Transaction Processing (Part II) and Concurrency Control

CO527 Advanced Database Systems

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Transaction T_1	Transaction T_2	Transaction T_3
read_item(X);	read_item(Z);	read_item(Y);
write_item(X);	read_item(Y);	read_item(Z);
read_item(Y);	write_item(Y);	write_item(Y);
write_item(Y);	read_item(X);	write_item(Z);
	write_item(X);	

2

Transaction T_1	Transaction T_2	Transaction T_3
read_item(X);	read_item(Z);	read_item(Y);
write_item(X);	read_item(Y);	read_item(Z);
read_item(Y);	write_item(Y);	write_item(Y);
write_item(Y);	read_item(X);	write_item(Z);
	write_item(X);	

Time	Transaction T_1	Transaction T_2	Transaction T_3

↓		read_item(Z);
		read_item(Y);
		write_item(Y);	

			read_item(Y);
			read_item(Z);

	read_item(X);
	write_item(X);		

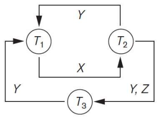
			write_item(Y);
			write_item(Z);

		read_item(X);	

	read_item(Y);
	write_item(Y);		

		write_item(X);	

Schedule E



Equivalent serial schedules

None

Reason

Cycle $X(T_1 \rightarrow T_2), Y(T_2 \rightarrow T_1)$
Cycle $X(T_1 \rightarrow T_2), YZ\ (T_2 \rightarrow T_3), Y(T_3 \rightarrow T_1)$

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Transaction T_1	Transaction T_2	Transaction T_3
read_item(X);	read_item(Z);	read_item(Y);
write_item(X);	read_item(Y);	read_item(Z);
read_item(Y);	write_item(Y);	write_item(Y);
write_item(Y);	read_item(X);	write_item(Z);
	write_item(X);	

Time	Transaction T_1	Transaction T_2	Transaction T_3

↓			read_item(Y);
			read_item(Z);

	read_item(X);
	write_item(X);		

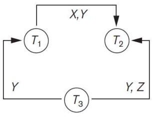
			write_item(Y);
			write_item(Z);

		read_item(Z);	

	read_item(Y);
	write_item(Y);		

		read_item(Y);
		write_item(Y);
		read_item(X);
		write_item(X);	

Schedule F



Equivalent serial schedules

$T_3 \rightarrow T_1 \rightarrow T_2$

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How Serializability is Used for Concurrency Control

- Being serializable is different from being serial
- Serializable schedule gives benefit of concurrent execution
  - Without giving up any correctness
- Difficult to test for serializability in practice
  - Factors such as system load, time of transaction submission, and process priority affect ordering of operations
  - If the schedule is not to be serializable, the schedule must be cancelled.
- Therefore, DBMS enforces protocols
  - Set of rules to ensure serializability

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View Equivalence and View Serializability

- View equivalence of two schedules
  - As long as each read operation of a transaction reads the result of the same write operation in both schedules, the write operations of each transaction must produce the same results
  - Read operations said to see the same view in both schedules
- View serializable schedule
  - View equivalent to a serial schedule

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View Equivalence and View Serializability (cont'd.)

- Conflict serializability similar to view serializability if constrained write assumption (no blind writes) applies
- Unconstrained write assumption
  - Value written by an operation can be independent of its old value
- Debit-credit transactions
  - Less-stringent conditions than conflict serializability or view serializability

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Transaction Support in SQL

- No explicit Begin_Transaction statement
- Every transaction must have an explicit end statement
  - COMMIT
  - ROLLBACK
- Access mode is READ ONLY or READ WRITE
- Diagnostic area size option
  - Integer value indicating number of conditions held simultaneously in the diagnostic area

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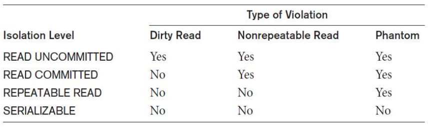
Transaction Support in SQL (cont'd.)

- Isolation level option
  - Dirty read
  - Nonrepeatable read
  - Phantoms



	Type of Violation		
Isolation Level	Dirty Read	Nonrepeatable Read	Phantom
READ UNCOMMITTED	Yes	Yes	Yes
READ COMMITTED	No	Yes	Yes
REPEATABLE READ	No	No	Yes
SERIALIZABLE	No	No	No

Table 20.1 Possible violations based on isolation levels as defined in SQL

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Transaction Support in SQL (cont'd.)

- Snapshot isolation
  - Used in some commercial DBMSs
  - Transaction sees data items that it reads based on the committed values of the items in the database snapshot when transaction starts
  - Ensures phantom record problem will not occur

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Summary

- Single and multiuser database transactions
- Uncontrolled execution of concurrent transactions
- System log
- Failure recovery
- Committed transaction
- Schedule (history) defines execution sequence
  - Schedule recoverability
  - Schedule equivalence
- Serializability of schedules

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Concurrency Control Techniques

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Introduction

- Concurrency control protocols
  - Set of rules to guarantee serializability
- Two-phase locking protocols
  - Lock data items to prevent concurrent access
- Timestamp
  - Unique identifier for each transaction
- Multiversion currency control protocols
  - Use multiple versions of a data item

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Two-Phase Locking Techniques for Concurrency Control

- Lock
  - Variable associated with a data item describing status for operations that can be applied
  - One lock for each item in the database
- Binary locks
  - Two states (values)
    - Locked (1)
      - Item cannot be accessed
    - Unlocked (0)
      - Item can be accessed when requested

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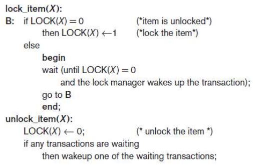
Two-Phase Locking Techniques for Concurrency Control (cont'd.)

- Transaction requests access by issuing a lock_item(X) operation



```
lock_item(X):
B:  if LOCK(X) = 0                  (*item is unlocked*)
        then LOCK(X) ←1             (*lock the item*)
    else
        begin
        wait (until LOCK(X) = 0
            and the lock manager wakes up the transaction);
        go to B
        end;
unlock_item(X):
    LOCK(X) ← 0;                    (* unlock the item *)
    if any transactions are waiting
        then wakeup one of the waiting transactions;
```

Figure 21.1 Lock and unlock operations for binary locks

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Two-Phase Locking Techniques for Concurrency Control (cont'd.)

- Lock table specifies items that have locks
- Lock manager subsystem
  - Keeps track of and controls access to locks
  - Rules enforced by lock manager module
- At most one transaction can hold the lock on an item at a given time
- Binary locking too restrictive for database items

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Two-Phase Locking Techniques for Concurrency Control (cont'd.)

- Shared/exclusive or read/write locks
  - Read operations on the same item are not conflicting
  - Must have exclusive lock to write
  - Three locking operations
    - read_lock(X)
    - write_lock(X)
    - unlock(X)

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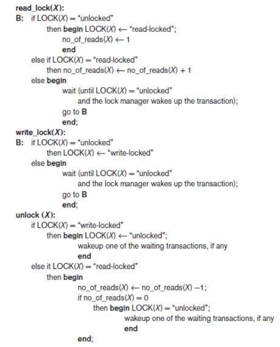
Figure 21.2 Locking and unlocking operations for two-mode (read/write, or shared/exclusive) locks



```
read_lock(X):
B:  if LOCK(X) = "unlocked"
        then begin LOCK(X) ← "read-locked";
            no_of_reads(X) ← 1
            end
    else if LOCK(X) = "read-locked"
        then no_of_reads(X) ← no_of_reads(X) + 1
    else begin
            wait (until LOCK(X) = "unlocked"
                and the lock manager wakes up the transaction);
            go to B
            end;
write_lock(X):
B:  if LOCK(X) = "unlocked"
        then LOCK(X) ← "write-locked"
    else begin
            wait (until LOCK(X) = "unlocked"
                and the lock manager wakes up the transaction);
            go to B
            end;
unlock (X):
    if LOCK(X) = "write-locked"
        then begin LOCK(X) ← "unlocked";
                wakeup one of the waiting transactions, if any
                end
    else it LOCK(X) = "read-locked"
        then begin
                no_of_reads(X) ← no_of_reads(X) −1;
                if no_of_reads(X) = 0
                    then begin LOCK(X) = "unlocked";
                            wakeup one of the waiting transactions, if any
                            end
                end;
```

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Two-Phase Locking Techniques for Concurrency Control (cont'd.)

- Lock conversion — Transaction that already holds a lock allowed to convert the lock from one state to another
- Upgrading — Issue a read_lock operation then a write_lock operation
- Downgrading — Issue a read_lock operation after a write_lock operation

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Guaranteeing Serializability by Two-Phase Locking

- Two-phase locking protocol
  - All locking operations precede the first unlock operation in the transaction
  - Phases
    - Expanding (growing) phase
      - New locks can be acquired but none can be released
      - Lock conversion upgrades must be done during this phase
    - Shrinking phase
      - Existing locks can be released but none can be acquired
      - Downgrades must be done during this phase

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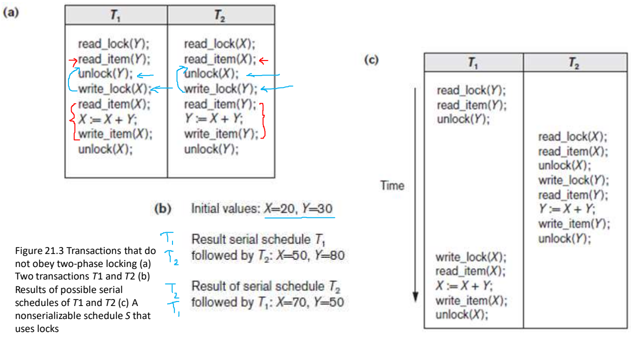

(a)

T_1	T_2

read_lock(Y);
read_item(Y);
unlock(Y);
write_lock(X);
read_item(X);
$X := X + Y$;
write_item(X);
unlock(X);
	read_lock(X);
	read_item(X);
	unlock(X);
	write_lock(Y);
	read_item(Y);
	$Y := X + Y$;
	write_item(Y);
	unlock(Y);

(b) Initial values: X=20, Y=30

T_1 T_2 Result serial schedule T_1 followed by T_2: X=50, Y=80

T_2 T_1 Result of serial schedule T_2 followed by T_1: X=70, Y=50

(c)

T_1	T_2

read_lock(Y);
read_item(Y);
unlock(Y);	

	read_lock(X);
	read_item(X);
	unlock(X);
	write_lock(Y);
	read_item(Y);
	$Y := X + Y$;
	write_item(Y);
	unlock(Y);

write_lock(X);
read_item(X);
$X := X + Y$;
write_item(X);
unlock(X);	

Figure 21.3 Transactions that do not obey two-phase locking (a) Two transactions *T1* and *T2* (b) Results of possible serial schedules of *T1* and *T2* (c) A nonserializable schedule *S* that uses locks

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Figure 21.4
Transactions T_1' and T_2', which are the same as T_1 and T_2 in Figure 21.3 but follow the two-phase locking protocol. Note that they can produce a deadlock.

T_1'	T_2'

read_lock(Y);
read_item(Y);
write_lock(X);
unlock(Y)
read_item(X);
$X := X + Y$;
write_item(X);
unlock(X);
	read_lock(X);
	read_item(X);
	write_lock(Y);
	unlock(X)
	read_item(Y);
	$Y := X + Y$;
	write_item(Y);
	unlock(Y);

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Guaranteeing Serializability by Two-Phase Locking

- If every transaction in a schedule follows the two-phase locking protocol, schedule guaranteed to be serializable
- Two-phase locking may limit the amount of concurrency that can occur in a schedule
- Some serializable schedules will be prohibited by two-phase locking protocol

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Variations of Two-Phase Locking

- ✓ Basic 2PL
  - Technique described on previous slides
- Conservative (static) 2PL
  - Requires a transaction to lock all the items it accesses before the transaction begins
    - Predeclare read-set and write-set
  - Deadlock-free protocol
- Strict 2PL
  - Transaction does not release exclusive (write) locks until after it commits or aborts

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Variations of Two-Phase Locking (cont'd.)

- Rigorous 2PL
  - Transaction does not release any locks until after it commits or aborts
- Concurrency control subsystem responsible for generating read_lock and write_lock requests
- Locking generally considered to have high overhead
- The use of locks can also cause two additional problems
  - deadlock and starvation.

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Dealing with Deadlock and Starvation

- Deadlock
  - Occurs when each transaction T in a set is waiting for some item locked by some other transaction *T'*
  - Both transactions stuck in a waiting queue

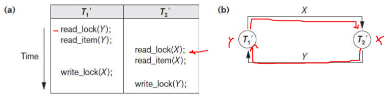

Figure 21.5 Illustrating the deadlock problem (a) A partial schedule of *T*1' and *T*2' that is in a state of deadlock (b) A wait-for graph for the partial schedule in (a)

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Dealing with Deadlock and Starvation (cont'd.)

- Deadlock prevention protocols
  - ✓ Every transaction locks all items it needs in advance
  - ✓ Ordering all items in the database
    - Transaction that needs several items will lock them in that order
  - Both approaches impractical
- Protocols based on a timestamp
  - ✓ Wait-die $T_1 < T_2$
  - ✓ Wound-wait

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Dealing with Deadlock and Starvation (cont'd.)

- No waiting algorithm
  - If transaction unable to obtain a lock, immediately aborted and restarted later
- Cautious waiting algorithm
  - Deadlock-free
- Deadlock detection
  - System checks to see if a state of deadlock exists
  - Wait-for graph

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Dealing with Deadlock and Starvation (cont'd.)

- Victim selection
  - Deciding which transaction to abort in case of deadlock
- Timeouts
  - If system waits longer than a predefined time, it aborts the transaction
- Starvation
  - Occurs if a transaction cannot proceed for an indefinite period of time while other transactions continue normally
  - Solution: first-come-first-served queue

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Concurrency Control Based on Timestamp Ordering

- Timestamp
  - Unique identifier assigned by the DBMS to identify a transaction
  - Assigned in the order submitted
  - Transaction start time
- Concurrency control techniques based on timestamps do not use locks
  - Deadlocks cannot occur

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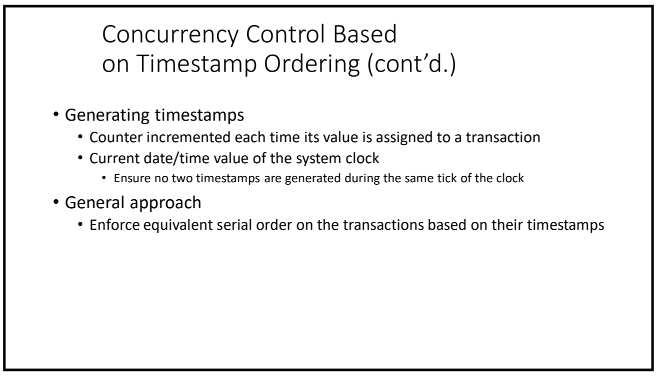

Concurrency Control Based on Timestamp Ordering (cont'd.)

- Generating timestamps
  - Counter incremented each time its value is assigned to a transaction
  - Current date/time value of the system clock
    - Ensure no two timestamps are generated during the same tick of the clock
- General approach
  - Enforce equivalent serial order on the transactions based on their timestamps

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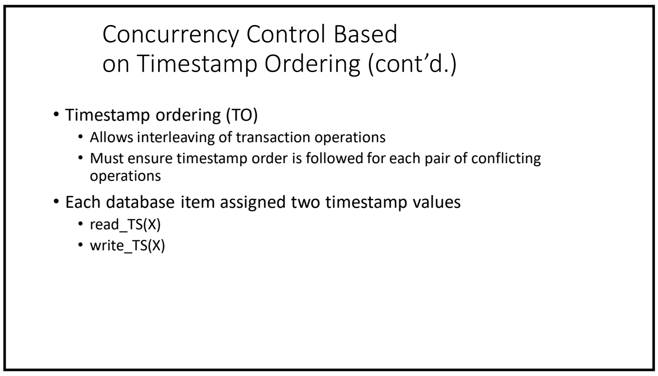

Concurrency Control Based on Timestamp Ordering (cont'd.)

- Timestamp ordering (TO)
  - Allows interleaving of transaction operations
  - Must ensure timestamp order is followed for each pair of conflicting operations
- Each database item assigned two timestamp values
  - read_TS(X)
  - write_TS(X)

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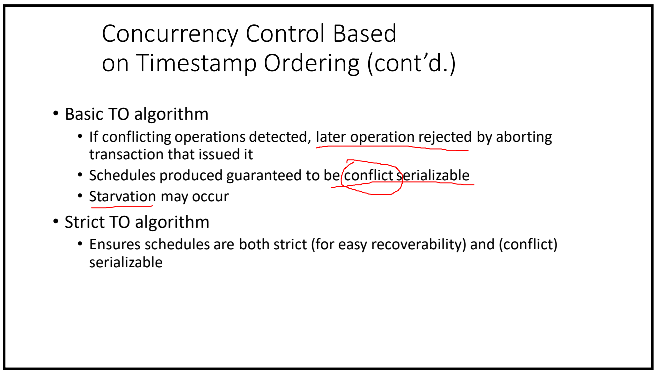

Concurrency Control Based on Timestamp Ordering (cont'd.)

- Basic TO algorithm
  - If conflicting operations detected, later operation rejected by aborting transaction that issued it
  - Schedules produced guaranteed to be conflict serializable
  - Starvation may occur
- Strict TO algorithm
  - Ensures schedules are both strict (for easy recoverability) and (conflict) serializable

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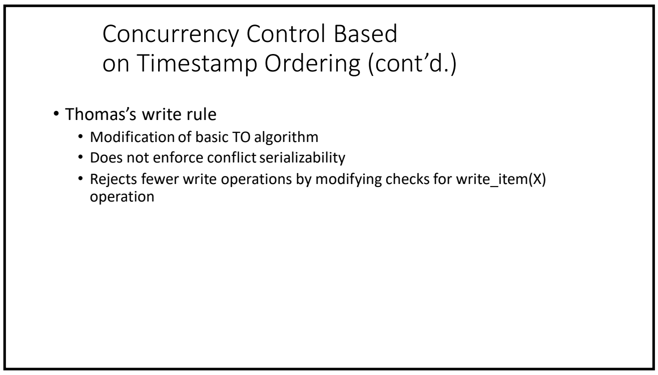

Concurrency Control Based on Timestamp Ordering (cont'd.)

- Thomas's write rule
  - Modification of basic TO algorithm
  - Does not enforce conflict serializability
  - Rejects fewer write operations by modifying checks for write_item(X) operation

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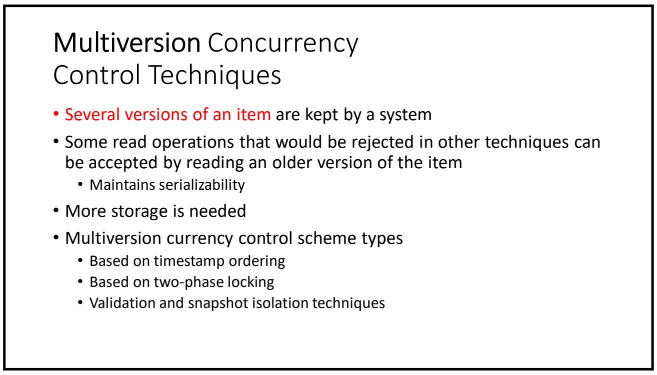

Multiversion Concurrency Control Techniques

- Several versions of an item are kept by a system
- Some read operations that would be rejected in other techniques can be accepted by reading an older version of the item
  - Maintains serializability
- More storage is needed
- Multiversion currency control scheme types
  - Based on timestamp ordering
  - Based on two-phase locking
  - Validation and snapshot isolation techniques

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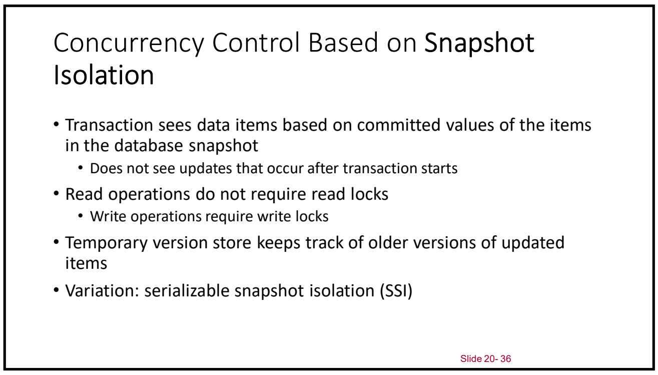

Concurrency Control Based on Snapshot Isolation

- Transaction sees data items based on committed values of the items in the database snapshot
  - Does not see updates that occur after transaction starts
- Read operations do not require read locks
  - Write operations require write locks
- Temporary version store keeps track of older versions of updated items
- Variation: serializable snapshot isolation (SSI)

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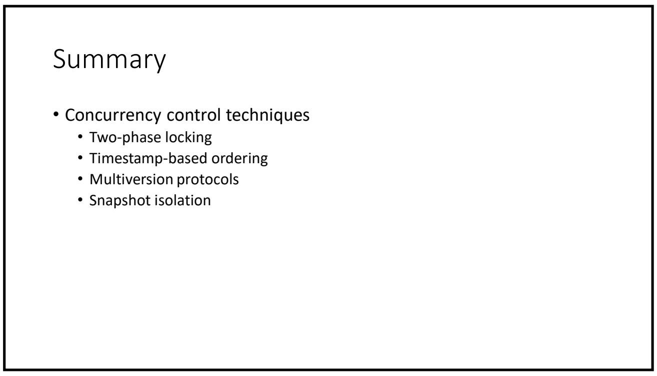

Summary

- Concurrency control techniques
    - Two-phase locking
    - Timestamp-based ordering
    - Multiversion protocols
    - Snapshot isolation

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