CSE 421/521 - Operating Systems
Fall 2018

Lecture - XXIII

Distributed Systems - II

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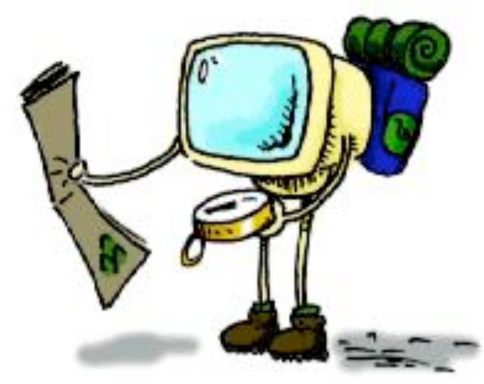
Roadmap

- Distributed Mutual Exclusion
- Distributed Deadlock Prevention
- Distributed Deadlock Detection



Distributed Mutual Exclusion (DME)

- Assumptions
  - The system consists of *n* processes; each process P_i resides at a different processor
  - Each process has a critical section that requires mutual exclusion
- Requirement
  - If P_i is executing in its critical section, then no other process P_j is executing in its critical section
- We present different approaches to ensure the mutual exclusion of processes in their critical sections

1. Centralized Approach

- One of the processes in the system is chosen to coordinate the entry to the critical section
- A process that wants to enter its critical section sends a request message to the coordinator
- The coordinator decides which process can enter the critical section next, and it sends that process a reply message
- When the process receives a reply message from the coordinator, it enters its critical section
- After exiting its critical section, the process sends a release message to the coordinator and proceeds with its execution
- This scheme requires three messages per critical-section entry: ***request***, ***reply***, ***release***
- Single point of failure! -> would need a new coordinator to be elected..

2. Fully Distributed Approach

- When process P_i wants to enter its critical section, it generates a new timestamp, *TS*, and sends the message *request* (P_i, *TS*) to all processes in the system
- When process P_j receives a *request* message, it may reply immediately or it may defer sending a reply back
- When process P_i receives a *reply* message from all other processes in the system, it can enter its critical section
- After exiting its critical section, the process sends *reply* messages to all its deferred requests

Fully Distributed Approach (Cont.)

- The decision whether process P_j replies immediately to a *request*(P_i, *TS*) message or defers its reply is based on three factors:
  - If P_j is in its critical section, then it defers its reply to P_i
  - If P_j does *not* want to enter its critical section, then it sends a *reply* immediately to P_i
  - If P_j wants to enter its critical section but has not yet entered it, then it compares its own request timestamp with the timestamp *TS*
    - If its own request timestamp is greater than *TS*, then it sends a *reply* immediately to P_i (P_i asked first)
    - Otherwise, the reply is deferred

  - Example: P1 sends a request to P2 and P3 (timestamp=10)
    P3 sends a request to P1 and P2 (timestamp=4)

Undesirable Consequences

- The processes need to know the identity of all other processes in the system, which makes the dynamic addition and removal of processes more complex

- If one of the processes fails, then the entire scheme collapses
  - This can be dealt with by continuously monitoring the state of all the processes in the system, and notifying all processes if a process fails

==> More suitable for small, stable set of coordinating processes

3. Token-Passing Approach

- Circulate a token among processes in system
  - **Token** is special type of message
  - Possession of token entitles holder to enter critical section
- Processes *logically* organized in a **ring structure**
- Unidirectional ring guarantees freedom from starvation
- Two types of failures
  - Lost token – election must be called
  - Failed processes – new logical ring established

Election Algorithms

- Determine where a new copy of the coordinator should be restarted
- Assume that a unique priority number is associated with each active process in the system, and assume that the priority number of process P_i is i
- The coordinator is always the process with the highest priority number. When a coordinator fails, the algorithm must elect that active process with the largest priority number
- Two algorithms, the bully algorithm and a ring algorithm, can be used to elect a new coordinator in case of failures

1. Bully Algorithm

- Applicable to systems where every process can send a message to every other process in the system
- If process P_i sends a request that is not answered by the coordinator within a time interval T, assume that the coordinator has failed; P_i tries to elect itself as the new coordinator
- P_i sends an election message to every process with a higher priority number, P_i then waits for any of these processes to answer within T

Bully Algorithm (Cont.)

- If no response within T, assume that all processes with numbers greater than i have failed; P_i elects itself the new coordinator
- If answer is received, P_i begins time interval T', waiting to receive a message that a process with a higher priority number has been elected
- If no message is sent within T', assume the process with a higher number has failed; P_i should restart the algorithm

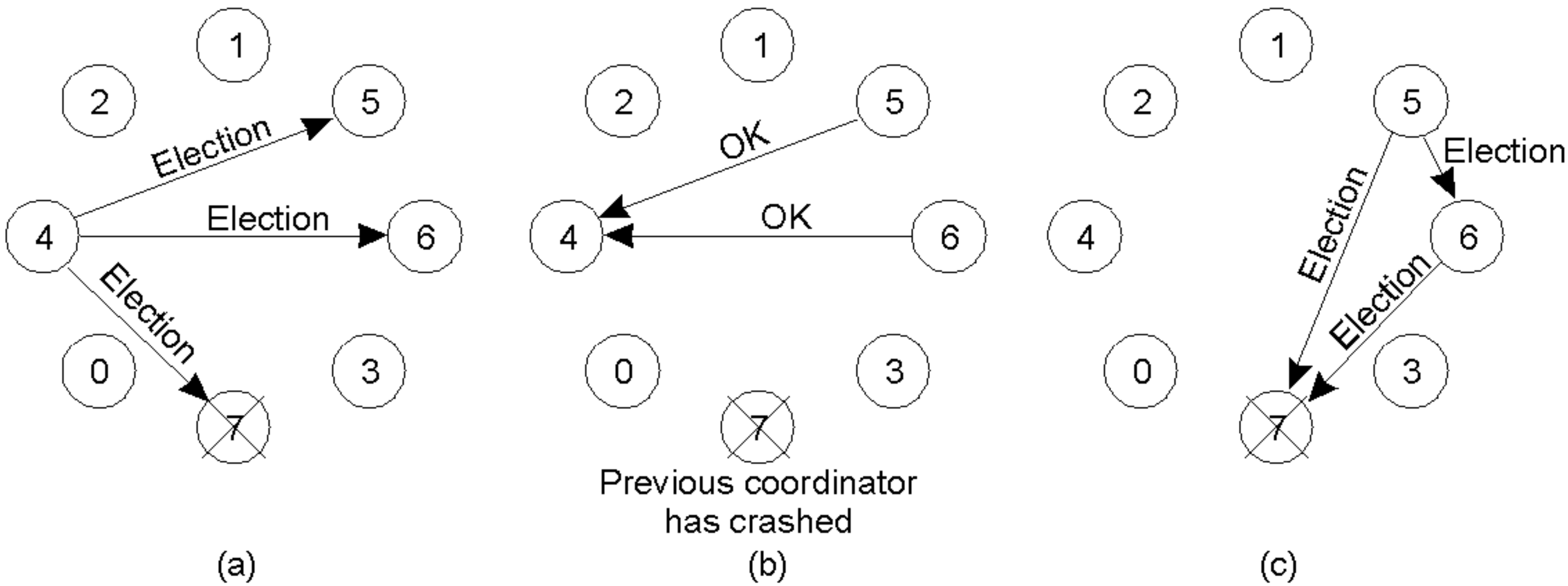
Bully Algorithm (Cont.)

- If P_i is not the coordinator, then, at any time during execution, P_i may receive one of the following two messages from process P_j
  - P_j is the new coordinator ($j > i$). P_i, in turn, records this information
  - P_j started an election ($j < i$). P_i, sends a response to P_j and begins its own election algorithm, provided that *Pi* has not already initiated such an election

- After a failed process recovers, it immediately begins execution of the same algorithm

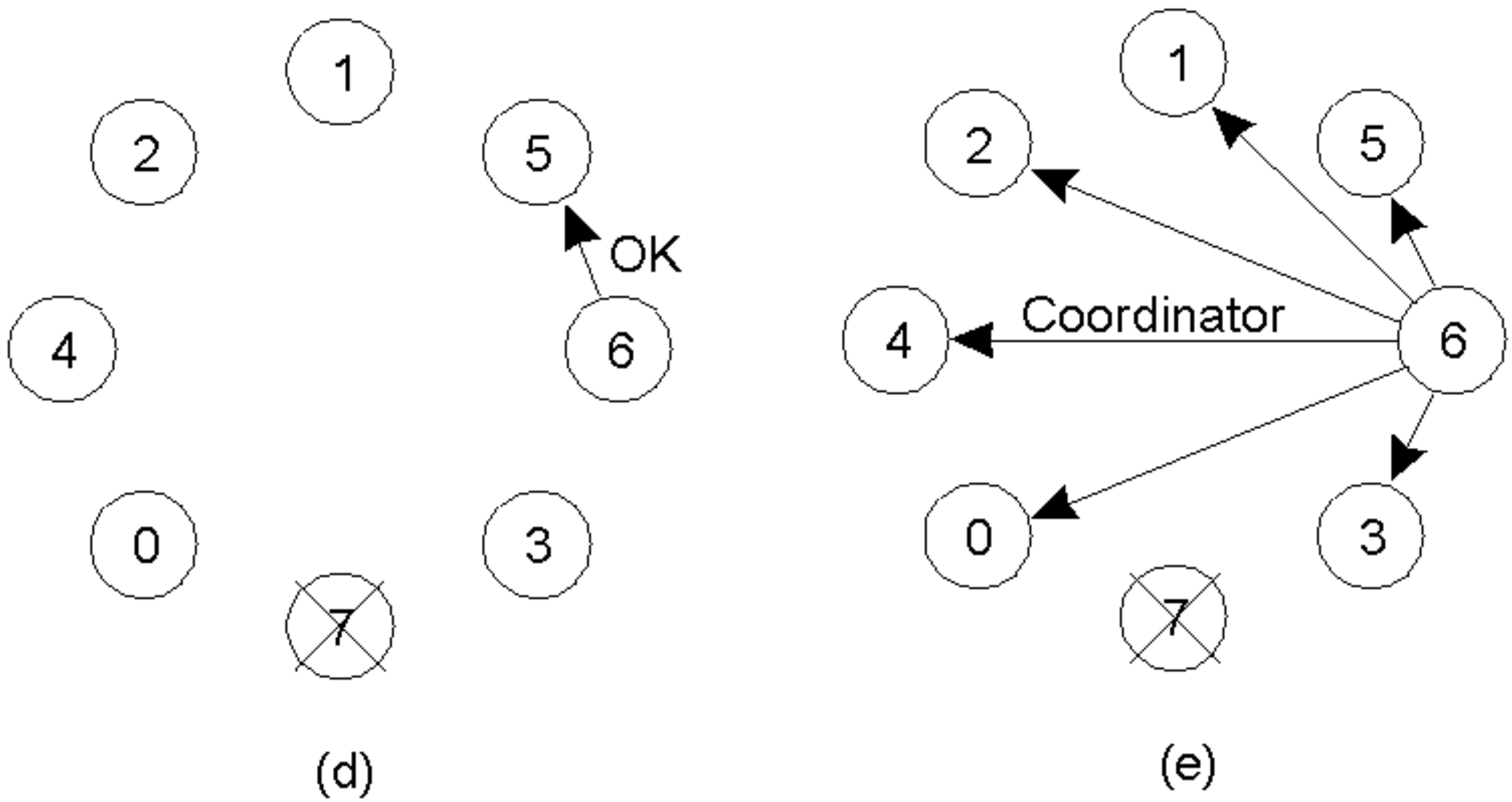
- If there are no active processes with higher numbers, the recovered process forces all processes with lower number to let it become the coordinator process, even if there is a currently active coordinator with a lower number

The Bully Algorithm (Example)



- Process 4 holds an election
- Process 5 and 6 respond, telling 4 to stop
- Now 5 and 6 each hold an election

The Bully Algorithm (Example)



Bully Algorithm Analysis

- Best case
  - The node with second highest identifier detects failure
  - Total messages = N-2
    - One message for each of the other processes indicating the process with the second highest identifier is the new coordinator.
- Worst case
  - The node with lowest identifier detects failure. This causes N-1 processes to initiate the election algorithm each sending messages to processes with higher identifiers.
  - Total messages = $O(N^2)$

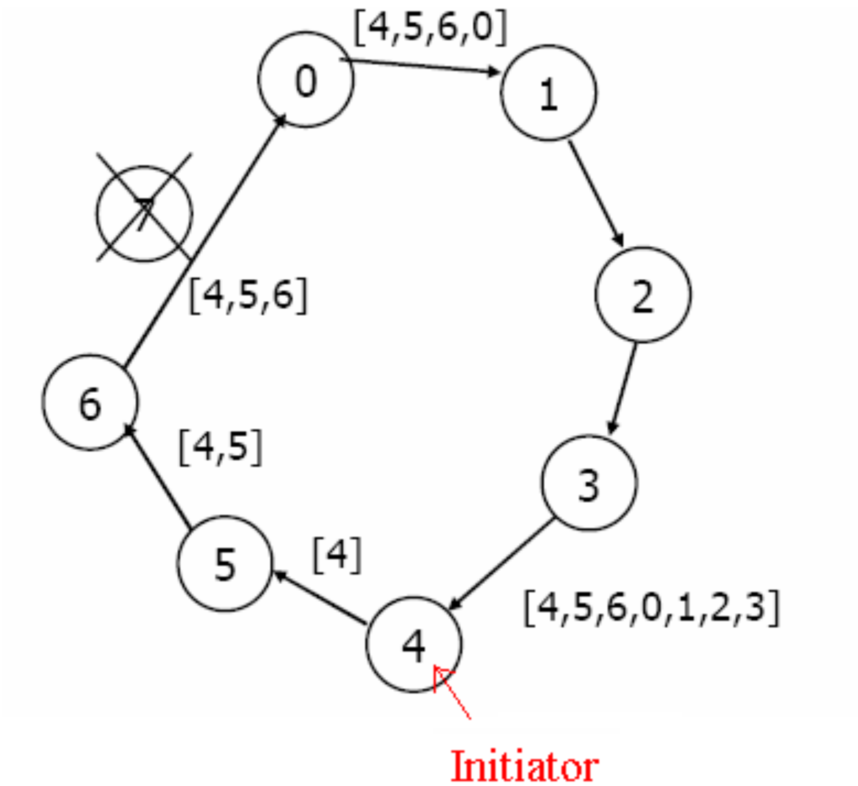
2. Ring Algorithm

- Applicable to systems organized as a ring (logically or physically)
- Assumes that the links are unidirectional, and that processes send their messages to their right neighbors
- Each process maintains an active list, consisting of all the priority numbers of all active processes in the system when the algorithm ends
- If process Pi detects a coordinator failure, it creates a new active list that is initially empty. It then sends a message elect(i) to its right neighbor, and adds the number i to its active list

Ring Algorithm (Cont.)

- If P_i receives a message elect(j) from the process on the left, it must respond in one of three ways:
  - ✦ If this is the first *elect* message it has seen or sent, P_i creates a new active list with the numbers i and j
    - It then sends the message *elect(i)*, followed by the message *elect(j)*
  - ✦ If $i \neq j$, the message dos not contain P_i
    - P_i adds j to its active list and forward message to the right
  - ✦ If $i = j$, then P_i receives the message *elect(i)*
    - The active list for P_i contains all the active processes in the system
    - P_i can now determine the largest number in the active list to identify the new coordinator process

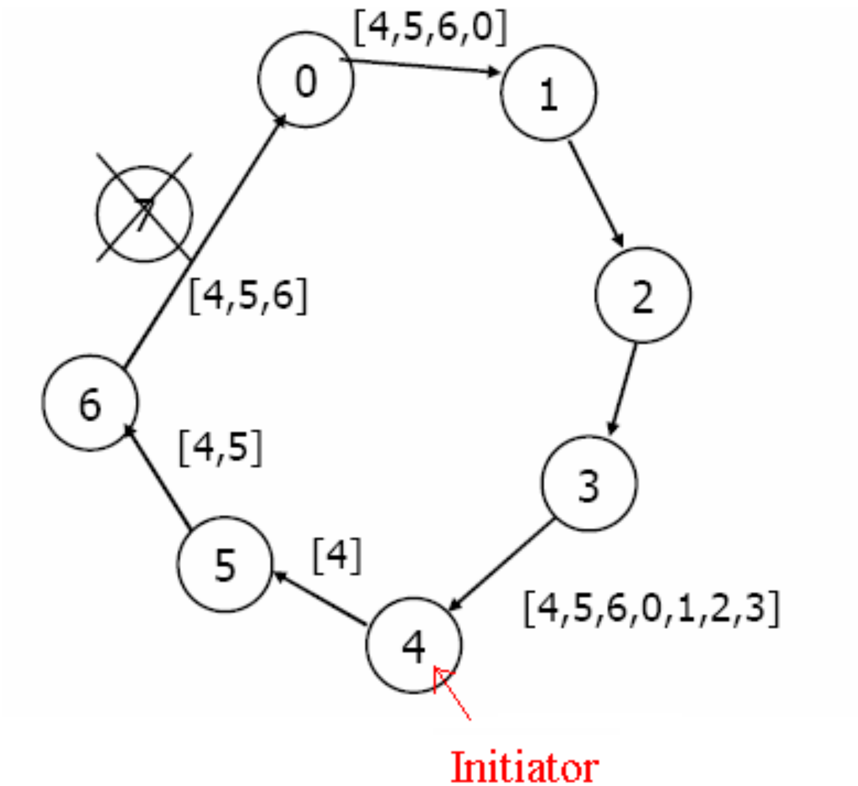
Ring Algorithm (Example)



Initiation:

1. Process 4 sends an ELECTION message to its successor (or next alive process) with its ID

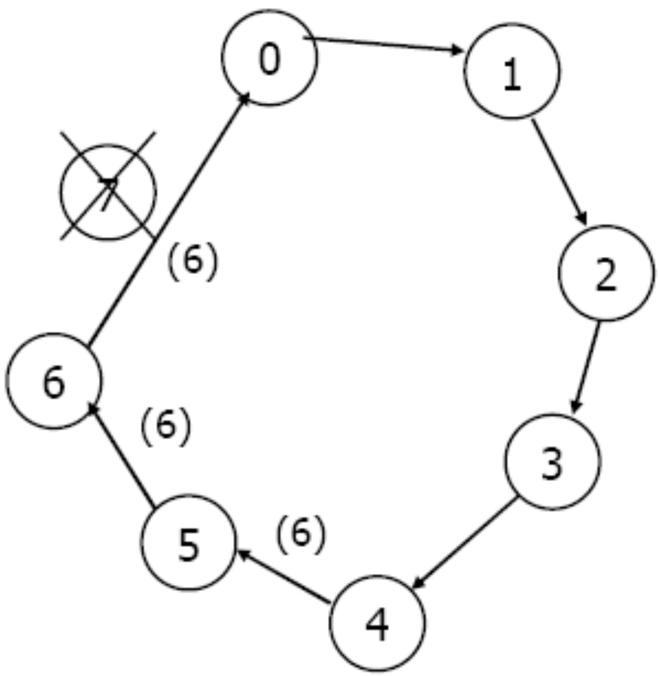
Ring Algorithm (Example)



Initiation:

2. Each process adds its own ID and forwards the ELECTION message

Ring Algorithm (Example)



Leader Election:

3. Message comes back to initiator, here the initiator is 4.
4. Initiator announces the winner by sending another message around the ring

Ring Algorithm Analysis

- At best 2(N-1) messages are passed
  - One round for the ELECTION message
  - One round for the COORDINATOR
  - Assumes that only a single process starts an election.
- Multiple elections cause an increase in messages but no real harm done.

Distributed Deadlock Prevention

- Resource-ordering deadlock-prevention

  =>define a *global* ordering among the system resources
  - Assign a unique number to all system resources
  - A process may request a resource with unique number *i* only if it is not holding a resource with a unique number grater than *i*
  - Simple to implement; requires little overhead

- Timestamp-ordering deadlock-prevention

  =>unique Timestamp assigned when each process is created

  1. wait-die scheme -- non-preemptive
  2. wound-wait scheme -- preemptive

1. Prevention: Wait-Die Scheme

- non-preemptive approach
- If P_i requests a resource currently held by P_j, P_i is allowed to wait only if it has a smaller timestamp than does P_j (P_i is older than P_j)
  - Otherwise, P_i is rolled back (dies - releases resources)

- Example: Suppose that processes P_1, P_2, and P_3 have timestamps 5, 10, and 15 respectively
  - if P_1 request a resource held by P_2, then P_1 will wait
  - If P_3 requests a resource held by P_2, then P_3 will be rolled back

- The older the process gets, the more waits

2. Prevention: Wound-Wait Scheme

- Preemptive approach, counterpart to the wait-die

- If P_i requests a resource currently held by P_j, P_i is allowed to wait only if it has a larger timestamp than does P_j (P_i is younger than P_j). Otherwise P_j is rolled back (P_j is wounded by P_i)

- Example: Suppose that processes P_1, $P_{2,}$ and P_3 have timestamps 5, 10, and 15 respectively
  - If P_1 requests a resource held by P_2, then the resource will be preempted from P_2 and P_2 will be rolled back
  - If P_3 requests a resource held by P_2, then P_3 will wait
- The rolled-back process eventually gets the smallest timestamp.

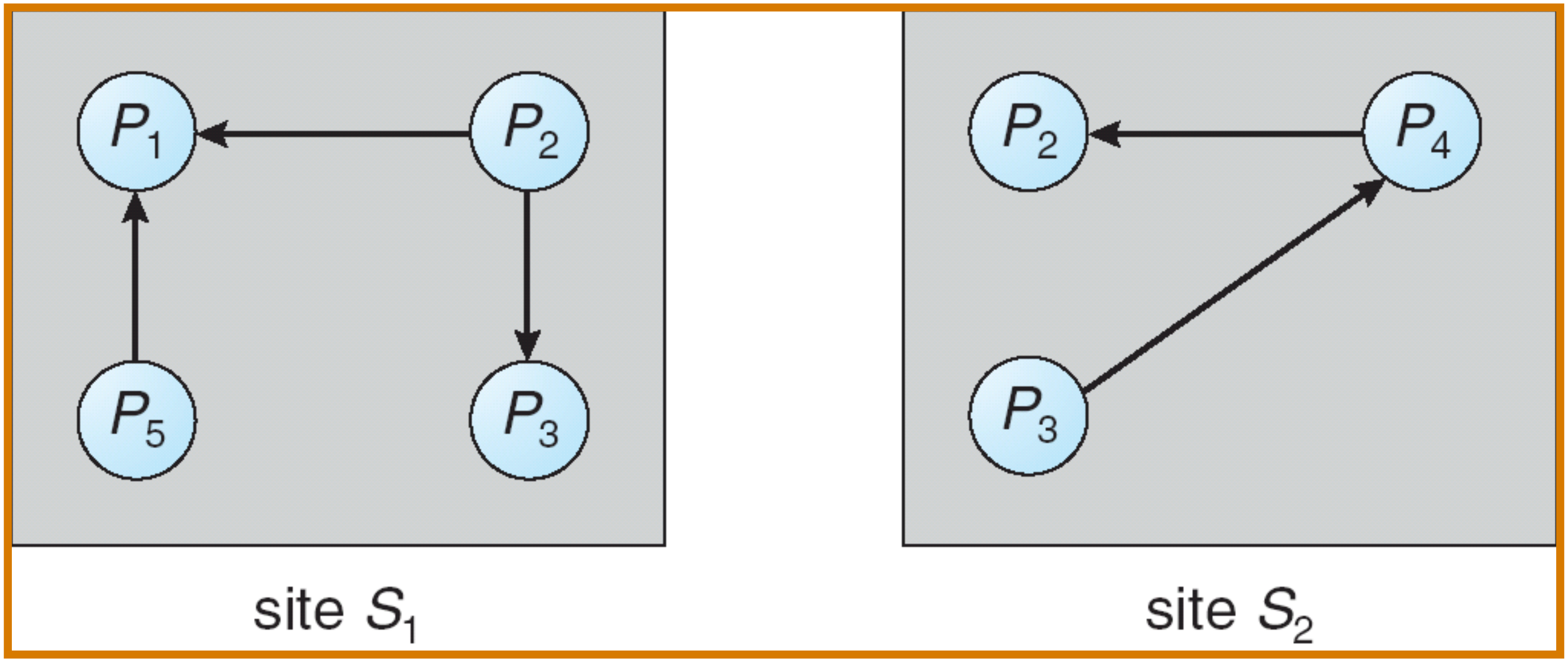
Comparison

- Both avoid starvation, provided that when a process is rolled back, it is not assigned a new timestamp

- In wait-die, older process must wait for the younger one to release its resources. In wound-wait, an older process never waits for a younger process.

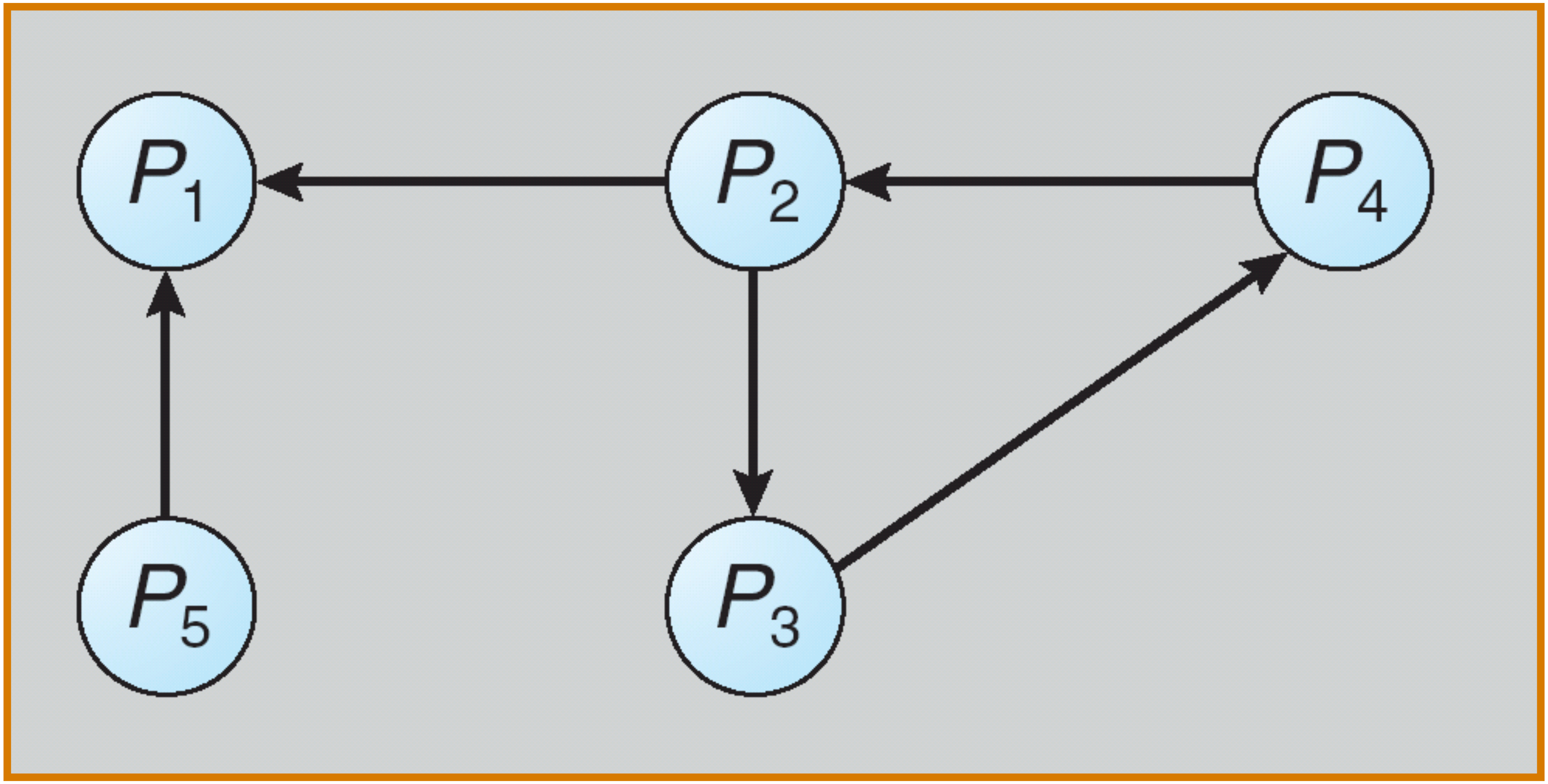
- There are fewer roll-backs in wound-wait
  - Assume Pi is younger than Pj
  - **Wait-Die:**
    - Pi->Pj; Pi dies, requests the same resources; Pi dies again...
  - **Wound-Wait:**
    - Pj->Pi; Pi wounded. requests the same resources; Pi waits..

Distributed Deadlock Detection



Two Local Wait-For Graphs

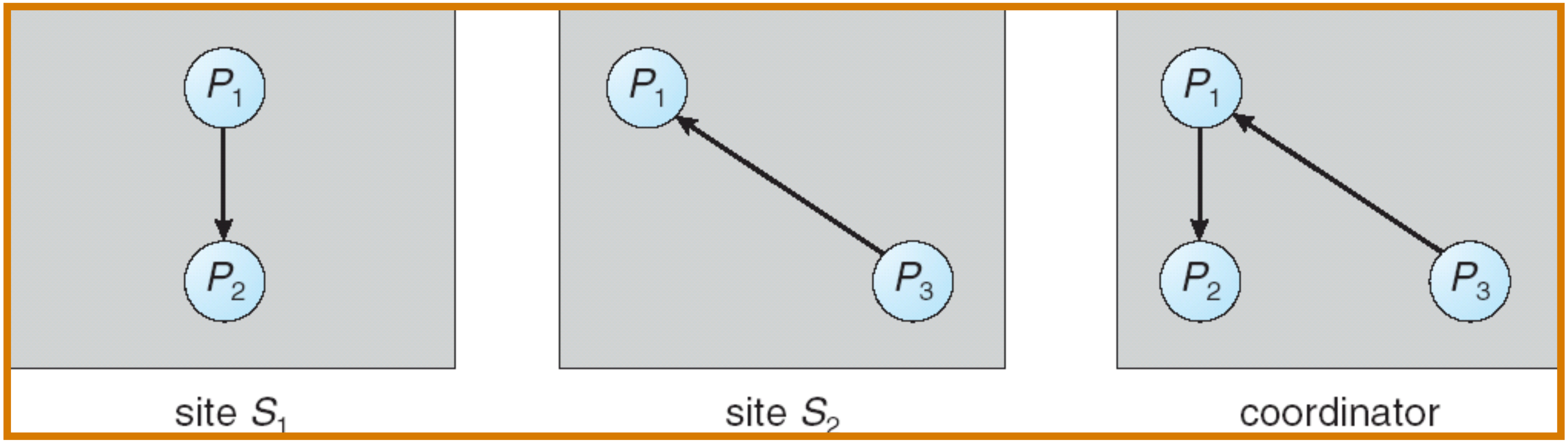
Global Wait-For Graph



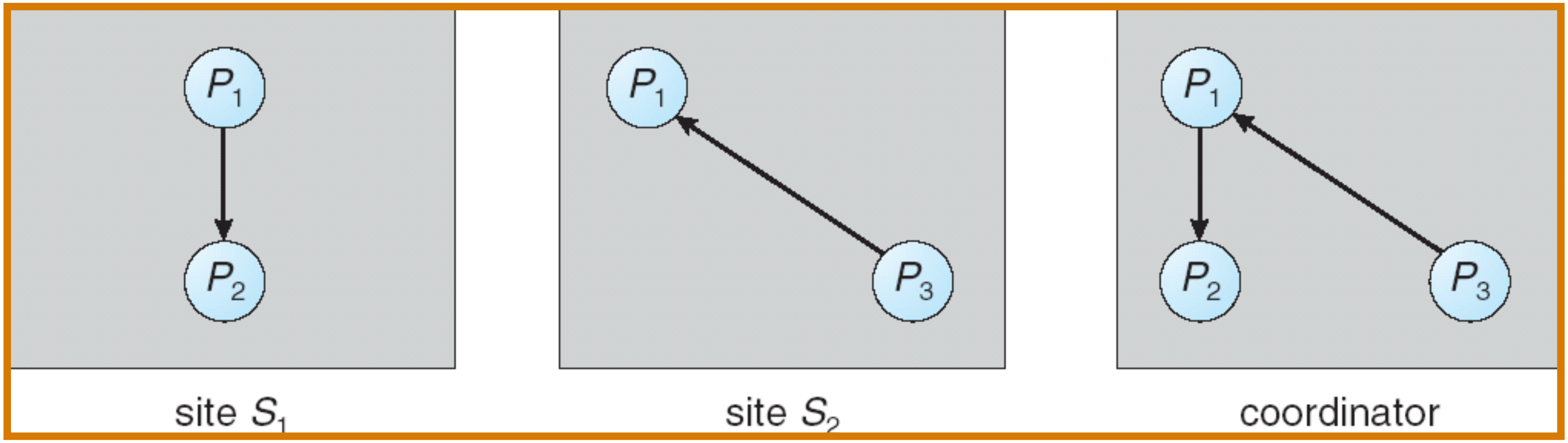
1. Deadlock Detection – Centralized Approach

- Each site keeps a local wait-for graph
  - The nodes of the graph correspond to all the processes that are currently either holding or requesting any of the resources local to that site; i.e., P1 is requesting a resource held by P2 on Site S2
- A global wait-for graph is maintained in a single coordination process; this graph is the union of all local wait-for graphs
- There are three different options (points in time) when the wait-for graph may be constructed:
  1. Whenever a new edge is inserted or removed in one of the local wait-for graphs
  2. Periodically, when a number of changes have occurred in a wait-for graph
  3. Whenever the coordinator needs to invoke the cycle-detection algorithm

Local and Global Wait-For Graphs



False Cycles

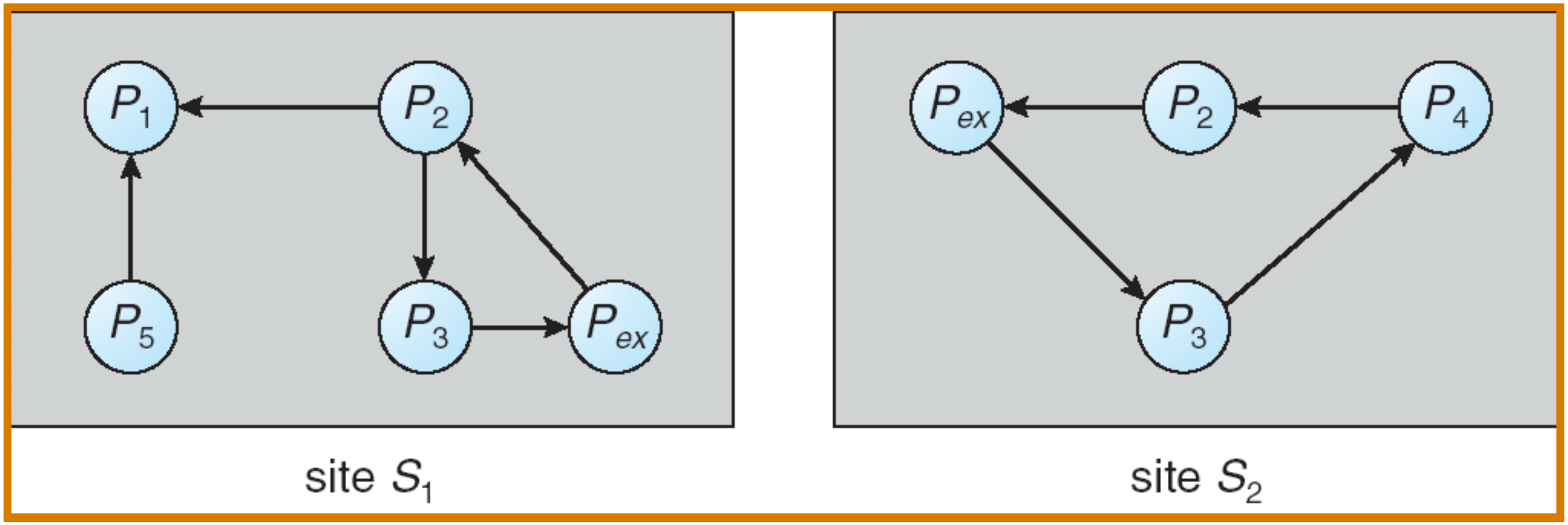


- Assume:
  - P2 releases the resource it was holding
    - (remove P1 —> P2)
  - P2 makes a request for a resource held by P3 on site S2
    - (add P2 —> P3)
- Consider option 1. What will happen if the update messages arrive to the coordination in wrong order?
  - ==> false deadlock alert!

2. Fully Distributed Approach

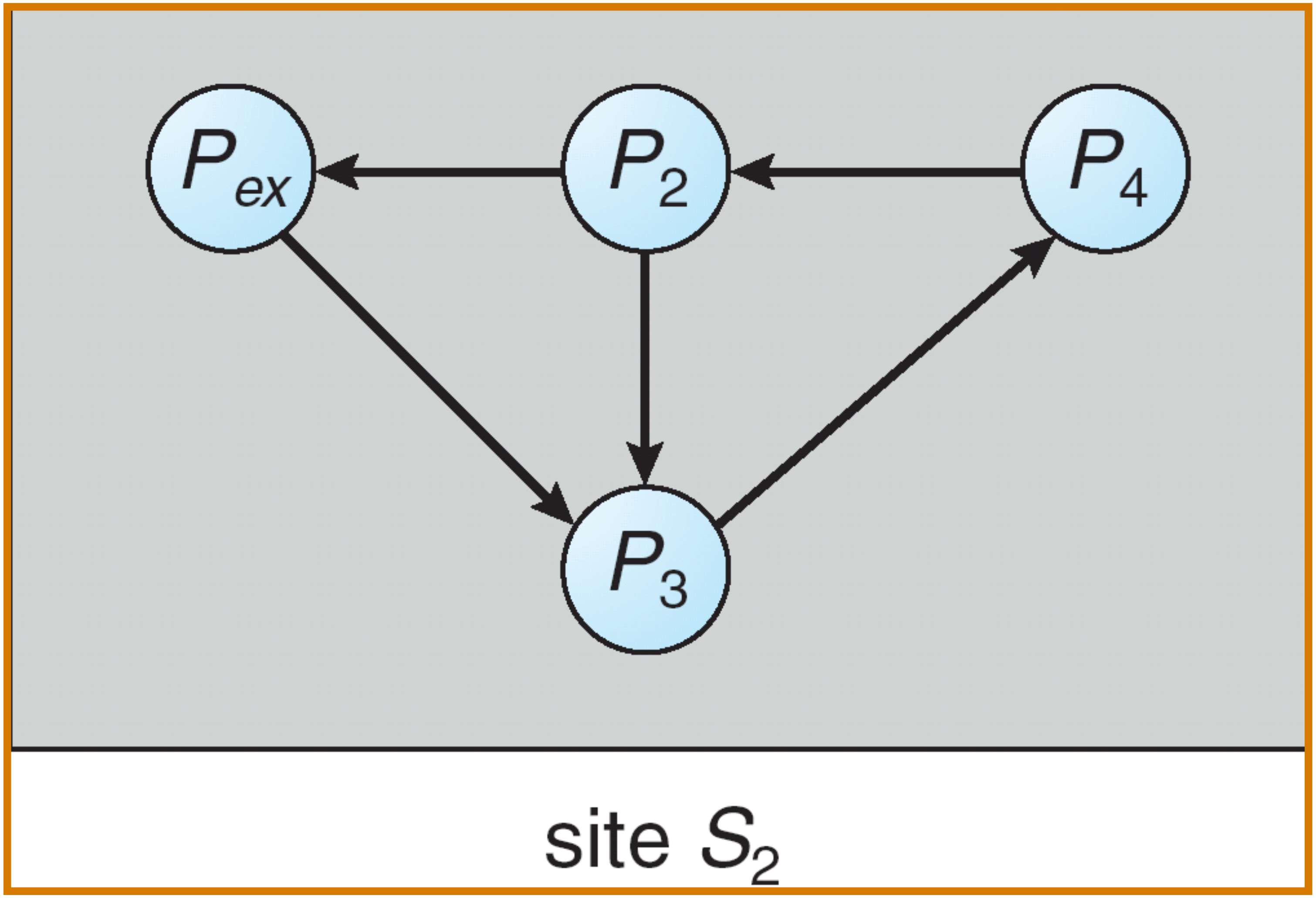
- All controllers share equally the responsibility for detecting deadlock
- Every site constructs a wait-for graph that represents a part of the total graph
- We add one additional node P_{ex} to each local wait-for graph
  - $P_i \rightarrow P_{ex}$ exists if P_i is waiting for a data item at another site being held by another process
- If a local wait-for graph contains a cycle that does not involve node P_{ex}, then the system is in a deadlock state
- A cycle involving P_{ex} implies the possibility of a deadlock
  - To ascertain whether a deadlock does exist, a distributed deadlock-detection algorithm must be invoked

Augmented Local Wait-For Graphs

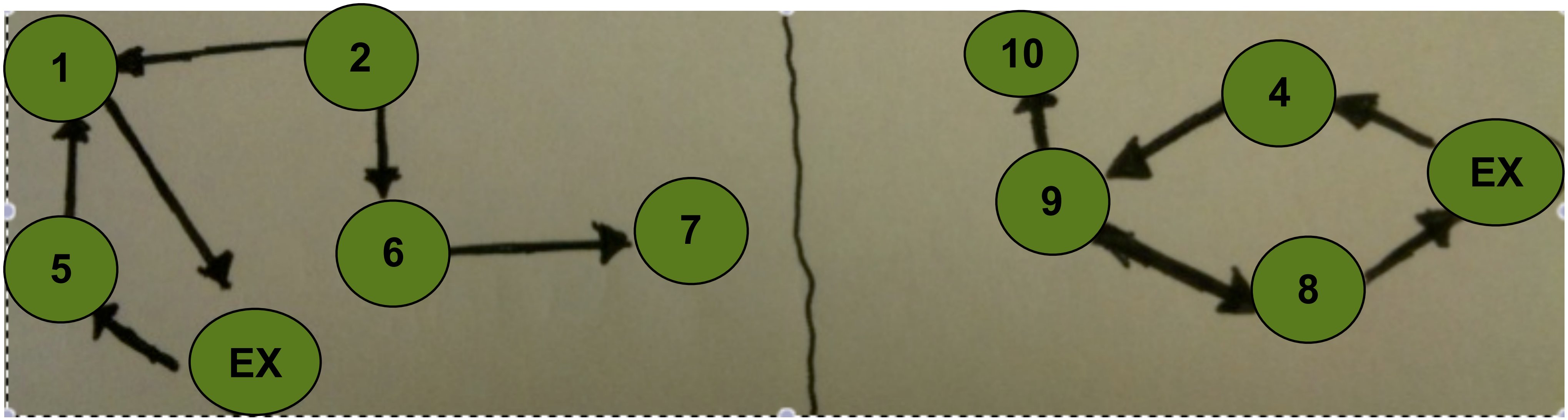


- S1 discovers cycle: Pex —> P2 —> P3 —> Pex
- S1 transmits this message to S2
- S2 learns additional edges from this message, such as P2 —> P3, and created and augmented graph (next slide)
- Now, S2 has a cycle which does not involve Ex —> deadlock
- Note: outcome wold be the same if S2 detected the local cycle first.

Augmented Local Wait-For Graph in Site S2

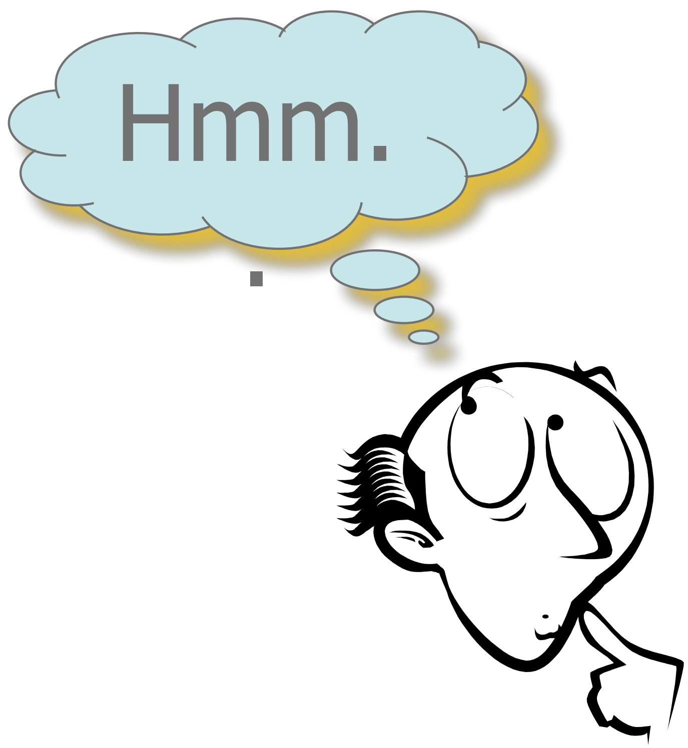


Exercise



Considering the above local wait-for graphs at sites S1 and S2, is the system D in a deadlocked state? If so, which processes are involved in the deadlock? Show how you would check the existence of a deadlock.

Any Questions?



Acknowledgements

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