Distributed Mutual Exclusion Algorithms

Course: Distributed Computing

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About this topic

This course covers various concepts in **Mutual Exclusion in Distributed Systems.** We will also focus on different types of distributed mutual exclusion algorithms in distributed contexts and their analysis

RECAP

What did you learn so far?

- → Challenges in Message Passing systems
- → Distributed Sorting
- → Space-Time Diagram
- → Partial Ordering / Causal Ordering
- → Concurrent Events
- → Local Clocks and Vector Clocks
- → Distributed Snapshots
- → Termination Detection
- → Topology Abstraction and Overlays
- → Leader Election Problem in Rings
- → Message Ordering / Group Communications

Topics to focus on …

- ➔ **Distributed Mutual Exclusion**

- ➔ Deadlock Detection
- ➔ Check pointing and rollback recovery
- ➔ Self-Stabilization
- ➔ Distributed Consensus
- ➔ Reasoning with Knowledge
- ➔ Peer – to – peer computing and Overlays
- ➔ Authentication in Distributed Systems

Mutual Exclusion in Distributed Systems

Let us explore mutex algorithms proposed for various interconnection networks

Why do we need MutEx?

- Mutual Exclusion
  - Operating systems: Semaphores
    - In a single machine, you could use semaphores to implement mutual exclusion
    - How to implement semaphores?
      - Inhibit interrupts
      - Use clever instructions (e.g. test-and-set)
    - On a multiprocessor shared memory machine, only the latter works

Characteristics

- Processes communicate only through messages – no shared memory or no global clocks
- Processes must expect unpredictable message delays
- Processes coordinate access to shared resources (printer, file, etc.) that should be used in a mutually exclusive manner

Race Conditions

- Consider Online systems – For example, Airline reservation systems maintain records of available seats
- Suppose two people buy the same seat, because each checks and finds the seat available, then each buys the seat
- Overlapped accesses generate different results than serial accesses
  - race condition

Distributed Mutual Exclusion

- Needs
  - Only one process should be in critical section at any point of time
  - What about resources?

Distributed Mutual Exclusion

- **No Deadlocks** – no set of sites should be permanently blocked, waiting for messages from other sites in that set
- **No starvation** – no site should have to wait indefinitely to enter its critical section, while other sites are executing the CS more than once
- **Fairness** - requests honored in the order they are made. This means processes have to be able to agree on the order of events. (Fairness prevents starvation.)
- **Fault Tolerance** – the algorithm is able to survive a failure at one or more sites

Distributed MutEx – An overview

Token-based solution: Processes share a special message known as a token

- Token holder has right to access shared resource
- Wait for/ask for (depending on algorithm) token; enter Critical Section (CS) when it is obtained, pass to another process on exit or hold until requested (depending on algorithm)
- If a process receives the token and doesn't need it, just pass it on

Distributed MutEx – A Few Issues

- Who can access the resource?
- When does a process to be privileged to access the resource?
- How long does a process access the resource? Any finite duration?
- How long can a process wait to be privileged?
- Computation complexity of the solution

Types of Distributed MutEx

- Token-based distributed mutual exclusion algorithms
  - Suzuki – Kasami's Algorithm
- Non-token based distributed mutual exclusion algorithms
  - Lamport's Algorithm
  - Ricart-Agartala's Algorithm

Token Based Methods

Advantages:

- Starvation can be avoided by efficient organization of the processes
- Deadlock is also avoidable

Disadvantage: Token Loss

- Must initiate a cooperative procedure to recreate the token
- Must ensure that only one token is created!

Non-Token Based Methods

- **Permission-based solutions:** a process that wishes to access a shared resource must first get permission from one or more other processes.

- Avoids the problems of token-based solutions, but is more complicated to implement

Performance Analysis

- Guarantees mutual exclusion
- No starvation: Only if requests served in order
- No deadlock
- Fault tolerant?
  - Single point of failure
  - Blocking requests mean client processes have difficulty distinguishing crashed coordinator from long wait
  - Bottlenecks
- The solution is simple and ease

Quorum Based algorithms

Why Quorum based algorithm?

- Lamports and Ricard-Agrawala' algorithm requires permission from all processes to enter into the critical section.

Modifications:

- Is it necessary to obtain permission from all processes before entering into the CS?
- How to reduce the message exchanges and increase the performance of MutEx algorithm?

Quorum Based algorithms

What is a Quorum?

- There are n requesting processes in a distributed system and any process may request for CS.
- Can we form such a subset of processes who request for Critical Section? YES !!
  - Such a set is said to be a Request Set or Quorum
  - In fact, we will have a separate Request set for each process P_i

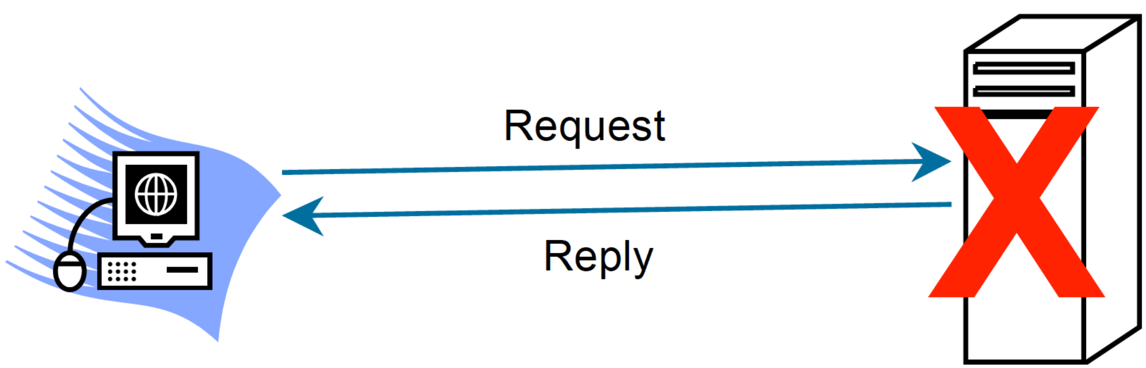
Quorum - Definition

- A quorum system is a collection of subsets of processes, called quorums, such that each pair of quorums have a non-empty intersection

- How do we formally define a quorum of processes in a distributed system?
- Let us look at some examples

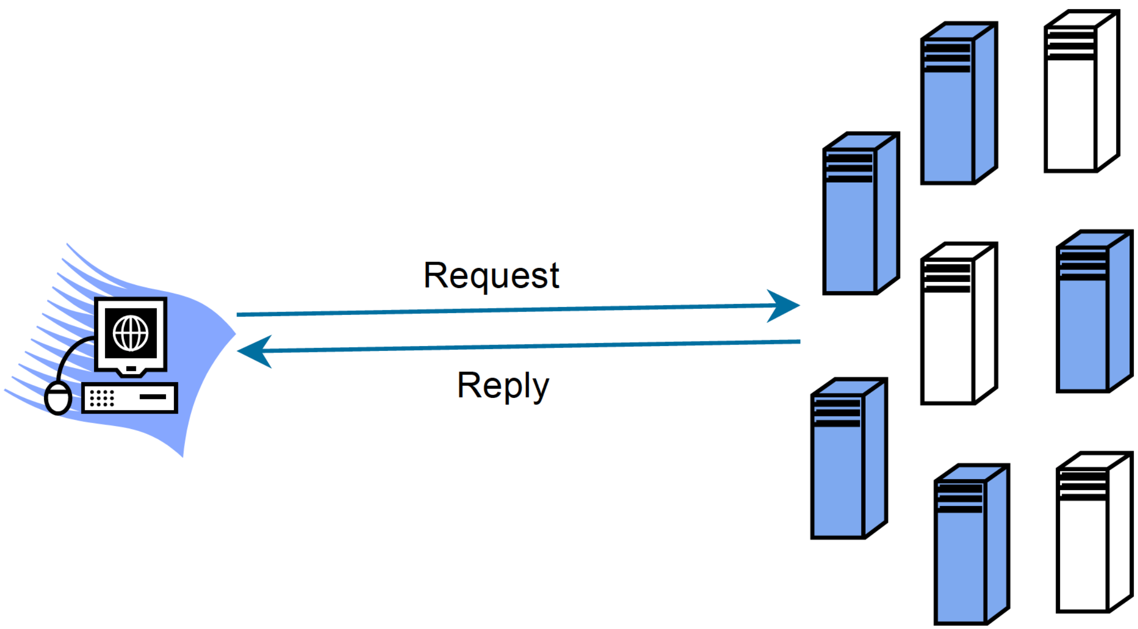
Quorum – Why?

- Process may not respond or may go down (any kind of failure)
- The requesting process can not get REPLY from all remaining processes
- It would infinitely wait for CS !!



Quorum – Why?

- Can the requesting process get permission from a quorum of processes to enter into CS?



Quorum - Definition

More Formally,

- Given a set of processes

$$P = \{P_1, P_2, \ldots, P_n\}$$

- A quorum system $Q \subseteq 2^P$ is a set of subsets of P such that

  for all Q_1, Q_2 in Q: $Q_1 \cap Q_2 \neq empty$

- Each Q_i in Q is called a quorum

Maekawa's Algorithm

- Permission obtained from only a subset of other processes, called the Request Set (or Quorum)

- Separate Request Set R_i, for each process i

Maekawa's Algorithm

Requirements

- For all i, j: $R_i \cap R_j \neq \Phi$
- For all i: $i \in R_i$
- For all i: $|R_i| = K$, for some K
- Any node i is contained in exactly D Request Sets, for some Request set D

- $K = D = sqrt(N)$ for Maekawa's algorithm

Maekawa's Algorithm - Steps

To Request Critical Section:

- P_i sends REQUEST message to all process in R_i

On receiving a REQUEST message:

- Send a REPLY message if no REPLY message has been sent since the last RELEASE message is received.
- Update status to indicate that a REPLY has been sent.
- Otherwise, queue up the REQUEST

To enter critical section:

- P_i enters critical section after receiving REPLY from all nodes in R_i

Maekawa's Algorithm – Steps (contd)

To release critical section:

- Send RELEASE message to all nodes in R_i
- On receiving a RELEASE message, send REPLY to next node in queue and delete the node from the queue.
- If queue is empty, update status to indicate no REPLY message has been sent

Computation Complexity

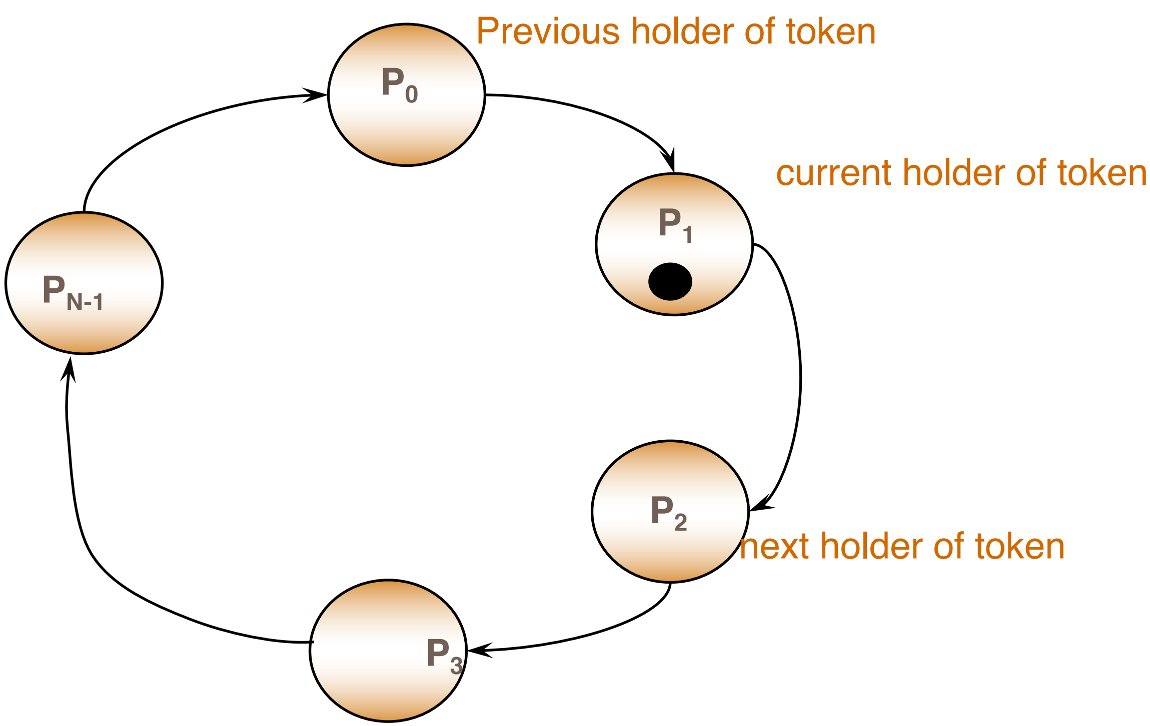
- Message Complexity: 3 * sqrt (N)
- Synchronization delay
  - 2*(max message transmission time)
- Major problem: DEADLOCK possible
- Need three more types of messages (FAILED, INQUIRE, YIELD) to handle deadlock.
  - Message complexity can be 5* sqrt(N N)
- Important Issue:
  - How to build the request sets?

Token Ring Approach

- Single token circulates, enter CS when token is present
- Mutual exclusion obvious
- Algorithms differ in how to find and get the token
- Uses sequence numbers rather than timestamps to differentiate between old and current requests

Token Rings – Illustration

- Request movements in an unidirectional ring network



Suzuki – Kasami's Algorithm

- Broadcast a request for the token
- Process with the token sends it to the requestor if it does not need it

- Issues:
  - Current versus outdated requests
  - Determining sites with pending requests
  - Deciding which site to give the token to

Data Structures

The token:

- ➔ Queue (FIFO) Q of requesting processes
- ➔ LN[1.. n] : sequence number of request that j executed most recently

The request message:

- ➔ REQUEST(i, k): request message from node i for its k^{th} critical section execution

Other data structures:

- ➔ RN_i [1.. n] for each node i, where , RN_i [j] is the largest sequence number received so far by i in a REQUEST message from j

Suzuki-Kasami's algorithm

To request critical section:

- If i does not have token, increment RN_i[i] and send REQUEST(i, RN_i[i]) to all nodes
- If i has token already, enter critical section if the token is idle (no pending requests), else follow rule to release critical section

On receiving REQUEST(i, s_n) at) j:

- Set RN_j[i] = max(RN_j[i], s_n)
- If j has the token and the token is idle then
  - send it to i if RN_j [i] = LN[i] + 1
  - If token is not idle, follow rule to release critical section

Suzuki-Kasami's algorithm

To enter critical section:

- Enter CS if token is present

To release critical section:

- Set LN[i] = RN_i[i]
- For every node j which is not in Q (in token), add node j to Q if RN_i[j] = LN[j] + 1
- If Q is non empty after the above, delete first node from Q and send the token to that node

Complexity

- No. of messages:
  - 0 if node holds the token already,
  - n otherwise
- Synchronization delay:
  - 0 (node has the token) or
  - max. message delay (token is elsewhere)
- No starvation

Raymond's Algorithm

- Forms a directed tree (logical) with the token token-holder as root
- Each node has variable "Holder" that points to its parent on the path to the root.
  - Root's Holder variable points to itself
- Each node P_i has a FIFO request queue Q_i

Raymond's Algorithm

- To request critical section:
  - Send REQUEST to parent on the tree, provided i does not hold the token currently and Q_i is empty. Then place is request in Q_i

- When a non-root node j receives a request from k
  - place request in Q_j
  - send REQUEST to parent if no previous REQUEST sent

Raymond's Algorithm (contd)

When the root receives a REQUEST:

- send the token to the requesting node
- set Holder variable to point to that node

When a node receives the token:

- delete first entry from the queue
- send token to that node
- set Holder variable to point to that node
- if queue is non non-empty, send a REQUEST message to the parent (node pointed at by Holder variable)

Raymond's Algorithm (contd)

- **To execute critical section:**
  - enter if token is received and own entry is at the top of the queue; delete the entry from the queue
- **To release critical section:**
  - if queue is non non-empty, delete first entry from the queue, send token to that node and make Holder variable point to that node
  - If queue is still non non-empty, send a REQUEST message to the parent (node pointed at by Holder variable)

Features of Raymond's Algo

- Average message complexity:
  - O(log n)
- Sync. Delay
  - (T log n)/2, where T = max. message delay

Summary

- ➔ Mutual Exclusion
- ➔ Various Types of MutEx algorithms
  - ➔ Non-Token based algorithm
    - ➔ Quorum based algorithm
  - ➔ Token based algorithm
    - ➔ Suzuki – Kasami's Algorithm
    - ➔ Raymond's Tree based algorithm
- ➔ Performance Metrics

➔ Stay tuned … More to come up … !!

How to reach me?

- ➔ Please leave me an email:

  rajendra [DOT] prasath [AT] iiits [DOT] in

- ➔ Visit my homepage @

  - ➔ http://www.iiits.ac.in/FacPages/index-rajendra.html

  OR

  - ➔ http://rajendra.2power3.com

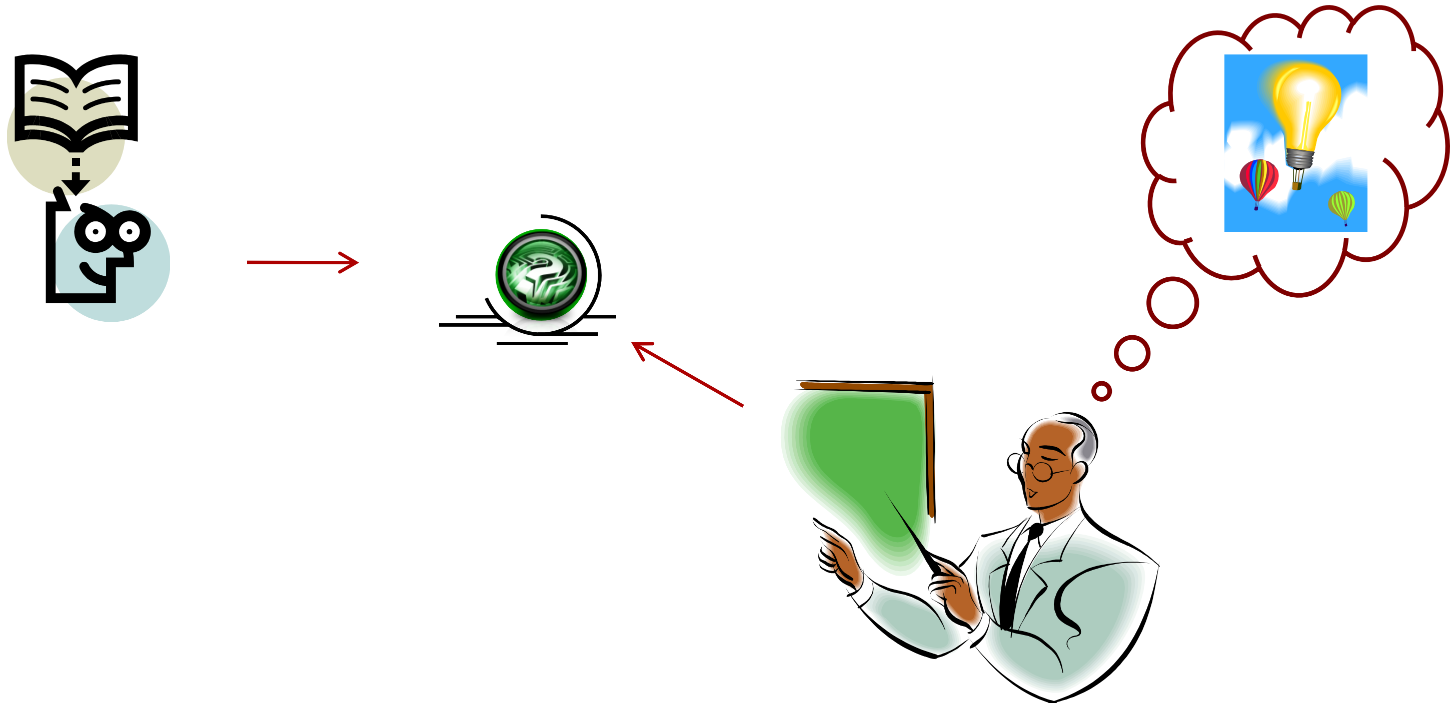
Help among Yourselves?

- **Perspective Students** (having CGPA above 8.5 and above)
- **Promising Students** (having CGPA above 6.5 and less than 8.5)

- **Needy Students** (having CGPA less than 6.5)
  - Can the above group help these students? (Your work will also be rewarded)

- You may grow a culture of **collaborative learning** by helping the needy students

Thanks ...



... Questions ???