

# Organizational Networks: Information Exchange and Robustness

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Principles of Complex Systems, Vols. 1, 2, & 3D  
CSYS/MATH 300, 303, & 394, 2022–2023 | @pocsvox

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Santa Fe Institute | University of Vermont



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Overview

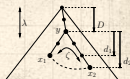
Toyota  
Ambiguous problems  
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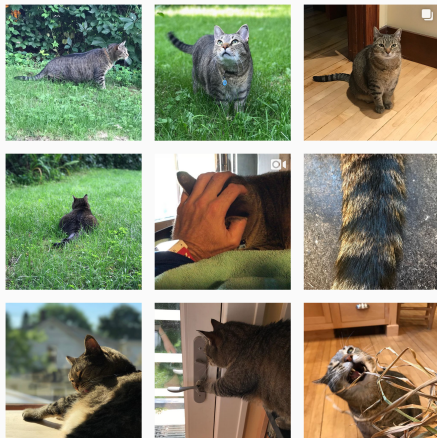


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## Special Guest Executive Producer



Overview

- Toyota
- Ambiguous problems
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 On Instagram at [pratchett\\_the\\_cat](https://www.instagram.com/pratchett_the_cat) 



# Outline

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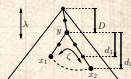
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# Overview

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## 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.

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# February, 1997:

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

- 🧱 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 <sup>[4]</sup>

“Fractal Design: Self-organizing Links in Supply Chain”

in “Knowledge Creation: A New Source of Value”

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## 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

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# Rebirth:

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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

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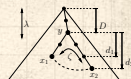
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## Ambiguity:

- 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?

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# 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.

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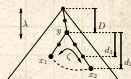
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# Why organizations exist:

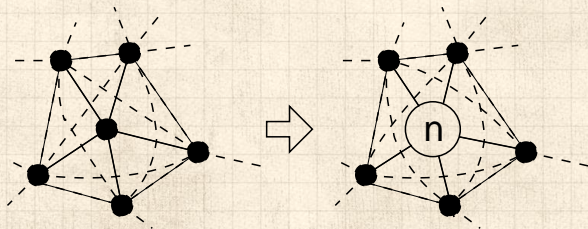


## "The Nature of the Firm" ↗

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




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## Hierarchy:

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

## Market:

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

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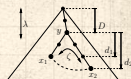
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# Organizations as efficient hierarchies

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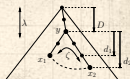
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 Economics: Organizations  $\equiv$  Hierarchies.

 e.g., Radner (1993)<sup>[5]</sup>, Van Zandt (1998)<sup>[7]</sup>

 Hierarchies performing associative operations:

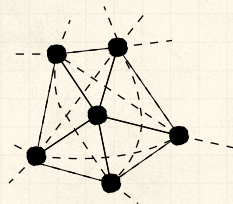
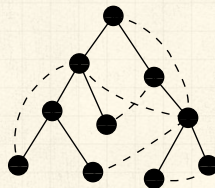
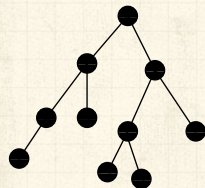


# Real organizations...

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



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"Heterarchy" 

David Stark,

The Biology of Business: Decoding the  
Natural Laws of the Enterprise., **New  
Series, 4**, 153–, 1999. <sup>[6]</sup>



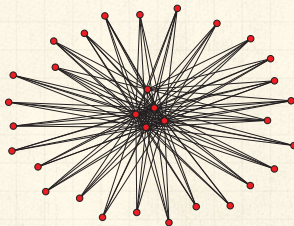
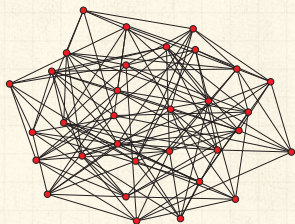
# Optimal network topologies for local search



“Optimal network topologies for local search with congestion” 

Guimerà et al.,

Phys. Rev. Lett., **89**, 248701, 2002. <sup>[3]</sup>



Parallel search and congestion.



Queueing and network collapse.



Exploration of random search mechanisms.

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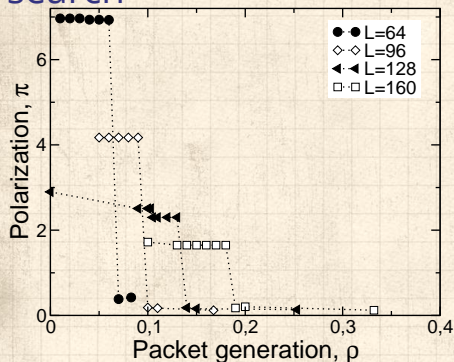
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# Optimal network topologies for local search





 Betweenness:  $\beta$ .


 Polarization:


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

  $L$  = number of links.

 Goal: minimize average search time.

 Few searches  $\Rightarrow$  hub-and-spoke network.

 Many searches  $\Rightarrow$  decentralized network.

 Phase transition?

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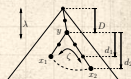
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# Desirable organizational qualities:

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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## "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
- $0 \leq m \leq (N - 1)(N - 2)/2$

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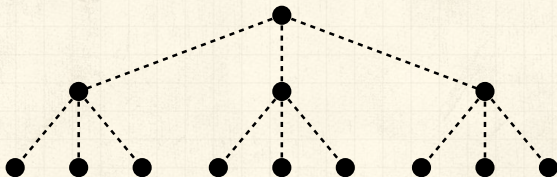


# Model—underlying hierarchy

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## Model—formal structure:



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

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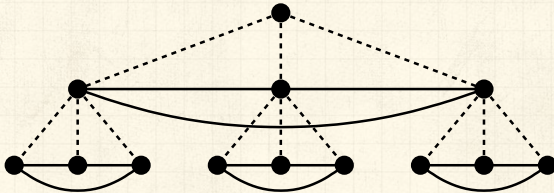


# Model—addition of links

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



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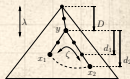
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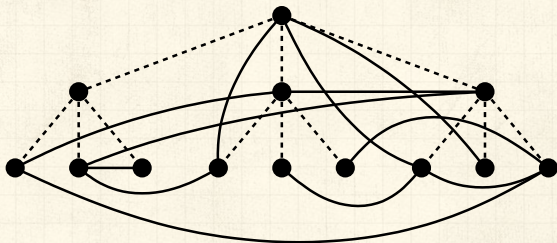


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Random networks ( $m = 12$ ):



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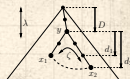
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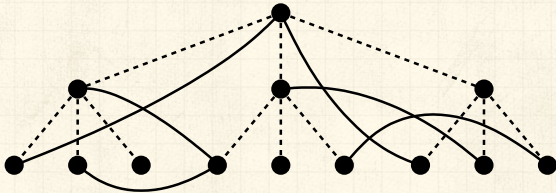


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## Random interdivisional networks ( $m = 6$ ):



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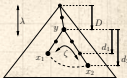
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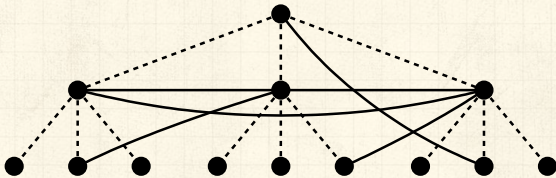


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## Core-periphery networks ( $m = 6$ ):



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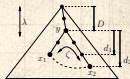
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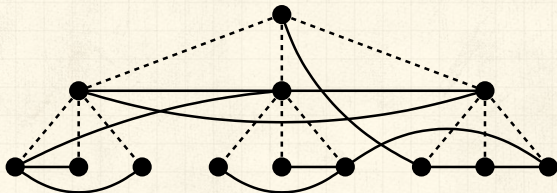


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Multiscale networks ( $m = 12$ ):



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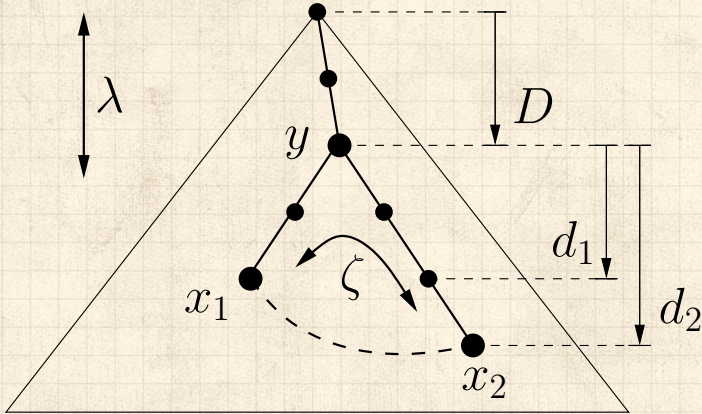
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# Model—construction





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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.



## 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:

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

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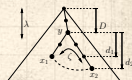
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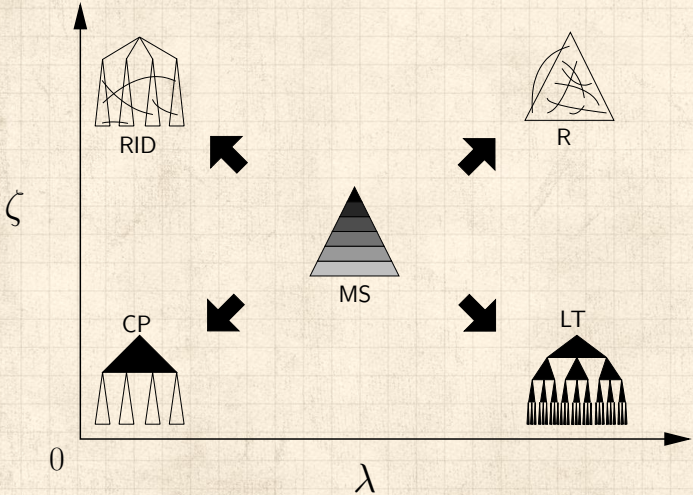
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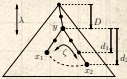





# Model—limiting cases




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# 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.

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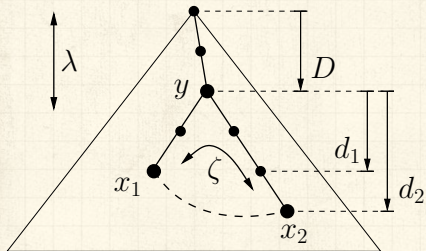
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# Message passing pattern:

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.

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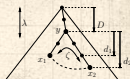
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## Simple message routing algorithm:

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

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# Message passing pattern

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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.

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# Message passing pattern

## Performance:

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

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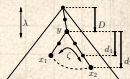
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## Parameter settings (unless varying):

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

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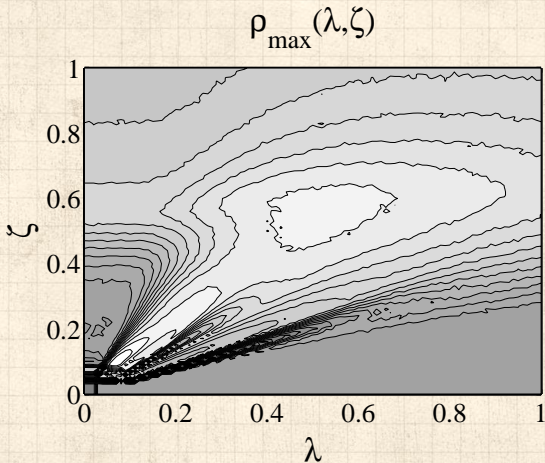
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# Results—congestion robustness

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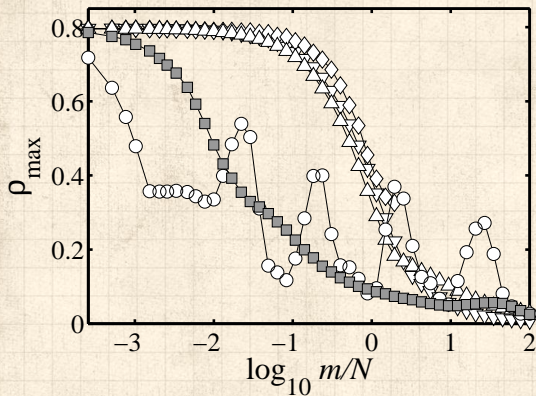




# Results—varying number of links added:

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◇=TB

▽=R

△=RID

○=CP

□=MS

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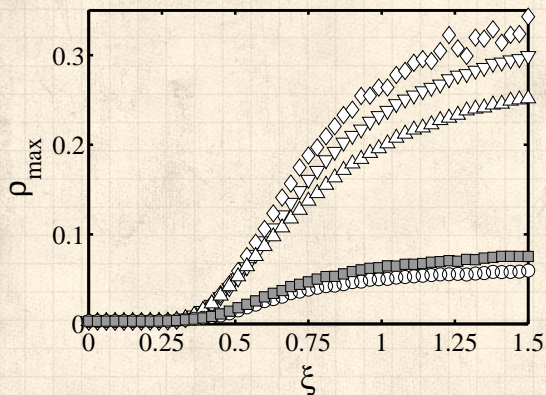
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# Results—varying message passing pattern

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◇=TB

▽=R

△=RID

○=CP

□=MS

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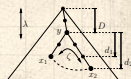
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# Results—Maximum firm size

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- 🧱 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.

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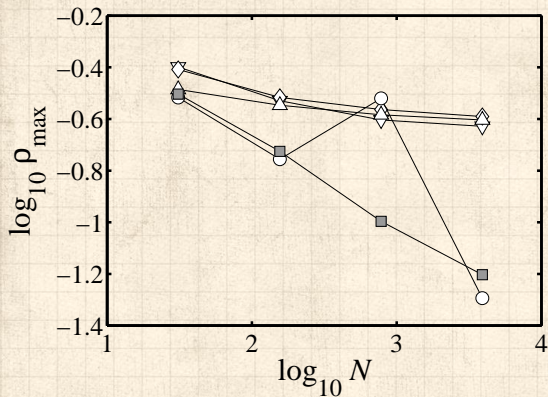
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# Scalability in complete uncertainty: $\xi = \infty$



◇=TB

▽=R

△=RID

○=CP

□=MS

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## 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.

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# Results—Connectivity Robustness

PoCS  
@pocsvox

Organizational  
Networks

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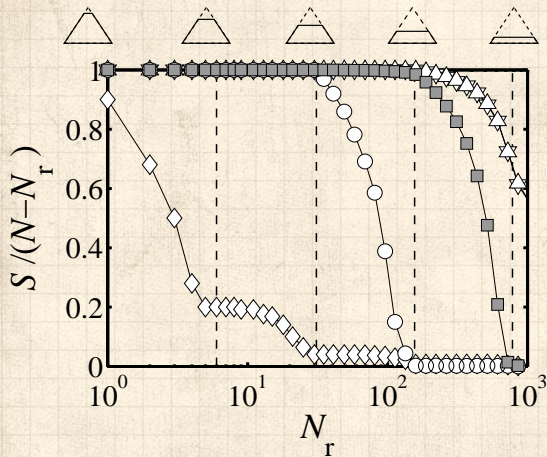
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# Summary of results


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

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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.

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# Conclusory moments

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Organizational  
Networks

- ⊞ 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  
organizational networks.

[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](#)

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[7] T. Van Zandt.

Organizations with an endogenous number of information processing agents.

In Organizations with Incomplete Information, chapter 7. Cambridge University Press, New York, 1998.

[8] D. J. Watts, P. S. Dodds, and M. E. J. Newman.

Identity and search in social networks.

Science, 296:1302–1305, 2002. [pdf](#) 

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