CSE 421/521 - Operating Systems
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LECTURE - XXIII

DISTRIBUTED SYSTEMS - II

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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

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 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

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

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, 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 (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 $i \neq j$, 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
  - ✦ 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.

Distributed Deadlock Handling

- 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-reemptive
  2. wound-wait scheme -- preemptive

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

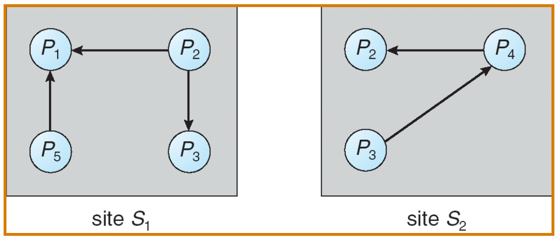
Prevention: Wound-Wait Scheme

- 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

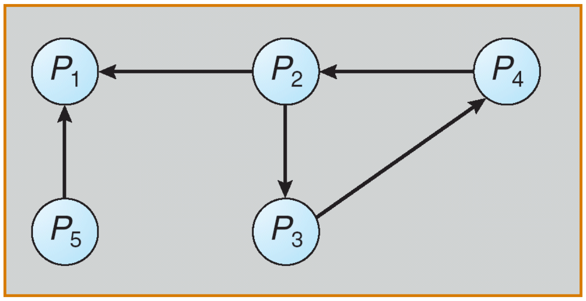
- Both avoid starvation, provided that when a process is rolled back, it is not assigned a new timestamp
- In wait-die, older process must wait for the younger one to release its resources. In wound-wait, an older process never waits for a younger process.
- There are fewer roll-backs in wound-wait.
  - Pi->Pj; Pi dies, requests the same resources; Pi dies again...
  - Pj->Pi; Pi wounded. requests the same resources; Pi waits..

Distributed Deadlock Detection



Two Local Wait-For Graphs

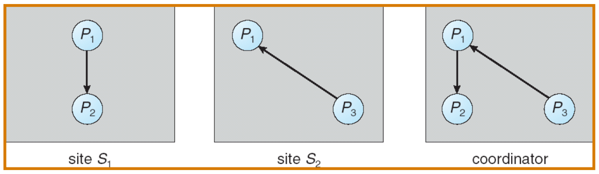
Global Wait-For Graph



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
- Option1: 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

Algorithm: Option 3

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

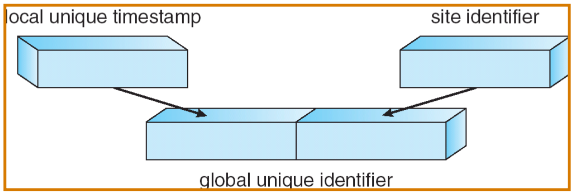
If the constructed graph contains a cycle ⇒ deadlock

*To avoid report of false deadlocks, requests from different sites appended with unique ids (timestamps)

Timestamping

- Generate unique timestamps in distributed scheme:
  - Each site generates a unique local timestamp
  - The global unique timestamp is obtained by concatenation of the unique local timestamp with the unique site identifier
  - Use a *logical clock* defined within each site to ensure the fair generation of timestamps
- Timestamp-ordering scheme – combine the centralized concurrency control timestamp scheme with the 2PC protocol to obtain a protocol that ensures serializability with no cascading rollbacks

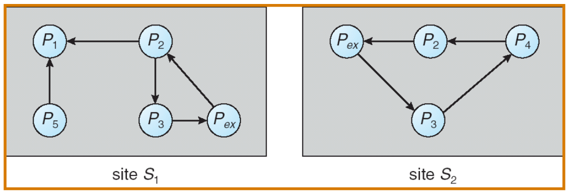
Generation of Unique Timestamps



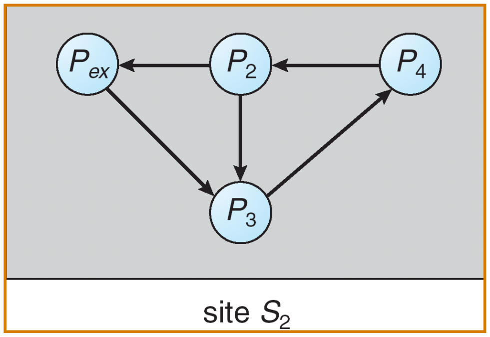
Fully Distributed Approach

- 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 ->P_{ex} exists if P_i is waiting for a data item at another site being held by any 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

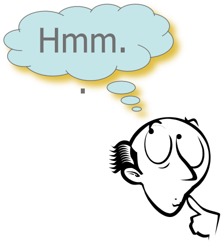
Augmented Local Wait-For Graphs



Augmented Local Wait-For Graph in Site S2



Any Questions?



Acknowledgements

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