CS315: Database Systems
Transactions and Recovery Systems

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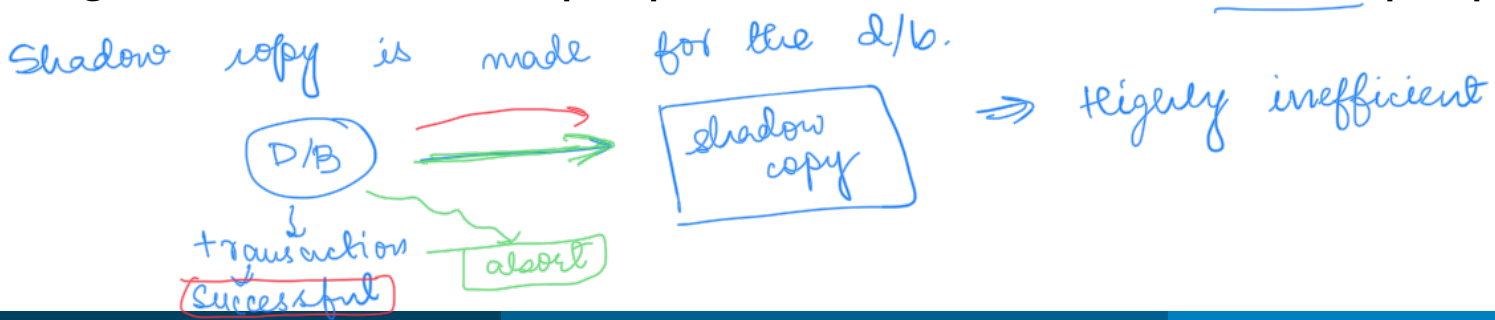
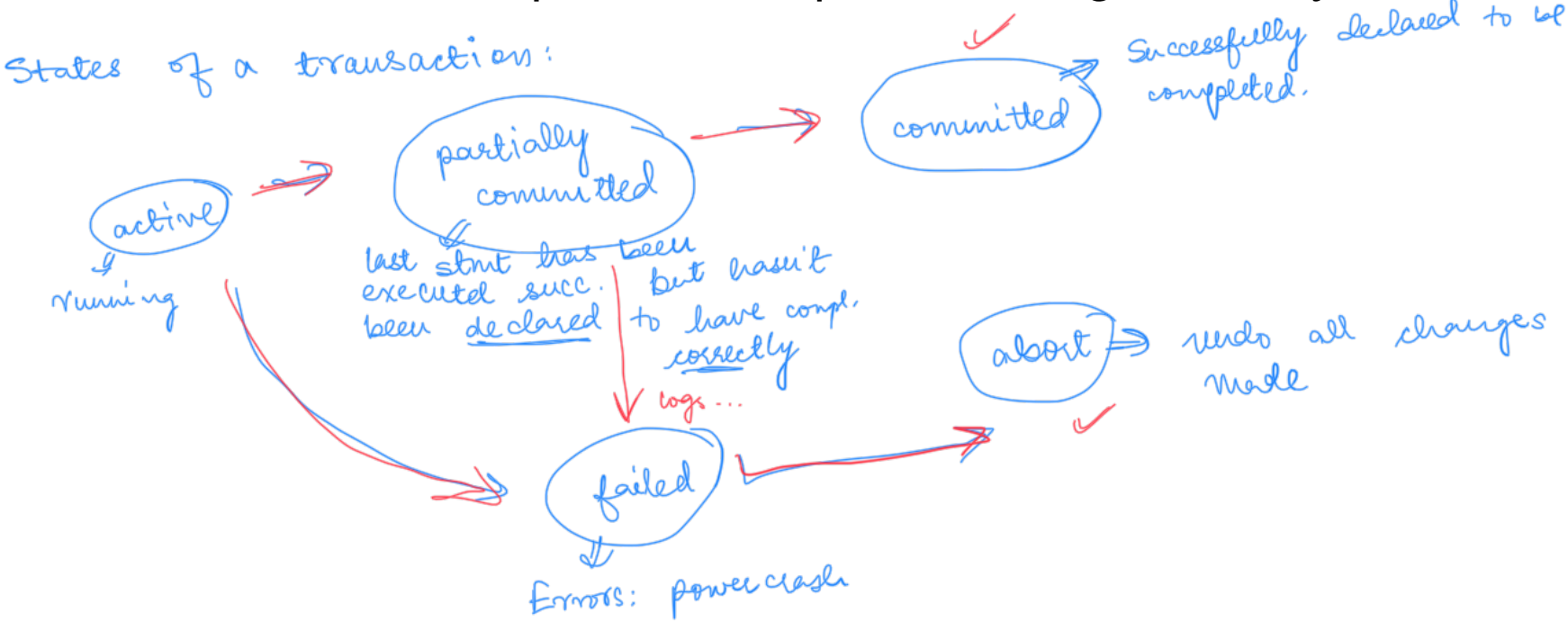
ACID Properties

- A transaction is a logical unit of a program
- To preserve data integrity, a database must follow four properties
  1. Atomicity: Either all operations of a transaction are reflected or none are reflected
  2. Consistency: If a database is consistent before the execution of the transaction, it must be consistent after it
  3. Isolation: Although multiple transactions may execute concurrently, each transaction must be unaware of others, i.e., to a transaction, it must seem that either any other transaction has completed execution or has not started execution at all
  4. Durability: After a transaction finishes successfully, the changes must be permanent in the database despite subsequent failures
- Together, these four properties are called the ACID properties



Transaction Model

- A transaction is a logical unit of a program that reads and writes various named data items
- Thus, a database is simply a collection of *named items*
- *Granularity* of data: field, record, block, relation
- Transaction concepts are independent of granularity



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- Conflicts with read and write
  - RAW: read-after-write
  - WAR: write-after-read
  - WAW: write-after-write

Two transaction T_1, T_2
T_1 reads T_2 writes
T_1 should read before T_2 writes

Not R-A-R conflict (No change in data)

Example

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- Isolation: If another transaction reads *a* and *b*, it must see one of the two states: before or after the transaction; otherwise $a + b$ is wrong
- Durability: If *b* is notified of credit, it must persist even if the database crashes

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- Temporary update or Dirty read: A transaction updates and then fails; another transaction reads it before it is reverted to original value

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Problems in Transactions

- Lost update: Update by one transaction is overwritten by another transaction
- Temporary update or Dirty read: A transaction updates and then fails; another transaction reads it before it is reverted to original value
- Incorrect summary: One transaction is updating values while other is computing an aggregate on them [happens bcoz of temp. update]

Causes of Transaction Failures

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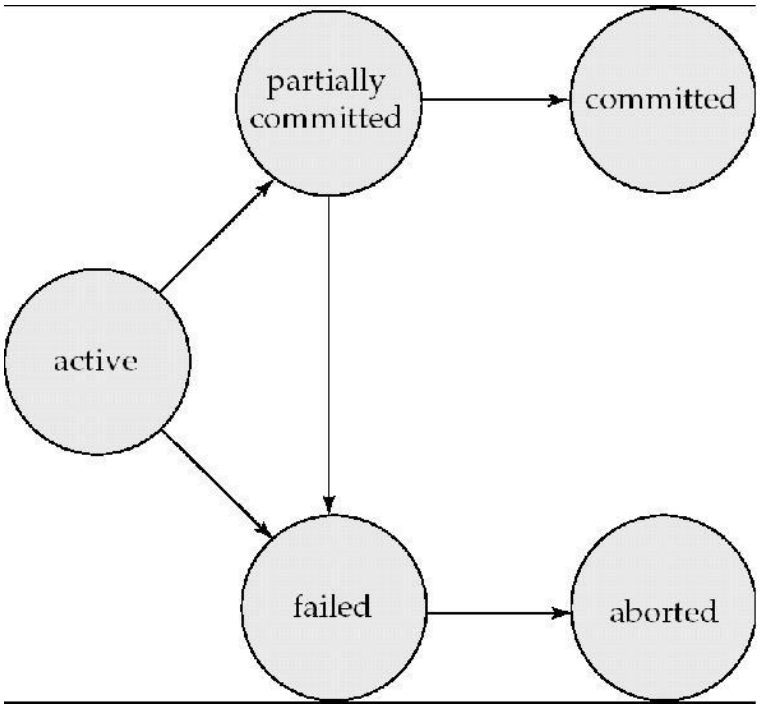
- System crash
  - Memory is lost
- System error
  - Divide by zero
- Exceptions
  - Insufficient account balance
- Concurrency enforcement
  - Deadlock detection
- Disk crash
  - Persistency fails
- Physical problems
  - Power failure, fire

States of a Transaction

- Active: transaction is executing
- Partially committed: after last statement has been executed but not logged
- Failed: when execution cannot proceed
- Committed: after successful completion
- Aborted: transaction has been rolled back and it has been ensured that there is no effect of the transaction



Commit Point

- A transaction reaches its commit point when all its operations have been executed successfully and they have been recorded in the log
- Beyond the commit point, the transaction is said to be *committed*, and its effect on the database is assumed to be permanent
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- A transaction needs to rollback if there is a (start, T) entry but no (commit, T) entry
  - It may also need to be rolled back if there is a (abort, T) entry
  - Undo operations need to be performed

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  - Undo operations need to be performed
- Before a transaction reaches its commit point, any portion of the log not yet written to disk must be flushed – this is called force-writing of the log
  - Ensures that redo operations can be done successfully

Concurrency

- Multiple transactions should be able to run concurrently
- Advantages
  - Increased processor and disk utilization leading to better *throughput*: one is using CPU, other is doing disk I/O
  - Reduced average response time: short transactions finish earlier and do not wait behind long ones
- Concurrency control schemes achieve isolation
- Must ensure correctness of concurrent executions
- Serializability imposes notion of correctness

Recovery management system

- Recovery management system of a database ensures that atomicity and durability properties are maintained despite failures
- Fail-stop assumption: Data on non-volatile storage is *not* lost due to system crash or power failure

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- Recovery management system of a database ensures that atomicity and durability properties are maintained despite failures
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- Recovery algorithms have two main parts
  1. Action taken *during normal execution* to ensure that enough information is collected to recover from failures
  2. Action taken *after a failure* that utilizes information collected so far to recover the database contents and maintain atomicity and durability
- Assume that transactions run serially, i.e., one after another

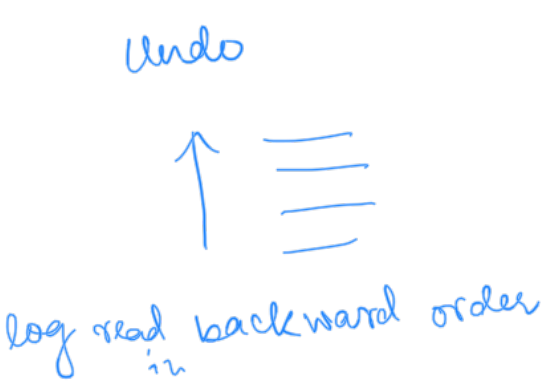
Log-Based Recovery

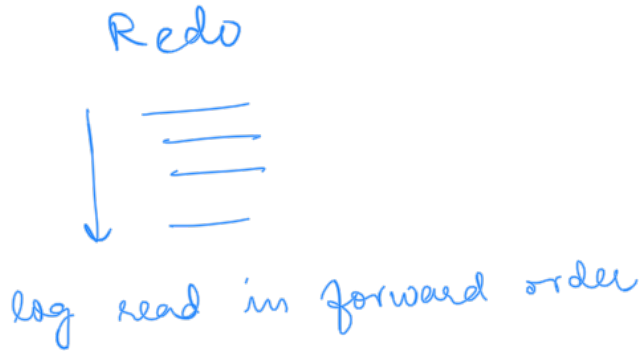
- Log or journal is maintained on *stable storage*
  - Stable storage: data is *never* lost
- Log records for every operation of a transaction are recorded
- When transaction T starts, (start, T) record is logged
- *Before* read or write, the corresponding log record is written
  - (write, T, x, old, new)
  - (read, T, x, val)
- When T finishes successfully, (commit, T) is logged
- If T fails, (abort, T) is logged
- Two approaches of recovery based on logs
  1. Deferred database modification
  2. Immediate database modification

Deferred Database Modification

- Defers *all* writes to after partial commit [No write is actually made to the disk]
- Write log record is of the form (write, T, x, new)
  - Old value of x is not needed
- After T partially commits, (commit, T) is recorded in the log and log is written to the stable storage
  - (abort, T) record is not needed
- Log records are then read to actually perform the writes on the database

As the log before commit can be checked & performed again ⇒ Redo





Abort ⇒ undo has to be done

After committing, it is permanent Now, undo can't be done, only Redo.

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- Log records are then read to actually perform the writes on the database
- When a transaction crashes, its (commit, T) record is searched
- If not found,

* All writes must happen on the disk for saying it's committed.
* If necessary, there is disk flush [everything in disk buffer goes to the disk] ⇒ Disk contains the new copy
* Forced write ⇒ Forcefully reading a commit

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- Log records are then read to actually perform the writes on the database
- When a transaction crashes, its (commit, T) record is searched
- If not found, nothing to do
  - No write has been performed on the database
- If found, redo all operations
  - Not sure if crash occurred while performing the deferred writes or after them
- Redo operation *must* be idempotent write same value again & again
  - Idempotent: Multiple operations has the same effect as single
- Also called a no-undo/redo recovery scheme
- Redos must be done in the order of serial transactions

Example

- (start, T0); (write, T0, A, 9); (commit, T0); (start, T1); (write, T1, A, 7); (commit, T1)
- Crash after (write, T0) statement

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- Crash after (write, T0) statement
  - Nothing needs to be done
- Crash after (write, T1) statement
  - T0 is redone
- Crash after (commit, T1) statement
  - Both T0 and T1 are redone
  - redo(T0) must be done before redo(T1)
  - Otherwise, value of *A* will be wrong

Immediate Database Modification

- Allows writes to modify database even for uncommitted transactions
- Write log record is of the form (write, T, x, old, new)
  - Old value of x is needed
- Log record of write must be written to stable storage before the corresponding write is performed on the database

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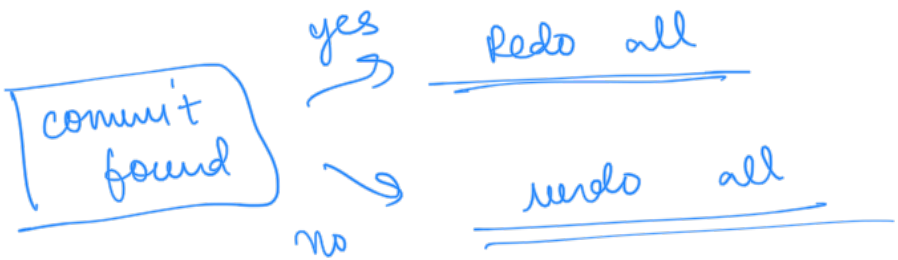
- When a transaction crashes, its (commit, T) record is searched
- If not found, undo all operations (requires old value)
  - Uncommitted writes have been performed on the database
- If found, redo all operations [not all of them may have gone to the database → Redo]
  - If (commit, T) record is deferred till all writes are performed on the database, redo is not required
- Both undo and redo operations *must* be idempotent
  - Crash may occur multiple times
- Also called a undo/redo (or undo/no-redo) recovery scheme
- Undos must be done in the reverse order of serial transactions
- Redos must be done in the forward order of serial transactions
- All undos must be done before any redo

Example

- (start, T0); (write, T0, A, 3, 9); (commit, T0); (start, T1); (write, T1, B, 2, 5); (write, T1, A, 9, 7); (commit, T1);
- Crash after (write, T0, A) statement



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- Crash after (write, T0, A) statement
  - T0 is undone
  - Value of *A* is set back to 3
- Crash after (write, T1, B) statement

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- Crash after (write, T0, A) statement
  - T0 is undone
  - Value of *A* is set back to 3
- Crash after (write, T1, B) statement
  - T1 is undone
  - T0 is redone
  - undo(T1) must be done before redo(T0)
  - Value of *A* is restored to 9 and that of *B* to 2
- Crash after (commit, T1) statement

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- Crash after (commit, T1) statement
  - Both T0 and T1 are redone
  - redo(T0) must be done before redo(T1)
  - Value of *A* is set correctly to 7

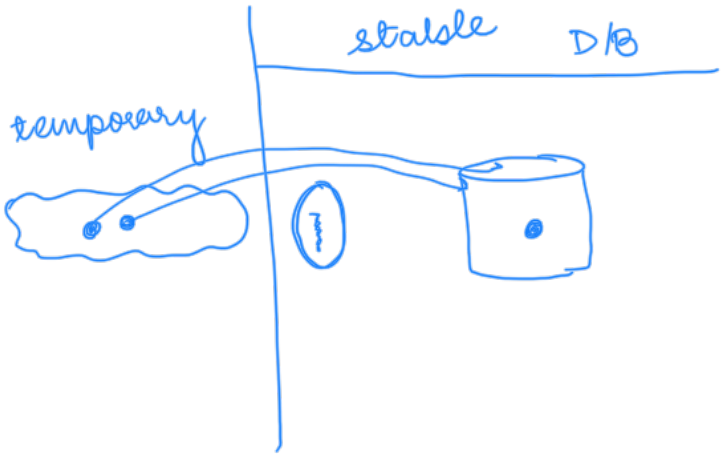
Checkpoints

- Logs can become very big
- Searching in logs become time-consuming
- Transactions may be re-done unnecessarily
- Checkpointing alleviates these problems
- Log records are flushed to stable storage
- All pending writes are performed on the database
- An entry (checkpoint) is made in the log, and it is written to the stable storage

(write, T, ...) → D/B

It is forced to go on the DB before the checkpt.

* We only need to worry about logs after the checkpoint



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- Log records are flushed to stable storage
- All pending writes are performed on the database
- An entry (checkpoint) is made in the log, and it is written to the stable storage
- During recovery, any transaction that has completed successfully before the checkpoint, i.e., have a (commit, T) entry need not be considered
- Any T_i with (commit, T_i) after checkpoint is redone
- Any T_j with (start, T_j) but no (commit, T_j) is undone

Concurrent Transactions

- (checkpoint L) entry contains a list L of transactions active at that point
- After crash, scan backwards to last checkpoint
- Add T_i to redo-list when (commit, T_i) entry is found
- Add T_j to undo-list when (start, T_j) entry is found
- Add T_k in L to undo-list if not present in redo-list

(start T_2) . . . (checkpoint {T_2}) →

(no commit)

T_2 has to be undone.

⇒ If there is an (abort, T_2) after checkpoint ⇒ It needs to be Undone

Concurrent Transactions

$L = \{T_0, T_2, T_5\}$

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- Add T_j to undo-list when (start, T_j) entry is found
- Add T_k in L to undo-list if not present in redo-list
- Undos done first in reverse order
- Redos done later in forward order

$\Rightarrow T_k$ is in L {active} but not in redo-list or undo-list $\Rightarrow$ undo-list

- Only operations after checkpoint need to be undone or redone

{checkpoint, L}

backwards

(start, T_j) → undo list {T_j added}

(commit, T_i) → Redo list {T_i added}

Example

- (start, T1); (write, T1, B, 2, 3); (start, T2); (commit, T1); (write, T2, C, 5, 7); (checkpoint, {T2}); (start, T3); (write, T3, A, 1, 9); (commit, T3); (start, T4); (write, T4, C, 7, 2) Crash
- Undo-list: T_4, T_2 { T_4 undone first then T_2 }
- Redo list: T_3 T_3 is redone

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- Undo-list: T4,

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- Undo-list: T4, T2
- Redo-list:

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- (start, T1); (write, T1, B, 2, 3); (start, T2); (commit, T1); (write, T2, C, 5, 7); (checkpoint, {T2}); (start, T3); (write, T3, A, 1, 9); (commit, T3); (start, T4); (write, T4, C, 7, 2)
- Undo-list: T4, T2
- Redo-list: T3
- Order:

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- Undo-list: T4, T2
- Redo-list: T3
- Order: T4,

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- Undo-list: T4, T2
- Redo-list: T3
- Order: T4, T2,

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- Undo-list: T4, T2
- Redo-list: T3
- Order: T4, T2, T3
- Order of operations:

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- Order of operations:
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- Undo-list: T4, T2
- Redo-list: T3
- Order: T4, T2, T3
- Order of operations:
  - T4: Revert value of C to 7
  - T2: X { no operation here }
  - T_3 : value of A is 9

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- Undo-list: T4, T2
- Redo-list: T3
- Order: T4, T2, T3
- Order of operations:
  - T4: Revert value of C to 7
  - T2: No operation
  - T3:

Example

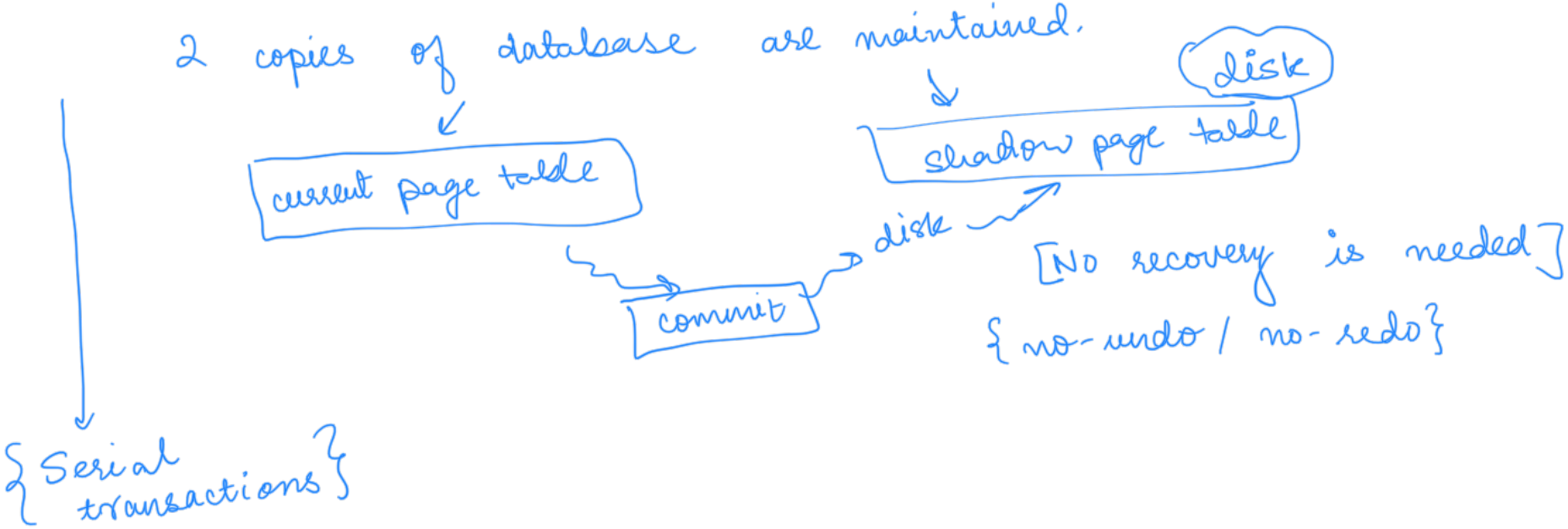
- (start, T1); (write, T1, B, 2, 3); (start, T2); (commit, T1); (write, T2, C, 5, 7); (checkpoint, {T2}); (start, T3); (write, T3, A, 1, 9); (commit, T3); (start, T4); (write, T4, C, 7, 2)
- Undo-list: T4, T2
- Redo-list: T3
- Order: T4, T2, T3
- Order of operations:
  - T4: Revert value of C to 7
  - T2: No operation
  - T3: Re-write value of A to 9

Log Record Buffering

- Log records are buffered in memory before a block is output to the stable storage
- Records are flushed in the order of appearance in the log
- Force-writing is used to flush log records to stable storage before a transaction enters the commit point
- The (commit, T) entry is also flushed
- Before a block of data is written to the database, all log records pertaining to it are flushed to stable storage
- This rule is called write-ahead logging or WAL rule

Shadow Paging

- Shadow database scheme
- Maintain two page tables: current page table and shadow page table
- Shadow page table is maintained on disk without any change



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  - Recovery is built-in
  - No overhead of writing log records