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Lecture 16
Concurrency Control
Reading: Chapter 16.1,2,4 and 17.1,2,3,5 (relevant parts)
Banking transaction for a customer (e.g., at ATM or browser)

Transfer $100 from saving to checking account;
Transfer $200 from money-market to checking account;
Withdraw $400 from checking account.

Transaction (invoked at client):

1. savings.withdraw(100)
   /* includes verification */
2. checking.deposit(100)
   /* depends on success of 1 */
3. mnymkt.withdraw(200)
   /* includes verification */
4. checking.deposit(200)
   /* depends on success of 3 */
5. checking.withdraw(400)
   /* includes verification */
6. dispense(400)
7. commit

/* Every step is an RPC */
Bank Server: Coordinator Interface

- All the following are RPCs from a client to the server
- Transaction calls that can be made at a client, and return values from the server:

  openTransaction() -> trans;
  starts a new transaction and delivers a unique transaction identifier (TID) trans. This TID will be used in the other operations in the transaction.

  closeTransaction(trans) -> (commit, abort);
  ends a transaction: a commit return value indicates that the transaction has committed; an abort return value indicates that it has aborted.

  abortTransaction(trans);
  aborts the transaction.

- TID can be passed implicitly (for other operations between open and close) with CORBA
Bank Server: Account, Branch interfaces

Operations of the Account interface

\[\text{deposit}(\text{amount})\]
- deposit amount in the account

\[\text{withdraw}(\text{amount})\]
- withdraw amount from the account

\[\text{getBalance}() \rightarrow \text{amount}\]
- return the balance of the account

\[\text{setBalance}(\text{amount})\]
- set the balance of the account to amount

Operations of the Branch interface

\[\text{create}(\text{name}) \rightarrow \text{account}\]
- create a new account with a given name

\[\text{lookup}(\text{name}) \rightarrow \text{account}\]
- return a reference to the account with the given name

\[\text{branchTotal}() \rightarrow \text{amount}\]
- return the total of all the balances at the branch
Sequence of operations that forms a single step, transforming the server data from one consistent state to another.

- All or nothing principle: a transaction either completes successfully, and the effects are recorded in the objects, or it has no effect at all. (even with multiple clients, or crashes)

A transaction is indivisible (atomic) from the point of view of other transactions

- No access to intermediate results/states of other transactions
- Free from interference by operations of other transactions

But…

- Transactions could run concurrently, i.e., with multiple clients
- Transactions may be distributed, i.e., across multiple servers
Transaction Failure Modes

Transaction:
1. savings.deduct(100)
2. checking.add(100)
3. mnymkt.deduct(200)
4. checking.add(200)
5. checking.deduct(400)
6. dispense(400)
7. commit

A failure at these points means the customer loses money; we need to restore old state.

This is the point of no return.

A failure at these points does not cause lost money, but old steps cannot be repeated.

A failure after the commit point (ATM crashes) needs corrective action; no undoing possible.
Transactions in Traditional Databases (ACID)

- **Atomicity**: All or nothing
- **Consistency**: If the server starts in a consistent state, the transaction ends the server in a consistent state.
- **Isolation**: Each transaction must be performed without interference from other transactions, i.e., the non-final effects of a transaction must not be visible to other transactions.
- **Durability**: After a transaction has completed successfully, all its effects are saved in permanent storage.

- **Atomicity**: Store tentative object updates (for later undo/redo) – many different ways of doing this
- **Durability**: Store entire results of transactions (all updated objects) to recover from permanent server crashes.
Concurrent Transactions: Lost Update Problem

- One transaction causes loss of info. for another:
  consider three account objects
  
<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>200</td>
<td>300</td>
</tr>
</tbody>
</table>

Transaction T1

- balance = b.getBalance()
- b.setBalance(balance*1.1)
- a.withdraw(balance*0.1)

Transaction T2

- balance = b.getBalance()
- b.setBalance(balance*1.1)
- c.withdraw(balance*0.1)

T1/T2’s update on the shared object, “b”, is lost
Partial, incomplete results of one transaction are retrieved by another transaction.

Transaction T1

<table>
<thead>
<tr>
<th>Action</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. withdraw(100)</td>
<td>100</td>
</tr>
<tr>
<td>b. deposit(100)</td>
<td>300</td>
</tr>
</tbody>
</table>

Transaction T2

<table>
<thead>
<tr>
<th>Action</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. getBalance()</td>
<td>0.00</td>
</tr>
<tr>
<td>total = total + b.getBalance</td>
<td>200</td>
</tr>
<tr>
<td>total = total + c.getBalance</td>
<td>500</td>
</tr>
</tbody>
</table>

T1’s partial result is used by T2, giving the wrong result for T2.
An interleaving of the operations of 2 or more transactions is said to be **serially equivalent** if the combined effect is the same as if these transactions had been performed sequentially (in some order).

**Concurrency Control:** “Serial Equivalence”

### Transaction T1

- balance = b.getBalance()
- b.setBalance(balance*1.1)
- a.withdraw(balance*0.1)

### Transaction T2

- balance = b.getBalance()
- b.setBalance(balance*1.1)
- a.withdraw(balance*0.1)
- c.withdraw(balance*0.1)

---

**States:**

- a: 100
- b: 200
- c: 300

**Transactions:**

- T1: a: 80, b: 220, c: 278
- T2: a: 80, b: 220, c: 278

**Result:**

- T1 (complete) followed by T2 (complete)
The effect of an operation refers to:
- The value of an object set by a write operation
- The result returned by a read operation.

Two operations are said to be conflicting operations, if their combined effect depends on the order they are executed, e.g., read-write, write-read, write-write (all on same variables). NOT read-read, NOT on different variables.

Two transactions are serially equivalent if and only if all pairs of conflicting operations (pair containing one operation from each transaction) are executed in the same order (transaction order) for all objects (data) they both access.

Why? Can start from original operation sequence and swap the order of non-conflicting operations to obtain a series of operations where one transaction finishes completely before the second transaction starts.

Why is the above result important? Because: Serial equivalence is the basis for concurrency control protocols for transactions.
# Read and Write Operation Conflict Rules

<table>
<thead>
<tr>
<th>Operations of different transactions</th>
<th>Conflict</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>read  read</td>
<td>No</td>
<td>Because the effect of a pair of read operations does not depend on the order in which they are executed</td>
</tr>
<tr>
<td>read  write</td>
<td>Yes</td>
<td>Because the effect of a read and a write operation depends on the order of their execution</td>
</tr>
<tr>
<td>write  write</td>
<td>Yes</td>
<td>Because the effect of a pair of write operations depends on the order of their execution</td>
</tr>
</tbody>
</table>
Concurrent Control: “Serial Equivalence”

- An interleaving of the operations of 2 or more transactions is said to be **serially equivalent** if the combined effect is the same as if these transactions had been performed sequentially (in some order).

**Transaction T1**

- `balance = b.getBalance()`  
- `b.setBalance(balance*1.1)`  
- `a.withdraw(balance*0.1)`

**Transaction T2**

- `balance = b.getBalance()`  
- `b.setBalance(balance*1.1)`  
- `c.withdraw(balance*0.1)`  
- `a: 80`  
- `b: 220`  
- `c: 300`

Pairs of Conflicting Operations:  
- `a: 80`  
- `b: 220`  
- `c: 300`

== T1 (complete) followed by T2 (complete)
Conflicting Operators Example

Transaction T1
- x = a.read()
- a.write(20)
- b.write(x)

Transaction T2
- y = b.read()
- b.write(30)
- z = a.read()

Non-serially equivalent interleaving of operations

Serially equivalent interleaving of operations (why?)

Conflicting Ops.
Inconsistent Retrieval Prob – Caught!

- Partial, incomplete results of one transaction are retrieved by another transaction.

Transaction T1
a. withdraw(100) → a: 00
b. deposit(100) → b: 300

Transaction T2
a. total = a.getBalance() → total = 0.00
b. total = total + b.getBalance → total = 200

T1’s partial result is used by T2, giving the wrong result for T2
### A Serially Equivalent Interleaving of T1 and T2

<table>
<thead>
<tr>
<th>Transaction T1</th>
<th>Transaction T2</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>a.withdraw(100);</code></td>
<td><code>aBranch.branchTotal();</code></td>
</tr>
<tr>
<td><code>b.deposit(100)</code></td>
<td></td>
</tr>
<tr>
<td><code>a.withdraw(100);</code></td>
<td>$100</td>
</tr>
<tr>
<td><code>b.deposit(100)</code></td>
<td>$300</td>
</tr>
<tr>
<td><code>total = a.getBalance()</code></td>
<td>$100</td>
</tr>
<tr>
<td><code>total = total+b.getBalance()</code></td>
<td>$400</td>
</tr>
<tr>
<td><code>total = total+c.getBalance()</code></td>
<td></td>
</tr>
</tbody>
</table>
Implementing Concurrent Transactions

How can we prevent isolation from being violated?

Concurrent operations must be consistent:

- If trans. T has executed a *read* operation on object A, a concurrent trans. U must not *write* to A until T commits or aborts.
- If trans. T has executed a *write* operation on object A, a concurrent U must not *read or write* to A until T commits or aborts.

How to implement this?

- First cut: locks
**Example: Concurrent Transactions**

- **Exclusive Locks**

Transaction T1

- OpenTransaction()
- balance = b.getBalance()

Transaction T2

- OpenTransaction()

b.setBalance(balance*1.1)

...  

a.withdraw(balance*0.1)

...  

CloseTransaction()

b.setBalance(balance*1.1)

c.withdraw(balance*0.1)

CloseTransaction()
Basic Locking

- Transaction managers (on server side) set locks on objects they need. A concurrent trans. cannot access locked objects.

- **Two phase locking:**
  - In the first (growing) phase of the transaction, new locks are only acquired, and in the second (shrinking) phase, locks are only released.
  - A transaction is not allowed acquire *any* new locks, once it has released *any* one lock.

- **Strict two phase locking:**
  - Locking on an object is performed only *before* the first request to read/write that object is about to be applied.
  - Unlocking is performed by the commit/abort operations of the transaction coordinator.
    - To prevent dirty reads and premature writes, a transaction waits for another to commit/abort

- However, use of separate *read* and *write* locks leads to more concurrency than a single *exclusive* lock – Next slide
### 2P Locking: Non-exclusive lock (per object)

<table>
<thead>
<tr>
<th>Lock already set</th>
<th>Lock requested read</th>
<th>Lock requested write</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>read</td>
<td>OK</td>
<td>WAIT</td>
</tr>
<tr>
<td>write</td>
<td>WAIT</td>
<td>WAIT</td>
</tr>
</tbody>
</table>

- A read lock is **promoted** to a write lock when the transaction needs write access to the same object.
- A read lock **shared** with other transactions’ read lock(s) cannot be promoted. Transaction waits for other read locks to be released.
- Cannot demote a write lock to read lock during transaction – violates the 2P principle.
When an operation accesses an object:

- if you can, promote a lock (nothing -> read -> write)
- Don’t promote the lock if it would result in a conflict with another transaction’s already-existing lock
  - wait until all shared locks are released, then lock & proceed

When a transaction commits or aborts:

- release all locks that were set by the transaction
Example: Concurrent Transactions

- Non-exclusive Locks

Transaction T1

OpenTransaction()
balance = b.getBalance()
Commit

Transaction T2

OpenTransaction()
balance = b.getBalance()
b.setBalance(balance*1.1)

\[ \text{Cannot Promote lock on B, Wait} \]

...
Example: Concurrent Transactions

What happens in the example below?

Transaction T1

OpenTransaction()
balance = b.getBalance()
b.setBalance(balance*1.1)

Transaction T2

OpenTransaction()
b.setBalance(balance*1.1)

Cannot Promote lock on B, Wait

...
Deadlocks

- Necessary conditions for deadlocks
  - Non-shareable resources (exclusive lock modes)
  - No preemption on locks
  - Hold & Wait or Circular Wait

Hold & Wait

Circular Wait
## Naïve Deadlock Resolution Using Timeout

<table>
<thead>
<tr>
<th>Transaction T</th>
<th>Operations</th>
<th>Locks</th>
<th>Transaction U</th>
<th>Operations</th>
<th>Locks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a.deposit(100);</td>
<td>write lockA</td>
<td></td>
<td>b.deposit(200)</td>
<td>write lockB</td>
</tr>
<tr>
<td></td>
<td>b.withdraw(100)</td>
<td>waits for U's</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>lock on B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(timeout elapses)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>T's lock on A becomes vulnerable, unlock A, abort T</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>a.withdraw(200);</td>
<td>waits for T’s lock on A</td>
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</tr>
</tbody>
</table>

Disadvantages?
Strategies to Fight Deadlock

- Lock timeout (costly and open to false positives)

- **Deadlock Prevention**: violate one of the necessary conditions for deadlock (from 2 slides ago), e.g., lock all objects before transaction starts, aborting entire transaction if any fails

- **Deadlock Avoidance**: Have transactions declare max resources they will request, but allow them to lock at any time (Banker’s algorithm)

- **Deadlock Detection**: detect cycles in the wait-for graph, and then abort one or more of the transactions in cycle
Summary

• Increasing concurrency important because it improves throughput at server (means more revenue $$$)

• Applications are willing to tolerate temporary inconsistency and deadlocks in turn
  – Need to detect and prevent these

• Driven and validated by actual application characteristics – mostly-read transactions abound
Midterm Statistics

- **Graduate Students:**
  - average: 93
  - median: 93
  - standard deviation: 6.64
  - min: 71
  - max: 100

- **Undergraduate Students:**
  - average: 84.8
  - median: 86
  - standard deviation: 9.64
  - min: 60
  - max: 100