Database Reliability

Problem:

How to maintain

atomicity

durability

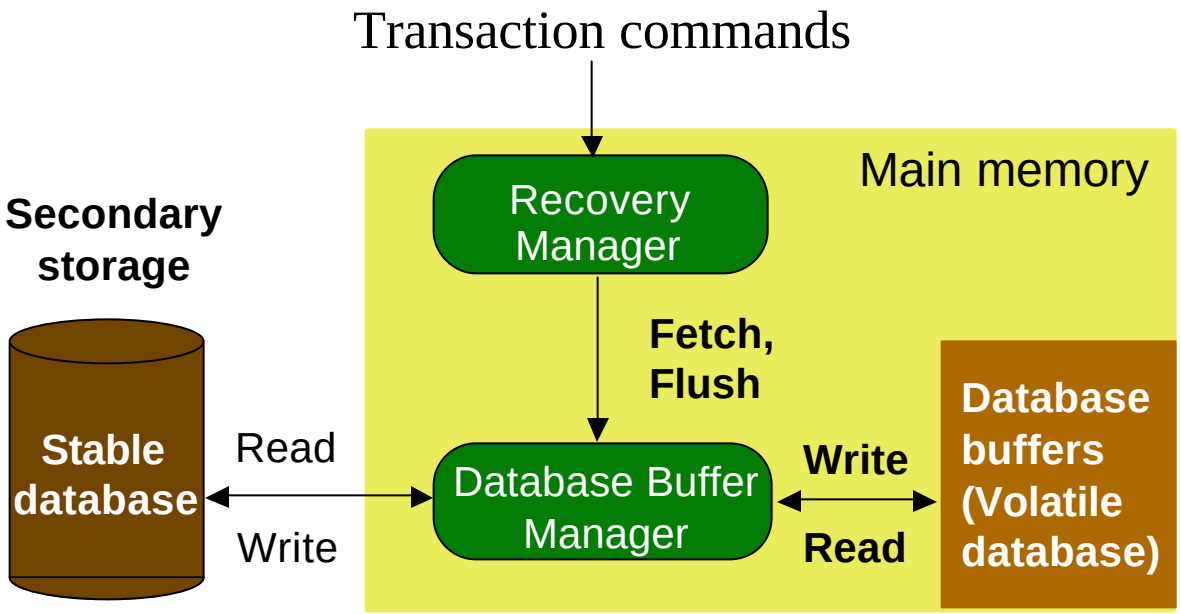
properties of transactions

Types of Failures

- Transaction failures
  - Transaction aborts (unilaterally or due to deadlock)
  - Avg. 3% of transactions abort abnormally
- System (site) failures
  - Failure of processor, main memory, power supply, …
  - Main memory contents are lost, but secondary storage contents are safe
  - Partial vs. total failure
- Media failures
  - Failure of secondary storage devices such that the stored data is lost
  - Head crash/controller failure

Recovery Management -Architecture

- Volatile storage
  - Consists of the main memory of the computer system (RAM).
- Stable storage
  - Resilient to failures and loses its contents only in the presence of media failures (e.g., head crashes on disks).
  - Implemented via a combination of hardware (non-volatile storage) and software (stable-write, stable-read, clean-up) components.

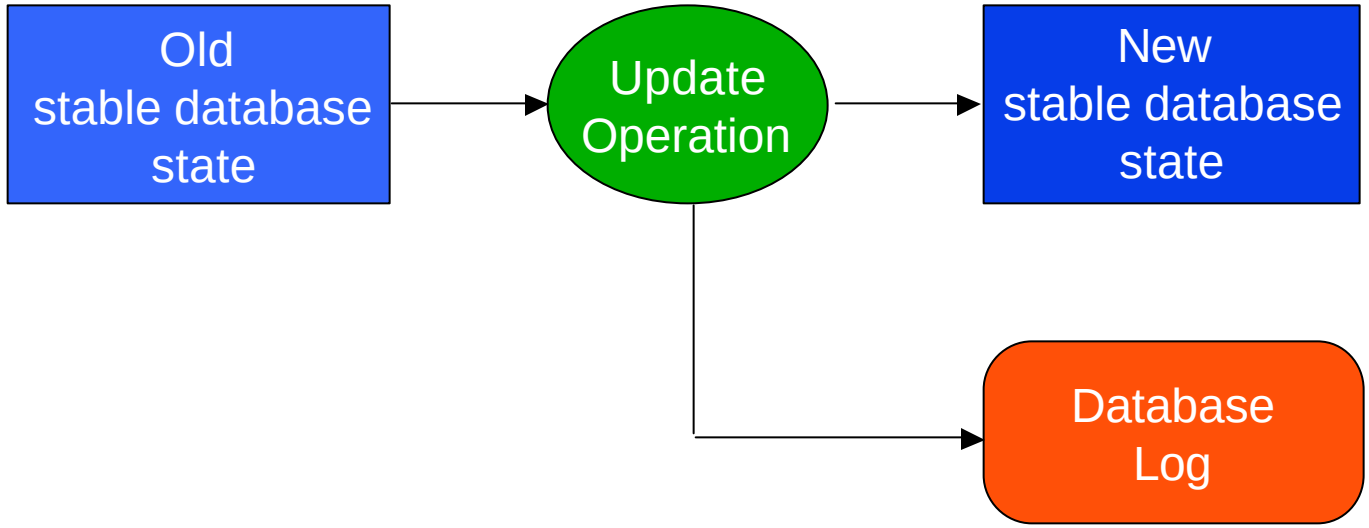


Update Strategies

- In-place update
  - Each update causes a change in one or more data values on pages in the database buffers
- Out-of-place update
  - Each update causes the new value(s) of data item(s) to be stored separate from the old value(s).
  - Shadowing
    - When an update occurs, don't change the old page, but create a shadow page with the new values and write it into the stable database.
    - Update the access paths so that subsequent accesses are to the new shadow page.
    - The old page retained for recovery.

In-Place Update – Database Log

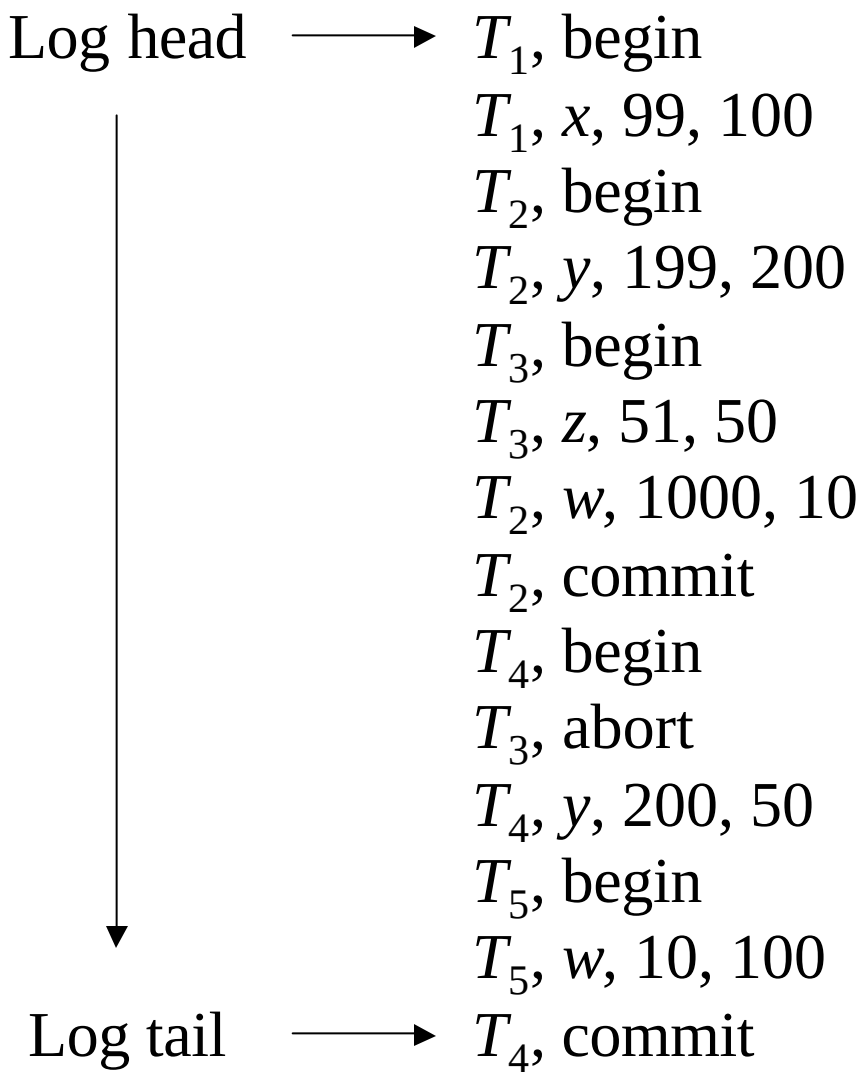
Every action of a transaction must not only perform the action, but must also write a *log* record to an append-only file.



Logging

- The log contains information used by the recovery process to restore the consistency of a system. This information may include
  - transaction identifier
  - type of operation (action)
  - items accessed by the transaction to perform the action
  - old value (state) of item (before image)
  - new value (state) of item (after image)
  - …

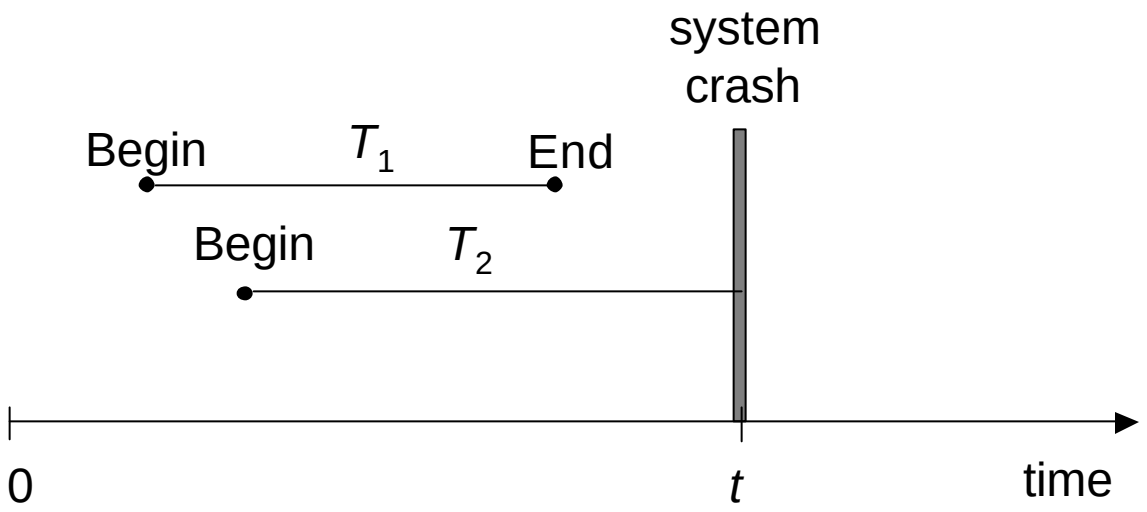
Log Example


Log head
T_1, begin
T_1, x, 99, 100
T_2, begin
T_2, y, 199, 200
T_3, begin
T_3, z, 51, 50
T_2, w, 1000, 10
T_2, commit
T_4, begin
T_3, abort
T_4, y, 200, 50
T_5, begin
T_5, w, 10, 100
Log tail
T_4, commit

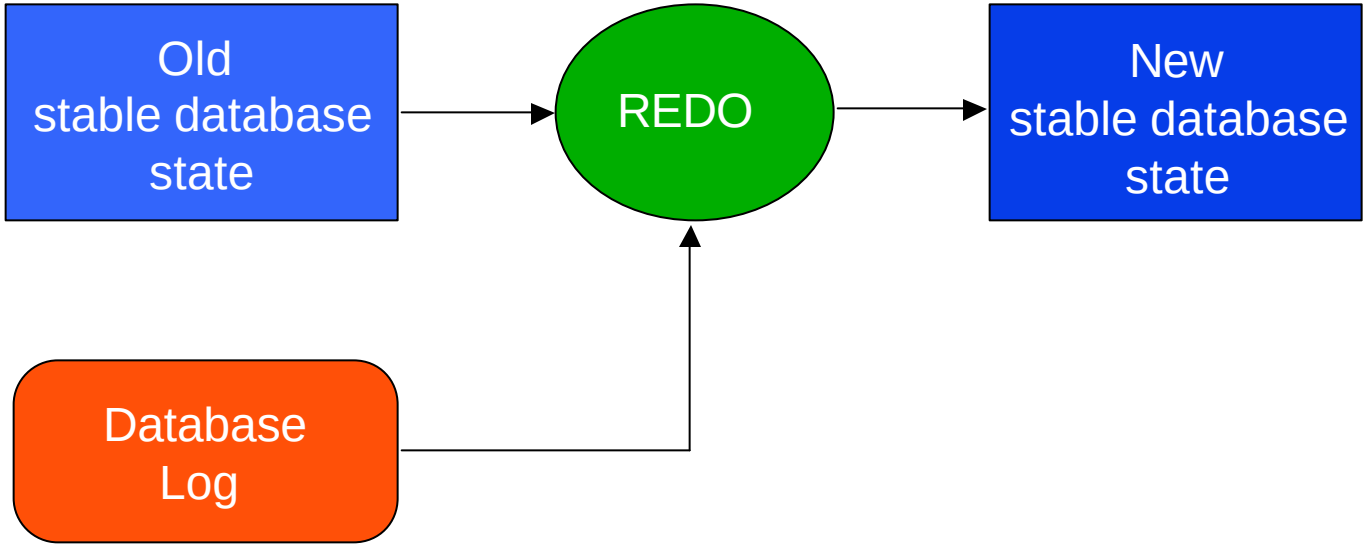
Why Logging?

Upon recovery:

- all of T_1's effects should be reflected in the database (REDO if necessary due to a failure)
- none of T_2's effects should be reflected in the database (UNDO if necessary)

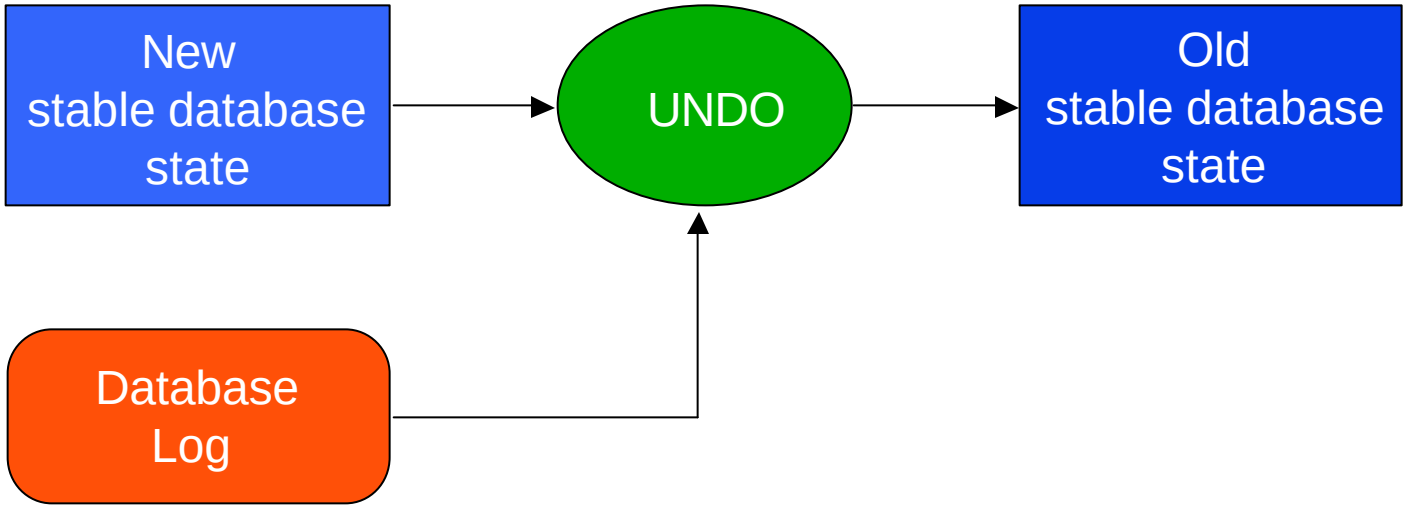


REDO Protocol



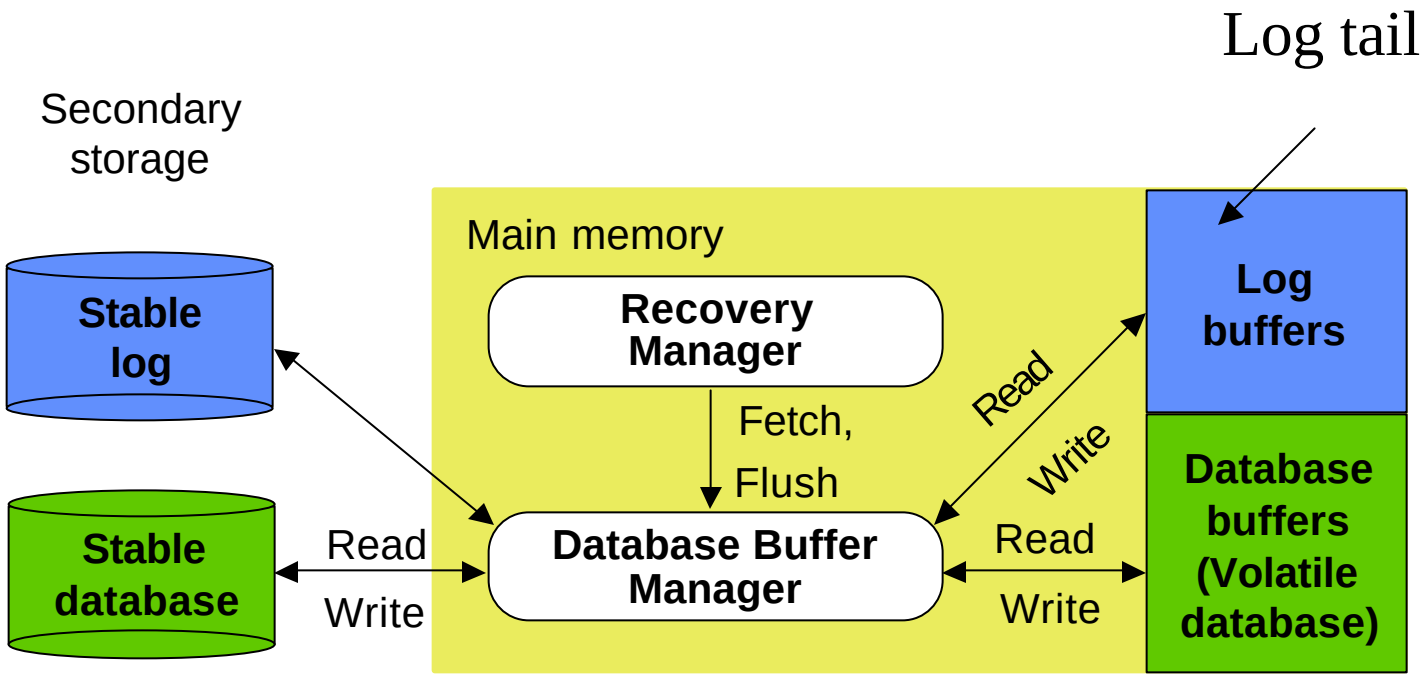
- REDO'ing an action means performing it again.
- The REDO operation uses the log information and performs the action that might have already executed or interrupted due to failures.
- The REDO operation generates the new image.

UNDO Protocol



- UNDO'ing an action means to restore the object to its before image.
- The UNDO operation uses the log information and restores the old value of the object.

Logging Interface



When to Write Log Records Into Stable Store?

Assume a transaction *T* updates a page *P*

- Fortunate case
  - System writes *P* in stable database
  - System updates stable log for this update
  - SYSTEM FAILURE OCCURS!... (before *T* commits)

  We can recover (undo) by restoring *P* to its old state by using the log
- Unfortunate case
  - System writes *P* in stable database
  - SYSTEM FAILURE OCCURS!... (before stable log is updated)

  We cannot recover from this failure because there is no log record to restore the old value.
- Solution: Write-Ahead Log (WAL) protocol

Write–Ahead Log Protocol

- Notice:
  - If a system crashes before a transaction is committed, then all the operations must be undone. Only need the before images (*undo portion* of the log).
  - Once a transaction is committed, some of its actions might have to be redone. Need the after images (*redo portion* of the log).
- WAL protocol :
  1. Before a stable database is updated, the undo portion of the log should be written to the stable log
  2. When a transaction commits, the redo portion of the log must be written to stable log prior to the updating of the stable database.

Recovery Manager/Buffer Manager Interaction

- Can the Buffer Manager (BM) decide to write some of the buffer pages being accessed by a transaction into stable storage or does it wait for Recovery Manager (RM) to instruct it?
  - steal/no-steal decision
  - no-steal means RM “pins” (or “fixes”) pages in the buffer
- Does the RM force the BM to write certain buffer pages into stable database at the end of a transaction's execution?
  - force/no-force decision
- Possible execution strategies:
  - steal/no-force
  - steal/force
  - no-steal/no-force
  - no-steal/force

Steal/No-Force

- Abort
  - BM may have written some of the updated pages into stable database
  - RM performs transaction undo (or partial undo)
- Commit
  - RM writes an “commit” record into the log.
- Recover
  - For those transactions that have both a “begin” and an “commit” record in the log, a partial redo is initiated by RM
  - For those transactions that only have a “begin” record in the log, a global undo is executed by RM

Steal/Force

- Abort
  - BM may have written some of the updated pages into stable database
  - RM performs transaction undo (or partial undo)
- Commit
  - RM issues a `flush` command to the buffer manager for all updated pages
  - RM writes a “commit” record into the log.
- Recover
  - No need to perform redo
  - Perform global undo

No-Steal/No-Force

- Abort
  - None of the updated pages have been written into stable database
  - Release the `fix`ed pages
- Commit
  - RM writes a “commit” record into the log.
  - RM sends an `unpin` command to the BM for all pages that were previously `pin`ned
- Recover
  - Perform partial redo
  - No need to perform global undo

No-Steal/Force

- Abort
  - None of the updated pages have been written into stable database
  - Release the `fix`ed pages
- Commit (the following have to be done atomically)
  - RM issues a `flush` command to the BM for all updated pages
  - RM sends an `unfix` command to the BM for all pages that were previously `fix`ed
  - RM writes a “commit” record into the log.
- Recover
  - No need to do anything if page level locking is used
  - May have to undo if finer locking is used

Checkpoints

- Shortens the amount of log that need to be undone or redone when a failure occurs.
- A checkpoint record contains a list of active transactions.
- Steps:
  1. Write a begin_checkpoint record into the log
  2. Collect the checkpoint data into the stable storage
  3. Write an end_checkpoint record into the log

Media Failures – Full Architecture