Distributed Systems

08. Mutual Exclusion & Election Algorithms

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Process Synchronization

- Techniques to coordinate execution among processes
  - One process may have to wait for another
  - Shared resource (e.g. critical section) may require exclusive access

Centralized Systems

- Achieve mutual exclusion via:
  - Test & set in hardware
  - Semaphores
  - Messages (inter-process)
  - Condition variables

Distributed Mutual Exclusion

- Assume there is agreement on how a resource is identified
  - Pass the identifier with requests
  - e.g., *lock("printer"), lock("table:employees"), lock("table:employees;row:15")*
- Goal:
  Create an algorithm to allow a process to request and obtain exclusive access to a resource that is available on the network.

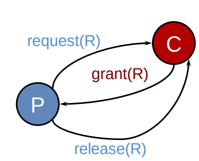
Categories of algorithms

- Centralized
  - A process can access a resource because a central coordinator allowed it to do so
- Token-based
  - A process can access a resource if it is holding a token permitting it to do so
- Contention-based
  - An process can access a resource via distributed agreement

Centralized algorithm

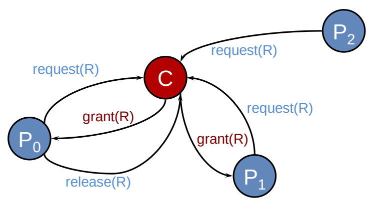
- Mimic single processor system
- One process elected as coordinator

1. **Request** resource
2. Wait for response
3. **Receive grant**
4. *access resource*
5. **Release resource**



Centralized algorithm

- If another process claimed resource:
  - Coordinator does not reply until release
  - Maintain queue
    - Service requests in FIFO order



Centralized algorithm

<u>Benefits</u>

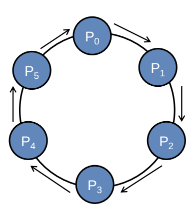
- Fair: All requests processed in order
- Easy to implement, understand, verify

<u>Problems</u>

- Process cannot distinguish being blocked from a dead coordinator
- Centralized server can be a bottleneck

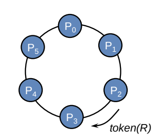
Token Ring algorithm

- Assume known group of processes
  - Some ordering can be imposed on group (unique process IDs)
  - Construct logical ring in software
  - Process communicates with its neighbor



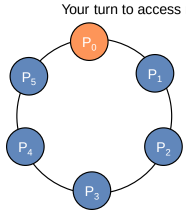
Token Ring algorithm

- Initialization
  - Process 0 creates a token for resource R
- Token circulates around ring
  - From P_i to $P_{(i+1)}$mod N
- When process acquires token
  - Checks to see if it needs to enter critical section
  - If no, send ring to neighbor
  - If yes, access resource
    - Hold token until done

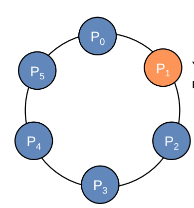


Token Ring algorithm

Your turn to access resource R

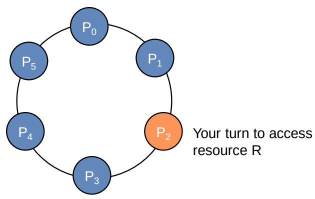


Token Ring algorithm

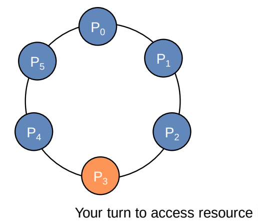


Your turn to access resource R

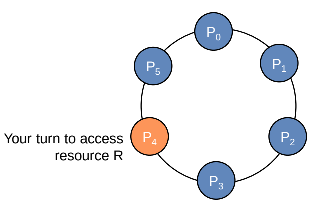
Token Ring algorithm



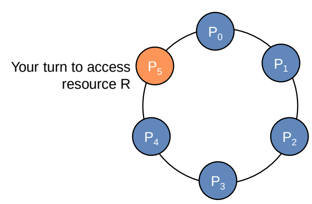
Token Ring algorithm



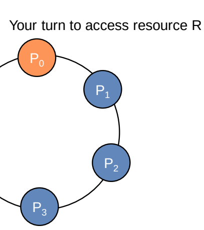
Token Ring algorithm



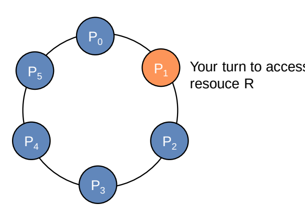
Token Ring algorithm



Token Ring algorithm



Token Ring algorithm



Token Ring algorithm summary

- Only one process at a time has token
  - Mutual exclusion guaranteed
- Order well-defined (but not necessarily first-come, first-served)
  - Starvation cannot occur
  - Lack of FCFS ordering may be undesirable sometimes
- If token is lost (e.g., process died)
  - It will have to be regenerated
  - Detecting loss may be a problem
    (*is the token lost or in just use by someone?*)

Lamport's Mutual Exclusion

- Each process maintains request queue
  - Queue contains mutual exclusion requests
  - Messages are sent reliably and in FIFO order
  - Each message is time stamped with totally ordered Lamport timestamps
    - Ensures that each timestamp is unique
    - Every node can make the same decision by comparing timestamps
  - Queues are sorted by message timestamps

Lamport's Mutual Exclusion

Request a critical section:

Lamport time

- Process P_i sends *request(i, T_i)* to all nodes
  - … and places request on its own queue
- When a process P_j receives a request:
  - It returns a timestamped *ack*
  - Places the request on its request queue

Process	Time stamp
P_4	1021
P_8	1022
P_1	3944
P_6	8201
P_{12}	9638

Sample request queue
Identical at each process

Enter a critical section (accessing resource):

- P_i has received acks from everyone
- P_i's request has the earliest timestamp in its queue

Release a critical section:

- Process P_i removes its request from its queue
- sends *release(i, T_i)* to all nodes
- Each process now checks if its request is the earliest in its queue
  - If so, that process now has the critical section

Lamport's Mutual Exclusion

- *N* points of failure
- A lot of messaging traffic
  - Requests & releases are sent to the entire group
- Not great … but demonstrates that a fully distributed algorithm is possible

Ricart & Agrawala algorithm

- Distributed algorithm using reliable multicast and logical clocks
- When a process wants to enter critical section:
  1. Compose message containing:
     - Identifier (machine ID, process ID)
     - Name of resource
     - Timestamp (e.g., totally-ordered Lamport)
  2. Reliably multicast request to all processes in group
  3. Wait until everyone gives permission
  4. Enter critical section / use resource

Ricart & Agrawala algorithm

- When process receives request:
  - If receiver not interested:
    - Send OK to sender
  - If receiver is in critical section
    - Do not reply; add request to queue
  - If receiver just sent a request as well: (*potential race condition*)
    - Compare timestamps on received & sent messages
    - Earliest wins
    - If receiver is loser, send OK
    - If receiver is winner, do not reply, queue it
- When done with critical section
  - Send OK to all queued requests

Ricart & Agrawala algorithm

- Not great either
  - *N* points of failure
  - A lot of messaging traffic
  - Also demonstrates that a fully distributed algorithm is possible

Lamport vs. Ricart & Agrawala

- Lamport
  - Everyone responds (acks) … always – no hold-back
  - *3(N-1)* messages
    - Request – ACK – Release
  - Process decides to go based on whether its request is the earliest in its queue
- Ricart & Agrawala
  - If you are in the critical section (or won a tie)
    - Don't respond with an ACK until you are done with the critical section
  - *2(N-1)* messages
    - Request – ACK
  - Process decides to go if it gets ACKs from everyone

Election algorithms

Elections

- Need one process to act as coordinator
- Processes have no distinguishing characteristics
- Each process can obtain a unique ID

Bully algorithm

- Select process with largest ID as coordinator
- When process P detects dead coordinator:
  - Send *election* message to all processes with higher IDs.
    - If nobody responds, P wins and takes over.
    - If any process responds, P's job is done.
  - Optional: Let all nodes with lower IDs know an election is taking place.
- If process receives an election message
  - Send *OK* message back
  - Hold election (unless it is already holding one)

Bully algorithm

- A process announces victory by sending all processes a message telling them that it is the new coordinator
- If a dead process recovers, it holds an election to find the coordinator.

Ring algorithm

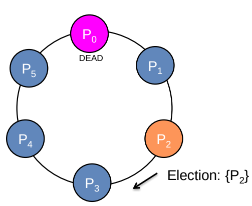
- Ring arrangement of processes
- If any process detects failure of coordinator
  - Construct election message with process ID and send to next process
  - If successor is down, skip over
  - Repeat until a running process is located
- Upon receiving an election message
  - Process forwards the message, adding its process ID to the body

Ring algorithm

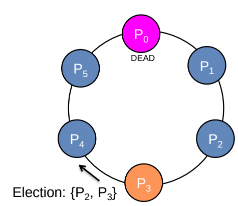
Eventually message returns to originator

- Process sees its ID on list
- Circulates (or multicasts) a **coordinator** message announcing coordinator
  - E.g. lowest numbered process

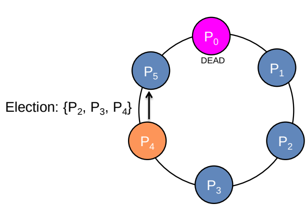
Ring algorithm



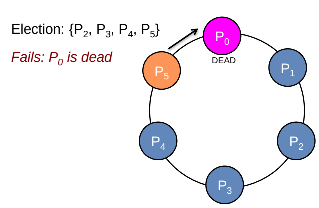
Ring algorithm



Ring algorithm



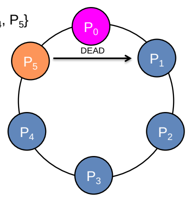
Ring algorithm



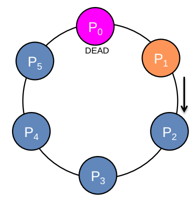
Ring algorithm

Election: {P_2, P_3, P_4, P_5}

Skip to P_1



Ring algorithm

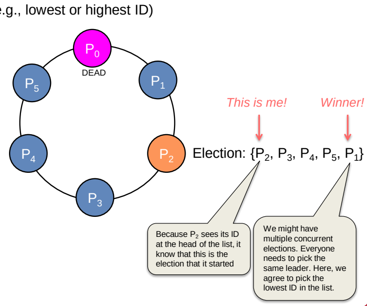


Election: {P_2, P_3, P_4, P_5, P_1}

Ring algorithm

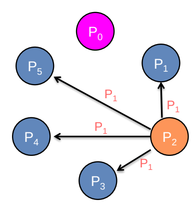
P_2 receives the election message that it initiated

P_2 now picks a leader (e.g., lowest or highest ID)



Ring algorithm

P_2 announces the new coordinator to the group



Chang & Roberts Ring Algorithm

- Optimize the ring
  - Message always contains <u>*one*</u> process ID
  - Avoid multiple circulating elections
  - If a process sends a message, it marks its state as a *participant*
- Upon receiving an election message:

  If PID(message) > PID(process)

  forward the message

  If PID(message) < PID(process)

  replace PID in message with PID(process)

  forward the new message

  If PID(message) < PID(process) AND process is *participant*

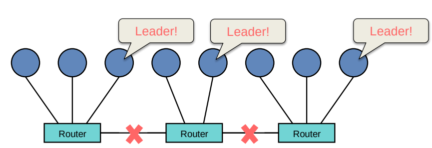
  discard the message

  If PID(message) == PID(process)

  the process is now the leader

Network Partitioning: Split Brain

- Network **partitioning** (segmentation)
  - **Split brain**
  - Multiple nodes may decide they're the leader



- Dealing with partitioning
  - Insist on a majority → if no majority, the system will not function
  - Rely on alternate communication mechanism to validate failure
    - Redundant network, shared disk, serial line, SCSI
- We will visit this problem later!

The End