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Local and NonLocal Information in Traffic Networks:

how important is the horizon?

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Outline

- Introduction
  - The Problem: decentralized information dissemination
  - Information and Transport
    - » What’s out there
    - » Inspiration for solutions
- The Model
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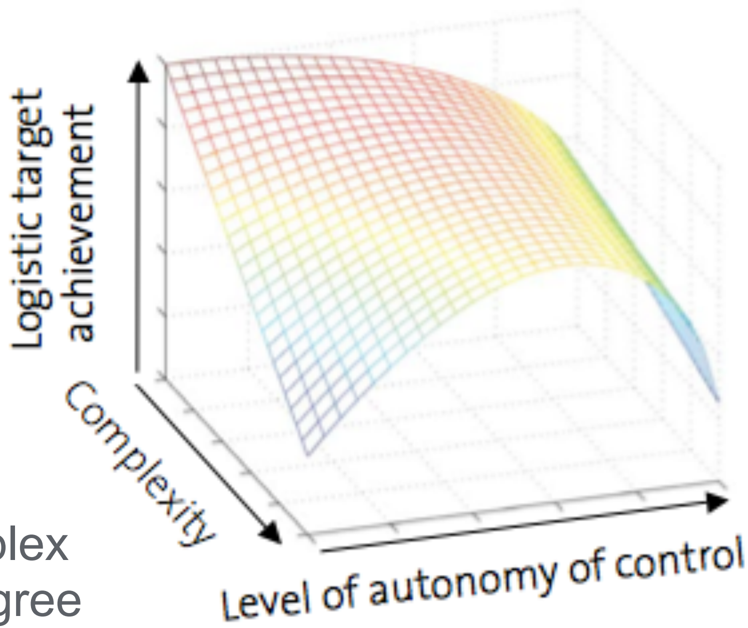
    - » Navigation Rules
    - » Self-organized Information Dissemination Length Scale
  - Simulations and Results
- Conclusions and Outlook

The Problem: Centralized or Decentralized?

I. Advantage of centralized control is large-scale coordination
   - London's Urban Traffic Control for example.
   - holds for any transport network (a.k.a. with a flow)

- Disadvantages are due to
  - Vulnerability of the network
  - Information overload
  - Wrong selection of control parameters
  - Delays in adaptive feedback control

- Decentralized control can perform better in complex systems with heterogeneous elements, large degree of fluctuations, and short-term predictability, because of greater flexibility to local conditions and greater robustness to perturbations



(Windt, Böse, Philipp, 2006)

The Problem: Information and Dynamics

Information on Networks

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Dynamics on Networks

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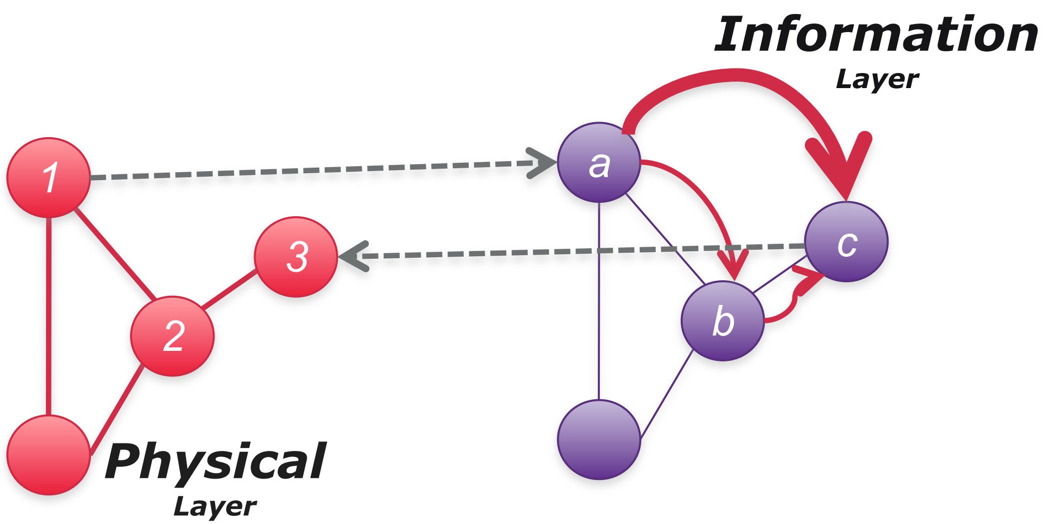


The Problem: Information Dissemination

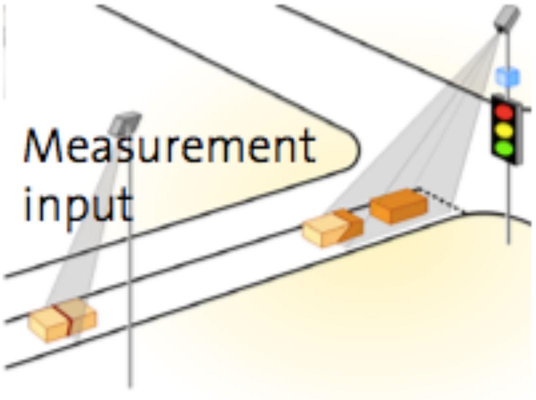
Take a real traffic network. What is this information?

1. Traffic Bulletins
2. Traffic light sensing
3. Radio broadcasts
4. Real-time traffic routes
5. Flow data etc…

We focus here on communication between traffic control devices and information collected locally.

e.g. junction-to-junction

communication



picture from Helbing et al, JSTAT 2008

Information and Traffic

There are a number of questions that arise…

» **What information is meaningful to broadcast/diffuse?**
  - Travel times, congestion state, failures?

» **Can decentralized systems reliably propagate information on large networks? Does it even make sense?**

» **Does an optimal (or even just useful) information diffusion scale exist?**
  - E.g. in SO traffic control how many nodes do I consider when optimizing a real network?

» **Can we build simple models to gain insights in these problems?**

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What's out there

From the perspective of ***network science***, there are a number of works about related subjects:

•Internet, peer-to-peer networks, gossip-spreading on networks

•Navigation in Networks (e.g. Tadic et al. 2009)

•Self organized topologies and traffic control (Kesting et al. 2009)

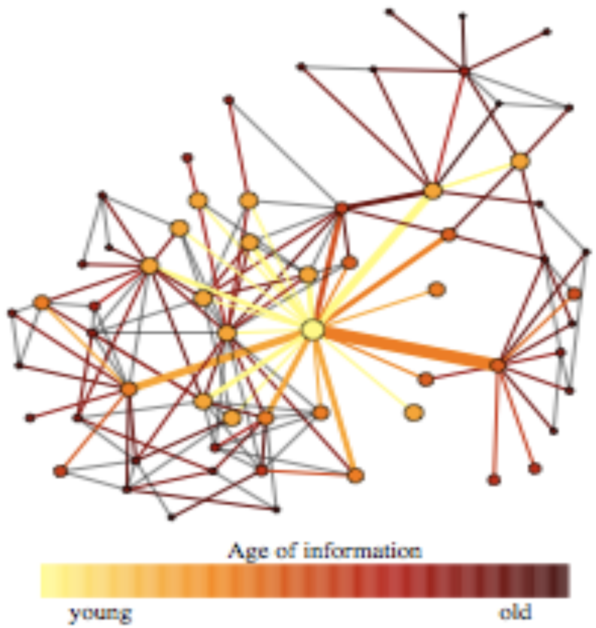
•Effects of interactions between nodes:

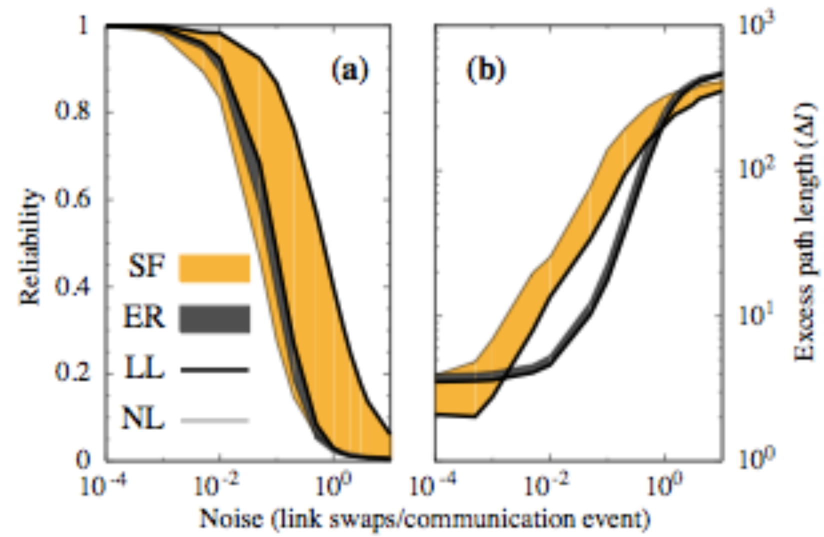
- Chaotic Behaviours (e.g. Yokoya 2004)
- Phase Transitions (e.g. De Martino et al. 2009)
- Condensation/Congestion phenomena

    e.g. Hub congested, rest of the networks relatively free

Information and Traffic: gossip-spreading on networks

It has been shown that it is possible to reliably transmit information over networks without a centralized control system.





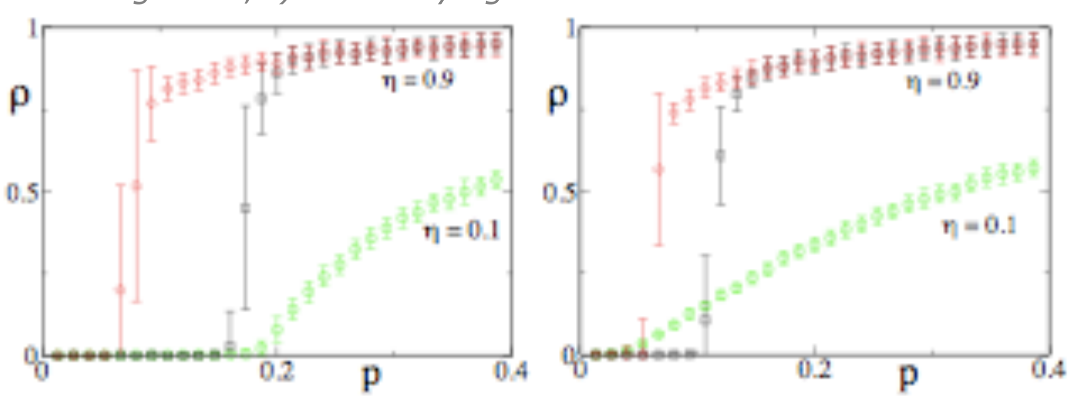
Rosvall et al. EPL 2007, Rosvall et al. , Chaos 2007

Information and Traffic: Routing and Congestion

Different local and non-local routing mechanisms on various topologies have been studied:

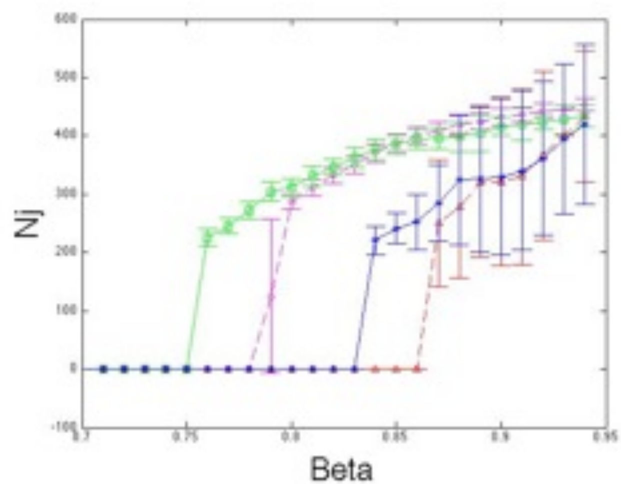
- many different microscopic rules
- varied topologies
- cooperative behaviors emerge, leading to sharp phase transitions
- can relief/reduce congestion emergence

Zero-Range Process (discrete agents, variable turning rates,..) with varying local avoidance rules



De Martino et al., JSTAT 2009

Continuous flow on different topologies with local and non local information



Petri et al., EPL 2009

Information and Traffic: Inspirations

A local congestion-aware rerouting mechanism is able to increase network performances under congested conditions:

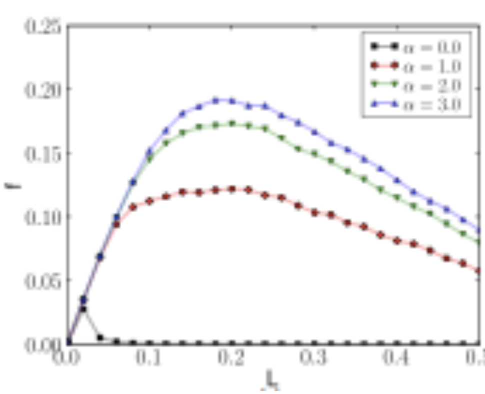
c_{in} = *congestion parameter on link i-n*
alpha = congestion awareness

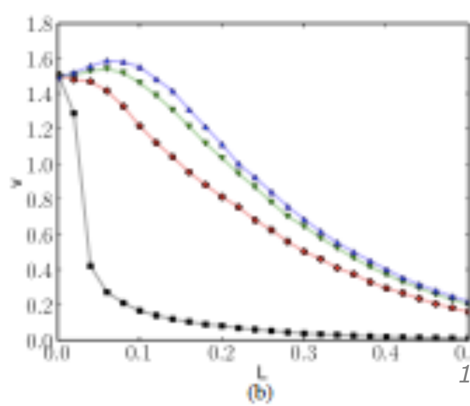
Local Navigation Rule

$$P_n = (d_{in} + d_{nt})(1 + c_{in})^{\alpha}$$

Global Navigation Rule

$$P_n = (d_{in} + d_{nt})(1 + \langle c_{in} \rangle)^{\alpha}$$





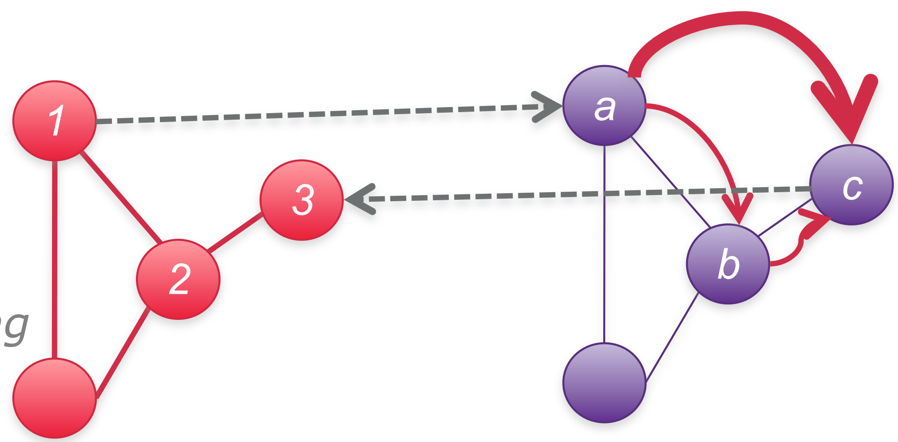
Increase in performance is due to dynamical homogenization effects

Scellato et al., EPJ B 2010

The Model: Description

- Two layers:
  - -Primal representation of traffic network (physical)
    - Nodes = junctions/decision points;
    - Links= streets/connections, have a buffer **B** and a maximal outflow **S<B**;
  - -Communication between nodes (informational)
    - Local interaction: node to node across one link;
    - Cascading dynamics: time scale separation needed for informational avalanches;
      - Creates the non-local effects

Physical
Layer
Cars/particles moving among nodes

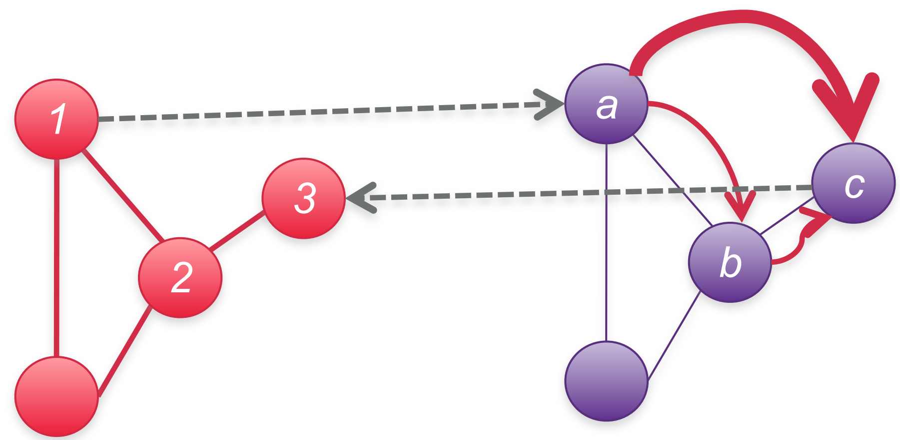


Information
Layer
Cascading dynamics
Congestion awareness
Self-organized length

The Model: Definitions

The congestion of a node creates information, that diffuses.

The diffusing information affects the dynamics of the moving particles/agents/cars.



NODE STATE

$$S_j(t+1) = \Theta\left(n_j(t) + \sum_{m\in\Gamma_j} B_{jl}S_l(t) - \tau \sum_{m\in\Gamma_j} B_{jl}\right)$$

S=1 Critical Node

depends on the state of outgoing links

TURNING RATES

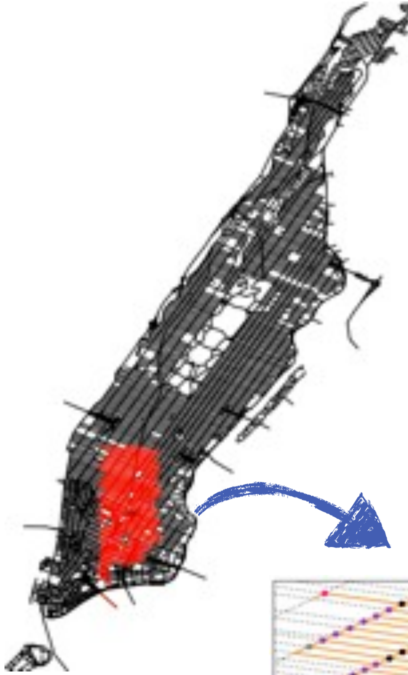
$$P_{ij}^d(A) = \frac{\beta_j\left(1 - c_A S_j(t)\right)/l_{ijd}^\alpha}{\sum_{m\in\Gamma_i}\beta_m\left(1 - c_A S_m(t)\right)/l_{imd}^\alpha},$$

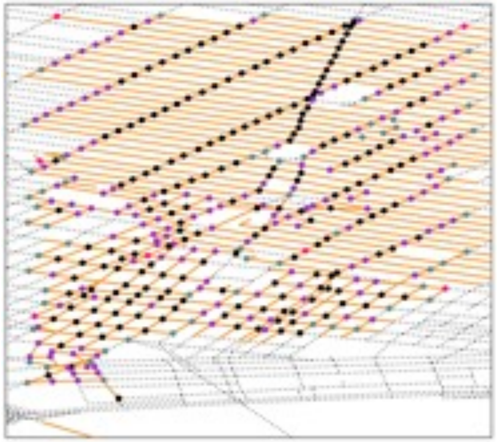
probability of choosing exit j for an agent on node i on route to d

Congestion appears when a link fills up, causing upstream links to become congested too, etc etc...

The Model: Simulations

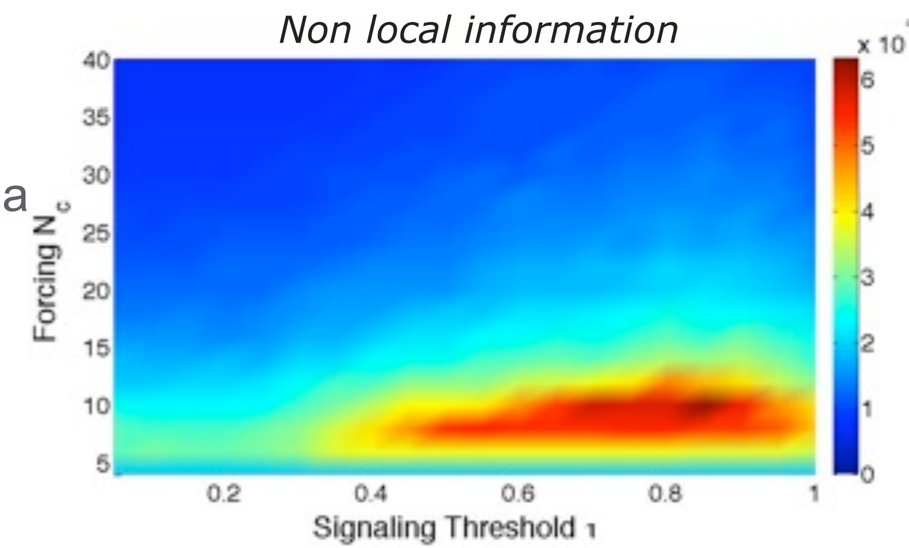
- Simulations were performed on:
  - Random graphs
  - Scale-free networks
  - Square Lattice graphs
  - "Realistic" networks (NYC)
- N_c particles introduced per time step
- OD chosen randomly (uniform prob. for pair).
- Of the incoming links on a node, only one is allowed to send flow through the node (similarly to a server queue, traffic light...)
- Compare LOCAL and NONLOCAL strategies

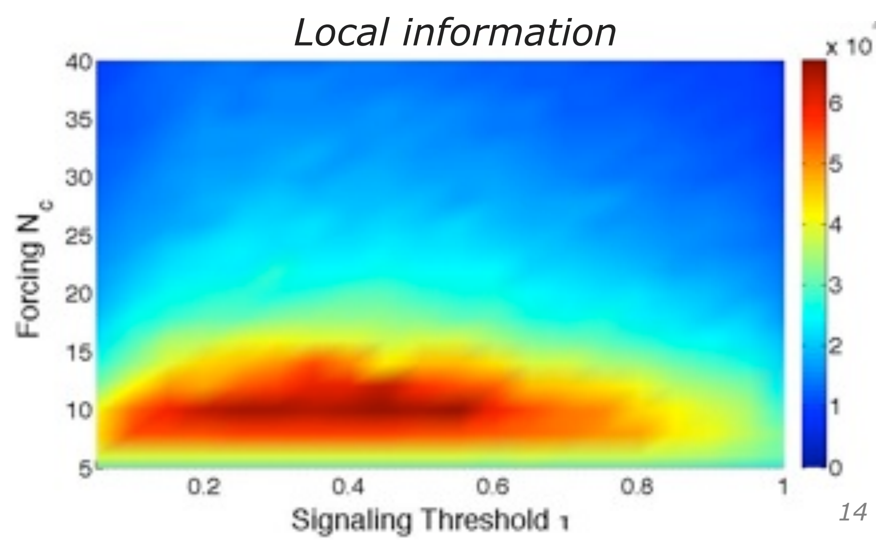




Results: Signaling Threshold

- Showing here results for NYC.
- For both local and non local information a an optimum τ_0 exists.
- τ_0 for local information < τ_0 for non-local information
  - » appearance of avalanches
  - » Sign of inefficiency of cascading model
- Local information is stable for larger range of values of N_c .
  - » information hinders transport over the network?





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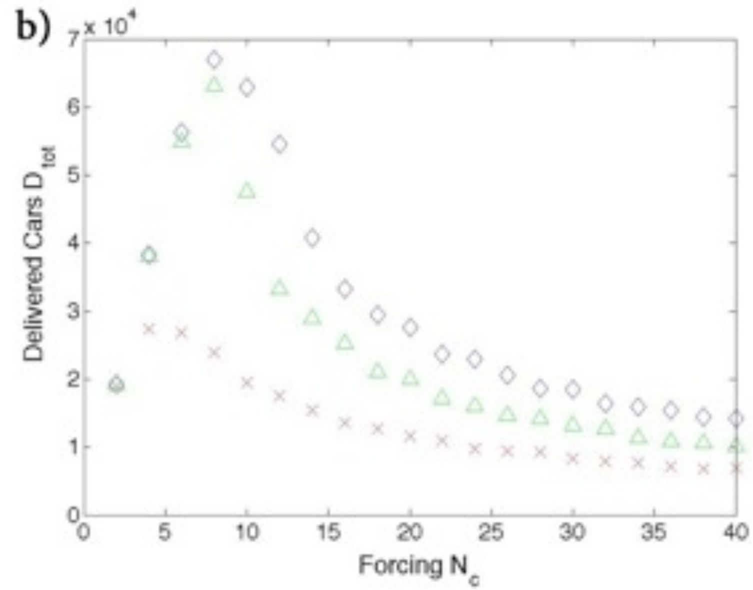
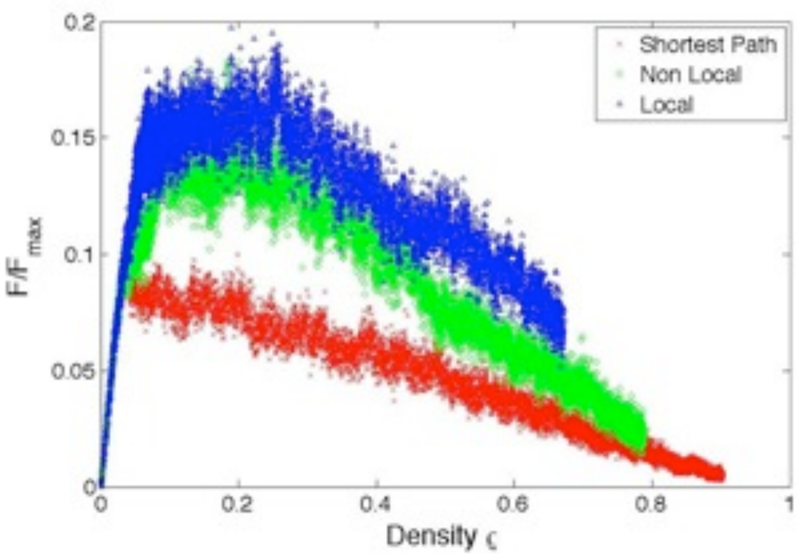
Results: Network performance

- One can measure how efficient a transport network by the number of delivered packets/agents/particles
- Until critical Nc local and non-local show same efficiency
- After critical Nc performance decays faster for non-local.





- Fundamental Diagram shows that local routing allows for larger flows at given densities
    - the spreading of information constrains the flow
- When the avalanches grow to age they become counterproductive.
    - limit the size with a “mass” term?

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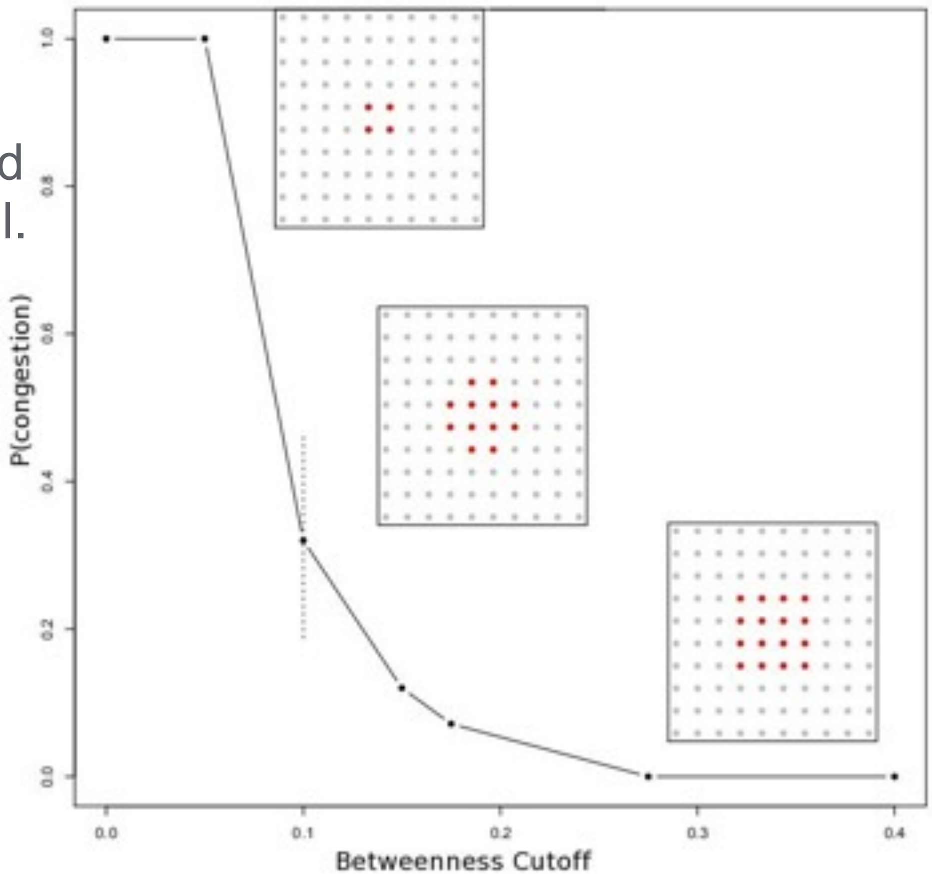
Results: Betweenness selection

- Betweenness = measure of “how central is a node”

- For simplicity we consider a lattice and allow only a fraction of nodes to signal.

- For N_c small, the probability of congestion is very low, until most of the nodes are not able to signal
  - » different from network attack resilience
  - » in this case it comes from the dynamics of spreading of congestion
  - » protecting the central nodes prevents seeds of congestion to appear.



Concluding….

- It is possible to use cascading information mechanism
  - » naturally outperforms shortest-path mechanisms.
  - » however it is outperformed by a local mechanism (in this form).
  - » avalanches grow too large and are not effective anymore.
  - » rerouted agents/particles become hindrance to the others.
- Avoid congestion seeds
  - » protecting a few very central (dynamically), allows to avoid congestion development by removing the seeds.
- Future outlook
  - » inhibitors for avalanches (too wide is counter productive).
  - » identification of sensitive nodes in heterogenous networks.
  - » chatting mechanism tuned by communication rate?

Acknowledgements

- Most of this work was done together with...

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working paper version available at:
http://tuvalu.santafe.edu/events/workshops/images/1/19/Traffic_cascading_info.pdf

BACKUP SLIDES

HIC SUNT LEONES!

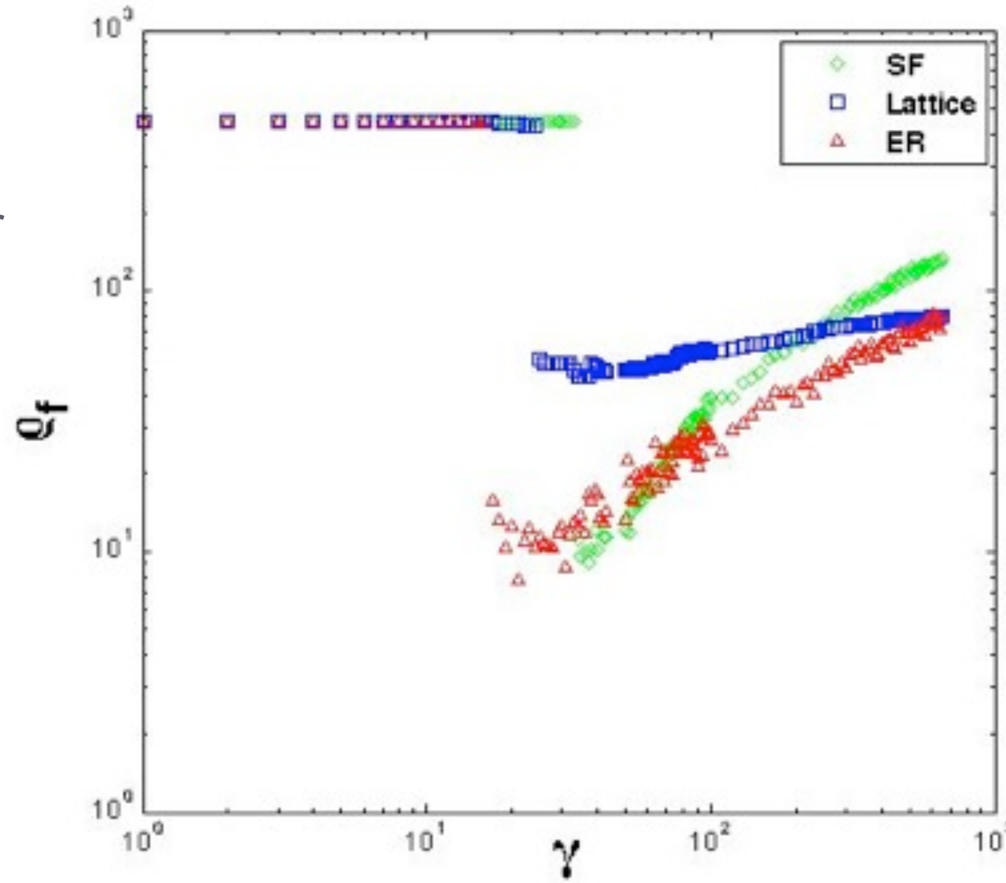
BS::Results: Total Population (with no navigation)

All topologies present distinct transitions

Decreasing lambda values allow for better performances

A critical lambda exists where the system freezes.

Critical lambda is larger for SF than homogeneous graphs.



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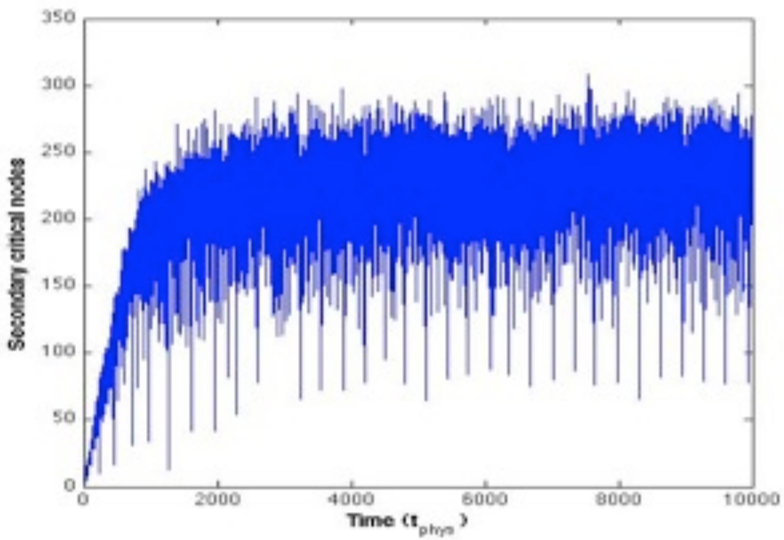
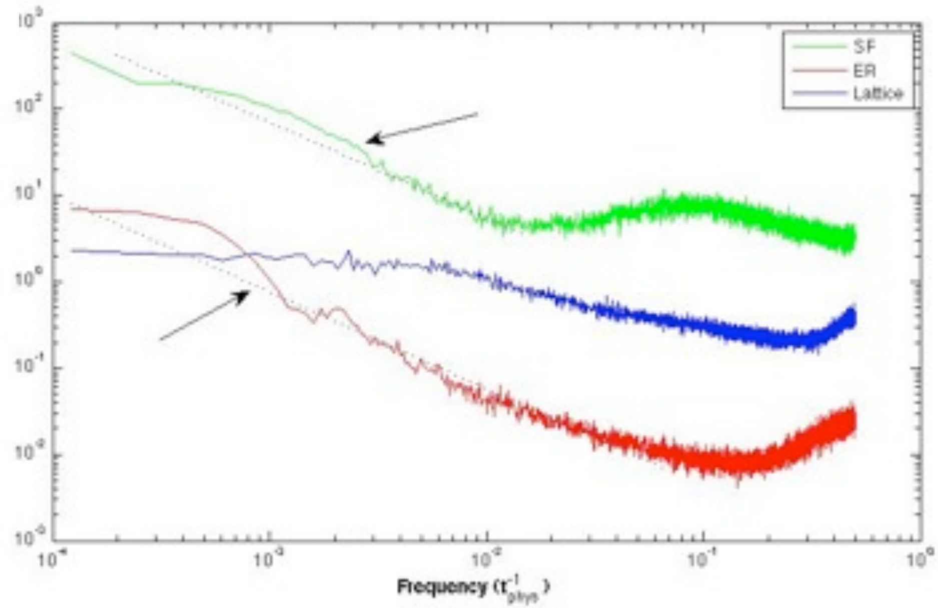
BS::Results: Stationary Critical Nodes (with no navigation)



The critical nodes total population remains stationary even when the total population drifts.

Temporal correlations develop near the phase transitions



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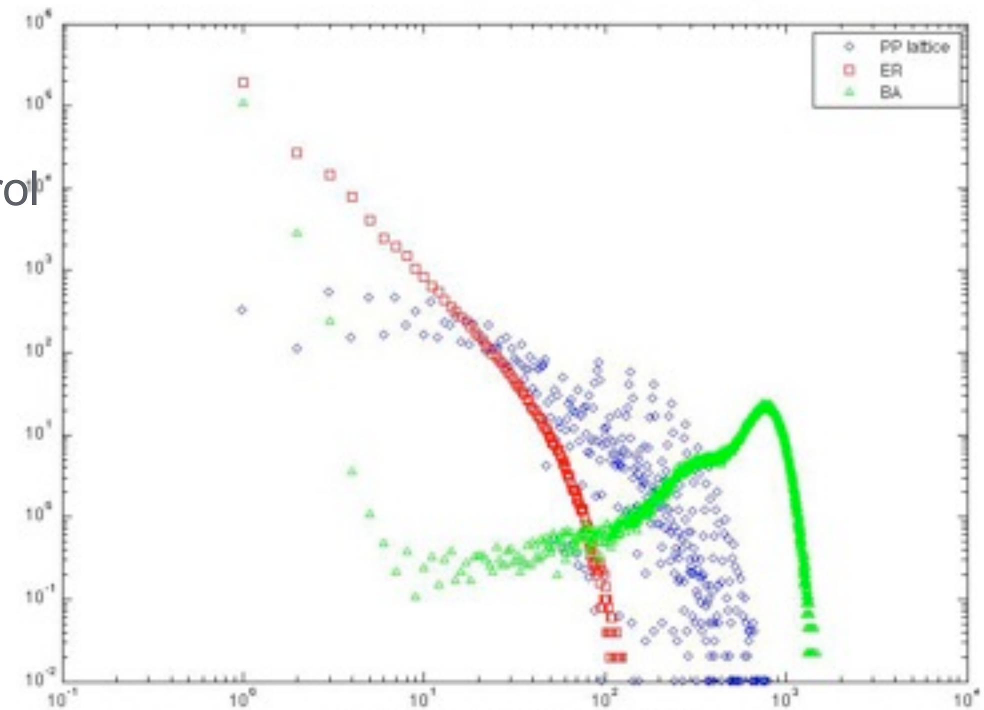
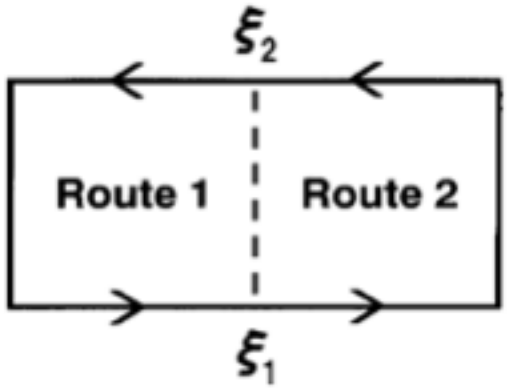
BS::Results: Critical Avalanches distribution (no navigation)

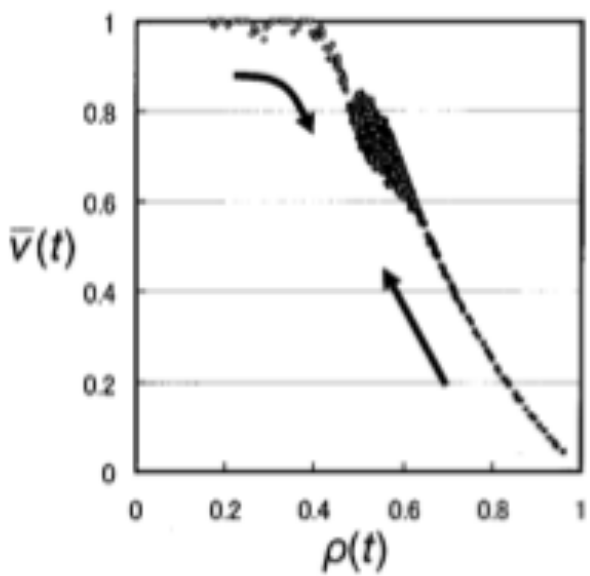
I. The size of connected components of critical nodes depend on the topology
   I. RG: Power-law distributed, communication length on all scales.
   II. Lattice: very flat distribution, consequence of the homogeneous topologies
   III. SF: Hub condensation.

- The $ß_{ij}$ could be used as active control mechanisms by a modification of the large scale network topology



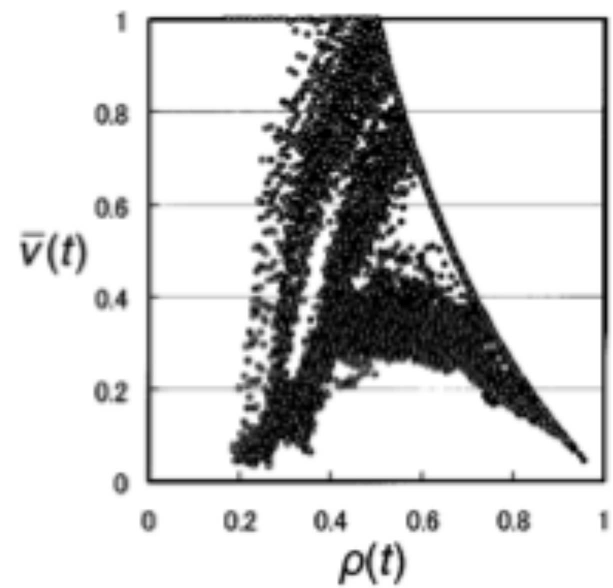
BS::A 2-route example: chaotic behaviors





No information

Good



With information

Bad