

Organizational Networks: Information Exchange and Robustness

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Principles of Complex Systems, Vols. 1, 2, & 3D
CSYS/MATH 6701, 6713, & a pretend number,
2023-2024 | @pocsvox

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Computational Story Lab | Vermont Complex Systems Center
Santa Fe Institute | University of Vermont



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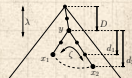
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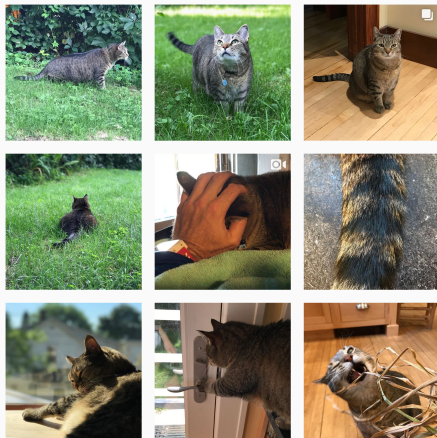
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Overview

The basic idea/problem/motivation/history:

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

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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]

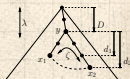
- 🧱 4 hours supply (“just in time”).
- 🧱 14,000 cars per day → 0 cars per day.
- 🧱 6 months before new machines would arrive.
- 🧱 Recovered in 5 days.

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



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:



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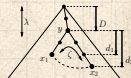
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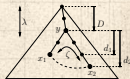
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LEHMAN BROTHERS



Rebirth:

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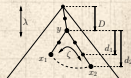
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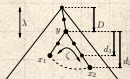
Motivation

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



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?



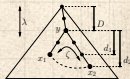
Let's modelify:

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:

- Avoidance of individual failures.
- Survival of organization even when failures do occur.



Why organizations exist:

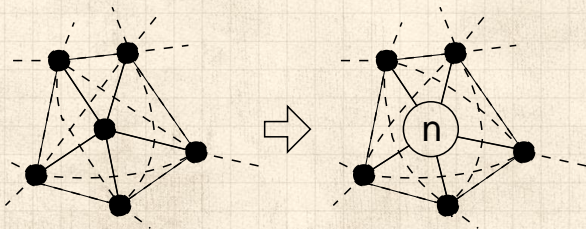


"The Nature of the Firm" ↗

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.



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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

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 Economics: Organizations \equiv Hierarchies.

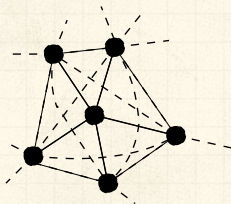
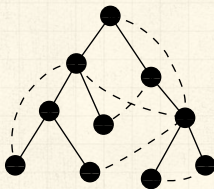
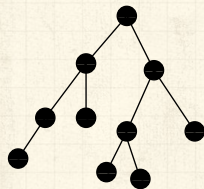
 e.g., Radner (1993)^[5], Van Zandt (1998)^[7]


 Hierarchies performing associative operations:



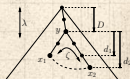
Real organizations...

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]

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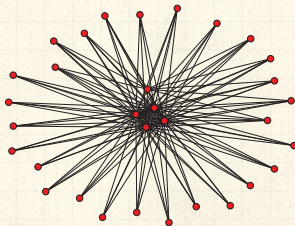
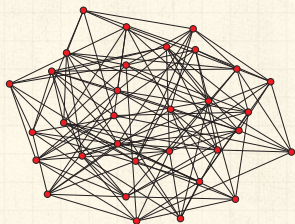
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Parallel search and congestion.



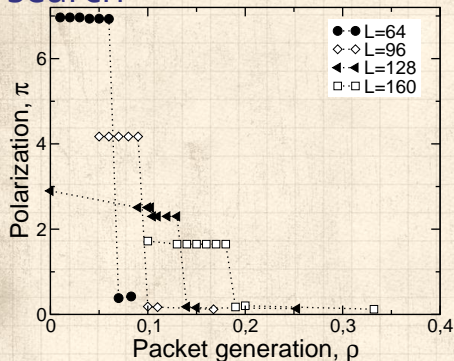
Queueing and network collapse.



Exploration of random search mechanisms.



Optimal network topologies for local search



Betweenness: β .

Polarization:

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

L = number of links.

Goal: minimize average search time.

Few searches \Rightarrow hub-and-spoke network.

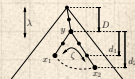
Many searches \Rightarrow decentralized network.

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).



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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

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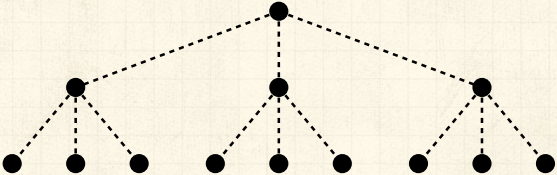
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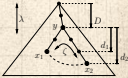
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Model—formal structure:



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



Model—addition of links

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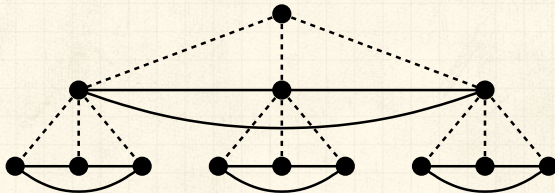
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Team-based networks ($m = 12$):



Model—addition of links

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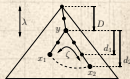
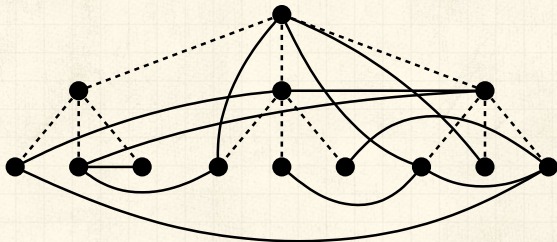
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Random networks ($m = 12$):



Model—addition of links

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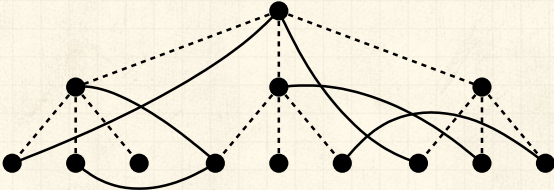
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Random interdivisional networks ($m = 6$):



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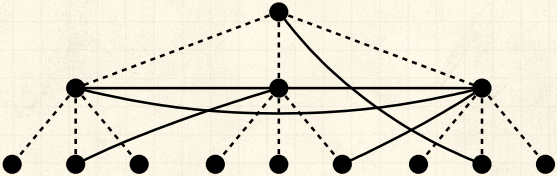
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Core-periphery networks ($m = 6$):



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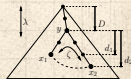
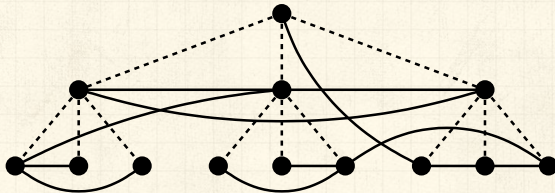
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Multiscale networks ($m = 12$):



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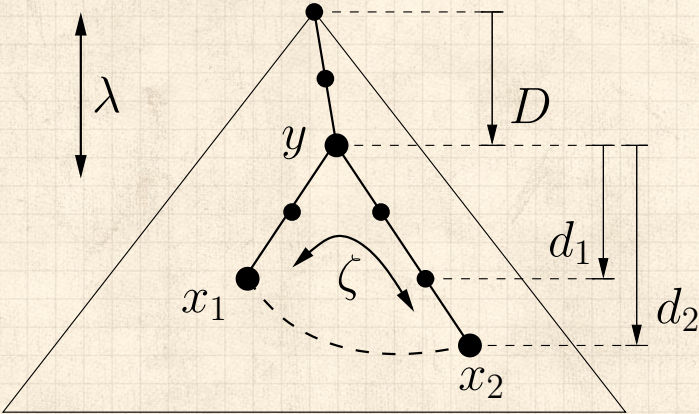
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 Link addition probability:

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

 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

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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 $d_1 = d_2$.

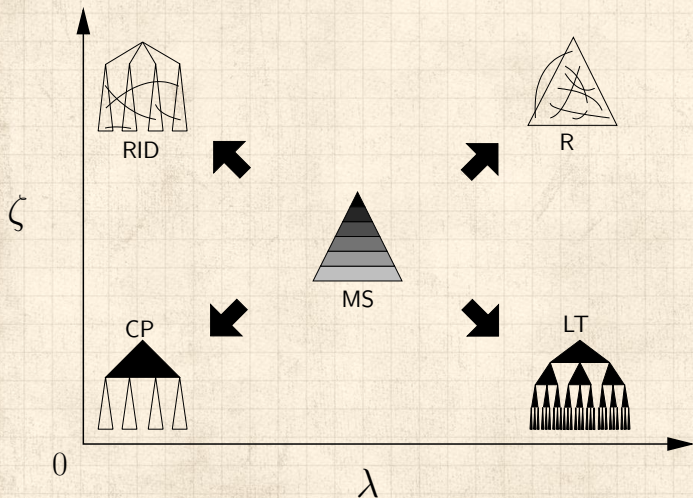
Simple function satisfying 1-4:

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

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



Model—limiting cases



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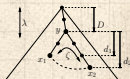
Message passing pattern

 Each of T time steps, each node generates a message with probability μ .

 Recipient of message chosen based on distance from sender.


$$P(\text{recipient at distance } d) \propto e^{-d/\xi}.$$

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



Message passing pattern:

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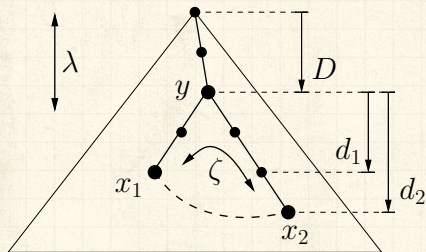
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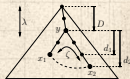
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Distance d_{12} between two nodes x_1 and x_2 :




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


 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

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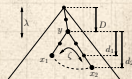
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Interpretations:

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 ρ_i , fraction of messages passing through node i .
- 🧱 Similar to betweenness centrality.
- 🧱 However: depends on
 1. Search algorithm;
 2. Task specification (μ, ξ) .
- 🧱 Congestion robustness comes from minimizing ρ_{\max} .



Performance testing:

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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

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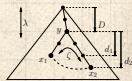
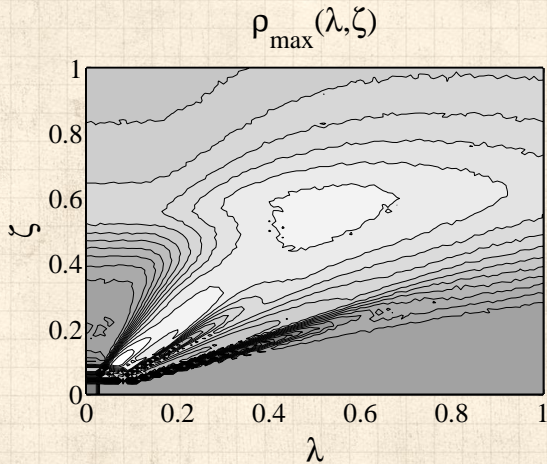
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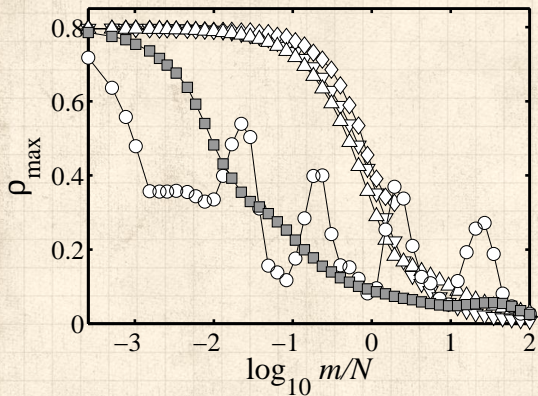
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Results—varying number of links added:



◇=TB

▽=R

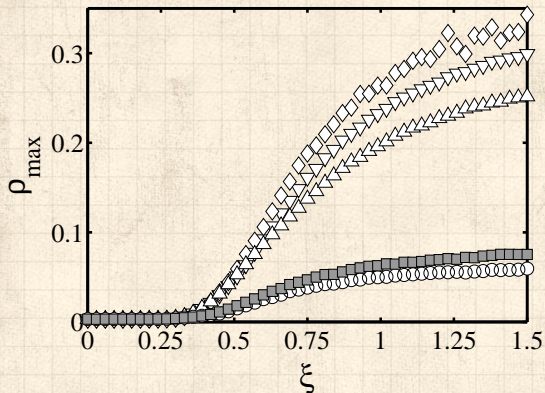
△=RID

○=CP

□=MS



Results—varying message passing pattern



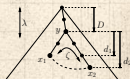
◇=TB

▽=R

△=RID

○=CP

□=MS



Results—Maximum firm size

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



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

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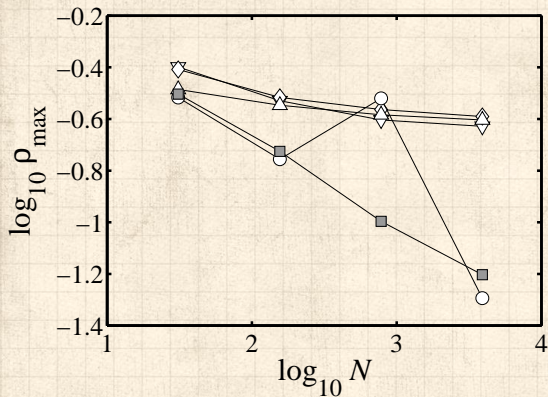
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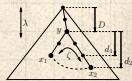
◇=TB

▽=R


△=RID


○=CP

□=MS




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

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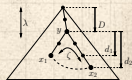
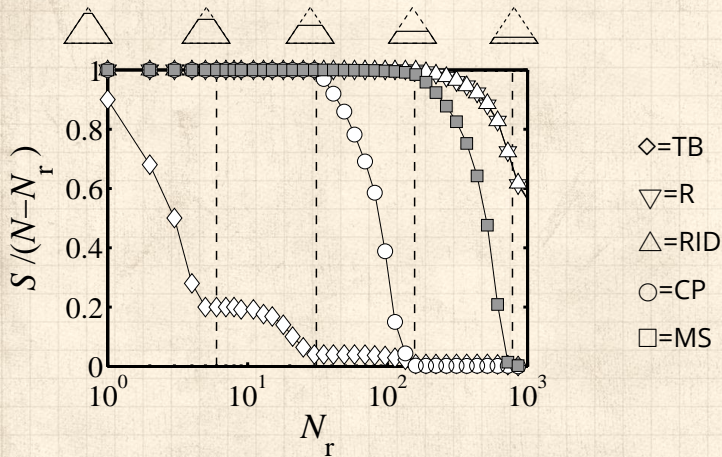
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Summary of results

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



Conclusory moments

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Multi-scale networks:

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

 Above suggests existence of multi-scale structure is plausible.



Conclusory 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...

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References I

[1] R. H. Coase.

The nature of the firm.

[Economica](#), New Series, 4(4):386–405, 1937. pdf ↗

[2] P. S. Dodds, D. J. Watts, and C. F. Sabel.

Information exchange and the robustness of
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[Proc. Natl. Acad. Sci.](#), 100(21):12516–12521, 2003. pdf ↗

[3] R. Guimerà, A. Diaz-Guilera, F. Vega-Redondo,
A. Cabrales, and A. A.

Optimal network topologies for local search with
congestion.

[Phys. Rev. Lett.](#), 89:248701, 2002. pdf ↗



References II

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