CDS@20

Murray@50
Doyle@60
Astrom@80

1993 Leave of Absence @CDS

IEEE Awards Ceremony


KUYA
BACARDI


Nassau Royale
COCONUT

‘Systemic Risk’ is the new ‘Robustness’

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EECS/LIDS/ESD

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Aug-2014

Systemic Risk

Systemic Risk is a term used to describe fragility in interconnected systems where small shocks at the subsystem level can result in large endogenous risk or in a cascade of failures causing a partial or a complete system shutdown.

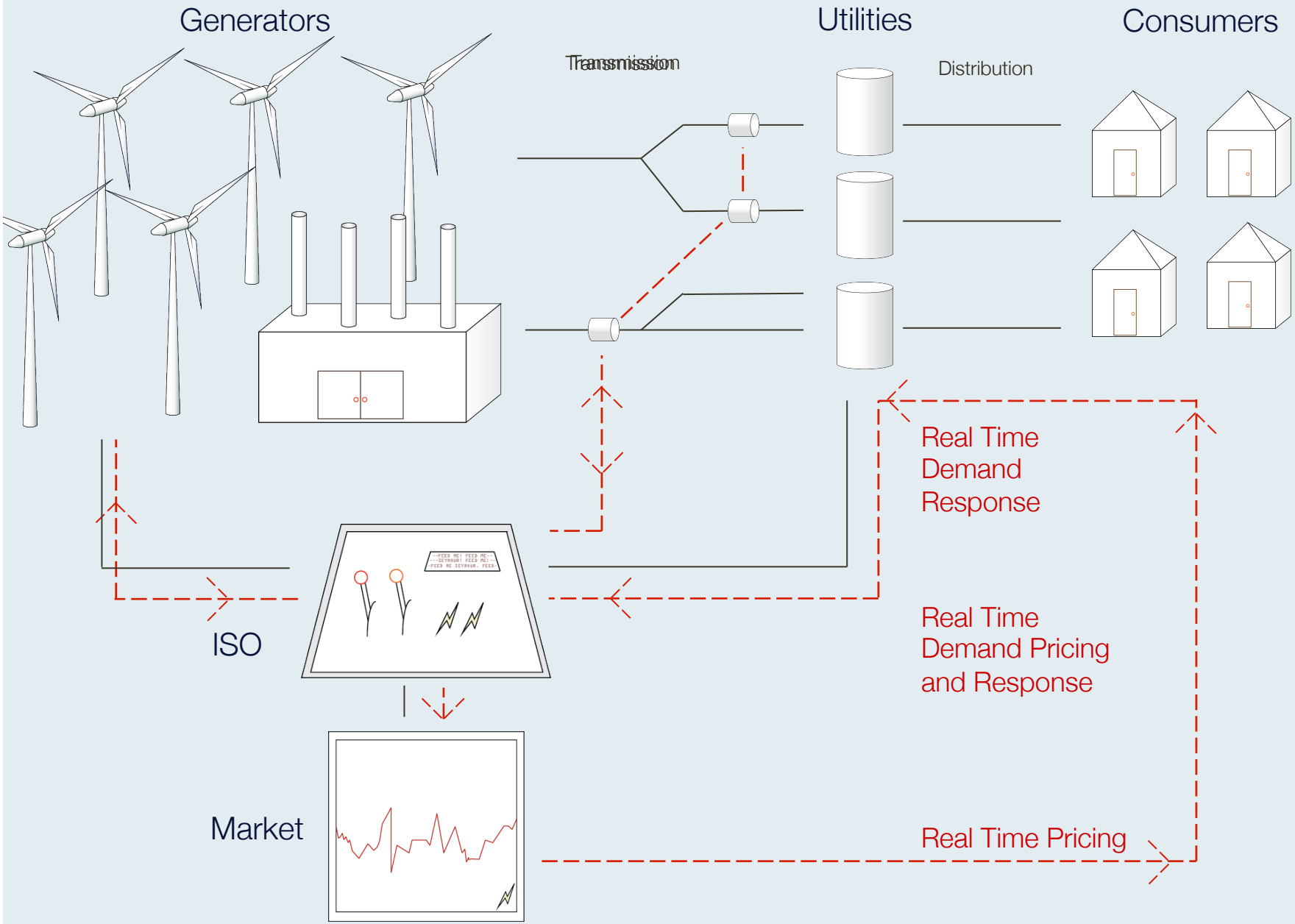
Air Traffic Congestion: $31.2B

Power Outages: $80B-$150B

Financial Crisis 2008: $500B + …

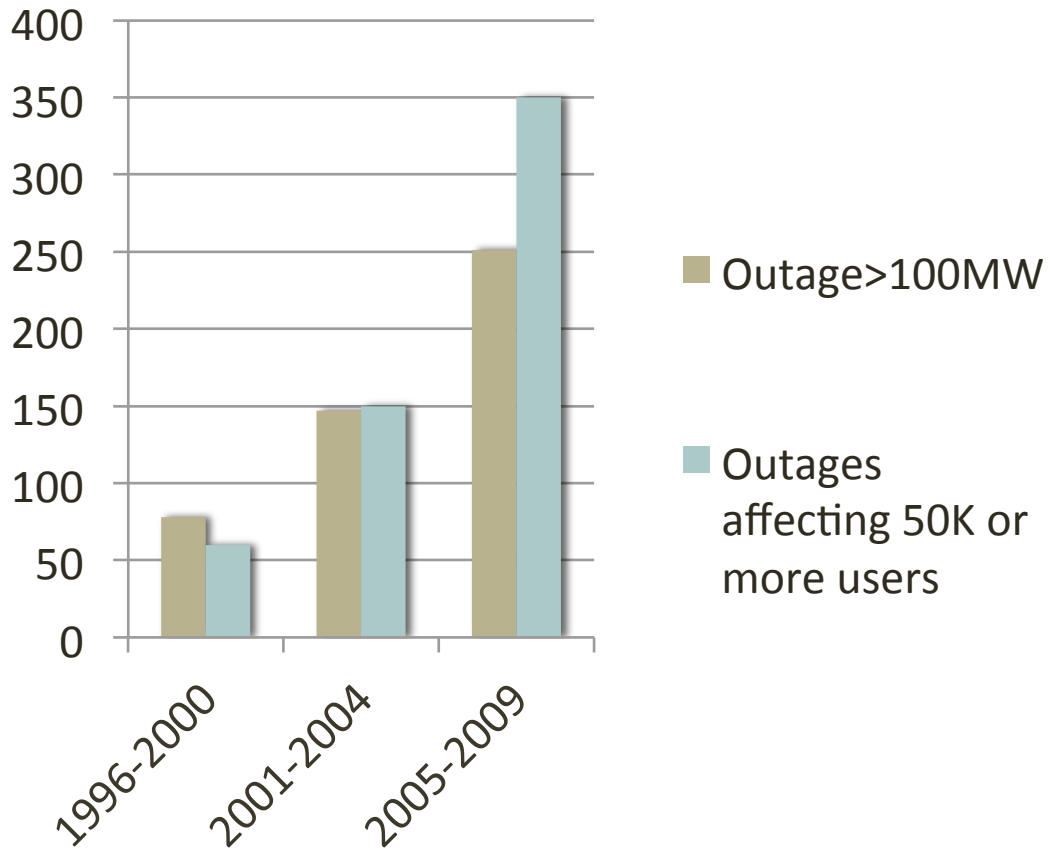
Major Disruptions: Fukushima, H1N1

The Smart Grid



Economics of Outages

- Power outages cost US economy $80B -150B annually (0.01 % of GDP)



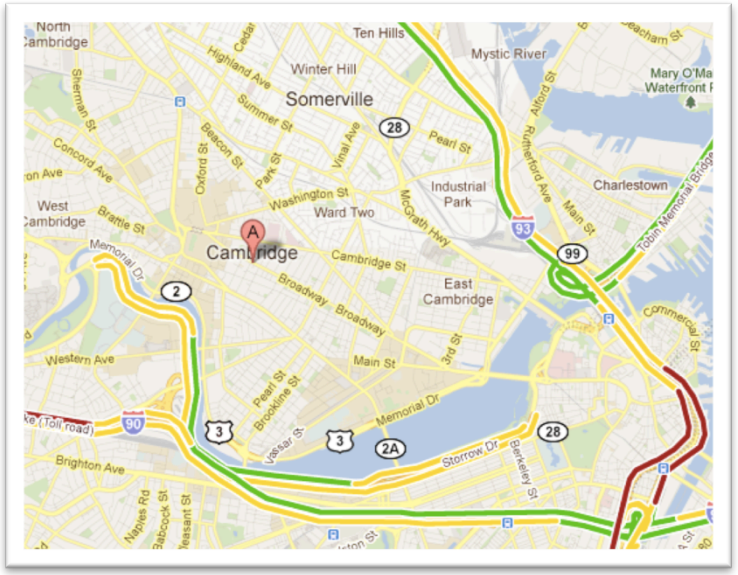
Crises

Motivation: self-fulfilling crises

- debt crises (PIGS)
- bank runs (Argentina 1999-2002)
- social upheavals (Arab revolutions)
- …

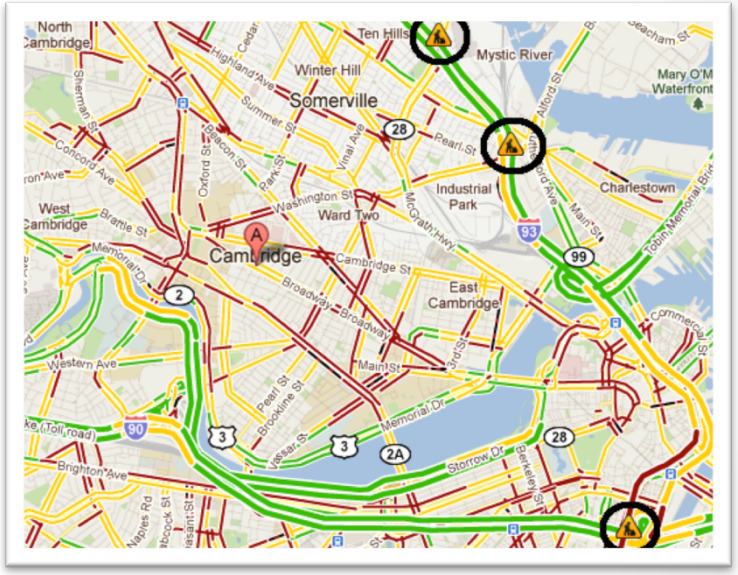
Information sharing (*locality*) enables coordination. How do equilibria depend on details of information sharing?

Disturbances in Urban Transportation Networks



Typical Monday at 6:30 p.m.

disturbance



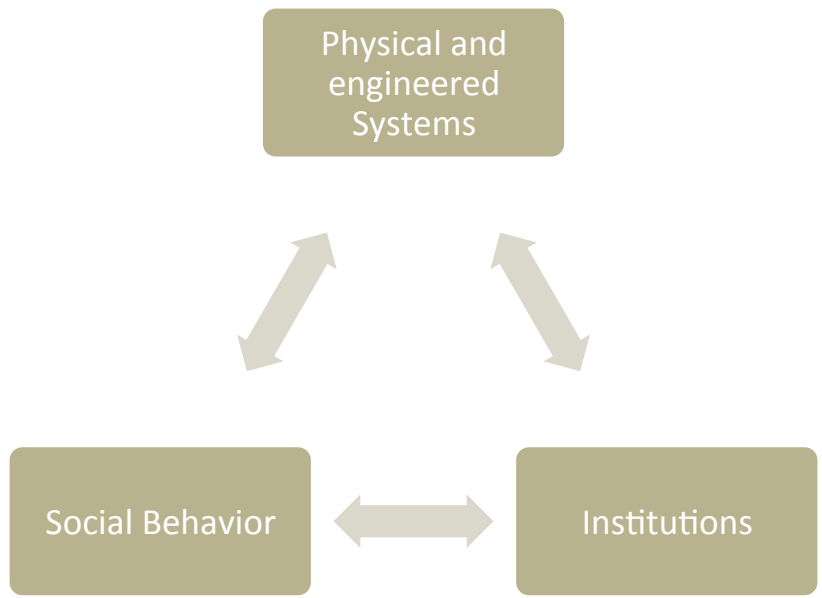
Monday November 7, 2011, 6:30 p.m.

(Courtesy: Google Maps)

The Opportunity

Interactions between engineered and natural physical systems, institutions, and social behavior (Complex Systems)

Availability of large heterogeneous data on such interactions



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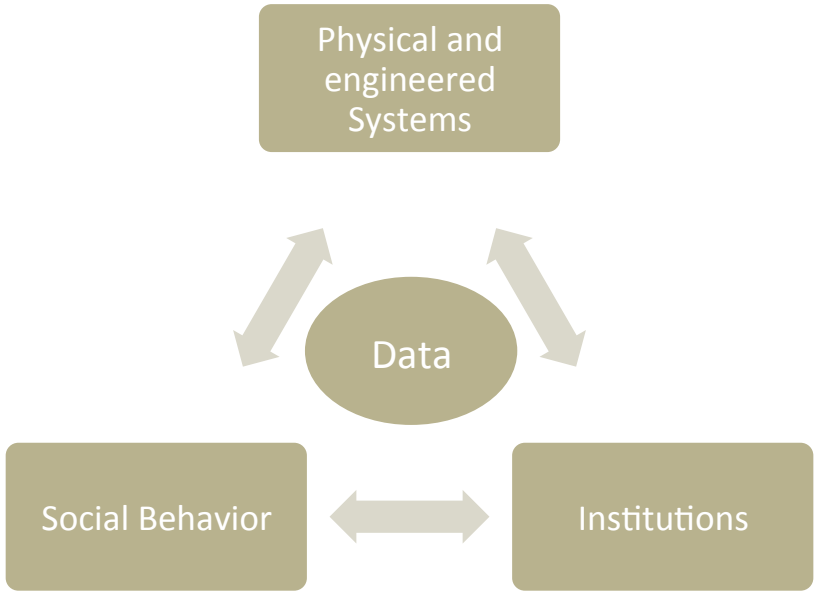


Systemic Risk

Characteristics

- Many heterogeneous decision makers
- Spatial/temporal dimensions (as an abstraction)
- Interconnections/feedback/Information Structure

Formulations

- Exogenous/idiosyncratic → indogenous risk
- Collective coordination on undesirable behavior
- Cascade (of spatial failures) → Temporal instability

Common Theme

- synchronization

What I will talk about ….

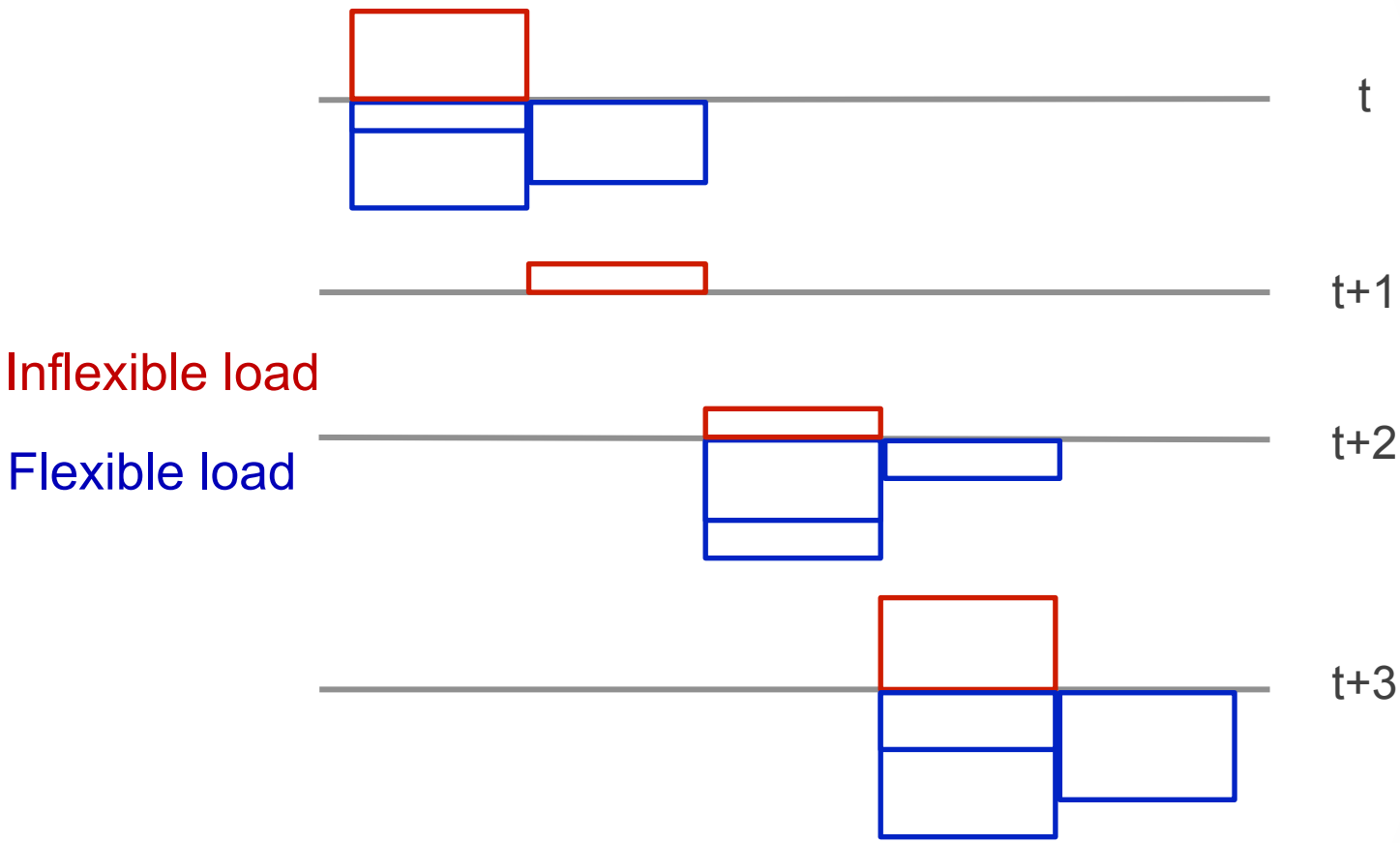
- Value of Anarchy
- Animal Spirit
- Network Effect

Value of Anarchy

Value of Anarchy

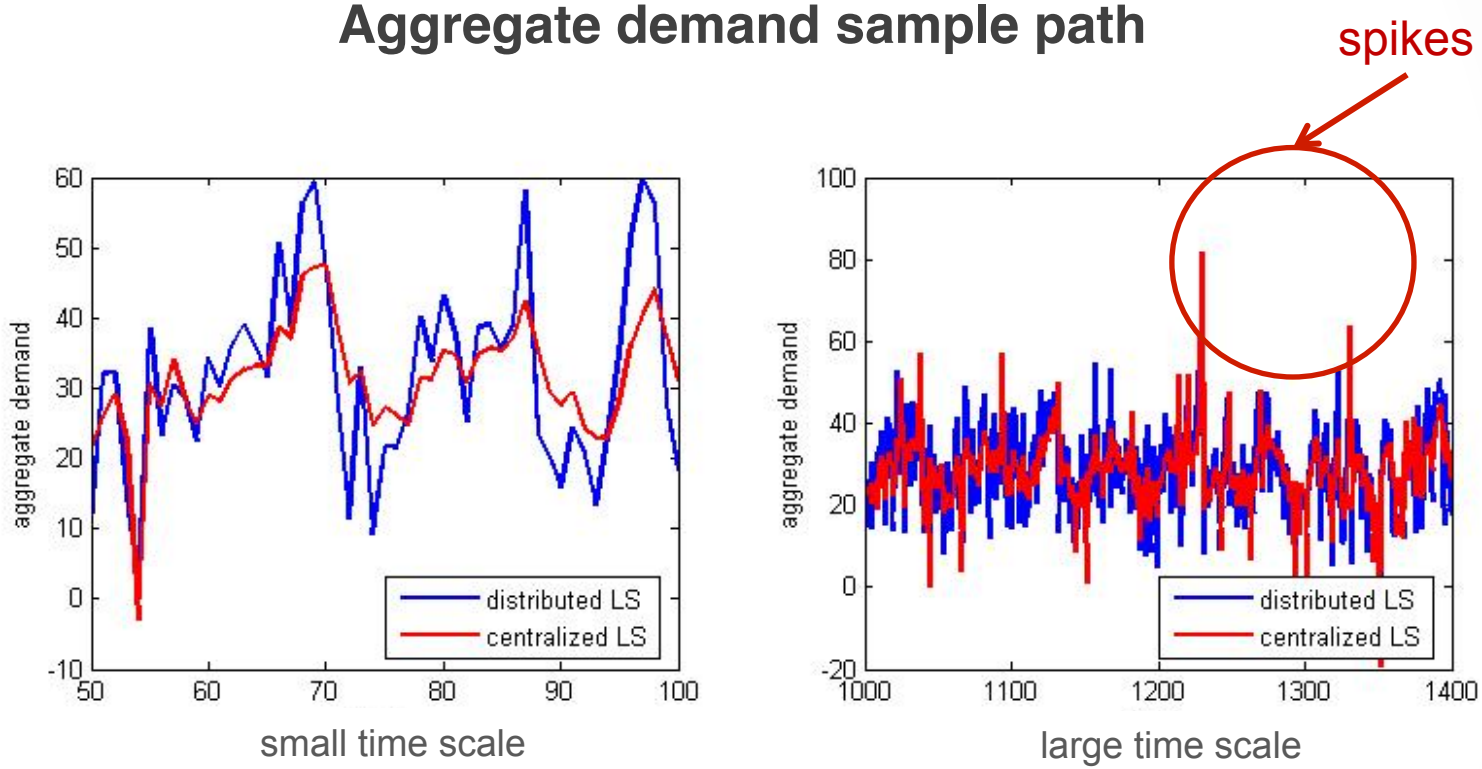
- Price of Anarchy: Loss in efficiency due to strategic interactions in contrast to a coordination
- Simple model: one agent with shiftable demand and another with instantaneous demand
- Contrast optimal efficient solution to a Stackelberg game of strategic behavior
- A tradeoff is emerging!

Setup



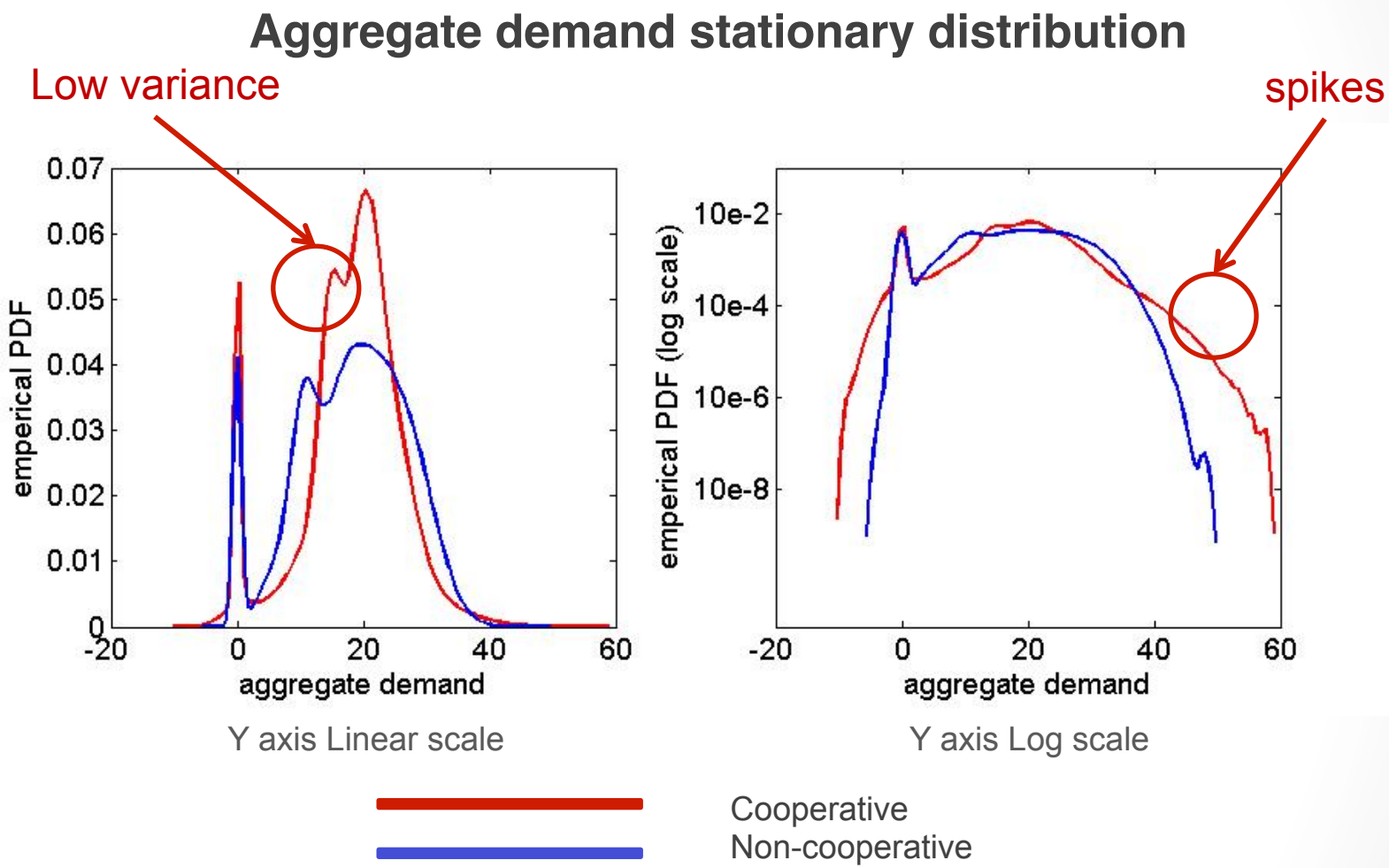
Price of Anarchy: what about risk?

Aggregate demand sample path



Cooperative
Non-cooperative

Example


Aggregate demand stationary distribution
Low variance
spikes
emperical PDF
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-20
0
20
40
60
aggregate demand
emperical PDF (log scale)
10e-2
10e-4
10e-6
10e-8
-20
0
20
40
60
aggregate demand
Y axis Linear scale
Y axis Log scale
Cooperative
Non-cooperative

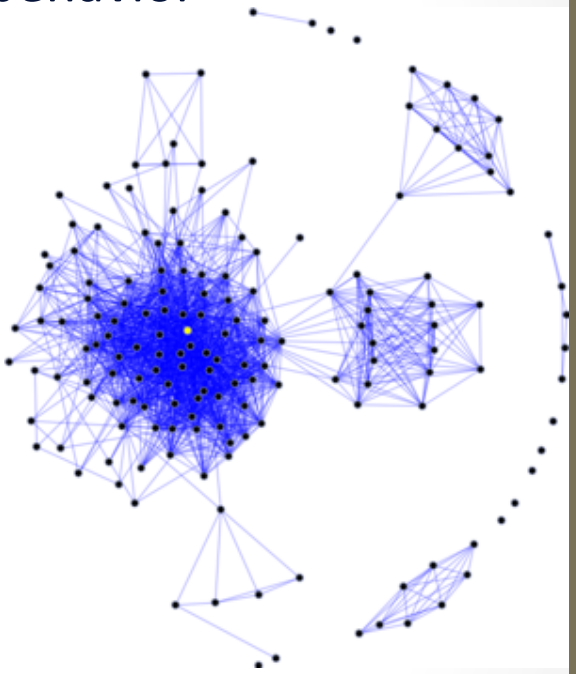
So….

Classical Tradeoff:
Performance vs Robustness

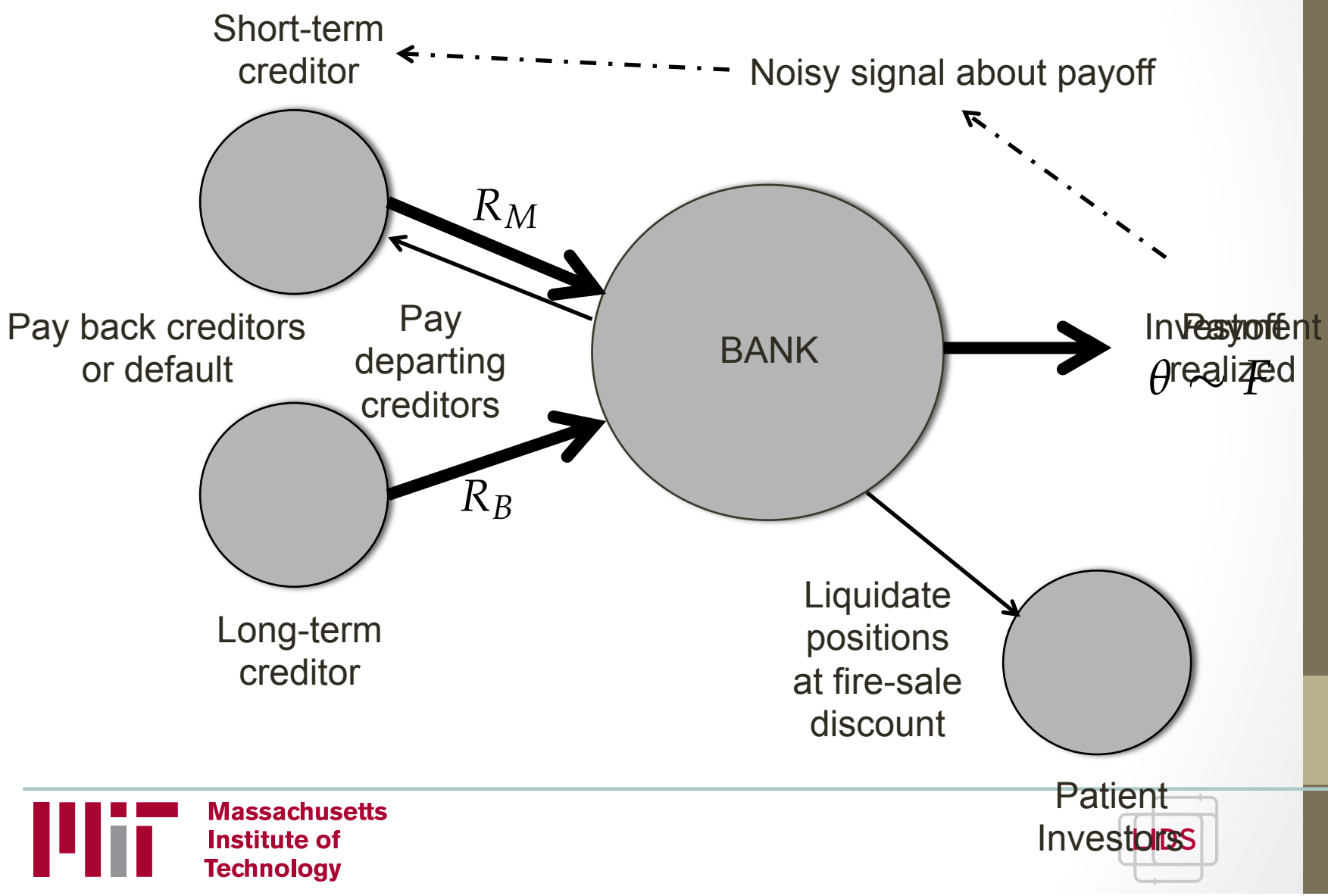
Animal Spirit: Boom-Bust Model

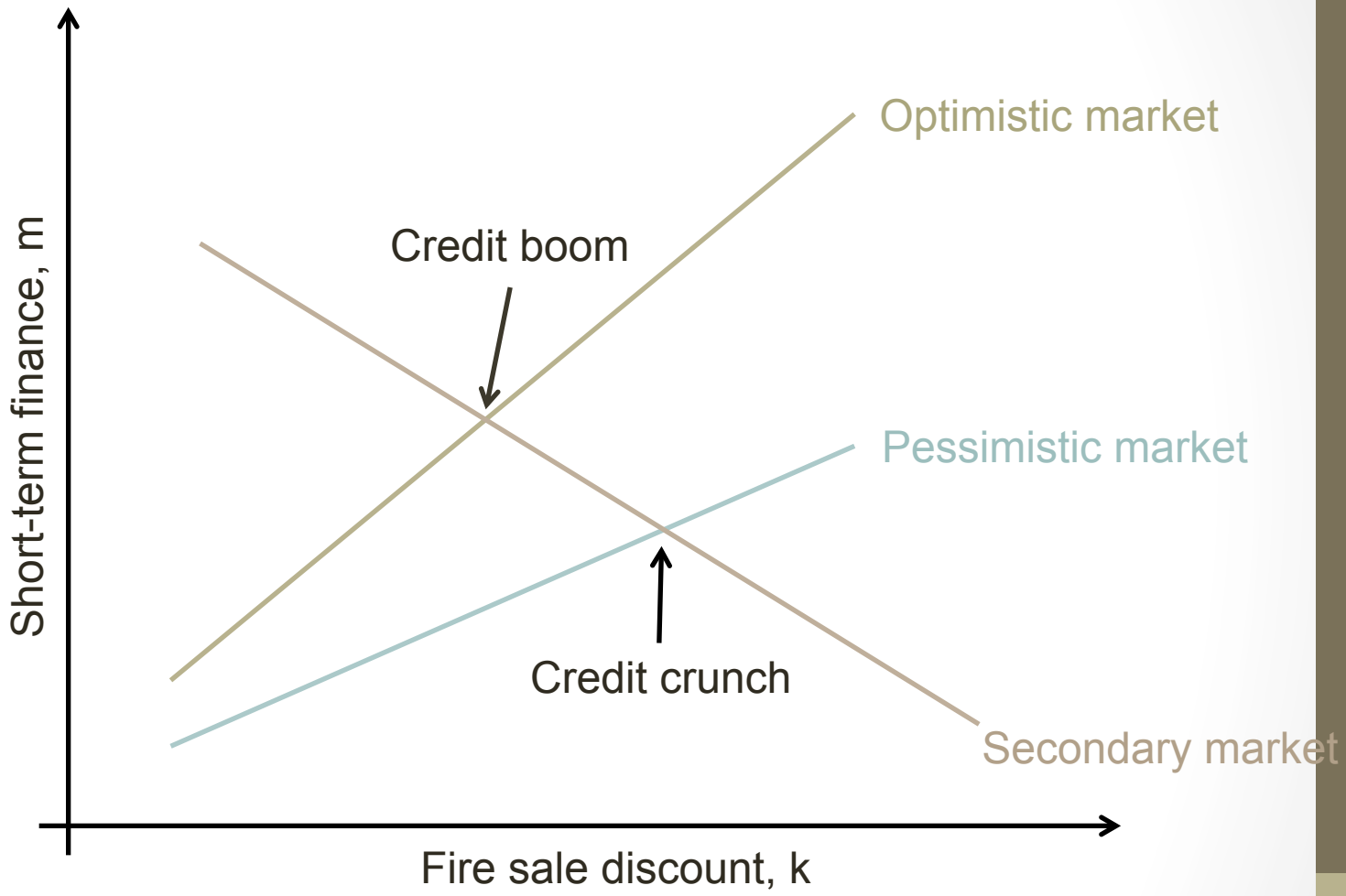
Animal Spirits

- Groups of people coordinate on a specific behavior
  - Behavior can have adverse effects
  - Impacted by information structure
- Global games provide a viable framework
- Financial Models



Boom-Bust


Short-term creditor
Noisy signal about payoff
R_M
Pay back creditors or default
Pay departing creditors
BANK
Investment realized
Payoff $\theta \sim F$
R_B
Long-term creditor
Liquidate positions at fire-sale discount
Patient Investors


Optimistic market
Credit boom
Pessimistic market
Credit crunch
Secondary market
Short-term finance, m
Fire sale discount, k

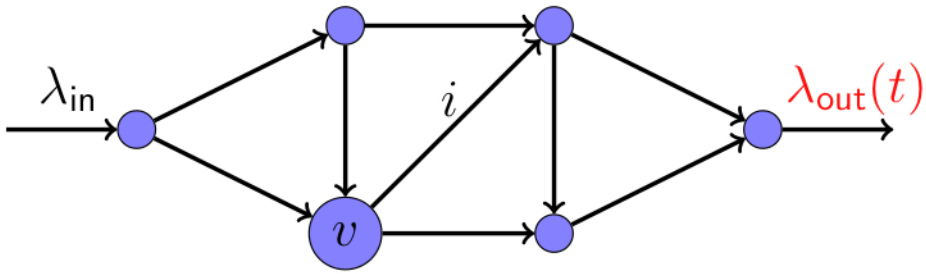
So….

Optimism and Pessimism about the market drive the Boom-Bust

Can this be actionable?

Network Effect: Flow Models

Network Effect: Flow Models



ρ_i : density on link i

- Congestion dynamics

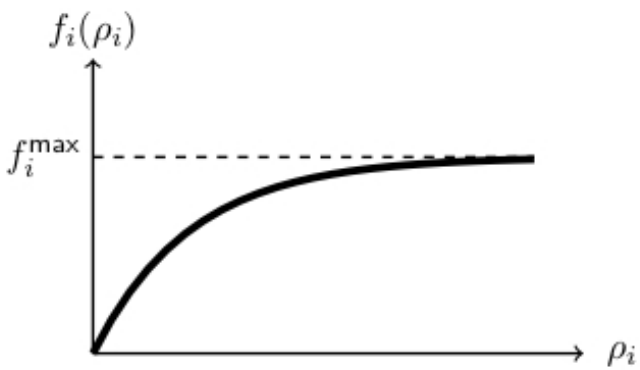
Rate of change of ρ_i = flow into link i – flow out of link i

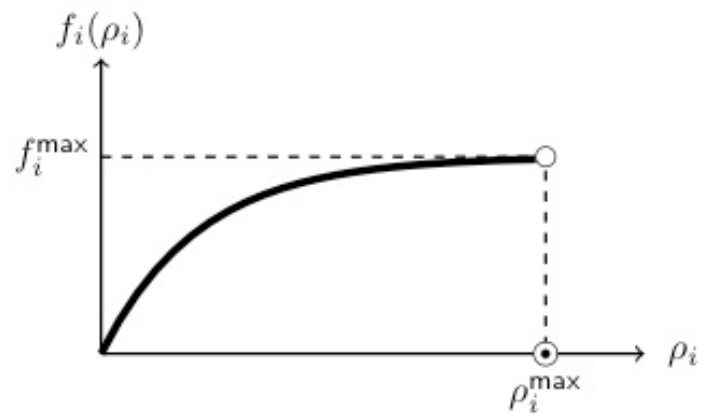
- Flow conservation

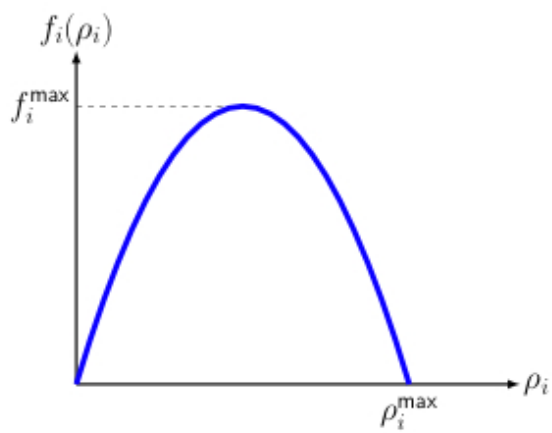
$$\sum_{i \text{ incoming to } v} f_i = \sum_{j \text{ outgoing from } v} f_j \qquad \forall v$$

Flow function

- Outflow on a link depends on the traffic density on that link: $f_j(\rho_j)$



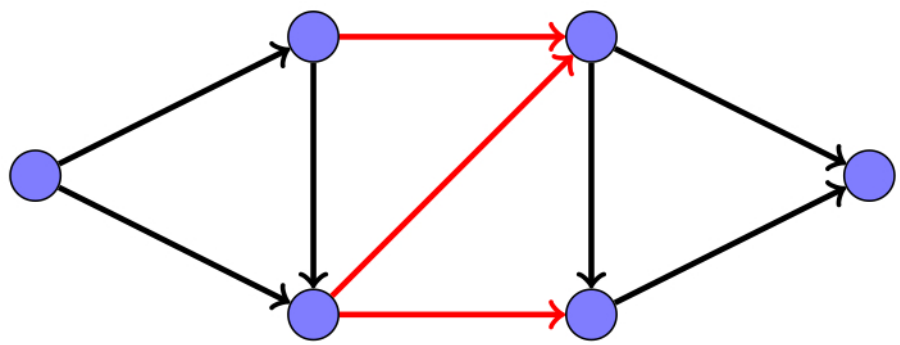




ρ_i : density on link

Outflow is not necessarily equal to inflow on a link

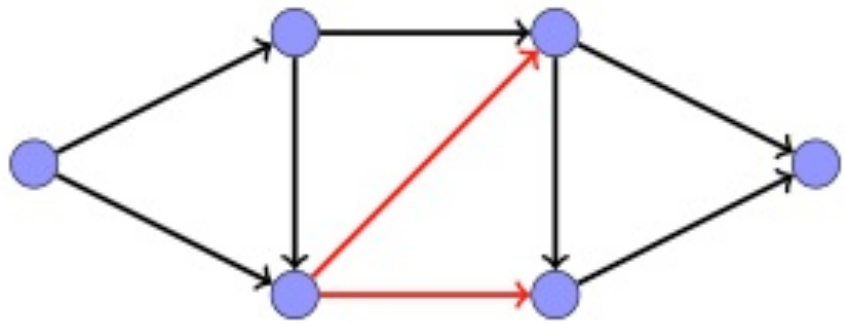
Upper Bound on Margin of Resilience



- $\forall G$, margin of resilience ≤ min cut residual capacity

$$:= \min_{\text{cut } \mathcal{C}} \sum_{i \in \mathcal{C}} (f_i^{\text{max}} - f_i^{\text{eq}})$$

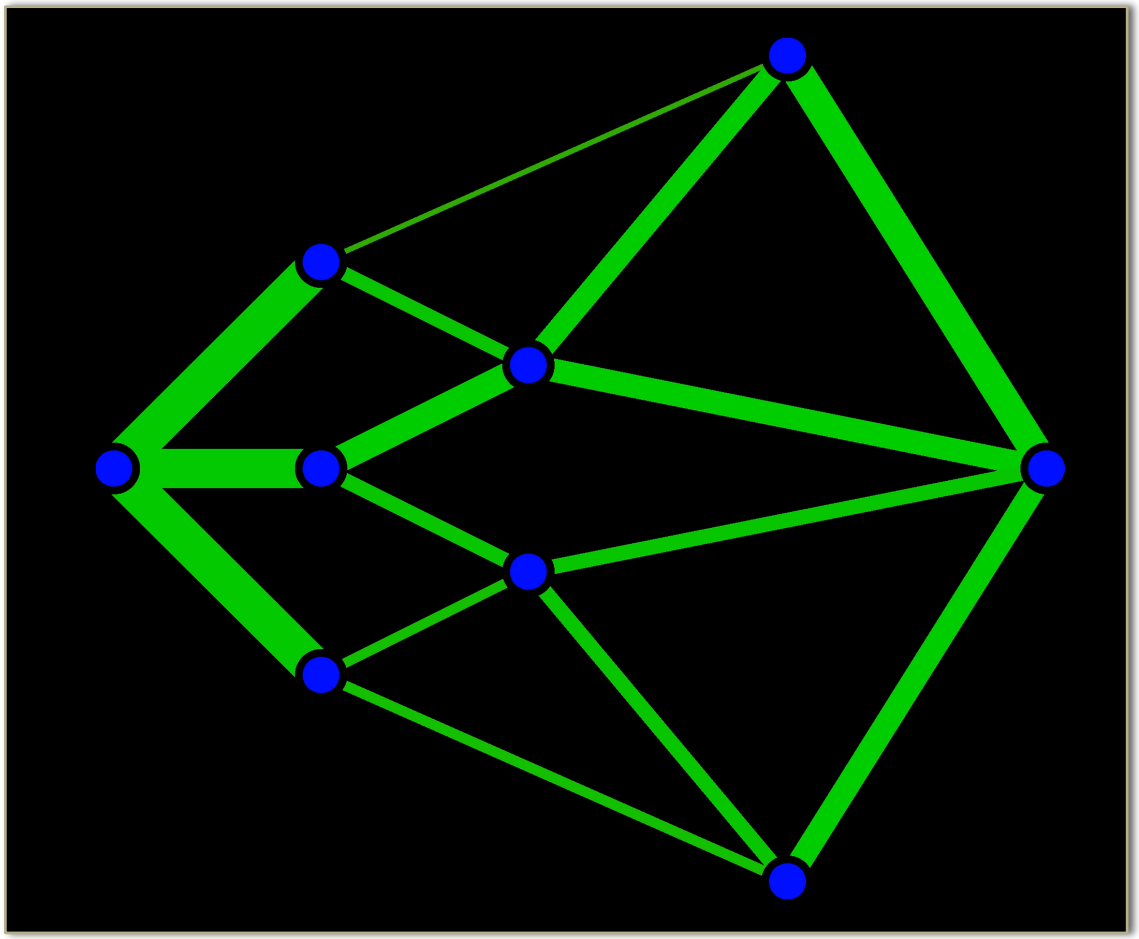
A Tighter Upper Bound



- $\forall G$, margin of resilience ≤ min node cut residual capacity

$$:= \min_{v} \sum_{i \text{ outgoing from } v} (f_i^{\max} - f_i^{\text{eq}})$$

Upstream Cascades



Just Scratching the surface …..

Conclusions

- New and exciting area!

- Characteristics
  - Many heterogeneous decision makers
  - Spatial/temporal dimensions (as an abstraction)
  - Interconnections/feedback/Information Structure

- Three Instances
  - Value of Anarchy: Classical tradeoff between optimality and robustness
  - Animal Spirits: Coordination on undesirable behavior
  - Flow Dynamics: Cascades

Collaborators

- Power Grid
  - Mardavij Roozbehani: MT
  - QinqQing Huang: MIT

- Transportation
  - Ketan Savla: USC
  - Giacomo Como: Lund University, Sweden
  - Daron Acemoglu: MIT
  - Emilio Frazzoli: MIT

- Finance
  - Diego Feijer: MIT
  - Spyros Zoumpoulis: INSEAD
  - Andrew Lo: MIT

Thank You