Networks and stability

Part 2A. – Network dynamics

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1. network topology (II.20-27.)

2. network dynamics (III.6.-13.)

(III.20.-27. no lectures)

3. examples for networks (IV.3.-10.)

(IV.17. Easter)

4. synthesis (IV.24., V.1. holiday, V.8.)

(V.13. consultation)

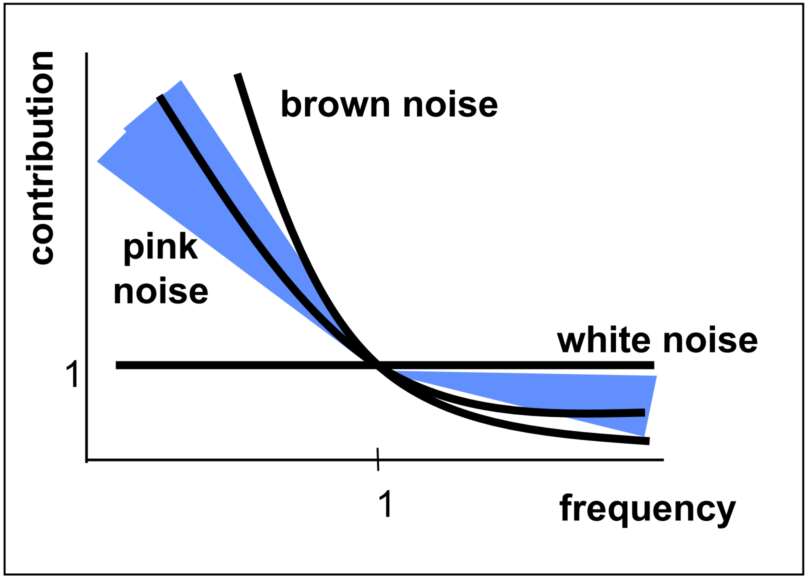
Network dynamics

- **perturbations, signal and noise**
- relaxation, self-organized criticality
- cascading failures
- topological phase transitions
- sync
- synthesis: engineering vs. tinkering

Network tasks: dissipation of noise and response to signals

noise: sum of sinusoidal waves, Fourier-transformation:

$$f(\omega) = \int_{-\infty}^{+\infty} f(t) e^{-i\omega t} dt = \int_{-\infty}^{+\infty} f(t)[\cos(\omega t) - i \sin(\omega t)] dt$$



$P = c\ D^{-\alpha}$

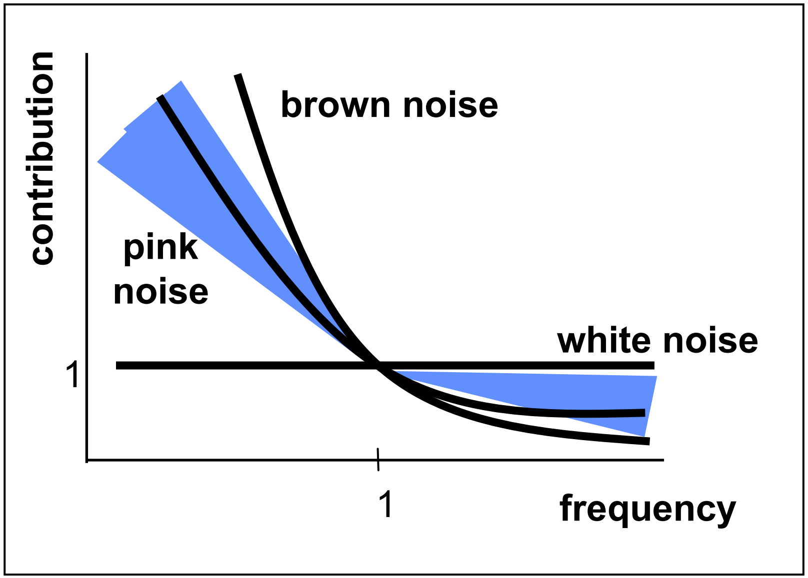
P, spectral density (contribution)

c, constant

D, frequency

α, scaling exponent

Noises



white noise (hiss)
• no correlation (no memory)
• relative bias to fast fluctuations (large frequencies)

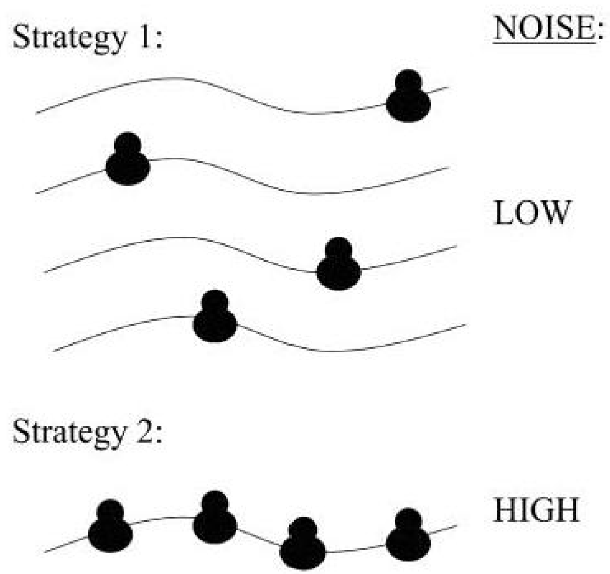
brown noise (Brownian noise)
• diffusion-like (next value is random next position is correlated)
• relative bias to slow fluctuations

pink noise (coloured, flicker, crackling, Barkhausen, 1/t noise)
• correlation (memory), 1/t: all event-classes equally contribute
• relative bias to unlikely events (small frequencies, reddening to white: pink)

$$\mathbf{P = c\ D^{-\alpha}}$$

$\alpha = 1$, 1/t noise

Noise is bad: minimization



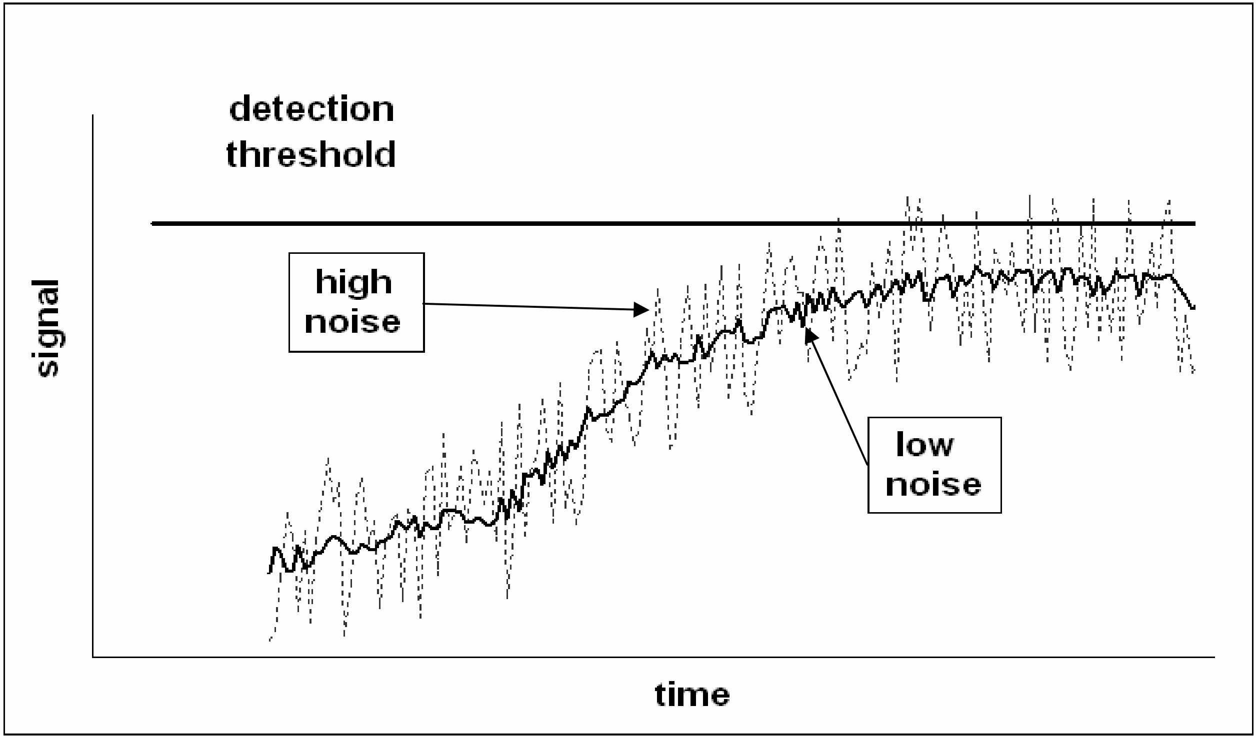
- essential genes, protein complexes
- low noise:
  - high transcription
  - low translation
- diseases, tumors (PNAS 99, 13783)
- error catastrophe (Eigen, PNAS 99. 13374)

Fraser et al, PLOS Biol. 2, 2004

Seminal review: Rao et al: Nature 420, 231

Noise is good: stochastic resonance

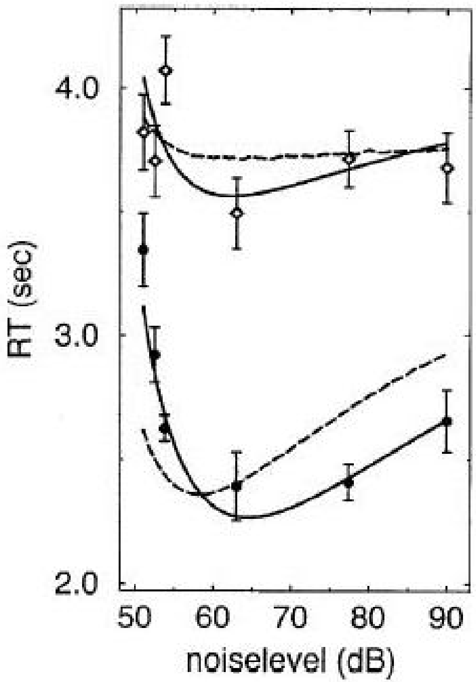
stochastic resonance: extrinsic noise
stochastic focusing: intrinsic noise



- rain calms rough seas (Reynolds, 1900)
- stochastic resonance: mechanoreceptors, hearing
- bone-growth, fish food finding is better

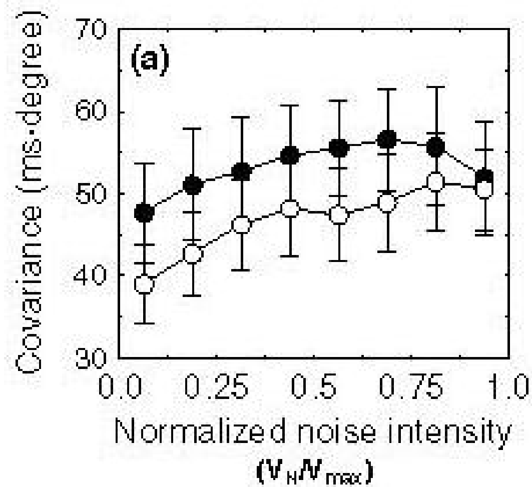
Stochastic resonance: memory retrieval, pink noise, music

response time



difficult task

easy task



1/t pink noise

white noise

music is pink noise

Soma et al, PRL 91, 078101

Usher & Feingold, Biol. Cybern. 83, L11-L16

Network dynamics

- perturbations, signal and noise
- **relaxation, self-organized criticality**
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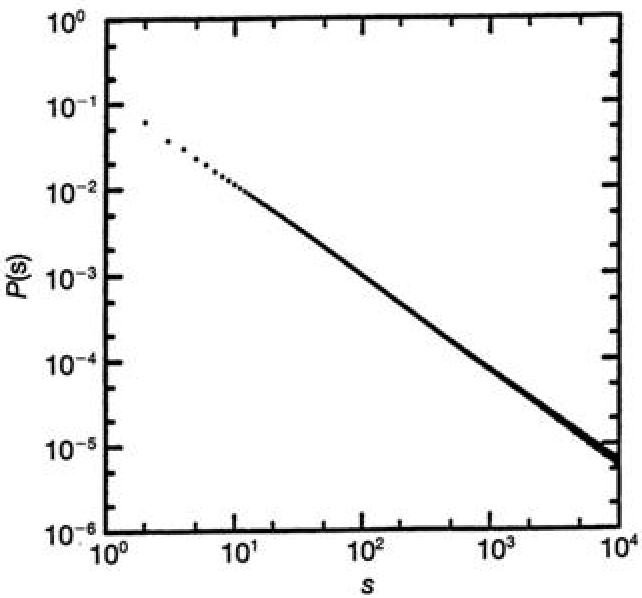
- synthesis: engineering vs. tinkering

Self-organized criticality: our every-day avalanches

Bak-Paczuski, PNAS 92, 6689



sand-pile avalanches
→ scale-free size + event distribution

- magnetization (Barkhauser-effect)
- protein quakes
- earthquakes
- vulcano-eruptions
- forest-fires
- cracks
- crackling noise
- dipping faucets
- breath
- rain
- solar flares
- quazar emissions
- cultural changes
- innovations

Self-organized criticality: a restricted relaxation phenomenon

- magnetization (Barkhauser-effect)
- protein quakes
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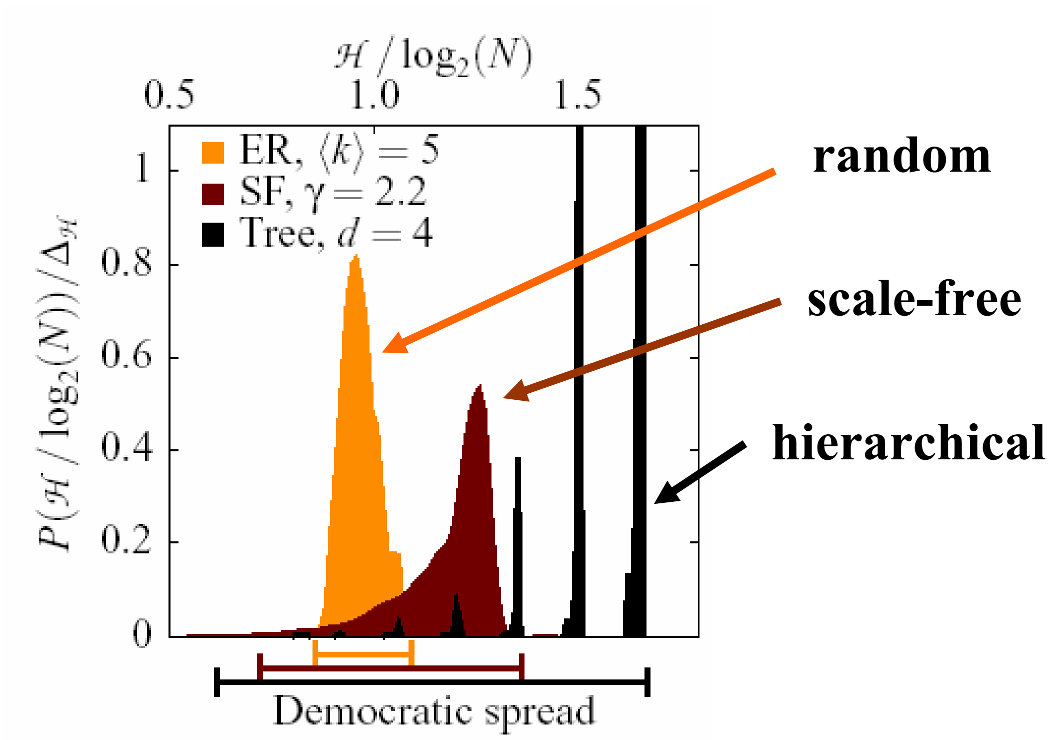
- continuously increasing tension
- partially restricted relaxation

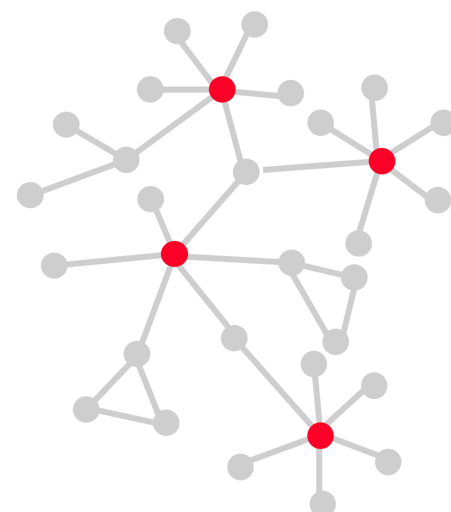
→ avalanche

Scale-free nets are hub-rich which hinders the information-flow



informed **uninformed**

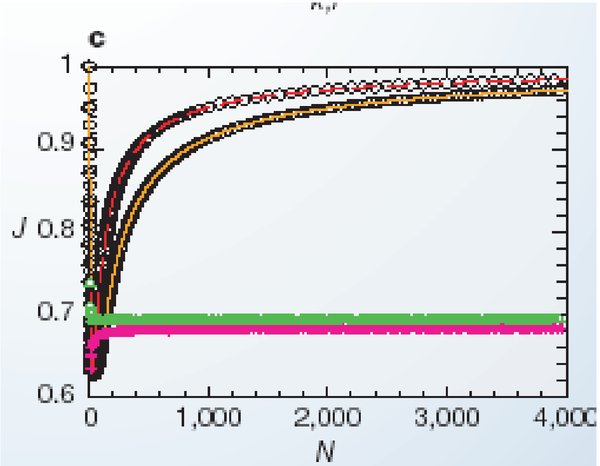
Rosvall et al., Phys. Rev. E 72, 046117



Why do we need hubs for this?

Scale-free networks give less jams than random graphs

connectivity increases traffic jams



Nature 428,716
PRE 71, 065105

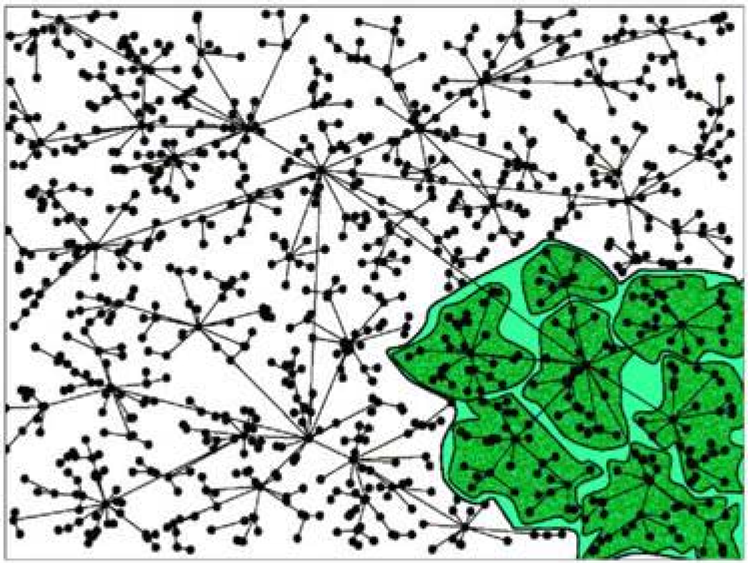
random

less traffic jams
at high connectivity
(low connectivity: opposite)

scale-free

jams at hubs:
re-routing
cond-mat/0505366

Optimal network has a network skeleton

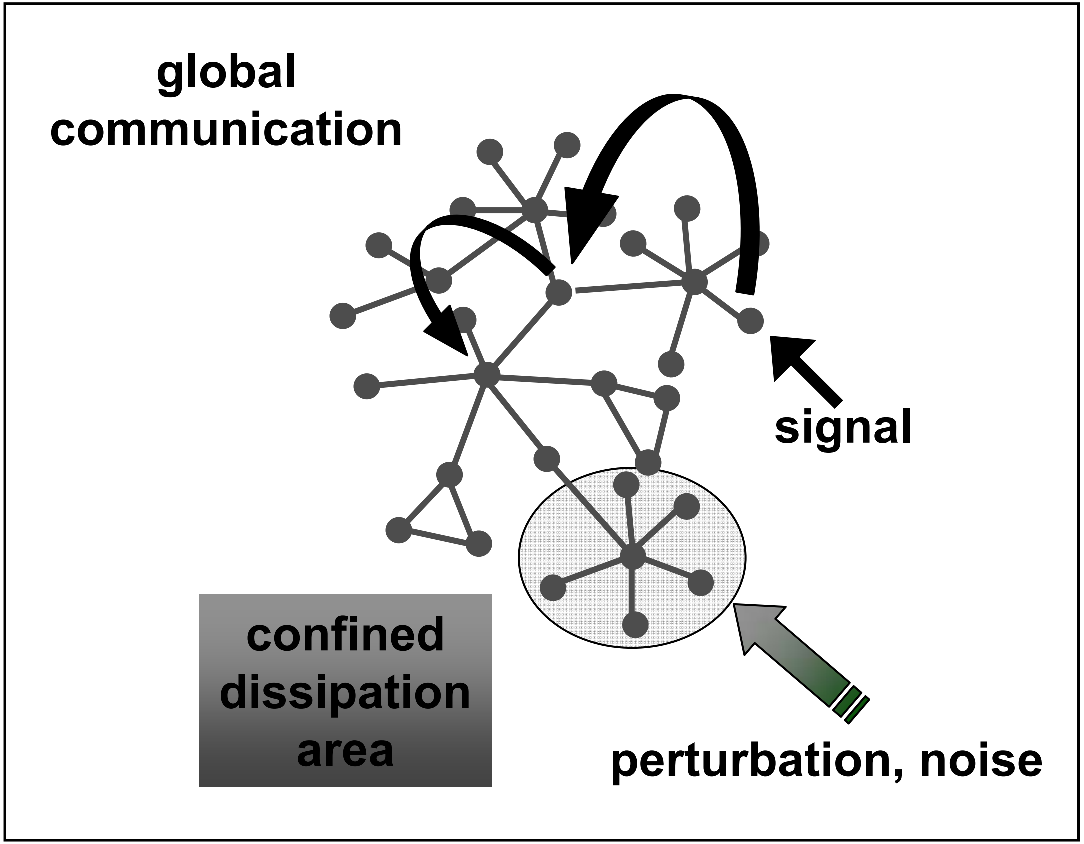


scale-free/hierarchical pattern:
minimal energy dissipated
by the network

(network skeleton)

www.arxiv.org/physics/0601203

Properties of a „good” (complex) network



small world

scale-free

Stability brings low flux – low flux needs stability

Proc. Natl. Acad. Sci. USA
Vol. 92, pp. 452–456, January 1995
Biochemistry

A relationship between protein stability and protein function

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Institute of Molecular Biology, Howard Hughes Medical Institute, and Department of Physics, University of Oregon, Eugene, OR 97403

Contributed by Brian W. Matthews, October 4, 1994

ABSTRACT Enzymes are thought to use their ordered structures to facilitate catalysis. A corollary of this theory suggests that enzyme residues involved in function are not optimized for stability. We tested this hypothesis by mutating functionally important residues in the active site of T4 lysozyme. Six mutations at two catalytic residues, Glu-11 and Asp-20, abolished or reduced enzymatic activity but increased thermal stability by 0.7–1.7 kcal·mol^{-1}. Nine mutations at two

Table 1. Stability and activity of T4 lysozymes with subst
in the substrate-binding site

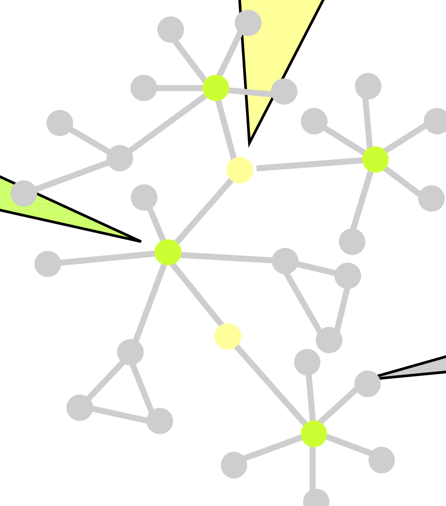
Protein	ΔT_m,† °C	$\Delta\Delta G_{stability}$,† kcal·mol^{-1}	ΔH (T_m), kcal·mol^{-1}
WT	0	0	140
WT*	0	0	131
E11F	4.3	1.7	138
E11M	4.1	1.6	134

transition time is high at low flux
low flux points need extra stability

Different roles in noise and signal distribution

Talented: few links to hubs, small traffic, **unusual signal** re-routing, unstable

Rich: many links, large traffic, **noise** distribution, unstable



Poor: few links, small traffic, **noise** dissipation, stable

Rich = Big; Poor = Small phenotype; Bateson et al., Nature 430, 419

Network dynamics

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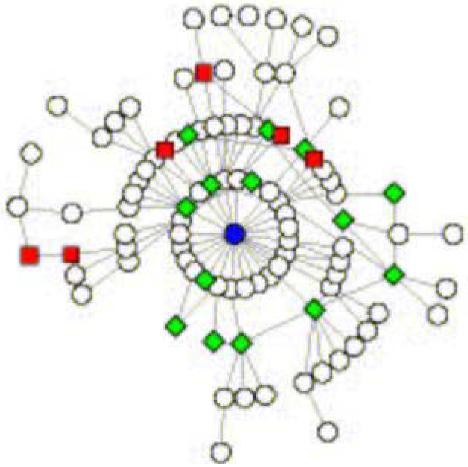
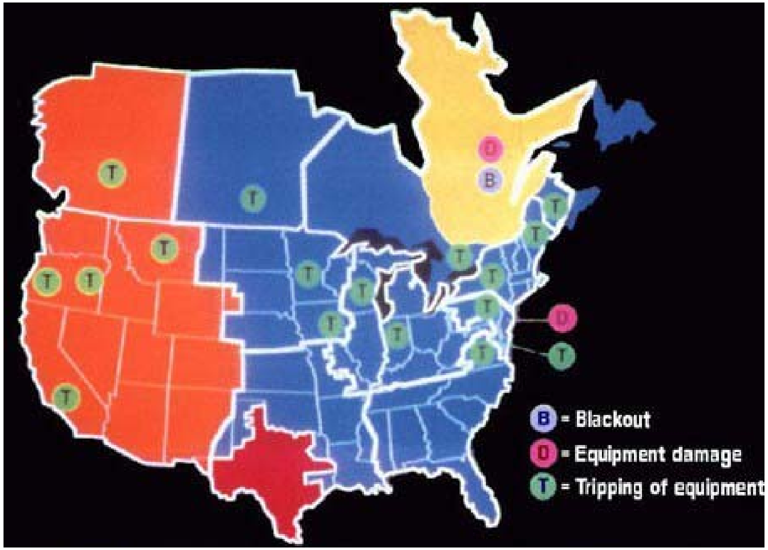
- **cascading failures**
- topological phase transitions
- sync
- synthesis: engineering vs. tinkering

Cascading failures



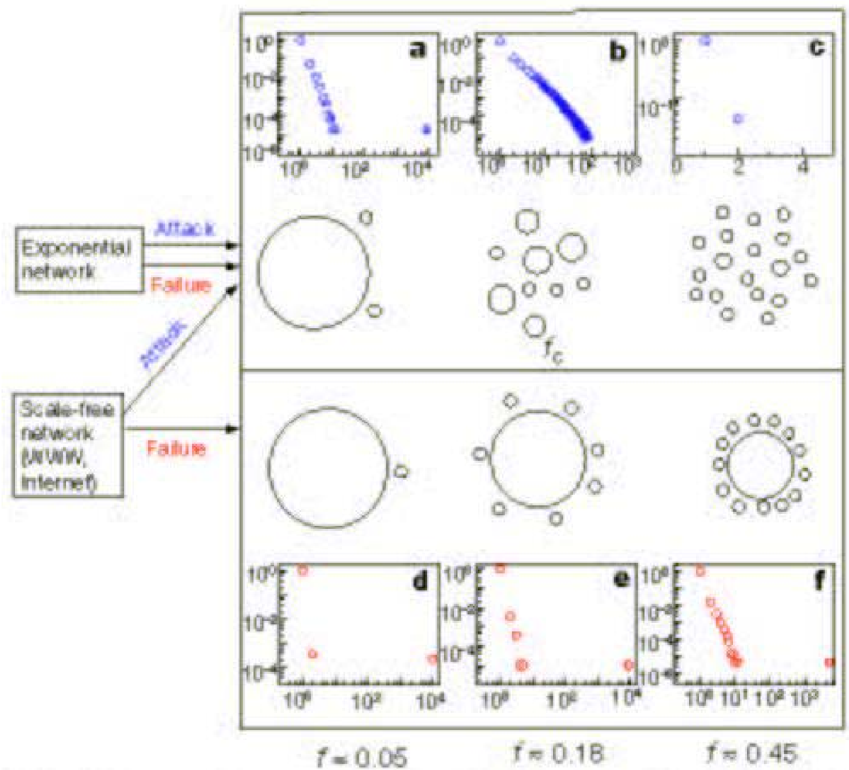
blue → green → red

cond-mat/0410684



March 13, 1989

Weak points in networks

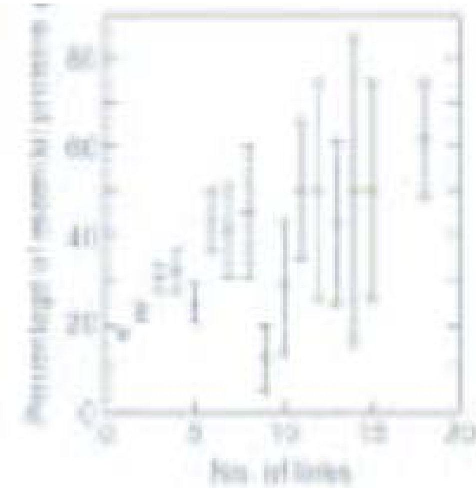


scale-free networks
are resistant against failure
but are vulnerable to attacks

Albert et al Nature 406, 378

Other weak points

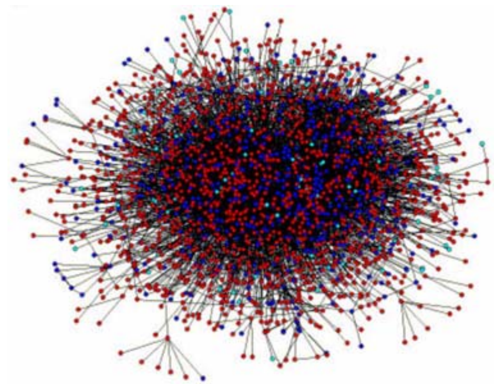
lethality



neighbors

Jeong et al Nature 411, 41

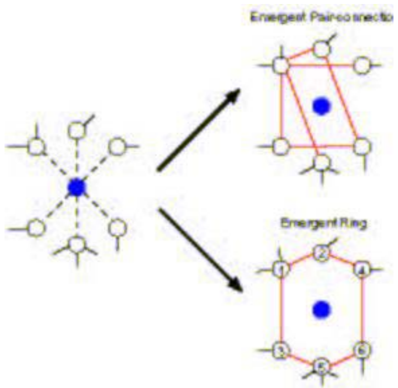
later: centrality
special reactions & complexes



- continuous failure (aging) PRE 63, 056125
- assortativity helps attack-resistance PRE 67, 026126
- overconnected networks PNAS 99, 5766

Repair of failures

rewiring

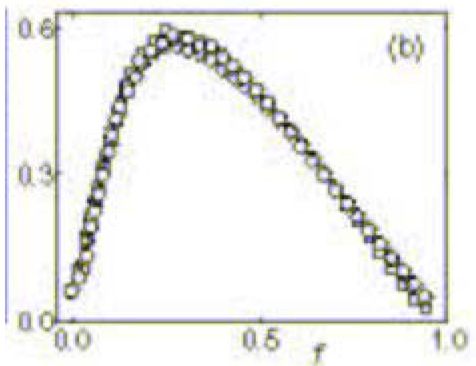


cond-mat/0503615

redistribution

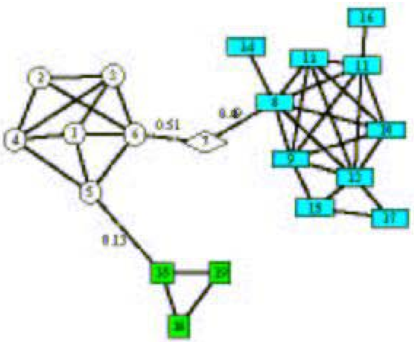
cond-mat/0505366

removing low flux nodes + jammed edges



cond-mat/0401074

module connector removal



cond-mat/0503593