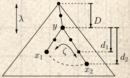
Organizational Networks: Information Exchange and Robustness

Last updated: 2023/08/22, 11:48:25 EDT

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

Prof. Peter Sheridan Dodds | @peterdodds

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



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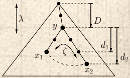

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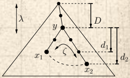

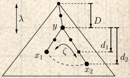

Outline


THE SUN
THE GOLDEN AGE OF REDUCTIONISM
THE MANIFESTO
THE WELL OF SCALES
THE LAWS OF DECAYING POWER
THE UNEXPECTED TRANSFIGURATION
MINISTRY OF RANDOM WALKS
THE RICH GET RICHER
THE DREAM OF EFFICIENT LANGUAGE
THE LAW OF DIGITS FIRST
THE SURPRISE OF BEING ROBUST YET FRAGILE
THE MISREADING OF THE BOOK OF SAND
THE MANY TAILS OF MANY TAILS
THE MEASURING
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THE POURING DATA
THE CHARMS OF THE MANY WRONG PATHS
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THE EMERGENCE OF THINKING
THE EMERGENCE OF STORIES
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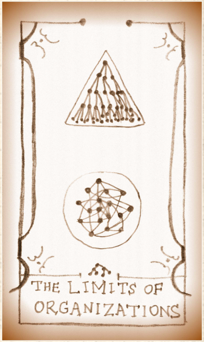
THE LIMITS OF ORGANIZATIONS


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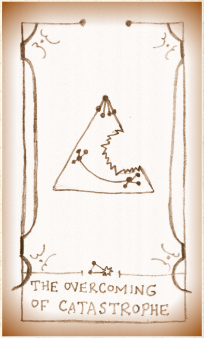
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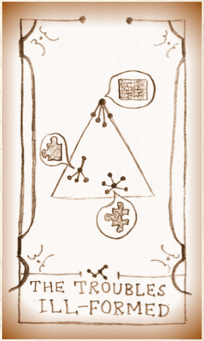
THE TROUBLES ILL-FORMED

Overview

The basic idea/problem/motivation/history:

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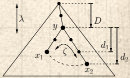

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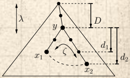

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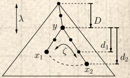

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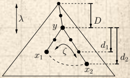

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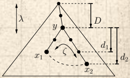

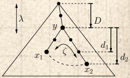

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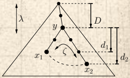

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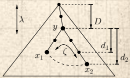
Results:

- Performance measures.



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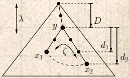

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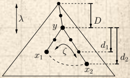

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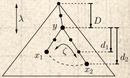

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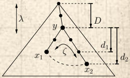

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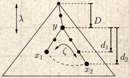

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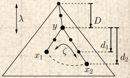

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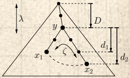
- Case study performed by Nishiguchi and Beaudet [4]
  "Fractal Design: Self-organizing Links in Supply Chain"
  in "Knowledge Creation: A New Source of Value"



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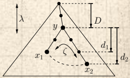

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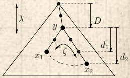

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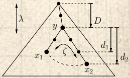

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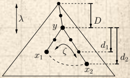


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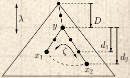
λ
D
y
d_1
d_2
x_1
ζ
x_2

Rebirth:


BANK
OF
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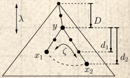
FORMERLY LEHMAN BROTHERS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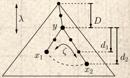

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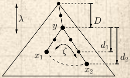

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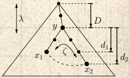

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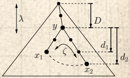

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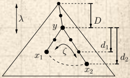

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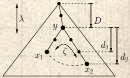
Frame:

- Collective solving of ambiguous problems



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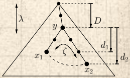

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- Question much less answer is not well understood.

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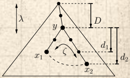

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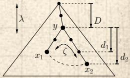

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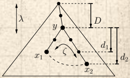

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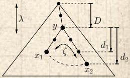

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- How do we define ambiguity?

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Modeling ambiguous problems is hard...

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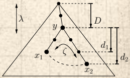
- Model response instead...



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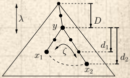

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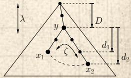

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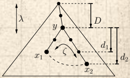

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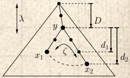

Let's modelify:

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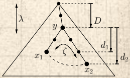
Focus on robustness:

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



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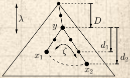

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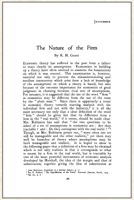

[NOVEMBER

The Nature of the Firm

By R. H. Coase

Economic theory has suffered in the past from a failure to state clearly its assumptions. Economists in building up a theory have often omitted to examine the foundations on which it was erected. This examination is, however, essential not only to prevent the misunderstanding and needless controversy which arise from a lack of knowledge of the assumptions on which a theory is based, but also because of the extreme importance for economics of good judgment in choosing between rival sets of assumptions. For instance, it is suggested that the use of the word "firm" in economics may be different from the use of the term by the "plain man."[1] Since there is apparently a trend in economic theory towards starting analysis with the individual firm and not with the industry,[2] it is all the more necessary not only that a clear definition of the word "firm" should be given but that its difference from a firm in the "real world," if it exists, should be made clear. Mrs. Robinson has said that "the two questions to be asked of a set of assumptions in economics are: Are they tractable? and: Do they correspond with the real world?"[3] Though, as Mrs. Robinson points out, "more often one set will be manageable and the other realistic," yet there may well be branches of theory where assumptions may be both manageable and realistic. It is hoped to show in the following paper that a definition of a firm may be obtained which is not only realistic in that it corresponds to what is meant by a firm in the real world, but is tractable by two of the most powerful instruments of economic analysis developed by Marshall, the idea of the margin and that of substitution, together giving the idea of substitution at

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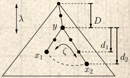

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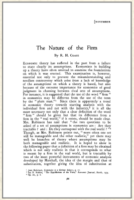

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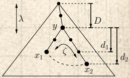

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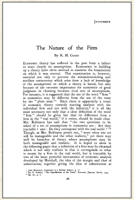
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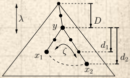

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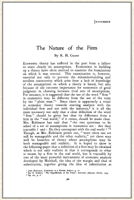

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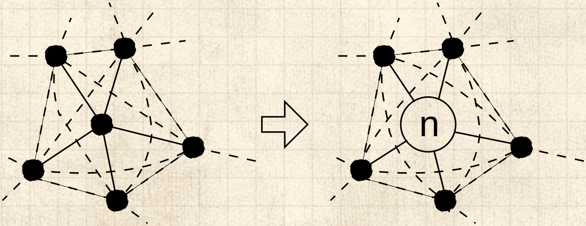

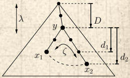

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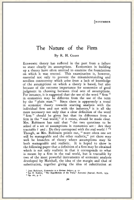

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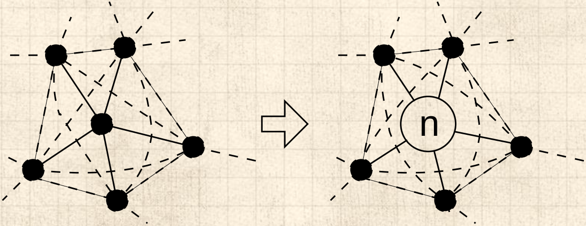
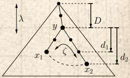
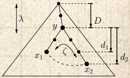




Real organizations—Extremes

Hierarchy:

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



Real organizations—Extremes

Hierarchy:

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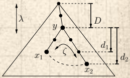
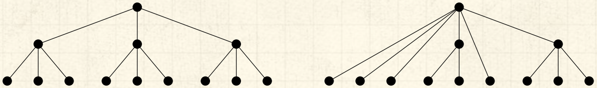
Market:

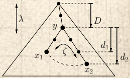
- Resilient,
- Suited to rapidly changing environment,
- Requires costless or low cost interactions.



Organizations as efficient hierarchies

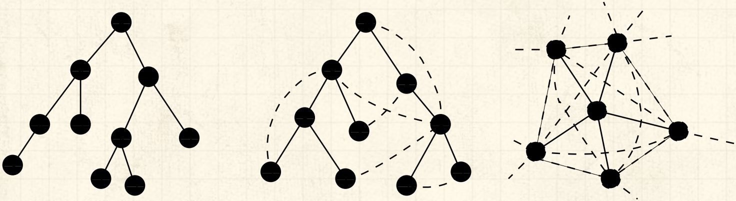
- Economics: Organizations ≡ Hierarchies.
- e.g., Radner (1993) [5], Van Zandt (1998) [7]
- Hierarchies performing associative operations:





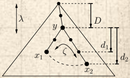
Real organizations...

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



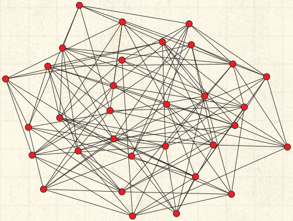
“Heterarchy”

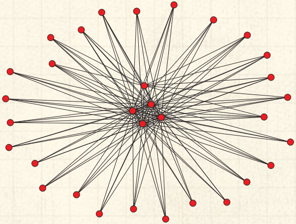
David Stark,
The Biology of Business: Decoding the Natural Laws of theEnterprise., **New Series, 4**, 153–, 1999. [6]



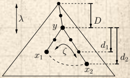
Optimal network topologies for local search

"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.



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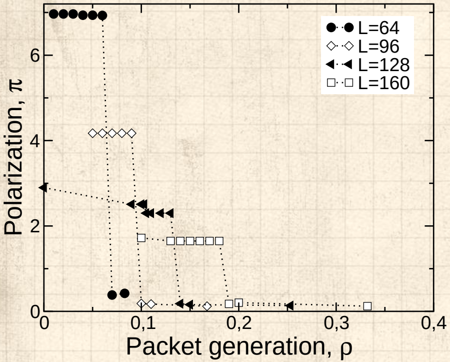
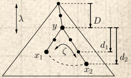


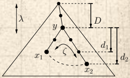
- Betweenness: β.
- Polarization:

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

- L = number of links.

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

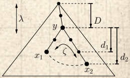




Outline

Desirable organizational qualities:

1. Low cost (requiring few links).



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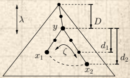

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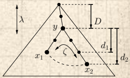

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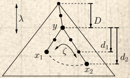

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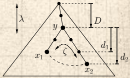
5. ‘Ultra-robustness’:



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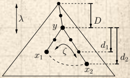

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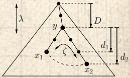
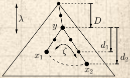
   II Connectivity robustness
   (Recoverability in the event of failure).



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]



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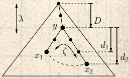


Information exchange and the robustness of organizational networks

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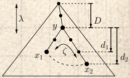


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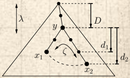


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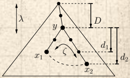

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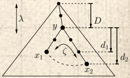
- Underlying hierarchy:

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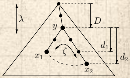
- Underlying hierarchy:
  - branching ratio b



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Formal organizational structure:

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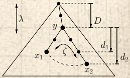
  - branching ratio b
  - depth L



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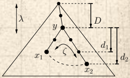
  - depth L
  - $N = (b^L - 1)/(b - 1)$ nodes

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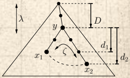

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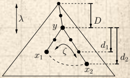


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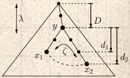


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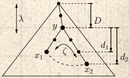
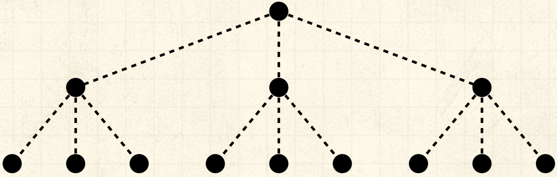
  - $0 \leq m \leq (N-1)(N-2)/2$

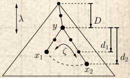


Model—underlying hierarchy

Model—formal structure:

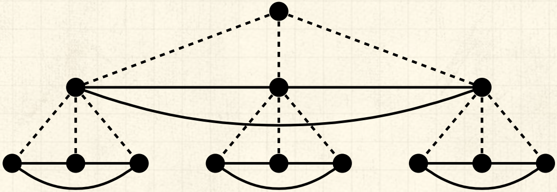


$$b = 3, \quad L = 3, \quad N = 13$$



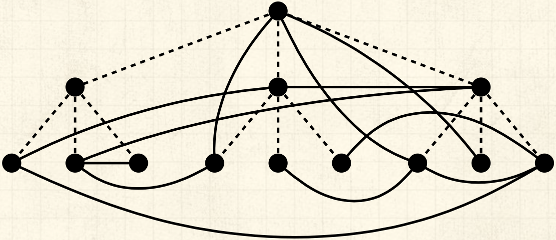
Model—addition of links

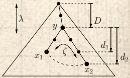
Team-based networks ($m = 12$):



Model—addition of links

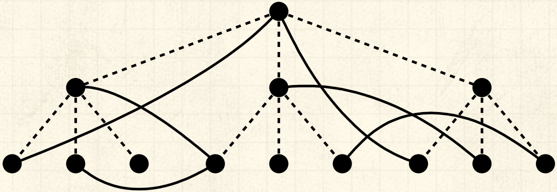
Random networks ($m = 12$):





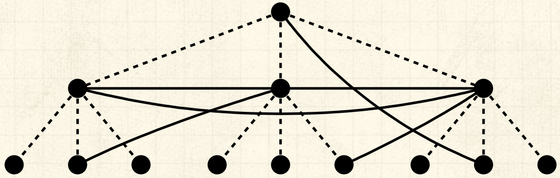
Model—addition of links

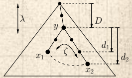
Random interdivisional networks ($m = 6$):



Model—addition of links

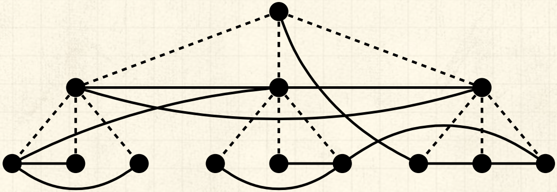
Core-periphery networks ($m = 6$):

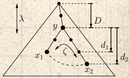




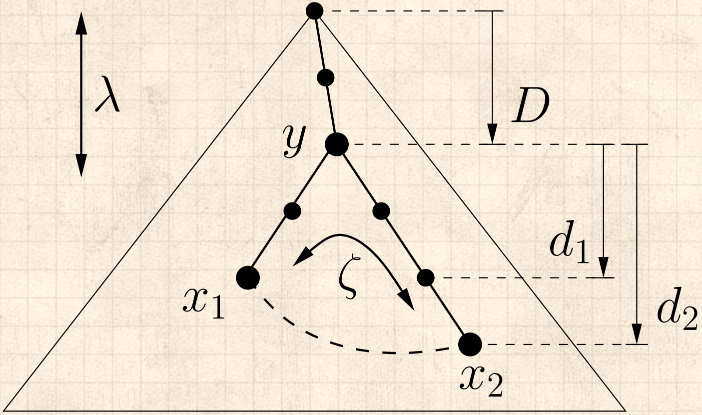
Model—addition of links

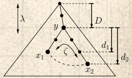
Multiscale networks $(m = 12)$:





Model—construction



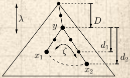


Model—construction

- Link addition probability:

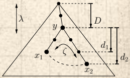
$$P(D, d_1, d_2) \propto e^{-D/\lambda} e^{-f(d_1, d_2)/\zeta}$$

- 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

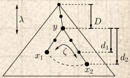
Requirements for $f(d_1, d_2)$:



Model—construction

Requirements for $f(d_1, d_2)$:

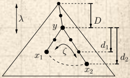
1. $f \geq 0$ for $d_1 + d_2 \geq 2$



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.



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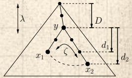
1. $f \geq 0$ for $d_1 + d_2 \geq 2$
2. f increases monotonically with d_1, d_2.
3. $f(d_1, d_2) = f(d_2, d_1)$.



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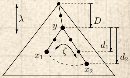

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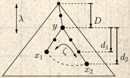
4. f is maximized when $d_1 = d_2$.

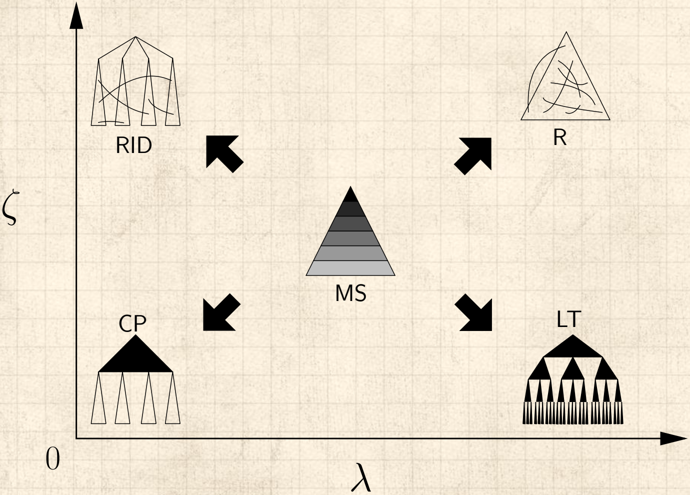
Simple function satisfying 1–4:

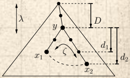
$$f(d_1, d_2) = (d_1^2 + d_2^2 - 2)^{1/2}$$

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

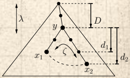


Model—limiting cases



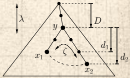


Outline



Message passing pattern

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



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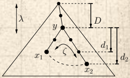
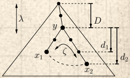


Message passing pattern

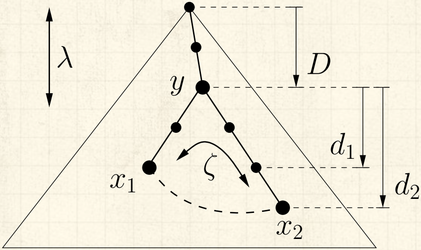
- Each of T time steps, each node generates a message with probability μ.
- Recipient of message chosen based on distance from sender.
- $$P(\text{recipient at distance } d) \propto e^{-d/\xi}.$$

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



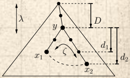
Message passing pattern:

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



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

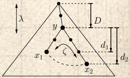
- Measure unchanged with presence of informal ties.



Message passing pattern

Simple message routing algorithm:

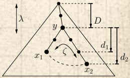
- Look ahead one step: always choose neighbor closest to recipient node.



Message passing pattern

Simple message routing algorithm:

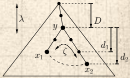
- Look ahead one step: always choose neighbor closest to recipient node.
- Pseudo-global knowledge:
  1. Nodes understand hierarchy.
  2. Nodes know only local informal ties.



Message passing pattern

Interpretations:

1. Sender knows specific recipient.



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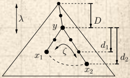
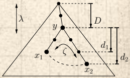


Message passing pattern

Interpretations:

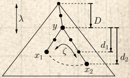
1. Sender knows specific recipient.
2. Sender requires certain kind of recipient.
3. Sender seeks specific information but recipient unknown.
4. Sender has a problem but information/recipient unknown.



Message passing pattern

Performance:

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



Message passing pattern

Performance:

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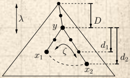
- Similar to betweenness centrality.



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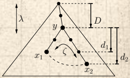
  1. Search algorithm;



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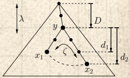

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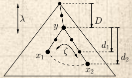
- Measure Congestion Centrality ρ_i, fraction of messages passing through node i.
- Similar to betweenness centrality.
- However: depends on
  1. Search algorithm;
  2. Task specification (μ, ξ).
- Congestion robustness comes from minimizing $\rho_{\max}$.



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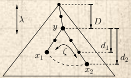
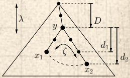


Performance testing:



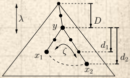
Parameter settings (unless varying):

- Underlying hierarchy: $b = 5$, $L = 6$, $N = 3096$;

Performance testing:

Parameter settings (unless varying):

- Underlying hierarchy: $b = 5$, $L = 6$, $N = 3096$;
- Number of informal ties: $m = N$.



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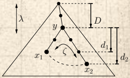
Parameter settings (unless varying):

- Underlying hierarchy: $b = 5$, $L = 6$, $N = 3096$;
- Number of informal ties: $m = N$.
- Link addition algorithm: $\lambda = \zeta = 0.5$.



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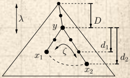
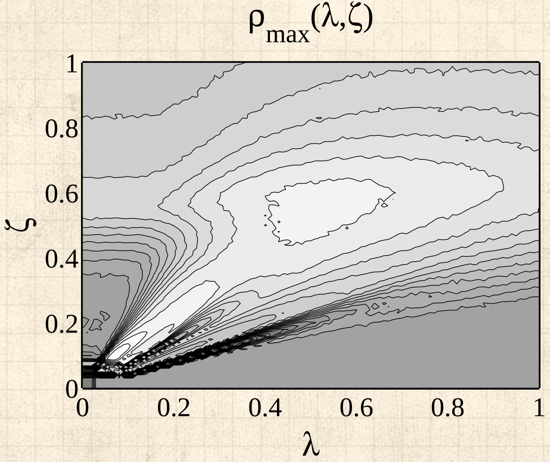
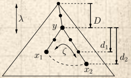
- Message passing: $\xi = 1$, $\mu = 10/N$, $T = 1000$.

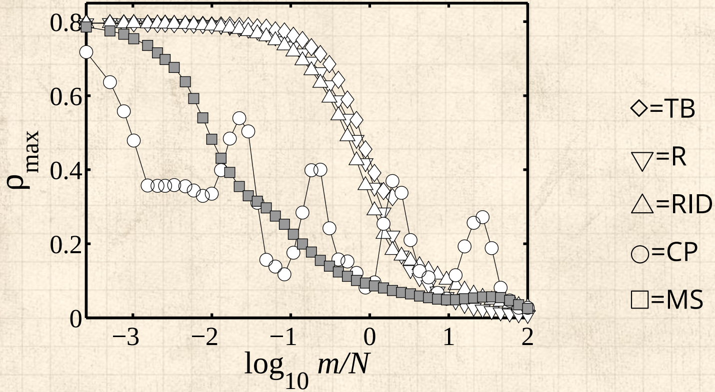


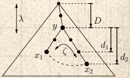
Results—congestion robustness



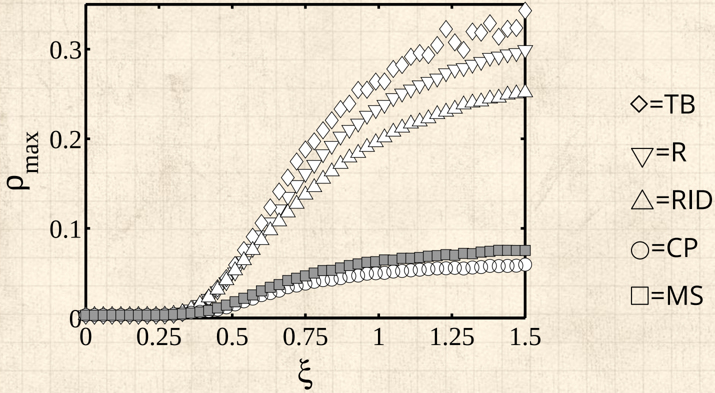


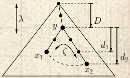
Results—varying number of links added:





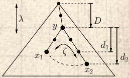
Results—varying message passing pattern





Results—Maximum firm size

- Congestion may increase with size of network.



Results—Maximum firm size

- Congestion may increase with size of network.
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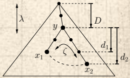

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- Congestion may increase with size of network.
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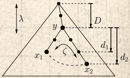
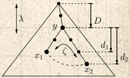
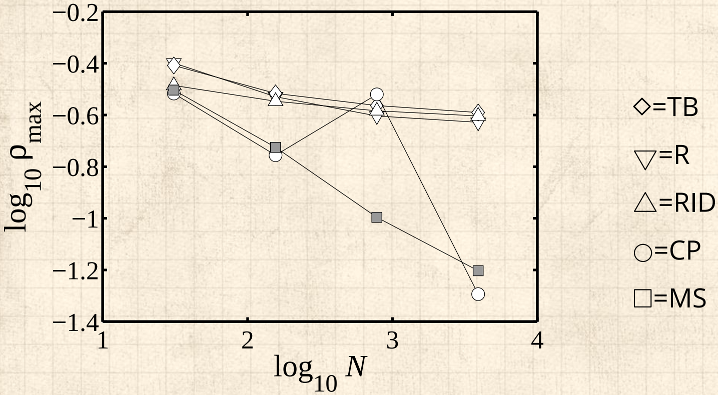


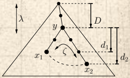
Results—Maximum firm size

- 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.

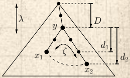


Scalability in complete uncertainty: $\xi = \infty$





Connectivity Robustness



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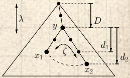

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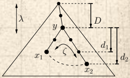
- Results largely independent of sequence.



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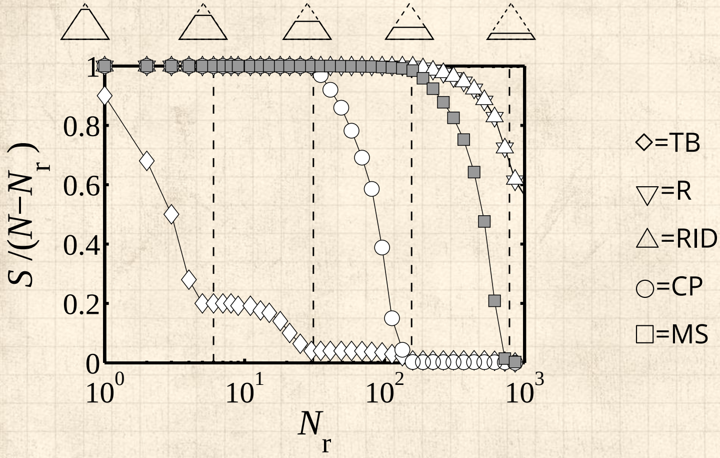
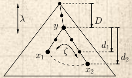
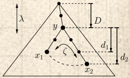




Summary of results

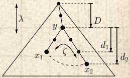
Feature	Congestion Robustness	Connectivity Robustness	Scalability
Core-periphery	good	average	average
Random	poor	good	poor
Rand. Interdivisional	poor	good	poor
Team-based	poor	poor	poor
Multiscale	good	good	good



Conclusary moments

Multi-scale networks:

1. Possess good Congestion Robustness and Connectivity Robustness $\Rightarrow$ Ultra-robust;



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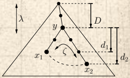

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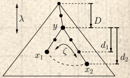

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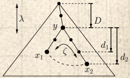
- Above suggests existence of multi-scale structure is plausible.



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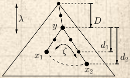

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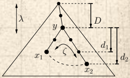

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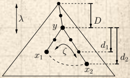

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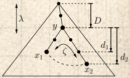
- Still a need for data on real organizations...



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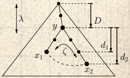

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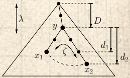

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