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)

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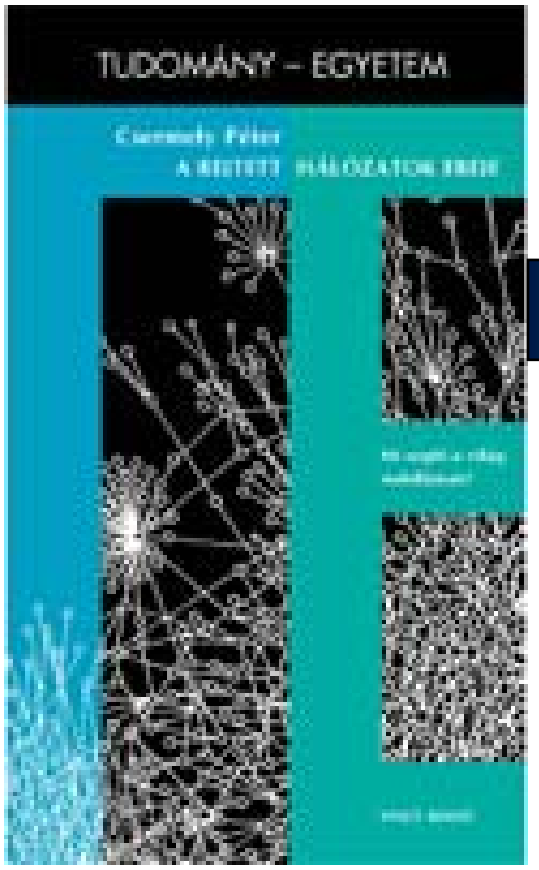
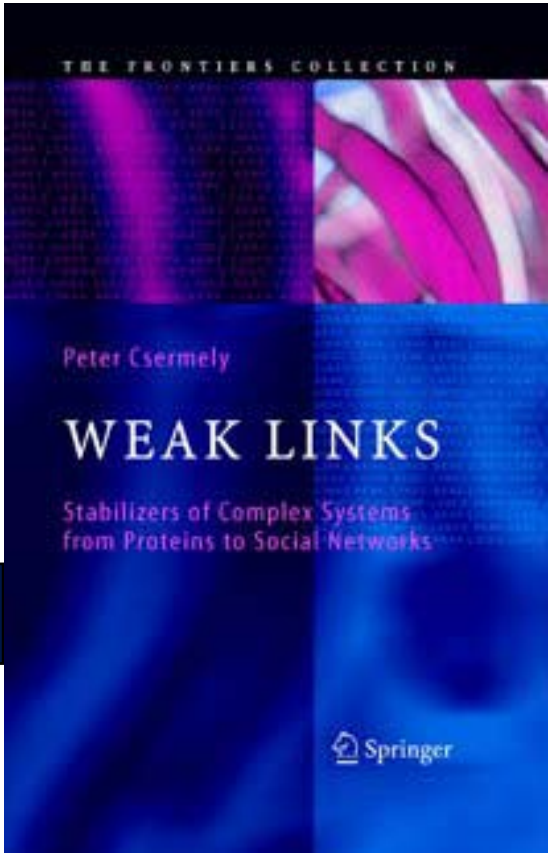


Hungarian

Vince Publisher, Budapest, 2005



English

Springer, 2006

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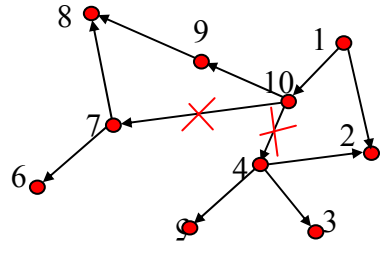
Weighted small worlds

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

$$\textit{Efficiency} \quad E = \frac{\sum_{i \neq j} \frac{1}{d_{i,j}}}{N(N-1)}$$



	1	2	3	4	5	6	7	8	9	10	
1	-	1	3	2	3	3	2	3	2	1	1
2	-	-	-	-	-	-	-	-	-	-	2
3	-	-	-	-	-	-	-	-	-	-	3
4	-	1	1	-	1	-	-	-	-	-	4
5	-	-	-	-	-	-	-	-	-	-	5
6	-	-	-	-	-	-	-	-	-	-	6
7	-	-	-	-	-	1	-	1	-	-	7
8	-	-	-	-	-	-	-	-	-	-	8
9	-	-	-	-	-	-	-	1	-	-	9
10	-	2	2	1	2	2	1	2	1	-	10

E = 0.181
E_{xx} = 0.104
(57.5%)

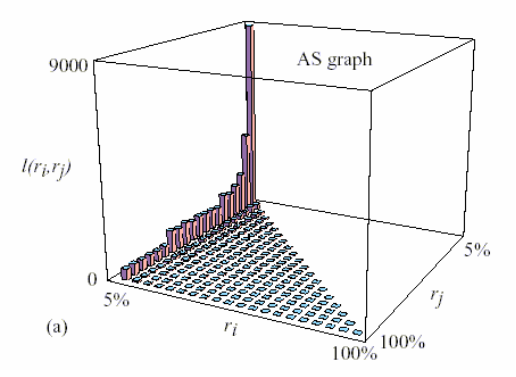
Latora and Marchiori PRL 87, 198701

Network topology

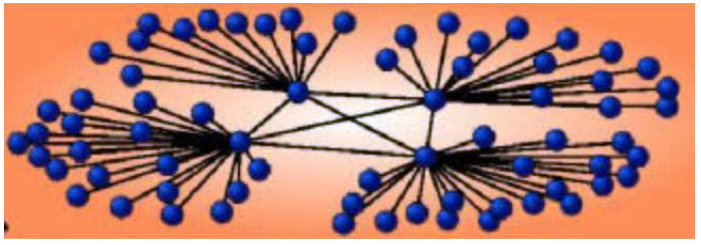
- small worlds
- scale-free degree distribution
- **network communities**
- network skeleton
- hierarchy and nestedness

Rich clubs, No. 2.

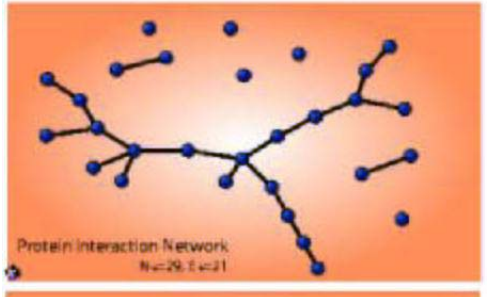
hubs associate with hubs
(assortativity: social nets)



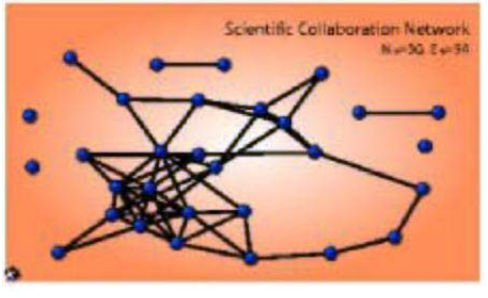
Zhou and Mondragon
IEEE Comm. Lett. 8, 180



a disassortative rich club



proteins

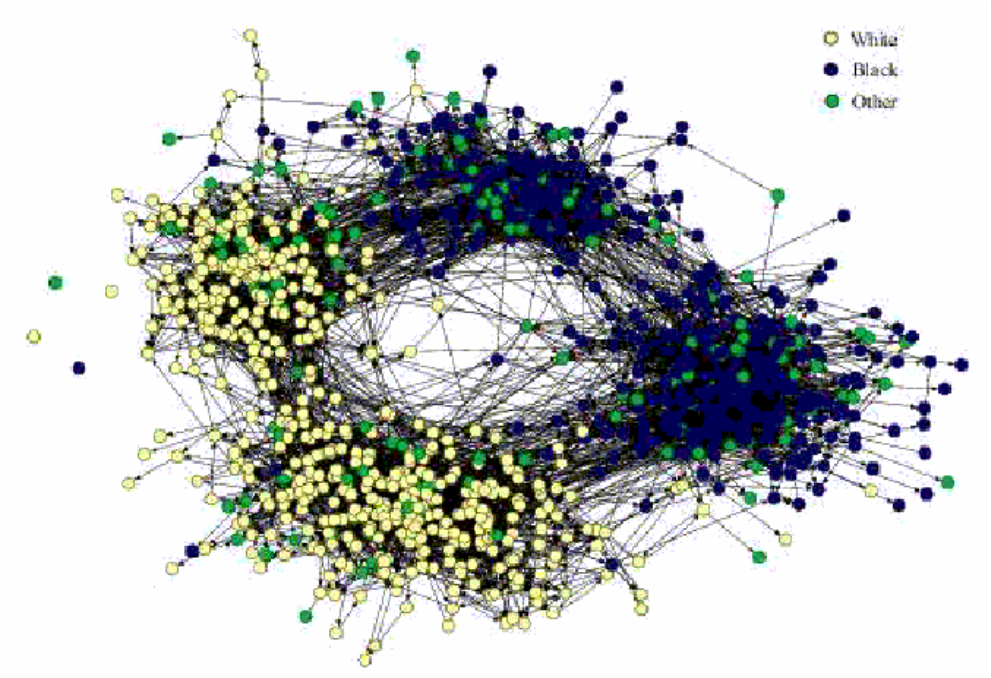


physicists

(Internet not)

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

Modules



modular nets

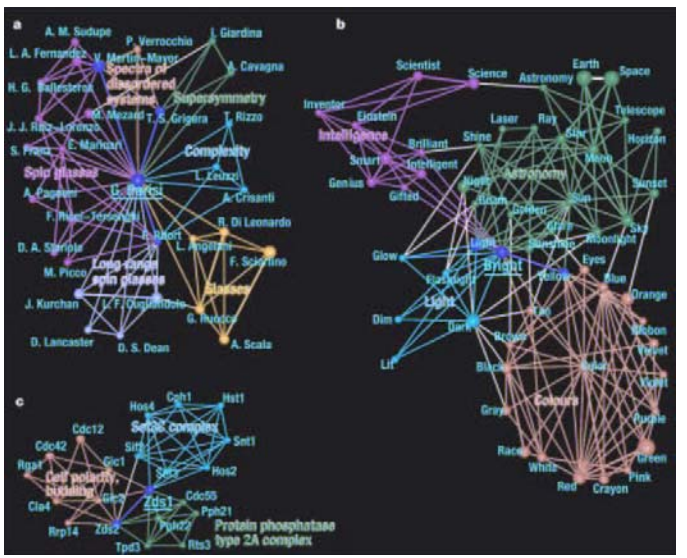
intermodular contacts are suppressed

Newman, SIAM Rev. 45, 167

Major methods of module determination

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

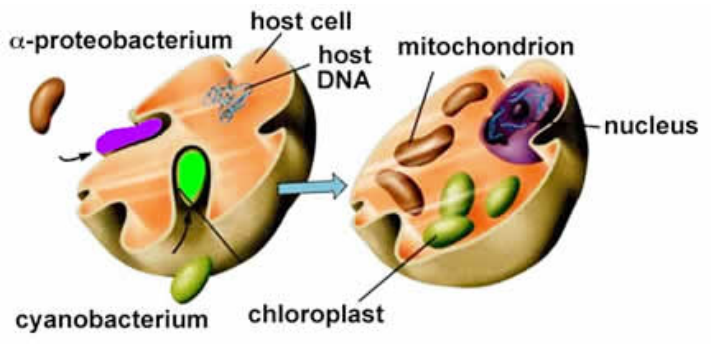
k-cliques method
to determine
overlapping modules



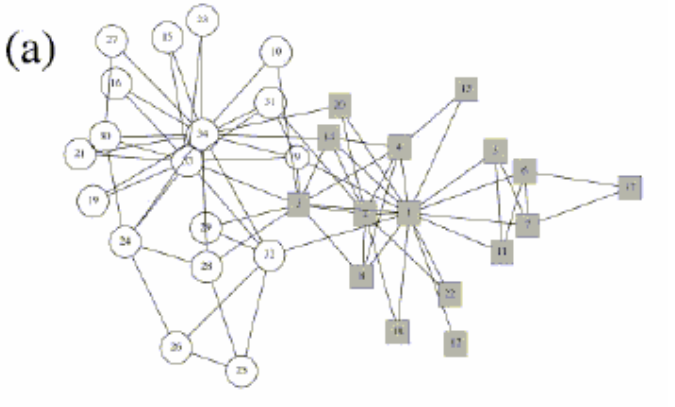
Palla et al., Nature 435, 814

How are modules formed?

integration
(symbiosis)



parcellation



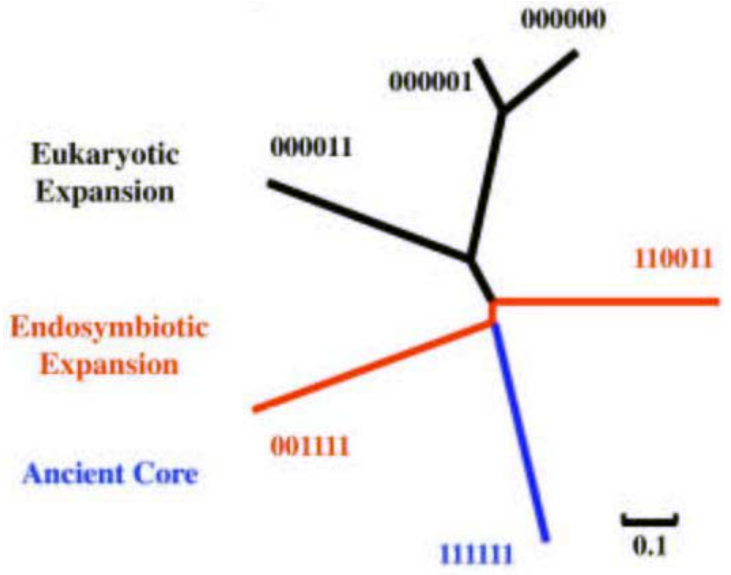
Zachary's charate club
administrator: circles
instructor: squares
Girvan-Newman, PNAS 99,7821

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?

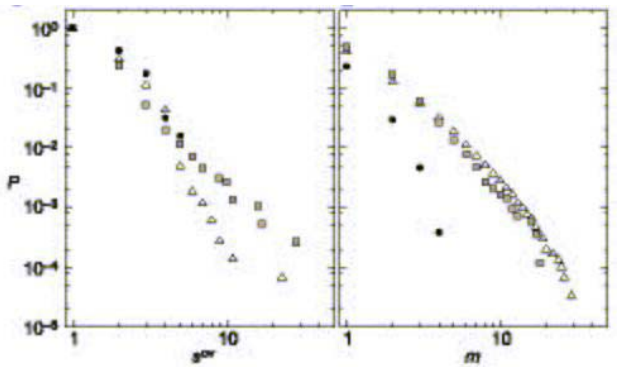
Am. J. Sociology 78, 1360

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)

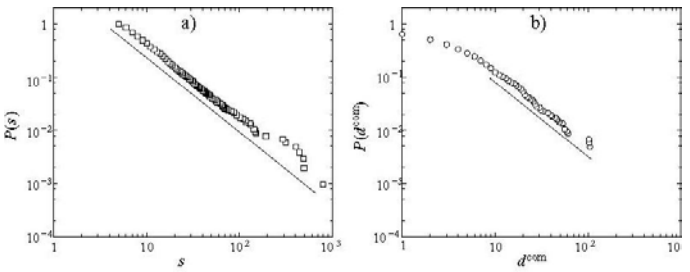
Modules have a scale-free size and degree distribution

www.arxiv.org/cond-mat
word-associations
yeast DIP protein network



Palla et al., Nature 435, 814
For size: Arenas et al.,
EPJ B38, 373

preferential attachment
model of modules



Pollner et al., Europhys. Lett, in press
Cond-mat/0601579

Network topology

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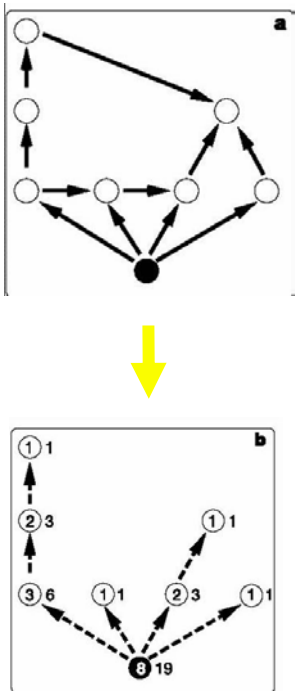
- network communities
- **network skeleton**
- hierarchy and nestedness

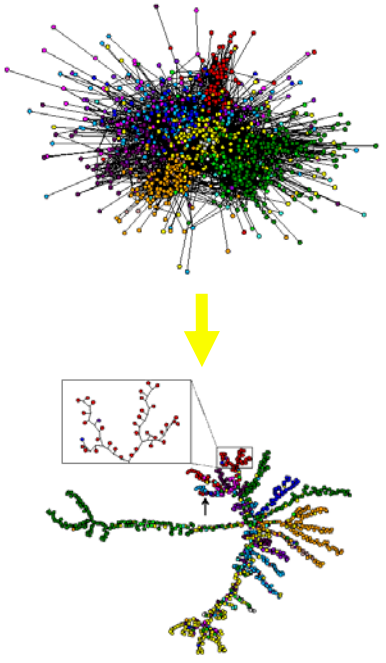
Network skeleton (fractal nets)

food-chain renorm.
(energy-flow)



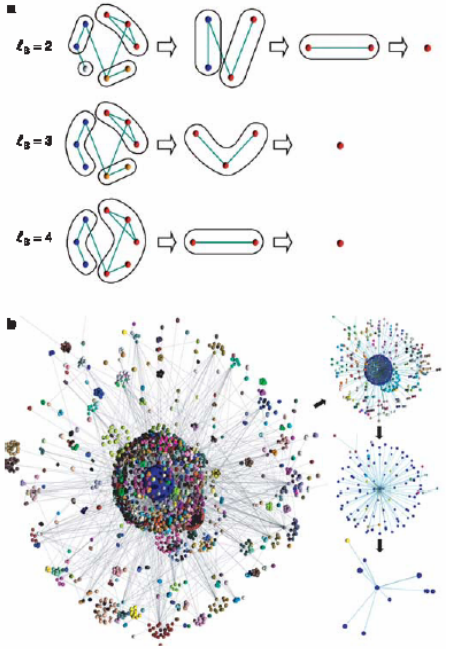
Garlaschelli et al., Nature 423,165

email-net renorm.
(betwenness)



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

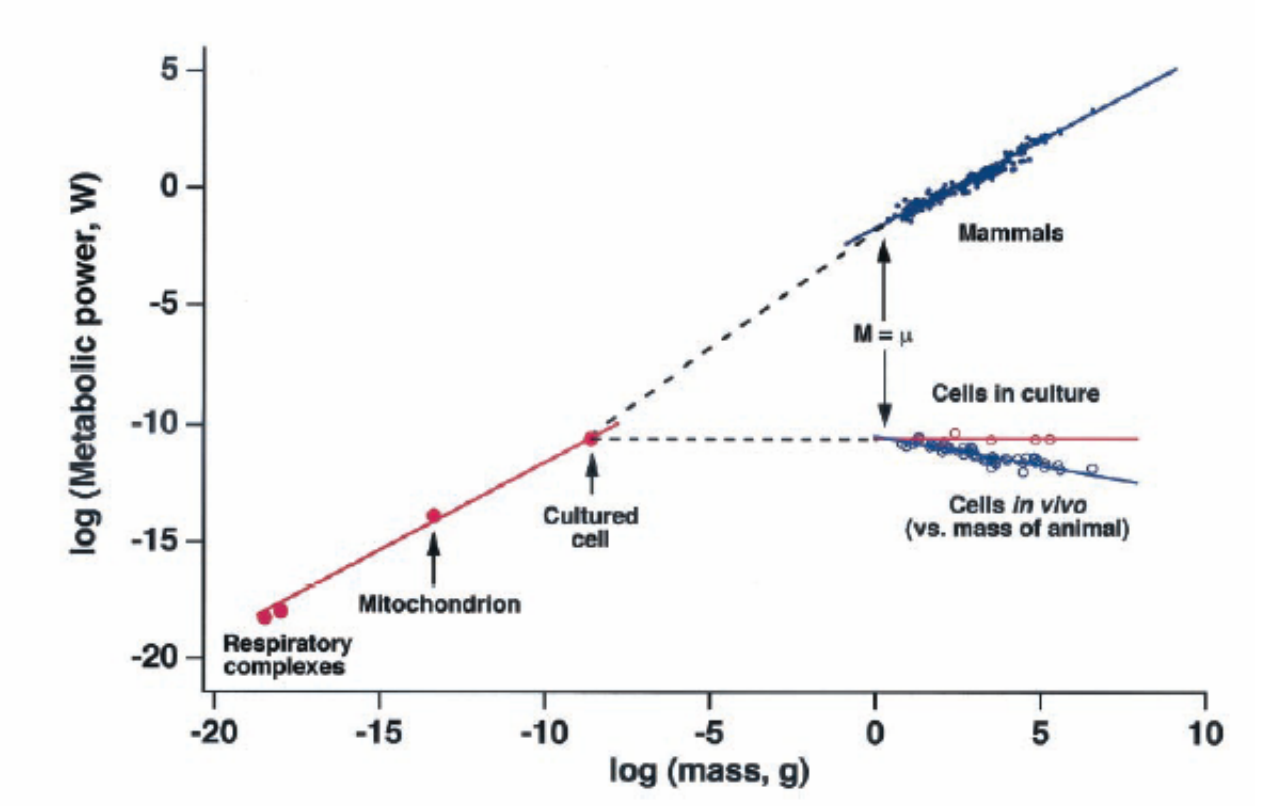
- 1932, M. Kleiber
  how the metabolic rate of mammals relates to their body mass?

$$B = B_0 M^{3/4}$$

- why is this surprising?

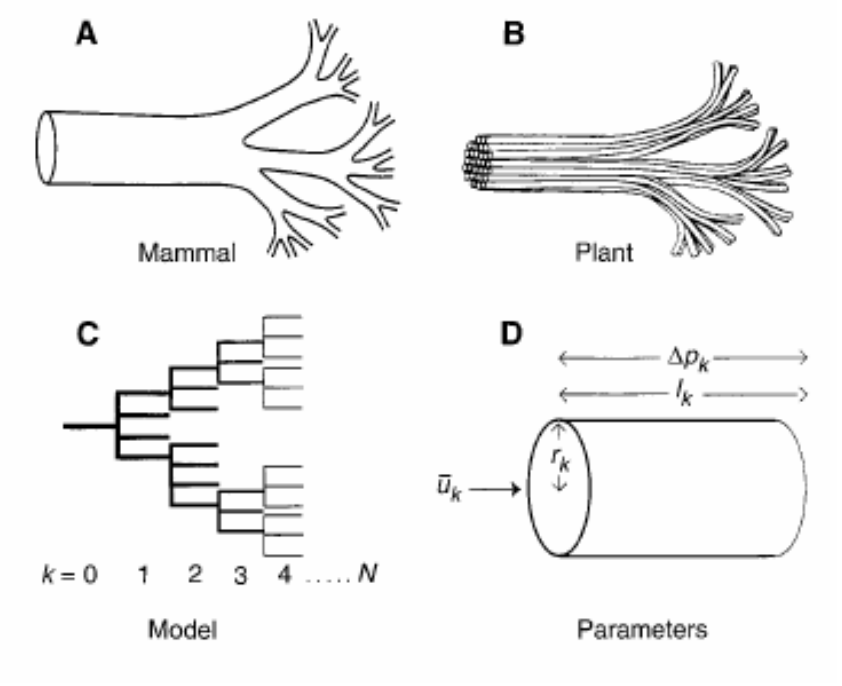
Should be linear (reactions) or
2/3 power (Euclidean surface to volume ratio)

Universality of allometric scaling I.

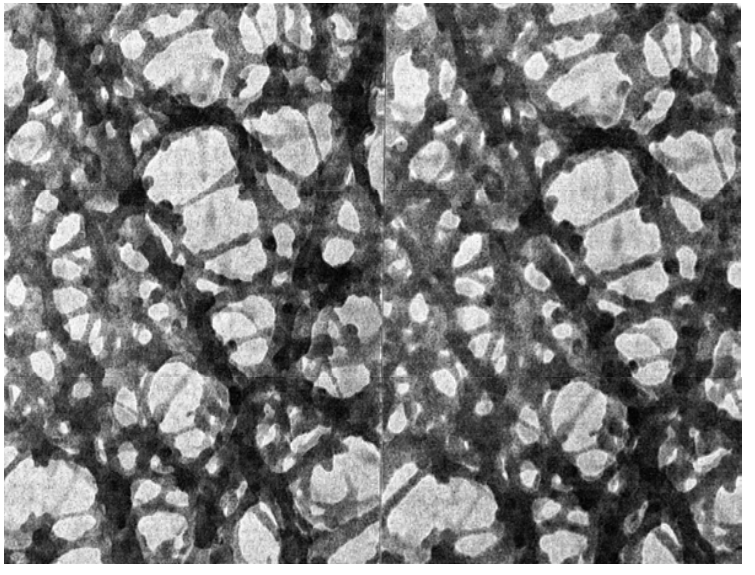


West et al., PNAS 99, 2473

Allometrice 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

Brown et al., Phil. Trans. Roy. Soc. London 357, 619

Scaling law and senescence

- lifespan is a subject of scaling law:
  - all mammals have 1.5 billion heart beats
  - all mitochondria have 1.5 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…

Network topology

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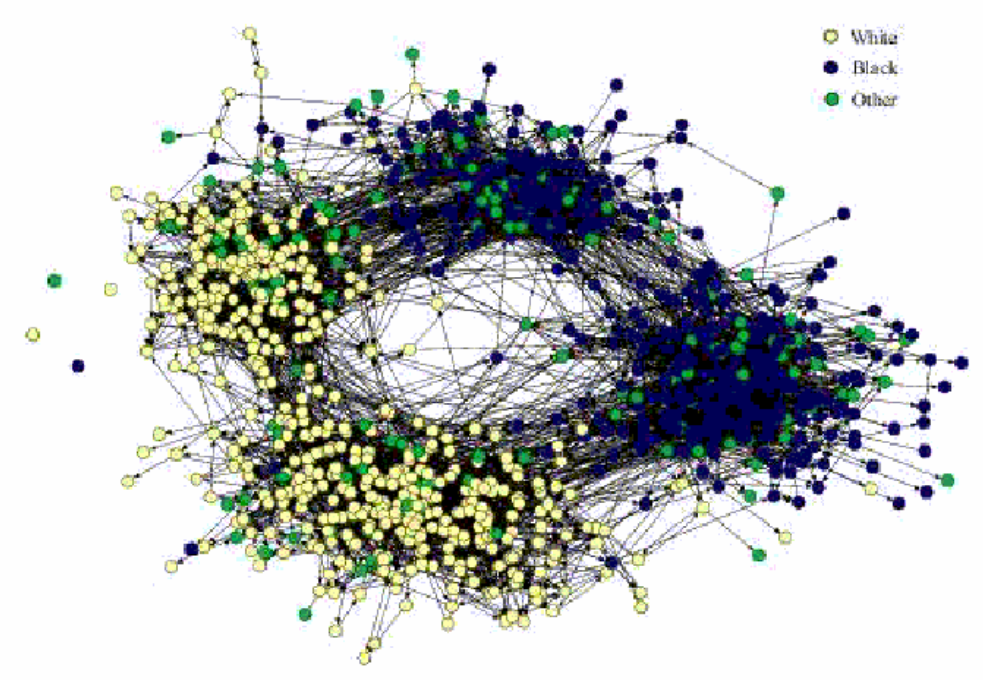
- **hierarchy and nestedness**

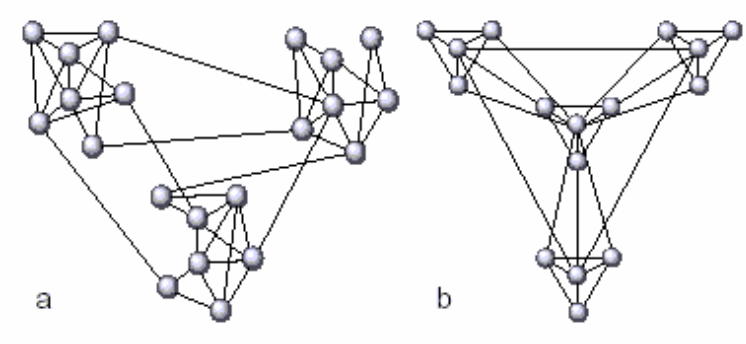
Modules



Newman, SIAM Rev. 45, 167

modular nets

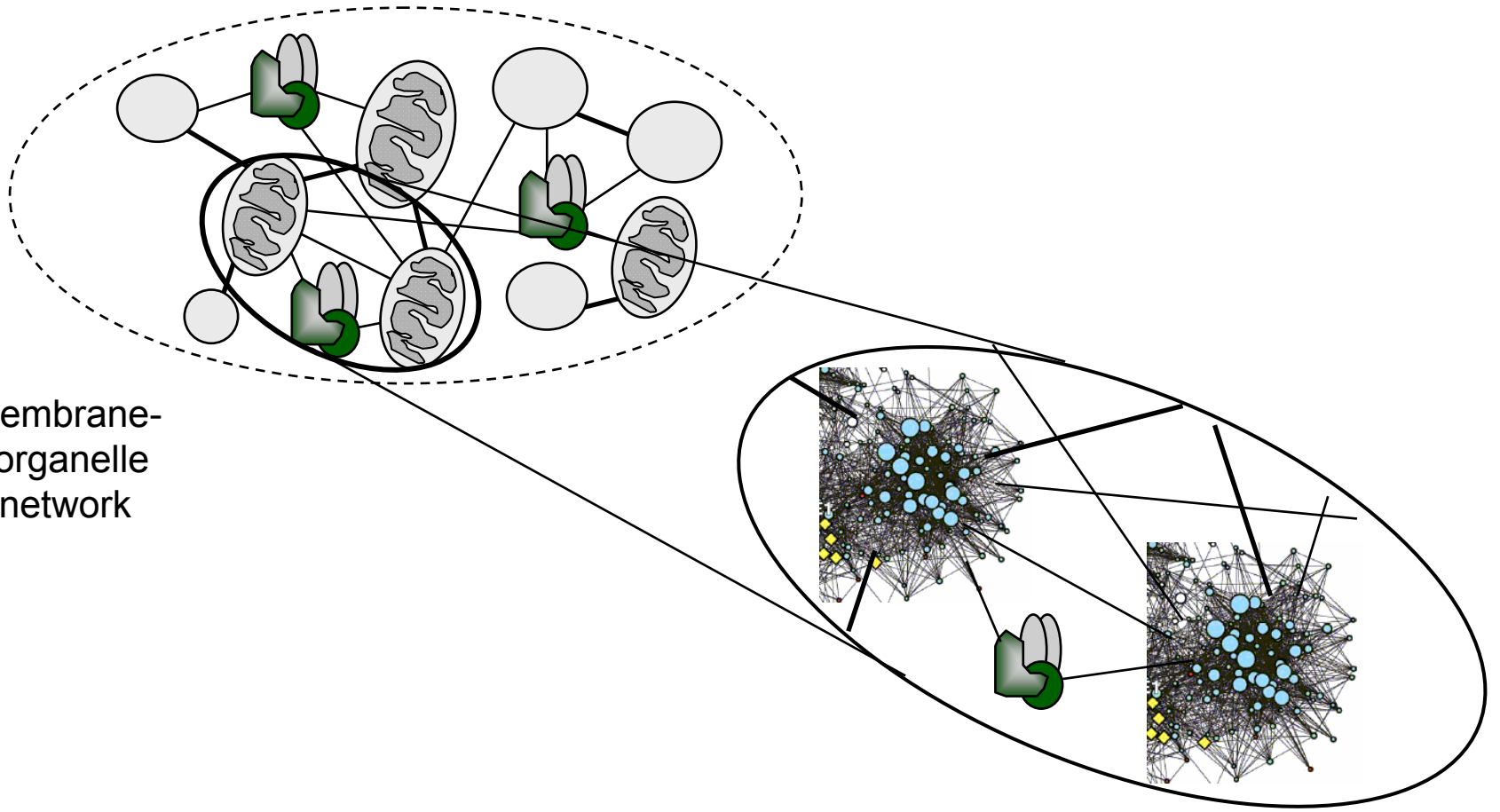
intermodular contacts
are suppressed



hierarchical net

intermodular contacts ar
preferentially suppresse

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?