Gossip-based self-organizing overlay networks

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Motivation

- Massively large scale distributed systems are now common
  - clouds, (desktop) Grid, P2P
- We want them to be efficient, cheap, available, reliable, robust
  - decentralization is often preferred
- Distributed overlay structures are needed over the nodes
  - construction, maintenance, repair

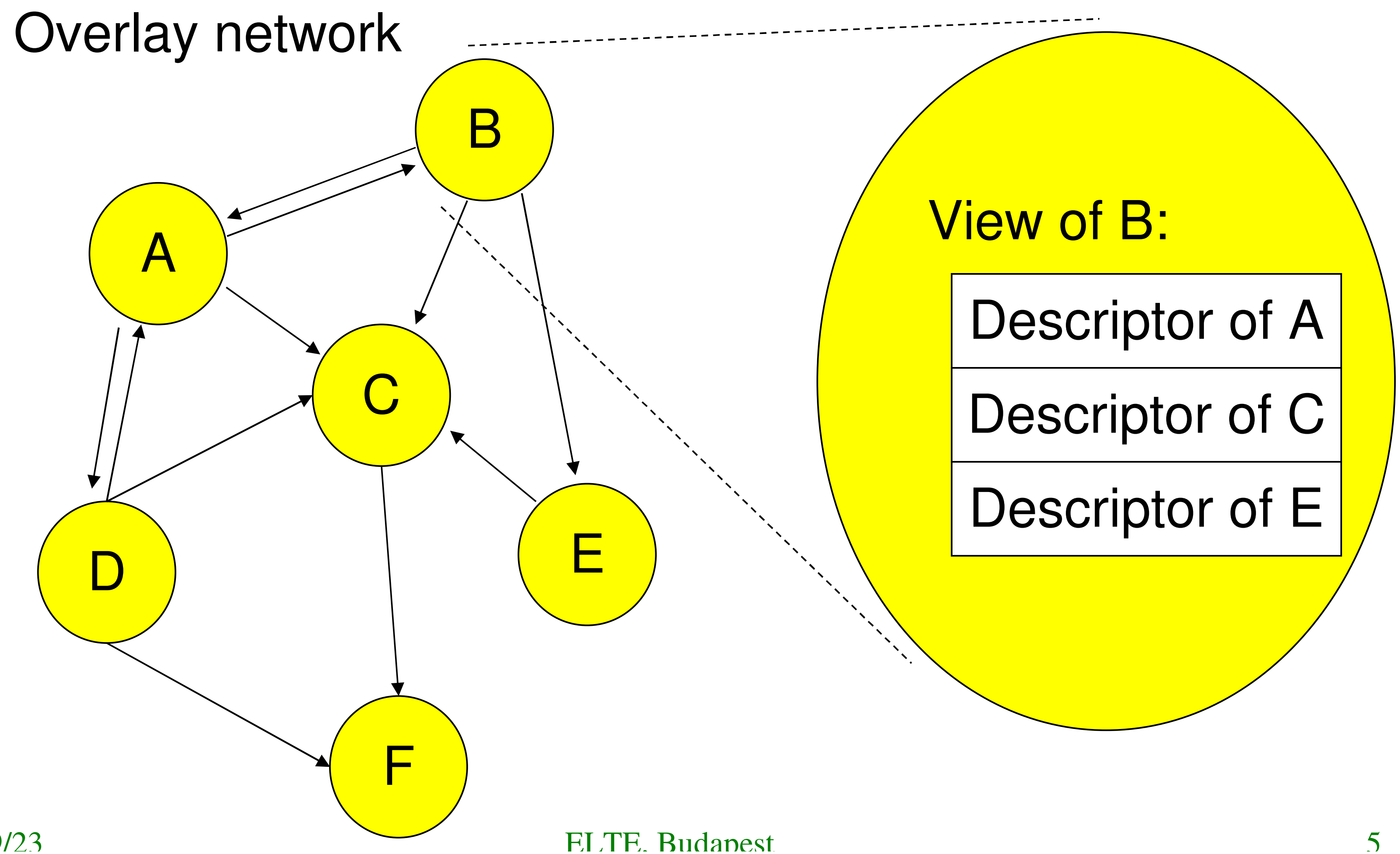
What is an overlay good for?

- multicasting (replacing IP multicast)
  - based on random or tree(ish) overlays
- distributed data structures to support data storage and lookup
  - eg, distributed hash tables
- semantic clustering to enhance keyword search
- etc

Overlay Networks

- nodes are processes with access to a computer network
  - overlays are in application layer
- links are defined by “knows-about” relation
  - virtual link, can be changed dynamically and flexibly
  - nodes use the network's transport layer (TCP/UDP) to pass messages based on target address, possibly passing many routers

An overlay network



Outline

- gossip protocols: the basic skeleton
- "gossip" to build structures
  - random networks
  - more structured networks such as ring, mesh, tree, clustering, sorting
- concluding remarks and open questions

A Gossip Skeleton

- the push-pull model is sown
- the active thread initiates communication (push) and receives peer state (pull)
- the passive thread mirrors this behavior

do once in each T time units at a random time
    p = selectPeer()
    send state to p
    receive $state_p$ from p
    state = update($state_p$)

active thread

do forever
    receive $state_p$ from p
    send state to p
    state = update($state_p$)

passive thread

Rumor mongering as an instance

- state: set of active updates
- selectPeer: a random peer from the network
  - very important component, we get back to this soon
- update: add the received updates to the local set of updates
- propagation of one given update can be limited (max k times or with some probability, etc)

Peer Sampling and random overlays

- A key method is selectPeer in all gossip protocols (influences performance and reliability)
- In earliest works all nodes had a global view to select a random peer from
  - scalability and dynamism problems
- We use a random overlay, and we maintain it through gossip
  - random overlay has many other applications

Gossip based peer sampling

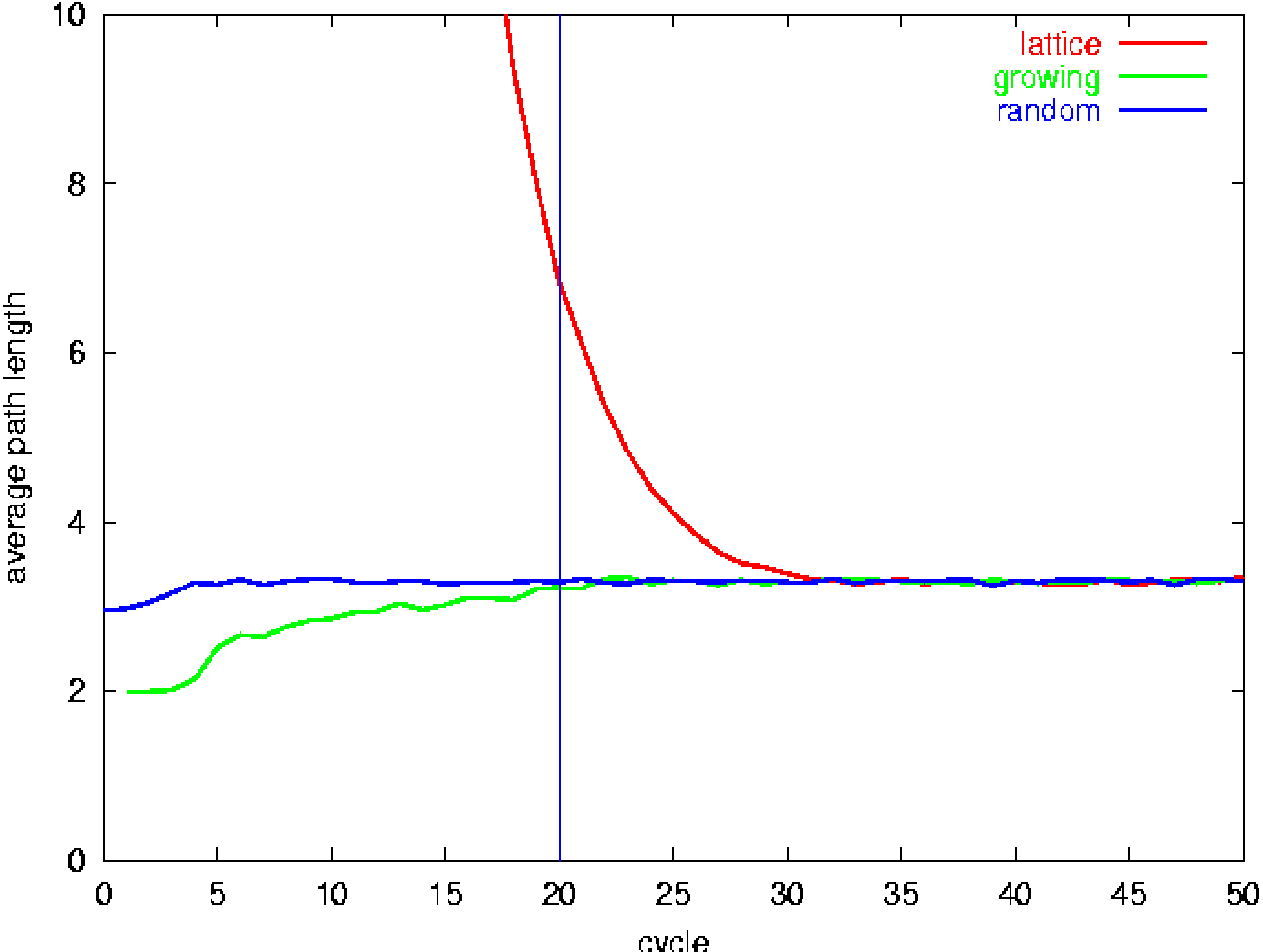
- basic idea: random peer samples are provided by a gossip algorithm: the peer sampling service
- The peer sampling service uses itself as peer sampling service
- state: a set of random overlay links to peers
- selectPeer: select a peer from the known set of random peers
- update: (simplified) for example, keep a random subset of the union of the received and the old link set

Gossip based peer sampling

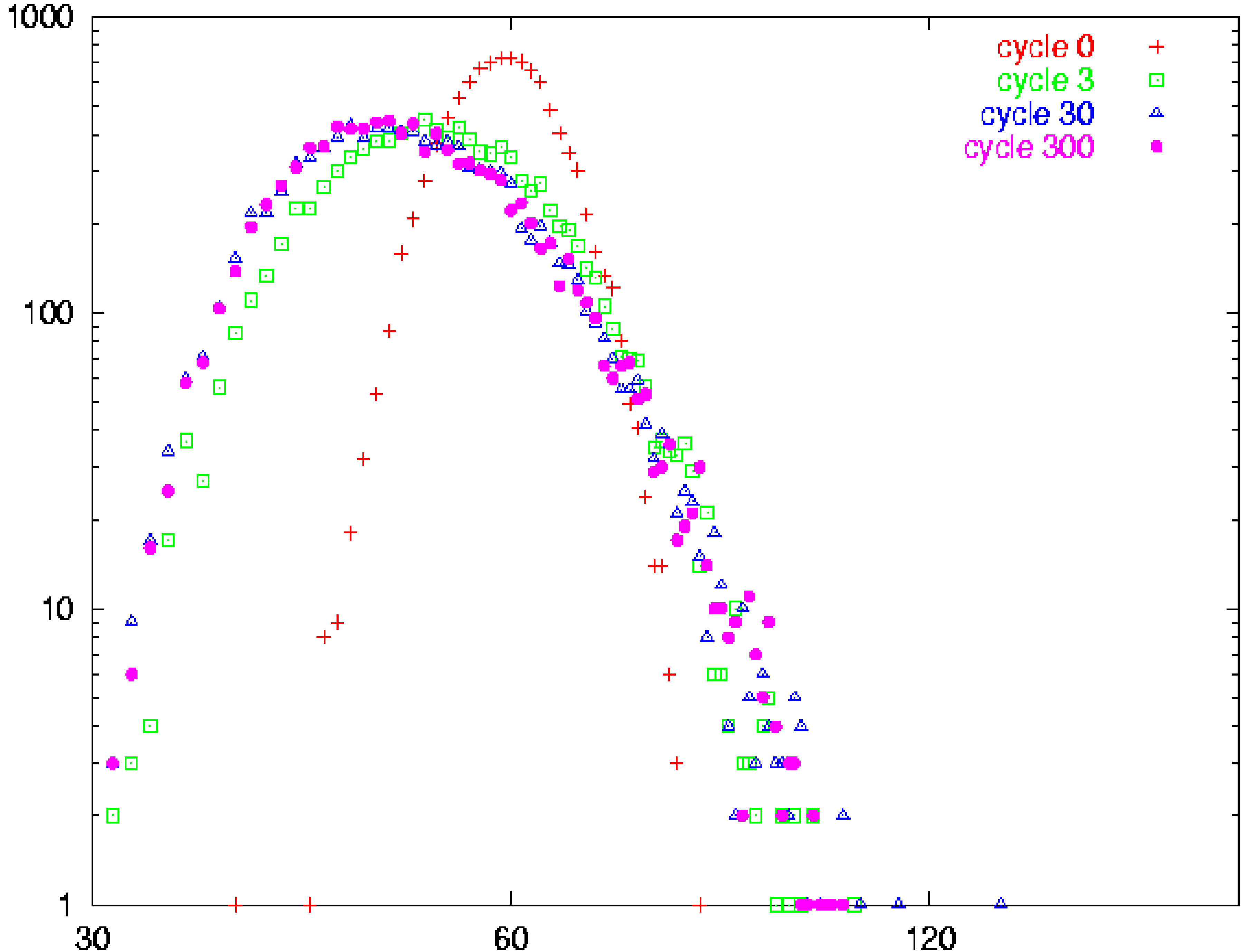
- in reality a huge number of variations exist
  - timestamps on the overlay links can be taken into account: we can select peers with newer links, or in update we can prefer links that are newer
- these variations represent important differences w.r.t. fault tolerance and the quality of samples
  - the links at all nodes define a random-like overlay that can have different properties (degree distribution, clustering, diameter, etc)
  - turns out actually not really random, but still good for gossip

newscast: going for new information

- update: keep freshest links
- simulations: N=100 000, view size c=30
  - growing: start with no nodes, add 5000 nodes in each cycle, connecting them to first node only
  - lattice: start with regular lattice
  - random: start with c-out random topology



lattice
growing
random
average path length
cycle
0
2
4
6
8
10
0
5
10
15
20
25
30
35
40
45
50

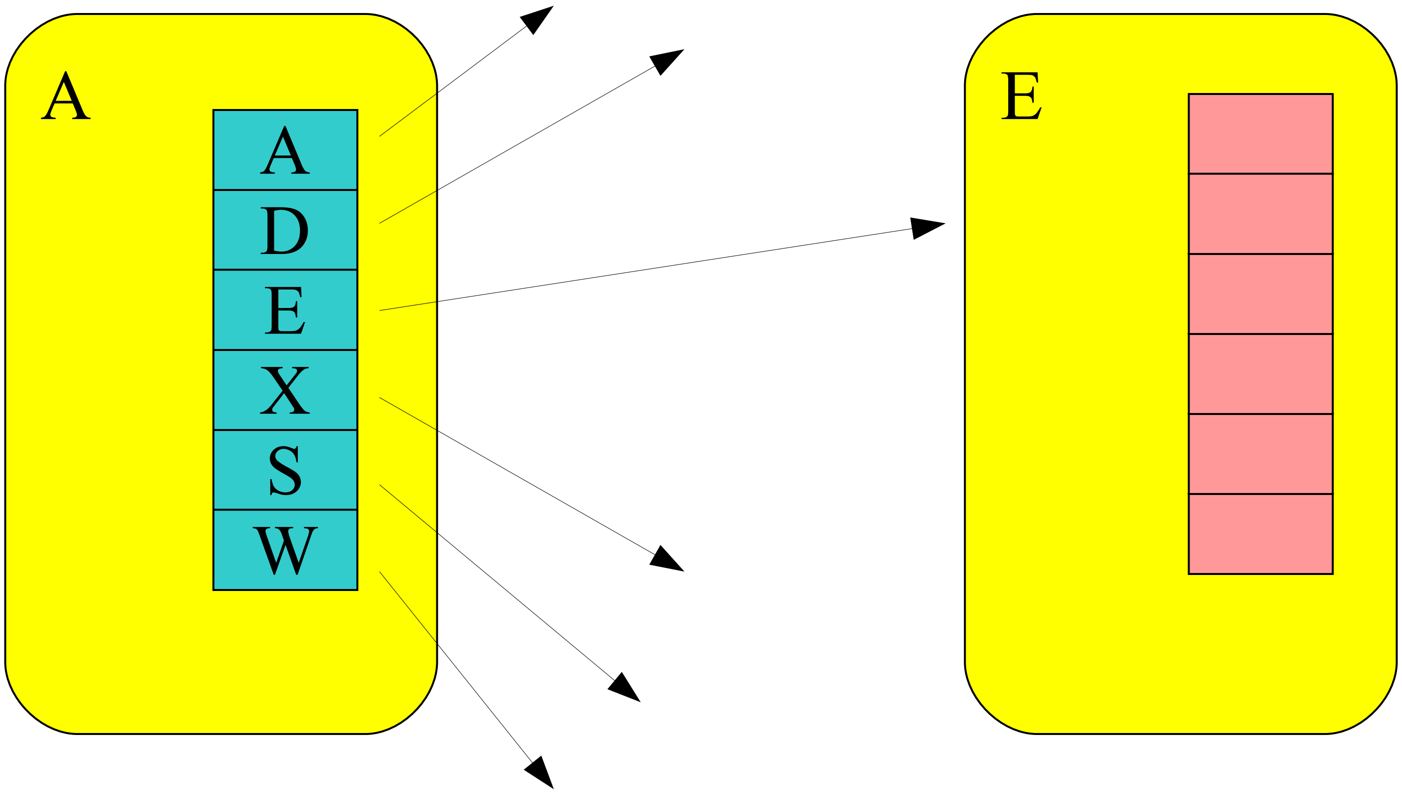


cycle 0
cycle 3
cycle 30
cycle 300
1000
100
10
1
30
60
120

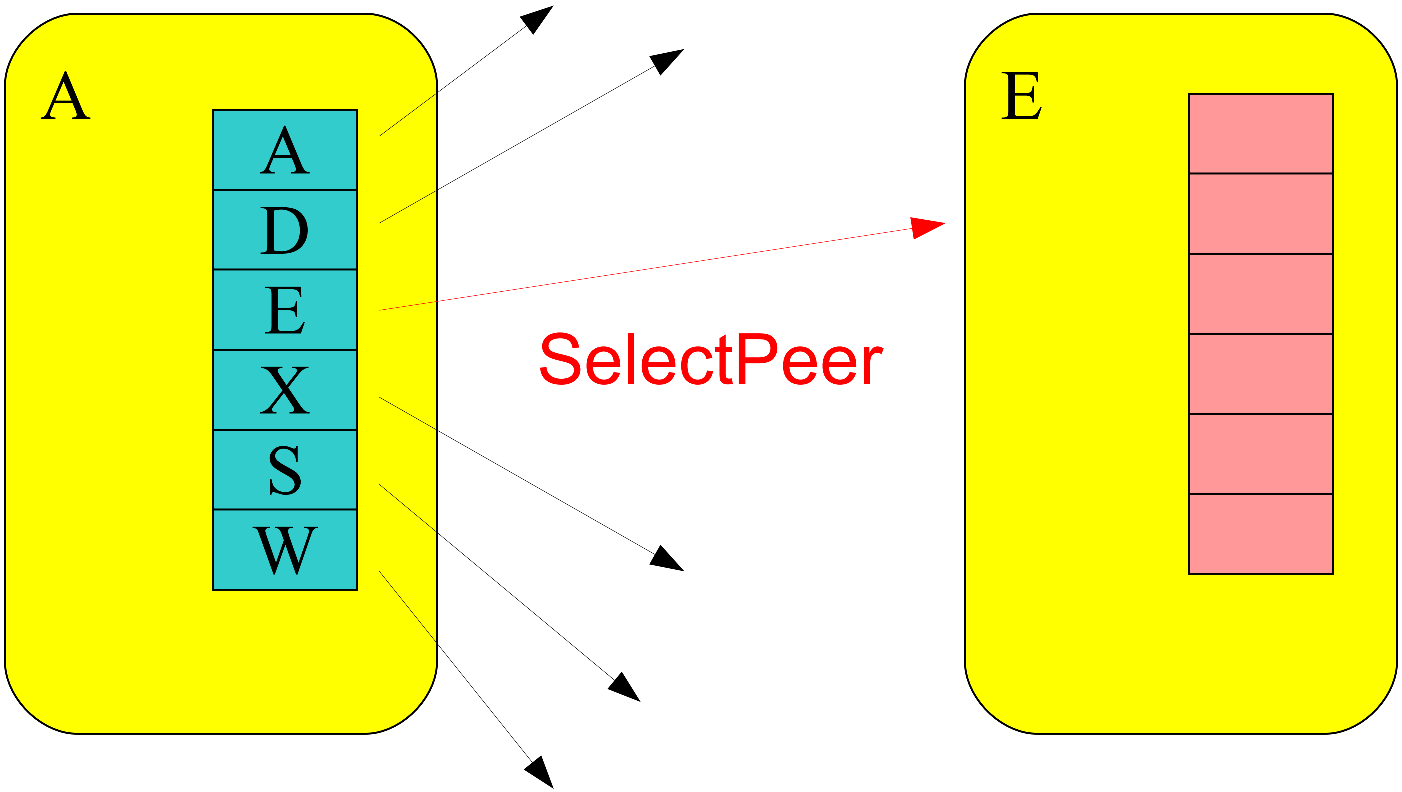
Gossip based topology management in general

- We saw we can build random networks. Can we build any network with gossip?
- Yes, many examples
  - proximity networks
  - DHT-s (Bamboo DHT: maintains Pastry structure with gossip inspired protocols)
  - semantic proximity networks
  - etc

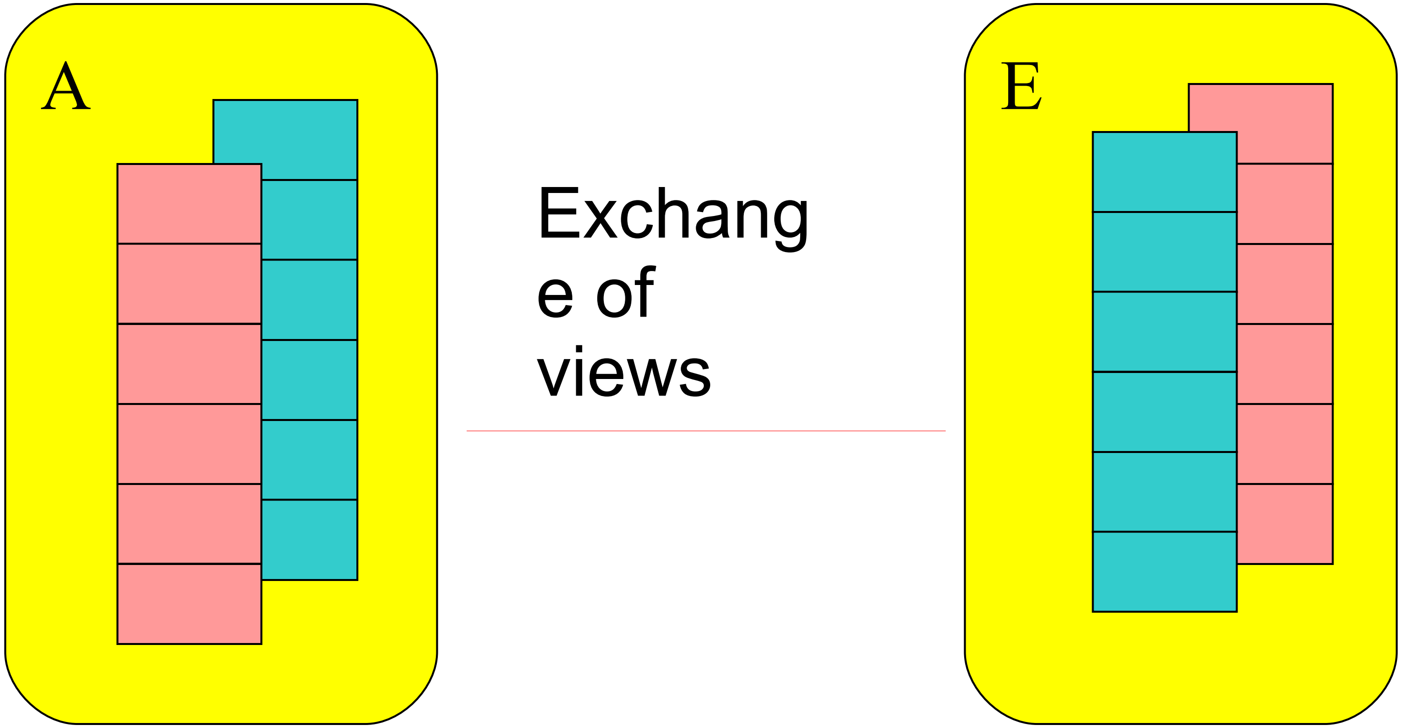
Gossip protocols for topology management in general



Gossip protocols for topology management in general

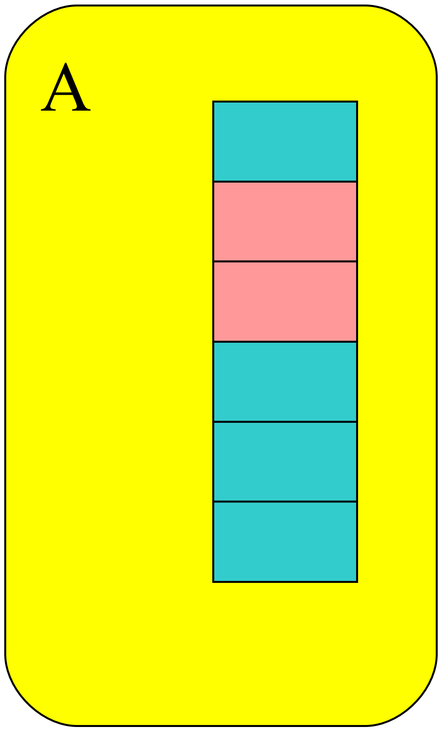


Gossip protocols for topology management in general



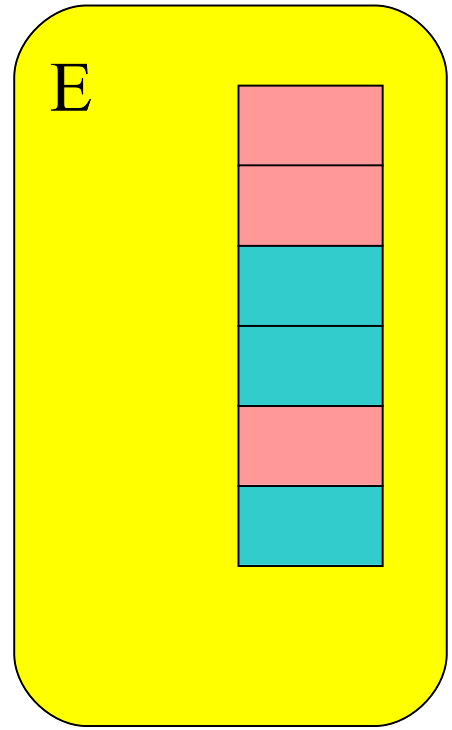
Exchange of views

Gossip protocols for topology management in general



Both sides apply update

thereby redefining topology

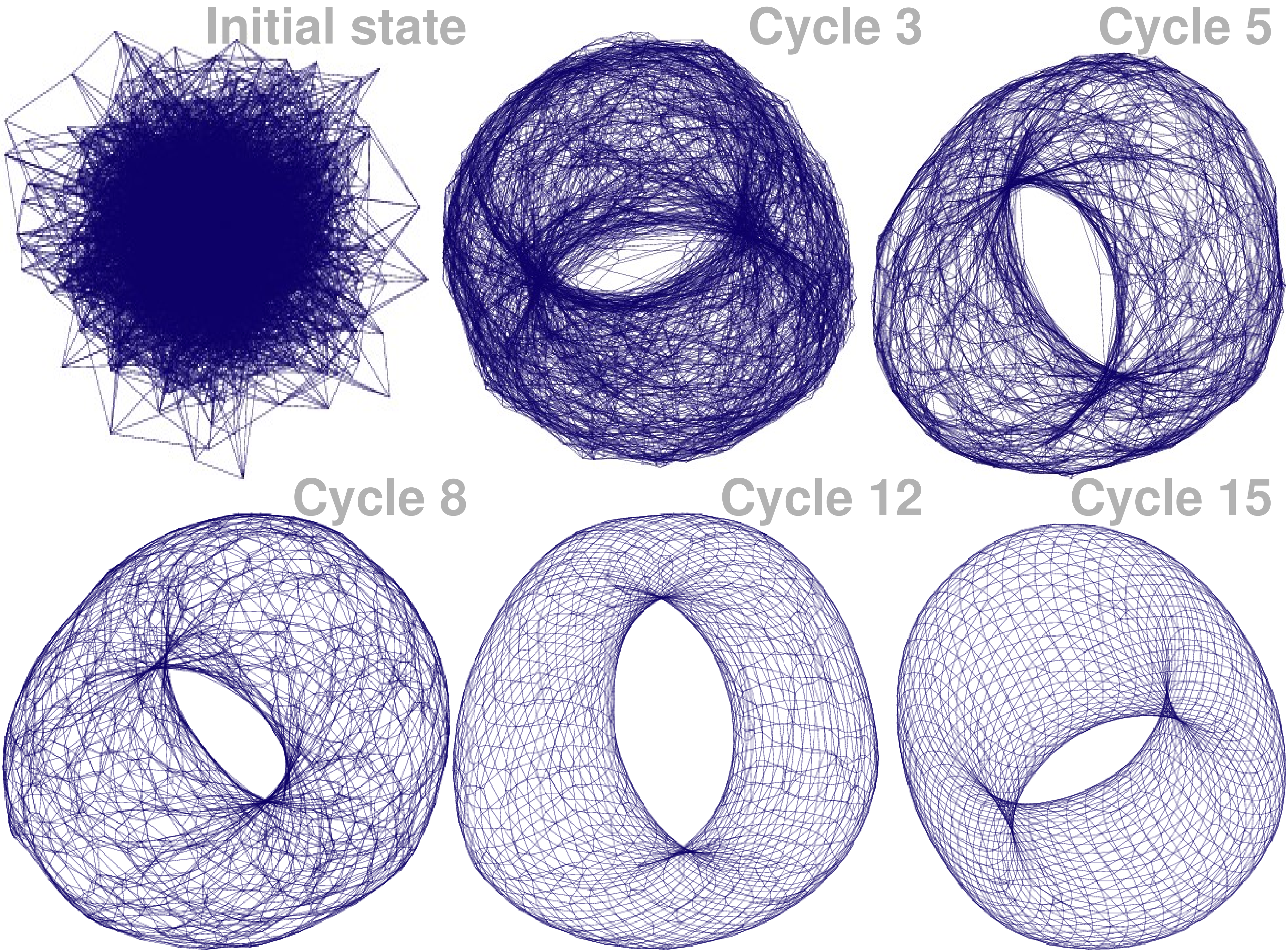


T-Man

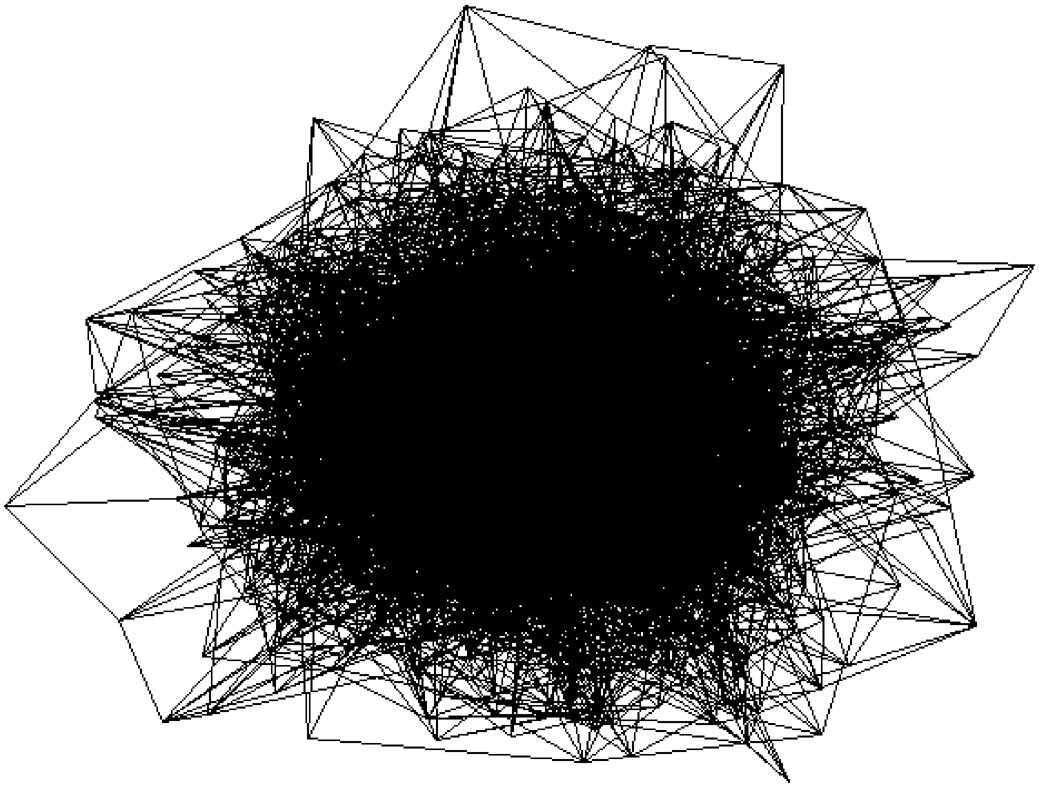
- T-MAN is a protocol that captures many of these in a common framework, with the help of the ranking method:
  - the ranking method orders any set of nodes according to their desirability to be a neighbor of some given node
  - for example, based on hop count in a target structure (ring, tree, etc)
  - or based on more complicated criteria not expressible by any distance measure

Gossip based topology management

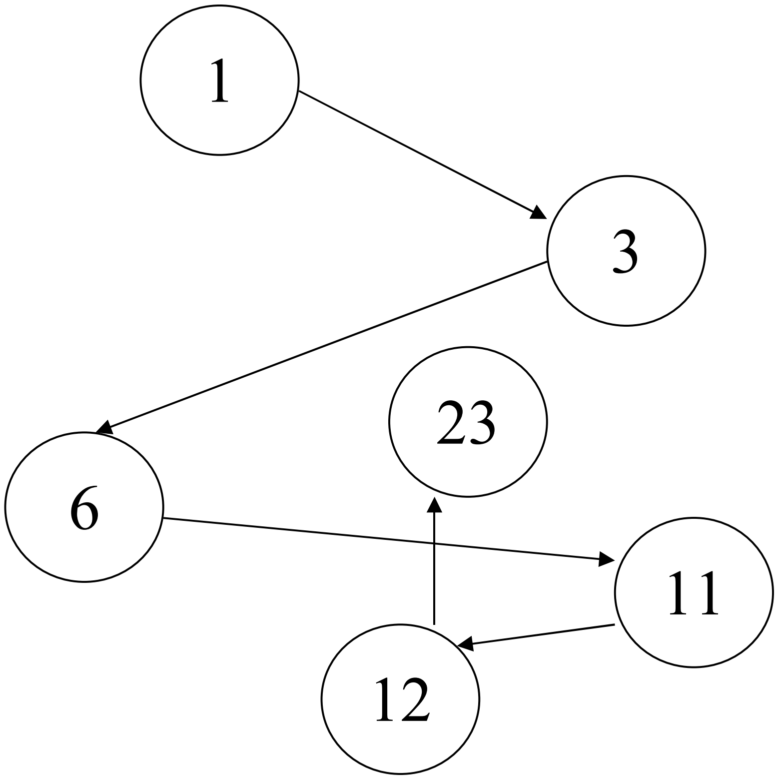
- basic idea: random peer samples are provided by a gossip algorithm: the peer sampling service
- state: a set of overlay links to peers
- selectPeer: select the peer from the known set of peers that ranks highest according to the ranking method
- update: keep those links that point to nodes that rank highest
- actual algorithm contains some more tricks...



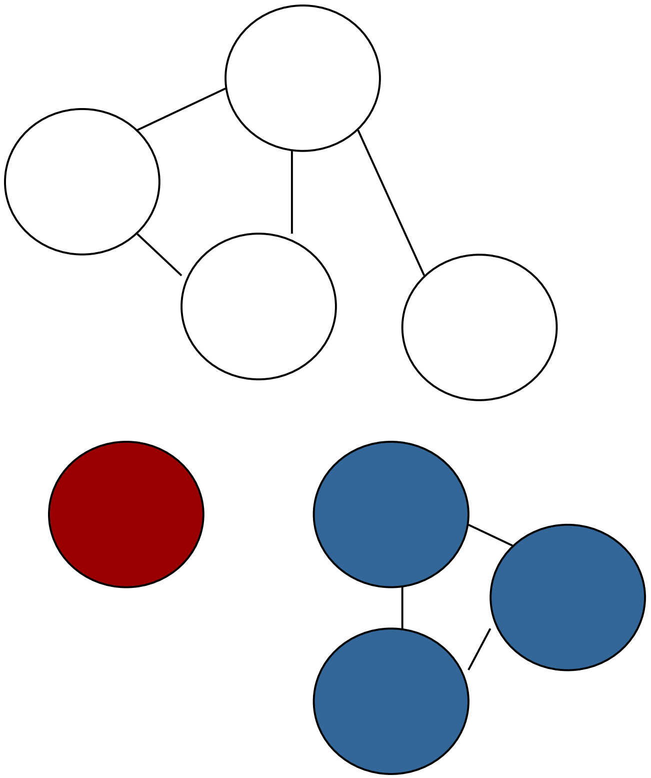
Initial state
Cycle 3
Cycle 5
Cycle 8
Cycle 12
Cycle 15



Sorting and clustering

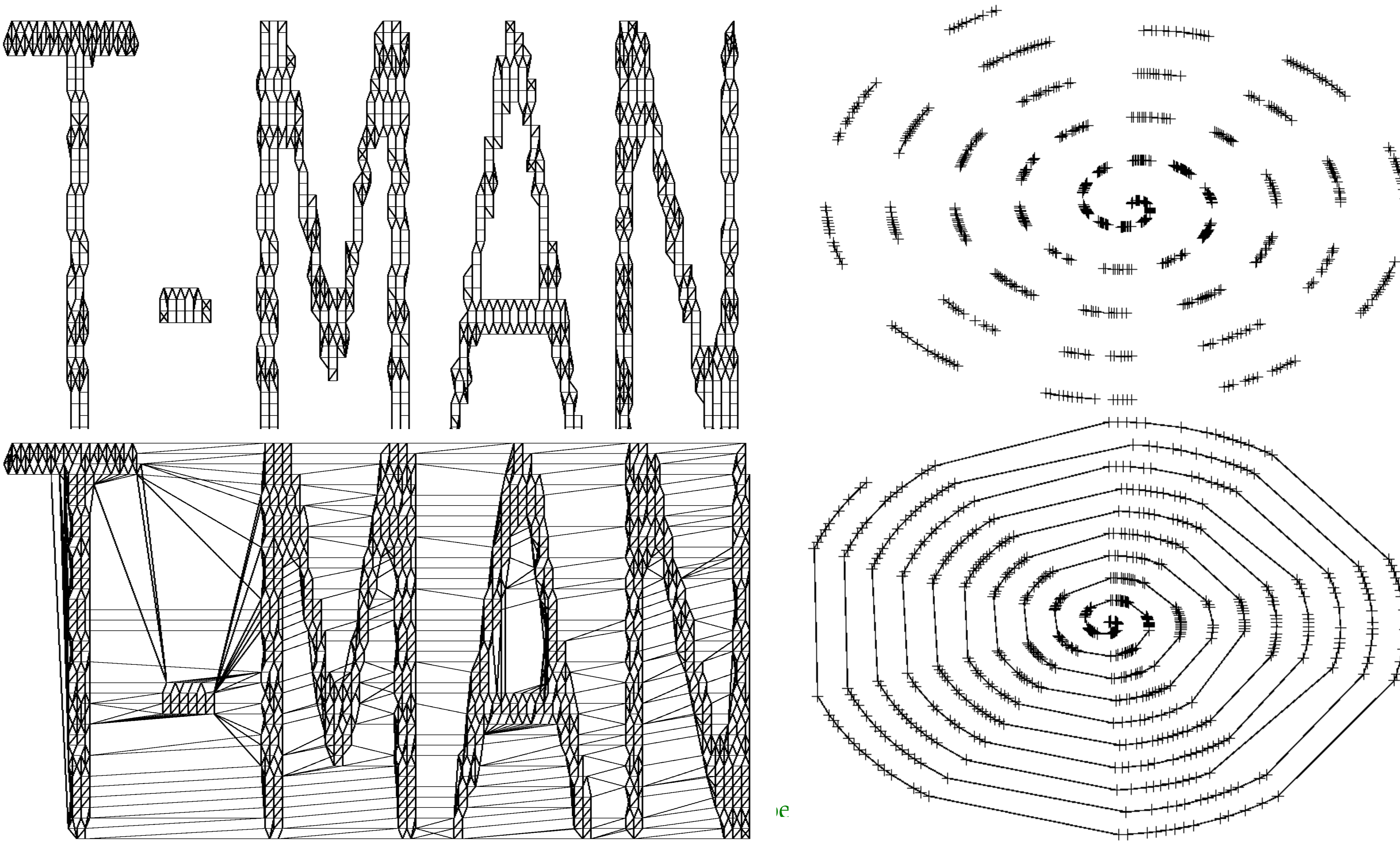


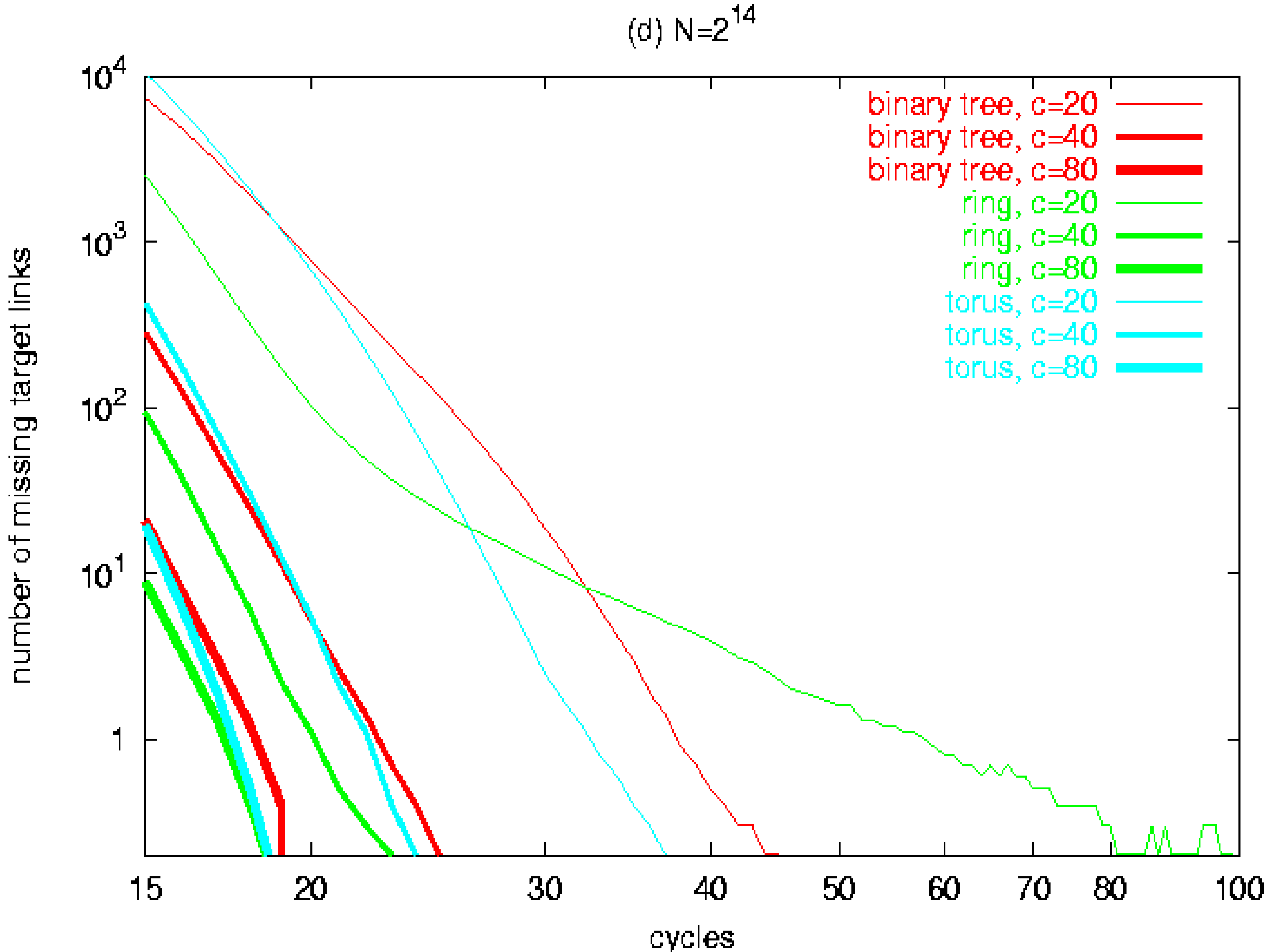
Sorting



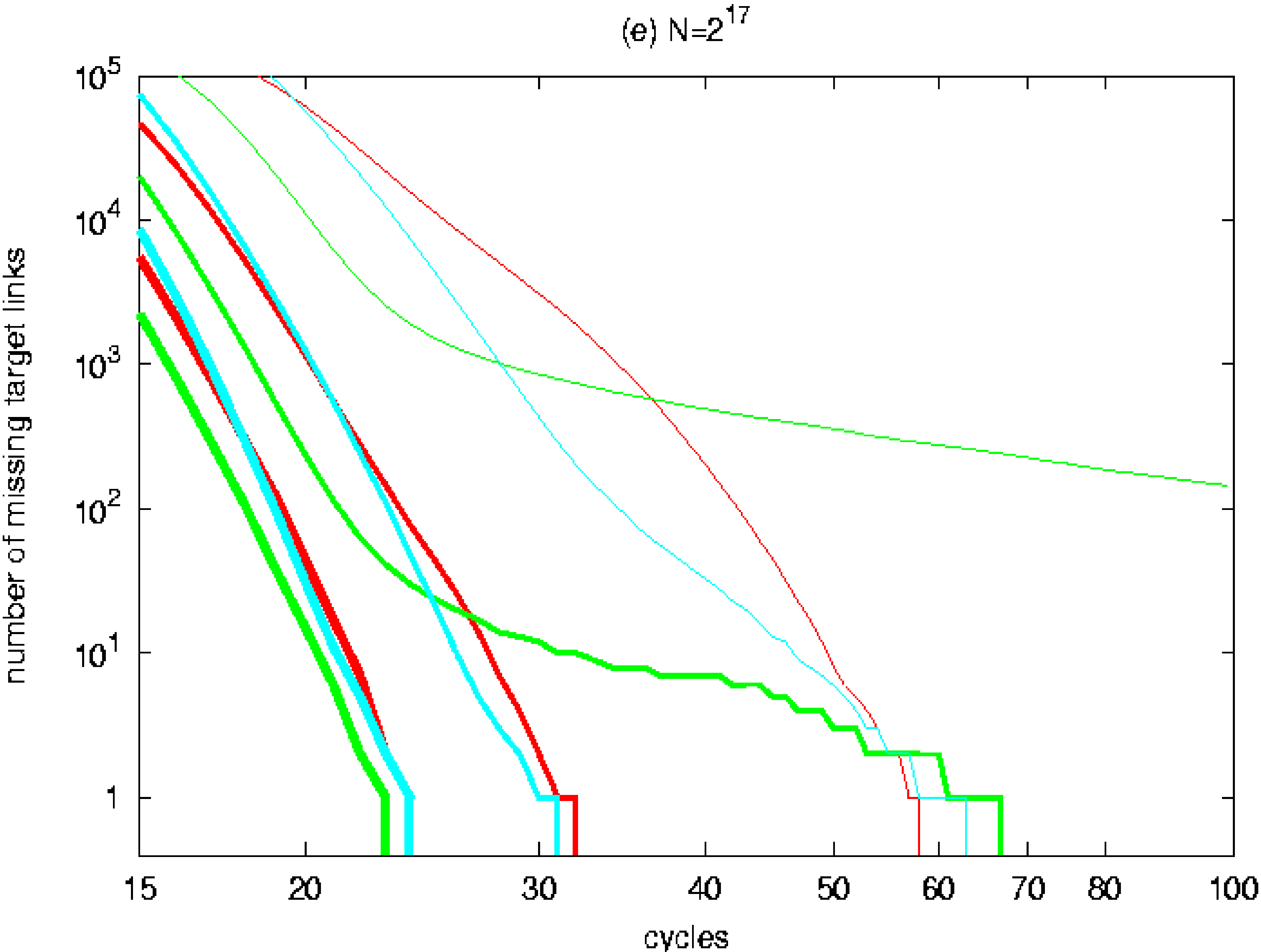
Clustering

Illustration of clustering and sorting

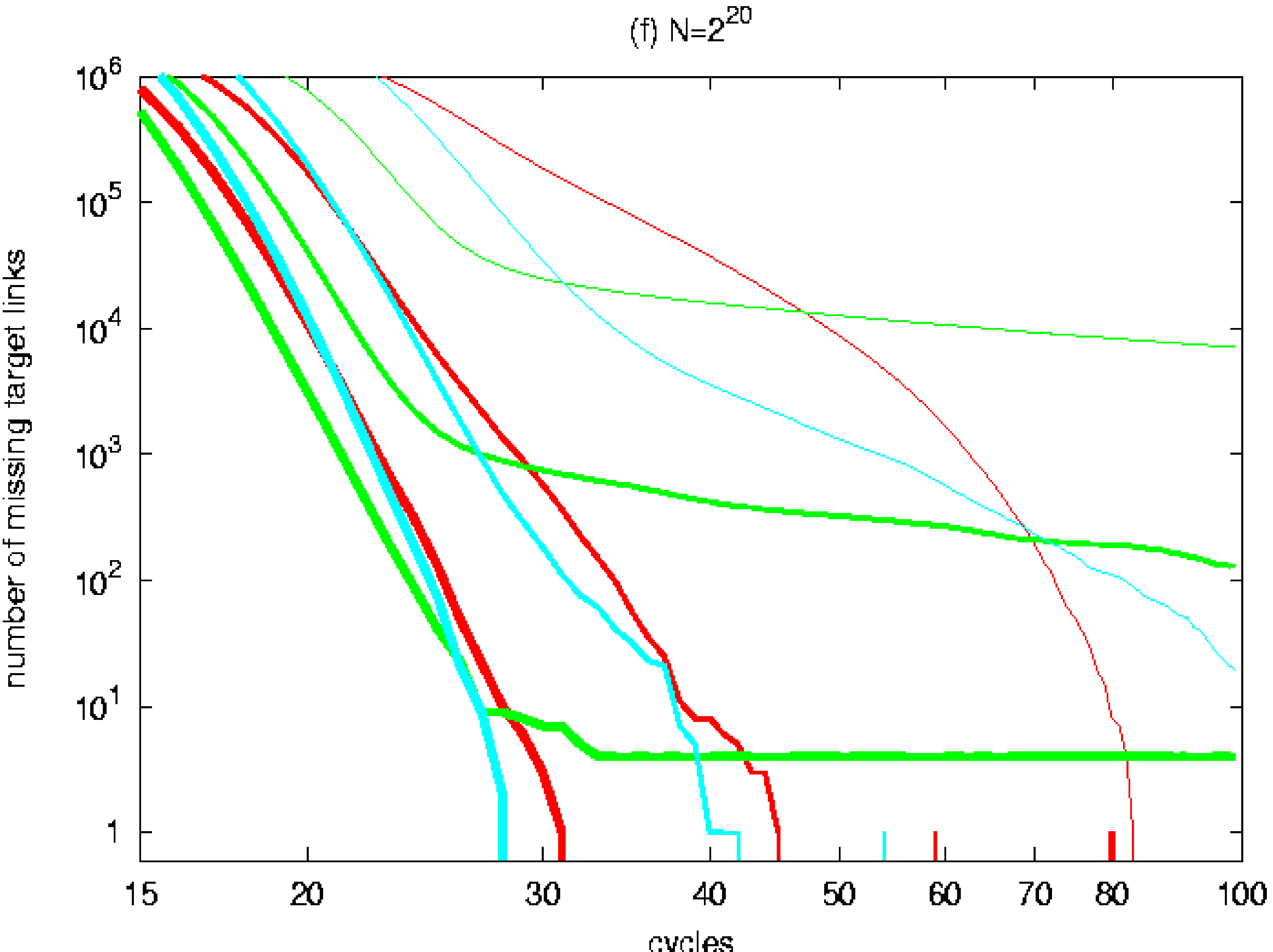




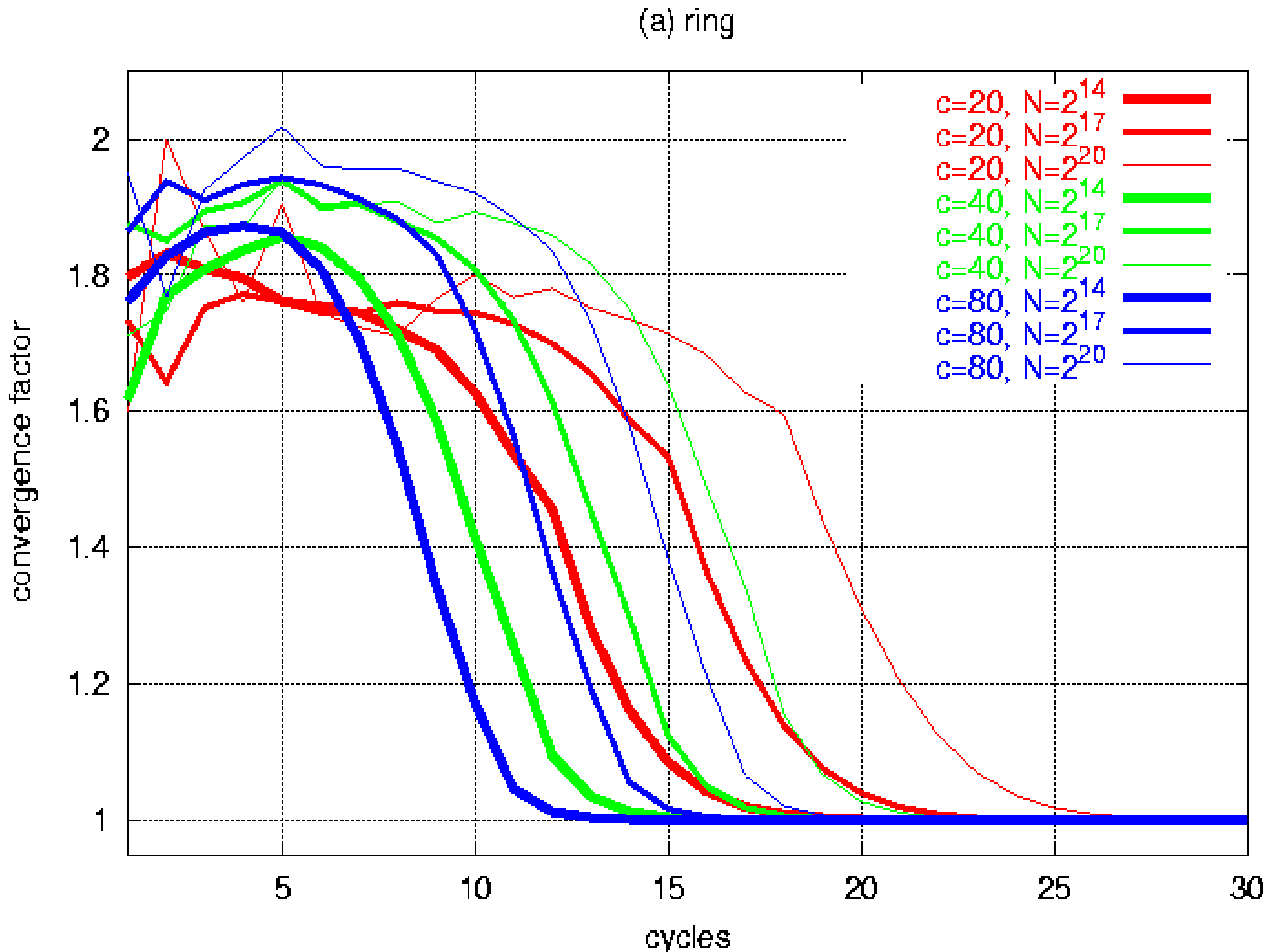
(d) N=2^14
binary tree, c=20
binary tree, c=40
binary tree, c=80
ring, c=20
ring, c=40
ring, c=80
torus, c=20
torus, c=40
torus, c=80
number of missing target links
cycles
10^4
10^3
10^2
10^1
1
15
20
30
40
50
60
70
80
100



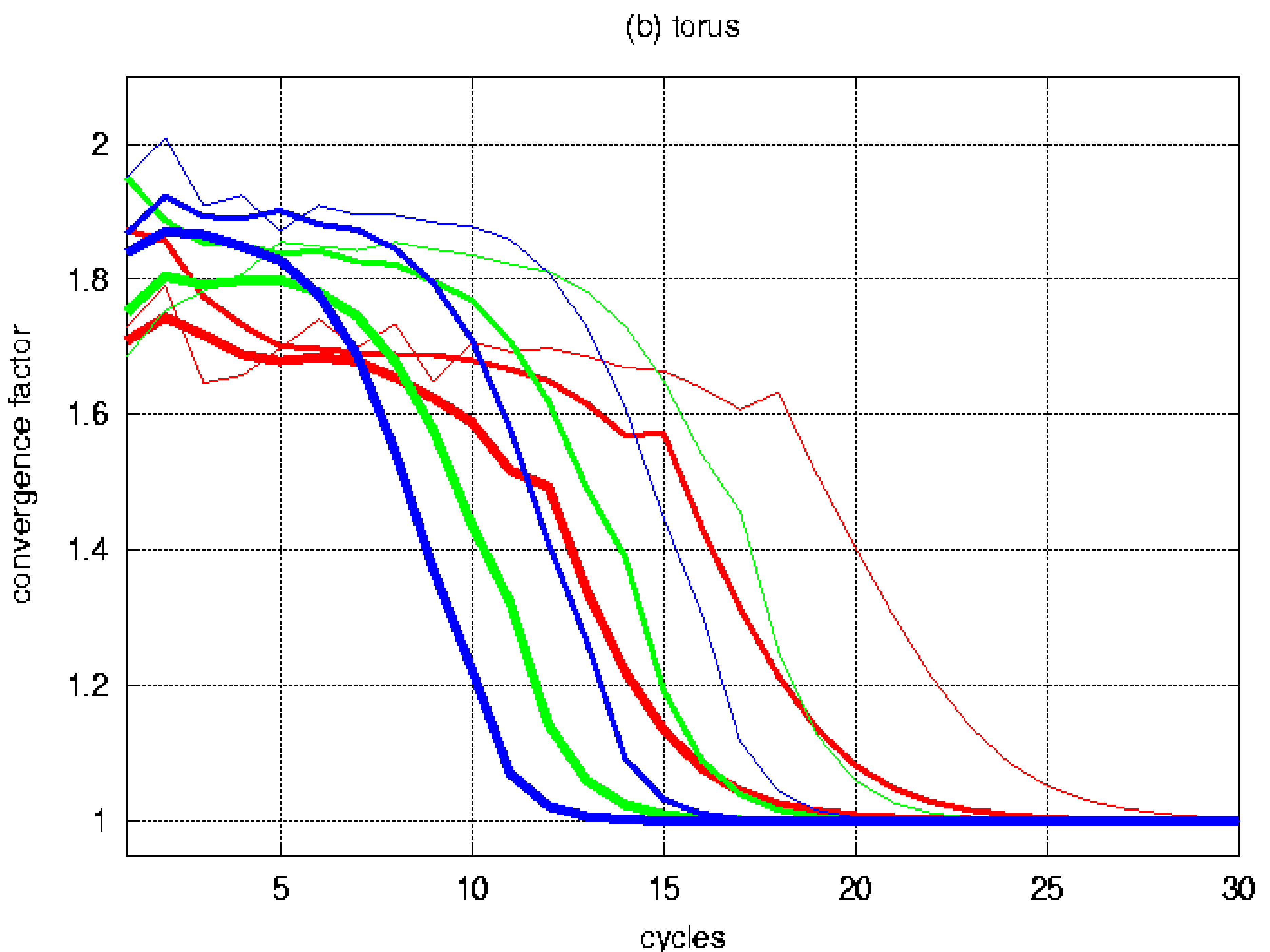
(e) N=2^17
number of missing target links
cycles
10^5
10^4
10^3
10^2
10^1
1
15
20
30
40
50
60
70
80
100



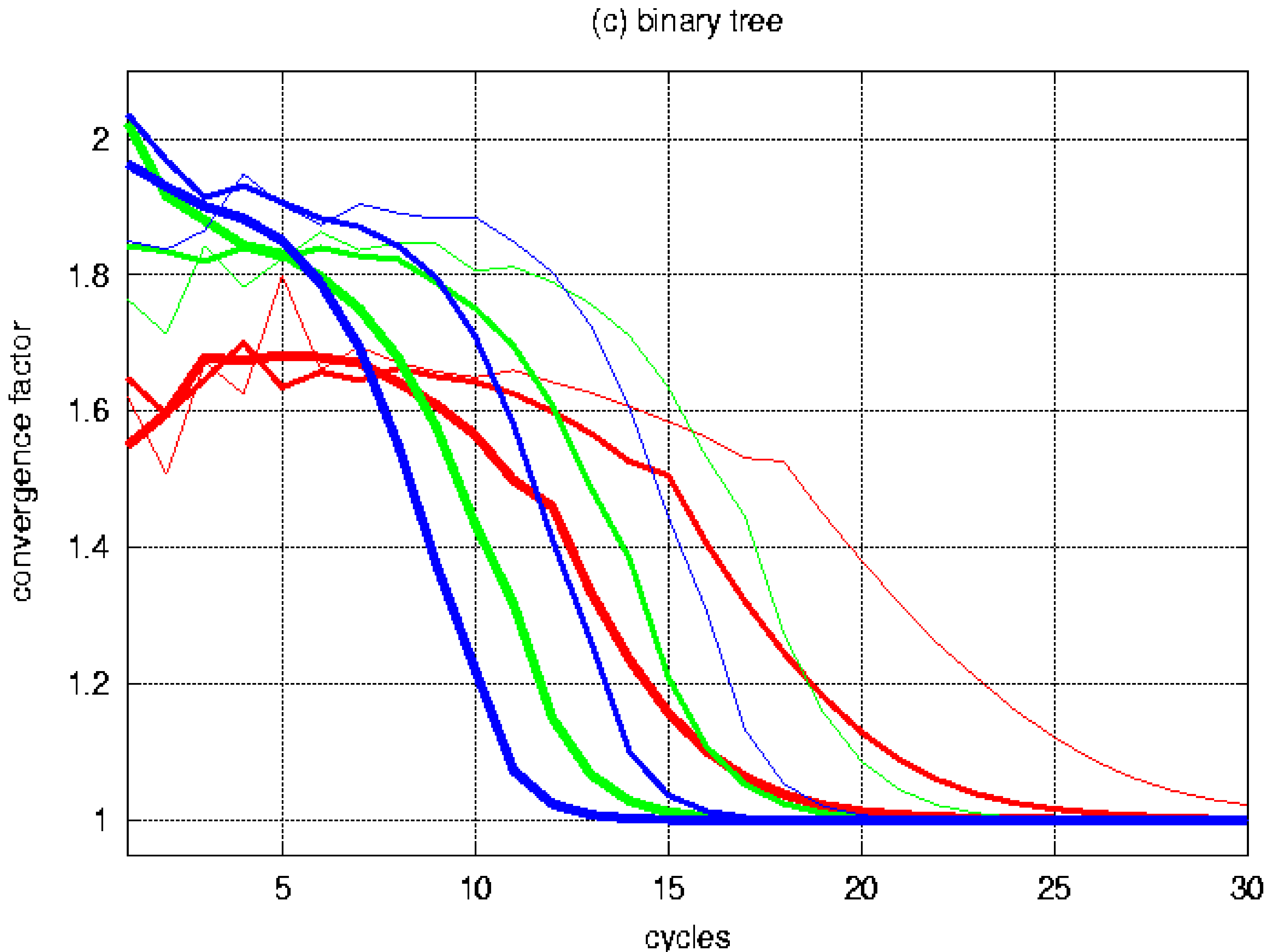
(f) N=2^20
number of missing target links
10^6
10^5
10^4
10^3
10^2
10^1
1
15
20
30
40
50
60
70
80
100
cycles



(a) ring
convergence factor
cycles
2
1.8
1.6
1.4
1.2
1
5
10
15
20
25
30
c=20, N=2^14
c=20, N=2^17
c=20, N=2^20
c=40, N=2^14
c=40, N=2^17
c=40, N=2^20
c=80, N=2^14
c=80, N=2^17
c=80, N=2^20



(b) torus
convergence factor
cycles
2
1.8
1.6
1.4
1.2
1
5
10
15
20
25
30



(c) binary tree
convergence factor
cycles
2
1.8
1.6
1.4
1.2
1
5
10
15
20
25
30

T-Man: summary

- T-Man generates a wide range of topologies
- the convergence is fast
  - approx. logarithmic in the number of nodes,
  - independently of the topologies we looked at
- not only approximate, but perfect embedding can be achieved
- applications include communiction topology, sorting and clustering

Some thoughts

- gossip protocols apply local operators to reduce global "energy"
  - this is true for not only structures: dissemination and many other applications too
- the operators are applied in a massively parallel way resulting in quick global convergence

Some thoughts

- strong analogies with
  - control theory,
  - heuristic optimization (simulated annealing, etc),
  - parallel matrix iterations,
  - etc
- theoretically very poorly understood!

Aggregation

- Calculate a global function over distributed data
  - eg average, but more complex examples include variance, network size, model fitting, etc
- usual structured/unstructured approaches exist
  - structured: create an overlay (eg a tree) and use that to calculate the function hierarchically
  - unstructured: design a stochastic iteration algorithm that converges to what you want (gossip)
- we look at gossip here

Implementation of aggregation

- state: current approximation of the average
  - initially the local value held by the node
- selectPeer: a random peer (based on peer sampling service)
- updateState(s_1,s_2)
  - $(s_1+s_2)/2$: result in averaging
  - $(s_1 s_2)^{1/2}$: results in geometric mean
  - $\max(s_1,s_2)$: results in maximum, etc

Illustration of averaging

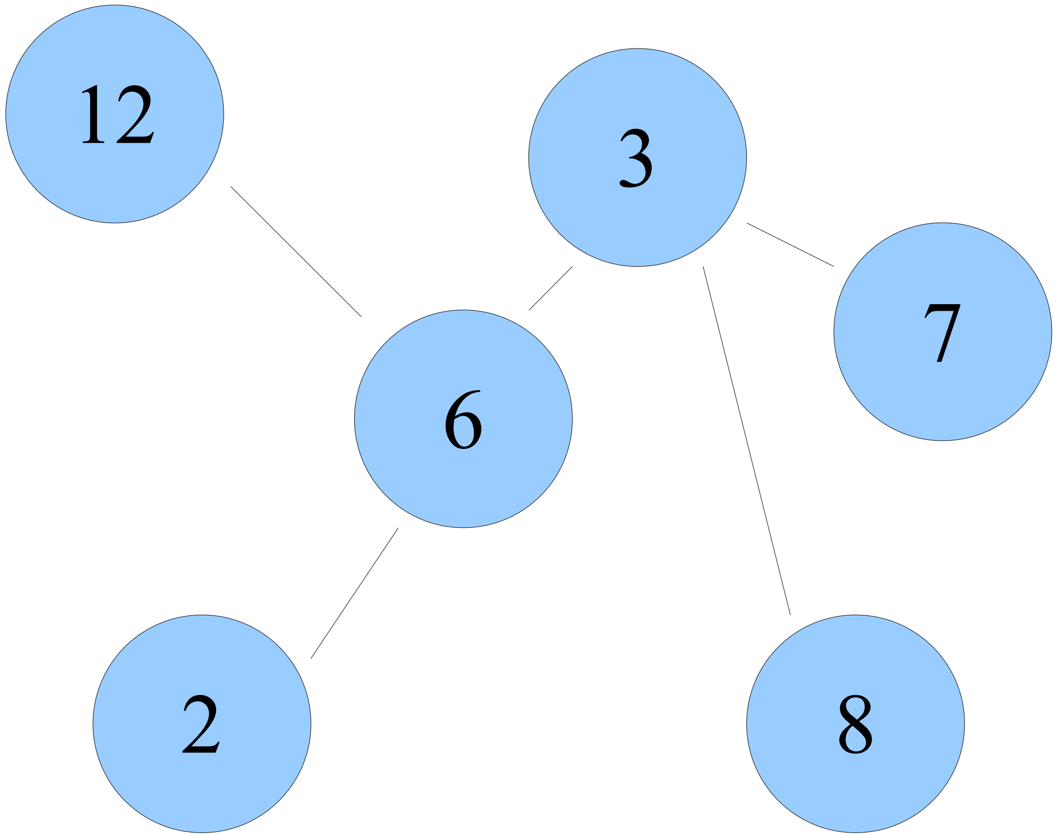
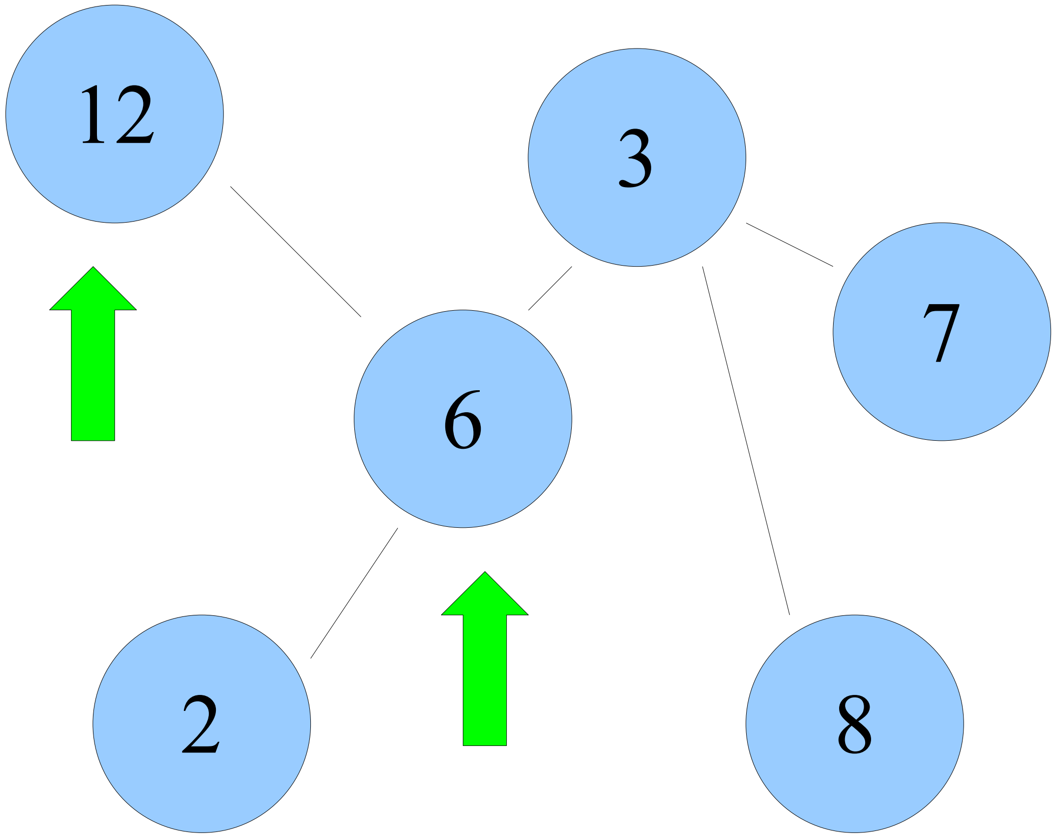


Illustration of averaging



(12+6)/2=9

Illustration of averaging

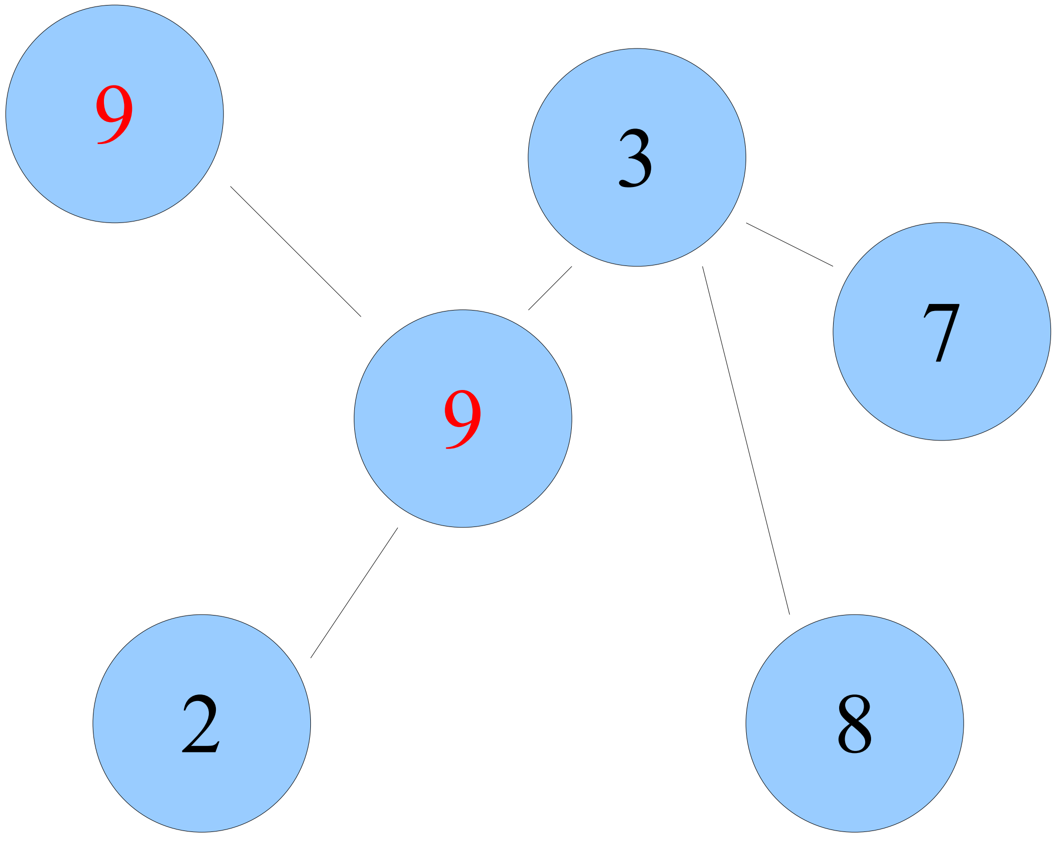


Illustration of averaging