knows specific recipient.
2. Sender requires certain kind of recipient.
3. Sender seeks specific information but recipient unknown.
4. Sender has a problem but information/recipient unknown.

# Message passing pattern



## Performance:

- Measure Congestion Centrality $\rho_i$, fraction of messages passing through node $i$.
- Similar to betweenness centrality.
- However: depends on
  1. Search algorithm;
  2. Task specification ($\mu$, $\xi$).
- Congestion robustness comes from minimizing $\rho_{\text{max}}$.



# Performance testing:



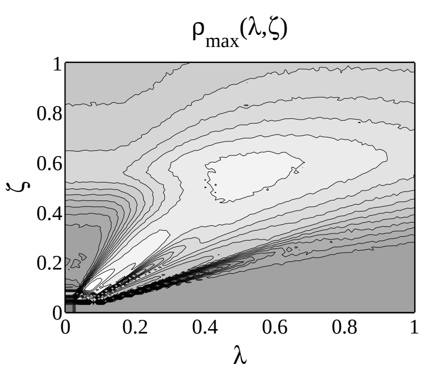
## Parameter settings (unless varying):

- Underlying hierarchy: $b = 5$, $L = 6$, $N = 3096$;
- Number of informal ties: $m = N$.
- Link addition algorithm: $\lambda = \zeta = 0.5$.
- Message passing: $\xi = 1$, $\mu = 10/N$, $T = 1000$.



# Results—congestion robustness

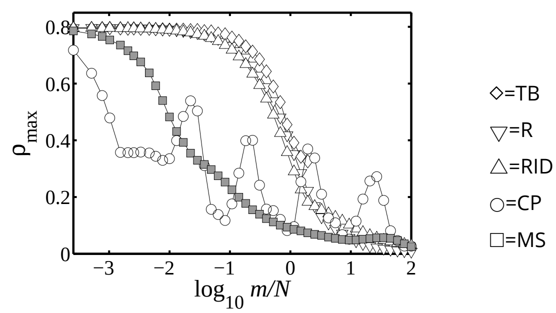







# Results—varying number of links added:

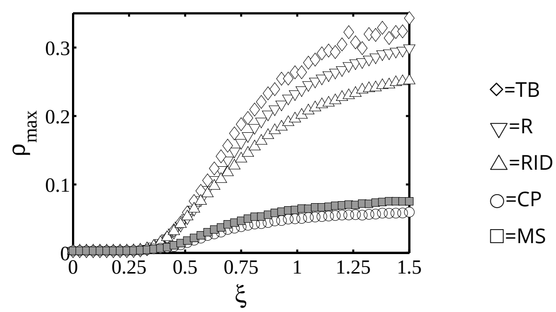







# Results—varying message passing pattern





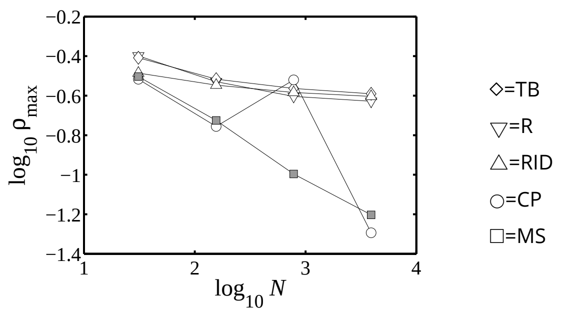



# Results—Maximum firm size



- Congestion may increase with size of network.
- Fix rate of message passing ($\mu$) and Message pattern ($\xi$).
- Fix branching ratio of hierarchy and add more levels.
- Individuals have limited capacity $\Rightarrow$ limit to firm size.

## Scalability in complete uncertainty: $\xi = \infty$










## Connectivity Robustness

### Inducing catastrophic failure:

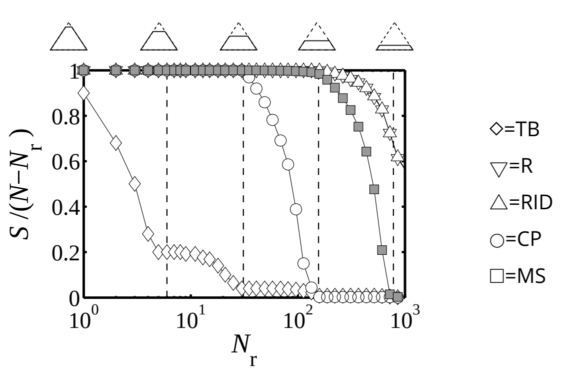
- Remove $N_r$ nodes and measure relative size of largest component $C = S/(N - N_r)$.
- Four deletion sequences:
  1. Top-down;
  2. Random;
  3. Hub;
  4. Cascading failure.
- Results largely independent of sequence.







## Results—Connectivity Robustness










## Summary of results

| Feature | Congestion Robustness | Connectivity Robustness | Scalability |
|---|---|---|---|
| Core-periphery | good | average | average |
| Random | poor | good | poor |
| Rand. Interdivisional | poor | good | poor |
| Team-based | poor | poor | poor |
| Multiscale | good | good | good |







## Conclusary moments

### Multi-scale networks:

1. Possess good Congestion Robustness and Connectivity Robustness ⇒ Ultra-robust;
2. Scalable;
3. Relatively insensitive to parameter choice;

- Above suggests existence of multi-scale structure is plausible.







## Conclusary moments

- Foregoing is an attempt to model what organizations might look like beyond simple hierarchies (2003).
- Possible work: develop 'bottom up' model of organizational networks based on social search, identity (emergent searchability).
- Balance of generalists versus specialists—how many middle managers does an organization need?
- Still a need for data on real organizations...

## References I



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The nature of the firm.
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