Networks and stability

Part 1B. – Network topology

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1. network topology
2. network dynamics
3. examples for networks
4. synthesis (complex equilibria, games, network evolution, trans-network effects)
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)
Weighted small worlds

Efficiency (+ cost):
a weighted world can be small
even if the non-weighted is not

\[
E = \frac{\sum \frac{1}{d_{i,j}}}{N(N-1)}
\]

Latora and Marchiori PRL 87, 198701

\[
E = 0.181 \\
E_{xx} = 0.104 \\
(57.5\%)
\]
Network topology

- small worlds
- scale-free degree distribution
- **network communities**
- network skeleton
- hierarchy and nestedness
Rich clubs, No. 2.
hubs associate with hubs
(assortativity: social nets)

Zhou and Mondragon
IEEE Comm. Lett. 8, 180

a disassortative rich club
proteins
physicists
(Internet not)

Colizza et al.
Nature Physics 2, 110 -06-
Modules

Newman, SIAM Rev. 45, 167

modular nets
intermodular contacts
are suppressed
Major methods of module determination

- clustering methods
- divisive methods (betweenness centrality)
- „fuzzy” methods (random element added)
- network walks

$k$-cliques method to determine overlapping modules

Palla et al., Nature 435, 814
How are modules formed?

integration
(symbiosis)

parcellation

Zachary’s charate club
administrator: circles
instructor: squares
Girvan-Newman, PNAS 99,7821
Why is it good if a network has modules?

modules
• stop noise, damage and sync
• can evolve independently
• separate functions (induce diversity)
• allow sophisticated regulation by fringe areas
Modules may have isotemporal clusters of elements

Quin et al., PNAS 100, 12820
Modularization and development

Does complexity lead to modularization?
(Does complexity need modularization?)

Will the
• Internet
• world economy
• Gaia
develop modules?

What determines the speed of modularization?
Useful information comes from a long distance

- Mark Granovetter (1973)
- transmodular links are weak
- these links stabilize the society
- unusual ideas, innovation (trust)
- cognitive flexibility
  (understanding completely different ideas)

Am. J. Sociology 78, 1360
Modules have a scale-free size and degree distribution

www.arxiv.org/cond-mat
word-associations
yeast DIP protein network
preferential attachment model of modules

Palla et al., Nature 435, 814
For size: Arenas et al.,
EPJ B38, 373
Pollner et al., Europhys. Lett, in press
Cond-mat/0601579
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Network skeleton (fractal nets)

- food-chain renorm. (energy-flow)
  - Garlaschelli et al., Nature 423, 165

- email-net renorm. (betweenness)
  - Guimera et al., PRE 68, 065103
  - Kim et al., PRE 70, 046126
  - Arenas et al, EPJ B38, 373

- www renormalization (unbranched ends)
  - Song et al., Nature 433, 392
Allometric scaling

• 1932, M. Kleiber
  how the metabolic rate of mammals relates to their body mass?

  \[ B = B_0 M^{3/4} \]

• why is this surprising?

  Should be linear (reactions) or 2/3 power (Euclidean surface to volume ratio)
Universality of allometric scaling I.

West et al., PNAS 99, 2473
Allometric scaling explanation: transport networks

West et al., Science 276, 122

Keith.R. Porter, PNAS 78, 4329
inside the cells:
microtrabecular lattice
Universality of allometric scaling II.

other scales
• ecosystems, river networks
other phenomena
• population doubling, growth rate
• plasma half lives, clearances
• cardiac cycle, respiration, muscle contraction
• reproductive maturity, lifespan

Scaling law and senescence

- Lifespan is a subject of scaling law:
  - All mammals have 1.5 billion heart beats
  - All mitochondria have $1.5 \times 10^{16}$ turnovers
  - Pigeons and rats have equal body size
    - Pigeons live 40 years, rats 4
    - Pigeon mitochondria have 10 times less oxygen production
Scaling law and cellular senescence

- number of mitochondria/per cell which can be supplied by oxygen
  - in man: 300
  - in mouse: 1700
  - in cultured cells: 5000
- calculate the shift…
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Modules

Newman, SIAM Rev. 45, 167

modular nets
intermodular contacts are suppressed

hierarchical net
intermodular contacts are preferentially suppressed
Modules and nestedness

membrane-organelle network
Modules *versus* bottom-networks

A module becomes a bottom-network, if
- we have many
- it is small
- it is structured
- it is separated
- it can live independently
- it has only a few constant links
The end of nestedness (?)

- atoms build molecules
- molecules build cells
- cells build organisms
- organisms build ecosystems
- ecosystems build Gaia

What does Gaia build?