CSE 486/586 Distributed Systems
Concurrency Control --- 1

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Banking Example

- 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
  1. savings.deduct(100)
  2. checking.add(100)
  3. mnymkt.deduct(200)
  4. checking.add(200)
  5. checking.deduct(400)
  6. dispense(400)

Transaction

- Abstraction for grouping multiple operations into one
- A transaction is indivisible (atomic) from the point of view of other transactions
  – No access to intermediate results/states
  – Free from interference by other operations
- Primitives
  – begin(): begins a transaction
  – commit(): tries completing the transaction
  – abort(): aborts the transaction as if nothing happened
- Why abort()?
  – A failure happens in the middle of execution.
  – A transaction is part of a bigger transaction (i.e., it's a sub-transaction), and the bigger transaction needs abort.
  – Etc.

Properties of Transactions: ACID

- Atomicity: All or nothing
- Consistency: if the server starts in a consistent state, the transaction ends with 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. (E.g., powering off the machine doesn't mean the result is gone.)

This Week

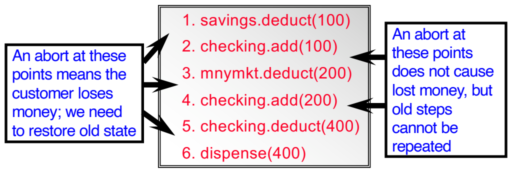
- Question: How to support multiple transactions?
  – When multiple transactions share data.
  – Assume a single processor (one instruction at a time).
- What would be your first strategy (hint: locks)?
  – One transaction at a time with one big lock, i.e., complete serialization
- Two issues
  – Performance
  – Abort

Performance?

• Process 1	• Process 2

lock(mutex);
savings.deduct(100);
checking.add(100);
mnymkt.deduct(200);
checking.add(200);
checking.deduct(400);
dispense(400);
unlock(mutex);
	lock(mutex);
	savings.deduct(200);
	checking.add(200);
	unlock(mutex);

Abort?



This Week

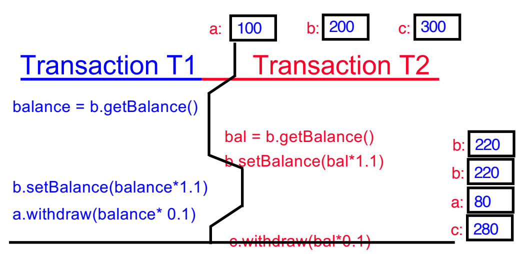
- Question: How to support transactions?
  - Multiple transactions share data.
- What would be your first strategy (hint: locks)?
  - Complete serialization
  - One transaction at a time with one big lock
  - Two issues: Performance and abort
- First, let's see how we can improve performance.

Possibility: Interleaving Transactions for Performance

• Process 1	• Process 2
savings.deduct(100);	savings.deduct(200);
checking.add(100);	checking.add(200);
mnymkt.deduct(200);	
checking.add(200);	
checking.deduct(400);	
dispense(400);	

- P2 will not have to wait until P1 finishes.

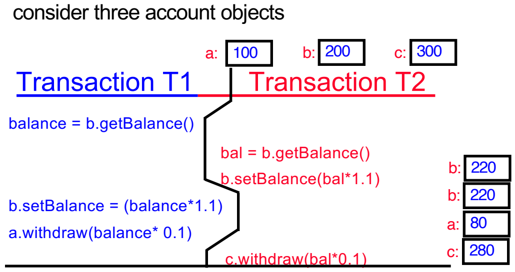
What Can Go Wrong?



- T1/T2's update on the shared object, "b", is lost

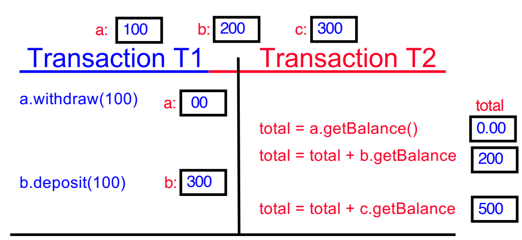
Lost Update Problem

- One transaction causes loss of info. for another: consider three account objects



- T1/T2's update on the shared object, "b", is lost

What Can Go Wrong?



- T1's partial execution result is used by T2, giving the wrong result

Inconsistent Retrieval Problem

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

a: 100 b: 200 c: 300

Transaction T1		Transaction T2	total
a.withdraw(100)	a: 00		0.00
		total = a.getBalance()	
		total = total + b.getBalance	200
b.deposit(100)	b: 300		
		total = total + c.getBalance	500

- T1's partial execution result is used by T2, giving the wrong result

What This Means

- Question: How to support transactions (with locks)?
  - Multiple transactions share data.
- Complete serialization is correct, but performance and abort are two issues.
- Interleaving transactions for performance
  - Problem: Not all interleavings produce a correct outcome

CSE 486/586 Administrivia

- PA2B & midterm grades
- PA3 is out.

What is "Correct"?

- How would you define correctness?
- For example, two independent transactions made by me and my wife on our three accounts.
- What do we care about at the end of the day?
  - Correct final balance for each account

a: 100 b: 200 c: 300

Transaction T1	Transaction T2
balance = b.getBalance()	bal = b.getBalance()
b.setBalance = (balance*1.1)	b.setBalance(bal*1.1)
a.withdraw(balance* 0.1)	c.withdraw(bal*0.1)

Concurrency Control: Providing "Correct" Interleaving

- 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.

a: 100 b: 200 c: 300

== T1 (complete) followed by T2 (complete)

Transaction T1		Transaction T2	
balance = b.getBalance()			
b.setBalance = (balance*1.1)	b: 220		
		bal = b.getBalance()	
		b.setBalance(bal*1.1)	b: 242
a.withdraw(balance* 0.1)	a: 80		
		c.withdraw(bal*0.1)	c: 278

Conditions for Correct Interleaving

- Case 1
  - T1.1 -> T1.2 -> T2.1 -> T2.2 -> T1.3 -> T2.3
- Case 2
  - T1.1 -> T2.1 -> T2.2 -> T1.2 -> T1.3 -> T2.3
- Which one's correct?

Transaction T1	Transaction T2
1. balance = b.getBalance()	1. bal = b.getBalance()
2. b.setBalance = (balance*1.1)	2. b.setBalance(bal*1.1)
3. a.withdraw(balance* 0.1)	3. c.withdraw(bal*0.1)

a: 100 b: 200 c: 300

Observation

- Case 1
  - T1.1 -> T1.2 -> T2.1 -> T2.2 -> T1.3 -> T2.3
- Correct: for a shared object (b), T1 is done producing the final outcome for b, and then T2 starts using it.

Transaction T1	Transaction T2
1. balance = b.getBalance()	
2. b.setBalance = (balance*1.1)	
	1. bal = b.getBalance()
	2. b.setBalance(bal*1.1)
3. a.withdraw(balance* 0.1)	
	3. c.withdraw(bal*0.1)

a: 100 b: 200 c: 300

Observation

- Case 2
  - T1.1 -> T2.1 -> T2.2 -> T1.2 -> T1.3 -> T2.3
- Incorrect: for a shared object (b), T1 is not done with producing the final outcome for b, but T2 starts using it.

Transaction T1	Transaction T2
1. balance = b.getBalance()	
	1. bal = b.getBalance()
	2. b.setBalance(bal*1.1)
2. b.setBalance = (balance*1.1)	
3. a.withdraw(balance* 0.1)	
	3. c.withdraw(bal*0.1)

a: 100 b: 200 c: 300

Another Example

Transaction T1	Transaction T2
x= a.read()	
a.write(x * 0.1)	
	b.write(100)
	a.write(200)
b.write(x)	

- T1 has produced the final outcome for a, and then T2 starts using it.
- T2 has produced the final outcome for b, and then T1 starts using it.
- But is this correct? No

Yet Another Example

Transaction T1	Transaction T2
x= a.read()	
b.write(x)	
	b.write(100)
a.write(x * 0.1)	
	a.write(200)

- T1 has produced the final outcome for a, then T2 uses it.
- T1 has produced the final outcome for b, then T2 uses it.
- Is this correct?
- Difference: T1 has produced the final outcomes for all shared objects, before T2 accesses it.

Generalizing the Observations

- Insight for serial equivalence
  - It's okay for a transaction to start using a shared object, if the final outcome of the shared object from a different transaction is already produced.
  - The above should be the case for each and every shared object in the same order.
  - E.g., if T1's final outcome on one shared object becomes visible to T2, then for each and every other shared object, T1 should produce the final outcome before T2 uses it.
- The other way around is possible, i.e., T2 first then T1.

Providing Serial Equivalence

- What operations are we considering?
  - Read/write
- What operations matter for correctness?
  - When write is involved

a: 100 b: 200 c: 300

Transaction T1	Transaction T2
balance = b.getBalance()	**bal = b.getBalance()**
b.setBalance = (balance*1.1)	**b.setBalance(bal*1.1)**
a.withdraw(balance* 0.1)	**c.withdraw(bal*0.1)**

Conflicting Operations

- Two operations are said to be in conflict, 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.

Operations of different transactions		*Conflict*	*Reason*
read	*read*	No	Because the effect of a pair of *read* operations does not depend on the order in which they are executed
read	*write*	Yes	Because the effect of a *read* and a *write* operation depends on the order of their execution
write	*write*	Yes	Because the effect of a pair of *write* operations depends on the order of their execution

Serial Equivalence and Conflicting Operations

- *Two transactions are serially equivalent 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.*

Serial Equivalence Example

- 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).

a: 100 b: 200 c: 300

Transaction T1 | Transaction T2

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

== T1 (complete) followed by T2 (complete)

b: 242
c: 278

Pairs of Conflicting Operations

More Examples

Transaction T1 | Transaction T2

x= a.read()
a.write(20)
Conflicting Ops.
y = b.read()
b.write(30)
b.write(x)
a.write(10)

*Non-*serially equivalent interleaving of operations

x= a.read()
a.write(20)
a.write(10)
b.write(x)
y = b.read()
b.write(30)

Serially equivalent interleaving of operations

Summary

- Transactions need to provide ACID
- Serial equivalence defines correctness of executing concurrent transactions
- It is handled by ordering conflicting operations

Acknowledgements

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