Epidemic Algorithms

Slides by Amir H. Payberah (amir@sics.se), Jim Dowling

Introduction

- Motivations
  - Existing information dissemination protocols have scalability problems.
  - Randomized protocols may have a smaller overhead.
  - Trade-off between reliability and scalability.

- Can be applied
  - To large-scale distributed systems (millions of nodes).
  - When real-time information dissemination is not required.

Epidemic Protocols

- Epidemics study the spread of a disease or infection in terms of populations of infected/uninfected individuals and their rates of change.

- How does it work?
  - Initially, a single individual is infective.
  - Individuals get in touch with each other, spreading the update.

- Our goal is to spread the infection (update) as fast and completely as possible!

Two Styles of Epidemic Protocols

- Anti-entropy
- Rumor mongering

Anti-entropy

- Each peer p periodically contacts a random partner q selected from the current population.

- Then, p and q engage in an information exchange protocol, where updates known to p but not to q are transferred from p to q (push), or vice-versa (pull), or in both direction (push-pull).

Rumor Mongering

- Peers are initially ignorant.
- When an update is learned by a peer, it becomes a hot rumor.
- While a peer holds a hot rumor, it periodically chooses a random peer from the current population and sends (pushes) the rumor to it.
- Eventually, a node will lose interest in spreading the rumor.

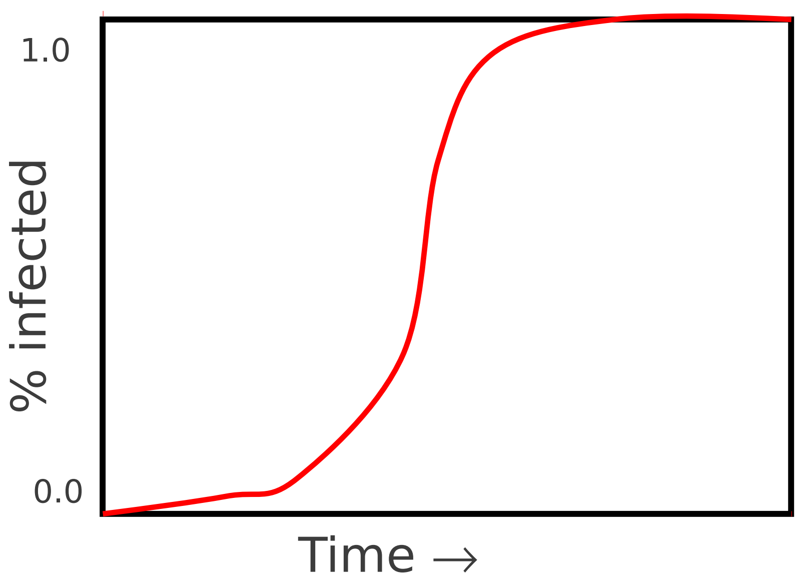
Rumor Mongering: Loss of Interest

- Counter vs. Coin
  - Counter: lose interest after k contacts.
  - Coin (random): lose interest with probability 1/k.

- Feedback vs. Blind
  - Feedback: lose interest only if the recipient knows the rumor.
  - Blind: lose interest regardless of the recipient.

Epidemic Protocols Scale Very Nicely

- Participants' load is independent of size
- Information spreads in log(system size) time.



Use of Epidemic Protocols

- Aggregation protocols
- Membership management (Cyclon)
- Topology management (T-man)
- Etc.

Aggregation Protocols

Aggregation Protocols

- Aggregation is a common name for a set of functions that provide an estimate of some global system property.

- Aggregation functions enable local access to global information, in order to simplify the task of controlling, monitoring, and optimizing distributed applications.

- Some examples of aggregation functions:
  - The average load of nodes in a distributed storage system.
  - The sum of free space in a distributed storage system.
  - The total number of nodes in a P2P system.

A Generic Aggregation Framework

// timed event

timer(T time units)

q = **SelectPeer()**

send S to q

// handle event

recv S_p from p

send S to p

S = **Update(** S, S_p **)**

// handle event

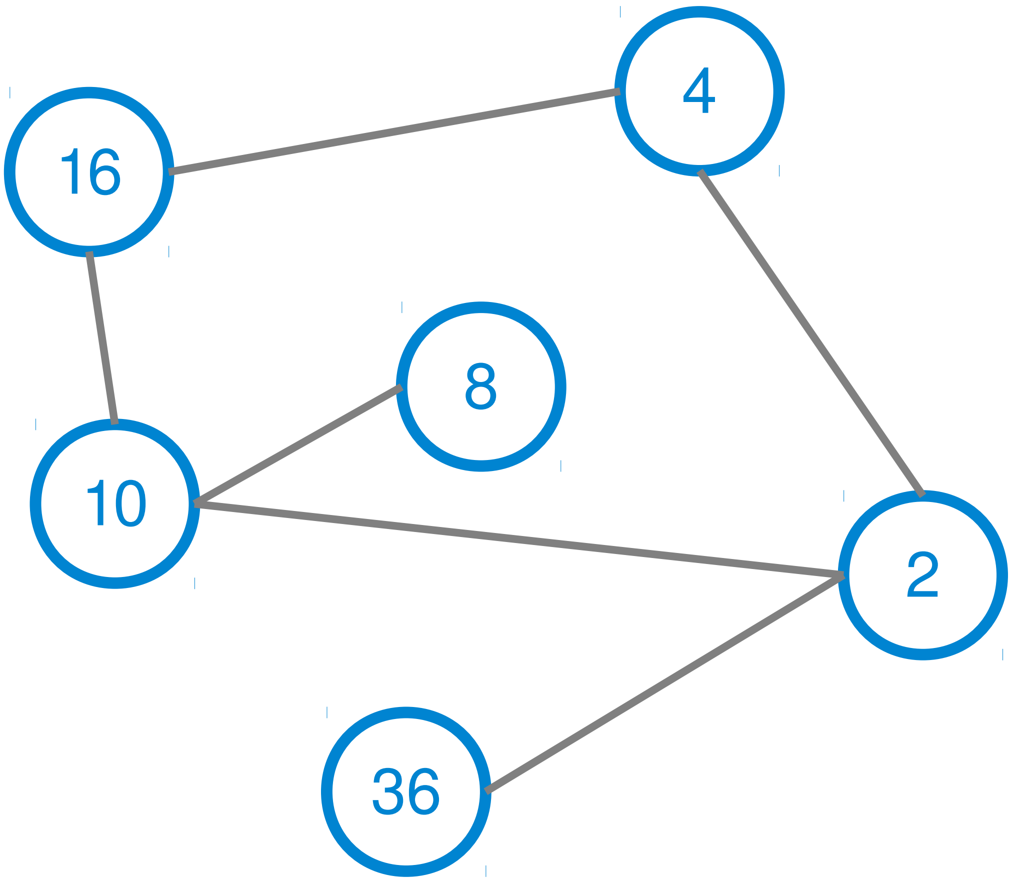
recv S_q from q

S = **Update(** S, S_q **)**

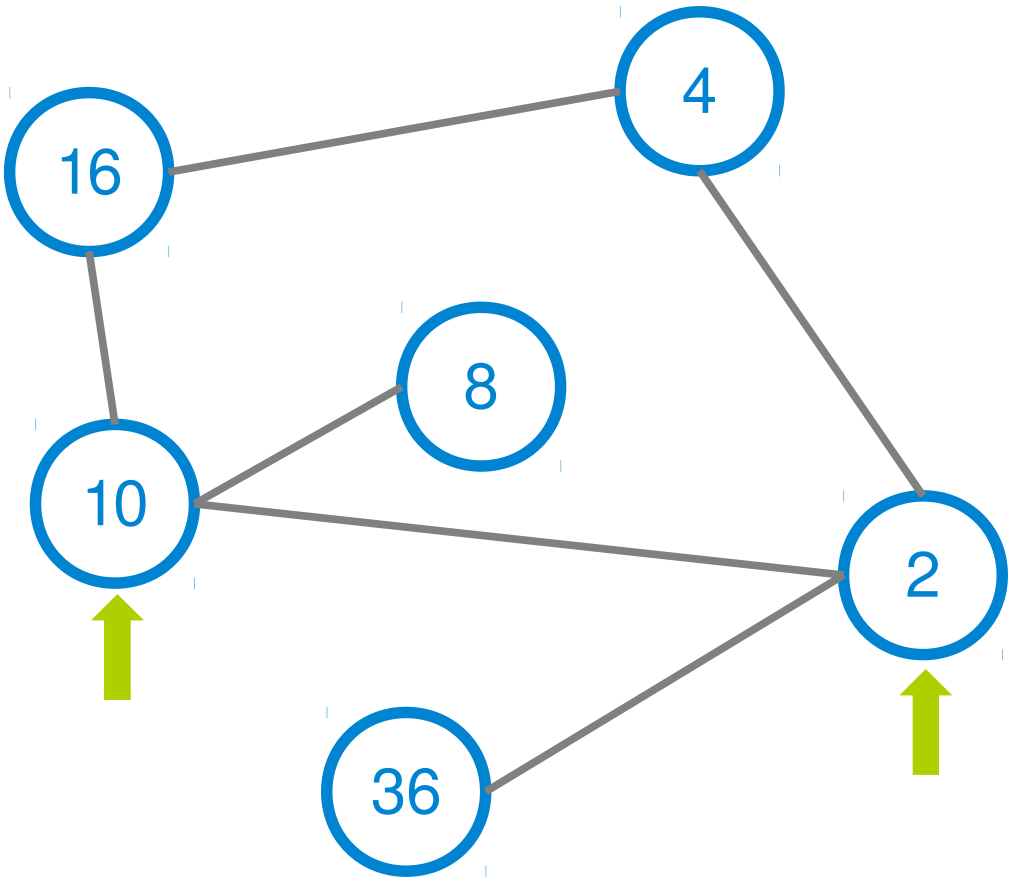
Some Comments

- Local state maintained by nodes:
  - a real number representing the value to be averaged.
- selectPeer()
  - performs a random selection among the set of current nodes.
- update(sp, sq)
  - Avg: return (sp+sq)/2
  - Max: return max(sp,sq)

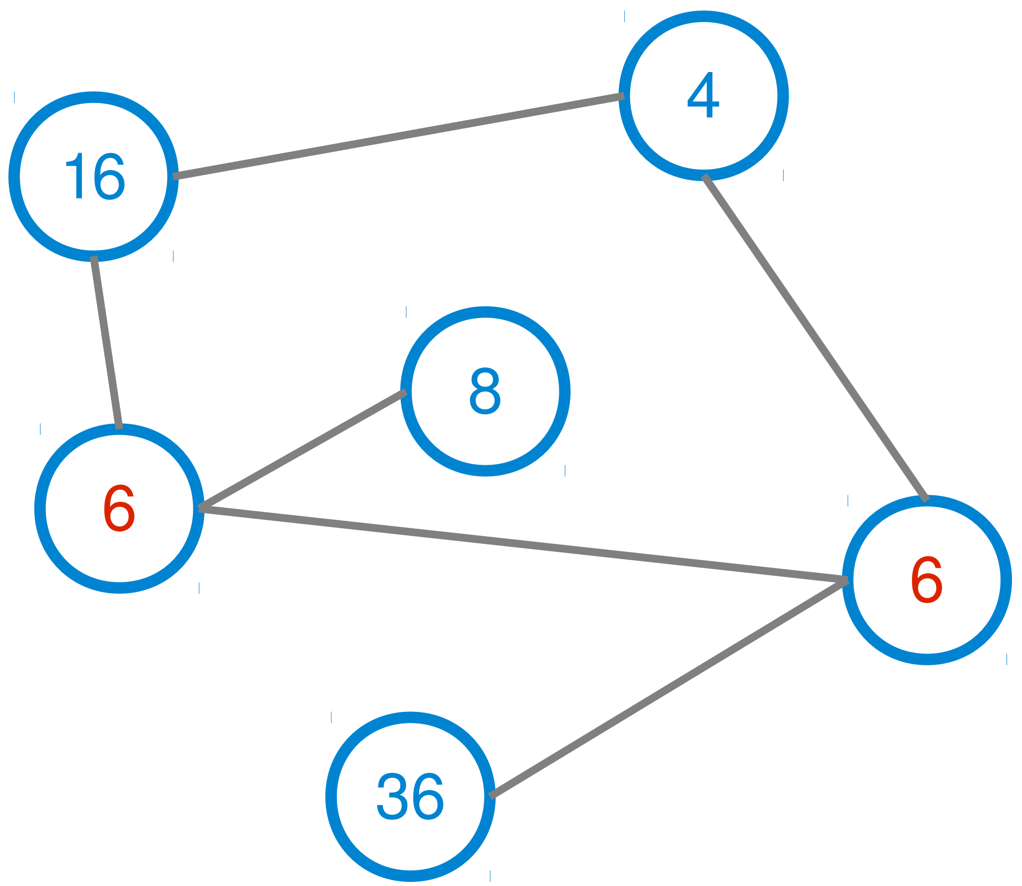
Average Aggregation (1/5)



Average Aggregation (2/5)

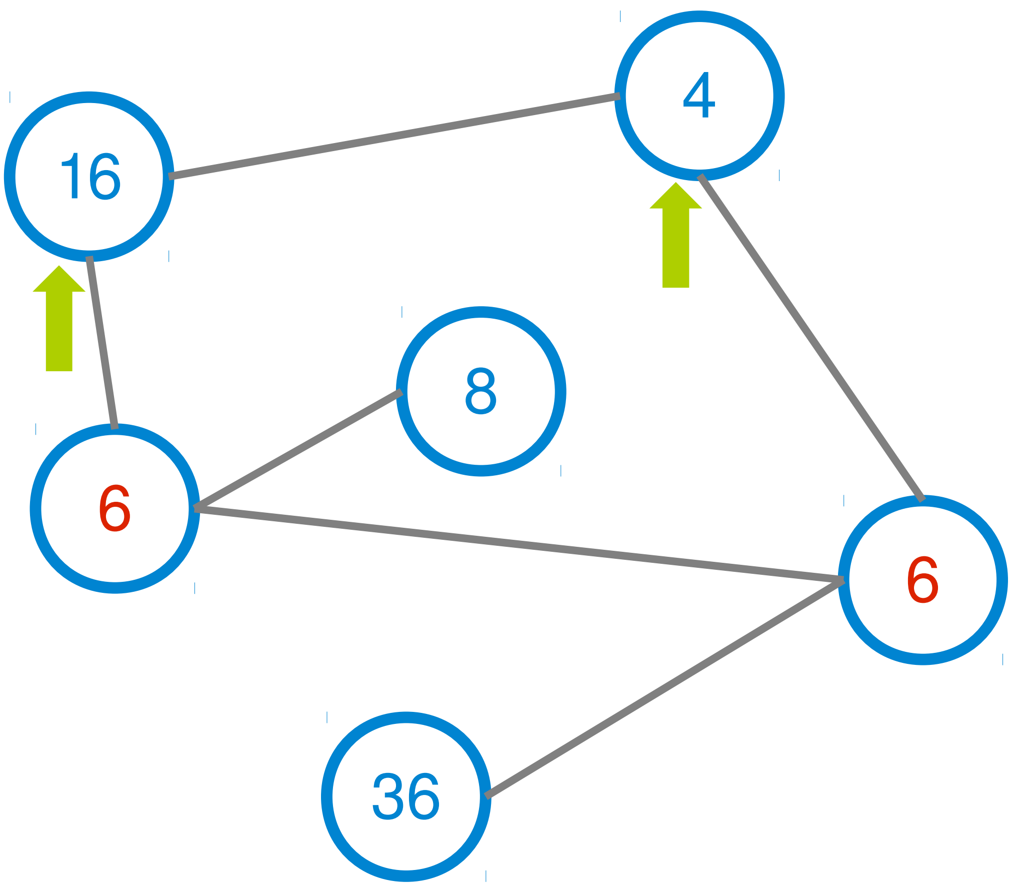


Average Aggregation (3/5)

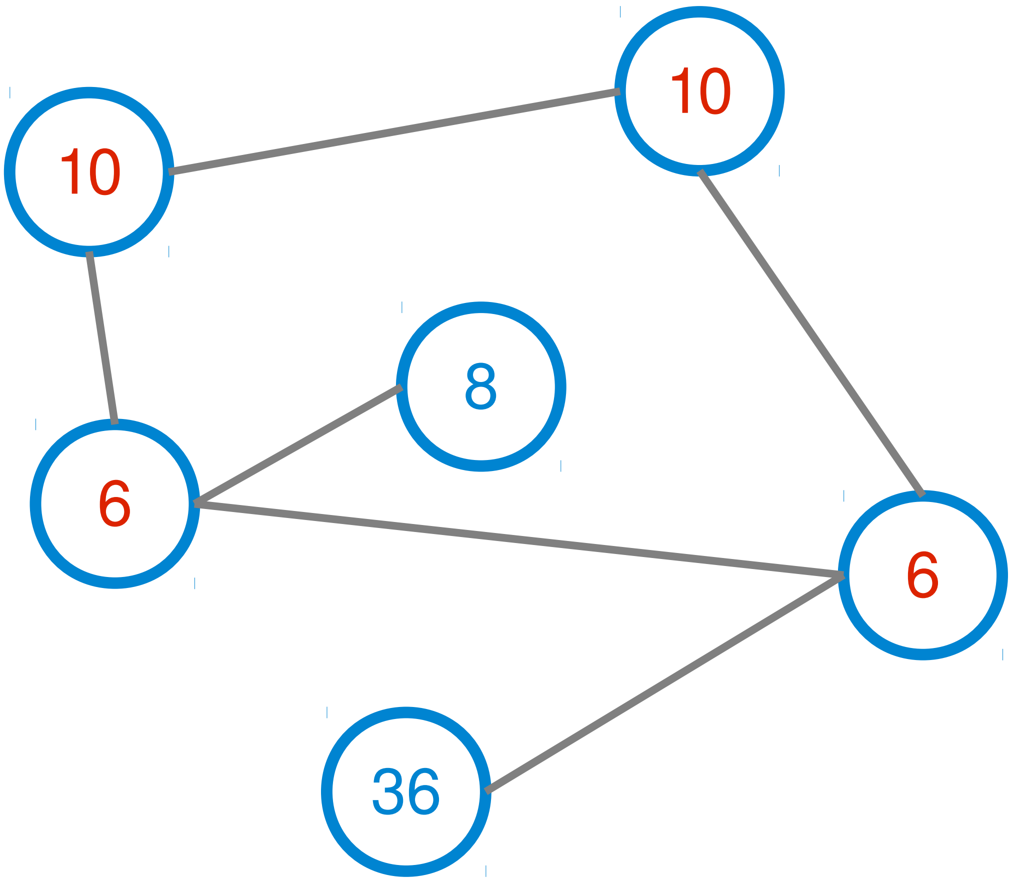


(10 + 2) / 2 = 6

Average Aggregation (4/5)



Average Aggregation (5/5)

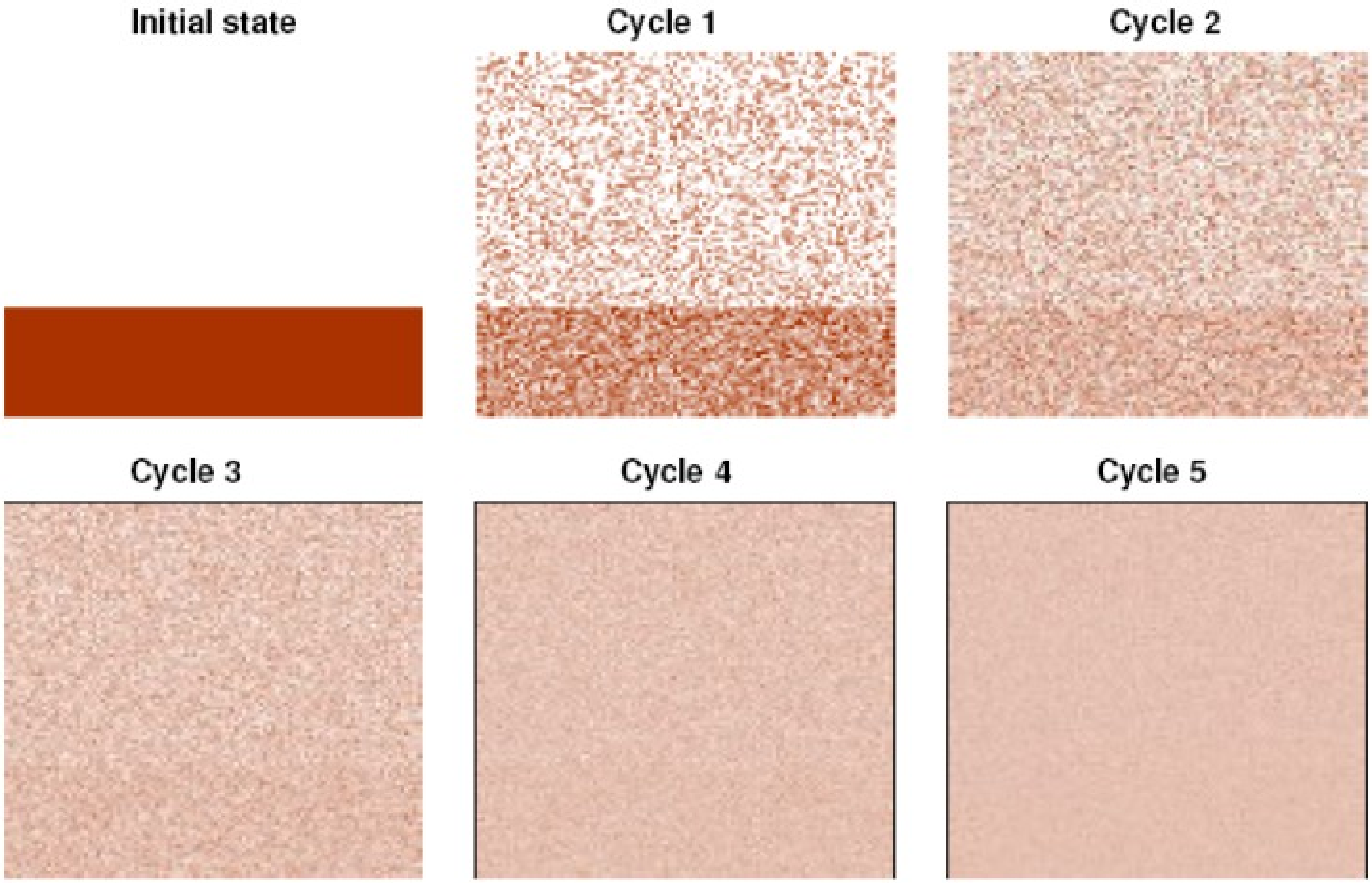


(16 + 4) / 2 = 10

Some Comments

- If the graph is connected, each node converges to the average of the original values.
- After each exchange the variance is reduced.

Illustration of Averaging



Network Size Estimation

- Any ideas?

Network Size Estimation

- Any ideas?
- All nodes set their states to 0.
- The initiator sets its state to 1 and starts gossiping for the average.
- Eventually (after predefined *k* rounds) all nodes converge to the avg=1/N.

Membership Management

Membership Management

- In a gossip-based protocol, each node in the system periodically exchanges information with a subset of peers.
- The choice of this subset is crucial.
- Ideally, the peers should be selected following a uniform random sample of all nodes currently in the system.

Achieving a Uniform Random Sample

- Each node may be assumed to know every other node in the system.

- However, providing each node with a complete membership table from which a random sample can be drawn, is unrealistic in a large-scale dynamic system.

An Alternative Solution

- Peer sampling
- Every node maintains a relatively small local membership table that provides a partial view on the complete set of nodes.
- Periodically refreshes the table using a gossiping procedure.

Peer Sampling Generic Framework (1/3)

```
// timed event every T time units
handle
    q = view.SelectPeer()
    buf = ((myAddress, 0))
    view.permute()
    move oldest H items to the end of view
    buf.append(view.head(c/2-1))
    send buf to q
    recv buf_q from q
    view.select(c, H, S, buf_q)
    view.increaseAge()
```

Peer Sampling Generic Framework (2/3)

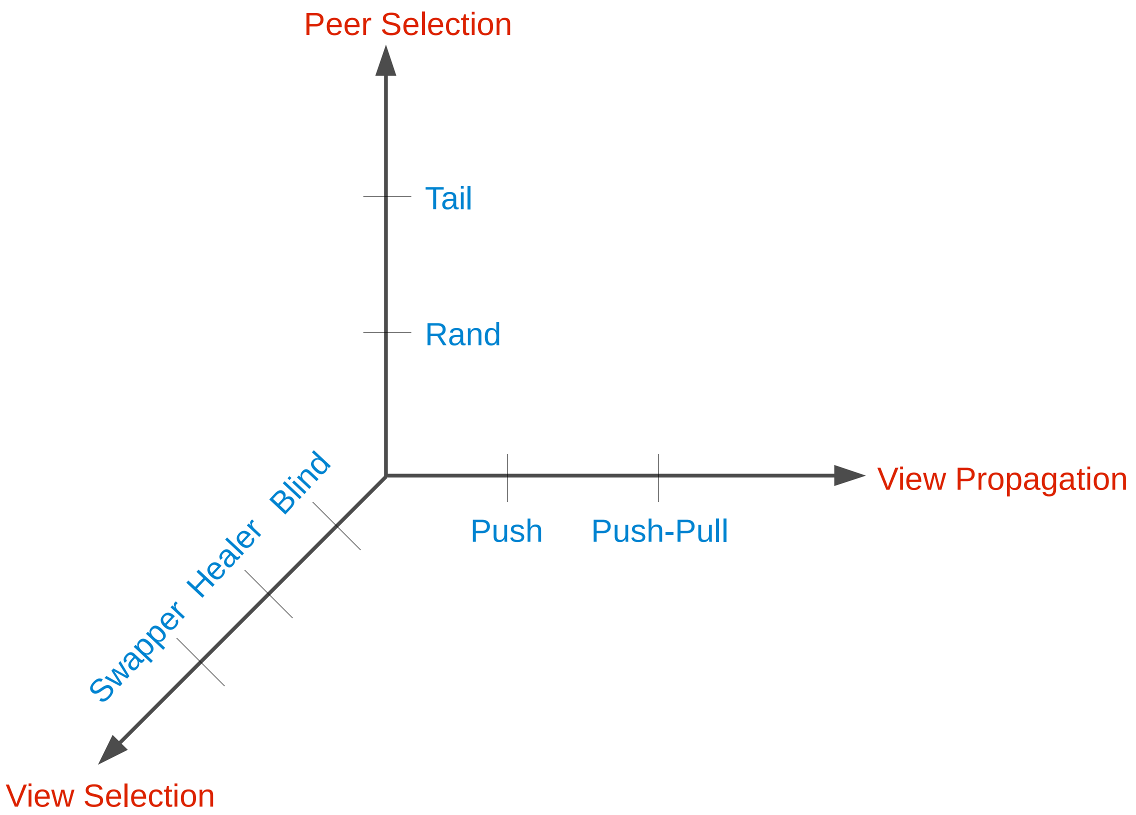
```
// receiver handler
handle
    recv buf_p from p
    buf = ((myAddress, 0))
    view.permute()
    move oldest H items to the end of view
    buf.append(view.head(c/2-1))
    send buf to p
    view.select(c, H, S, buf_p)
    view.increaseAge()
```

Peer Sampling Generic Framework (3/3)

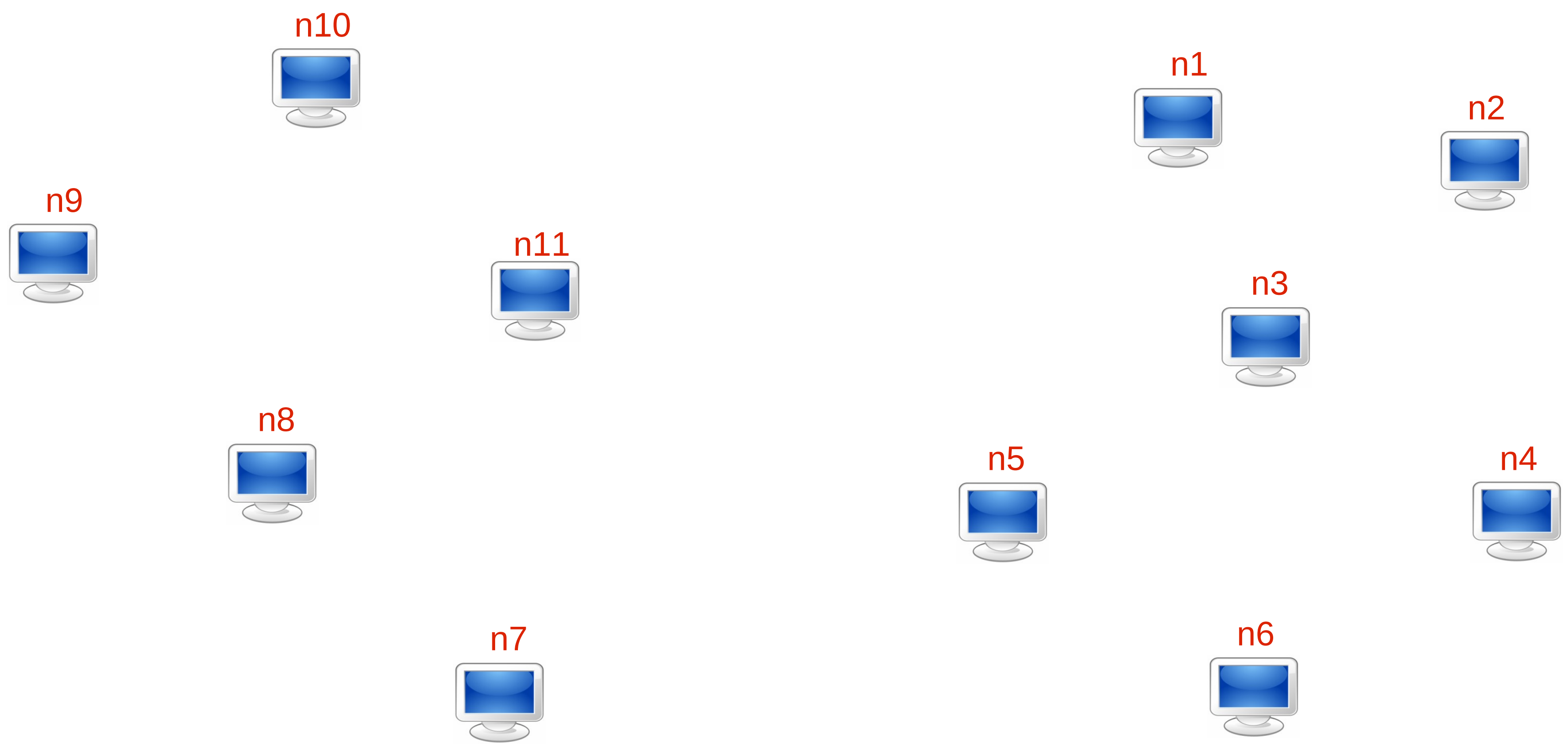
```
// view select method
method view.select(c, H, S, buf_p)
    view.append(buf_p)
    view.removeDuplicates()
    view.removeOldItems(min(H, view.size-c))
    view.removeHead(min(S, view.size-c))
    view.removeAtRandom(view.size-c)
```

Design Space

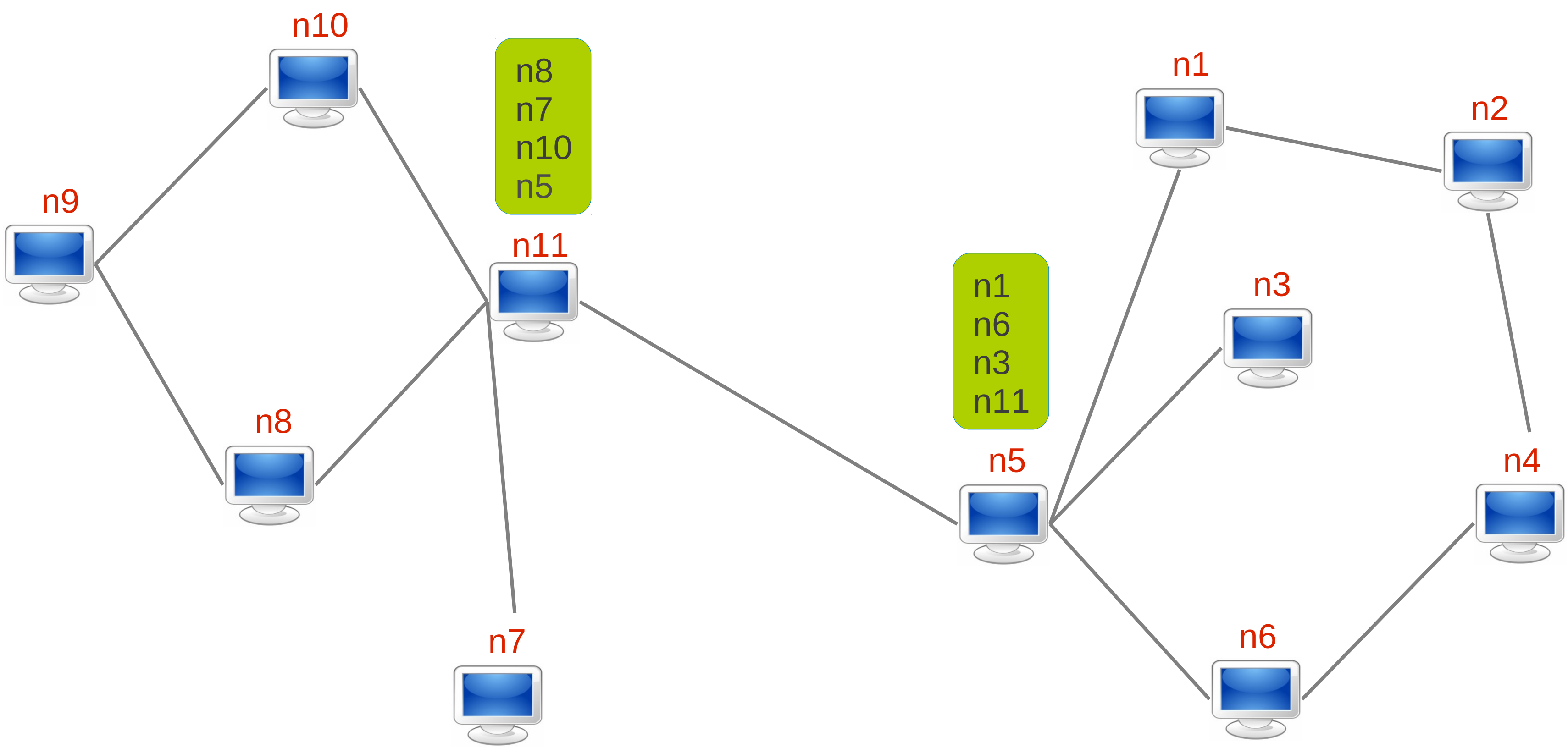
- Peer Selection
  - Rand: uniform random
  - Tail: highest age
- View Propagation
  - Push
  - Push-Pull
- View Selection
  - Blind: H = 0, S = 0
  - Healer: H = c / 2
  - Swapper: H = 0, S = c / 2



Gossip-based Peer Sampling Protocol (1/7)



Gossip-based Peer Sampling Protocol (2/7)



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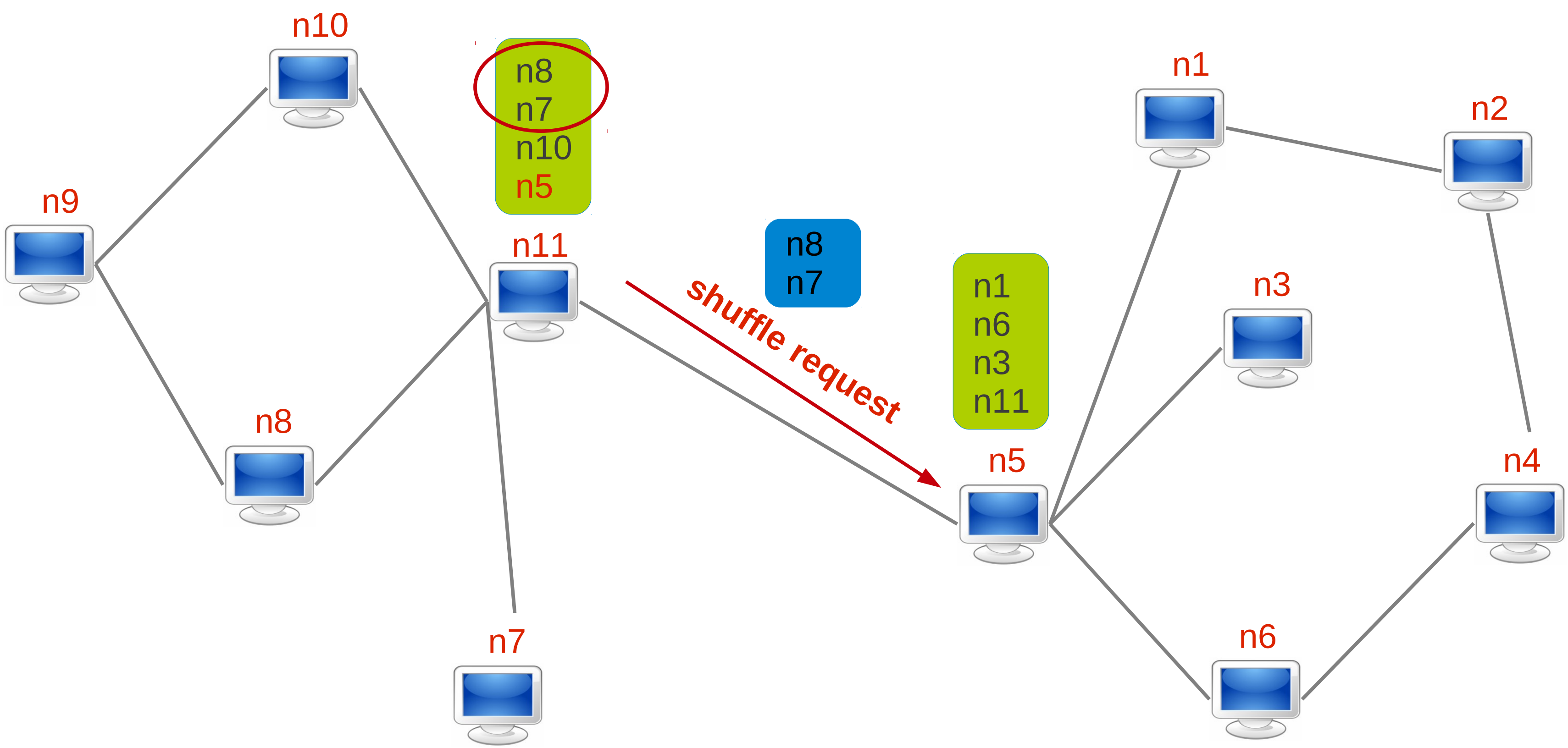
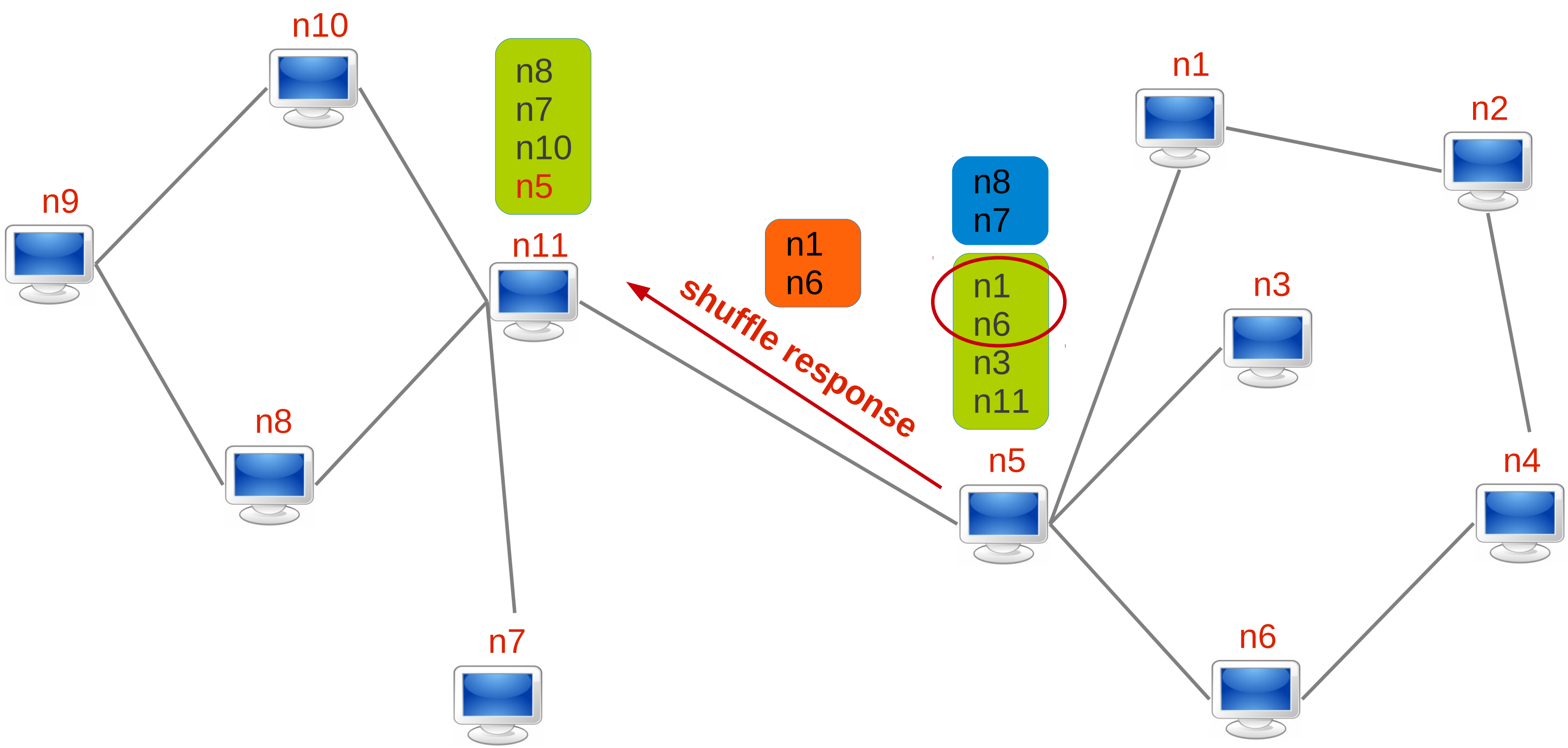
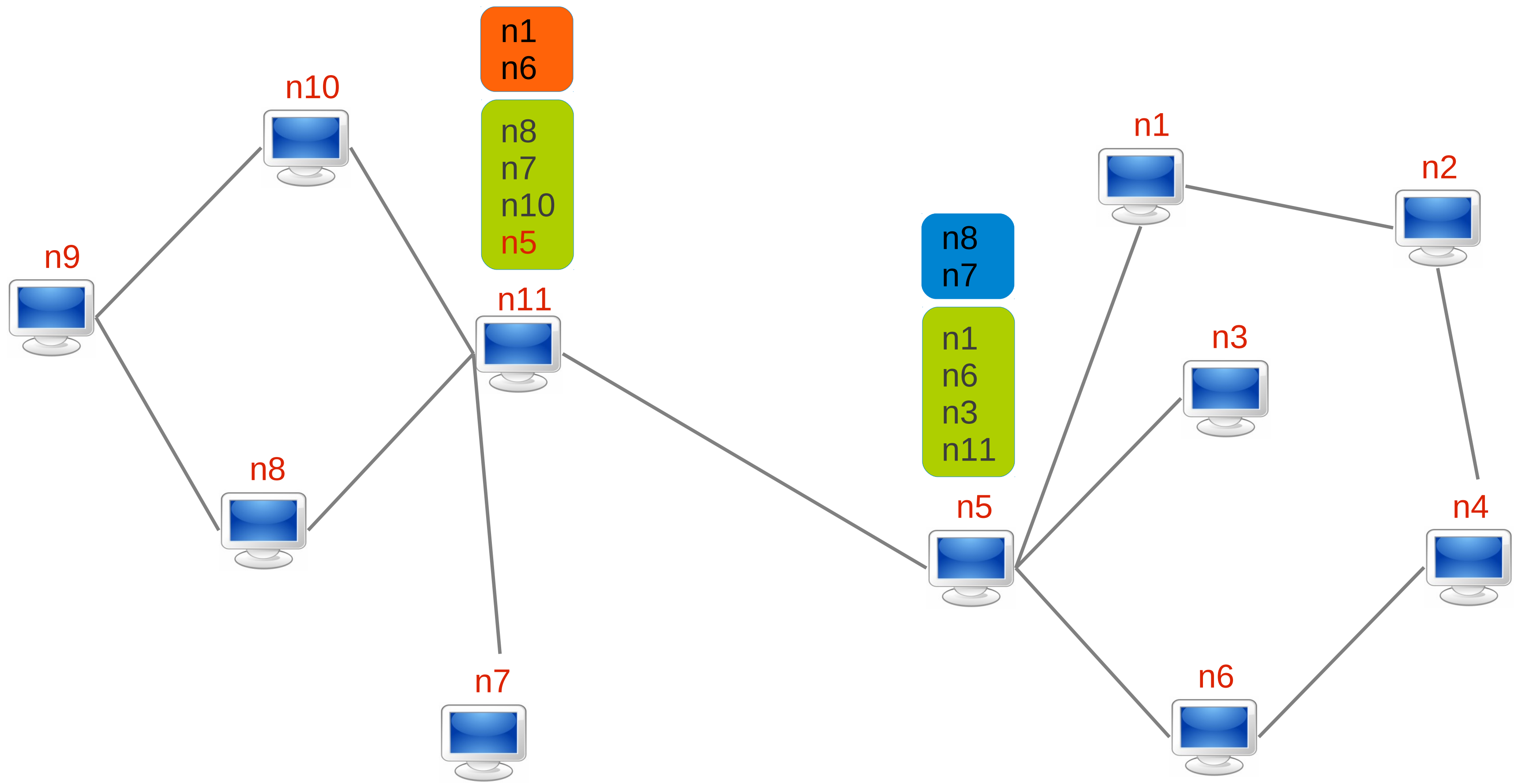


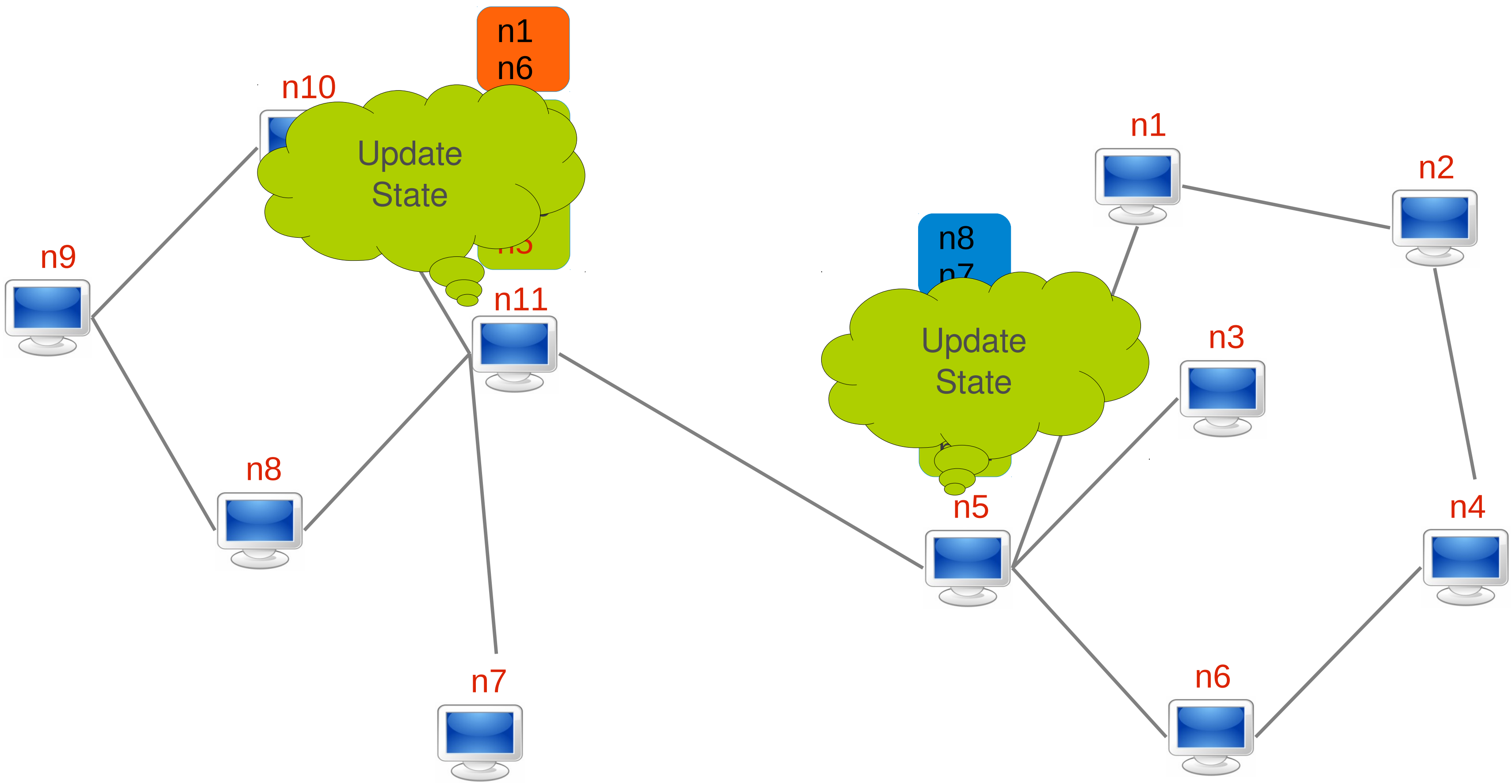
Gossip-based Peer Sampling Protocol (4/7)



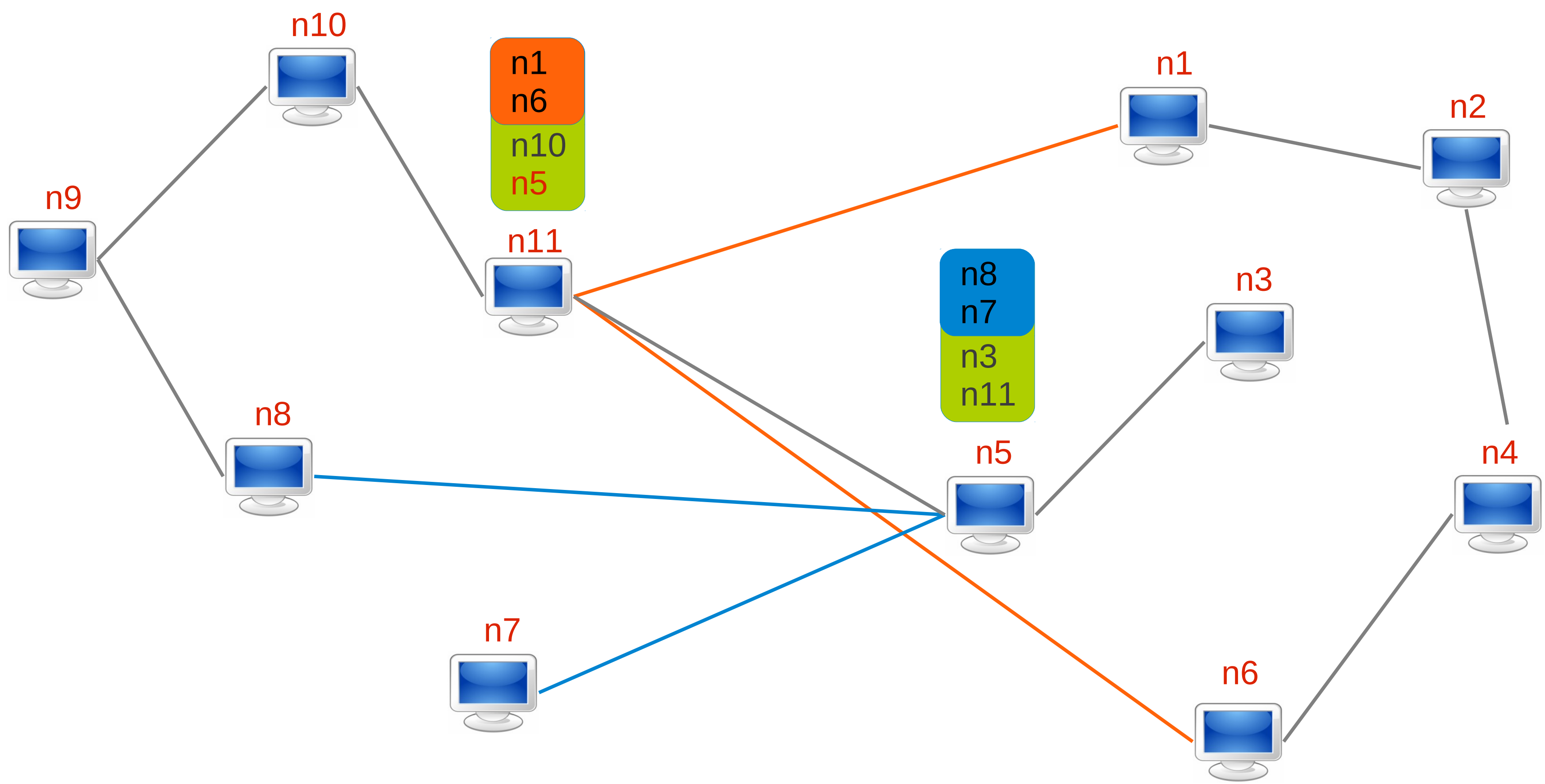
Gossip-based Peer Sampling Protocol (5/7)



Gossip-based Peer Sampling Protocol (6/7)



Gossip-based Peer Sampling Protocol (7/7)



Newscast as a Peer Sampling Example

- Peer Selection
  - Rand: uniform random
  - Tail: highest age
- View Propagation
  - Push
  - Push-Pull
- View Selection
  - Blind: H = 0, S = 0
  - Healer: H = c / 2
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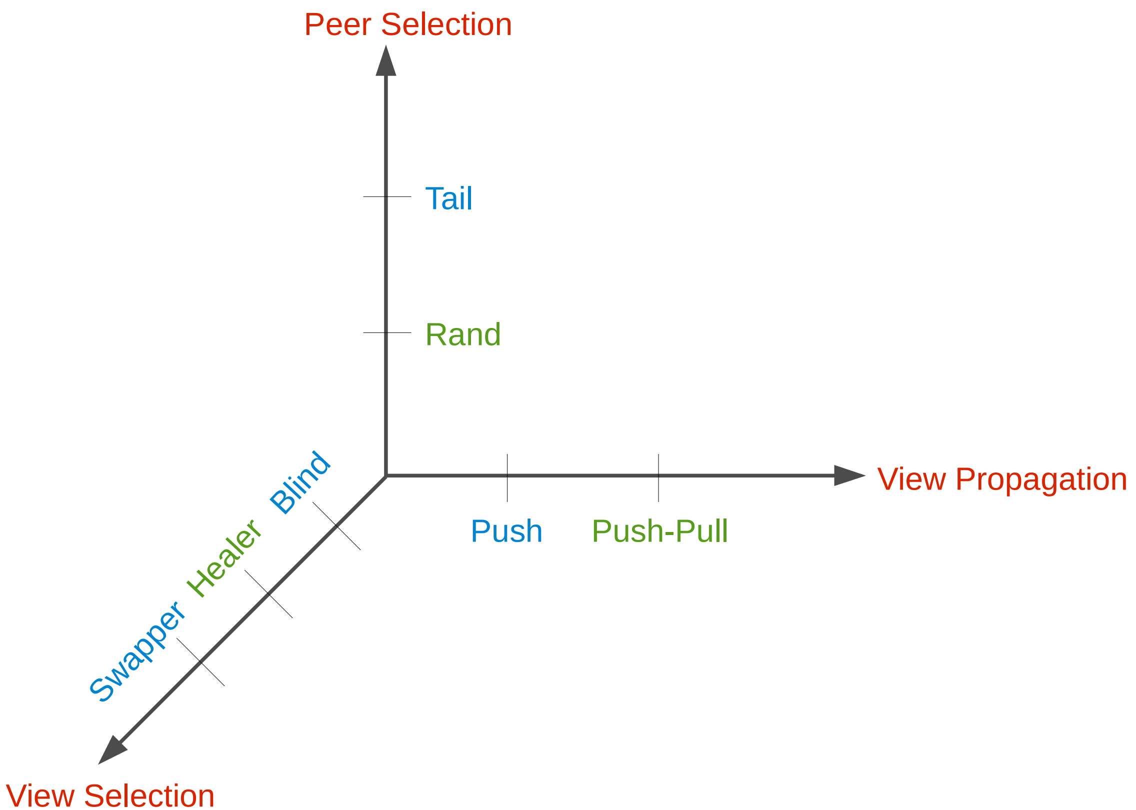
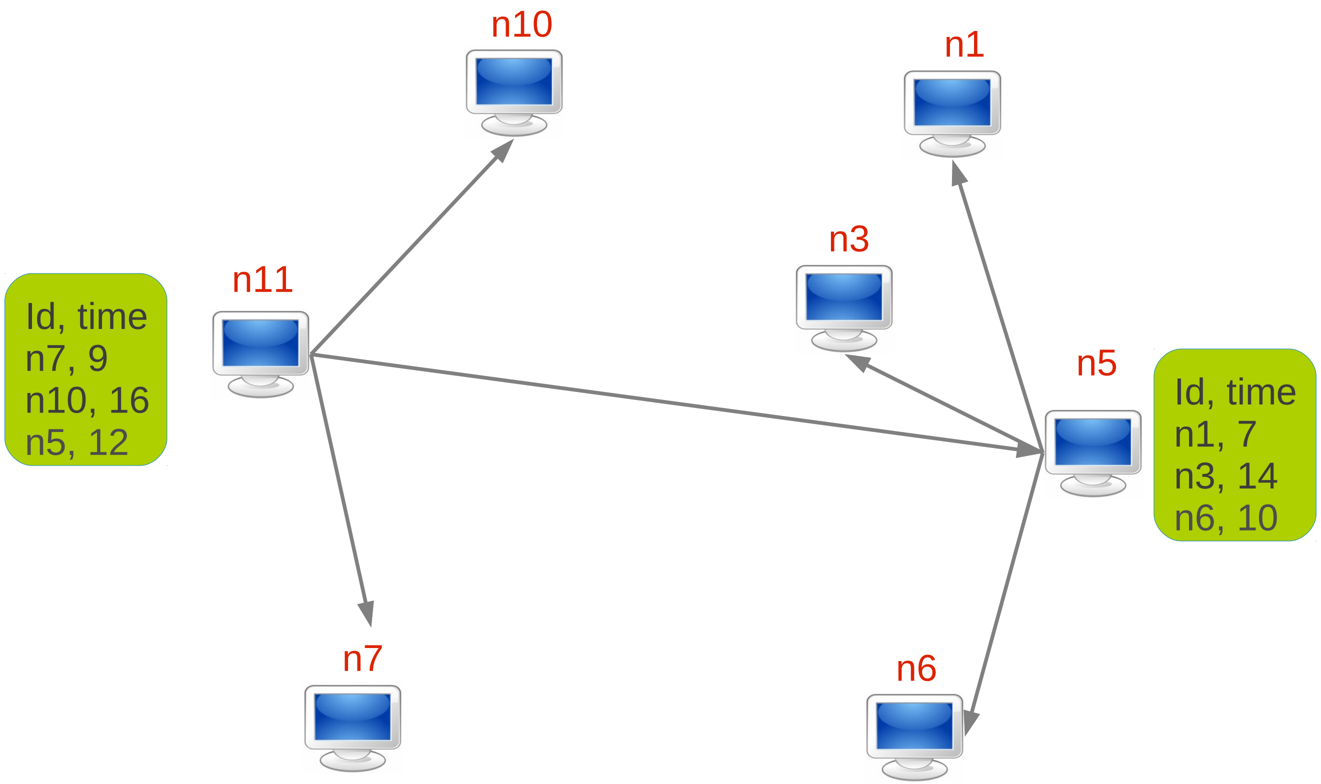
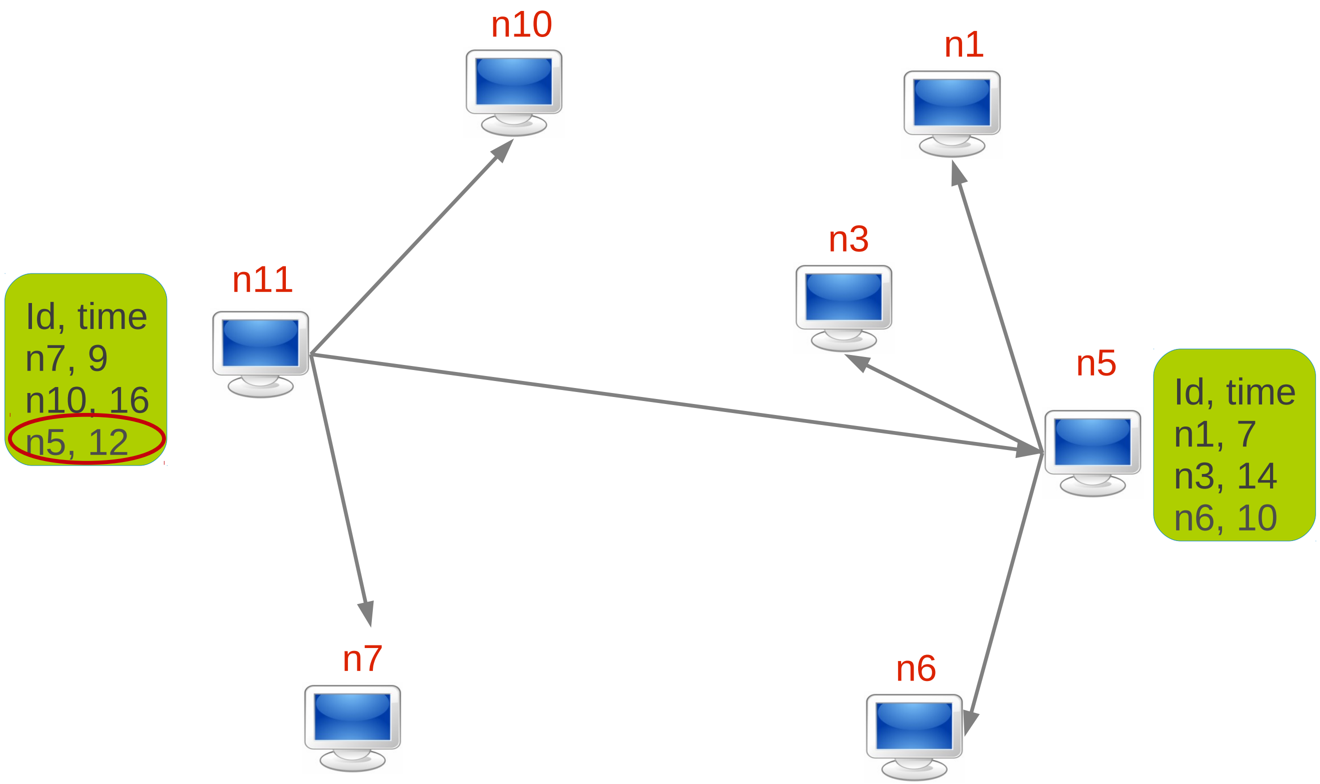


Newscast (1/7)

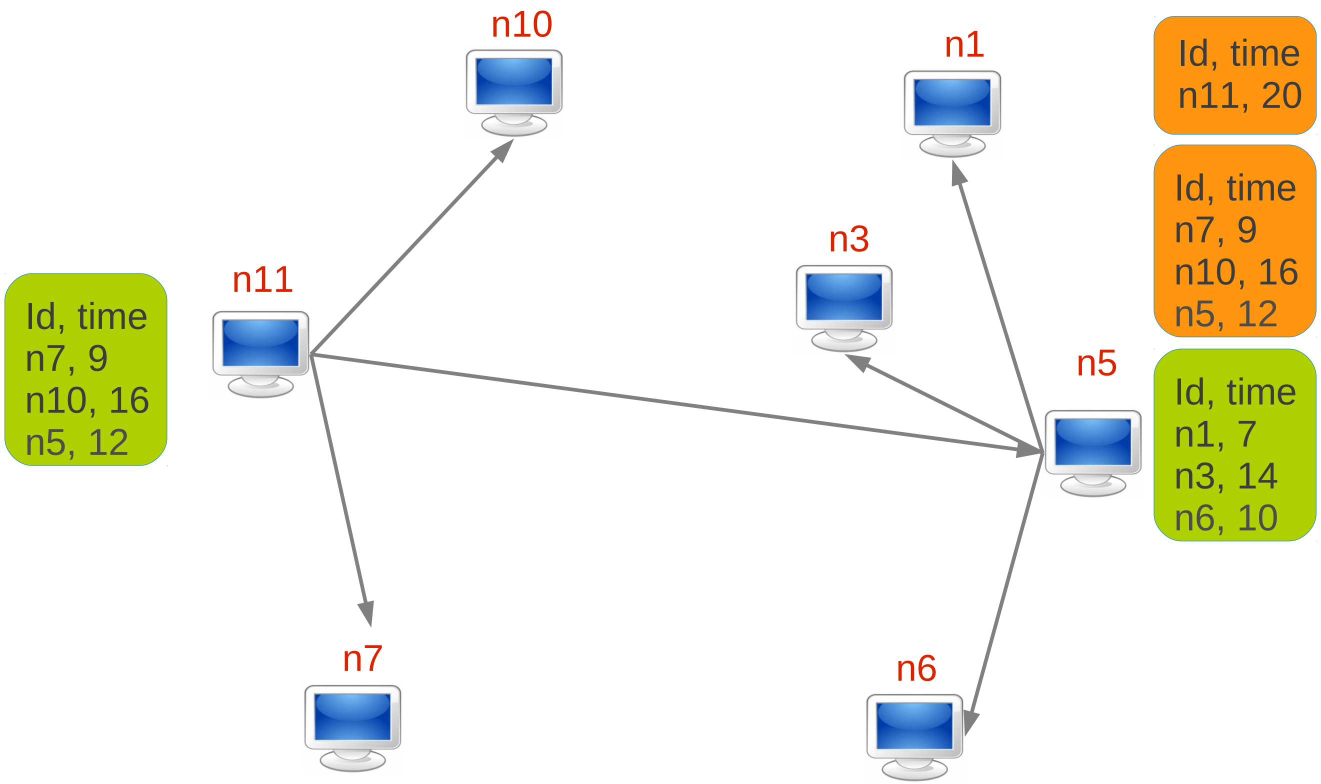

n10
n1
n3
n11
Id, time
n7, 9
n10, 16
n5, 12
n5
Id, time
n1, 7
n3, 14
n6, 10
n7
n6

Newscast (2/7)



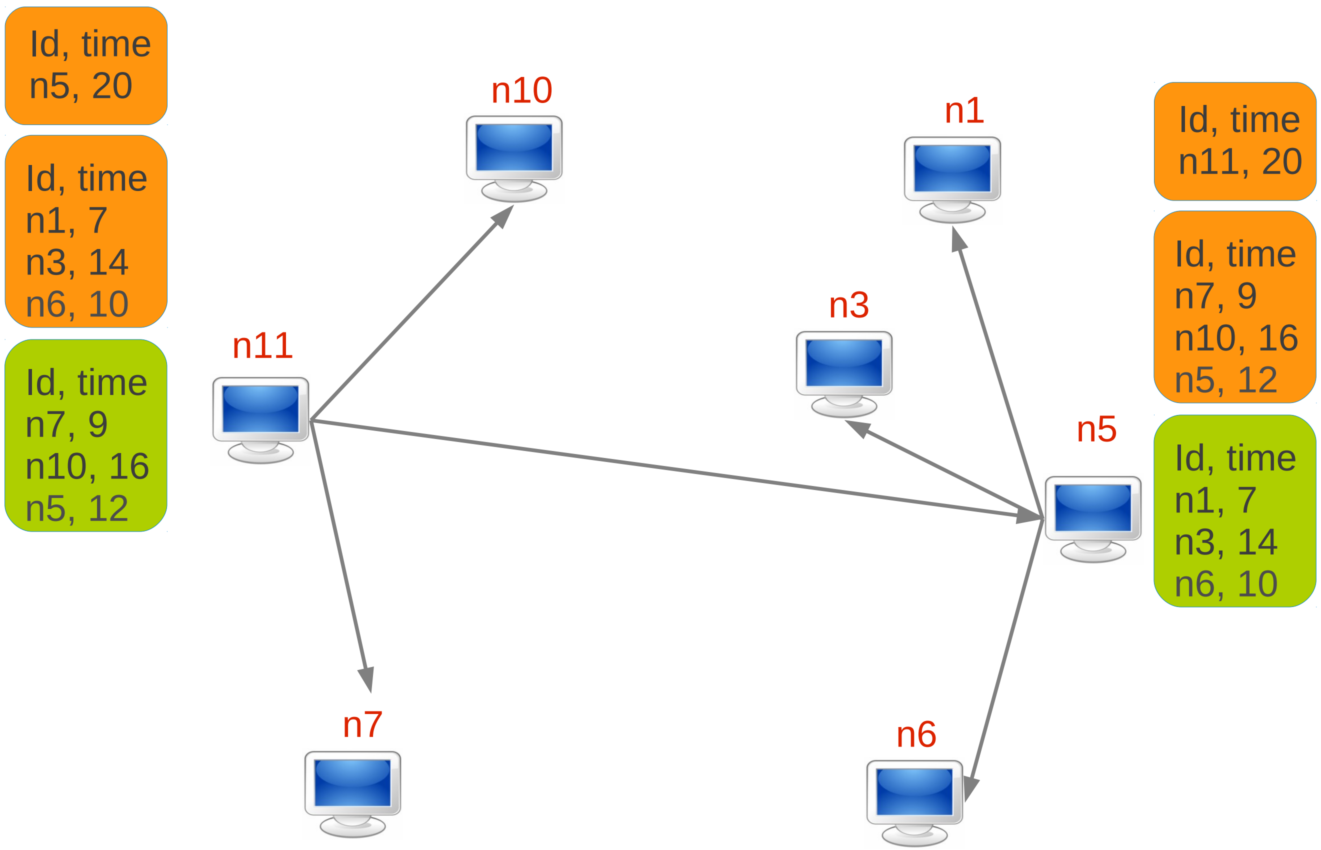
- Pick a random peer from my view

Newscast (3/7)



- Pick a random peer from my view
- Send each other view + own fresh link

Newscast (4/7)



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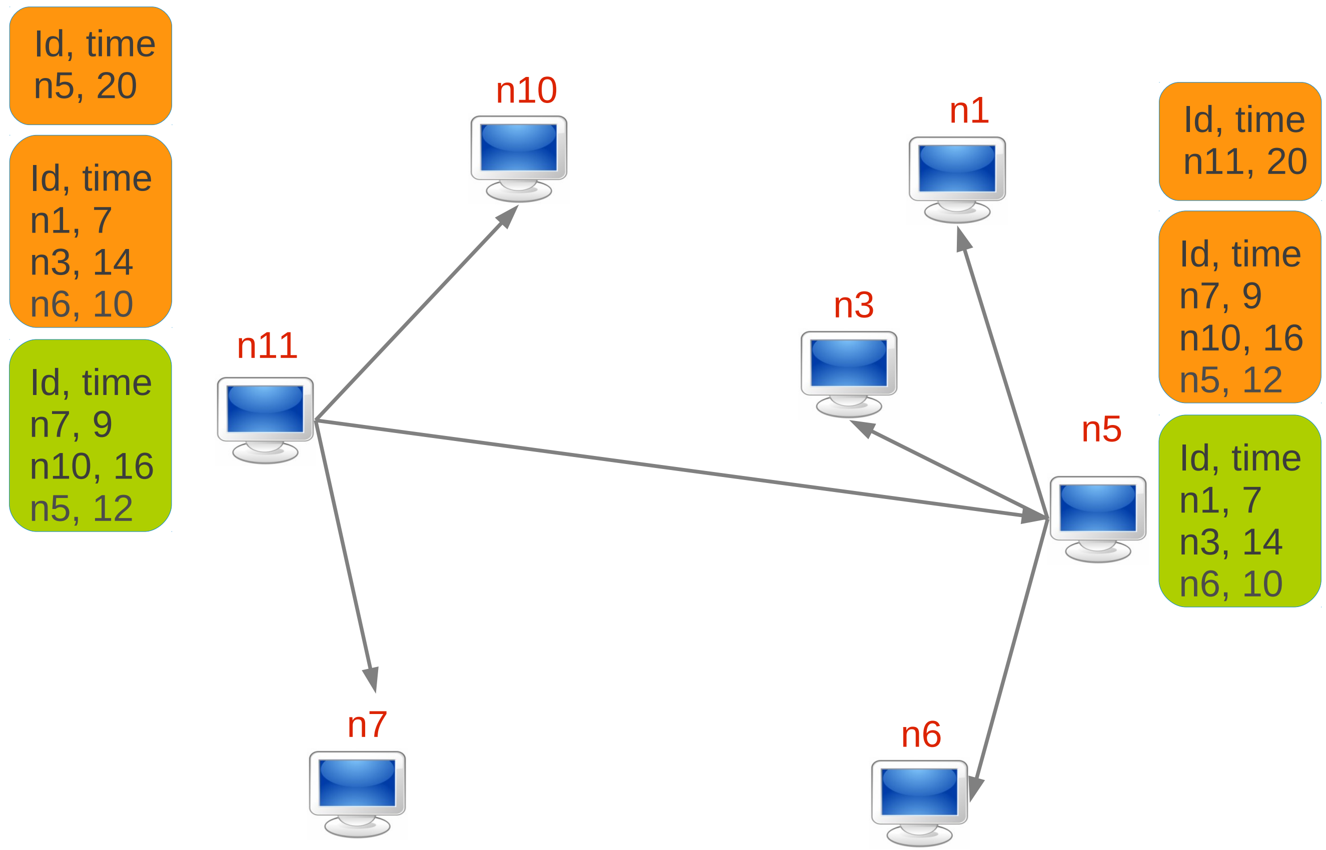
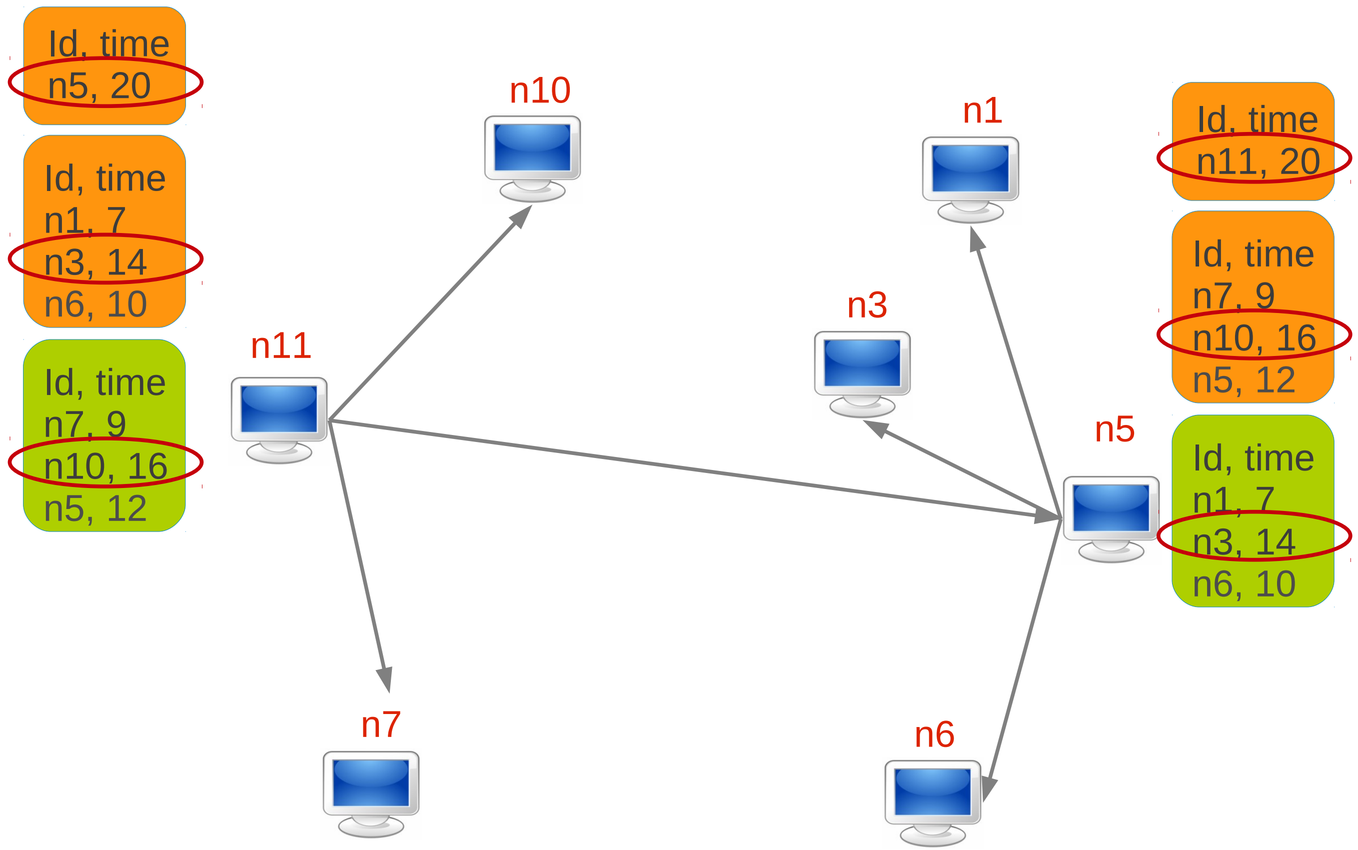
Newscast (5/7)



- Pick a random peer from my view
- Send each other view + own fresh link
- Keep c freshest links (remove own info and duplicates)

Newscast (6/7)



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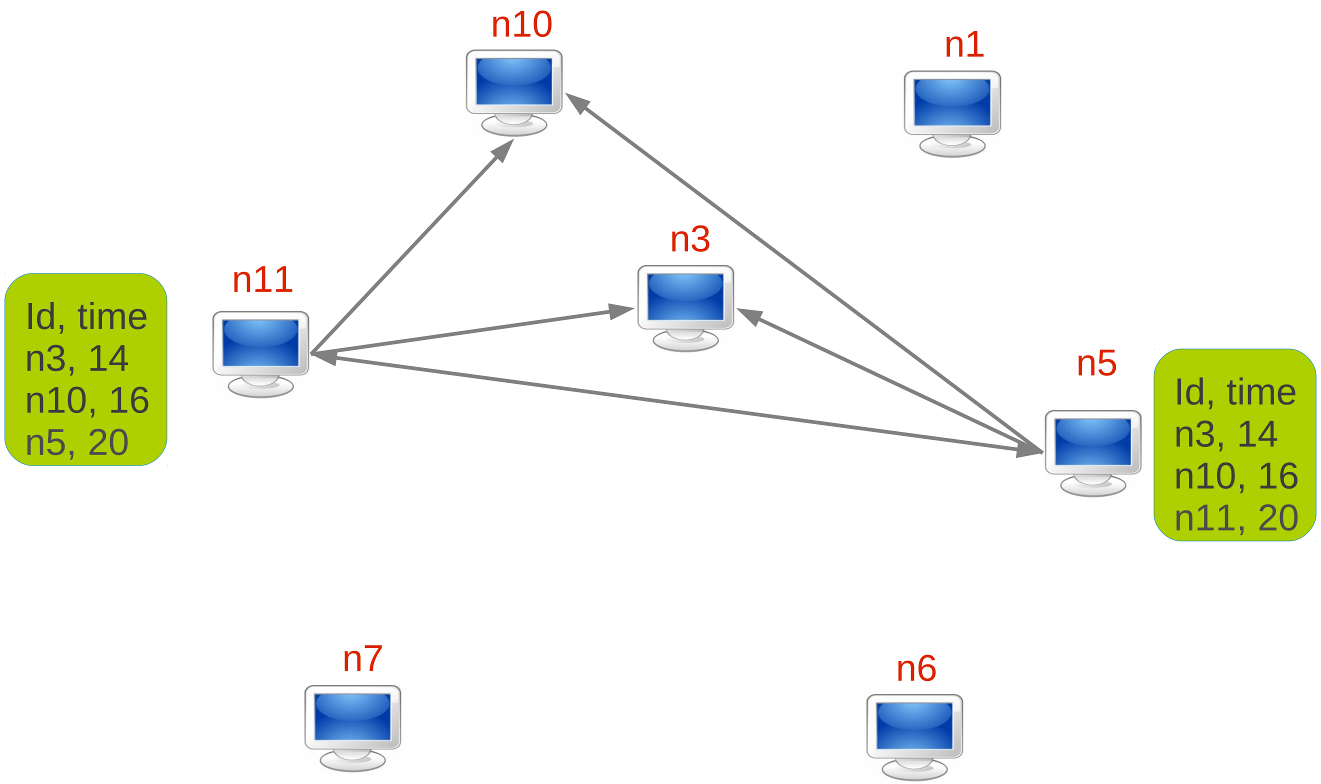

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Cyclon as a Peer Sampling Example

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- View Propagation
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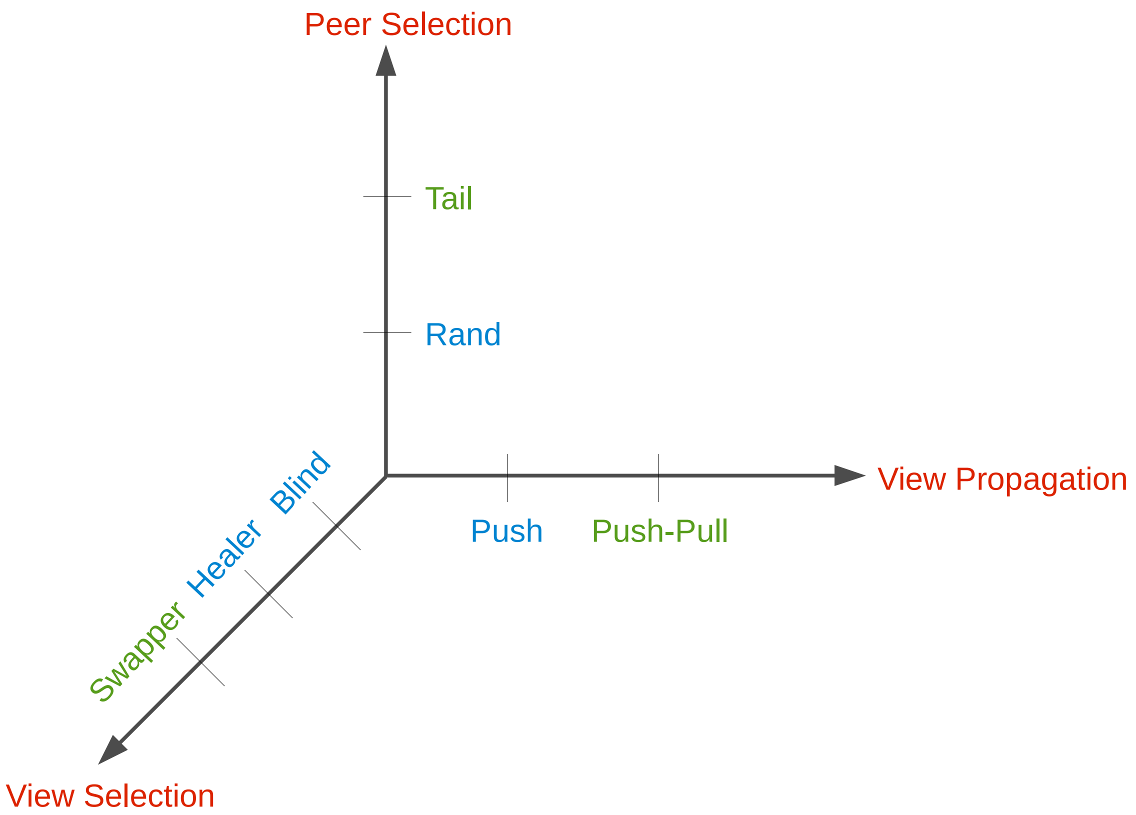
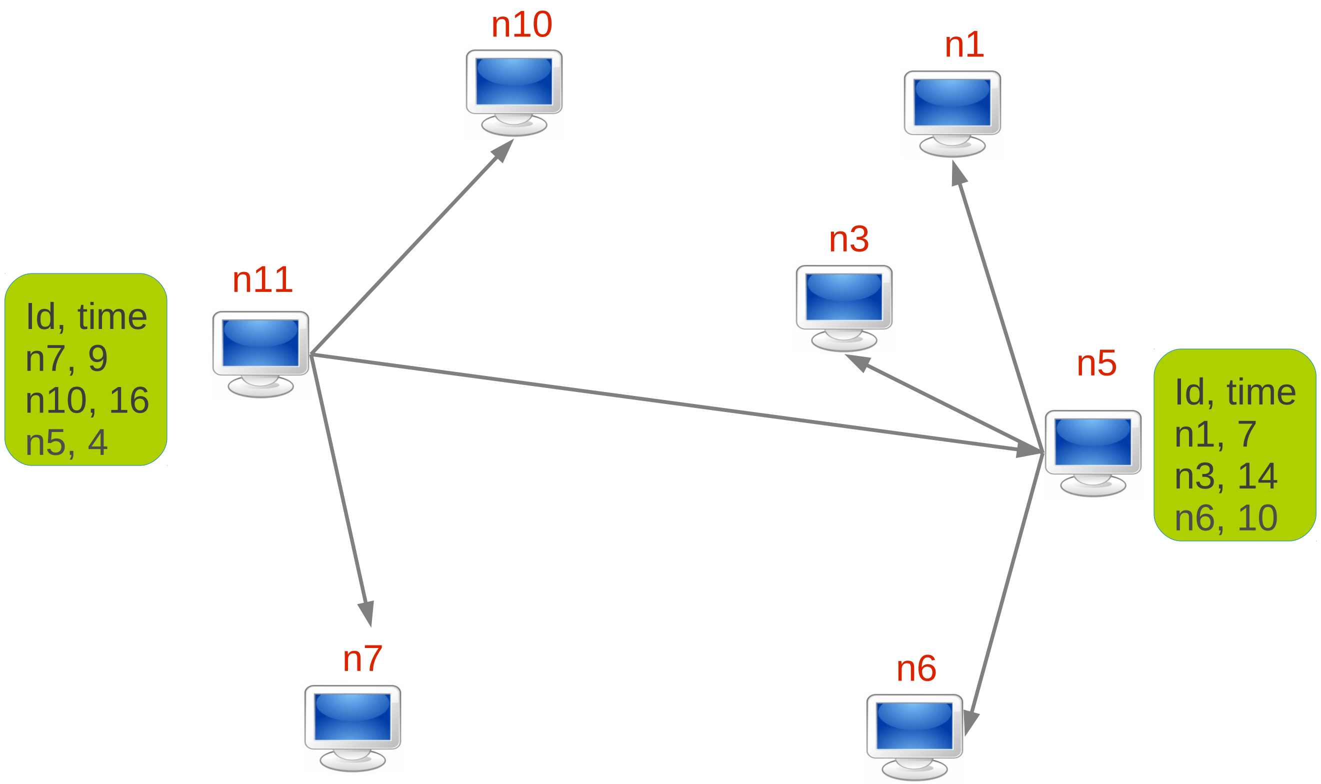
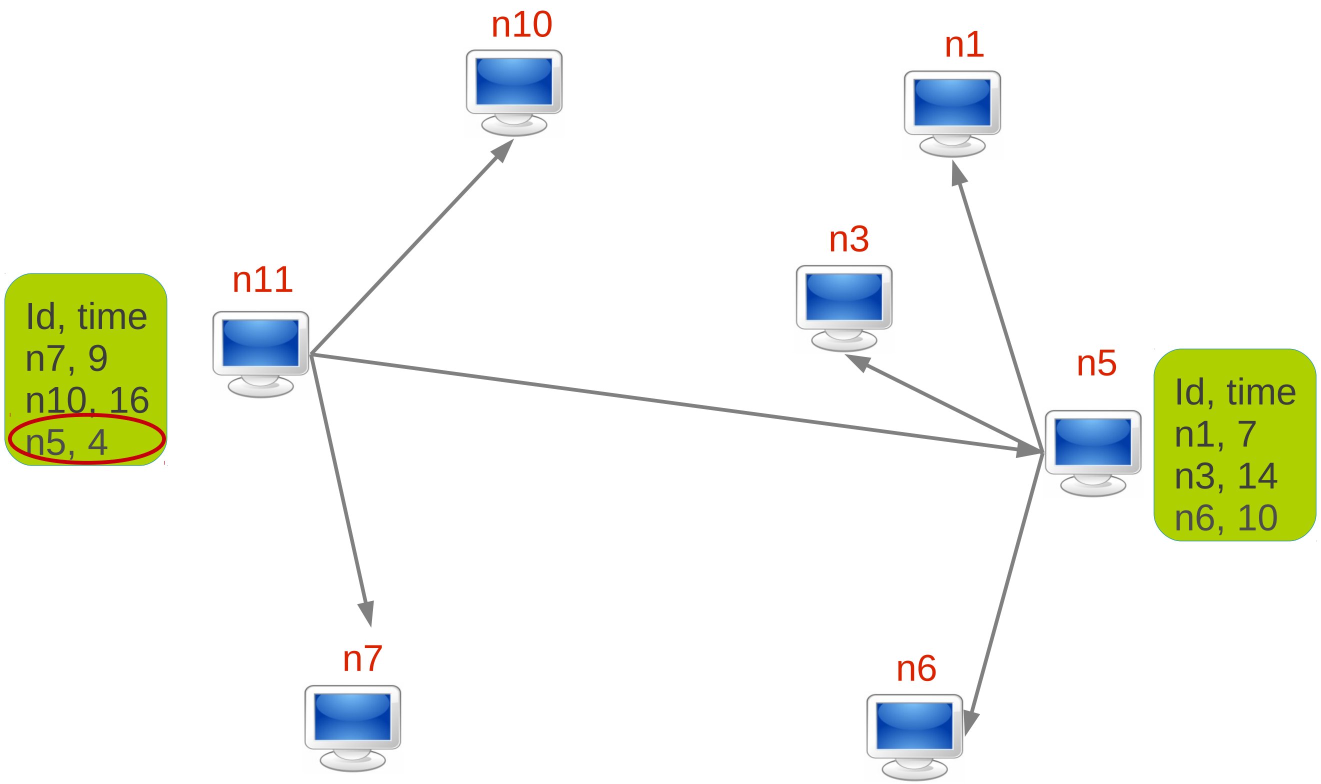


Cyclon (1/5)



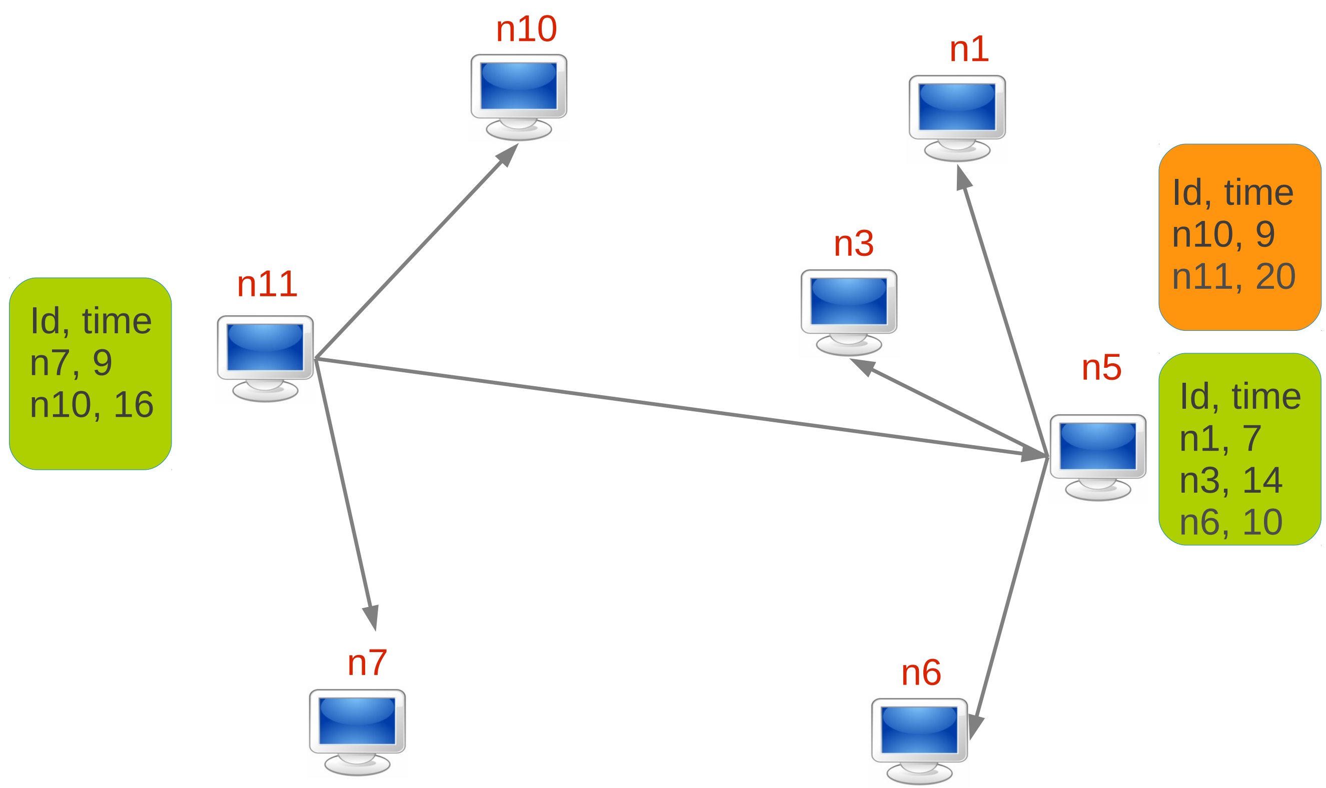
n10
n1
n3
n11
Id, time
n7, 9
n10, 16
n5, 4
n5
Id, time
n1, 7
n3, 14
n6, 10
n7
n6

Cyclon (2/5)



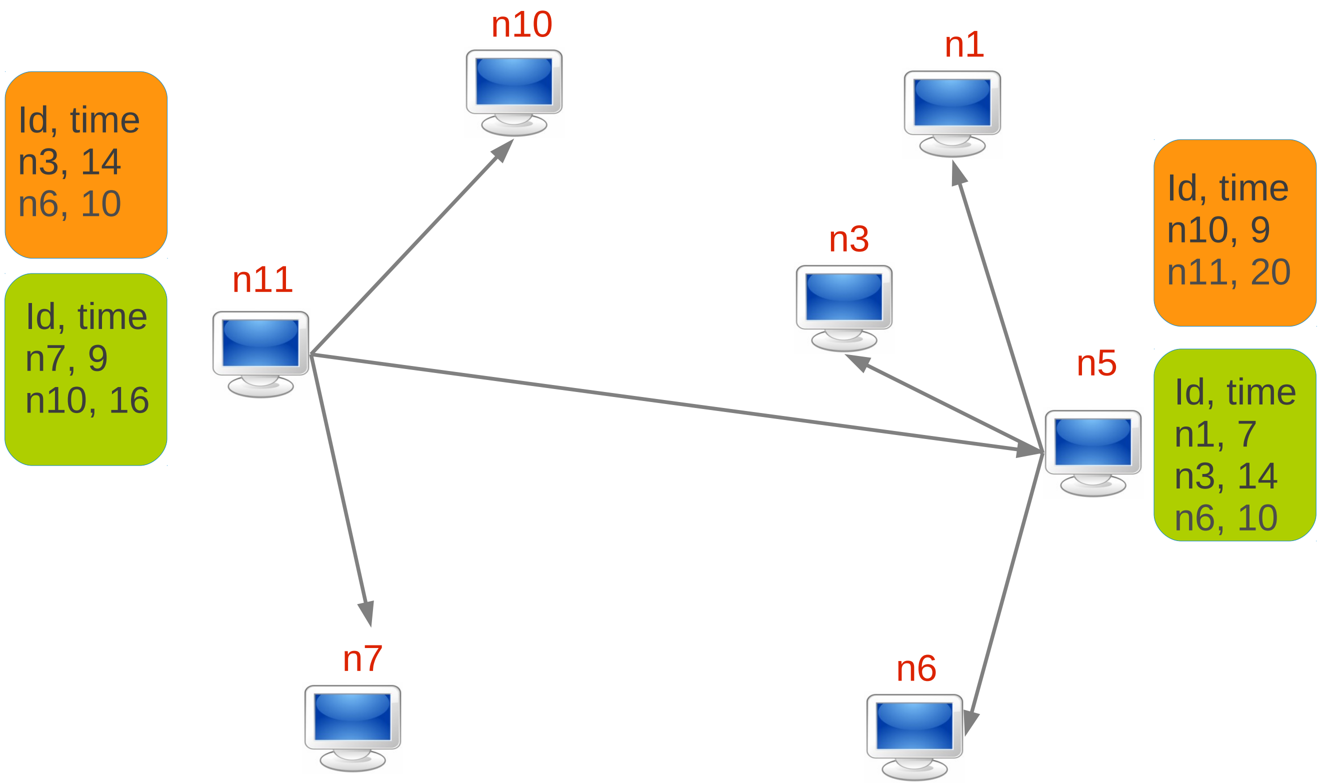
- Pick the oldest peer from my view and remove it from the view.

Cyclon (3/5)



- Pick the oldest peer from my view and remove it from the view.
- Exchange some of the peers in neighbours (swap policy)
- The active peer sends its fresh address

Cyclon (4/5)



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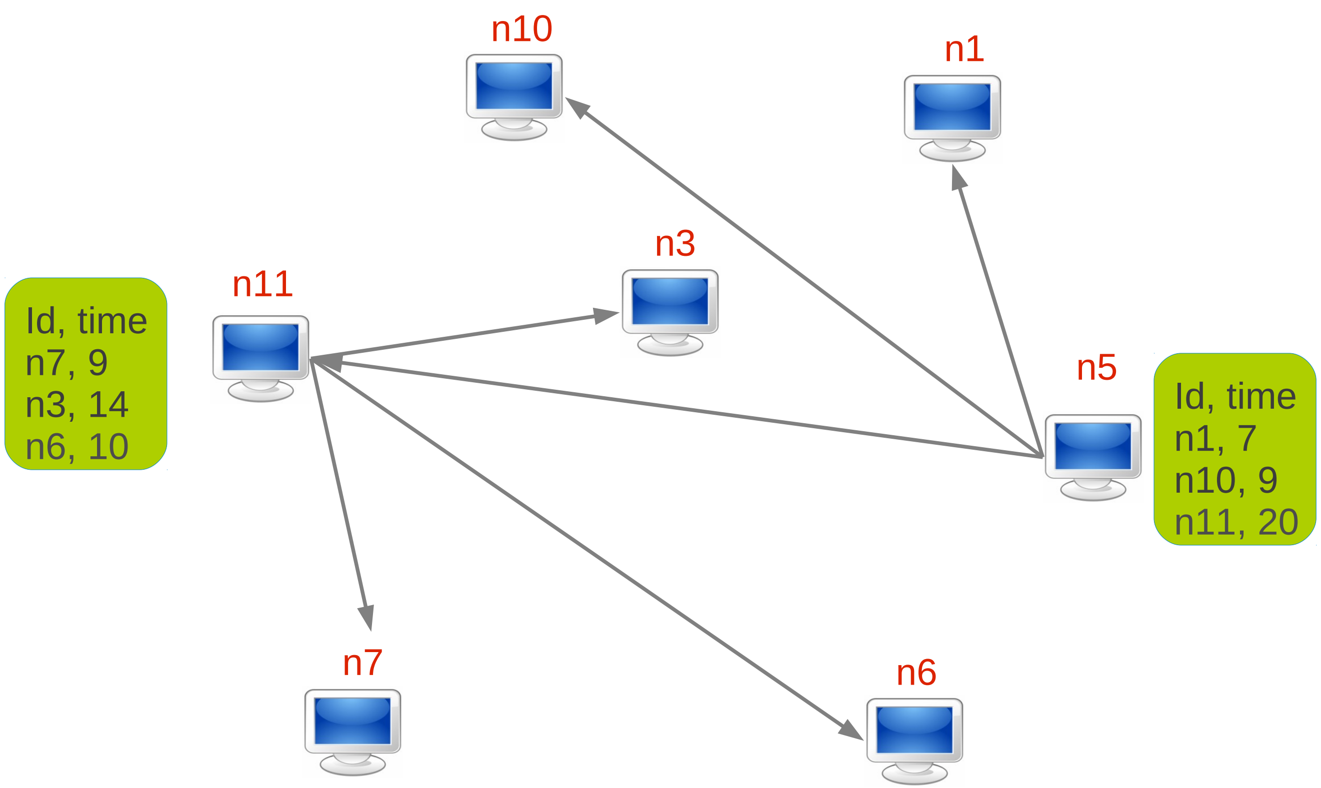
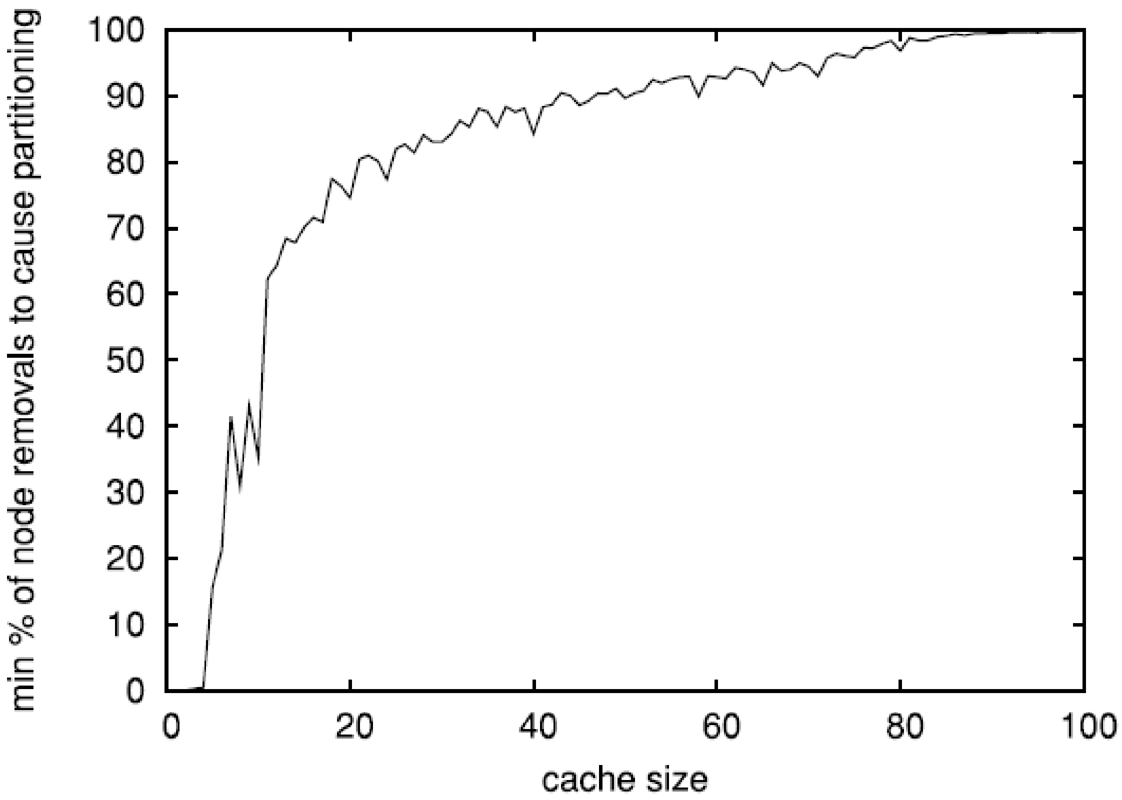
Cyclon (5/5)



- Pick the oldest peer from my view and remove it from the view.
- Exchange some of the peers in neighbours (swap policy).
- The active peer sends its fresh address

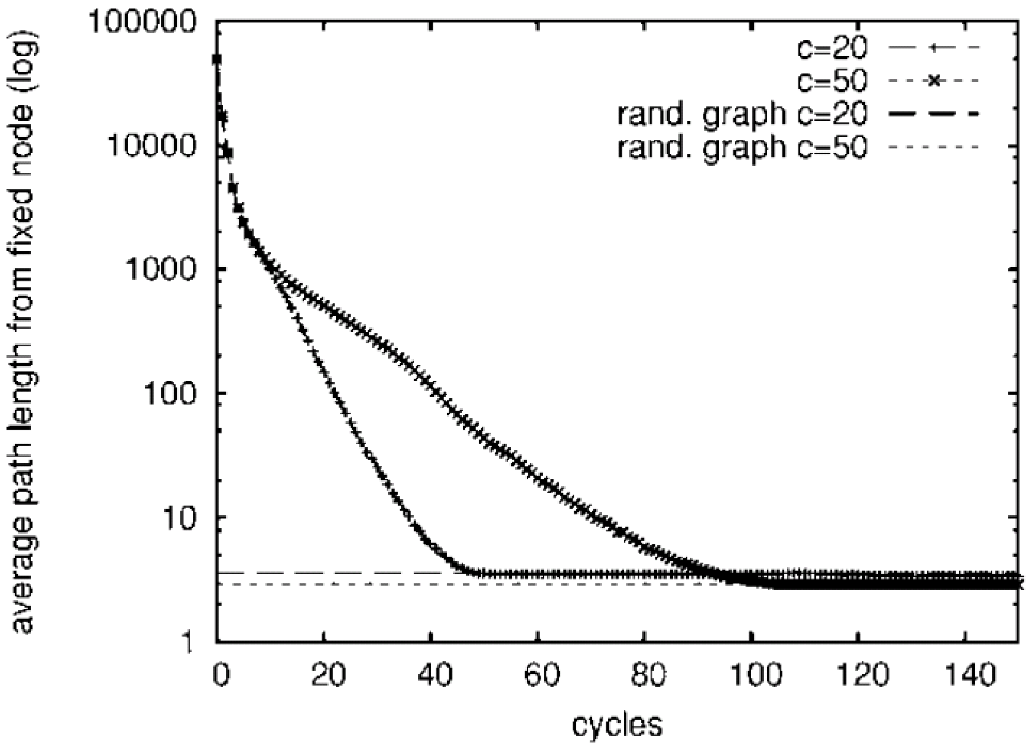
Cyclon Properties: Connectivity

- In a fail-free environment, no peer becomes disconnected in the undirected graph.
- Pointers move, so peers change from being neighbor of one peer to being the neighbor of another peer



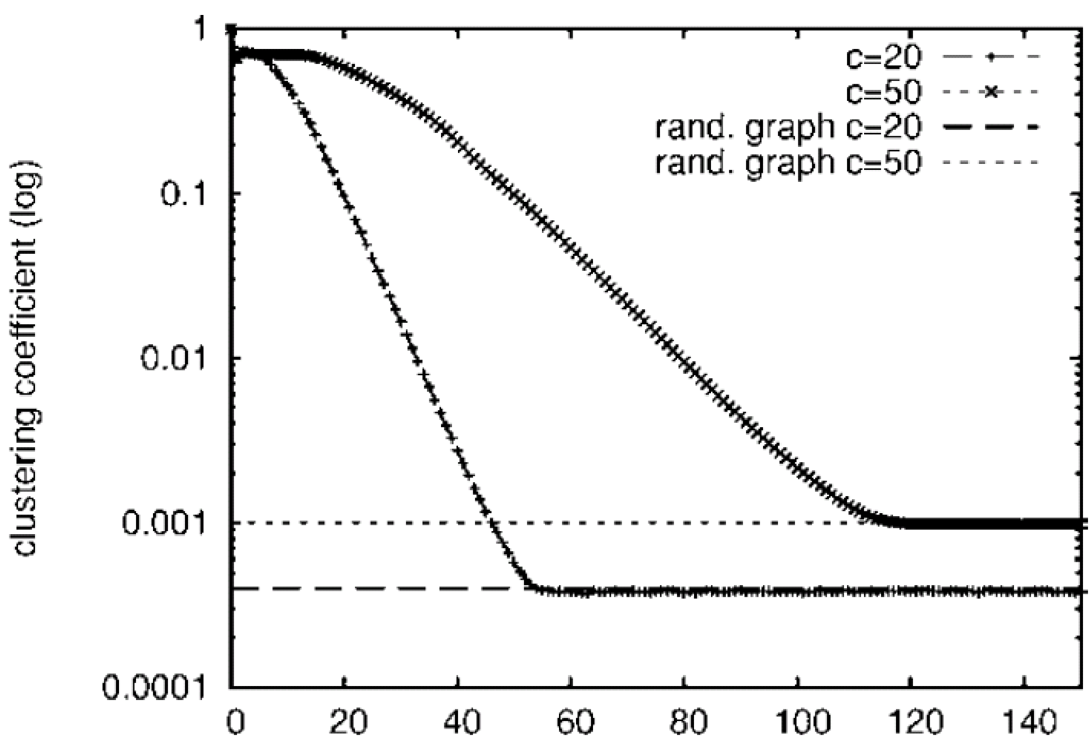
Cyclon Properties: Convergence

- Starting from a state, where peers are connected in a chain.
- Convergence is defined by having the same average path length as a random graph.

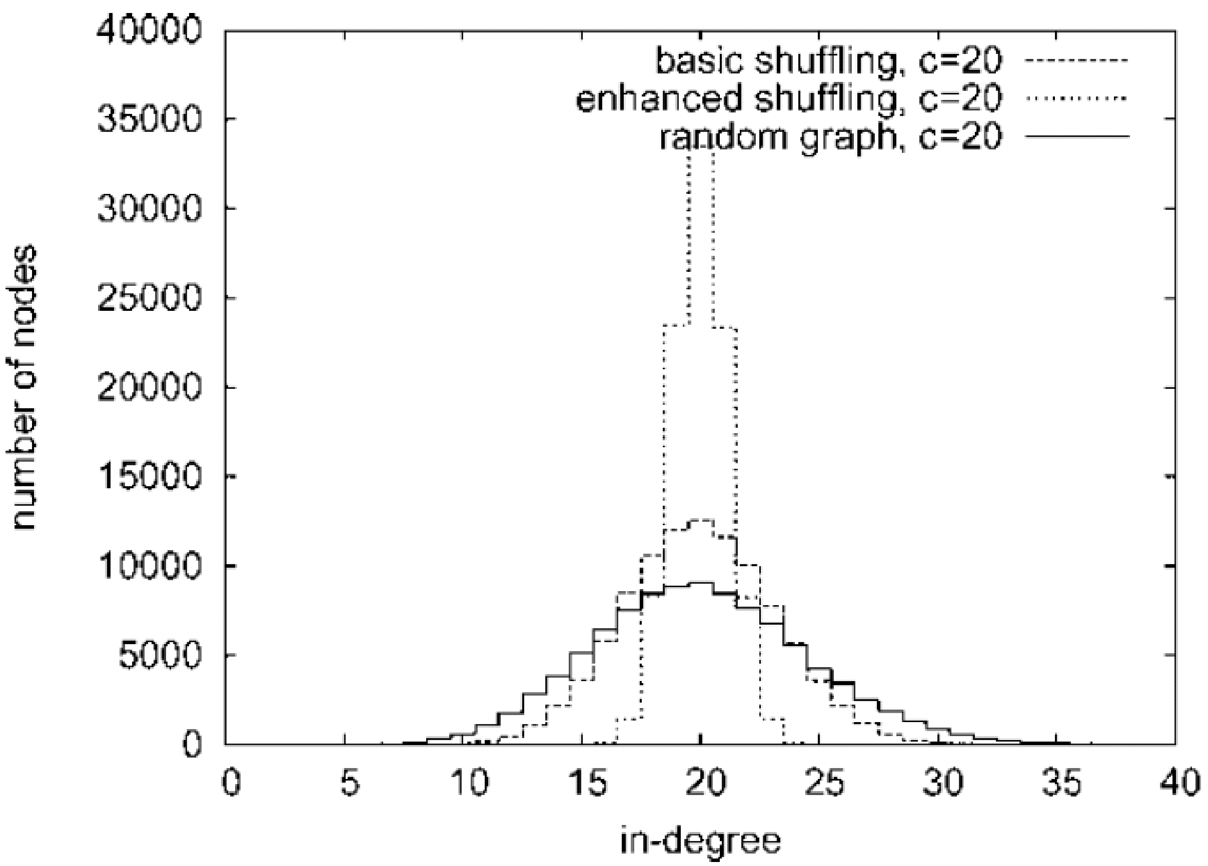


Cyclon Properties: Clustering Coefficient

- Clustering Coefficient (of a node): the ratio of existing links among the node's neighbors over the total number of possible links among them.
- Shows what percentage the neighbors of a node are also neighbors among themselves.



Cyclon Properties: Indegree Distribution



Topology Management

T-Man

- T-man is a protocol that can construct and maintain any topology with the help of a ranking function.

- The ranking function orders any set of nodes according to their desirability to be neighbors of a given node

A Generic T-Man Framework (1/2)

```
// timed event every T time units
handle
    q = view.selectPeer()
    myDescriptor = (myAddress, myProfile)
    buf = merge(view, myDescriptor)
    buf = merge(buf, rnd.view)
    send buf to q
    recv buf_q from q
    buf = merge(buf_q,view)
    view = selectView(buf)
```

A Generic T-Man Framework (2/2)

```
// receiver handler
Handle
    recv buf_p from p
    myDescriptor = (myAddress, myProfile)
    buf = merge(view, myDescriptor)
    buf = merge(buf, rnd.view)
    send buf to p
    buf = merge(buf_p,view)
    view = selectView(buf)
```

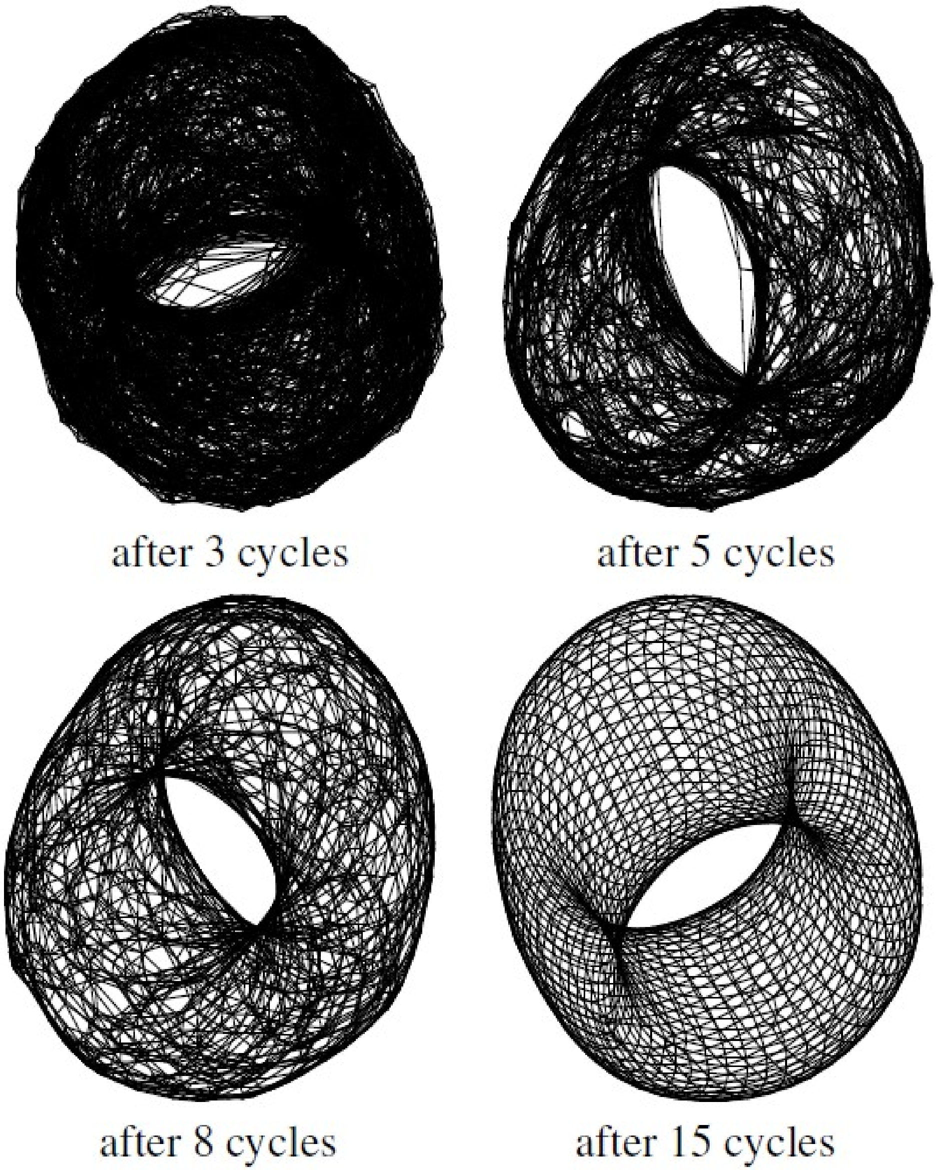
Some Comments

- SelectPeer
  - Sort all nodes in the view based on ranking.
  - Pick randomly one node from the first half.
- rnd.view
  - provides a random sample of the nodes from the entire network, e.g., using cyclon
- SelectView
  - Sort all nodes in buffer (about double size of the view)
  - Pick out c highest ranked nodes.

Ranking Function

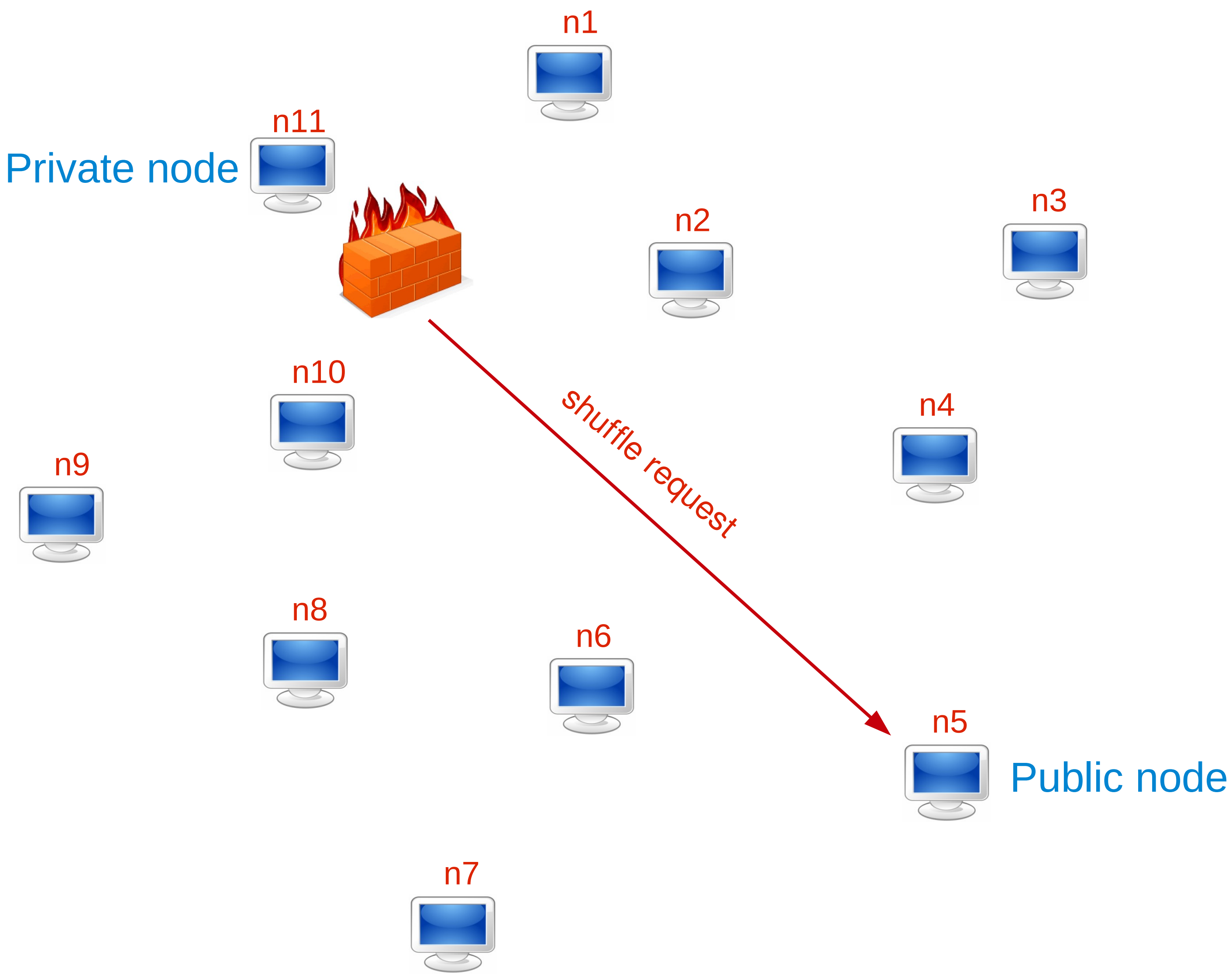
- Sample ranking functions:
  - Line: $d(a, b) = |a - b|$
  - Ring: $d(a, b) = \min(N - |a - b|, |a - b|)$

Illustration of T-Man

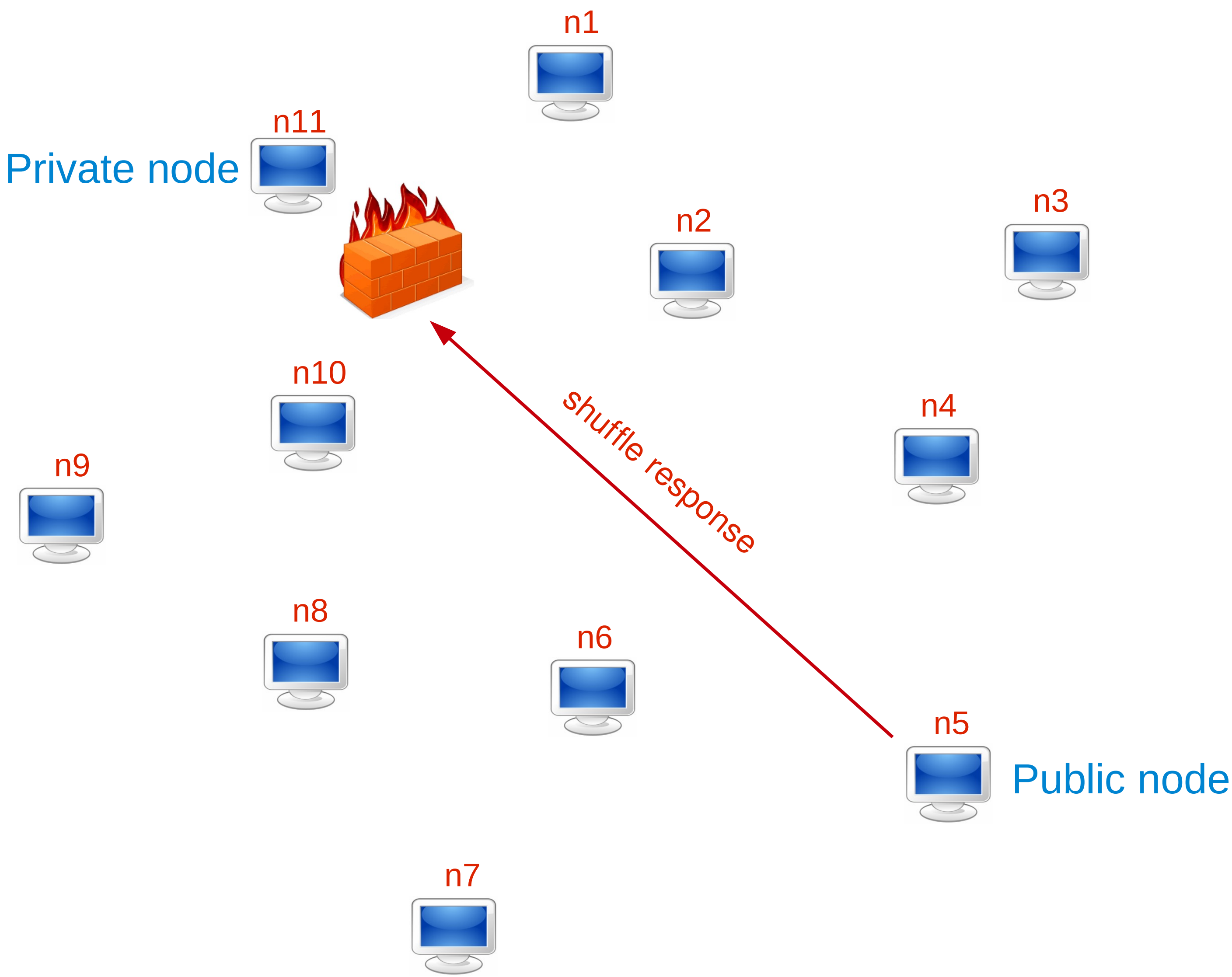


Connectivity Problems on the Open Internet

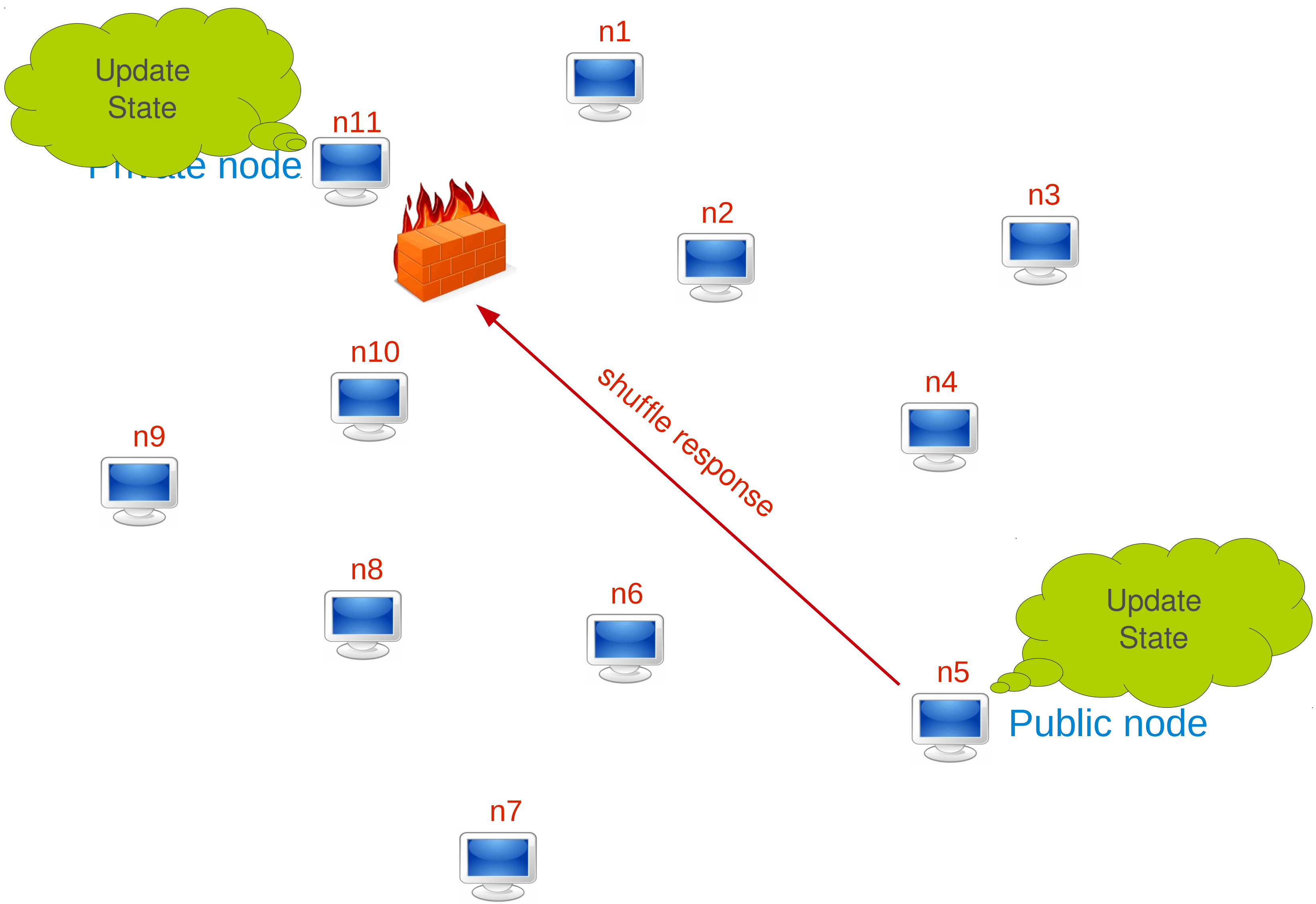
NAT Environments (1/4)



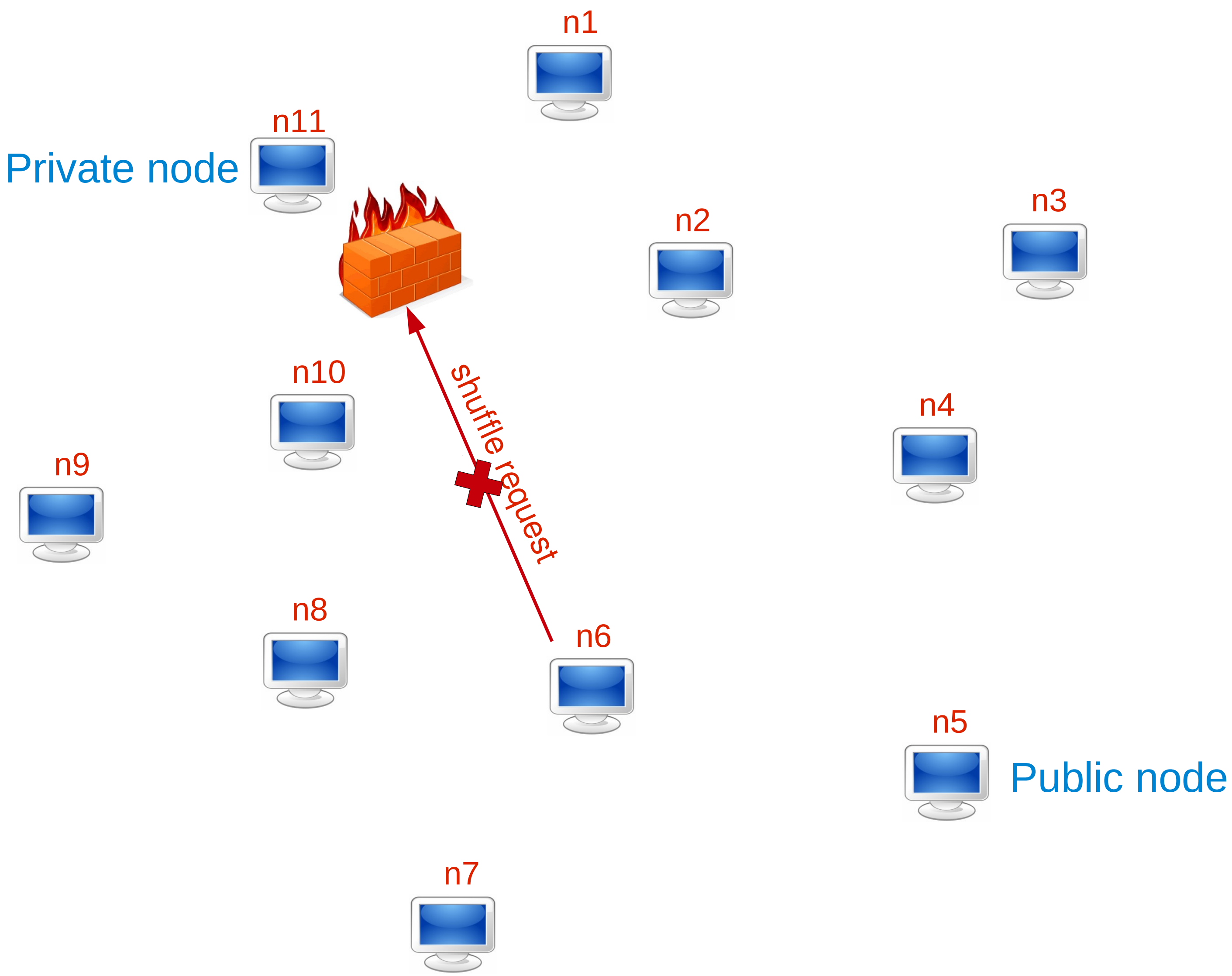
NAT Environments (1/4)



NAT Environments (1/4)

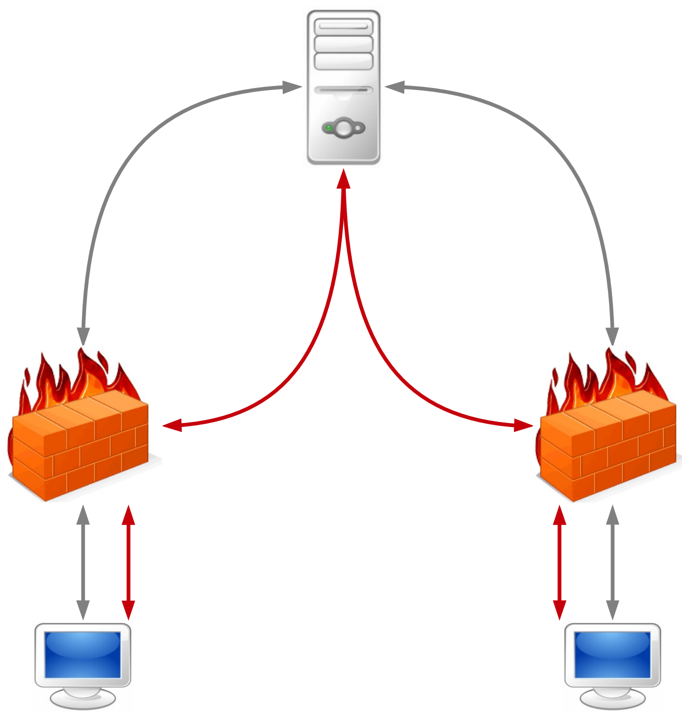


NAT Environments (1/4)



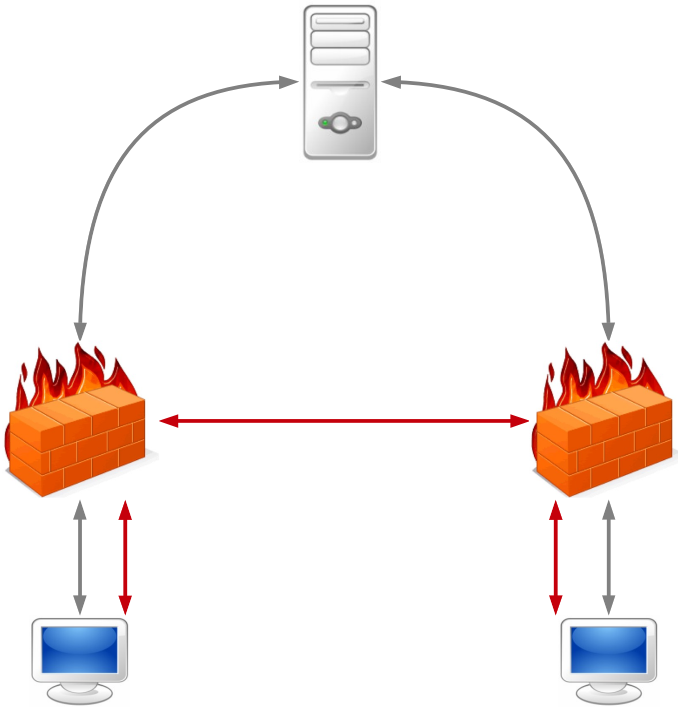
Solutions for Communicating with Private Nodes (1/2)

- Relay communications to the private node using a public relay node.



Solutions for Communicating with Private Nodes (2/2)

- Use a NAT hole-punching algorithm to establish a direct connection to the private node using a public rendezvous node.



Relaying or Hole Punching?

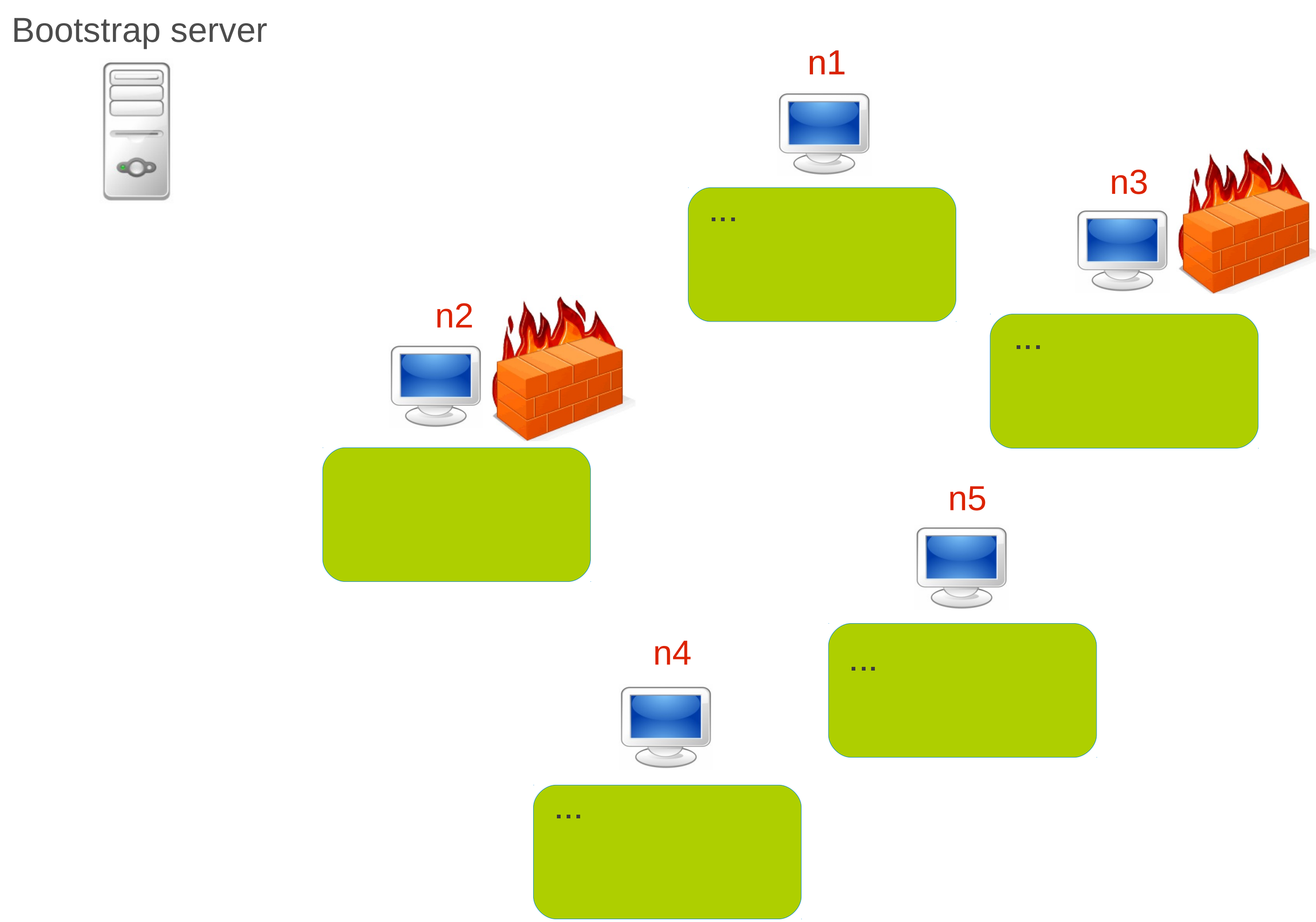
- Relaying?
  - Lower latency message exchange.
    - Enables lower gossip cycle periods.
    - Necessary in dynamic networks

- Hole punching?
  - Decreases load on public nodes.
    - But not if shuffle messages are small.

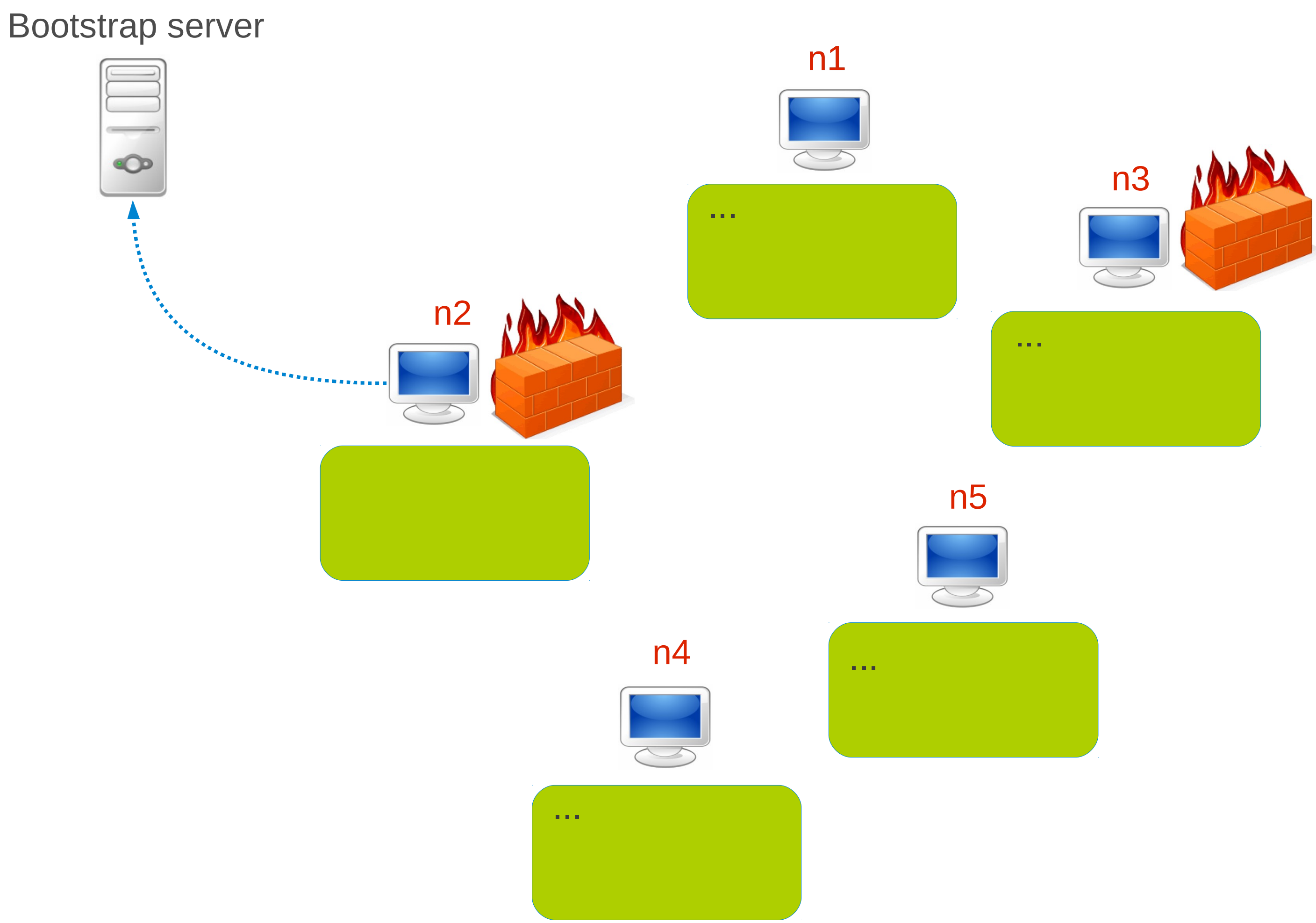
Gozar as a NAT-aware Peer Sampling Example

- In Gozar, each private node connects to one or more public nodes, called partners that act as a relay or rendezvous server on behalf of the private node.
- A node's descriptor consists of both its own address, its NAT type, and its partners' addresses at the time of descriptor creation.
- When a node wants to gossip with a private node, it uses the partner addresses in its descriptor to communicate with the private node.

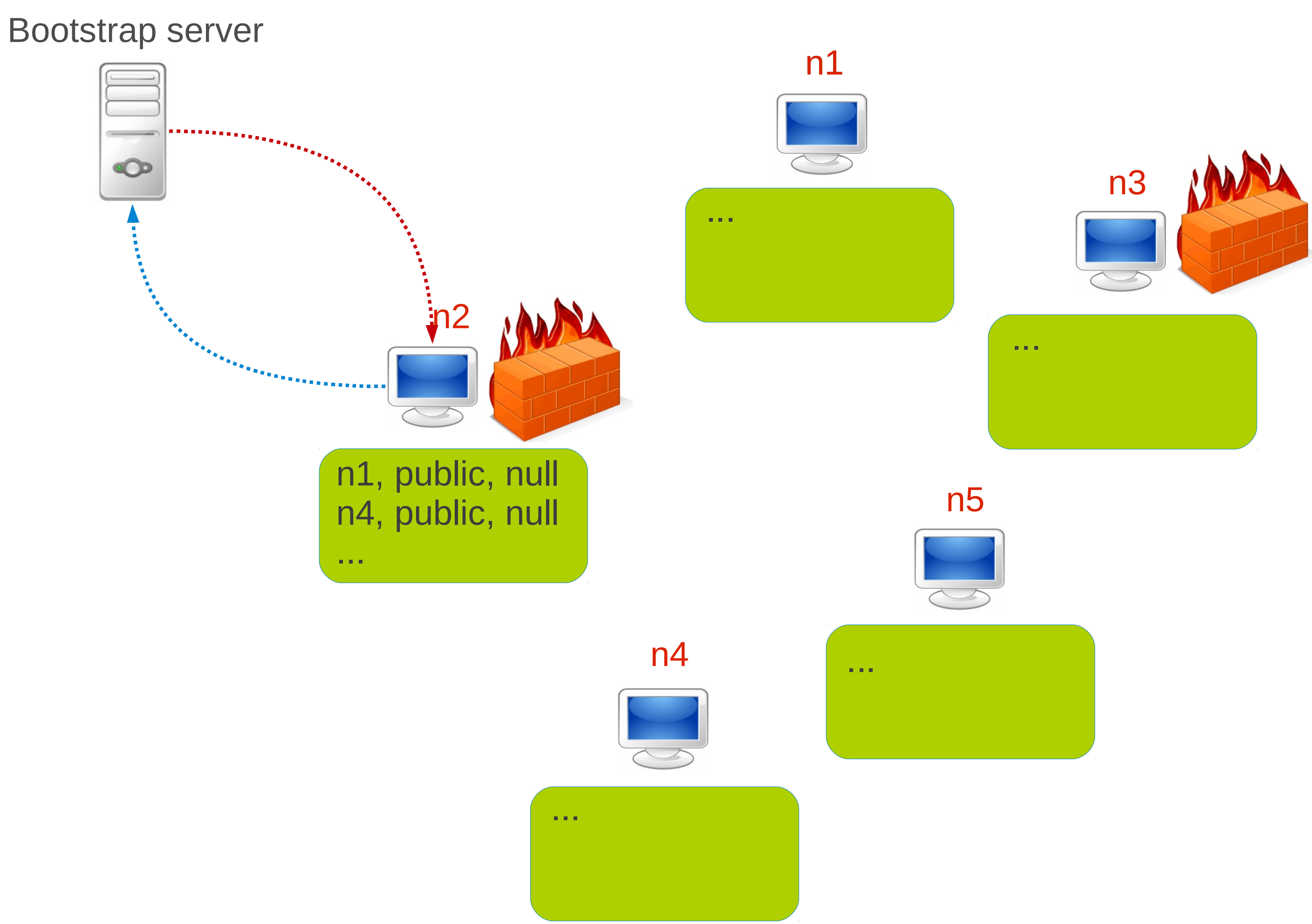
Partnering (1/10)



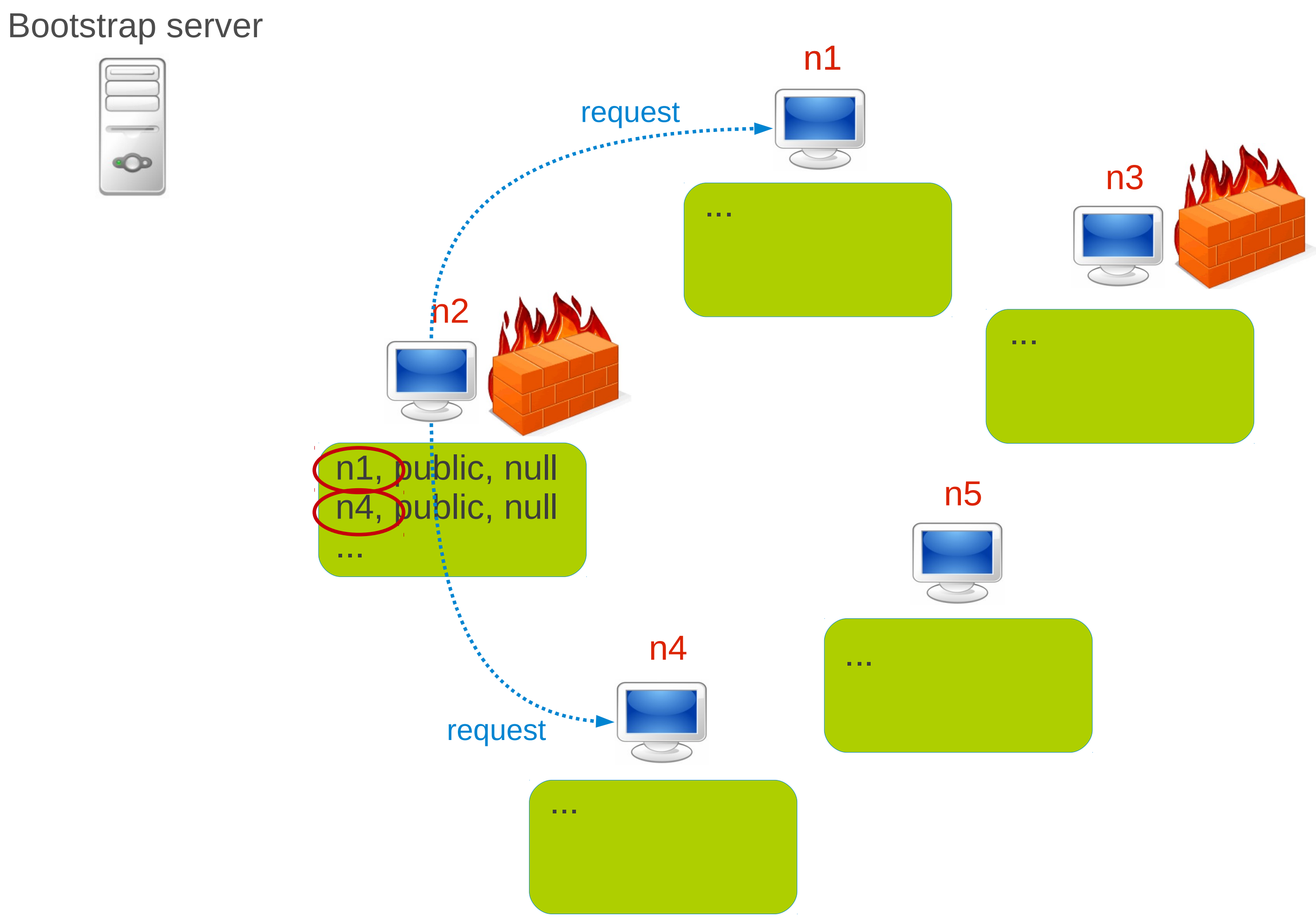
Partnering (2/10)



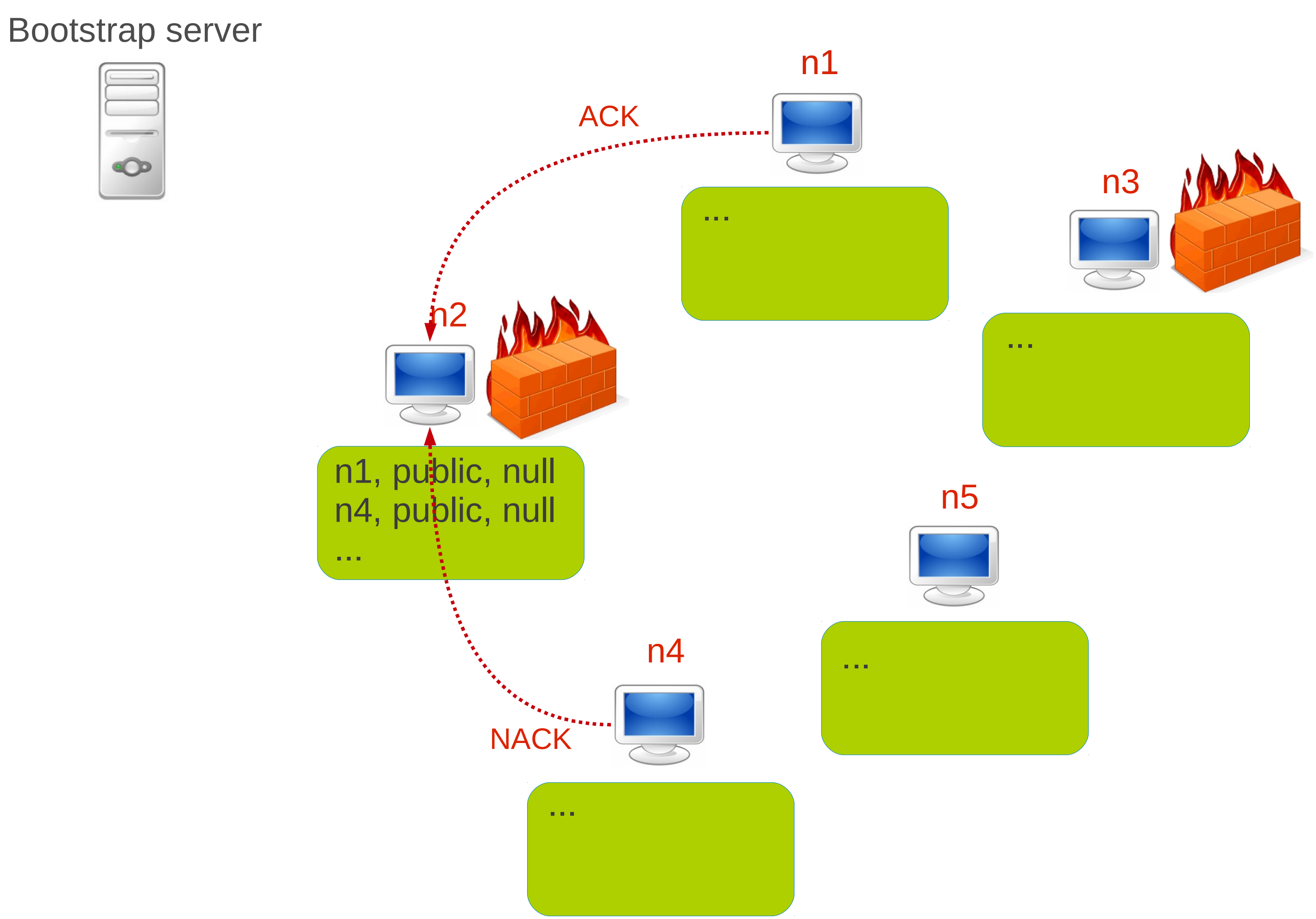
Partnering (3/10)



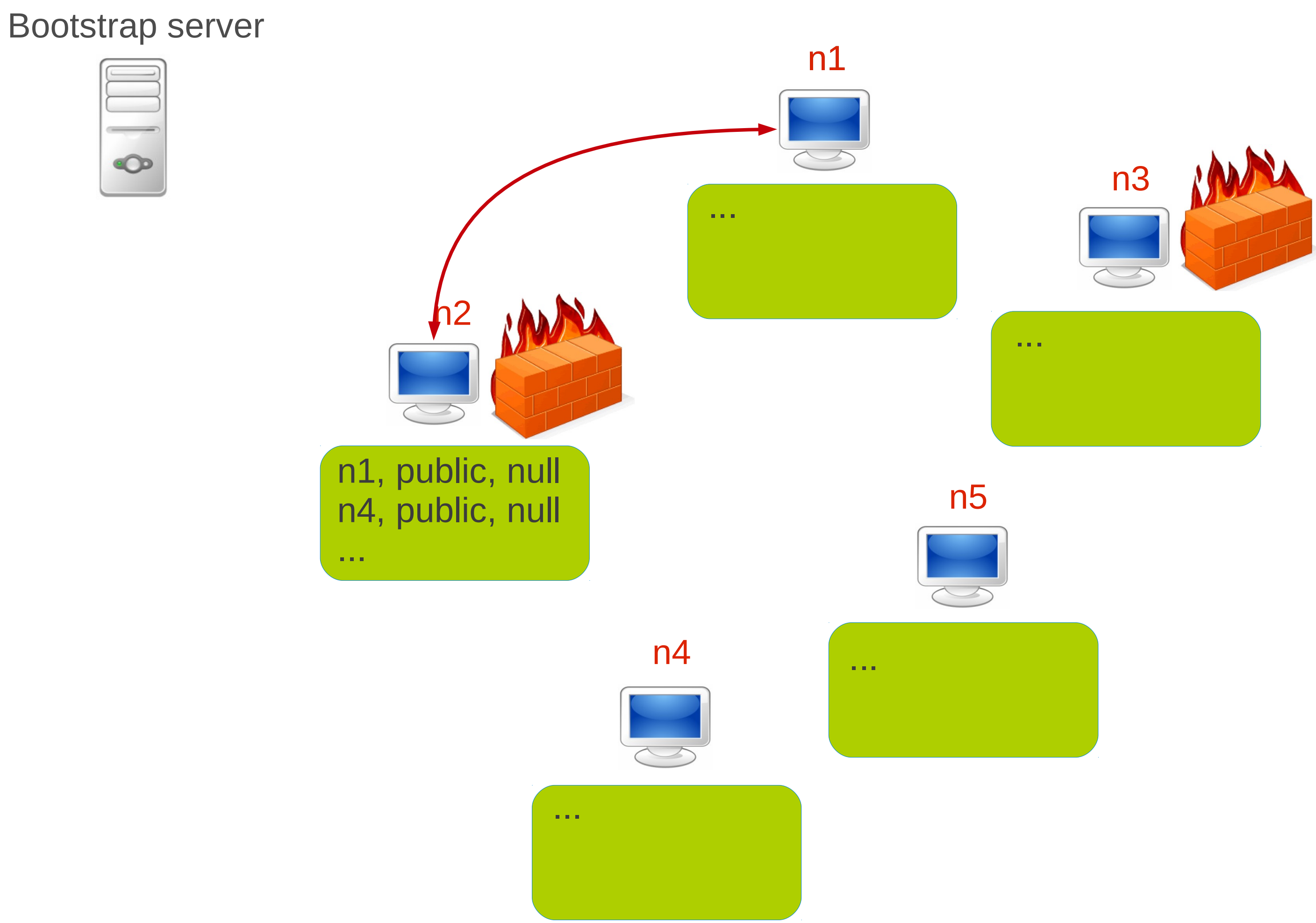
Partnering (4/10)



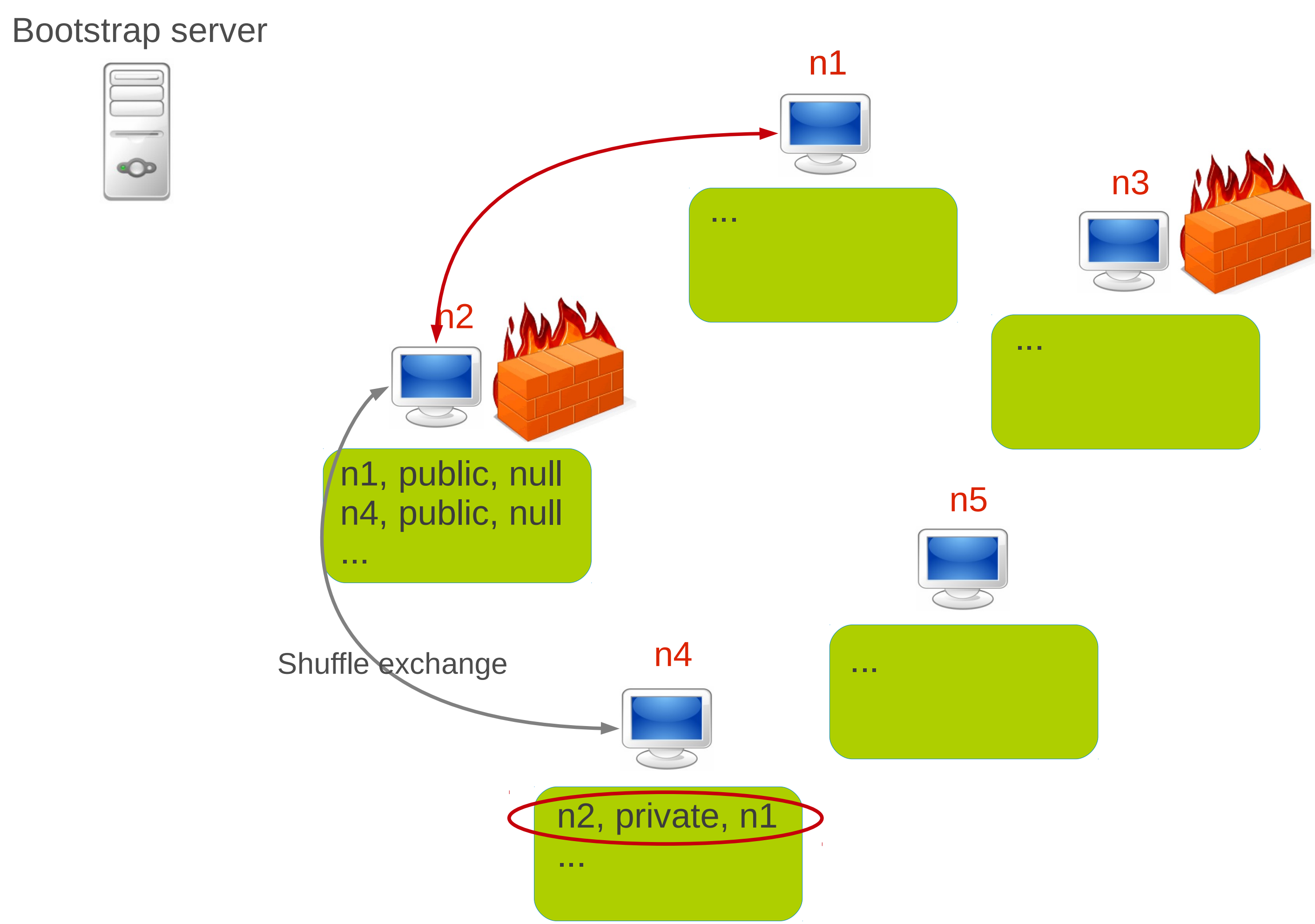
Partnering (5/10)



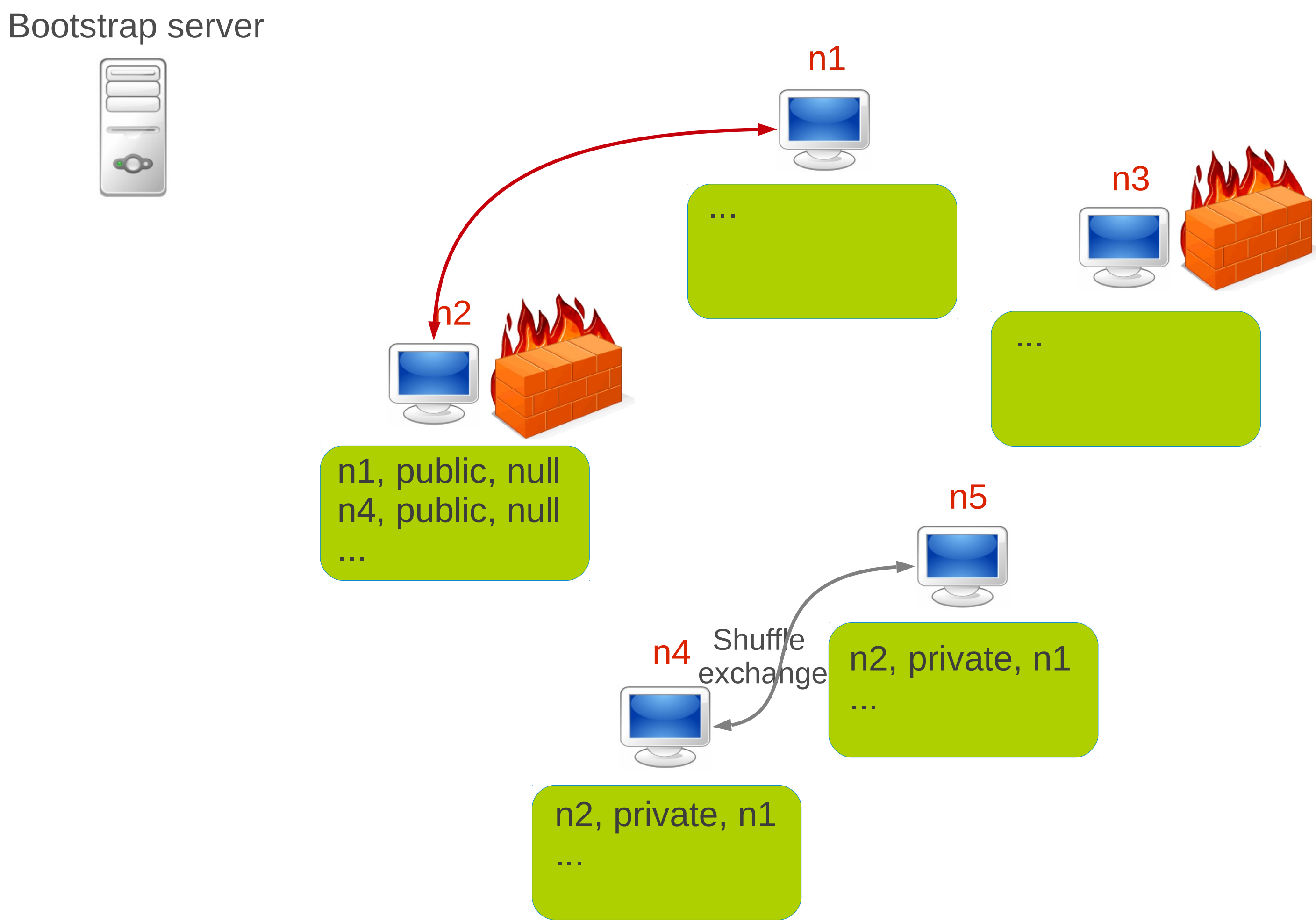
Partnering (6/10)



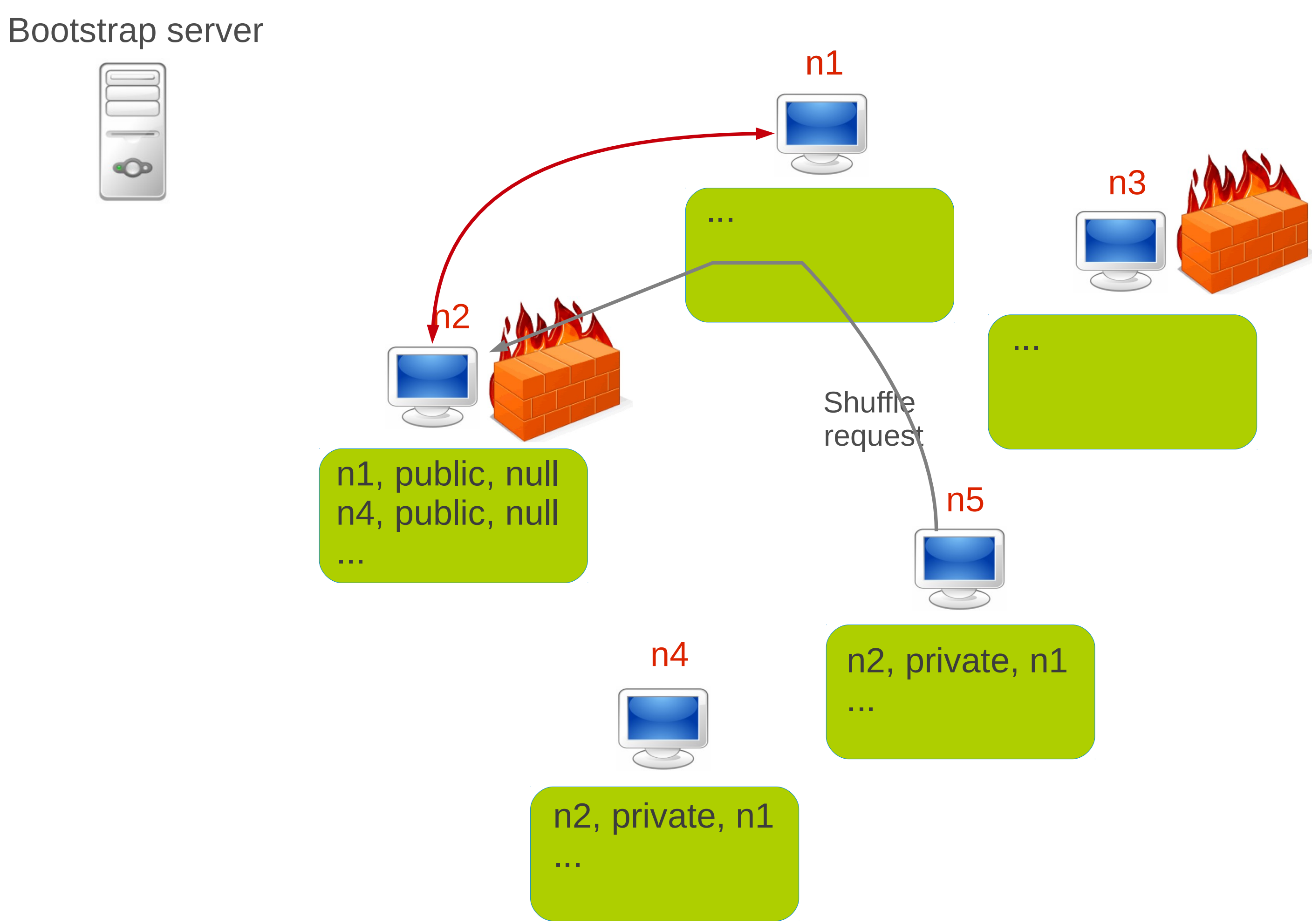
Partnering (7/10)



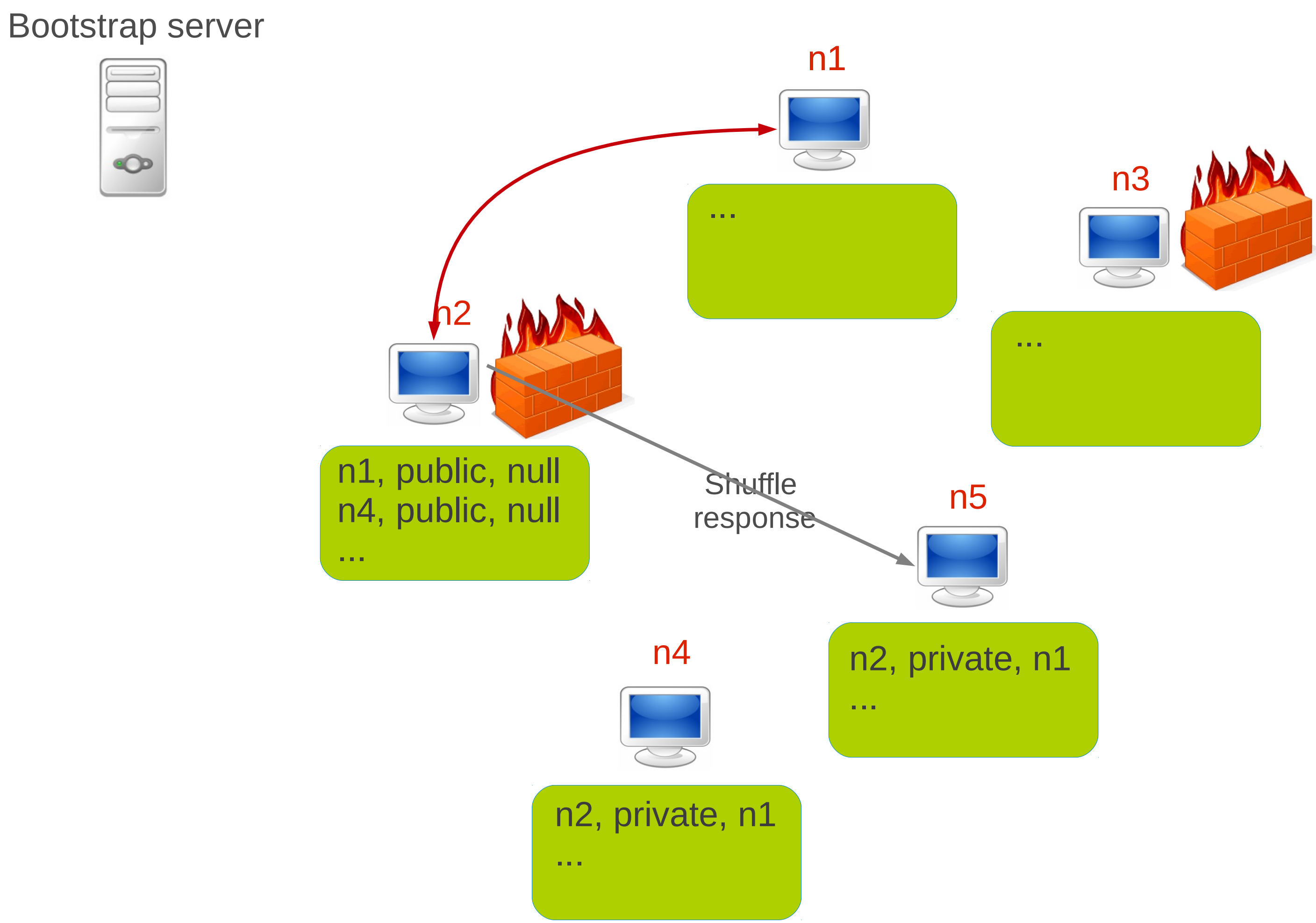
Partnering (8/10)



Partnering (9/10)



Partnering (10/10)



Summary

Summary

- Epidemics algorithms are important technique to solve problems in dynamic large scale systems
  - Scalable
  - Simple
  - Robust to node failures, message loss and transient network disruptions (network partitions …)

- Applications:
  - Aggregation
  - Membership management
  - Topology management

Question

Acknowledgement
Some slides were derived from the slides of Alberto Montresor and Seif Haridi