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Lecture 6: Logging (Part 2)

CREATING THE NEXT®

Today's Agenda

Recap

Crash Recovery

- Recovery algorithms are techniques to ensure database **consistency**, transaction **atomicity**, and **durability** despite failures.
- Recovery algorithms have **two parts**:
  - Actions during normal txn processing to ensure that the DBMS can recover from a failure.
  - Actions after a failure to recover the database to a state that ensures atomicity, consistency, and durability.

Failure Classification

- Type 1 – **Transaction Failures**
- Type 2 – **System Failures**
- Type 3 – **Storage Media Failures**

Undo vs. Redo

- **Undo:** The process of removing the effects of an incomplete or aborted txn.
- **Redo:** The process of re-instating the effects of a committed txn for durability.
- How the DBMS supports this functionality depends on how it manages the buffer pool…

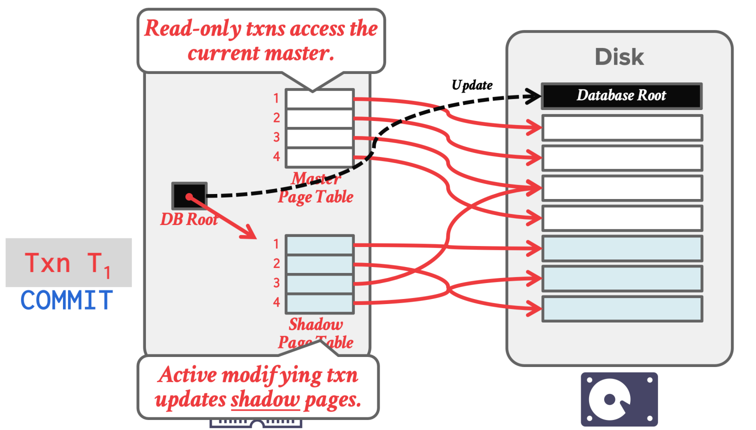
NO-STEAL + FORCE

- This approach is the easiest to implement:
  - Never have to undo changes of an aborted txn because the changes were not written to disk.
  - Never have to redo changes of a committed txn because all the changes are guaranteed to be written to disk at commit time (assuming atomic hardware writes).
- Cannot support **write sets** that exceed the amount of physical memory available.

Shadow Paging

- Maintain two separate copies of the database:
  - Master: Contains only changes from committed txns.
  - Shadow: Temporary database with changes made from uncommitted txns.
- Txns only make updates in the shadow copy.
- When a txn commits, atomically switch the shadow to become the new master.
- **Buffer Pool Policy:** NO-STEAL + FORCE

Shadow Paging – Example



Shadow Paging – Disadvantages

- Copying the entire page table is expensive:
  - Use a page table structured like a B+tree.
  - No need to copy entire tree, only need to copy paths in the tree that lead to updated leaf nodes.
- Commit overhead is high:
  - Flush every updated page, page table, and root.
  - Data gets fragmented.
  - Need garbage collection.
  - Only supports one writer txn at a time or txns in a batch.

Observation

- Shadowing page requires the DBMS to perform writes to random non-contiguous pages on disk.
- We need a way for the DBMS convert random writes into sequential writes.

Write-Ahead Logging

Write-Ahead Logging (WAL) Protocol

- Maintain a **log file** separate from data files that contains the changes that txns make to **database**.
  - Assume that the log is on stable storage.
  - Log contains enough information to perform the necessary undo and redo actions to restore the database.

WAL Protocol

- DBMS must write to disk the log file records that correspond to changes made to a database object **before** it can flush that object to disk.
- **Buffer Pool Policy:** STEAL + NO-FORCE
  - This **decouples** writing a transaction's dirty pages to database on disk from committing the transaction.
  - We only need to write its corresponding log records.
  - If a txn updates a 100 tuples stored in 100 pages, we only need to write 100 log records (which could be a few pages) instead of 100 dirty pages.

WAL Protocol

- The DBMS stages all a txn's log records in volatile storage (usually backed by buffer pool).
- All log records pertaining to an updated page are written to non-volatile storage before the page itself is over-written in non-volatile storage.
- A txn is not considered committed until all its log records have been written to stable storage.

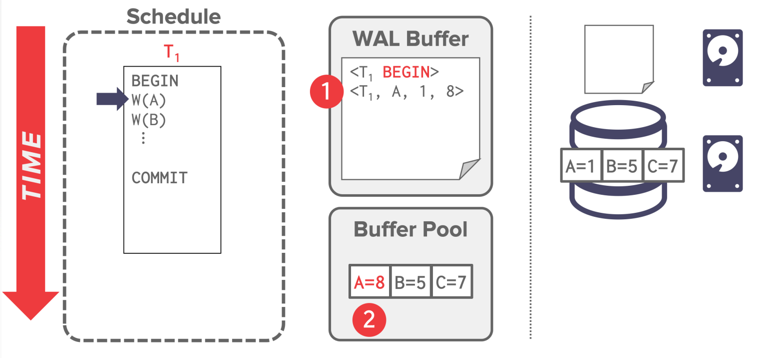
WAL Protocol

- Write a **<BEGIN>** record to the log for each txn to mark its starting point.
- When a txn finishes, the DBMS will:
  - Write a **<COMMIT>** record on the log
  - Make sure that all log records are flushed before it returns an acknowledgement to application.
  - This allows us to later **redo** the changes of the committed txns by replaying the log records.

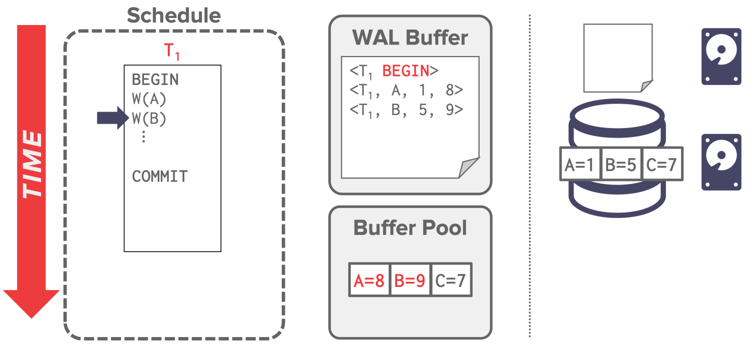
WAL Protocol

- Each log entry contains information about the change to a single object:
  - Transaction Id
  - Object Id
  - Before Value (UNDO)
  - After Value (REDO)

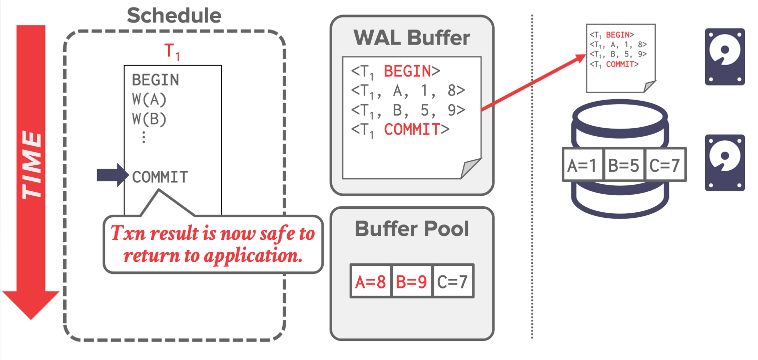
WAL – Example


Schedule
TIME
T1
BEGIN
W(A)
W(B)
⋮
COMMIT
WAL Buffer
<T1 BEGIN>
<T1, A, 1, 8>
1
Buffer Pool
A=8
B=5
C=7
2
A=1
B=5
C=7

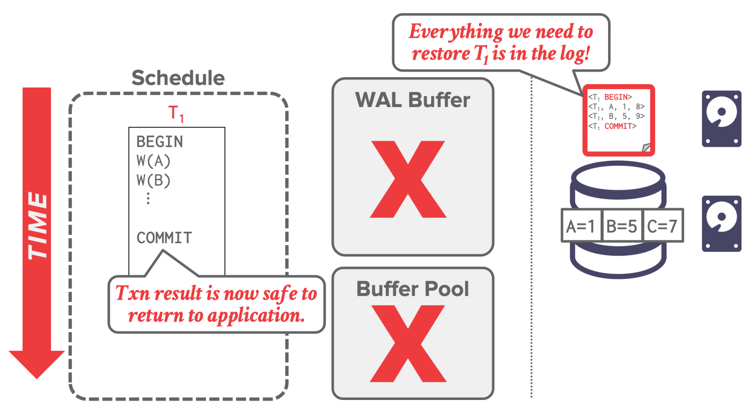
WAL – Example


Schedule
TIME
T1
BEGIN
W(A)
W(B)
⋮
COMMIT
WAL Buffer
<T1 BEGIN>
<T1, A, 1, 8>
<T1, B, 5, 9>
Buffer Pool
A=8 B=9 C=7
A=1 B=5 C=7

WAL – Example


Schedule
TIME
T_1
BEGIN
W(A)
W(B)
⋮
COMMIT
Txn result is now safe to return to application.
WAL Buffer
<T1 BEGIN>
<T1, A, 1, 8>
<T1, B, 5, 9>
<T1 COMMIT>
Buffer Pool
A=8 B=9 C=7
<T1 BEGIN>
<T1, A, 1, 8>
<T1, B, 5, 9>
<T1 COMMIT>
A=1 B=5 C=7

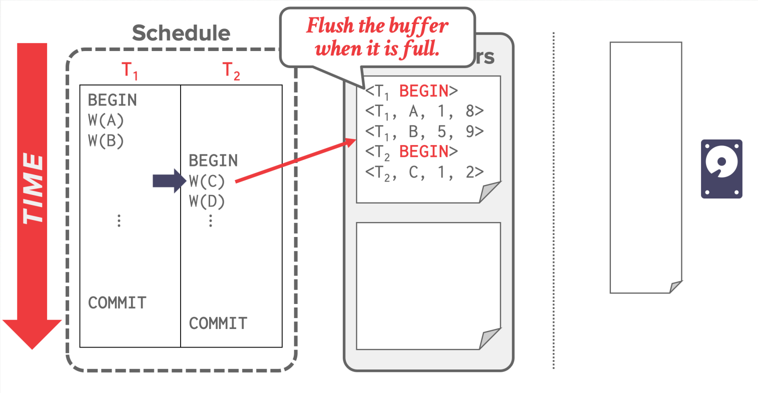
WAL – Example


Everything we need to restore T1 is in the log!
Schedule
T1
BEGIN
W(A)
W(B)
COMMIT
TIME
Txn result is now safe to return to application.
WAL Buffer
Buffer Pool
<T1 BEGIN>
<T1, A, 1, 8>
<T1, B, 5, 9>
<T1 COMMIT>
A=1
B=5
C=7

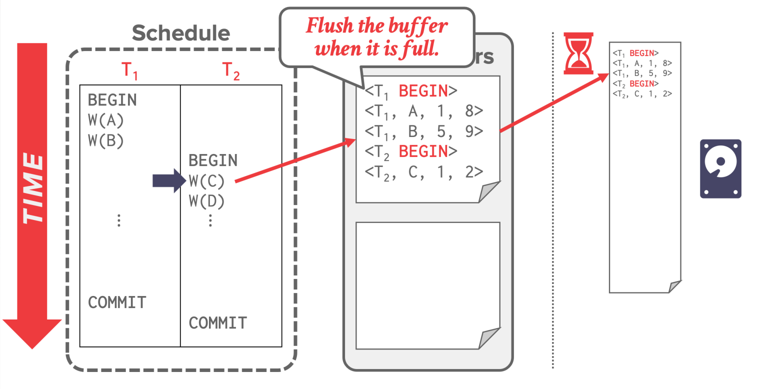
WAL – Implementation

- When should the DBMS write log entries to disk?
  - When the transaction commits.
  - Can use **group commit** to batch multiple log flushes together to amortize overhead.

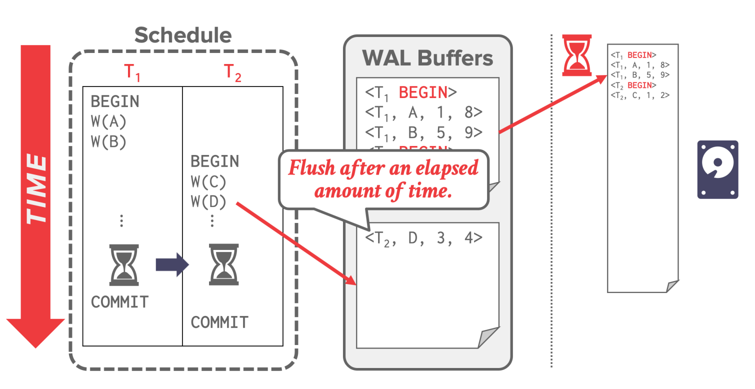
WAL – Group Commit



WAL – Group Commit



WAL – Group Commit



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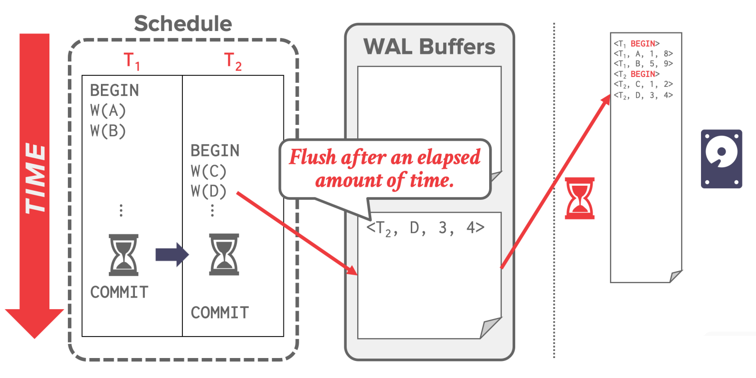
WAL – Group Commit

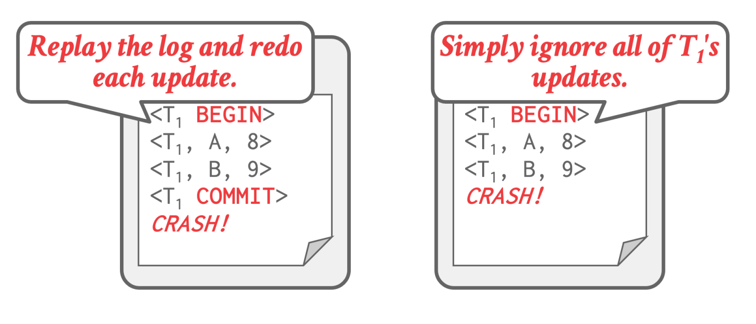


WAL – Implementation

- When should the DBMS write log entries to disk?
  - When the transaction commits.
  - Can use **group commit** to batch multiple log flushes together to amortize overhead.
- When should the DBMS write dirty records to disk?
  - Every time the txn executes an update?
  - Once when the txn commits?

WAL – Deferred Updates

- If we prevent the DBMS from writing dirty records to disk until the txn commits, then the DBMS does not need to store their original values.



WAL – Deferred Updates

- This won't work if the change set of a txn is larger than the amount of memory available.
- The DBMS cannot undo changes for an aborted txn if it doesn't have the original values in the log.
- We need to use the **STEAL** policy.

Buffer Pool Policies

- Almost every DBMS uses NO-FORCE + STEAL

Runtime Performance

	NO-STEAL	STEAL
NO-FORCE	–	Fastest
FORCE	Slowest	–

Recovery Performance

	NO-STEAL	STEAL
NO-FORCE	–	Slowest
FORCE	Fastest	–

Buffer Pool Policies

- Almost every DBMS uses NO-FORCE + STEAL

Runtime Performance

	NO-STEAL	STEAL
NO-FORCE	–	Fastest
FORCE	Slowest	–

Recovery Performance

	NO-STEAL	STEAL
NO-FORCE	–	Slowest
FORCE	Fastest	–

Undo + Redo

No Undo + No Redo

Logging Schemes

Logging Schemes

- **Physical Logging**
  - Record the changes made to a specific location in the database.
  - **Example:** git diff
- **Logical Logging**
  - Record the high-level operations executed by txns.
  - Not necessarily restricted to single page.
  - **Example:** The UPDATE, DELETE, and INSERT queries invoked by a txn.

Physical vs. Logical Logging

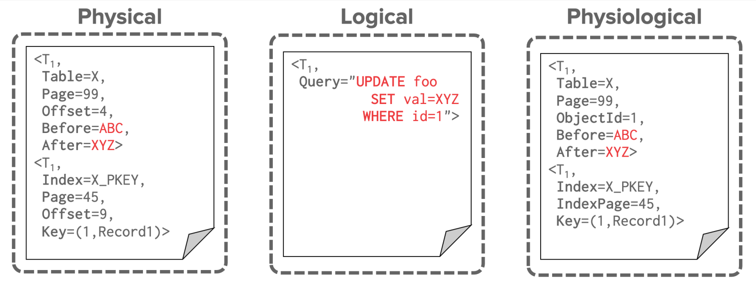
- Logical logging requires less data written in each log record than physical logging.
- Difficult to implement recovery with logical logging if you have concurrent txns.
  - Hard to determine which parts of the database may have been modified by a query before crash.
  - Also takes longer to recover because you must re-execute every txn all over again.

Physiological Logging

- Hybrid approach where log records target a single page but do **<u>not</u>** specify data organization of the page.
- This is the most popular approach.

Logging Schemes

UPDATE foo SET val = XYZ WHERE id = 1;



Log Flushing

- **Approach 1: All-at-Once Flushing**
  - Wait until a txn has fully committed before writing out log records to disk.
  - Do not need to store abort records because uncommitted changes are never written to disk.
- **Approach 2: Incremental Flushing**
  - Allow the DBMS to write a txn's log records to disk before it has committed.

Group Commit Optimization

- Batch together log records from multiple txns and flush them together with a single **fsync**.
  - Logs are flushed either after a timeout or when the buffer gets full.
  - Originally developed in IBM IMS FastPath in the 1980s
- This amortizes the cost of I/O over several txns.

Early Lock Release Optimization

- A txn's locks can be released **before** its commit record is written to disk if it does not return results to the client before becoming durable.
- Other txns that speculatively read data updated by a **pre-committed** txn become dependent on it and must wait for their predecessor's log records to reach disk.

Checkpoints

Checkpoints

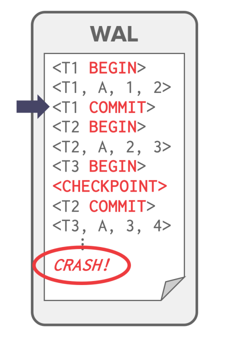
- The WAL will grow forever.
- After a crash, the DBMS has to replay the entire log which will take a long time.
- The DBMS periodically takes a **checkpoint** where it flushes all buffers out to disk.

Checkpoints

- Output onto stable storage all log records currently residing in main memory.
- Output to the disk all modified blocks.
- Write a **<CHECKPOINT>** entry to the log and flush to stable storage.

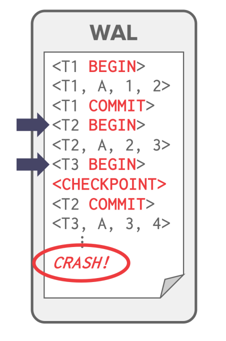
Checkpoints

- Any txn that committed before the checkpoint is ignored (T1).



Checkpoints

- T2 + T3 did not commit before the last checkpoint.
  - Need to redo T2 because it committed after checkpoint.
  - Need to undo T3 because it did not commit before the crash.



Checkpoints – Challenges

- We have to stall all txns when take a checkpoint to ensure a consistent snapshot.
- Scanning the log to find uncommitted txns can take a long time.
- Not obvious how often the DBMS should take a checkpoint...

Checkpoints – Frequency

- Checkpointing too often causes the runtime performance to degrade.
  - System spends too much time flushing buffers.
- But waiting a long time is just as bad:
  - The checkpoint will be large and slow.
  - Makes recovery time much longer.

Conclusion

Parting Thoughts

- Write-Ahead Logging is (almost) always the best approach to handle loss of volatile storage.
  - Use incremental updates (STEAL + NO-FORCE) with checkpoints.
  - On recovery: undo uncommitted txns + redo committed txns.

Next Class

- Recovery with ARIES protocol.