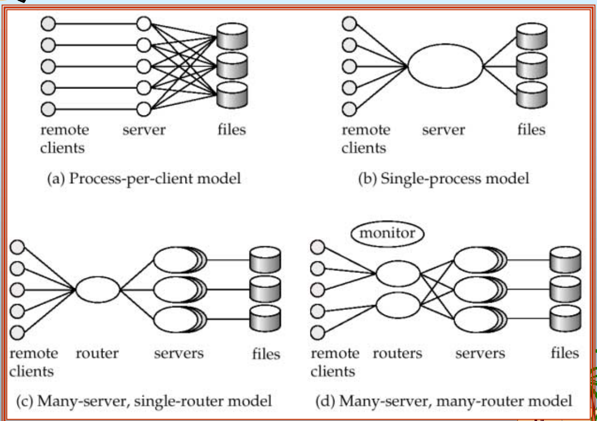
Chapter 24: Advanced Transaction Processing

- Transaction-Processing Monitors
- Transactional Workflows
- High-Performance Transaction Systems
  - Main memory databases
  - Real-Time Transaction Systems
- Long-Duration Transactions
- Transaction management in multidatabase systems

Transaction Processing Monitors

- TP monitors initially developed as multithreaded servers to support large numbers of terminals from a single process.
- Provide infrastructure for building and administering complex transaction processing systems with a large number of clients and multiple servers.
- Provide services such as:
  - Presentation facilities to simplify creating user interfaces
  - Persistent queuing of client requests and server responses
  - Routing of client messages to servers
  - Coordination of two-phase commit when transactions access multiple servers.
- Some commercial TP monitors: CICS from IBM, Pathway from Tandem, Top End from NCR, and Encina from Transarc

TP Monitor Architectures



(a) Process-per-client model

(b) Single-process model

(c) Many-server, single-router model

(d) Many-server, many-router model

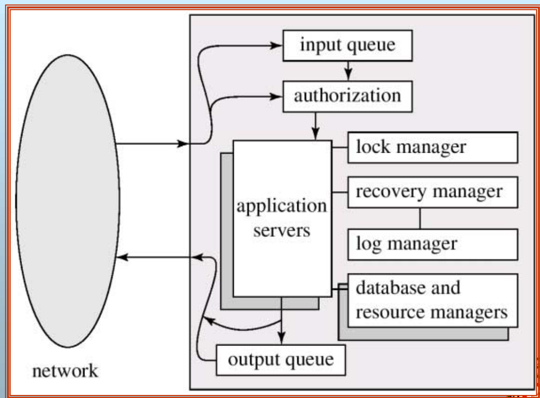
TP Monitor Architectures (Cont.)

- Process per client model - instead of individual login session per terminal, server process communicates with the terminal, handles authentication, and executes actions.
  - Memory requirements are high
  - Multitasking- high CPU overhead for context switching between processes
- Single process model - all remote terminals connect to a single server process.
  - Used in client-server environments
  - Server process is multi-threaded; low cost for thread switching
  - No protection between applications
  - Not suited for parallel or distributed databases

TP Monitor Architectures (Cont.)

- Many-server single-router model - multiple application server processes access a common database; clients communicate with the application through a single communication process that routes requests.
  - Independent server processes for multiple applications
  - Multithread server process
  - Run on parallel or distributed database
- Many server many-router model - multiple processes communicate with clients.
  - Client communication processes interact with router processes that route their requests to the appropriate server.
  - Controller process starts up and supervises other processes.

Detailed Structure of a TP Monitor



Detailed Structure of a TP Monitor

- Queue manager handles incoming messages
- Some queue managers provide persistent or durable message queueing contents of queue are safe even if systems fails.
- Durable queueing of outgoing messages is important
  - application server writes message to durable queue as part of a transaction
  - once the transaction commits, the TP monitor guarantees message is eventually delevered, regardless of crashes.
  - ACID properties are thus provided even for messages sent outside the database
- Many TP monitors provide locking, logging and recovery services, to enable application servers to implement ACID properties by themselves.

Application Coordination Using TP Monitors

- A TP monitor treats each subsystem as a resource manager that provides transactional access to some set of resources.
- The interface between the TP monitor and the resource manager is defined by a set of transaction primitives
- The resource manager interface is defined by the X/Open Distributed Transaction Processing standard.
- TP monitor systems provide a **transactional remote procedure call (transactional RPC)** interface to their service
  - Transactional RPC provides calls to enclose a series of RPC calls within a transaction.
  - Updates performed by an RPC are carried out within the scope of the transaction, and can be rolled back if there is any failure.

Workflow Systems

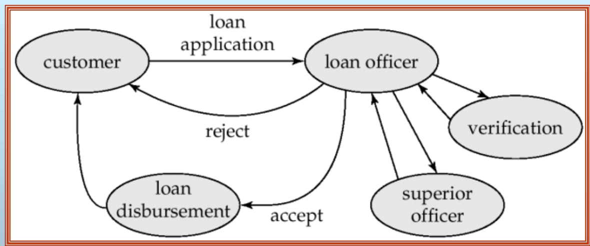
Transactional Workflows

- **Workflows** are activities that involve the coordinated execution of multiple tasks performed by different processing entities.
- With the growth of networks, and the existence of multiple autonomous database systems, workflows provide a convenient way of carrying out tasks that involve multiple systems.
- Example of a workflow delivery of an email message, which goes through several mails systems to reach destination.
  - Each mailer performs a tasks: forwarding of the mail to the next mailer.
  - If a mailer cannot deliver mail, failure must be handled semantically (delivery failure message).
- Workflows usually involve humans: e.g. loan processing, or purchase order processing.

Examples of Workflows

Workflow application	Typical task	Typical processing entity
electronic-mail routing	electronic-mail message	mailers
loan processing	form processing	humans, application software
purchase-order processing	form processing	humans, application software, DBMSs

Loan Processing Workflow



- In the past, workflows were handled by creating and forwarding paper forms
- Computerized workflows aim to automate many of the tasks. But the humans still play role e.g. in approving loans.

Transactional Workflows

- Must address following issues to computerize a workflow.
  - Specification of workflows - detailing the tasks that must be carried out and defining the execution requirements.
  - Execution of workflows - execute transactions specified in the workflow while also providing traditional database safeguards related to the correctness of computations, data integrity, and durability.
  - E.g.: Loan application should not get lost even if system fails.
- Extend transaction concepts to the context of workflows.
- State of a workflow - consists of the collection of states of its constituent tasks, and the states (i.e. values) of all variables in the execution plan.

Workflow Specification

- **Static specification** of task coordination:
  - Tasks and dependencies among them are defined before the execution of the workflow starts.
  - Can establish preconditions for execution of each task: tasks are executed only when their preconditions are satisfied.
  - Defined preconditions through dependencies:
    - Execution states of other tasks.

      "task t_i cannot start until task t_j has ended"
    - Output values of other tasks.

      "task t_i can start if task t_j returns a value greater than 25"
    - External variables, that are modified by external events.

      "task t_i must be started within 24 hours of the completion of task t_j"

Workflow Specification (Cont.)

- **Dynamic task coordination**
  E.g. Electronic mail routing system in which the text to be schedule for a given mail message depends on the destination address and on which intermediate routers are functioning.

Failure-Automicity Requirements

- Usual ACID transactional requirements are too strong/unimplementable for workflow applications.
- However, workflows must satisfy some limited transactional properties that guarantee a process is not left in an inconsistent state.
- **Acceptable termination states** - every execution of a workflow will terminate in a state that satisfies the failure-atomicity requirements defined by the designer.
  - Committed - objectives of a workflow have been achieved.
  - Aborted - valid termination state in which a workflow has failed to achieve its objectives.
- A workflow must reach an acceptable termination state even in the presence of system failures.

Execution of Workflows

Workflow management systems include:

- Scheduler - program that process workflows by submitting various tasks for execution, monitoring various events, and evaluation conditions related to intertask dependencies
- Task agents - control the execution of a task by a processing entity.
- Mechanism to query to state of the workflow system.

Workflow Management System Architectures

- Centralized - a single scheduler schedules the tasks for all concurrently executing workflows.
  - used in workflow systems where the data is stored in a central database.
  - easier to keep track of the state of a workflow.
- Partially distributed - has one (instance of a) scheduler for each workflow.
- Fully distributed - has no scheduler, but the task agents coordinate their execution by communicating with each other to satisfy task dependencies and other workflow execution requirements.
  - used in simplest workflow execution systems
  - based on electronic mail

Workflow Scheduler

- Ideally scheduler should execute a workflow only after ensuring that it will terminate in an acceptable state.
- Consider a workflow consisting of two tasks S_1 and S_2. Let the failure-atomicity requirement be that either both or neither of the subtransactions should be committed.
  - Suppose systems executing S_1 and S_2 do not provide prepared-to-commit states and S_1 or S_2 do not have compensating transactions.
  - It is then possible to reach a state where one subtransaction is committed and the other aborted. Both cannot then be brought to the same state.
  - Workflow specification is unsafe, and should be rejected.
- Determination of safety by the scheduler is not possible in general, and is usually left to the designer of the workflow.

Recovery of a Workflow

- Ensure that is a failure occurs in any of the workflow-processing components, the workflow eventually reaches an acceptable termination state.
- Failure-recovery routines need to restore the state information of the scheduler at the time of failure, including the information about the execution states of each task. Log status information on stable storage.
- Handoff of tasks between agents should occur exactly once in spite of failure.
- Problem: Repeating handoff on recovery may lead to duplicate execution of task; not repeating handoff may lead to task not being executed.
  - Solution: Persistent messaging systems

Recovery of a Workflow (Cont.)

- Persistent messages: messages are stored in permanent message queue and therefore not lost in case of failure.
  - Described in detail in Chapter 19 (Distributed Databases)
- Before an agent commits, it writes to the persistent message queue whatever messages need to be sent out.
- The persistent message system must make sure the messages get delivered eventually if and only if the transaction commits.
- The message system needs to resend a message when the site recovers, if the message is not known to have reached its destination.
- Messages must be logged in stable storage at the receiving end to detect multiple receipts of a message.

High Performance Transaction Systems

High-Performance Transaction Systems

- High-performance hardware and parallelism help improve the rate of transaction processing, but are insufficient to obtain high performance:
  - Disk I/O is a bottleneck — I/O time (10 milliseconds) has no decreased at a rate comparable to the increase in processor speeds.
  - Parallel transactions may attempt to read or write the same data item, resulting in data conflicts that reduce effective parallelism
- We can reduce the degree to which a database system is disk bound by increasing the size of the database buffer.

Main-Memory Database

- Commercial 64-bit systems can support main memories of tens of gigabytes.
- Memory resident data allows faster processing of transactions.
- Disk-related limitations:
  - Logging is a bottleneck when transaction rate is high.
  - Use group-commit to reduce number of output operations (Will study two slides ahead.)
  - If the update rate for modified buffer blocks is high, the disk data-transfer rate could become a bottleneck.
  - If the system crashes, all of main memory is lost.

Main-Memory Database Optimizations

- To reduce space overheads, main-memory databases can use structures with pointers crossing multiple pages. In disk databases, the I/O cost to traverse multiple pages would be excessively high.
- No need to pin buffer pages in memory before data are accessed, since buffer pages will never be replaced.
- Design query-processing techniques to minimize space overhead - avoid exceeding main memory limits during query evaluation.
- Improve implementation of operations such as locking and latching, so they do not become bottlenecks.
- Optimize recovery algorithms, since pages rarely need to be written out to make space for other pages.

Group Commit

- Idea: Instead of performing output of log records to stable storage as soon as a transaction is ready to commit, wait until
  - log buffer block is full, or
  - a transaction has been waiting sufficiently long after being ready to commit
- Results in fewer output operations per committed transaction, and correspondingly a higher throughput.
- However, commits are delayed until a sufficiently large group of transactions are ready to commit, or a transaction has been waiting long enough-leads to slightly increased response time.
- Above delay acceptable in high-performance transaction systems since log buffer blocks will fill up quickly.

Real-Time Transaction Systems

- In systems with real-time constraints, correctness of execution involves both database consistency and the satisfaction of deadlines.
  - **Hard deadline** – Serious problems may occur if task is not completed within deadline
  - **Firm deadline** - The task has zero value if it completed after the deadline.
  - **Soft deadline** - The task has diminishing value if it is completed after the deadline.
- The wide variance of execution times for read and write operations on disks complicates the transaction management problem for time-constrained systems
  - main-memory databases are thus often used
  - Waits for locks, transaction aborts, contention for resources remain as problems even if data is in main memory
- Design of a real-time system involves ensuring that enough processing power exists to meet deadline without requiring excessive hardware resources.

Long Duration Transactions

Traditional concurrency control techniques do not work well when user interaction is required:

- **Long duration**: Design edit sessions are very long
- **Exposure of uncommitted data**: E.g., partial update to a design
- **Subtasks**: support partial rollback
- **Recoverability**: on crash state should be restored even for yet-to-be committed data, so user work is not lost.
- **Performance**: fast response time is essential so user time is not wasted.

Long-Duration Transactions

- Represent as a nested transaction
  - atomic database operations (read/write) at a lowest level.
- If transaction fails, only active short-duration transactions abort.
- Active long-duration transactions resume once any short duration transactions have recovered.
- The efficient management of long-duration waits, and the possibility of aborts.
- Need alternatives to waits and aborts; alternative techniques must ensure correctness without requiring serializability.

Concurrency Control

- Correctness without serializability:
  - Correctness depends on the specific consistency constraints for the databases.
  - Correctness depends on the properties of operations performed by each transaction.
- Use database consistency constraints as to split the database into subdatabases on which concurrency can be managed separately.
- Treat some operations besides read and write as fundamental low-level operations and extend concurrency control to deal with them.

Concurrency Control (Cont.)

A non-conflict-serializable schedule that preserves the sum of A + B

T_1	T_2
read(A) $A := A - 50$ write(A)	
	read(B) $B := B - 10$ write(B)
read(B) $B := B + 50$ write(B)	
	read(A) $A := A + 10$ write(A)

Nested and Multilevel Transactions

- A **nested or multilevel transaction** T is represented by a set $T = \{t_1, t_2, ..., t_n\}$ of subtransactions and a partial order P on T.
- A subtransaction t_i in T may abort without forcing T to abort.
- Instead, T may either restart t_i, or simply choose not to run t_i.
- If t_i commits, this action does not make t_i, permanent (unlike the situation in Chapter 15). Instead, t_i, commits to T, and may still abort (or require compensation) if T aborts.
- An execution of T must not violate the partial order P, i.e., if an edge $t_i \rightarrow t_j$ appears in the precedence graph, then $t_j \rightarrow t_i$ must not be in the transitive closure of P.

Nested and Multilevel Transactions (Cont.)

- Subtransactions can themselves be nested/multilevel transactions.
  - Lowest level of nesting: standard read and write operations.
- Nesting can create higher-level operations that may enhance concurrency.
- Types of nested/ multilevel transactions:
  - **Multilevel transaction**: subtransaction of T is permitted to release locks on completion.
  - **Saga**: multilevel long-duration transaction.
  - **Nested transaction**: locks held by a subtransaction t_i of T are automatically assign to T on completion of t_i.

Example of Nesting

- Rewrite transaction T_1 using subtransactions T_a and T_b that perform increment or decrement operations:
  - T_1 consists of
    - $T_{1,1}$, which subtracts 50 from A
    - $T_{1,2}$, which adds 50 to B
- Rewrite transaction T_2 using subtransactions T_c and T_d that perform increment or decrement operations:
  - T_2 consists of
    - $T_{2,1}$, which subtracts 10 from B
    - $T_{2,2}$, which adds 10 to A
- No ordering is specified on subtransactions; any execution generates a correct result.

Compensating Transactions

- Alternative to undo operation; compensating transactions deal with the problem of cascading rollbacks.
- Instead of undoing all changes made by the failed transaction, action is taken to "compensate" for the failure.
- Consider a long-duration transaction T_i representing a travel reservation, with subtransactions $T_{i,1}$, which makes airline reservations, $T_{i,2}$ which reserves rental cars, and $T_{i,3}$ which reserves a hotel room.
  - Hotel cancels the reservation.
  - Instead of undoing all of T_i, the failure of $T_{i,3}$ is compensated for by deleting the old hotel reservation and making a new one.
  - Requires use of semantics of the failed transaction.

Implementation Issues

- For long-duration transactions to survive system crashes, we must log not only changes to the database, but also changes to internal system data pertaining to these transactions.
- Logging of updates is made more complex by physically large data items (CAD design, document text); undesirable to store both old and new values.
- Two approaches to reducing the overhead of ensuring the recoverability of large data items:
  - Operation logging. Only the operation performed on the data item and the data-item name are stored in the log.
  - Logging and shadow paging. Use logging from small data items; use shadow paging for large data items. Only modified pages need to be stored in duplicate.

Transaction Management in Multidatabase Systems

- Transaction management is complicated in multidatabase systems because of the assumption of autonomy
  - **Global 2PL** -each local site uses a strict 2PL (locks are released at the end); locks set as a result of a global transaction are released only when that transaction reaches the end.
    - Guarantees global serializability
  - Due to autonomy requirements, sites cannot cooperate and execute a common concurrency control scheme
    - E.g. no way to ensure that all databases follow strict 2PL
- Solutions:
  - provide very low level of concurrent execution, or
  - use weaker levels of consistency

Transaction Management

- Local transactions are executed by each local DBMS, outside of the MDBS system control.
- Global transactions are executed under multidatabase control.
- Local autonomy - local DBMSs cannot communicate directly to synchronize global transaction execution and the multidatabase has no control over local transaction execution.
  - local concurrency control scheme needed to ensure that DBMS's schedule is serializable
  - in case of locking, DBMS must be able to guard against local deadlocks.
  - need additional mechanisms to ensure global serializability

Two-Level Serializability

- DBMS ensures local serializability among its local transactions, including those that are part of a global transaction.
- The multidatabase ensures serializability among global transactions alone- *ignoring the orderings induced by local transactions*.
- 2LSR does not ensure global serializability, however, it can fulfill requirements for **strong correctness**.
  1. Preserve consistency as specified by a given set of constraints
  2. Guarantee that the set of data items read by each transaction is consistent
- **Global-read protocol** : Global transactions can read, but not update, local data items; local transactions do not have access to global data. There are no consistency constraints between local and global data items.

Two-Level Serializability (Cont.)

- **Local-read protocol** : Local transactions have read access to global data; disallows all access to local data by global transactions.
- A transaction has a value dependency if the value that it writes to a data item at one site depends on a value that it read for a data item on another site.
- For strong correctness: No transaction may have a value dependency.
- **Global-read-write/local-read protocol**; Local transactions have read access to global data; global transactions may read and write all data;
- No consistency constraints between local and global data items.
- No transaction may have value dependency.

Global Serializability

- Even if no information is available concerning the structure of the various concurrency control schemes, a very restrictive protocol that ensures serializability is available.
- Transaction-graph : a graph with vertices being global transaction names and site names.
- An undirected edge (T_i, S_k) exists if T_i is active at site S_k.
- Global serializability is assured if transaction-graph contains no undirected cycles.

Ensuring Global Serializability

- Each site S_i has a special data item, called **ticket**
- Every transaction T_j that runs at site S_k writes to the ticket at site S_i
- Ensures global transactions are serialized at each site, regardless of local concurrency control method, so long as the method guarantees local serializability
- Global transaction manager decides serial ordering of global transactions by controlling order in which tickets are accessed
- However, above protocol results in low concurrency between global transactions.

End of Chapter

Weak Levels Consistency

- Use alternative notions of consistency that do not ensure serializability, to improve performance.
- **Degree-two consistency** avoids cascading aborts without necessarily ensuring serializability.
  - Unlike two-phase locking, S-locks may be released at any time, and licks may be acquired at any time.
  - X-locks be released until the transaction either commits or aborts.

Example Schedule with Degree-Two Consistency

Nonserializable schedule with degree-two consistency (Figure 20.5) where T_3 reads the value if Q before and after that value is written by T_4.

T_3	T_4
lock-S (Q)	
read (Q)	
unlock (Q)	
	lock-X (Q)
	read (Q)
	write (Q)
	unlock (Q)
lock-S (Q)	
read (Q)	
unlock (Q)	

Cursor Stability

- Form of degree-two consistency designed for programs written in general-purpose, record-oriented languages (e.g., Pascal, C, Cobol, PL/I, Fortran).
- Rather than locking the entire relation, cursor stability ensures that
  - The tuple that is currently being processed by the iteration is locked in shared mode.
  - Any modified tuples are locked in exclusive mode until the transaction commits.
- Used on heavily accessed relations as a means of increasing concurrency and improving system performance.
- Use is limited to specialized situations with simple consistency constraints.