# Distributed Operating Systems Issues
# Chapters 16 and 18

# Objectives

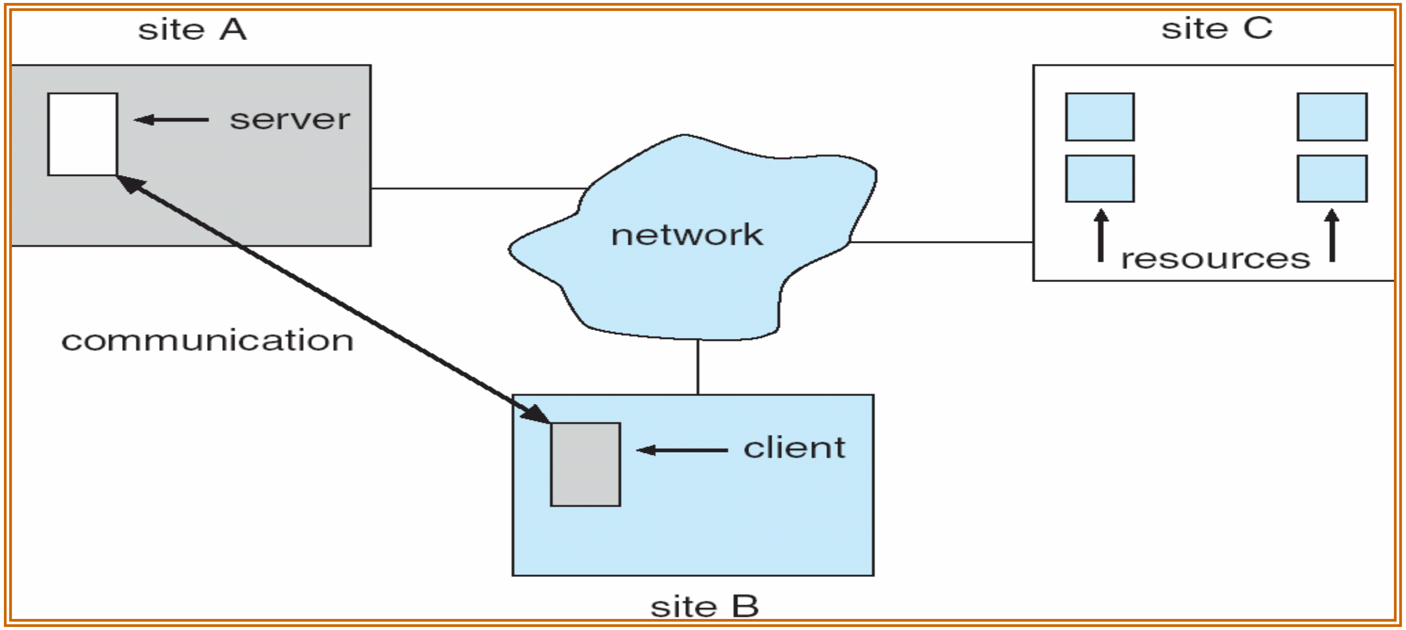
- To provide a high-level overview of distributed systems
- To discuss the general structure of distributed operating systems
- To describe various methods for achieving mutual exclusion in a distributed system
- To present schemes for handling deadlock prevention, deadlock avoidance, and deadlock detection in a distributed system
- To present distributed algorithms used in case of failure

# Outline

- Motivation **(16.1)**
- Types of Distributed Operating Systems **16.2)**
- Event Ordering **(18.1)**
- Mutual Exclusion **(18.2)**
- Deadlock Handling **(18.5)**
- Election Algorithms **(18.6)**

# - Motivation ...

- **Distributed system** is collection of loosely coupled processors interconnected by a communications network
- Processors variously called *nodes, computers, machines, hosts*
  - *Site* is location of the processor



# ... - Motivation

- Reasons for distributed systems
  - Resource sharing
    - sharing and printing files at remote sites
    - processing information in a distributed database
    - using remote specialized hardware devices
  - Computation speedup – load sharing
  - Reliability – detect and recover from site failure, function transfer, reintegrate failed site
  - Communication – message passing

# - Types of Distributed Operating Systems ...

- Network Operating Systems
  - Users are aware of multiplicity of machines. Access to resources of various machines is done explicitly by:
    - Remote logging into the appropriate remote machine (telnet, ssh)
    - Transferring data from remote machines to local machines, via the File Transfer Protocol (FTP) mechanism
- Distributed Operating Systems
  - Users not aware of multiplicity of machines
    - Access to remote resources similar to access to local resources
  - Data Migration – transfer data by transferring entire file, or transferring only those portions of the file necessary for the immediate task
  - Computation Migration – transfer the computation, rather than the data, across the system

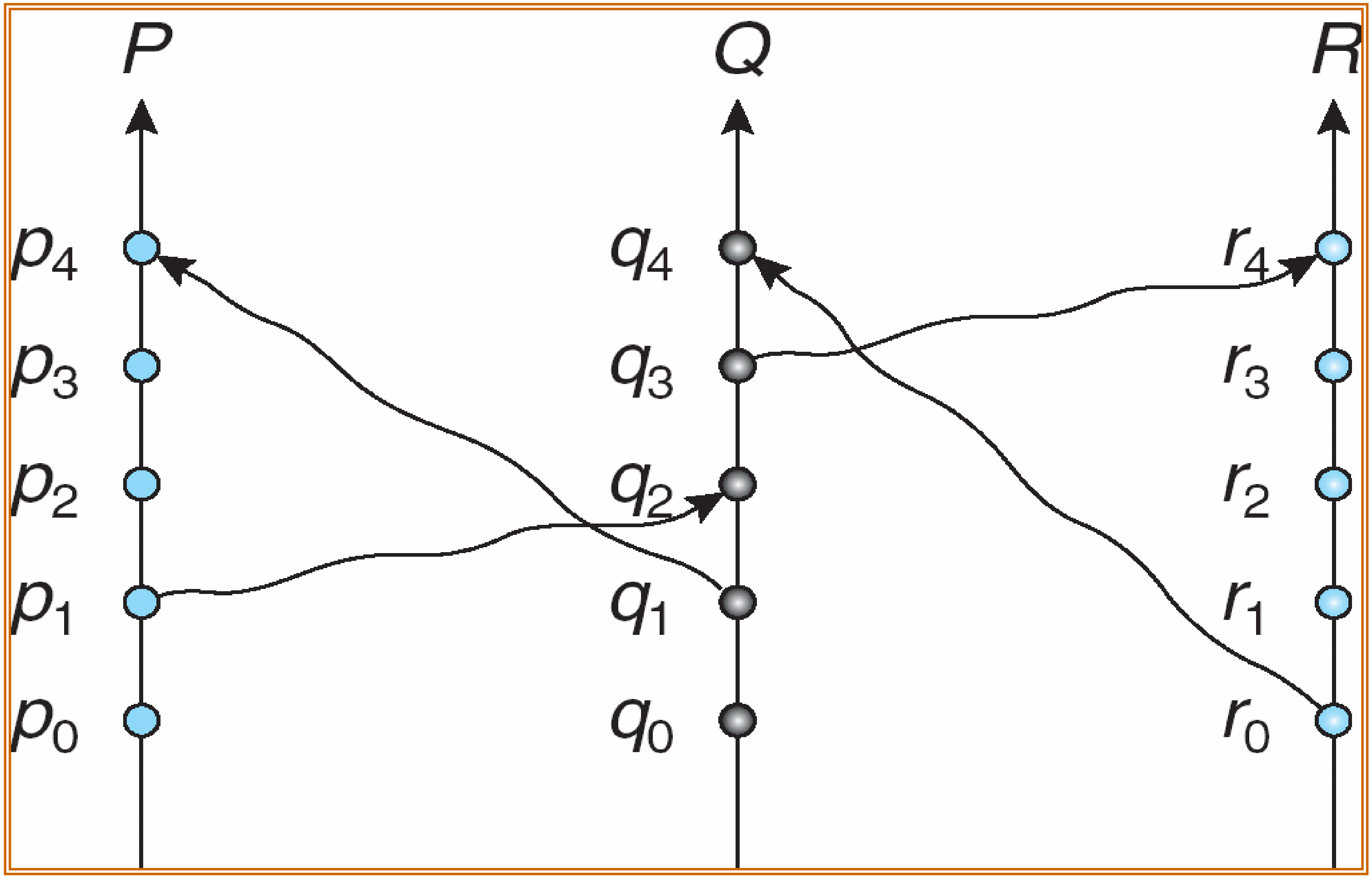
# ... - Distributed-Operating Systems

- Process Migration – execute an entire process, or parts of it, at different sites
  - Load balancing – distribute processes across network to even the workload
  - Computation speedup – subprocesses can run concurrently on different sites
  - Hardware preference – process execution may require specialized processor
  - Software preference – required software may be available at only a particular site
  - Data access – run process remotely, rather than transfer all data locally

## - Event Ordering

- *Happened-before* relation (denoted by $\rightarrow$)
  - If $A$ and $B$ are events in the same process, and $A$ was executed before $B$, then $A \rightarrow B$
  - If $A$ is the event of sending a message by one process and $B$ is the event of receiving that message by another process, then $A \rightarrow B$
  - If $A \rightarrow B$ and B $\rightarrow C$ then $A \rightarrow C$

# -- Relative Time for Three Concurrent Processes



# -- Implementation of $\rightarrow$

- Associate a timestamp with each system event
  - Require that for every pair of events A and B, if A $\rightarrow$ B, then the timestamp of A is less than the timestamp of B
- Within each process $P_i$ a **logical clock**, $LC_i$ is associated
  - The logical clock can be implemented as a simple counter that is incremented between any two successive events executed within a process
    - Logical clock is **monotonically increasing**
- A process advances its logical clock when it receives a message whose timestamp is greater than the current value of its logical clock
- If the timestamps of two events A and B are the same, then the events are concurrent
  - We may use the process identity numbers to break ties and to create a total ordering

# - 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 two algorithms to ensure the mutual exclusion execution of processes in their critical sections
  - Centralized approach
  - Fully distributed approach

# -- DME: 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 its 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

# -- DME: 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 other 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

# ... -- DME: Fully Distributed Approach

- 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

# -- Desirable Behavior of Fully Distributed Approach

- Freedom from Deadlock is ensured
- Freedom from starvation is ensured, since entry to the critical section is scheduled according to the timestamp ordering
  - The timestamp ordering ensures that processes are served in a first-come, first served order
- The number of messages per critical-section entry is

$$2 \times (n - 1)$$

This is the minimum number of required messages per critical-section entry when processes act independently and concurrently.

## -- Three 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
- Processes that have not entered their critical section must pause frequently to assure other processes that they intend to enter the critical section
  - This protocol is therefore suited for small, stable sets of cooperating processes

# -- 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**
- Algorithm similar to Chapter 6 algorithm 1 but token substituted for shared variable
- Unidirectional ring guarantees freedom from starvation
- Two types of failures
  - Lost token – election must be called
  - Failed processes – new logical ring established

# - Deadlock Handling

- The following 3 deadlock algorithms presented in Chapter 7 can be used with distributed systems, provided that appropriate modifications are made
  - Avoidance
    - Banker's Algorithm
  - Prevention
  - Detection and recovery

# -- Deadlock Avoidance

- Banker's algorithm
  - designate one of the processes in the system as the process that maintains the information necessary to carry out the Banker's algorithm
    - Every resource request must be channeled through the designated process.
    - Also implemented easily, but may require too much overhead
  - Not practical because the designated process may become a bottleneck due to excessive messages that it has to process

# -- Deadlock Prevention

- Resource-ordering deadlock-prevention Scheme
- Time stamped Deadlock-Prevention Scheme
  - Wait-Die Scheme
  - Would-Wait Scheme

## --- Resource-ordering deadlock-prevention Scheme

- 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.

# -- Time stamped Deadlock-Prevention Scheme

- Each process $P_i$ is assigned a unique priority number
- Priority numbers are used to decide whether a process $P_i$ should wait for a process $P_j$; otherwise $P_i$ is rolled back
- The scheme prevents deadlocks
  - For every edge $P_i \rightarrow P_j$ in the wait-for graph, $P_i$ has a higher priority than $P_j$
  - Thus a cycle cannot exist
- Disadvantage -  starvation
  - Solution :- priorities based on timestamps
    - Wait-die scheme (nonpreemptive)
    - Wound-wait scheme (preemptive)

# --- Wait-Die Scheme

- 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)

- In short, if the requesting process is:
  - Old: waits
  - Young: dies

- 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

# --- Would-Wait Scheme

- 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 $P_i$)

- In short, if the requesting process:
  - young: wait
  - old: never waits-wounds the young

- 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

# --- Both (Wait-die and Wound-wait) schemes

- In Wait-die
  - Older waits for younger
  - Younger is not allowed to wait (Killed)
- In Wound-wait
  - Older never waits for younger
  - Younger is allowed to wait
- In both schemes unnecessary rollback can occur
- Both schemes can avoid starvation provided that, when a process is rolled back its timestamp doesn’t change.

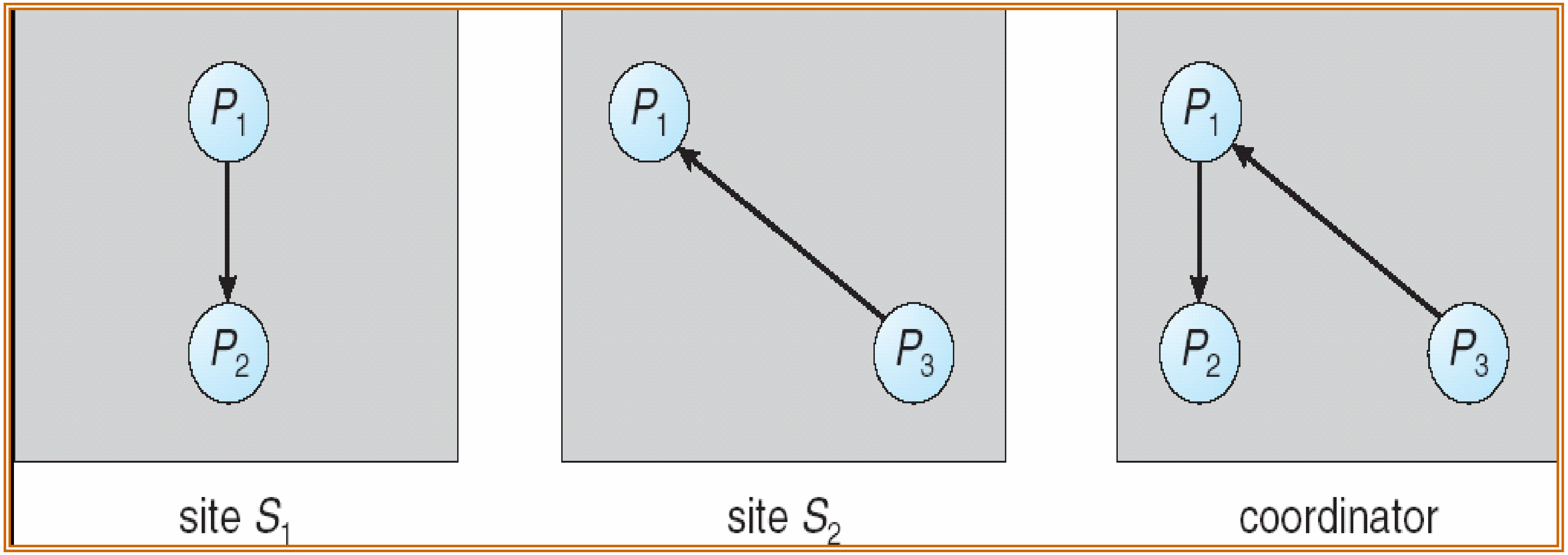
# -- Deadlock Detection

- Centralized Approach
- Fully Distributed Approach

## --- 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
- A global wait-for graph is maintained in a single coordination process; this graph is the union of all local wait-for graphs

# ---- Local and Global Wait-For Graphs



# ... --- Centralized Approach ...

- 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

- With options 1 and 2, Unnecessary rollbacks may occur as a result of false cycles

# ... --- Centralized Approach ...

- Option 3:
  - Append unique identifiers (timestamps) to requests from different sites
  - When process $P_i$, at site *A*, requests a resource from process $P_j$, at site *B*, a request message with timestamp *TS* is sent
  - The edge $P_i \rightarrow P_j$ with the label *TS* is inserted in the local wait-for of *A*. The edge is inserted in the local wait-for graph of *B* only if *B* has received the request message and cannot immediately grant the requested resource

# … --- Centralized Approach: Option 3-Algorithm

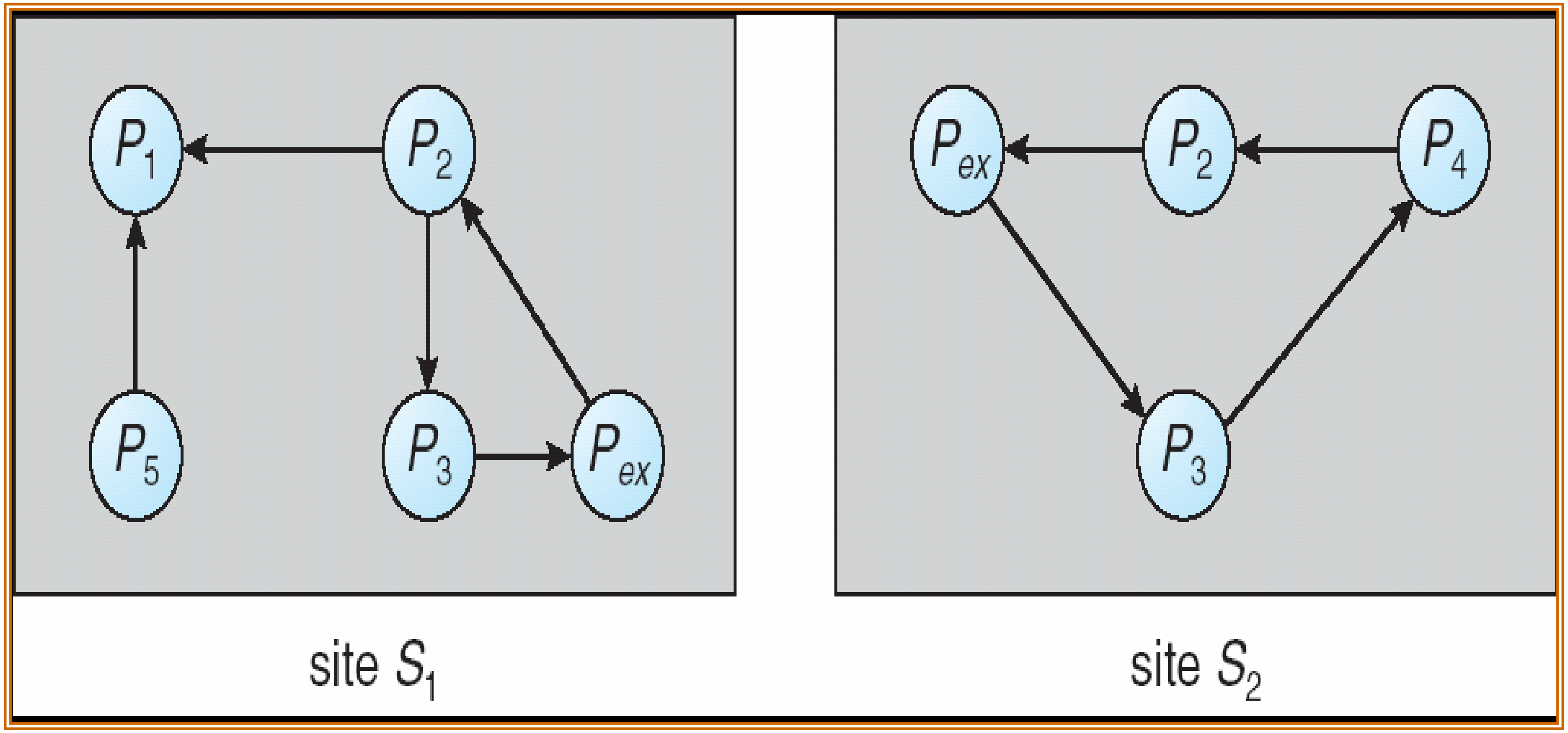
1. The controller sends an initiating message to each site in the system
2. On receiving this message, a site sends its local wait-for graph to the coordinator
3. When the controller has received a reply from each site, it constructs a graph as follows:
   (a) The constructed graph contains a vertex for every process in the system
   (b) The graph has an edge Pi $\rightarrow$ Pj if and only if
      (1) there is an edge Pi $\rightarrow$ Pj in one of the wait-for graphs, or
      (2) an edge Pi $\rightarrow$ Pj with some label TS appears in more than one wait-for graph

If the constructed graph contains a cycle $\Rightarrow$ deadlock

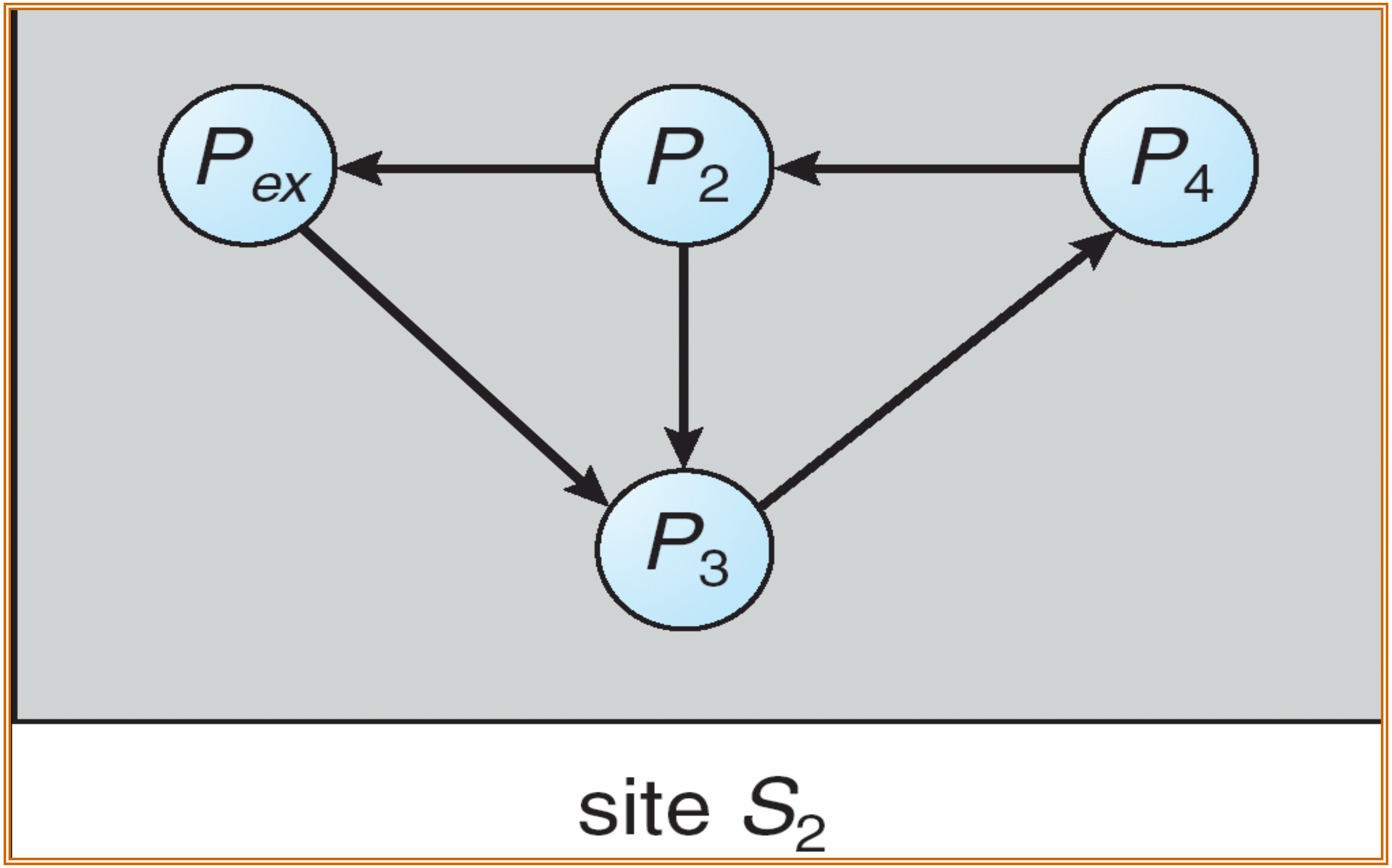
# --- Fully Distributed Approach

- 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
- 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



# ---- Augmented Local Wait-For Graph in Site S2



# - 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 $i$
- Assume a one-to-one correspondence between processes and sites
- The coordinator is always the process with the largest 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

# -- 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
- $P_{\mathrm{i}}$ 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 ...

- 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

- 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

# -- 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 $P_i$ detects a coordinator failure, I 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

- If $P_i$ receives a message elect($j$) from the process on the left, it must respond in one of three ways:

1. 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)*
2. If $i \neq j$, then the active list for $P_i$ now contains the numbers of 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
3. 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 new coordinator process.

# End of Chapter 16 and 18