

Organizational Networks: Information Exchange and Robustness

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

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Overview

- Toyota
- Ambiguous problems
- Models of organizations:

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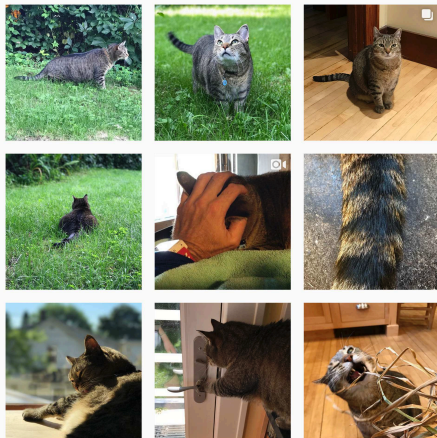
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 On Instagram at [pratchett_the_cat](https://www.instagram.com/pratchett_the_cat) 



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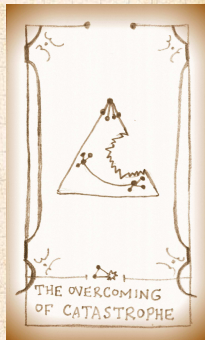
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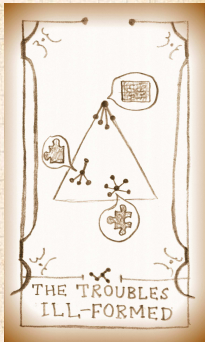
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The basic idea/problem/motivation/history:

- 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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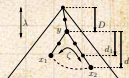
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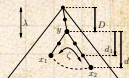
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February, 1997:

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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 \rightarrow 0 cars per day.
- 6 months before new machines would arrive.
- Recovered in 5 days.

- Case study performed by Nishiguchi and Beaudet [21]
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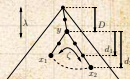
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February, 1997:


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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:

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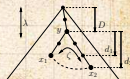
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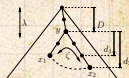
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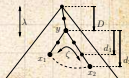
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Motivation

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Recovery from catastrophe involves solving problems that are:

- 1. Unanticipated,
- 2. Unprecedented,
- 3. Ambiguous (nothing is obvious),
- 4. Distributed (knowledge/people/resources),
- 5. Limited by existing resources,
- 6. Critical for survival.

Frame:

- 1. Collective solving of ambiguous problems

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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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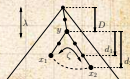
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Let's modelify:

Modeling ambiguous problems is hard...

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

Focus on robustness:

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

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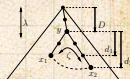
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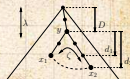
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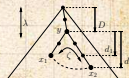
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Why organizations exist:



"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.

🐛 Coase ↗ had a solid career ↗

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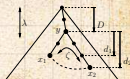
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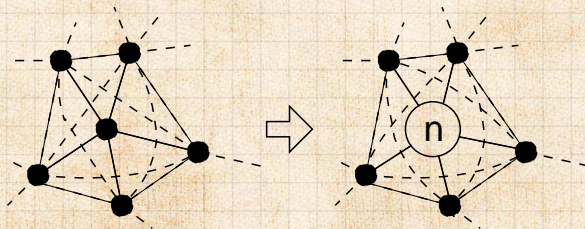


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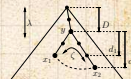
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Why organizations exist:

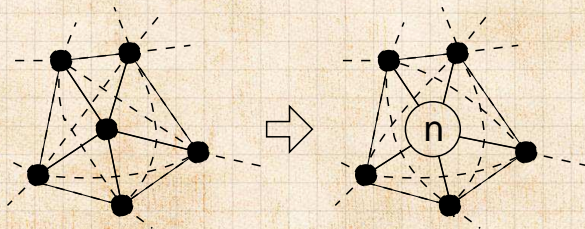
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"The Nature of the Firm" ↗
Ronald H. Coase,
Economica, **New Series**, 4, 386–405, 1937. [1]

🧱 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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Organizations as efficient hierarchies

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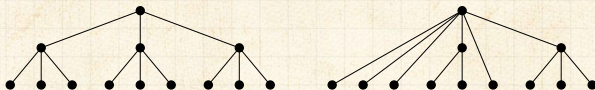
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 Economics: Organizations \equiv Hierarchies.

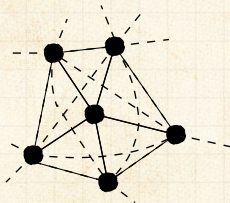
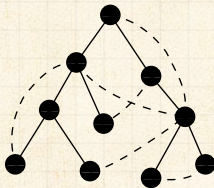
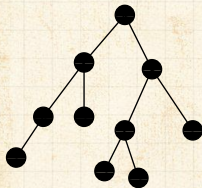
 e.g., Radner (1993)^[5], Van Zandt (1998)^[7]


 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]



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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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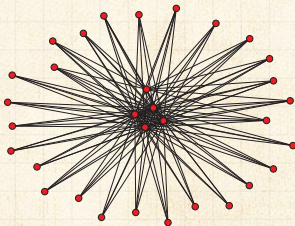
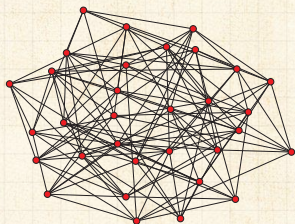
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Parallel search and congestion.



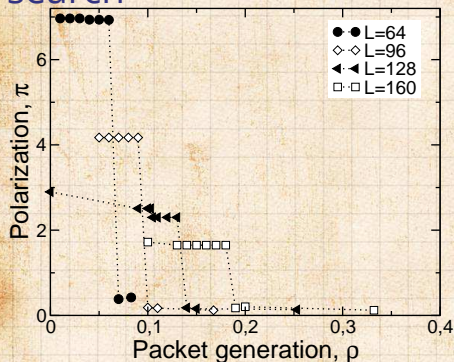
Queueing and network collapse.



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?

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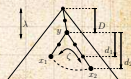
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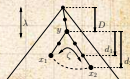
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Desirable organizational qualities:

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 (e.g., information exchange)

- II. Connectivity robustness

- Recoverability in the event of failure

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- III Connectivity robustness

- IV Recoverability in the event of failure



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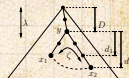
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Small world problem:

- 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]



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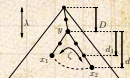
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"Information exchange and the robustness of organizational networks" ↗

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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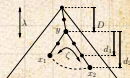
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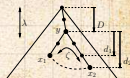
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Formal organizational structure:

 Underlying hierarchy:

 branching factor k

 depth D

 average number of links λ

 $\lambda = k \cdot D$

 Additional informal ties:

 Choose m links according to a two-parameter probability distribution

 $0 \leq m \leq \lfloor N \cdot \lambda \cdot (1 - \alpha) / 2 \rfloor$

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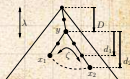
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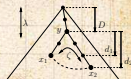
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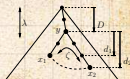
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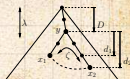
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Model—underlying hierarchy

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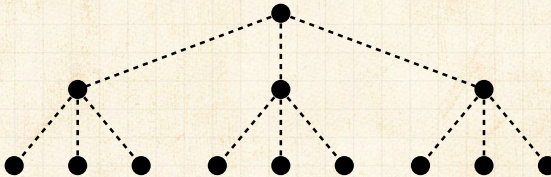
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Model—formal structure:



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



Model—addition of links

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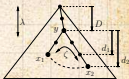
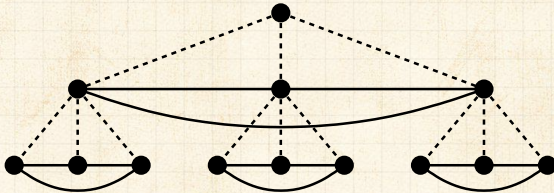
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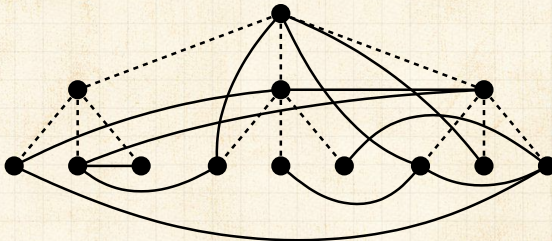
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Team-based networks ($m = 12$):



Model—addition of links

Random networks ($m = 12$):



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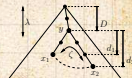
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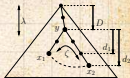
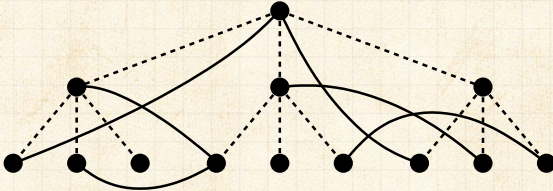
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Random interdivisional networks ($m = 6$):



Model—addition of links

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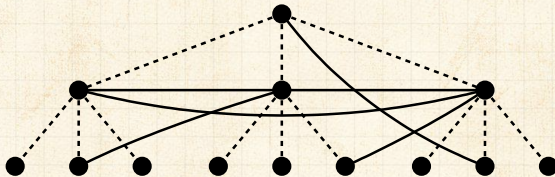
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Core-periphery networks ($m = 6$):



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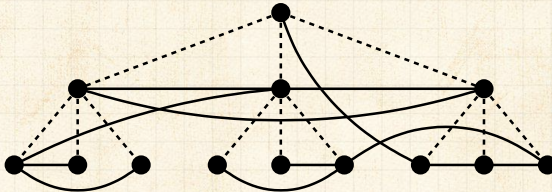
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Multiscale networks ($m = 12$):



Model—construction

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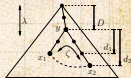
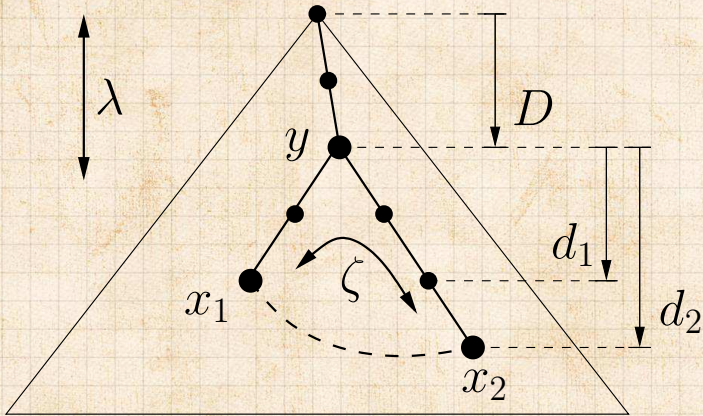
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 Link addition probability:

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

 First choose (D, d_1, d_2) .

 Randomly choose (y, x_1, x_2) given (D, d_1, d_2) .

 Choose links without replacement.



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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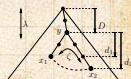
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Requirements for $f(d_1, d_2)$:

1. $f \geq 0$ for $d_1 + d_2 \geq 2$
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3. $f(d_1, d_2) = f(d_2, d_1)$.
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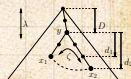
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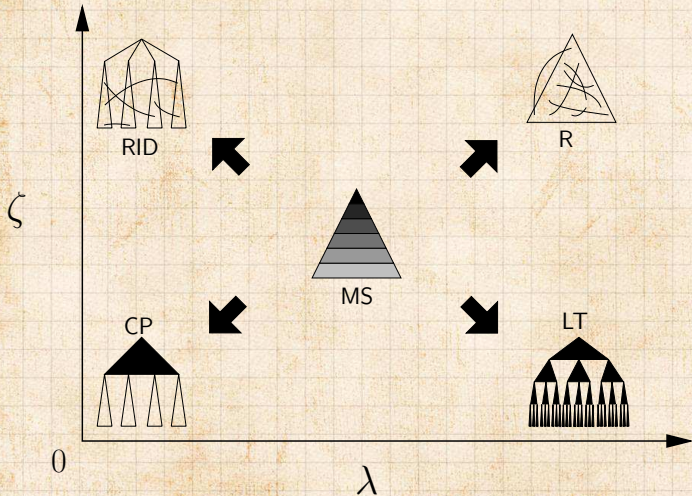
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Model—limiting cases



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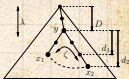
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Message passing pattern

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

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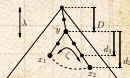
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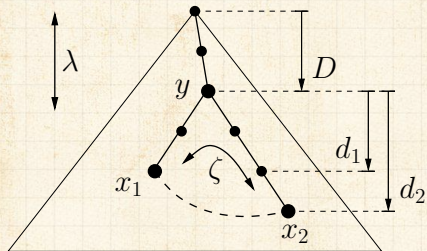
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Message passing pattern:

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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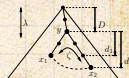
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Simple message routing algorithm:

 Look ahead one step: always choose neighbor closest to recipient node.

 Pseudo-global knowledge:

1. Nodes understand hierarchy.
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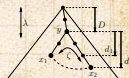
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Message passing pattern

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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.
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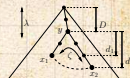
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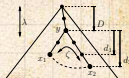
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Message passing pattern

Performance:

📦 Measure Congestion Centrality ρ_i , fraction of messages passing through node i .

📦 Similar to betweenness centrality.

📦 However: depends on

📦 Search algorithm

📦 Skis simulation

📦 Congestion robustness comes from minimizing ρ_{\max} .

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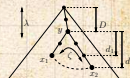
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Parameter settings (unless varying):

- 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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Results—congestion robustness

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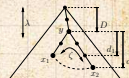
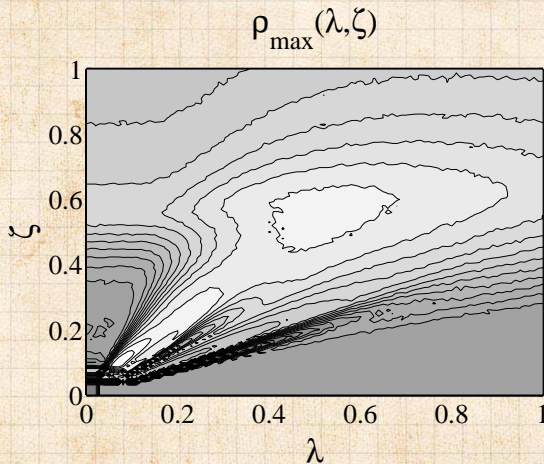
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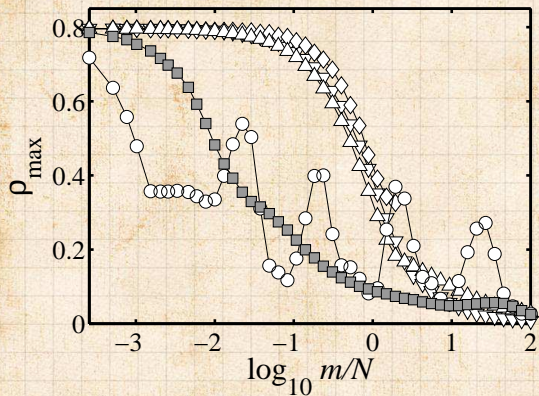
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Results—varying number of links added:



- \diamond = TB
- ∇ = R
- \triangle = RID
- \circ = CP
- \square = MS

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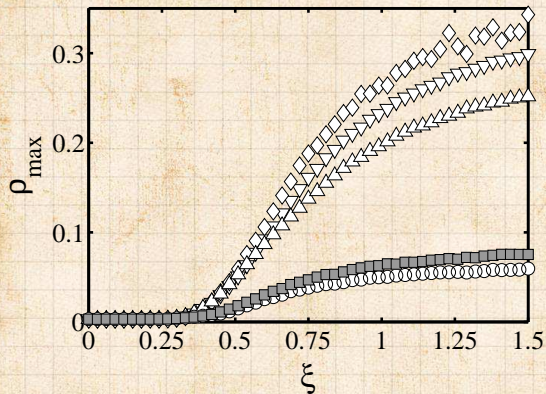
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Results—varying message passing pattern



◇=TB

▽=R

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Results—Maximum firm size

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

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Results—Maximum firm size

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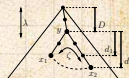
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Scalability in complete uncertainty: $\xi = \infty$

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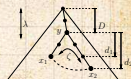
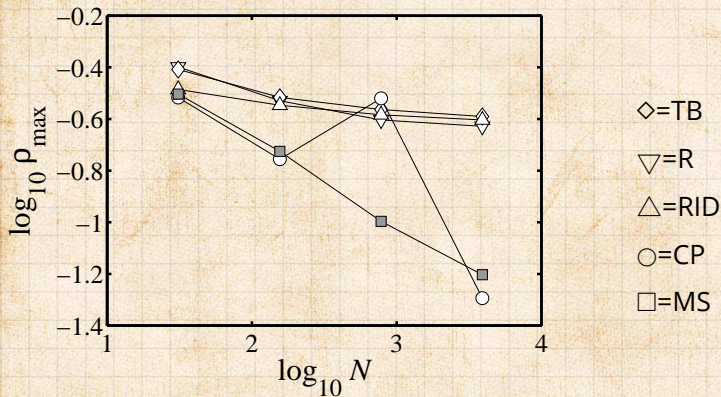
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Inducing catastrophic failure:

 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

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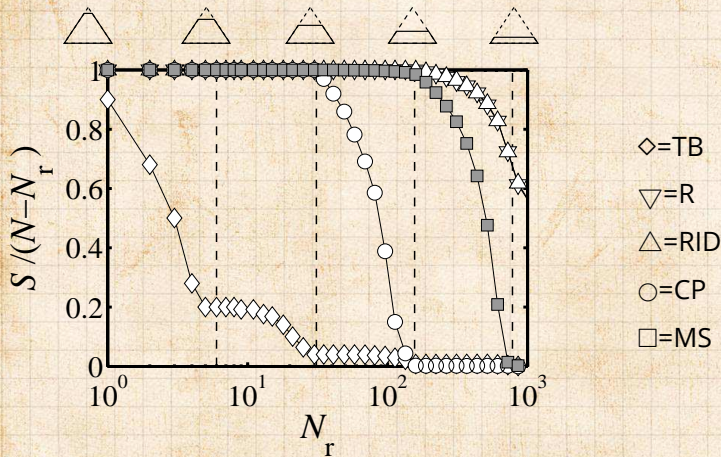
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Summary of results

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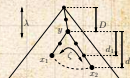
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Feature	Congestion Robustness	Connectivity Robustness	Scalability
Core-periphery	good	average	average
Random	poor	good	poor
Rand. Interdivisional	poor	good	poor
Team-based	poor	poor	poor
Multiscale	good	good	good



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Multi-scale networks:

1. Possess good Congestion Robustness and Connectivity
Robustness \Rightarrow Ultra-robust;
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 3. Relatively insensitive to parameter choice;
4. Above suggests existence of multi-scale structure is plausible.



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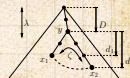
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Conclusory moments

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 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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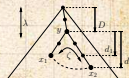
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