Chapter 18: Distributed Coordination

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- Event Ordering
- Mutual Exclusion
- Atomicity
- Concurrency Control
- Deadlock Handling
- Election Algorithms
- Reaching Agreement

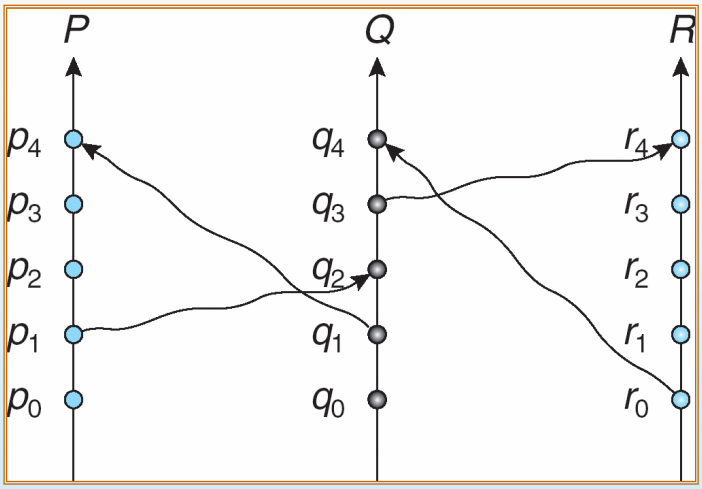
Chapter Objectives

- To describe various methods for achieving mutual exclusion in a distributed system
- To explain how atomic transactions can be implemented in a distributed system
- To show how some of the concurrency-control schemes discussed in Chapter 6 can be modified for use in a distributed environment
- To present schemes for handling deadlock prevention, deadlock avoidance, and deadlock detection in a distributed system

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 →

- Associate a timestamp with each system event
  - Require that for every pair of events A and B, if A → B, then the timestamp of A is less than the timestamp of B
- Within each process Pi a **logical clock**, LCi 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

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 (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

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

Atomicity

- Either all the operations associated with a program unit are executed to completion, or none are performed
- Ensuring **atomicity** in a distributed system requires a **transaction coordinator**, which is responsible for the following:
  - Starting the execution of the transaction
  - Breaking the transaction into a number of subtransactions, and distribution these subtransactions to the appropriate sites for execution
  - Coordinating the termination of the transaction, which may result in the transaction being committed at all sites or aborted at all sites

Two-Phase Commit Protocol (2PC)

- Assumes fail-stop model
- Execution of the protocol is initiated by the coordinator after the last step of the transaction has been reached
- When the protocol is initiated, the transaction may still be executing at some of the local sites
- The protocol involves all the local sites at which the transaction executed
- Example: Let T be a transaction initiated at site S_i and let the transaction coordinator at S_i be C_i

Phase 1: Obtaining a Decision

- C_i adds <prepare T> record to the log
- C_i sends <prepare T> message to all sites
- When a site receives a <prepare T> message, the transaction manager determines if it can commit the transaction
  - If no: add <no T> record to the log and respond to C_i with <abort T>
  - If yes:
    - add <ready T> record to the log
    - force *all log records* for T onto stable storage
    - transaction manager sends <ready T> message to C_i

Phase 1 (Cont.)

- Coordinator collects responses
  - All respond “ready”, decision is *commit*
  - At least one response is “abort”, decision is *abort*
  - At least one participant fails to respond within time out period, decision is *abort*

Phase 2: Recording Decision in the Database

- Coordinator adds a decision record

  <abort *T*> or <commit *T*>

  to its log and forces record onto stable storage
- Once that record reaches stable storage it is irrevocable (even if failures occur)
- Coordinator sends a message to each participant informing it of the decision (commit or abort)
- Participants take appropriate action locally

Failure Handling in 2PC – Site Failure

- The log contains a <commit *T*> record
  - In this case, the site executes **redo**(*T*)
- The log contains an <abort *T*> record
  - In this case, the site executes **undo**(*T*)
- The contains a <ready *T*> record; consult C_i
  - If C_i is down, site sends **query-status** *T* message to the other sites
- The log contains no control records concerning *T*
  - In this case, the site executes **undo**(*T*)

Failure Handling in 2PC – Coordinator C_i Failure

- If an active site contains a <commit T> record in its log, the T must be committed
- If an active site contains an <abort T> record in its log, then T must be aborted
- If some active site does *not* contain the record <ready T> in its log then the failed coordinator C_i cannot have decided to commit T
  - Rather than wait for C_i to recover, it is preferable to abort T
- All active sites have a <ready T> record in their logs, but no additional control records
  - In this case we must wait for the coordinator to recover
  - Blocking problem – T is blocked pending the recovery of site S_i