CSC 4103 - Operating Systems
Spring 2007

LECTURE - XXIV

DISTRIBUTED SYSTEMS - III

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May 1st , 2007

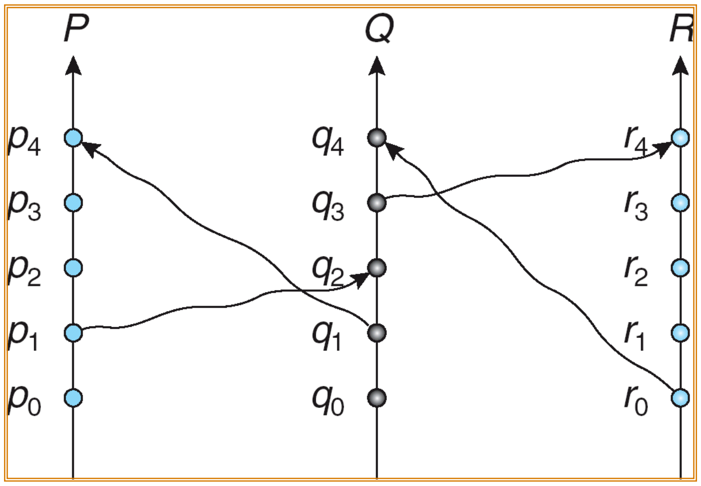
Distributed Coordination

- Ordering events and achieving synchronization in centralized systems is easier.
  - We can use common clock and memory
- What about distributed systems?
  - No common clock or memory
  - *happened-before* relationship provides partial ordering
  - How to provide total ordering?

Event Ordering

- Happened-before relation (denoted by $\rightarrow$)
  - If *A* and *B* are events in the same process (assuming sequential processes), 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 $A \rightarrow C$
  - If two events A and B are not related by the $\rightarrow$ relation, then these events are executed concurrently.

Relative Time for Three Concurrent Processes



Which events are concurrent and which ones are ordered?

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 Pi, define a **logical clock**
  - 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
  - Assume A sends a message to B, $LC_1(A)=200$, $LC_2(B)=195$
- 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

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 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 (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

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

Deadlock Handling

- 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
- 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
  - Also implemented easily, but may require too much overhead

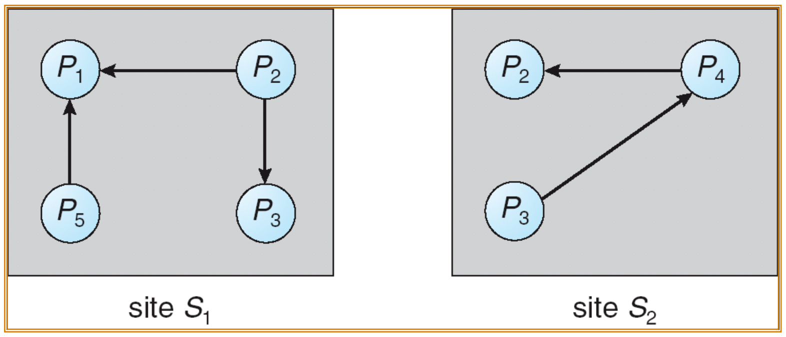
Prevention: Wait-Die Scheme

- Based on a nonpreemptive technique
- 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)
- 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

Prevention: Would-Wait Scheme

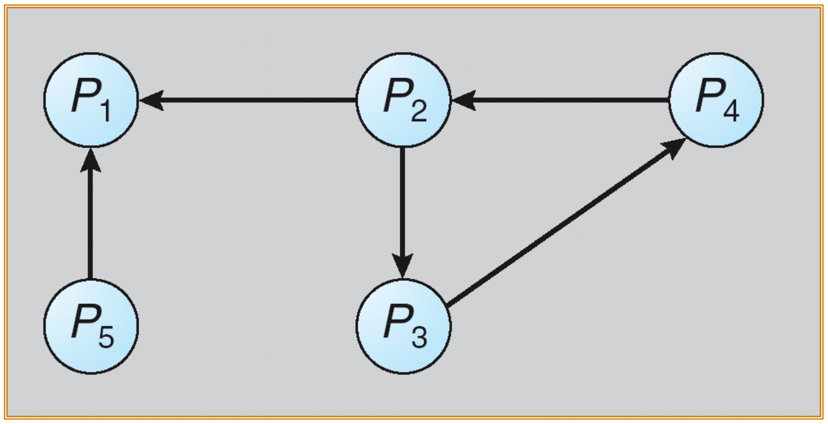
- Based on a preemptive technique; counterpart to the wait-die system
- If P_i requests a resource currently held by P_j, P_i is allowed to wait only if it has a larger timestamp than does P_j (P_i is younger than P_j). Otherwise P_j is rolled back (P_j is wounded by P_i)
- Example: Suppose that processes 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

Deadlock Detection



Two Local Wait-For Graphs

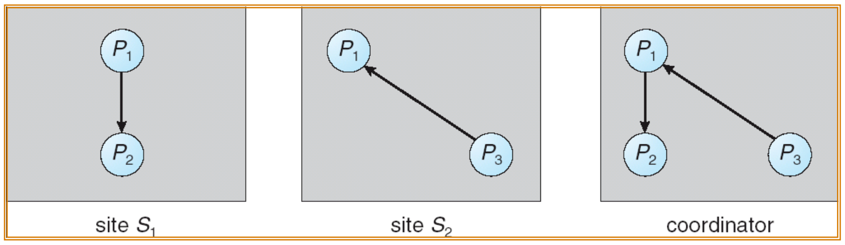
Global Wait-For Graph



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
- 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
- Unnecessary rollbacks may occur as a result of false cycles

Local and Global Wait-For Graphs



Detection Algorithm Based on Option 3

- Append unique identifiers (timestamps) to requests form 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

The 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 → Pj if and only if
      - there is an edge Pi → Pj in one of the wait-for graphs, or
      - an edge Pi → Pj with some label TS appears in more than one wait-for graph

If the constructed graph contains a cycle ⇒ deadlock

Any Questions?

Reading Assignment

- Read chapter 18 from Silberschatz.

Acknowledgements

- "Operating Systems Concepts" book and supplementary material by Silberschatz, Galvin and Gagne.