Database Technology

Topic 10: Concurrency Control

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Goal

- Preserve Isolation of the ACID properties

Transaction Processing Model

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Simple Database Model

- Database: simply, a collection of named items
- Granularity (size) of these data items is unimportant
  - May be a field, a tuple, or a file block, etc
  - Transaction processing concepts are independent of granularity

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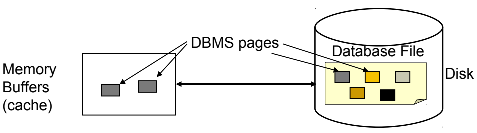
Basic Operations

- read_item(X): reads item X into a program variable (for simplicity, assume that the variable is also named X)
- write_item(X): write the value of program variable X into the database item named X
- These operations take some amount of time to execute
- Basic unit of data transfer between the disk and the computer main memory is a file block/page



Steps of Read / Write Operations

- read_item(X) consists of the following steps:
  1. Find address of the file block that contains item X
  2. Copy the file block into a buffer in main memory (if the block is not already in main memory)
  3. Copy item X from the buffer to the program variable X
- write_item(X) consists of the following steps:
  1. Find address of the file block that contains item X
  2. Copy the file block into a buffer in main memory (if the block is not already in main memory)
  3. Copy item X from the program variable named X into its correct location in the buffer
  4. Store the updated block from the buffer back to disk (either immediately or at some later point in time)

Transaction Notation

- Focus on read and write operations
  - For instance, $w_5(Z)$ means that transaction 5 writes data item Z
- b_i and e_i specify transaction boundaries (begin and end)
  - i specifies a unique transaction identifier (TID)
- Example:

T_1	T_2

read_item(X);
$X := X - N$;
write_item(X);
read_item(Y);
$Y := Y + N$;
write_item(Y);
	read_item(X);
	$X := X + M$;
	write_item(X);

  - T_1: b_1, $r_1(X)$, $w_1(X)$, $r_1(Y)$, $w_1(Y)$, e_1
  - T_2: b_2, $r_2(Y)$, $w_2(Y)$, e_2

Initial Concepts

Schedule

- Sequence of interleaved operations from multiple TAs
- Example:

	at ATM window #1	at ATM window #2
1	read_item(savings);	
2	savings = savings - $100;	
3		read_item(checking);
4	write_item(savings);	
5	read_item(checking);	
6		checking = checking - $20;
7		write_item(checking);
8	checking = checking + $100;	
9	write_item(checking);	
10		dispense $20 to customer;

  - S: b_1, $r_1(s)$, b_2, $r_2(c)$, $w_1(s)$, $r_1(c)$, $w_2(c)$, $w_1(c)$, e_1, e_2

Quiz

What can be concluded from the following schedule?

…, r_3(EMPLOYEE), b_4, w_2(STUDENT), …

A: Some employee has read a student record.

B: A transaction has read some data and then written it back.

C: At least three transactions were running concurrently.

D: All of the above.

E: None of the above.

Serial Schedules

- Definition: a schedule is *serial* if the operations of any TA are executed directly one after the other
  - i.e., no interleaving of operations from different TAs
- Characteristics:
  - Serial schedules trivially guarantee the isolation property
  - For n transactions, there are $n!$ serial schedules
  - Each of them produces a correct result (assuming the consistency preservation property)
  - However, not all of them might produce the *same* result
    - For instance, If two people try to reserve the last seat on a plane, only one gets it. The serial order determines which one. The two orderings have different results, but either one is correct.

Serial Schedules (cont'd)

Serial schedules are *not feasible* for performance reasons:

- Long transactions force other transactions to wait
- When a transaction is waiting for disk I/O or any other event, system cannot switch to other transaction
- Solution: allow *some* interleaving (without sacrificing correctness!)

Acceptable Interleavings

(Serializability)

Conflicts

- Executing some operations in a different order causes a different outcome
  - … $r_1(X)$, $w_2(X)$, … *vs.* … $w_2(X)$, $r_1(X)$, …
    T_1 will read a different value for X
  - … $w_1(Y)$, $w_2(Y)$, … *vs.* … $w_2(Y)$, $w_1(Y)$, …
    value for Y after both operations will be different
- Note that two read operations do not have this issue
  - … $r_1(Z)$, $r_2(Z)$, … *vs.* … $r_2(Z)$, $r_1(Z)$, …
    both TAs read the same value of Z

Conflicts and Equivalence

Definition: Two operations **conflict** if

1. they access the same data item X,
2. they are from two different transactions, and
3. at least one of them is a write operation.

Definition: Two schedules are **conflict equivalent** if the relative order of *any two conflicting operations* is the same in both schedules.

Example:

S1: b_1, $r_1(s)$, b_2, $r_2(c)$, $w_1(s)$, $r_1(c)$, $w_2(c)$, $w_1(c)$, e_1, e_2

S2: b_1, $r_1(s)$, $r_1(c)$, b_2, $r_2(c)$, $w_1(s)$, $w_2(c)$, $w_1(c)$, e_2, e_1

Serializability

Definition: A schedule with *n* transactions is **serializable** if it is conflict equivalent to *some* serial schedule of the same *n* transactions.

- Serializable schedule "correct" because equivalent to some serial schedule, and any serial schedule acceptable
  - Transactions see data as if they were executed serially
  - Transactions leave DB state as if they were executed serially (hence, serializable schedules will leave the database in a consistent state)
- Efficiency achievable through interleaving and concurrent execution

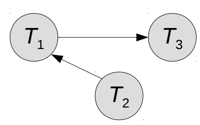
Testing Serializability

- Construct a *serialization graph* for the schedule
  - Node for each transaction in the schedule
  - Direct edge from T_i to T_j if some read or write operation in T_i appears before a conflicting operation in T_j
- A schedule is serializable if and only if its serialization graph has no cycles

Example

- Consider the following schedule

  S: b_1, $r_1(X)$, b_2, $r_2(Y)$, $w_1(X)$, b_3, $w_2(Y)$, e_2, $r_1(Y)$, $r_3(X)$, e_3, $w_1(Y)$, e_1
- Serialization graph of *S*:



- No cycles! Hence, *S* is serializable.
  - Equivalent to the following serial schedule:

S': b_2, $r_2(Y)$, $w_2(Y)$, e_2, b_1, $r_1(X)$, $w_1(X)$, $r_1(Y)$, $w_1(Y)$, e_1, b_3, $r_3(X)$, e_3

T_2 T_1 T_3

Quiz

Remember

- If the initial value of checking is $500, what value does it have after the following interleaved execution completes?

	at ATM window #1	at ATM window #2
1	read_item(savings);	
2	savings = savings - $100;	
3		read_item(checking);
4	write_item(savings);	
5	read_item(checking);	
6		checking = checking - $20;
7		write_item(checking);
8	checking = checking + $100;	
9	write_item(checking);	
10		dispense $20 to customer;

A: $480 **B:** $500 **C:** $580 **D:** $600

– *S*: b_1, $r_1(s)$, b_2, $r_2(c)$, $w_1(s)$, $r_1(c)$, $w_2(c)$, $w_1(c)$, e_1, e_2

Key Question

Can we make sure that we only get serializable schedules?

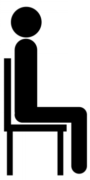
Locking Techniques for Concurrency Control

Database Locks

- Locks can be used to ensure that conflicting operations cannot occur
- **Exclusive lock** for writing, **shared lock** for reading
  - Transaction cannot read item without first getting a shared or an exclusive lock on it
  - Transaction cannot write item without first getting exclusive lock on it

Database Locks (cont'd)

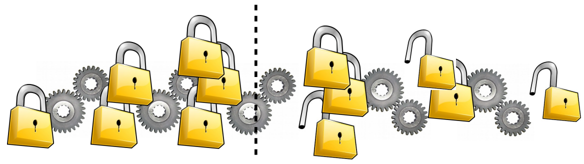
- Request for lock may cause transaction to **block** (wait) because write lock is exclusive
  - Any lock on *X* (read or write) cannot be granted if some other transaction holds write lock on *X*
  - Write lock on *X* cannot be granted if some other transaction holds *any* lock on *X*



- Blocked transactions are unblocked and granted the requested lock when conflicting transaction(s) release their lock(s)

Two-Phase Locking (2PL)

Definition: A transaction follows the two-phase locking (2PL) protocol if *all* of its read_lock() and write_lock() operations come before its first unlock() operation.



- A transaction that follows the 2PL protocol has an *expansion phase* and a *shrinking phase*
- If all transactions in a schedule follow the 2PL protocol, then the schedule is serializable

Deadlock

- Two or more transactions wait for one another to unlock some data item
  - T_i waits for T_j waits for … waits for T_n waits for T_i
- Deadlock prevention:
  - Conservative 2PL protocol: Wait until you can lock all the data to be used beforehand
  - Wait-die
  - Wound-wait
  - No waiting
  - Cautious waiting
- Deadlock detection:
  - Wait-for graph
  - timeouts

Starvation

- A transaction is not executed for an indefinite period of time while other transactions are executed normally
  - e.g., *T* waits for write lock and other TAs repeatedly grab read locks before all read locks are released
- Starvation prevention:
  - First-come-first-served waiting scheme
  - Wait-die
  - Wound-wait
  - etc.

Summary

Summary

- Characterizing schedules based on serializability
  - Serial and non-serial schedules
  - Conflict equivalence of schedules
  - Serialization graph
- Two-phase locking
  - Guarantees conflict serializability
  - Possible problems: deadlocks and starvation

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