THE UNIVERSITY of EDINBURGH
informatics

Distributed Systems

Predicates and Mutual Exclusion

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Non-stable Predicates

- Where snapshots are not useful
- Non-stable predicates, e.g.
  - Was this file opened at some time?
  - Was x1-x2 < δ ever?
  - Was the antenna accessed for two transmissions at the same time?
  - Non-stable predicates may have happened, but then system state changes..

Non-stable Predicates

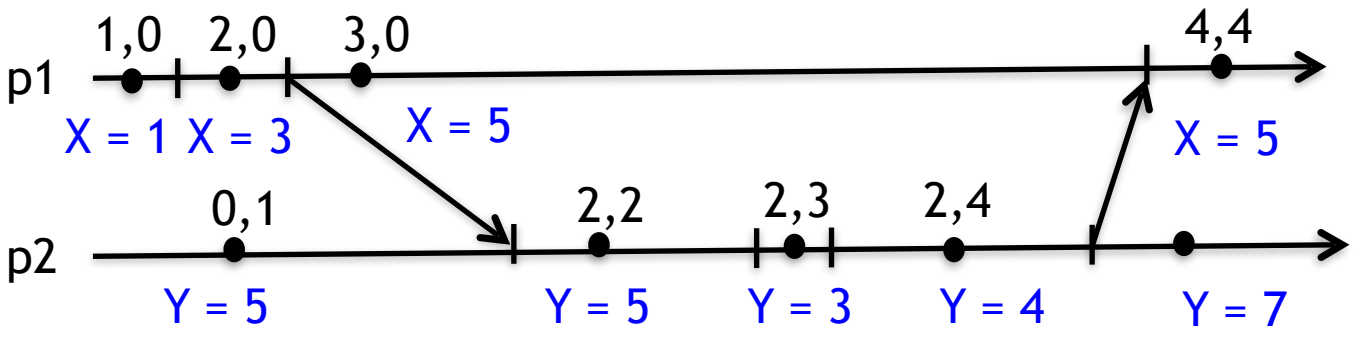
- **Possibly** B:
  - B could have happened
- **Definitely** B:
  - B definitely happened
- How can we check for definitely B and possibly B?

Collecting Global States

- Each process notes its state & vector timestamp
  - Sends it to a server for recording
  - Note: we do not need to save every time a state changes: only when it affects the predicates to be checked
    - Assuming we know what predicates will be checked
- The server looks at these and tries to figure out if predicate B was possibly or definitely true

Possible States

- Server checks for possible states: consistent cuts for B: x=y



Possible States

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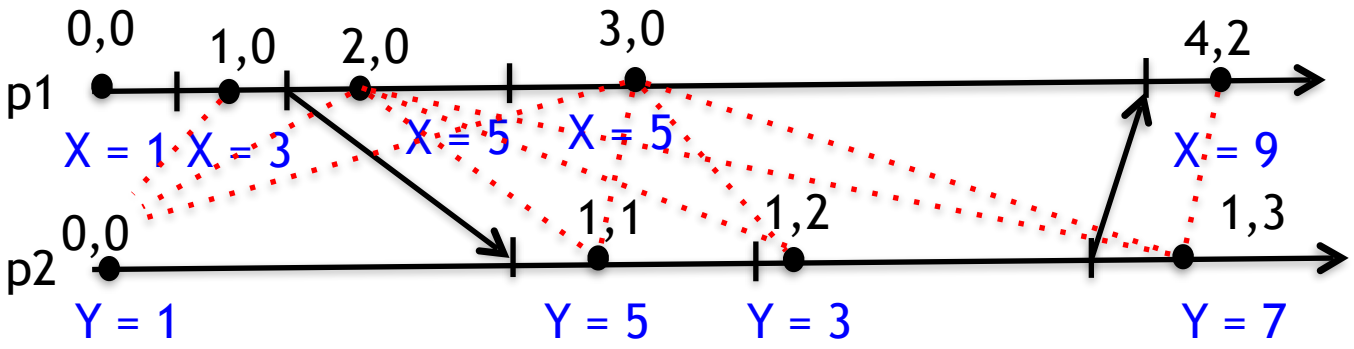
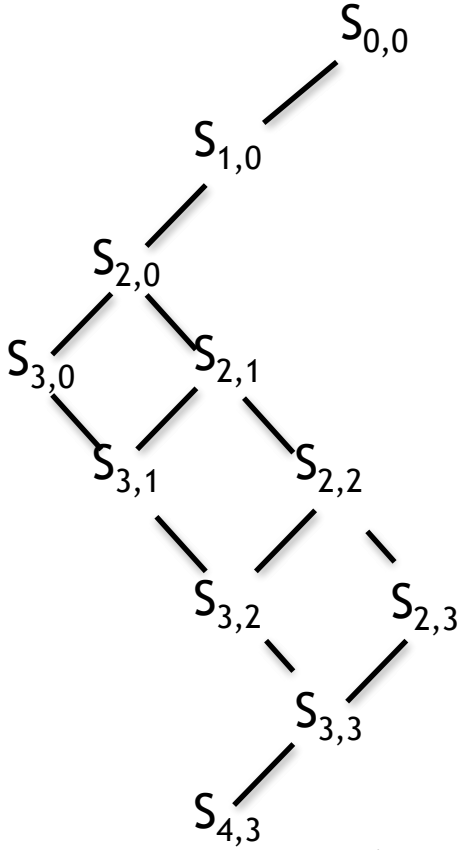
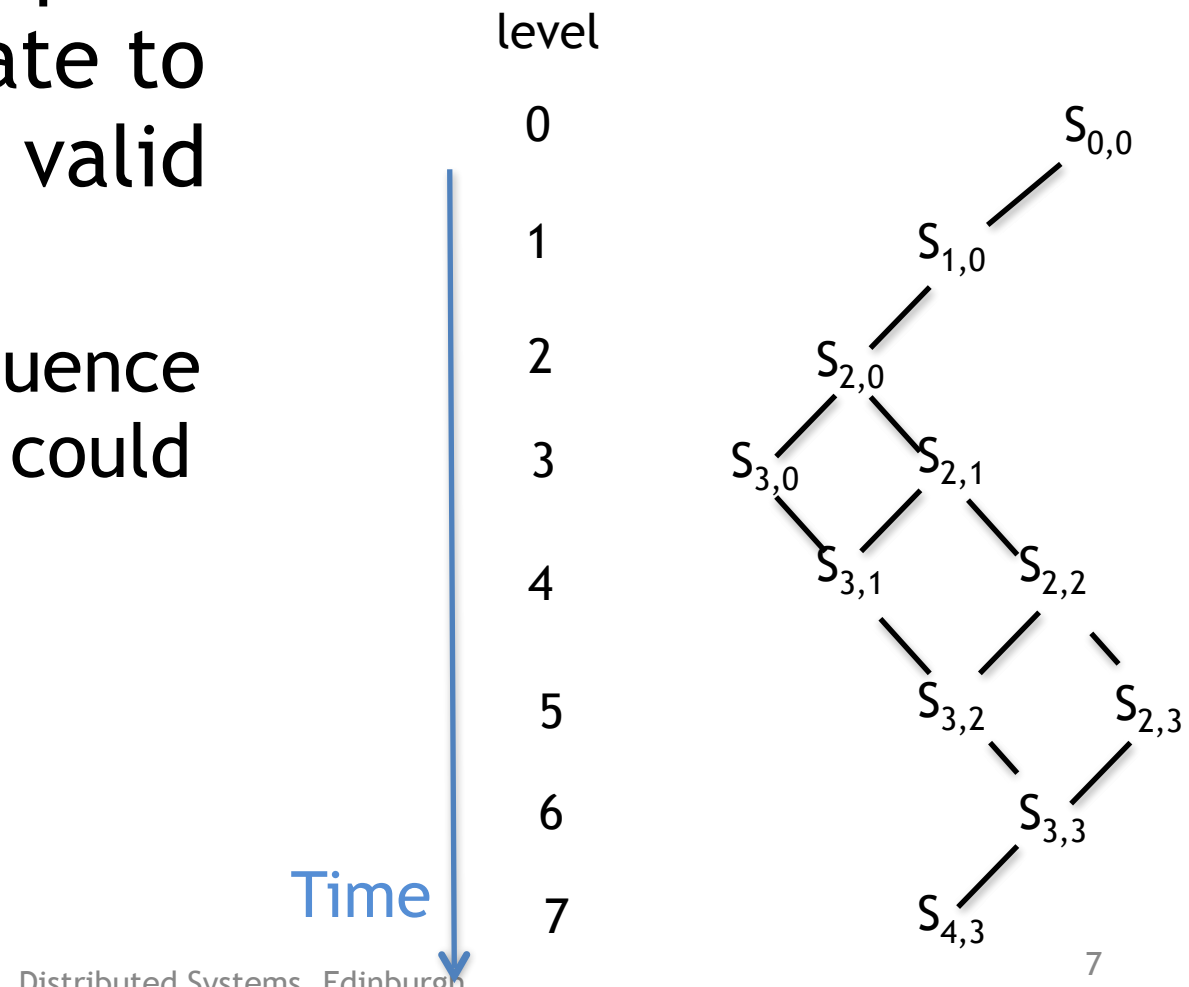




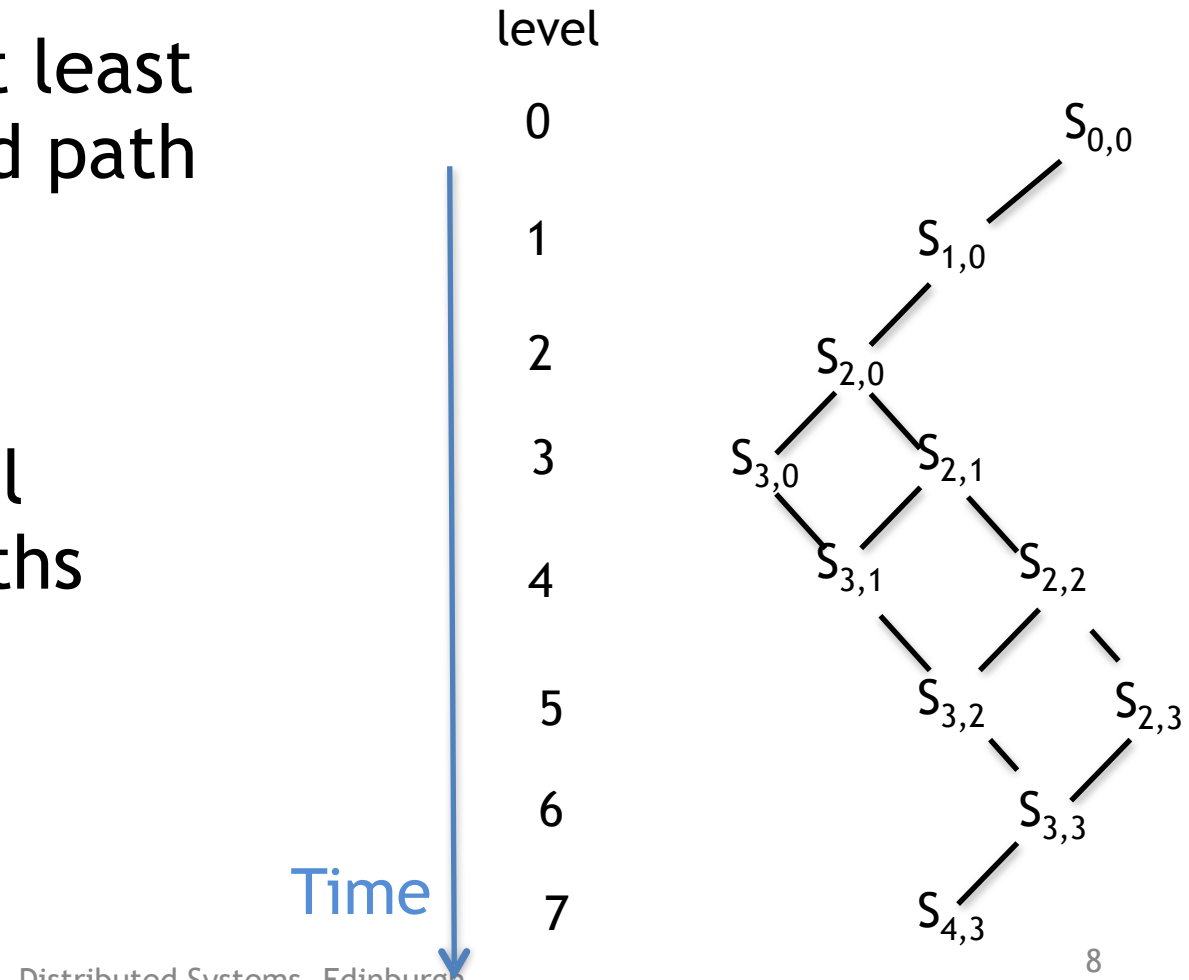
Lattice of global states (consistent cuts)

- Any downward path from Initial state to final state is a valid execution
  - A possible sequence of states that could have existed



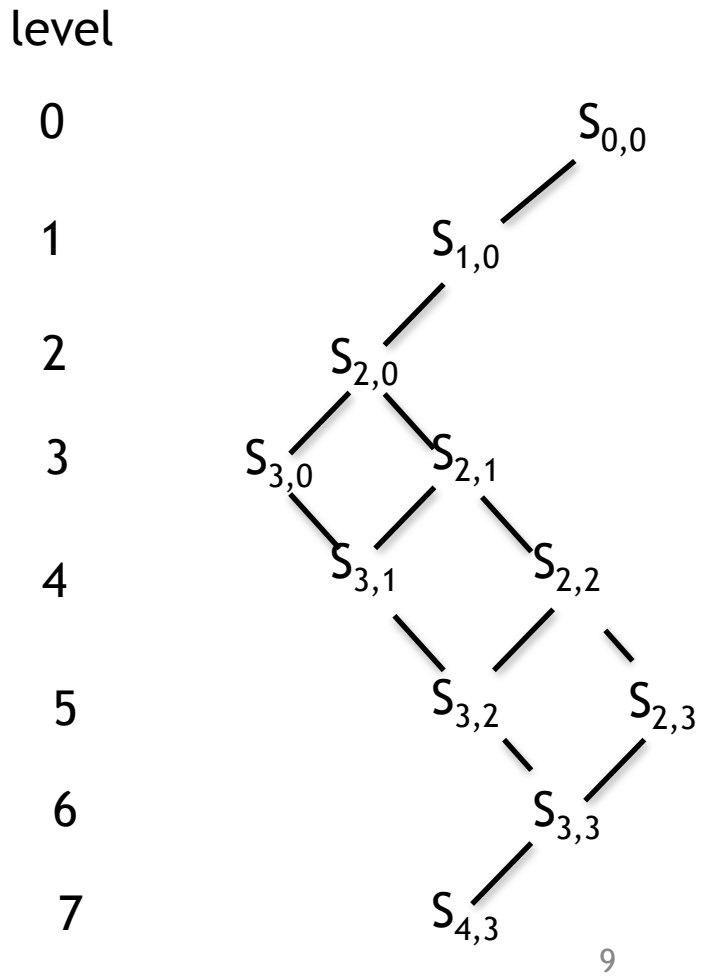
Lattice of global states (consistent cuts)

- **Possibly** B:
  - B occurs on at least one downward path
- **Definitely** B
  - B occurs on all downward paths



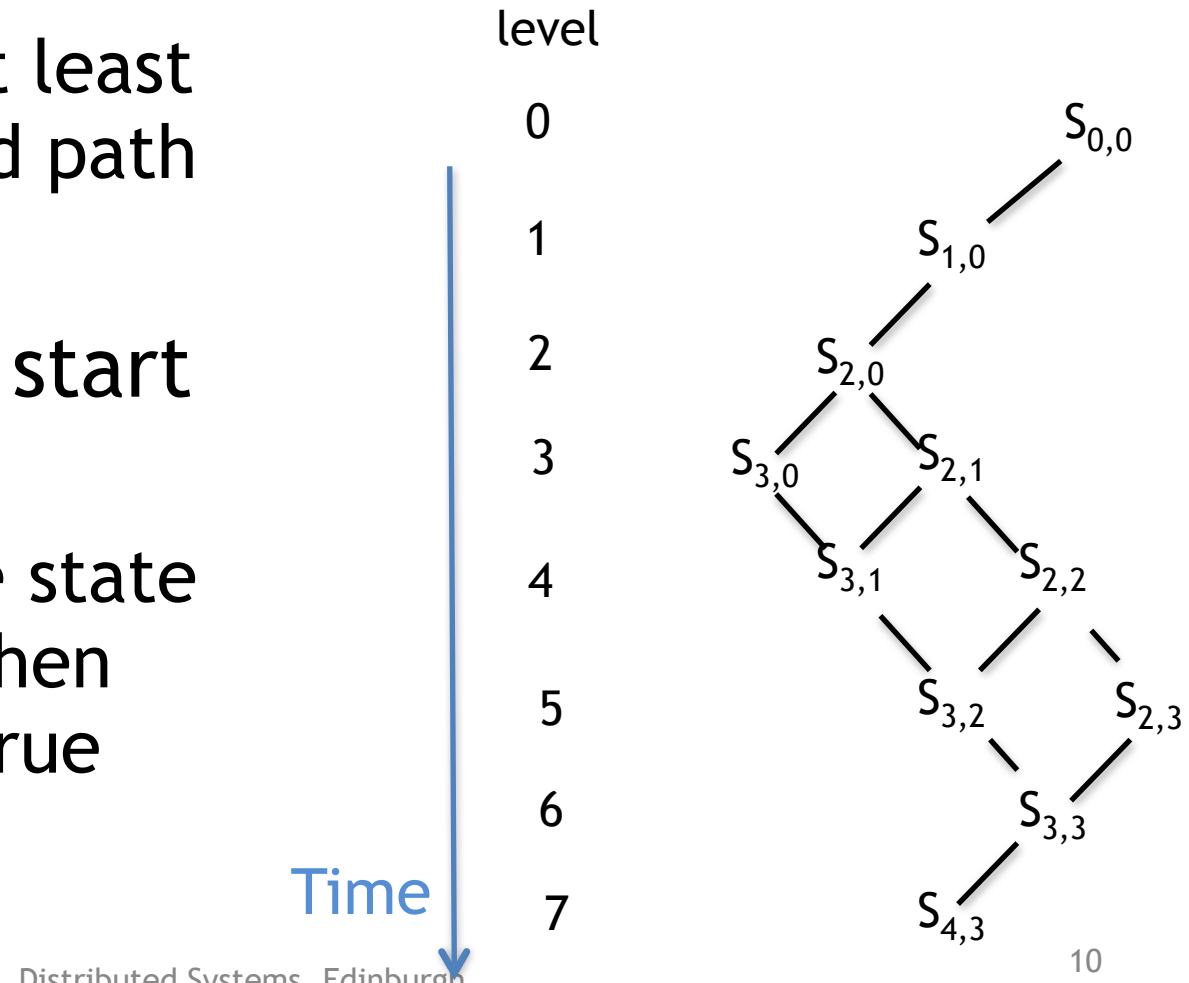
Lattice of global states (consistent cuts)

- How do you compute possibly and definitely B?



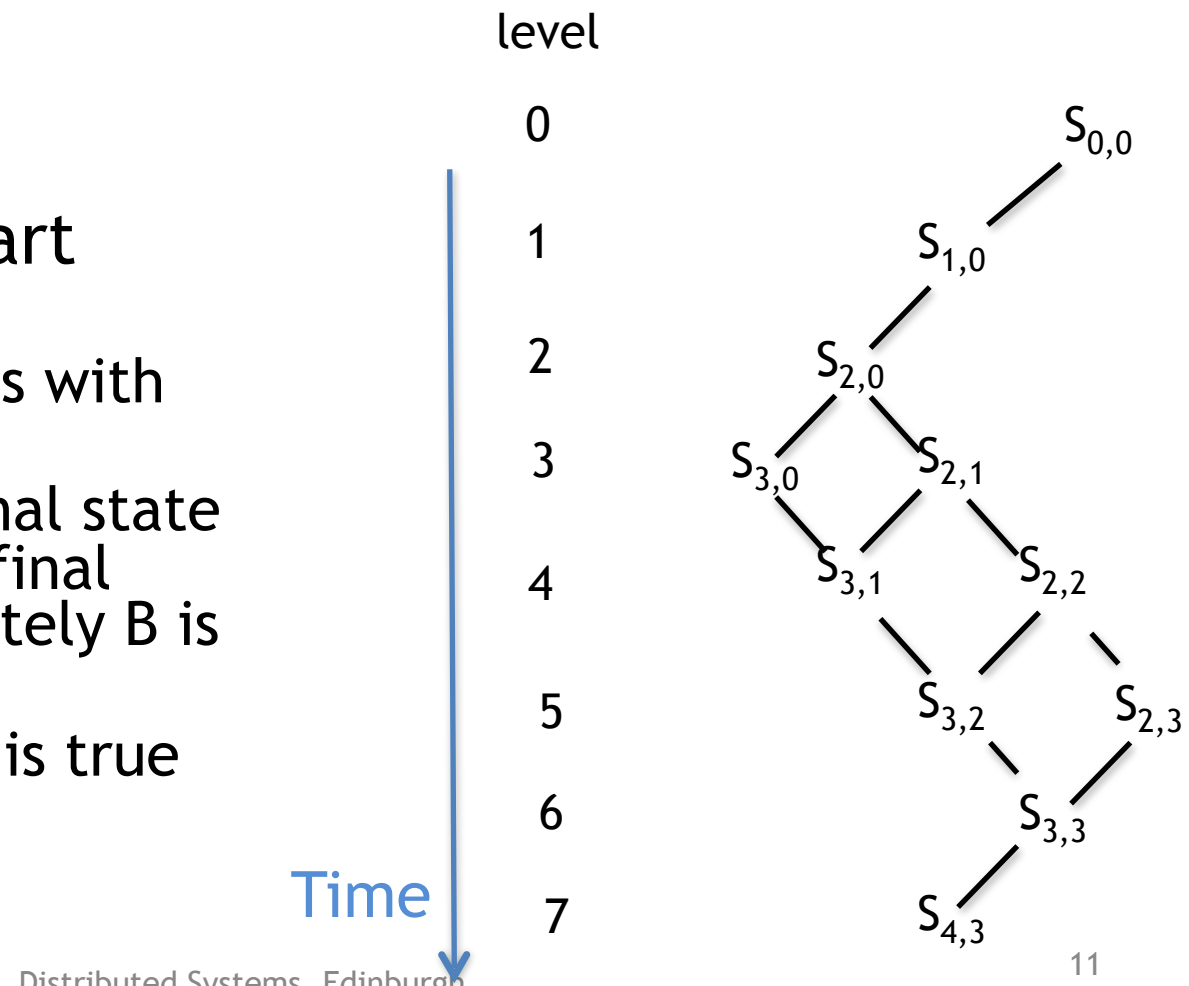
Lattice of global states (consistent cuts)

- Possibly B:
  - B occurs on at least one downward path
- Do a BFS from start state
  - If there is one state with B true, then possibly B is true



Lattice of global states (consistent cuts)

- Definitely B
  - B occurs on all downward paths
- Do a BFS from start state
  - Do not visit nodes with B: true
  - If BFS reaches final state and B is false in final state then Definitely B is false
  - Else Definitely B is true



What is the computational complexity?

What is the computational complexity?

- Possibly exponential in number of processes
- Problem is NP-complete

- Observation: more messages reduces complexity!

Mutual exclusion

Ref: CDK, VG

- Multiple processes should not use the same resource at once
  - Eg. Print to the same printer
  - Transmit/receive using the same antenna
  - Update the same database table

- Critical section (CS): the part of code that uses the restricted resource
- Mutual exclusion : restrict access to critical section to at most one process at one time

Properties in ME

- **Safety**: Two processes should not use critical section simultaneously

Properties in ME

- **Safety**: Two processes should not use critical section simultaneously

- **Liveness**: Every live request for CS is eventually granted
- **Fairness**: Requests must be granted in the order they are made (wrt logical time)

Distributed vs Centralized Mutex

- On a single computer, OS can manage access to a shared variable
- On a distributed system, we have to use messages

Assumption

- There is only one resource in question
- In reality there can be more, but for now, let us focus on just one
- All channels are FIFO

Central server algorithm

- There is a server or coordinator
  - Holds a "token" for the resource
- Other processes send token request to the server
- Server puts incoming requests in a queue
- Sends token to first process in queue
- Process returns token when done
- Server sends to next process

Central server algorithm

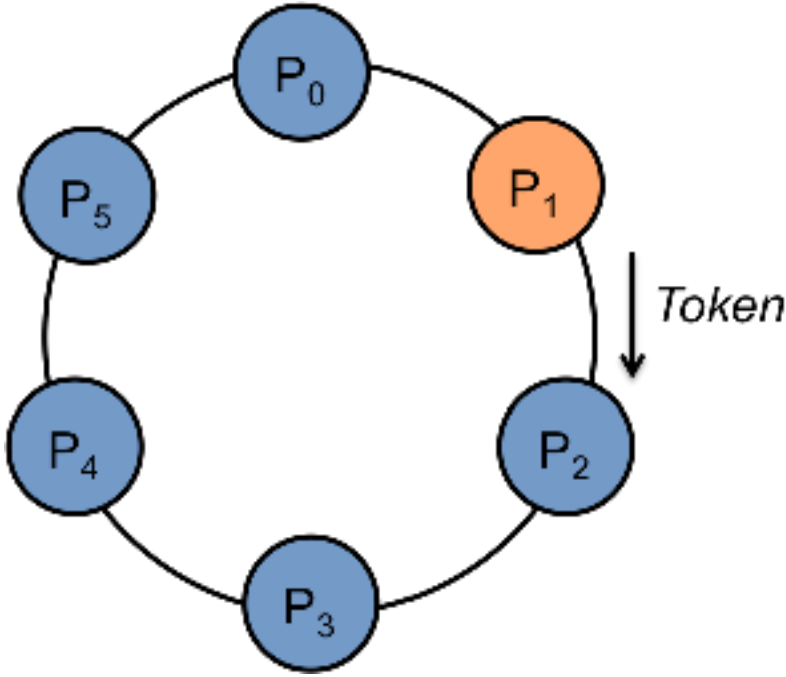
- What are the advantages and disadvantages?

Central server algorithm

- **Advantages**
  - Simple
  - Constant complexity per message
- **Disadvantages**
  - Central point of failure
  - Central bottleneck
  - Does not preserve order in asynchronous systems
  - Server must be selected/elected

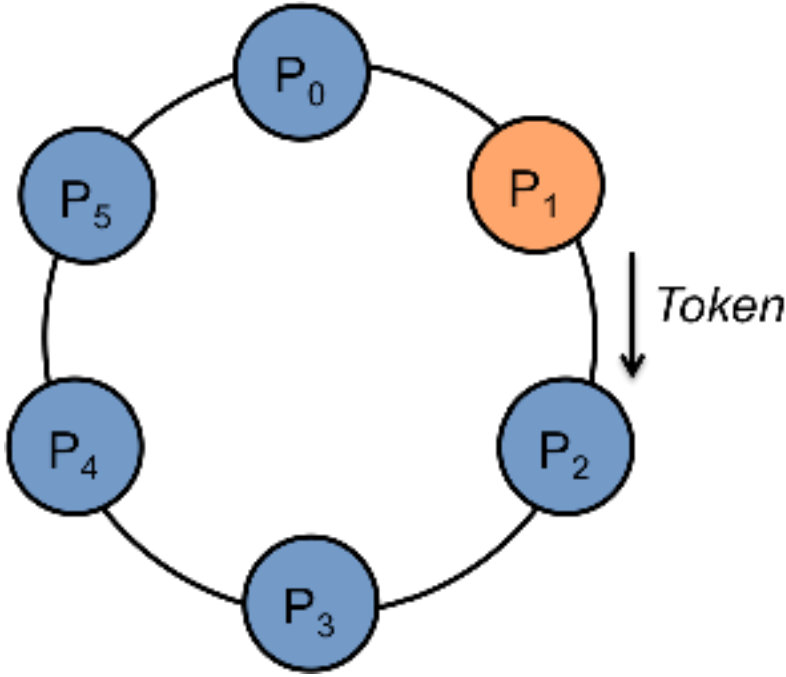
Token ring algorithm

- Processes are arranged in a ring
- The token is continuously passed in one direction
- A process on receiving token:
  - If it does not need CS, passes token to next one
  - If it needs CS, it holds token, executes CS and then passes token



Token ring algorithm

- Observe:
  - Processes do not need to be in an actual ring
  - Each process just needs to know the next process and have a method to send it a message



Token ring

- Problems:

Token ring

- Problems:
  - Not in-order
  - Long delay in getting token
    - Upto n-1
  - One failure breaks the ring
  - Passes token around even when there are no requests

Lamport's algorithm

- Every node i has a queue q_i of requests
  - Keeps requests sorted by logical timestamps
- Process i sends CS request:
  - Timestamped REQUEST (tsi, i) to all processes
  - Enters (tsi,i) to its own queue q_i
- Process j receives REQUEST (tsi,i)
  - Send timestamped REPLY to i
  - Enter (tsi,i) to q_j

Lamport's Algorithm

- Process i enters CS if
  - (tsi,i) is at head of its own queue
  - It has received REPLY from all processes
- To release CS
  - Process i sends RELEASE message to all
- On receiving RELEASE, process j
  - Removes (tsi,i) from q_j

Observations

- Requests granted in order consistent with happened before
- 3(n-1) messages per CS

Ricart and Agrawala's algorithm

- Main modification:
  - Node j does not send a REPLY if j has a request with timestamp lower than i's request
  - j simply delays the REPLY until its RELEASE message

Ricart-Agrawala's algorithm

- Process i sends CS request:
  - Timestamped REQUEST (tsi, i) to all processes
- Process j receives REQUEST (tsi,i)
  - If j has no outstanding request of its own earlier than (tsi,i) or is not executing CS
    - Send timestamped REPLY to i
    - Enter (tsi,i) to q_j
  - Else keep (tsi,i) pending

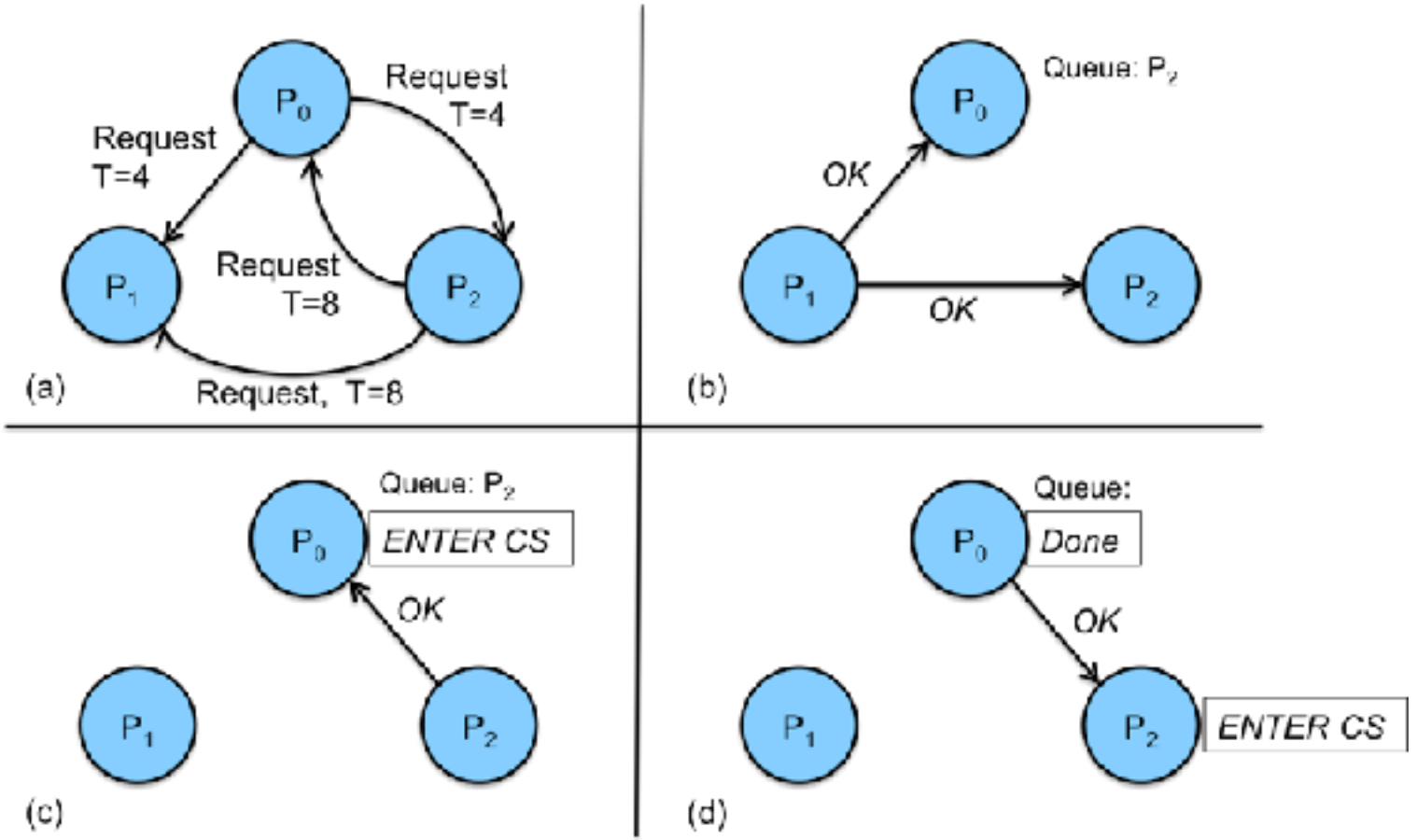
Ricart-Agrawala's algorithm

- Process i enters CS if
  - It has received REPLY from all processes
- To release CS
  - Sends REPLY message to pending processes

Ricart-Agrawala's algorithm

- Has no queues at processes
- The queue is maintained distributedly across all processes through timestamps and delayed replies
- Uses 2(n-1) messages

Ricart-Agrawala's algorithm



Maekawa's Quorum algorithm

- Idea: instead of getting permission from all processes, get permission from only a subset of processes

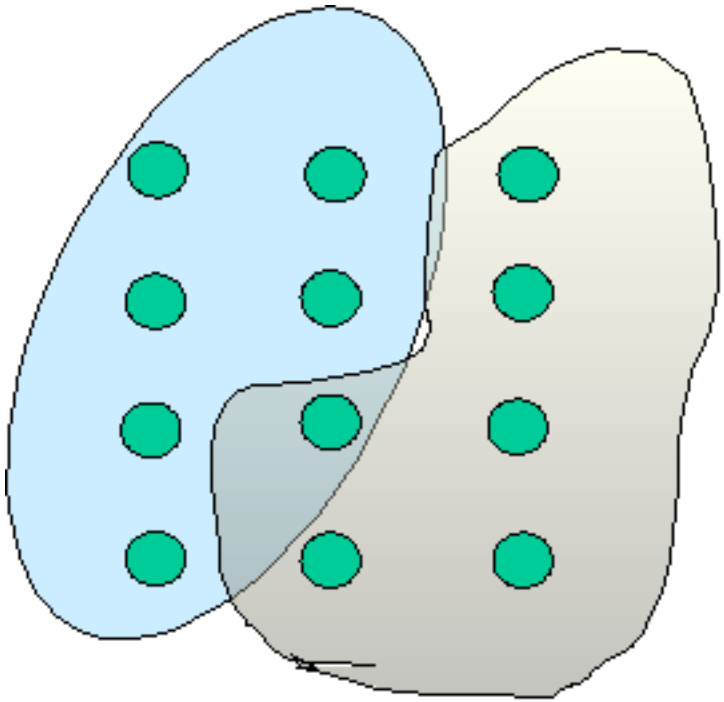
- For each process i, we have a voting set (quorum) V_i
  - For all i,j: $V_i \cap V_j \neq \varnothing$
  - For all i, $i \in V_i$
  - Voting sets are same size, each node is part of same number of sets

Maekawa's Quorum algorithm

- Idea:
  - Arrange nodes in a square grid
  - Quorum for node i:
    - All nodes in same row or same column as i
  - Any two quorums intersect

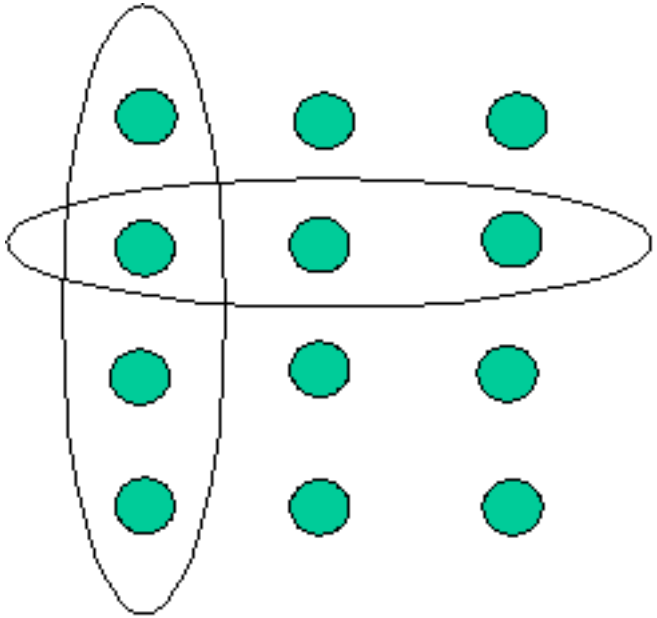
- Complexity?

Maekawa's Quorum algorithm



Let processes compete for votes. If a process has received more votes than any other process, it can enter the CS. If it does not have enough votes, it waits until the process in the CS is done and releases its votes. Quorums have the property that any two groups have a non-empty intersection.Simple majorities are quorums. Any 2 sets whose sizes are simple majorities must have at least one element in common.

Maekawa's Quorum algorithm



Grid quorum: arrange nodes in logical grid (square). A quorum is all of a row and all of a column.

- Complexity per CS: O(√n)

Resources

- Non-stable Predicates
  - Reading: CDK 11.5 Global states
- Mutual exclusion
  - Reading: CDK 15.2 Distributed mutual exclusion
  - https://www.youtube.com/watch?v=r7SJOhGF4Nc
  - https://www.youtube.com/watch?v=yBnRO2gGock
  - https://www.risc.jku.at/software/daj/