Computer Science 425
Distributed Systems

CS 425 / CSE 424 / ECE 428

Fall 2012

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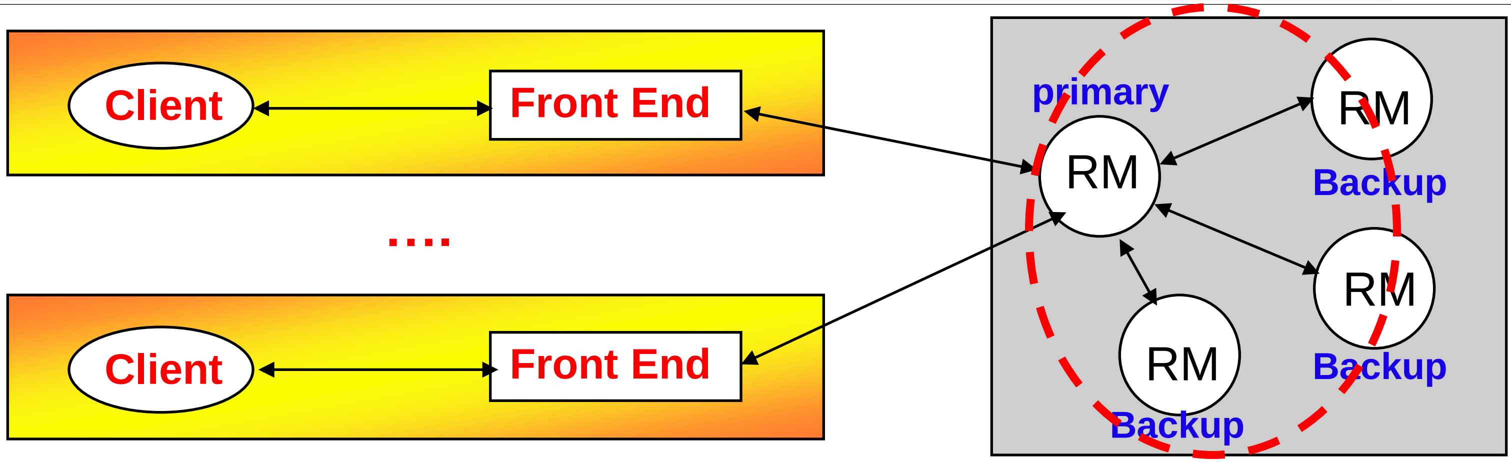
Lecture 19

Gossiping

Reading: Section 18.4 (relevant parts)

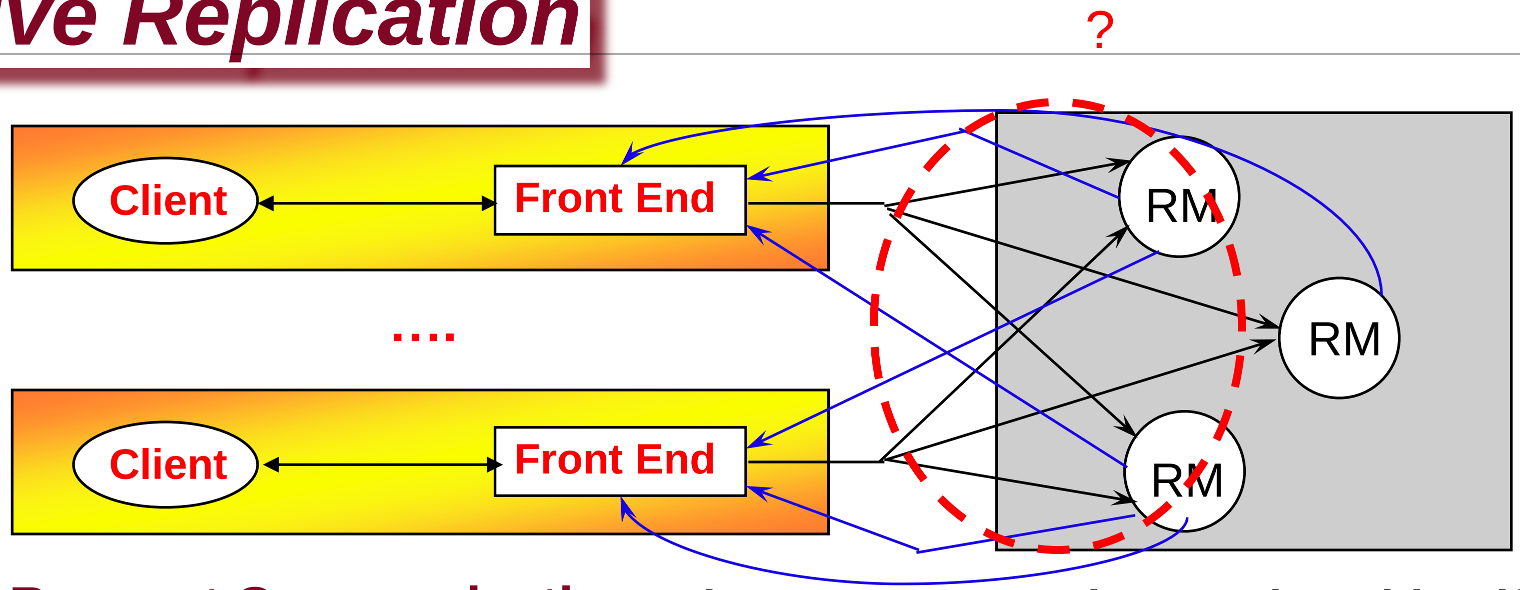
Passive (Primary-Backup) Replication

?



- **Request Communication:** the request is issued to the primary RM and carries a unique request id.
- **Coordination:** Primary takes requests atomically, in order, checks id (resends response if not new id.)
- **Execution:** Primary executes & stores the response
- **Agreement:** If update, primary sends updated state/result, req-id and response to all backup RMs (1-phase commit enough).
- **Response:** primary sends result to the front end

Active Replication



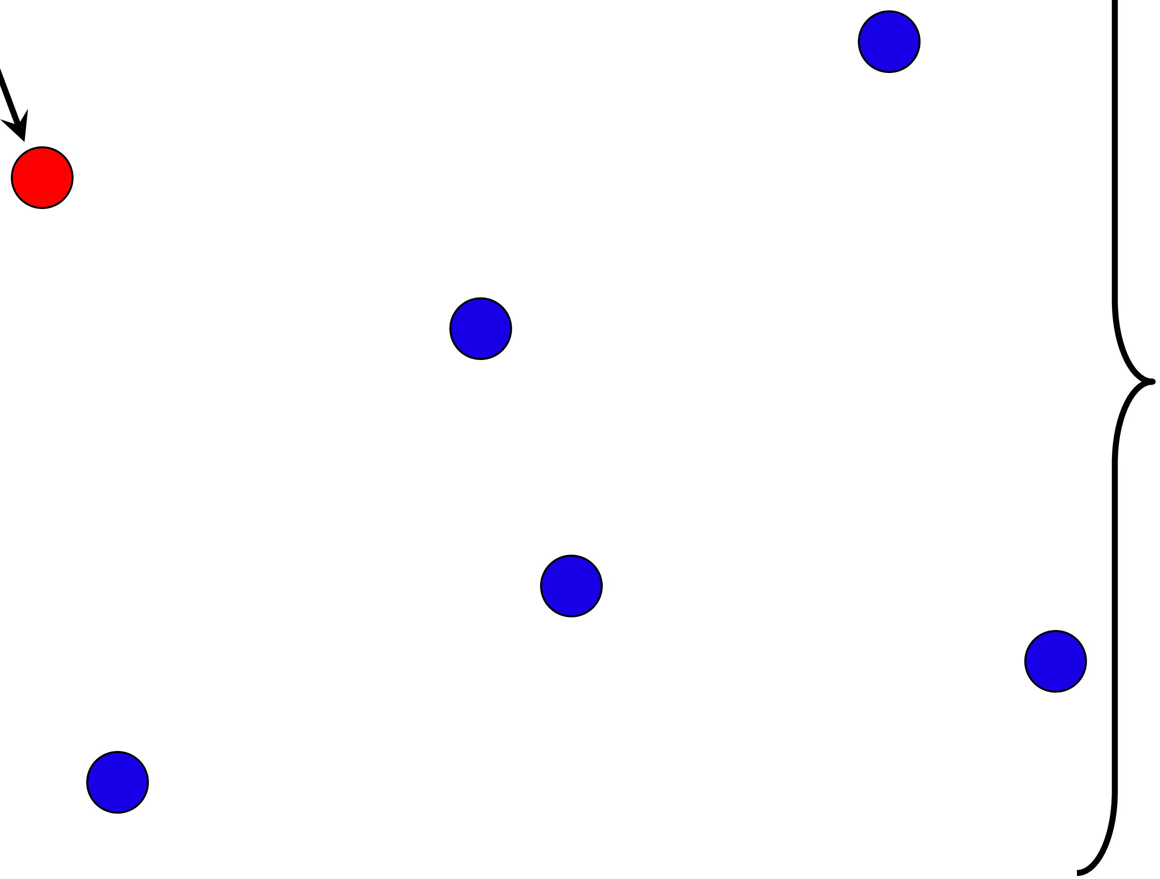
- **Request Communication:** The request contains a unique identifier and is multicast to all by a reliable totally-ordered multicast.
- **Coordination:** Group communication ensures that requests are delivered to each RM in the same order (but may be at different physical times!).
- **Execution:** Each replica executes the request. (Correct replicas return same result since they are running the same program, i.e., they are *replicated protocols* or *replicated state machines*)
- **Agreement:** No agreement phase is needed, because of multicast delivery semantics of requests
- **Response:** Each replica sends response directly to FE

Eager versus Lazy

- **Eager replication, e.g., B-multicast, R-multicast, etc. (previously in the course)**
  - **Multicast request to all RMs immediately**
- **Alternative: Lazy replication**
  - **"Don't hurry; Be lazy."**
  - **Allow replicas to converge eventually and lazily**
  - **Propagate updates and queries lazily, e.g., when network bandwidth available**
  - **Allow other RMs to be disconnected/unavailable**
  - **May provide weaker consistency than sequential consistency, but <u>improves performance</u>**
- **Lazy replication can be provided by using gossiping**

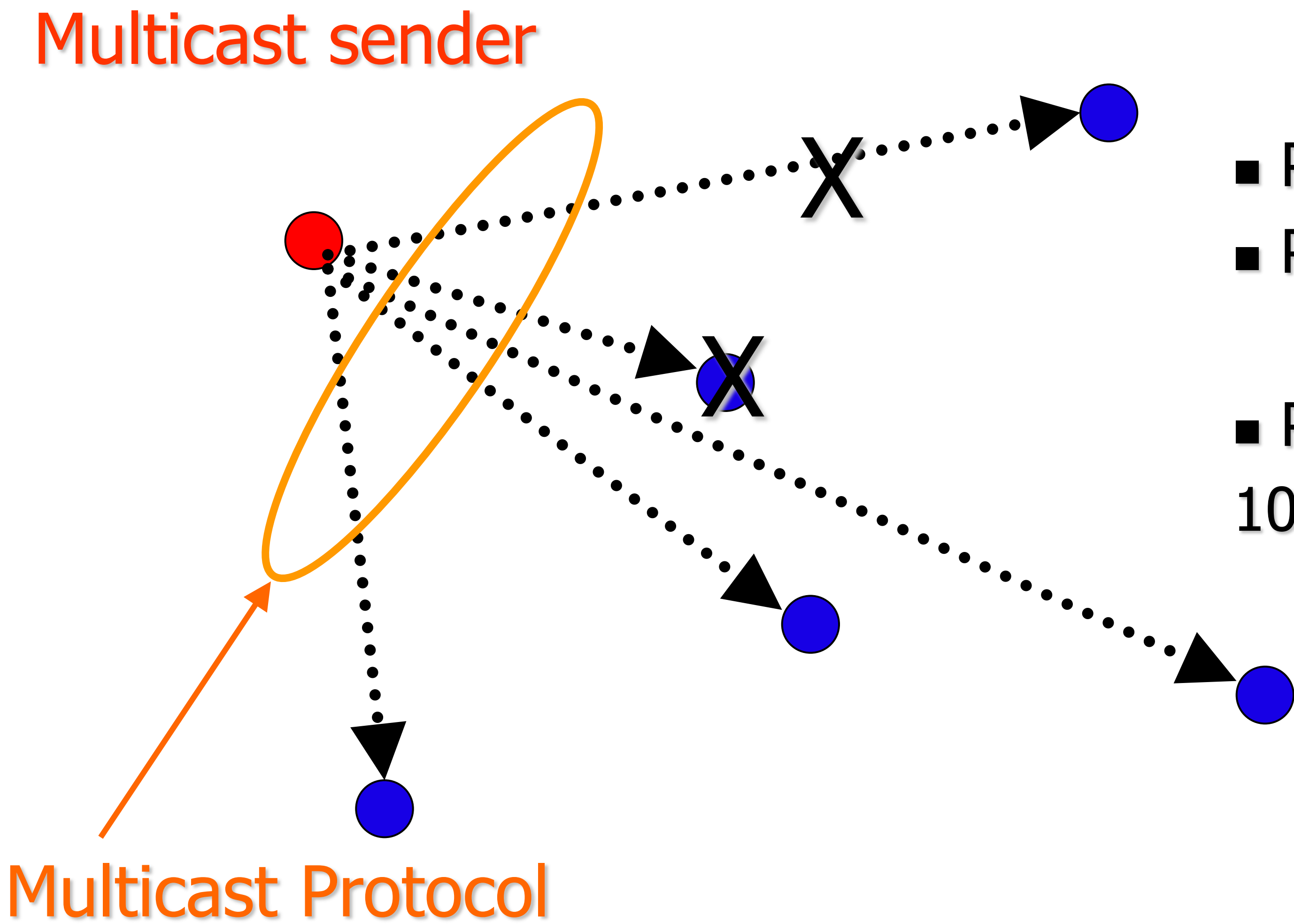
Multicast

Process with a piece of information
to be communicated to everyone



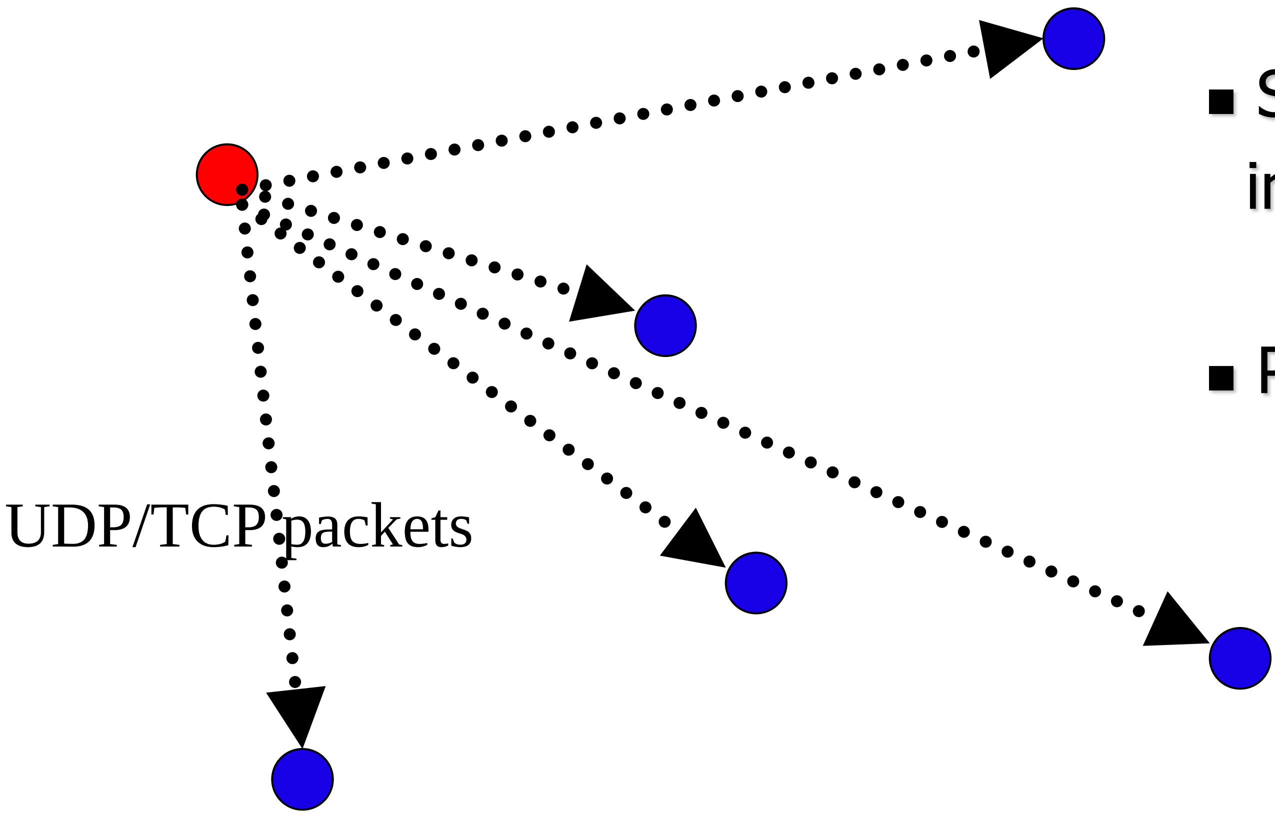
Distributed
Group of
Processes
at Internet-
based hosts

Fault-tolerance and Scalability



- Process crashes
- Packets may be dropped
- Possibly 1000's of processes

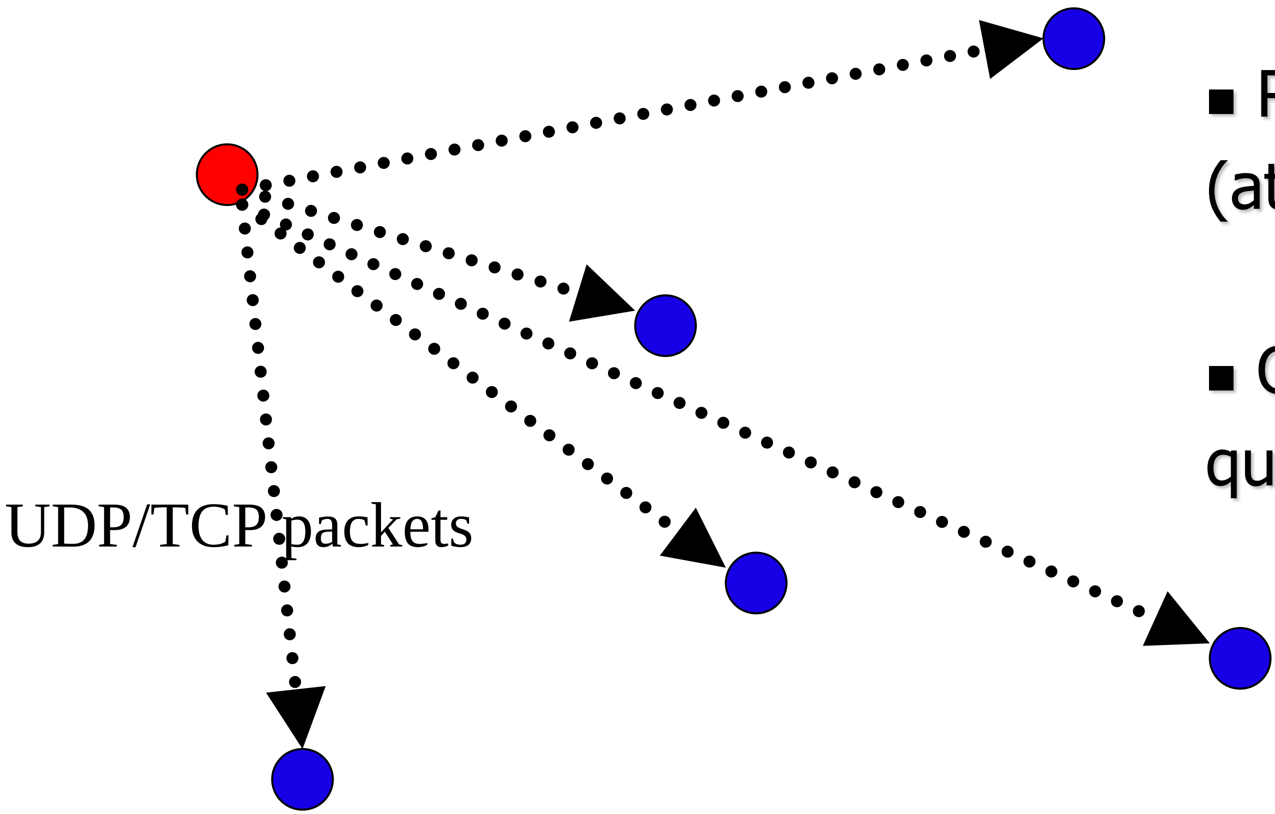
Centralized (B-multicast)



- Simplest implementation
- Problems?

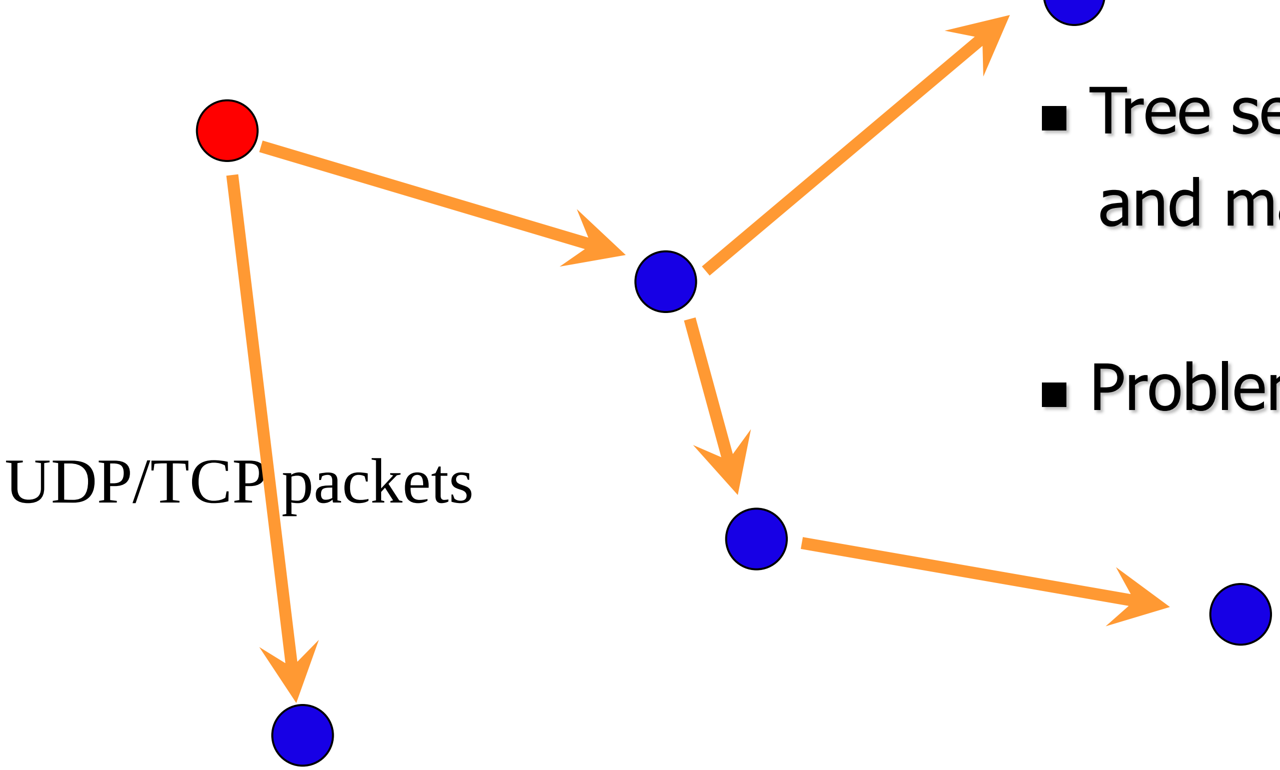
R-multicast

+ Every process B-multicasts the message



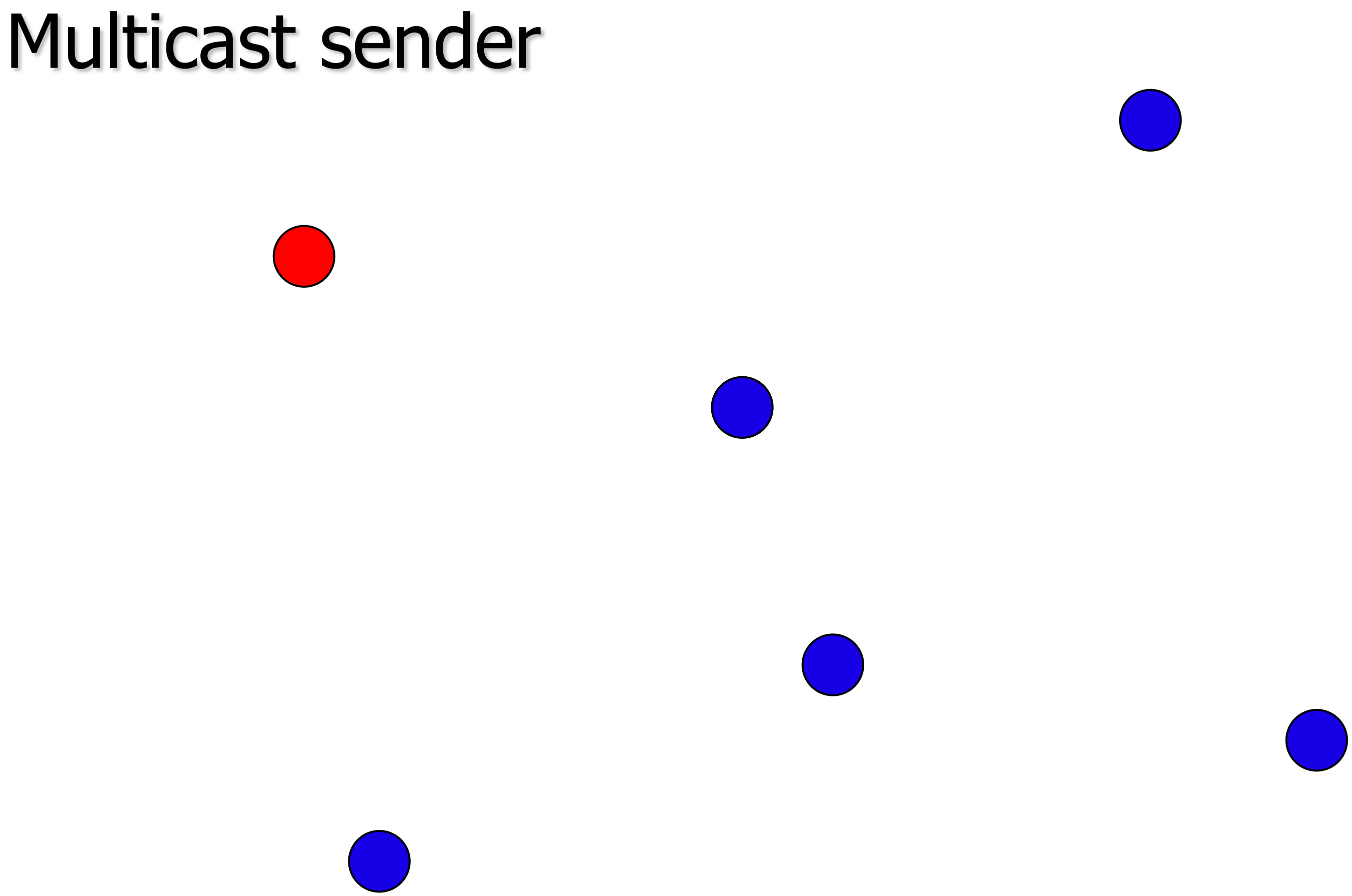
- Reliability (atomicity)
- Overhead is quadratic in N

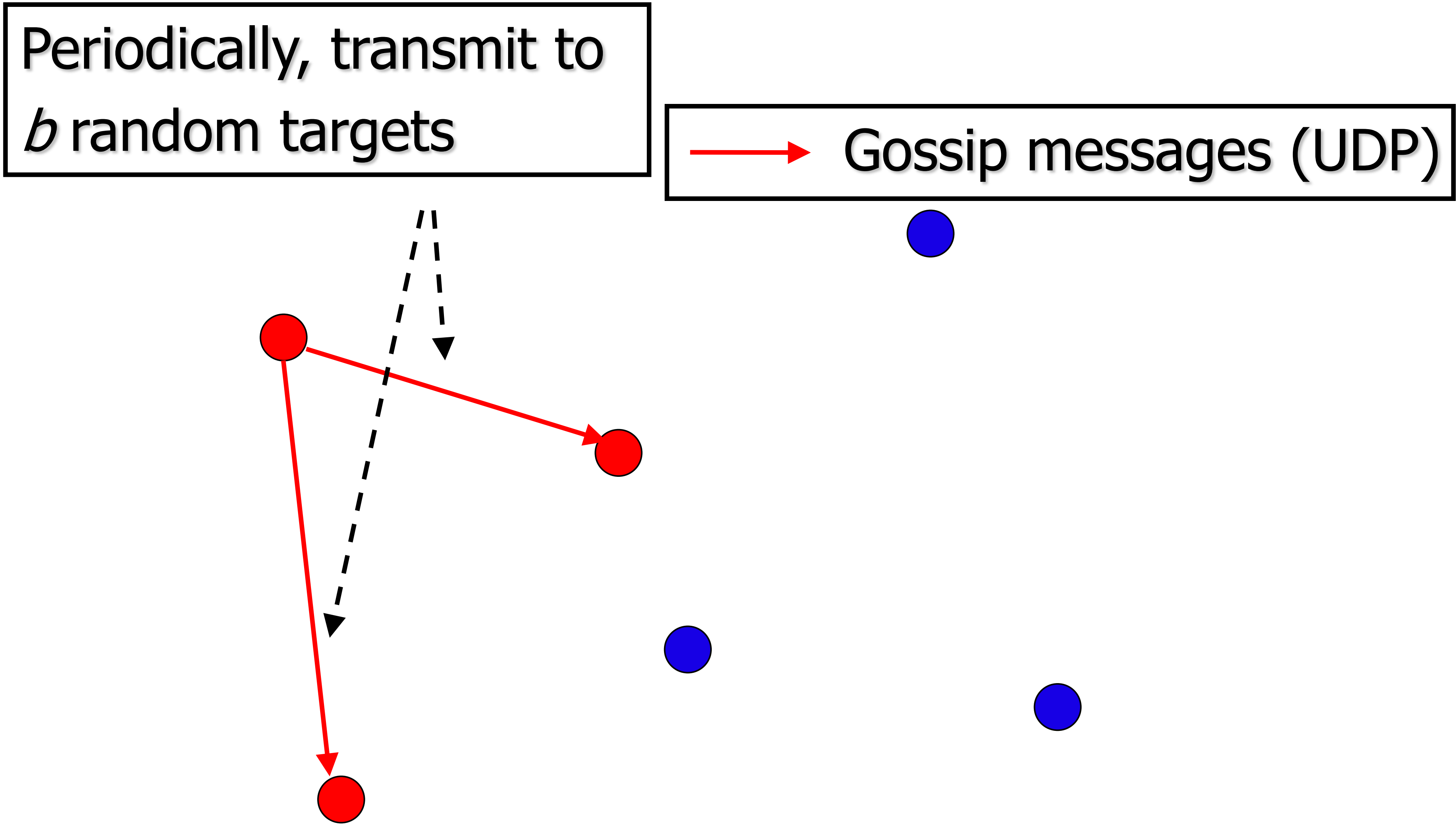
Tree-Based

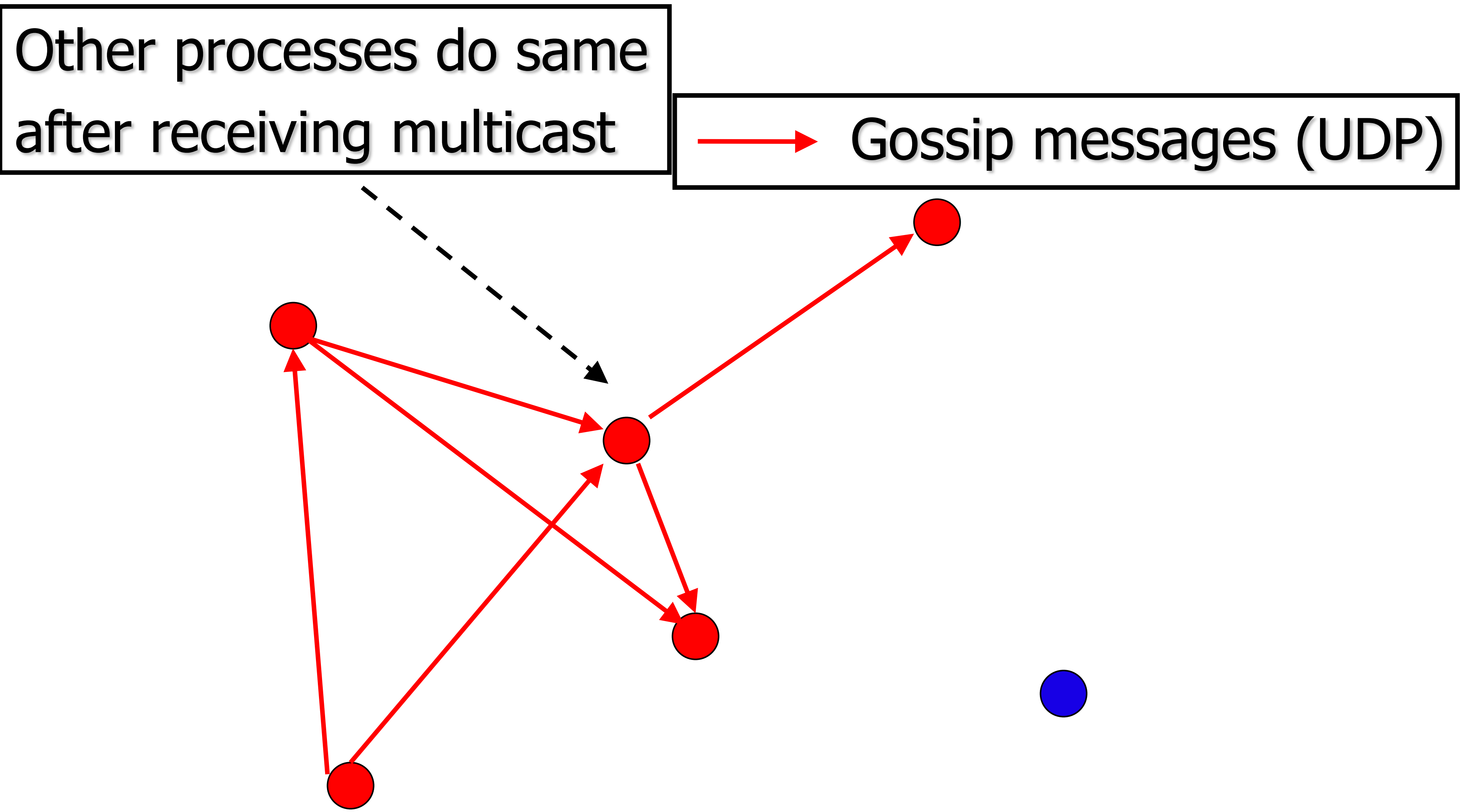


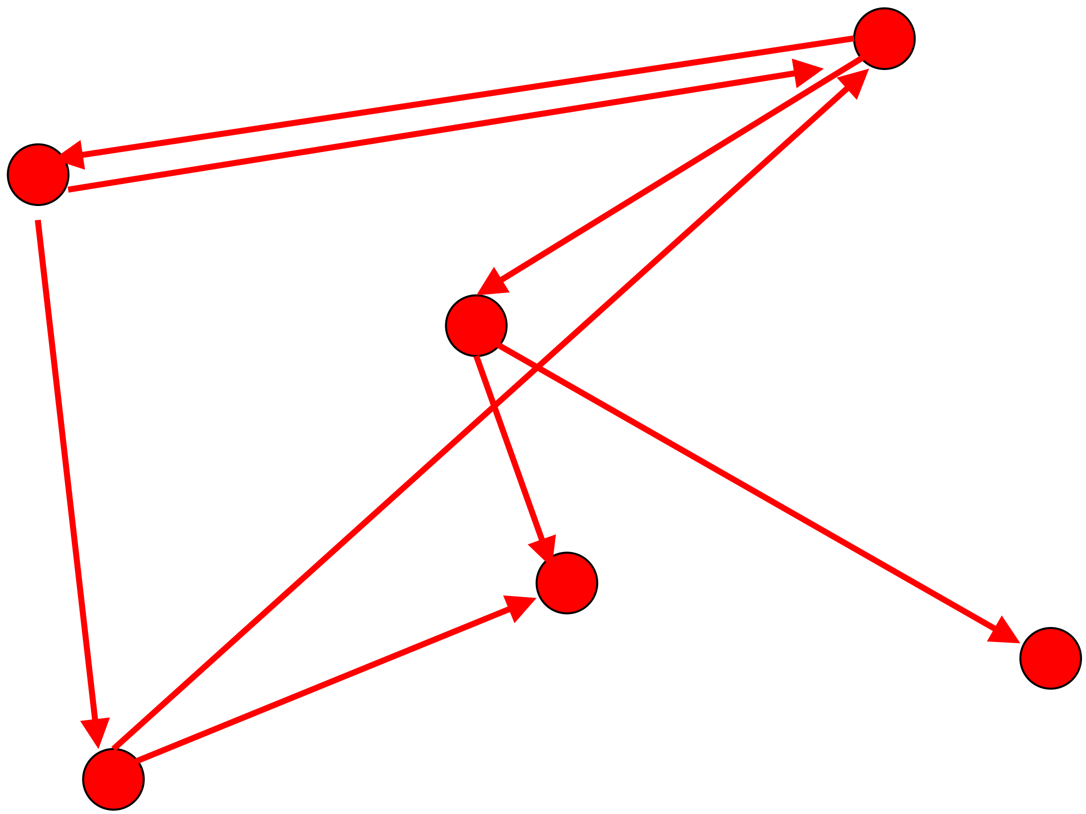
- Application-level: SRM, RMTP, TRAM,TMTP
- Also network-level: IP multicast
- Tree setup and maintenance
- Problems?

A Third Approach

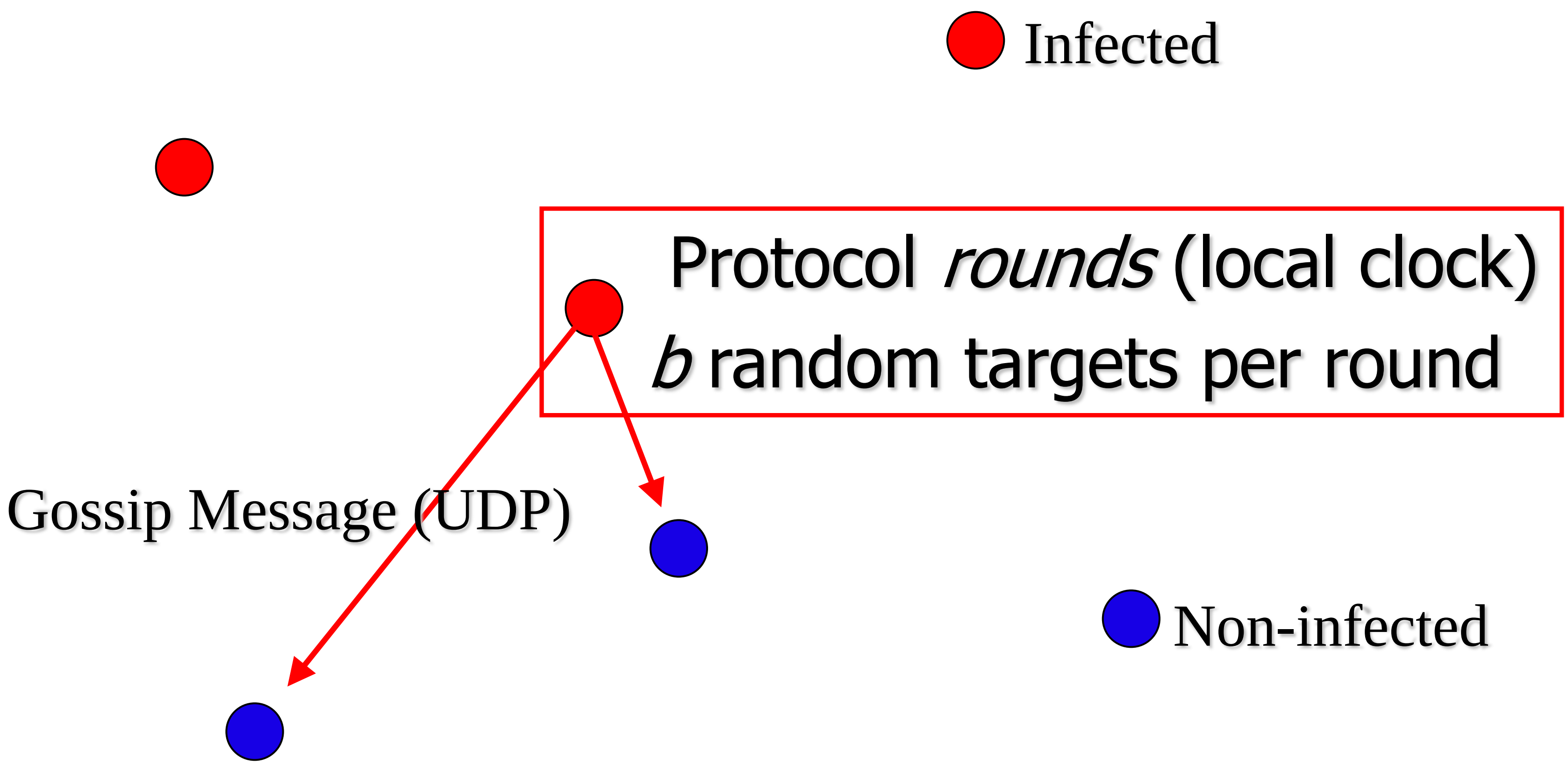



Periodically, transmit to
b random targets
Gossip messages (UDP)


Other processes do same
after receiving multicast
Gossip messages (UDP)



"Epidemic" Multicast (or "Gossip")



Properties

Claim that this simple protocol

- **Is lightweight in large groups**
- **Spreads a multicast quickly**
- **Is highly fault-tolerant**

Analysis

- **For analysis purposes, assume loose synchronization and # gossip targets (i.e., b) = 1**
- **In the first few rounds, gossip spreads like a tree**
  - **Very few processes receive multiple gossip messages**
- **Later, if *q(i)* = fraction of <u>non</u>-infected processes after round i, then *q(i)* is initially close to 1, and:**
- $$q(i+1) = q(i).(1-1/N)^{N.(1-q(i))}$$
  - **Prob.(given process is non-infected after i+1) =**

    Prob.(given process was non-infected after i) TIMES

    Prob. (not being picked as gossip target during round i+1)
  - ***N(1-q(i))* gossips go out, each to a random process**
  - **Probability of a given non-infected process not being picked by any given gossip is (1-1/N)**

Source: "Epidemic algorithms for replicated database management", Demers et al http://dl.acm.org/citation.cfm?id=41841&bnc=1

Gossip is fast and lightweight

(1) In first few rounds, takes O(log(N)) rounds to get to about half the processes

- **Think of a binary tree**

- **Later, if *q(i)* is the fraction of processes that have <u>not</u> received the gossip after round i, then:**
- $$q(i+1) = q(i).(1 - 1/N)^{N.(1-q(i))}$$
- **For large N and q(i+1) close to 0, approximates to:**
- $$q(i+1) = q(i).e^{-1}$$

(2) In the end game, it takes O(log(N)) rounds for *q(i+1)* to be whittled down to close to 0

(1)+(2) = O(log(N))

- **Latency of gossip with high probability**
- **Average number of gossips each process sends out**

Source: “Epidemic algorithms for replicated database management”, Demers et al
http://dl.acm.org/citation.cfm?id=41841&bnc=1

Fault-tolerance

- **Packet loss**
  - **50% packet loss: analyze with *b* replaced with *b/2***
  - **To achieve same reliability as 0% packet loss, takes twice as many rounds**
  - **Work it out!**
- **Process failure**
  - **50% of processes fail: analyze with *N* replaced with *N/2* and *b* replaced with *b/2***
  - **Same as above**
  - **Work it out!**

Fault-tolerance

- **With failures, is it possible that the epidemic might die out quickly?**
- **Possible, but improbable:**
  - **Once a few processes are infected, with high probability, the epidemic will not die out**
  - **So the analysis we saw in the previous slides is actually behavior *with high probability***
- **Think: why do rumors spread so fast? why do infectious diseases cascade quickly into epidemics? why does a worm like Blaster spread rapidly?**

So,…

- Is this all theory and a bunch of equations?
- Or are there implementations yet?

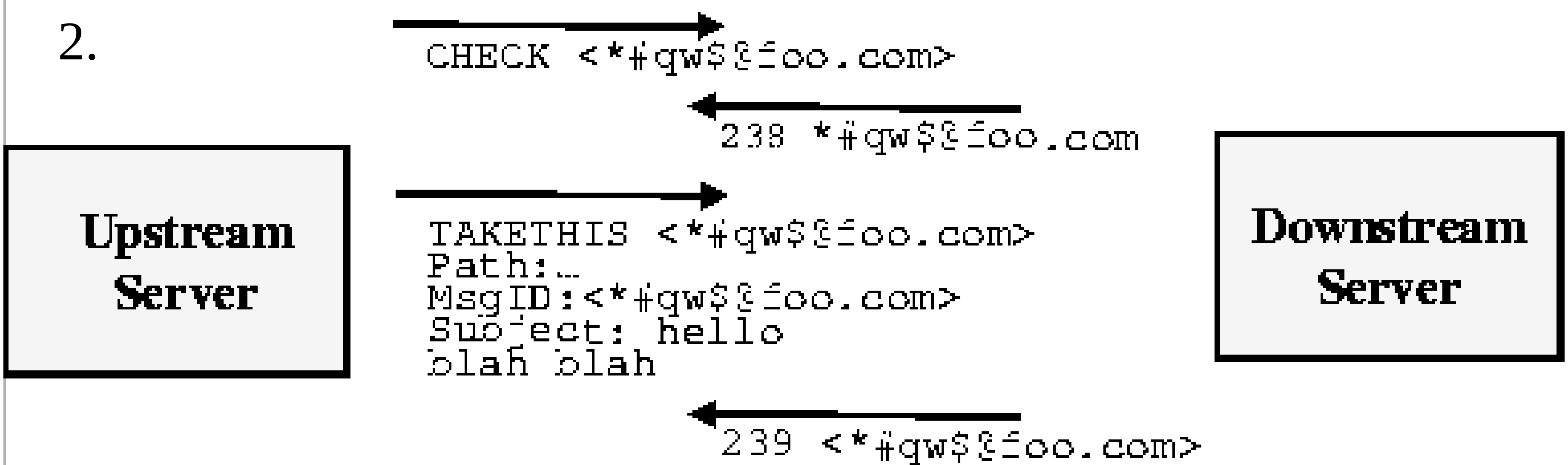
Some implementations

- Amazon Web Services EC2/S3 (rumored)
- Clearinghouse project: email and database transactions [PODC ‘87]
- refDBMS system [Usenix ‘94]
- Bimodal Multicast [ACM TOCS ‘99]
- Ad-hoc networks [Li Li et al, Infocom ‘02]
- Delay-Tolerant Networks [Y. Li et al ‘09]
- Usenet NNTP (Network News Transport Protocol) ! [‘79] – Newsgroup servers use gossip

NNTP Inter-server Protocol

1. Each client uploads and downloads news posts from a news server

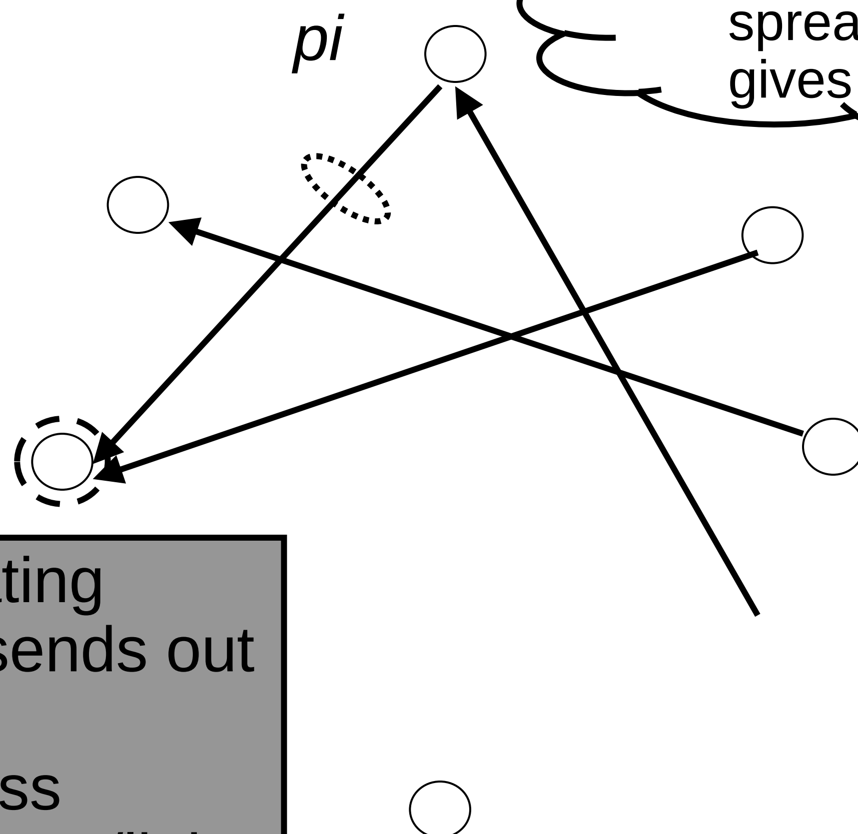
2.



Server retains news posts for a while, transmits them lazily, deletes them after a while

Using Gossip for Failure Detection: Gossip-style Heartbeating

☺ Using gossip to spread heartbeats gives better accuracy



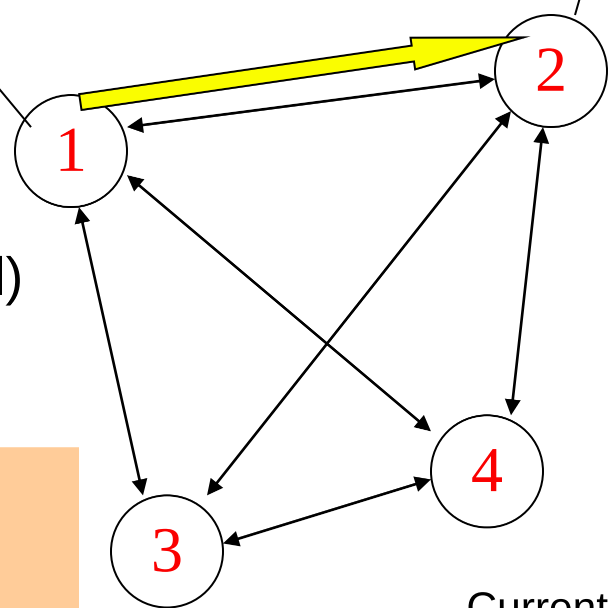
All-to-all heartbeating

- Each process sends out heartbeats to every other process
- Con: Slow process/link causes false positives

Gossip-Style Failure Detection

1	10120	66
2	10103	62
3	10098	63
4	10111	65

Address
Heartbeat Counter
Time (local)



1	10118	64
2	10110	64
3	10090	58
4	10111	65

1	10120	70
2	10110	64
3	10098	70
4	10111	65

Protocol:

- Processes periodically gossip their membership list
- On receipt, the local membership list is updated

Current time : 70 at process 2

(asynchronous clocks)

Fig and animation by: Dongyun Jin and Thuy Ngyuen

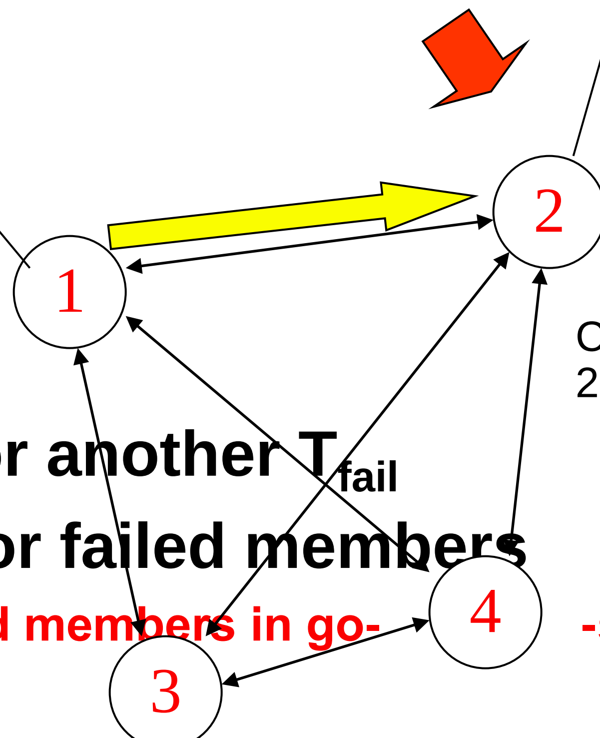
Gossip-Style Failure Detection

- If the heartbeat has not increased for more than T_{fail} seconds (according to local time), the member is considered failed
- But don't delete it right away
- Wait another $T_{cleanup}$ seconds, then delete the member from the list

Gossip-Style Failure Detection

- **What if an entry pointing to a failed process is deleted right after T_{fail} seconds?**

1	10120	66
2	10103	62
3	10098	55
4	10111	65



1	10120	66
2	10110	64
3	10098	75
4	10111	65

Current time : 75 at process 2

- **Fix: remember for another T_{fail}**
- **Ignore gossips for failed members**
  - **Don't include failed members in go- -ssip messages**

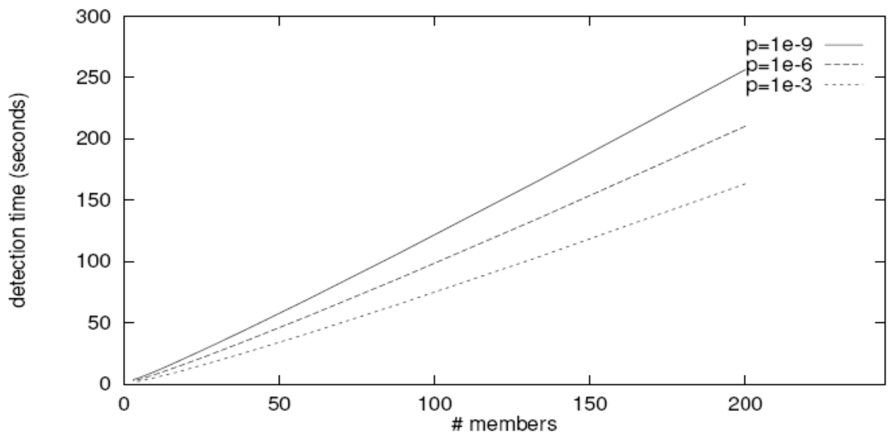
Analysis/Discussion

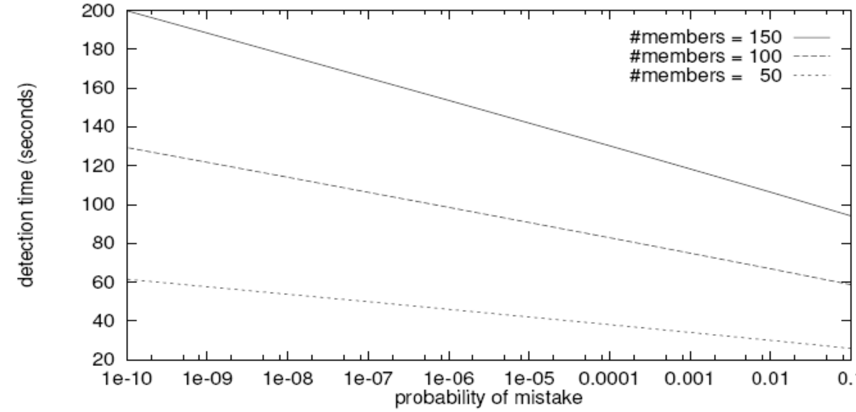
- **What happens if gossip period T_{gossip} is decreased?**
- **A single heartbeat takes O(log(N)) time to propagate. So: N heartbeats take:**
  - **O(log(N)) time to propagate, if bandwidth allowed per process is allowed to be O(N)**
  - **O(N.log(N)) time to propagate, if bandwidth allowed per process is only O(1)**
- **What happens to $P_{mistake}$ (false positive rate) as T_{fail} ,$T_{cleanup}$ is increased?**
- **Tradeoff: False positive rate vs. detection time vs Bandwidth**

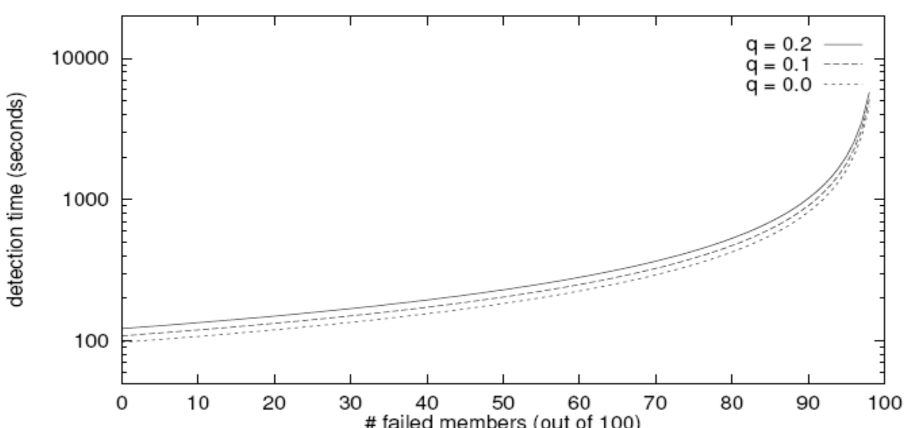
Simulations

- As # members increases, the detection time increases

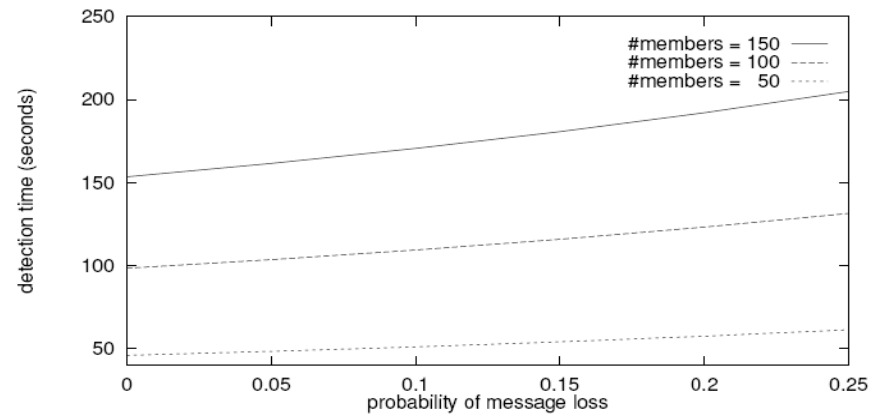
- As requirement is loosened, the detection time decreases





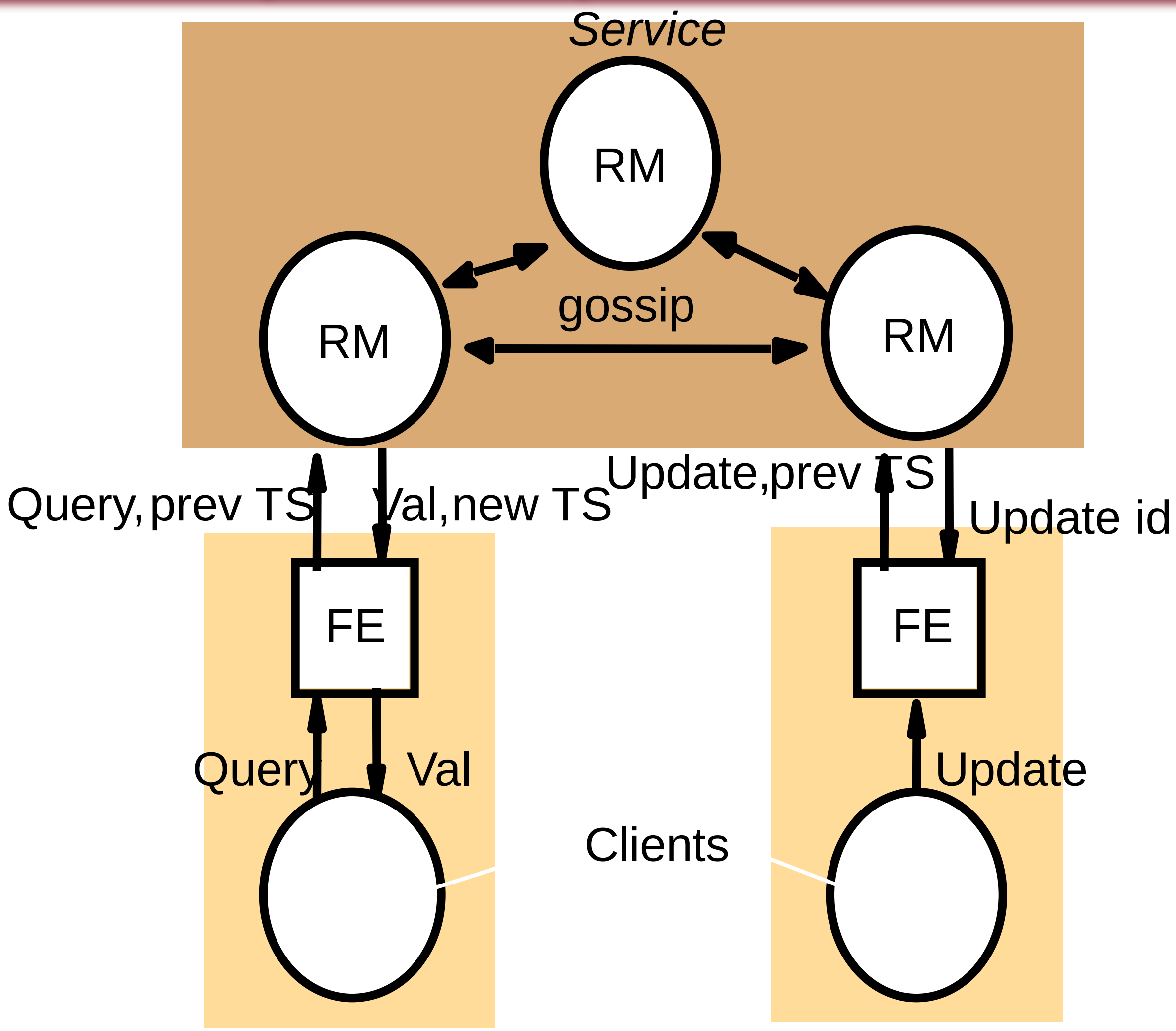


- As # failed members increases, the detection time increases slowly at first



- The algorithm is resilient to message loss

Gossip in Replication Management: Query and Update Operations



Gossiping Architecture

- The RMs exchange "gossip" messages

  (1) periodically and (2) amongst each other. Gossip messages convey updates they have each received from clients, and serve to achieve anti-entropy (convergence of all RMs).
- Guarantee:
  - Each client obtains a consistent service over time: in response to a query, an RM may have to wait until it receives "required" updates from other RMs. The RM then provides client with data that at least reflects the updates that the client has observed so far.
  - Relaxed consistency among replicas: RMs may be inconsistent at any given point of time. Yet all RMs eventually receive all updates and they apply updates with ordering guarantees.
- Provides eventual consistency

Summary

- **Reading for this lecture: Section 18.4**
- **MP3: By now you must have a design and must have started coding**
- **HW3 due Nov 6 (next Tuesday!)**

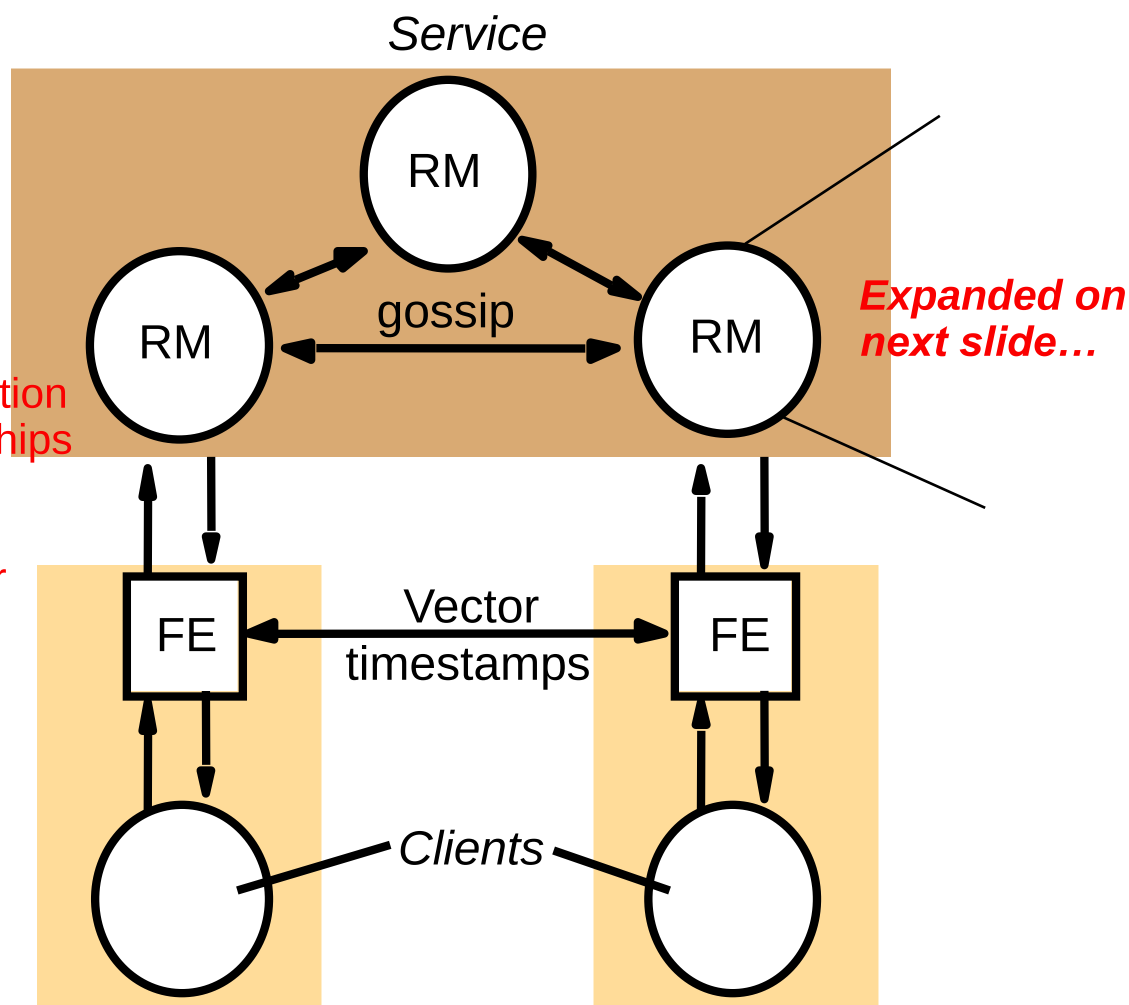
Optional Slides (Not Covered)

Various Timestamps

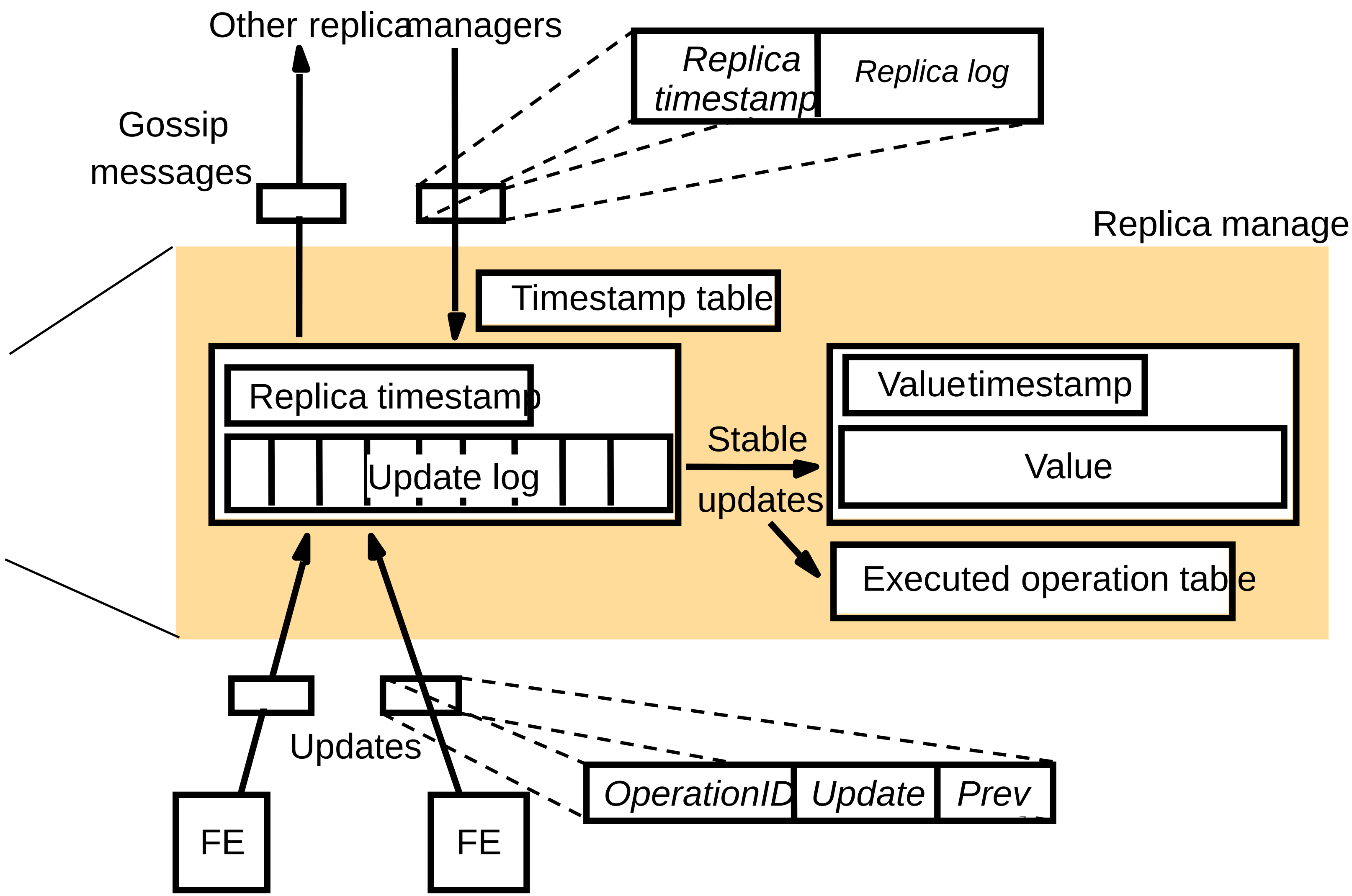
- Virtual timestamps are used to control the order of operation processing. The timestamp contains an entry for each RM (i.e., it is a vector timestamp).
- Each front end keeps a vector timestamp, *prev*, that reflects the latest data values accessed by that front end. The FE sends this along with every request it sends to any RM.
- Replies to FE:
  - When an RM returns a value as a result of a query operation, it supplies a new timestamp, *new*.
  - An update operation returns a timestamp, *update id*.
- Each returned timestamp is *merged* with the FE′s previous timestamp to record the data that has been observed by the client.
  - Merging is a pairwise max operation applied to each element i (from 1 to N)

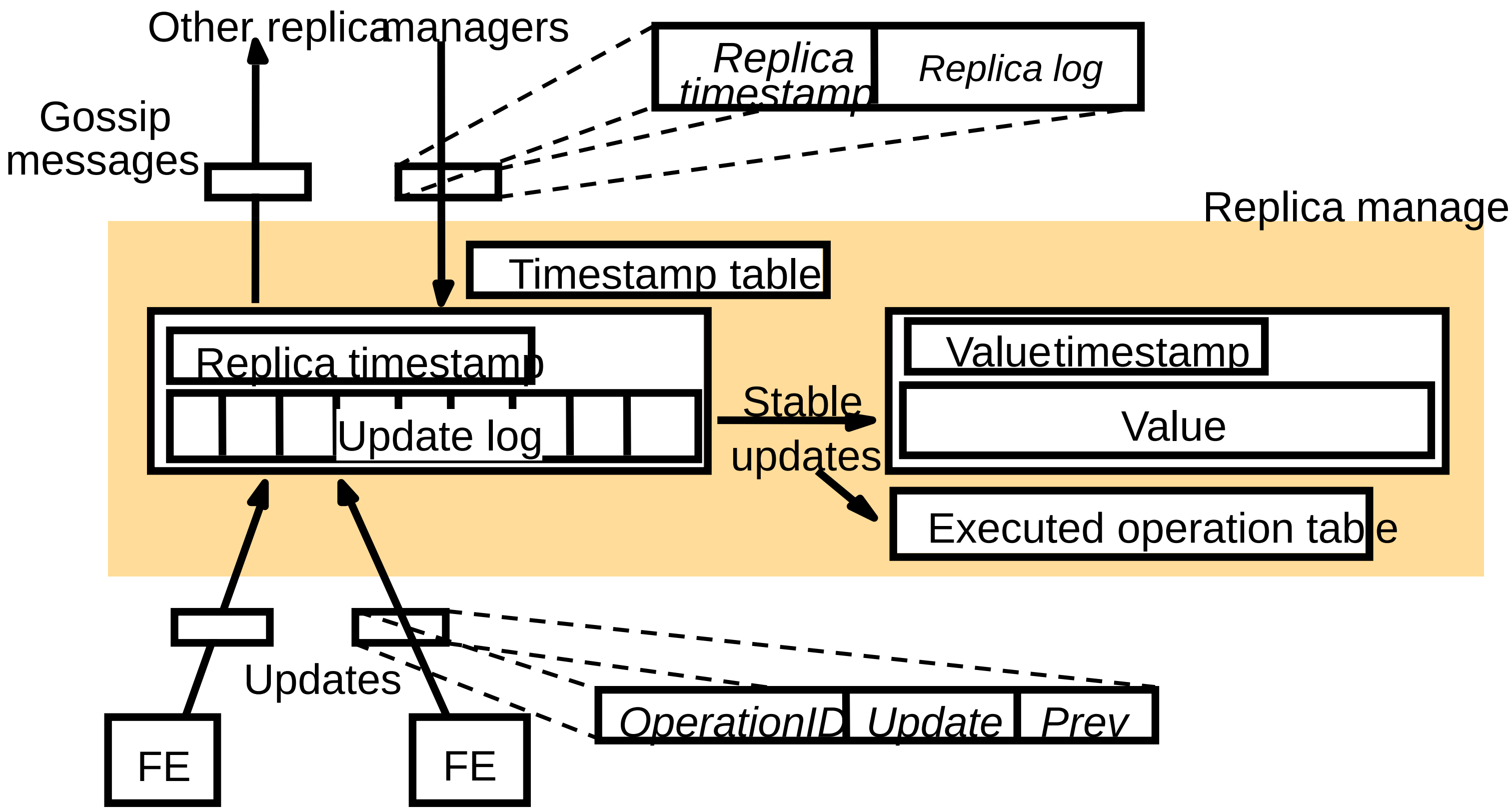
Front ends Propagate Their Timestamps

Since client-to-client communication can also lead to causal relationships between operations applied to services, the FE piggybacks its timestamp on messages to other clients.

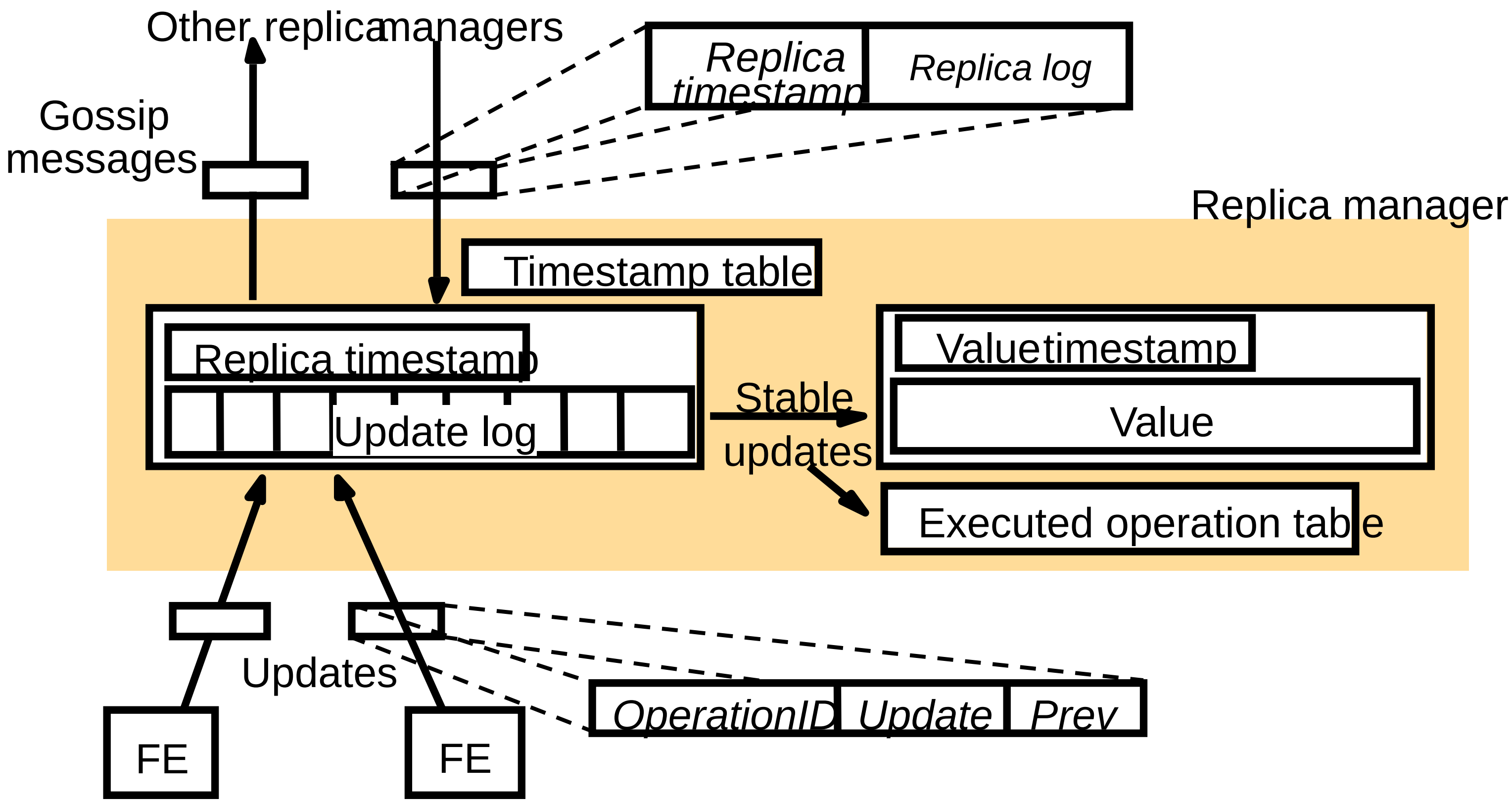


A Gossip Replica Manager

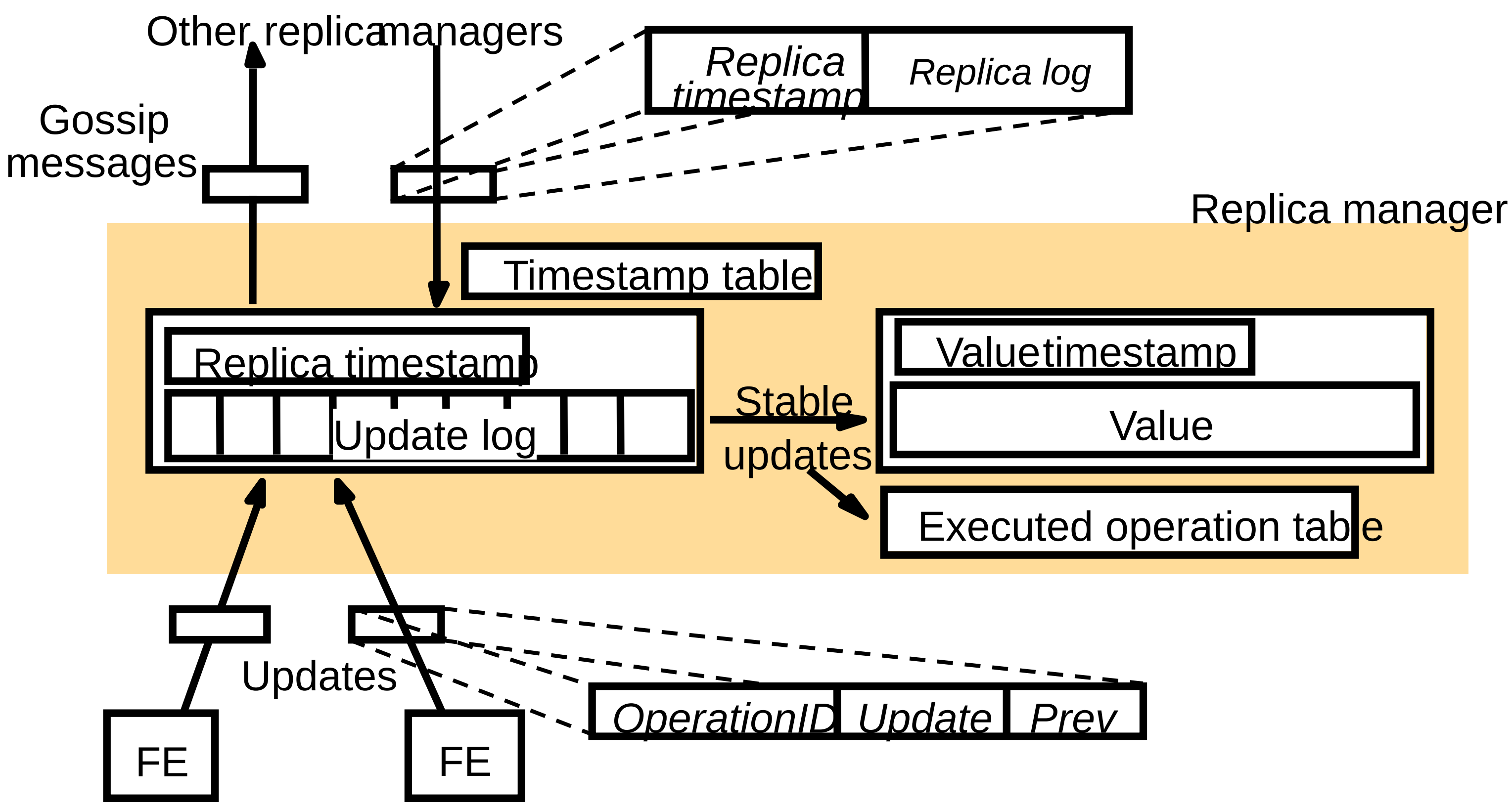




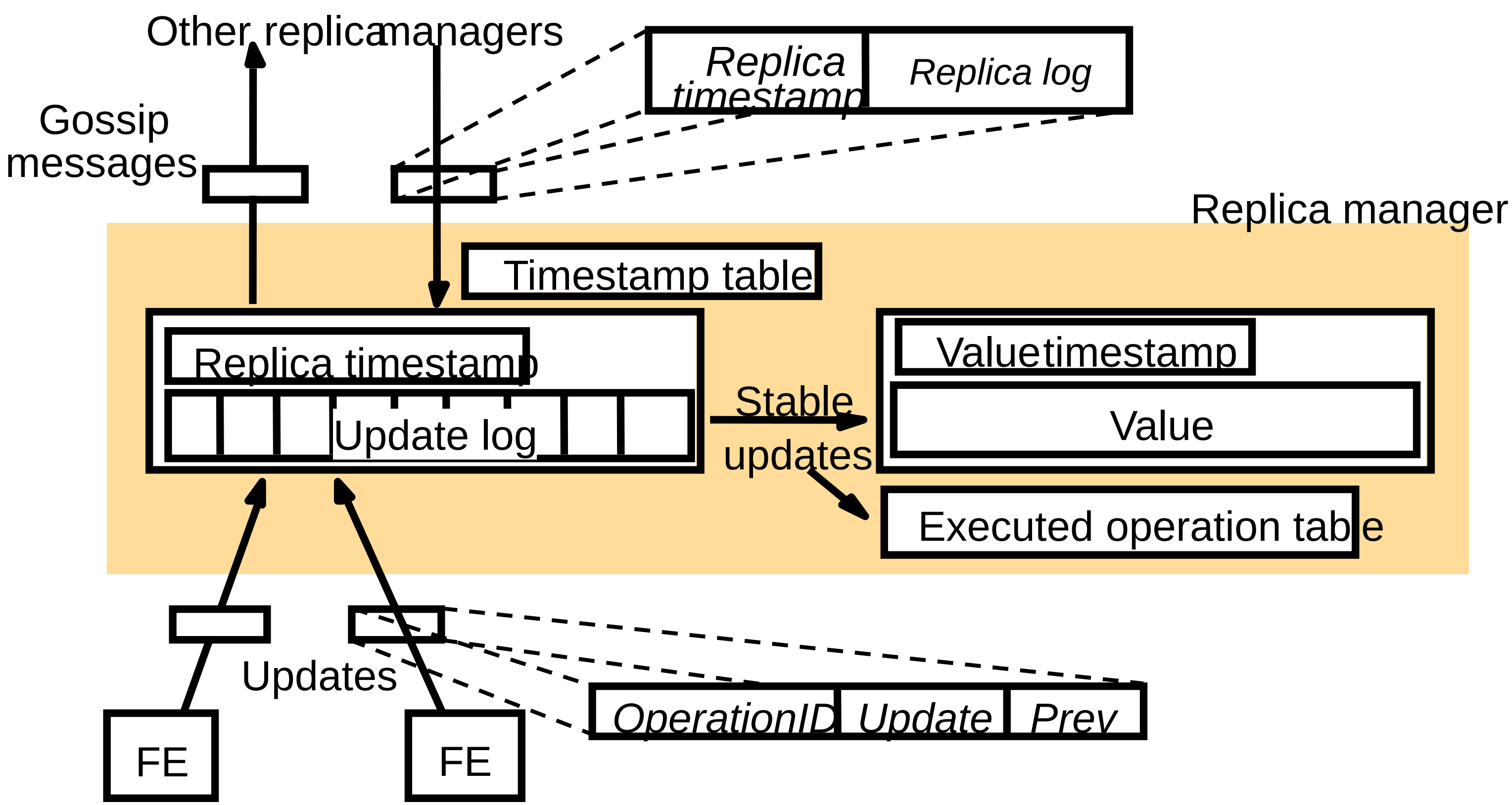
- **Value: value of the object maintained by the RM.**
- **Value timestamp: the timestamp that represents the updates reflected in the value. Updated whenever an update operation is applied.**



- **Update log: records all update operations as soon as they are received, until they are reflected in Value.**
  - **Keeps all the updates that are not stable, where a stable update is one that has been received by all other RMs and can be applied consistently with its ordering guarantees.**
  - **Keeps stable updates that have been applied, but cannot be purged yet, because no confirmation has been received from all other RMs.**
- **Replica timestamp: represents updates that have been accepted by the RM into the log.**



- **Executed operation table: contains the FE-supplied ids of updates (stable ones) that have been applied to the value.**
  - **Used to prevent an update being applied twice, as an update may arrive from a FE and in gossip messages from other RMs.**
- **Timestamp table: contains, for each other RM, the latest timestamp that has arrived in a gossip message from that other RM.**



- **The *ith* element of a vector timestamp held by RM_i corresponds to the total number of updates received from FEs by RM_i**
- **The *jth* element of a vector timestamp held by RM_i (*j* not equal to *i*) equals the number of updates received by RM_j that have been forwarded to RM_i *in gossip messages.***

Update Operations

- **Each update request *u* contains**
  - **The update operation, *u.op***
  - **The FE′s timestamp, *u.prev***
  - **A unique id that the FE generates, *u.id*.**
- **Upon receipt of an update request, the RM *i***
  - **Checks if u has been processed by looking up u.id in the executed operation table and in the update log.**
  - **If not, increments the *i*-th element in the replica timestamp by 1 to keep track of the number of updates directly received from FEs.**
  - **Places a record for the update in the RM′s log.**

    logRecord := <i, ts, u.op, u.prev, u.id>

    where ts is derived from u.prev by replacing u.prev′s ith element by the ith element of its replica timestamp.
  - **Returns *ts* back to the FE, which merges it with its timestamp.**

Update Operation (Cont'd)

- **The stability condition for an update *u* is**

  u.prev* <= *valueTS

  i.e., All the updates on which this update depends have already been applied to the value.
- **When the update operation *u* becomes stable, the RM does the following**
  - ***value := apply(value, u.op)***
  - ***valueTS := merge(valueTS, ts) (update the value timestamp)***
  - ***executed := executed U {u.id} (update the executed operation table)***

Exchange of Gossiping Messages

- **A gossip message *m* consists of the log of the RM, *m.log*, and the replica timestamp, *m.ts*.**
  - **Replica timestamp contains info about non-stable updates**
- **An RM that receives a gossip message *m* has three tasks:**
  - **(1) Merge the arriving log with its own.**
    - » **Let *replicaTS* denote the recipient RM's replica timestamp. A record *r* in *m.log* is added to the recipient's log unless *r.ts* <= *replicaTS*.**
    - » ***replicaTS* ← *merge(replicaTS, m.ts)***
  - **(2) Apply any updates that have become stable but not been executed (stable updates in the arrived log may cause some pending updates to become stable)**
  - **(3) Garbage collect: Eliminate records from the log and the executed operation table when it is known that the updates have been applied everywhere.**

Query Operations

- A query request *q* contains the operation, *q.op*, and the timestamp, *q.prev*, sent by the FE.
- Let *valueTS* denote the RM′s value timestamp, then *q* can be applied if

  q.prev <= *valueTS*
- The RM keeps *q* on a hold back queue until the condition is fulfilled.
  - *If valueTs is (2,5,5) and q.prev is (2,4,6), then one update from* RM_3 *is missing.*
- Once the query is applied, the RM returns

  new ← *valueTS*

  to the FE (along with the value), and the FE merges *new* with its timestamp.

Selecting Gossip Partners

- The frequency with which RMs send gossip messages depends on the application.
- Policy for choosing a partner to exchange gossip with:
  - Random policies: choose a partner randomly (perhaps with weighted probabilities)
  - Deterministic policies: a RM can examine its timestamp table and choose the RM that is the furthest behind in the updates it has received.
  - Topological policies: arrange the RMs into an overlay graph. Choose graph edges based on small round-trip times (RTTs), or a ring or Chord.
    - » Each has its own merits and drawbacks. The ring topology produces relatively little communication but is subject to high transmission latencies since gossip has to traverse several RMs.
- *Example: Network News Transport Protocol (NNTP) uses gossip communication. Your updates to class.cs425 are spread among News servers using the gossip protocol!*
- Gives probabilistically reliable and fast dissemination of data with very low background bandwidth
  - Analogous to the spread of gossip in society.

More Examples

- **Bayou**
  - **Replicated database with weaker guarantees than sequential consistency**
  - **Uses gossip, timestamps and concept of *anti-entropy***
  - **Section 15.4.2**
- **Coda**
  - **Provides high availability in spite of disconnected operation, e.g., roving and transiently-disconnected laptops**
  - **Based on AFS**
  - **Aims to provide *Constant data availability***
  - **Section 15.4.3**