Networks and stability

Part 2A. – Network dynamics

Peter Csermely

www.weaklink.sote.hu
csermelypeter@yahoo.com
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
\( \alpha \), 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)

\[ P = c \, D^{-\alpha} \]
\[ \alpha = 1, \, 1/t \, noise \]
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
Noise is good: stochastic resonance

- 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

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

Soma et al, PRL 91, 078101
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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
- earthquakes
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- innovations

- continuously increasing tension
- partially restricted relaxation
  → avalanche
Scale-free nets are hub-rich which hinders the information-flow

Why do we need hubs for this?

Roslav'e et al., Phys. Rev. E 72, 046117
Scale-free networks give less jams than random graphs

Connectivity increases traffic jams

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

- Global communication
- Confined dissipation area
- Signal
- Perturbation, noise

Small world
Scale-free
Stability brings low flux – low flux needs stability

A relationship between protein stability and protein function

BRIAN K. SHOICHET, WALTER A. BAASE, RYOTA KUROKI†, AND BRIAN W. MATTHEWS‡

Institute of Molecular Biology, Howard Hughes Medical Institute, and Department of Physics, University of Oregon, Eugene, OR 97405

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

transition time is high at low flux low flux points need extra stability
Different roles in noise and signal distribution

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

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

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

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

- lethal 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
- removing low flux nodes + jammed edges
- module connector removal

cond-mat/0503615
cond-mat/0401074
cond-mat/0505366
cond-mat/0503593