Georgia Tech

Lecture 5: Logging (Part I)

CREATING THE NEXT®

Today's Agenda

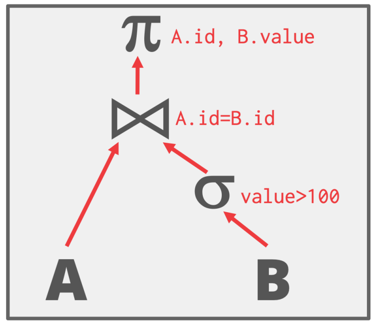
Georgia Tech

Recap

Query Plan

- The operators are arranged in a tree.
- Data flows from the leaves of the tree up towards the root.
- The output of the root node is the result of the query.

```
SELECT A.id, B.value
  FROM A, B
  WHERE A.id = B.id AND B.value > 100
```



Query Processing

- Access methods are the alternative ways for retrieving specific tuples
- Hashing is almost always better than sorting for operator execution.
- Caveats:
  - Sorting is better on non-uniform data.
  - Sorting is better when result needs to be sorted.
- Good DBMSs use either or both.

Process Models

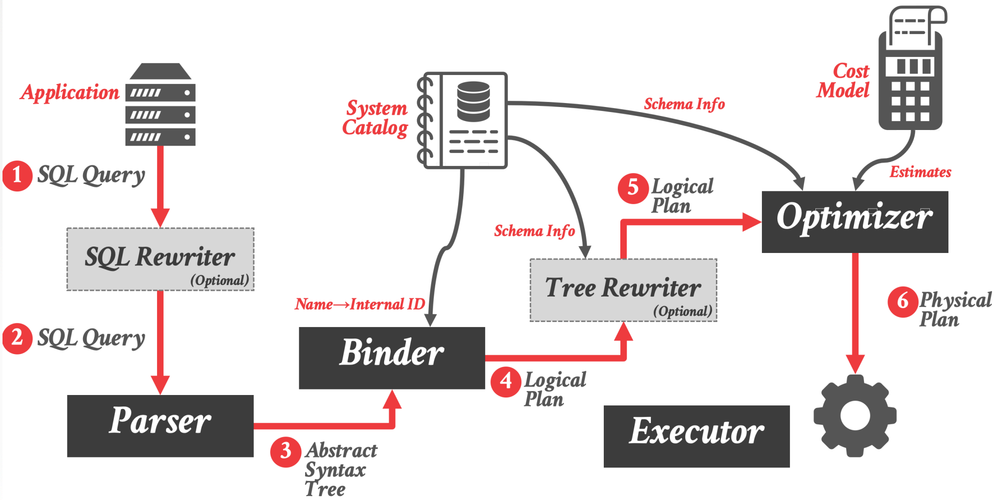
- The same query plan be executed in multiple ways.
- A DBMS's **processing model** defines how the system executes a query plan.
- (Most) DBMSs will want to use an index scan as much as possible.
- Parallel execution is important.
- (Almost) every DBMS supports this.
- This is really hard to get right.

Today's Agenda

- Motivation
- Failure Classification
- Buffer Pool Policies
- Shadow Paging

Motivation

Anatomy of a Database System [Monologue]



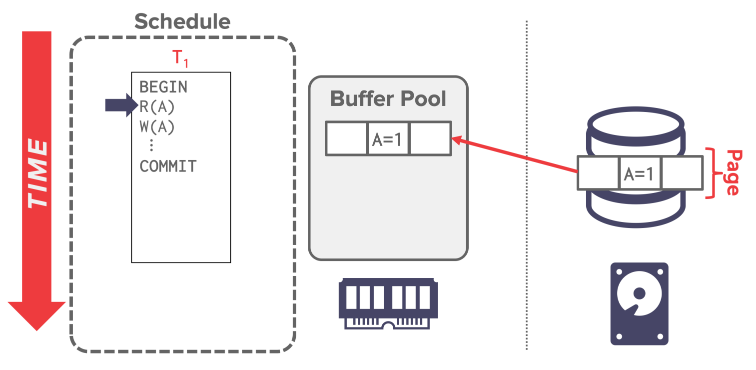
Anatomy of a Database System [Monologue]

- Process Manager
  - Manages client connections
- Query Processor
  - Parse, plan and execute queries on top of storage manager
- Transactional Storage Manager
  - Knits together buffer management, concurrency control, logging and recovery
- Shared Utilities
  - Manage hardware resources across threads

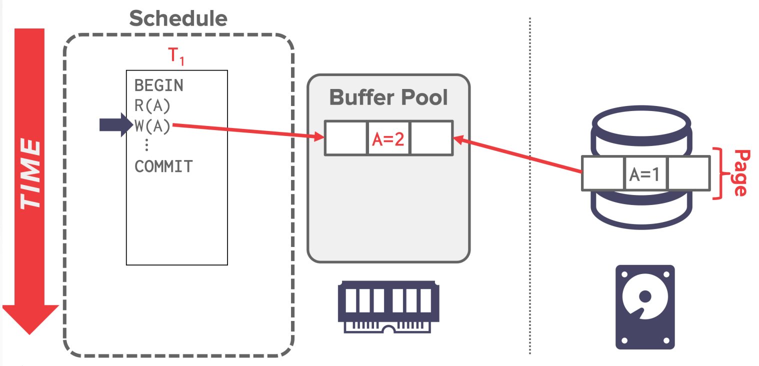
Anatomy of a Database System [Monologue]

- Process Manager
  - Connection Manager + Admission Control
- Query Processor
  - Query Parser
  - Query Optimizer (*a.k.a.*, Query Planner)
  - Query Executor
- Transactional Storage Manager
  - Lock Manager
  - Access Methods (*a.k.a.*, Indexes)
  - Buffer Pool Manager
  - Log Manager
- Shared Utilities
  - Memory, Disk, and Networking Manager

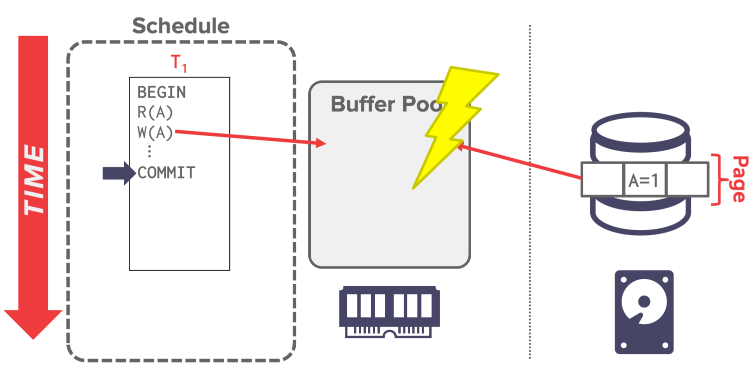
Motivation



Motivation



Motivation



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

Crash Recovery

- DBMS is divided into different components based on the underlying storage device.
- We must also classify the different **types of failures** that the DBMS needs to handle.

Storage Types

- **Volatile Storage**
  - Data does not persist after power loss or program exit.
  - Examples: DRAM, SRAM
- **Non-volatile Storage**
  - Data persists after power loss and program exit.
  - Examples: HDD, SDD
- **Stable Storage**
  - A non-existent form of non-volatile storage that survives all possible failures scenarios.
  - Approximated using a collection of storage devices.

Failure Classification

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

Transaction Failures

- **Logical Errors:**
  - Transaction cannot complete due to some internal error condition (*e.g.*, integrity constraint violation).
- **Internal State Errors:**
  - DBMS must terminate an active transaction due to an error condition (*e.g.*, deadlock).

System Failures

- **Software Failure:**
  - Problem with the DBMS implementation (*e.g.*, uncaught divide-by-zero exception).
- **Hardware Failure:**
  - The computer hosting the DBMS crashes (*e.g.*, power plug gets pulled).
  - **Fail-stop Assumption:** Non-volatile storage contents are assumed to not be corrupted by system crash.

Storage Media Failure

- **Non-Repairable Hardware Failure:**
  - A head crash or similar disk failure destroys all or part of non-volatile storage.
  - Destruction is assumed to be detectable (*e.g.*, disk controller use checksums to detect failures).
- No DBMS can recover from this! Database must be restored from archived version.

Observation

- The primary storage location of the database is on non-volatile storage, but this is much slower than volatile storage.
- Use volatile memory for faster access:
  - First copy target record into memory.
  - Perform the writes in memory.
  - Write dirty records back to disk.

Observation

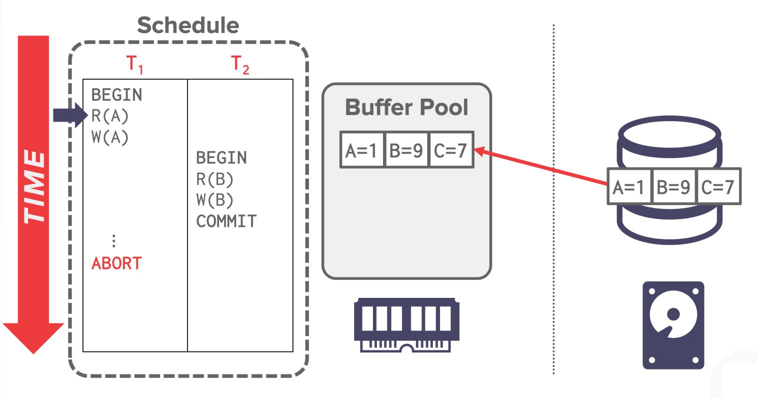
- The DBMS needs to ensure the following guarantees:
  - The changes for any txn are durable once the DBMS has told somebody that it committed.
  - No partial changes are durable if the txn aborted.

Buffer Pool Policies

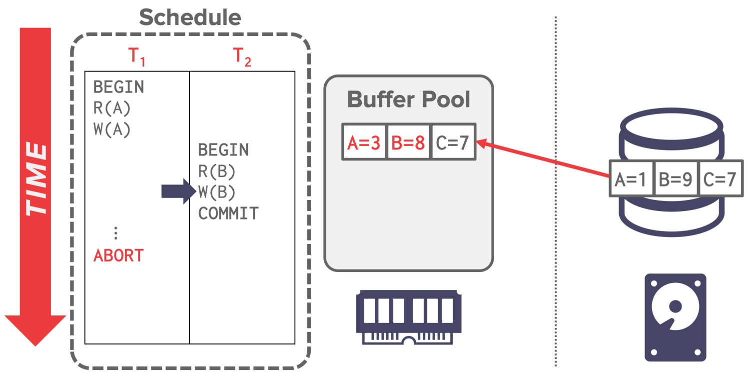
Undo vs. Redo

- **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...

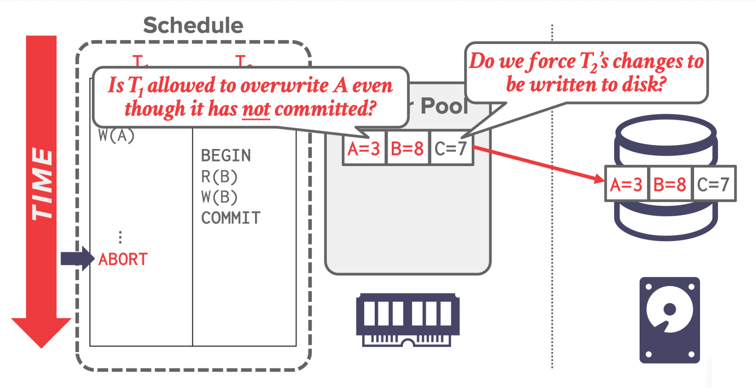
Buffer Pool


Schedule
TIME
T1
T2
BEGIN
R(A)
W(A)
ABORT
BEGIN
R(B)
W(B)
COMMIT
Buffer Pool
A=1
B=9
C=7
A=1
B=9
C=7

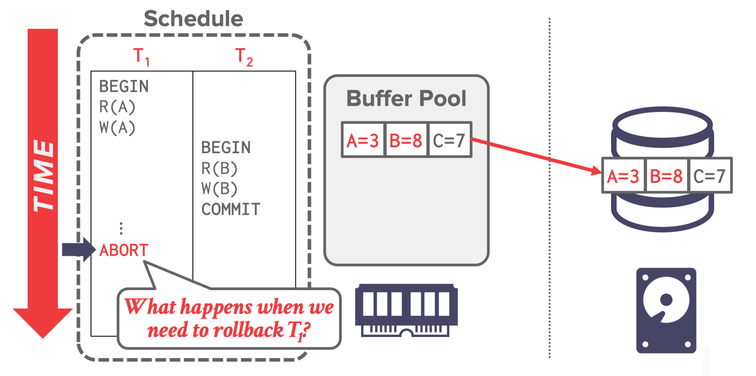
Buffer Pool


Schedule
TIME
T1
T2
BEGIN
R(A)
W(A)
BEGIN
R(B)
W(B)
COMMIT
ABORT
Buffer Pool
A=3
B=8
C=7
A=1
B=9
C=7

Buffer Pool


Schedule
TIME
W(A)
⋮
ABORT
BEGIN
R(B)
W(B)
COMMIT
Is T_1 allowed to overwrite A even though it has not committed?
Pool
A=3
B=8
C=7
Do we force T_2's changes to be written to disk?
A=3
B=8
C=7

Buffer Pool


Schedule
TIME
T1
T2
BEGIN
R(A)
W(A)
BEGIN
R(B)
W(B)
COMMIT
ABORT
What happens when we need to rollback T1?
Buffer Pool
A=3
B=8
C=7
A=3
B=8
C=7

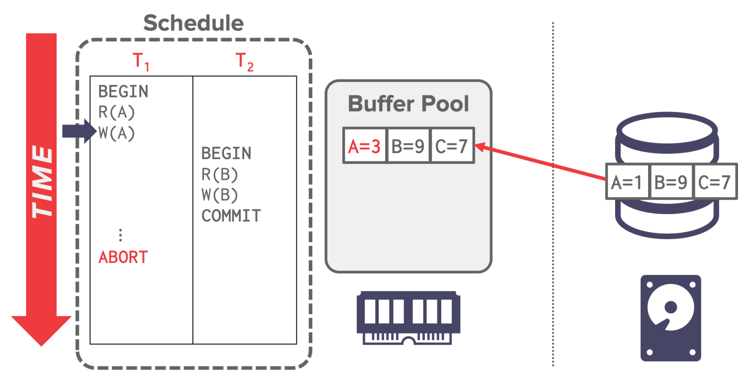
Steal Policy

- Whether the DBMS allows an uncommitted txn to overwrite the most recent committed value of an object in non-volatile storage.
- **STEAL:** Is allowed.
- **NO-STEAL:** Is **not** allowed.

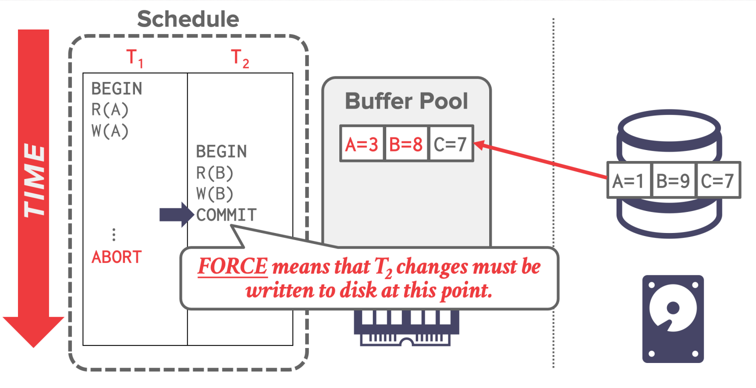
Force Policy

- Whether the DBMS requires that all updates made by a txn are reflected on non-volatile storage before the txn is allowed to commit.
- **FORCE:** Is required.
- **NO-FORCE:** Is **not** required.

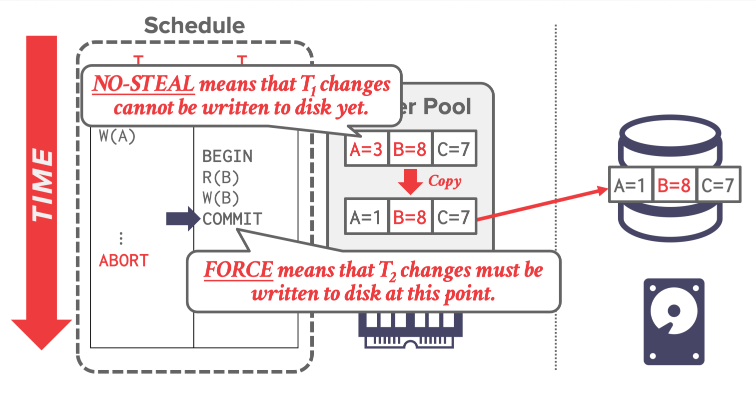
NO-STEAL + FORCE



NO-STEAL + FORCE

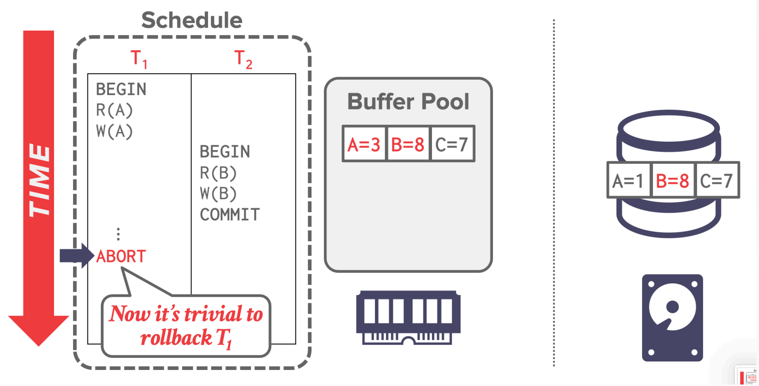


NO-STEAL + FORCE



Georgia Tech

NO-STEAL + FORCE



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).
- Previous example cannot support **write sets** that exceed the amount of physical memory available.

Shadow Paging

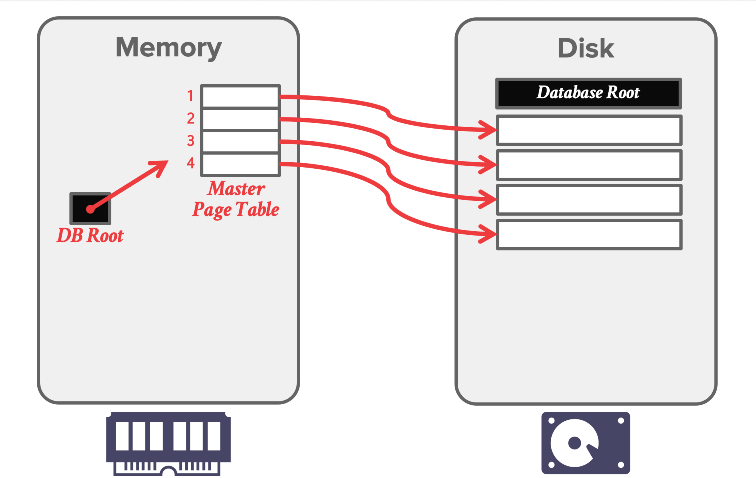
Shadow Paging

- 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

- Instead of copying the entire database, the DBMS copies pages on write.
- Organize the database pages in a tree structure where the root is a single disk page.
- There are two copies of the tree, the master and shadow
  - The root points to the master copy.
  - Updates are applied to the shadow copy.

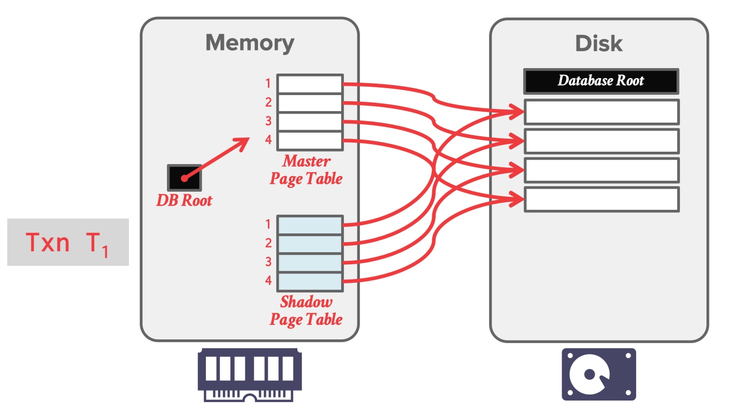
Shadow Paging – Example



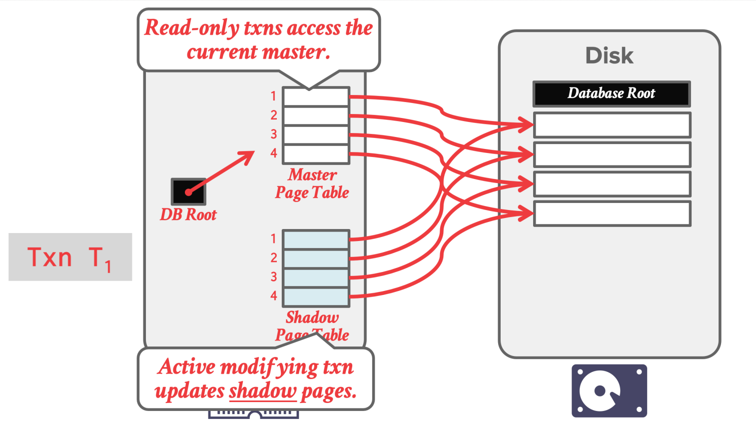
Shadow Paging

- To install the updates, overwrite the root so it points to the shadow, thereby swapping the master and shadow:
  - Before overwriting the root, none of the txn's updates are part of the disk-resident database
  - After overwriting the root, all the txn's updates are part of the disk-resident database.

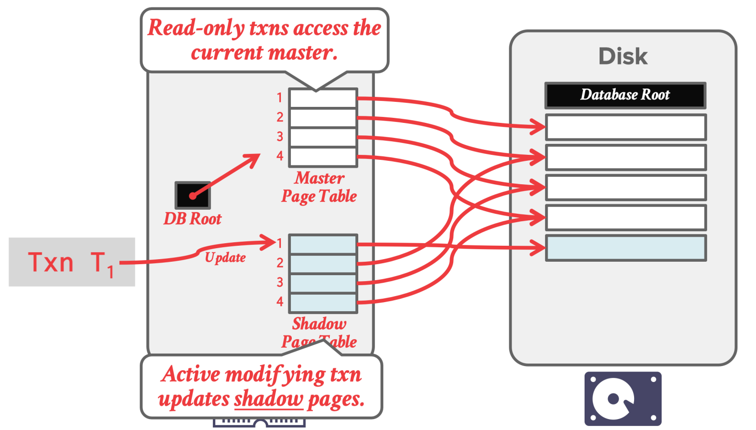
Shadow Paging – Example



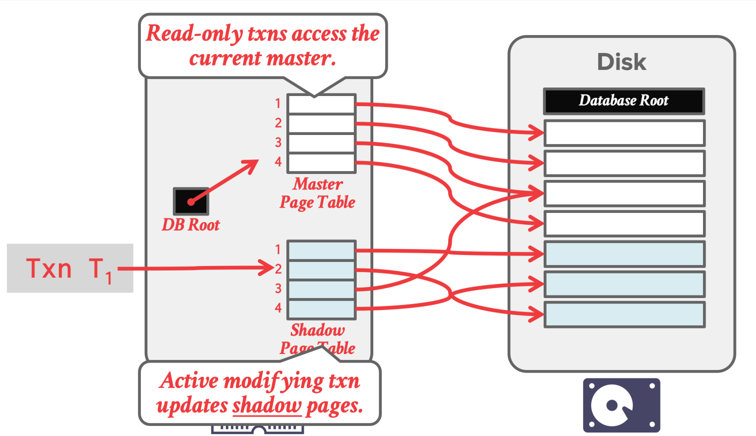
Shadow Paging – Example



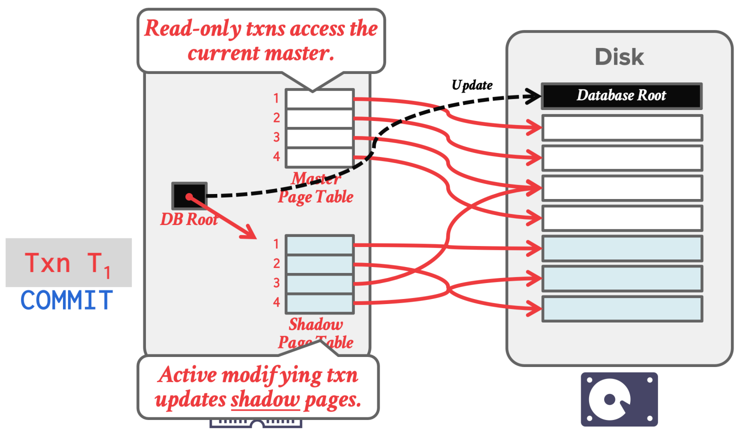
Shadow Paging – Example



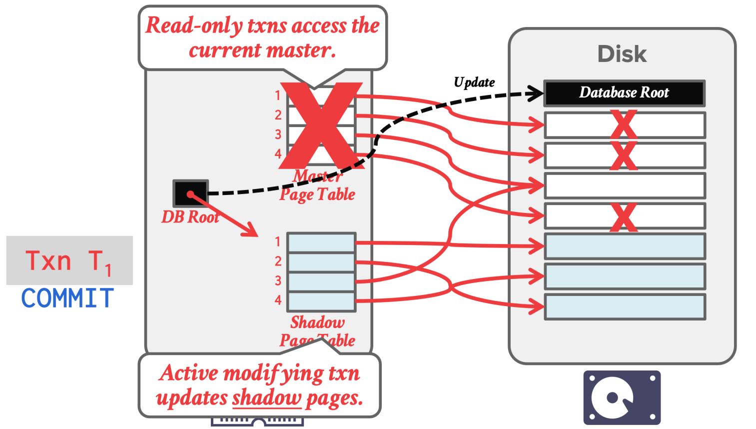
Shadow Paging – Example



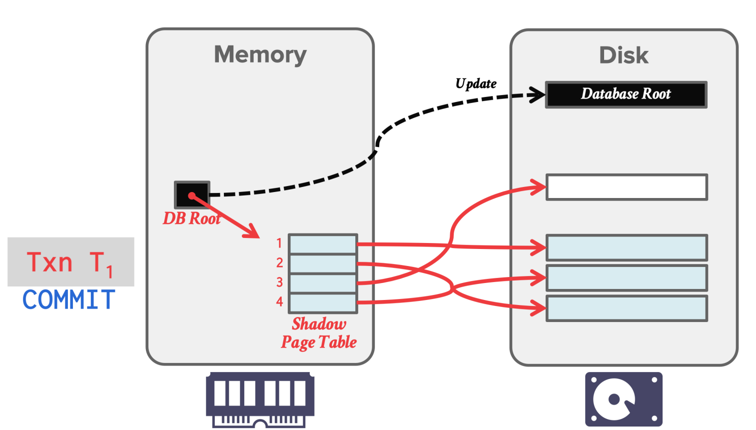
Shadow Paging – Example



Shadow Paging – Example



Shadow Paging – Example



Shadow Paging – Undo/Redo

- Supporting rollbacks and recovery is easy.
- **Undo:** Remove the shadow pages. Leave the master and the DB root pointer alone.
- **Redo:** Not needed at all.

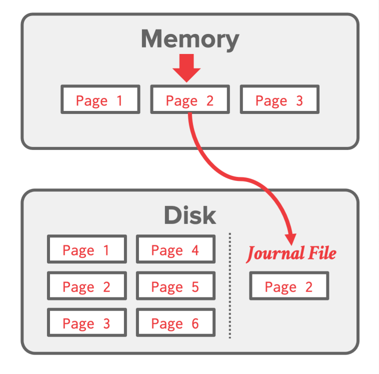
Shadow Paging – Disadvantages

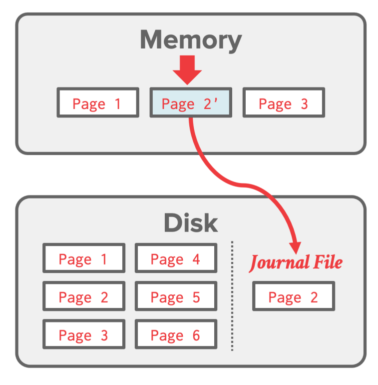
- Copying the entire page table is expensive:
  - Use a page table structured like a B+tree.
  - No need to copy entire tree, only need to copy paths in the tree that lead to updated leaf nodes.
- Commit overhead is high:
  - Flush every updated page, page table, and root.
  - Data gets fragmented.
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

SQLITE (PRE-2010)

- When a txn modifies a page, the DBMS copies the original page to a separate **journal file** before overwriting master version.
- After restarting, if a journal file exists, then the DBMS restores it to undo changes from uncommitted txns.

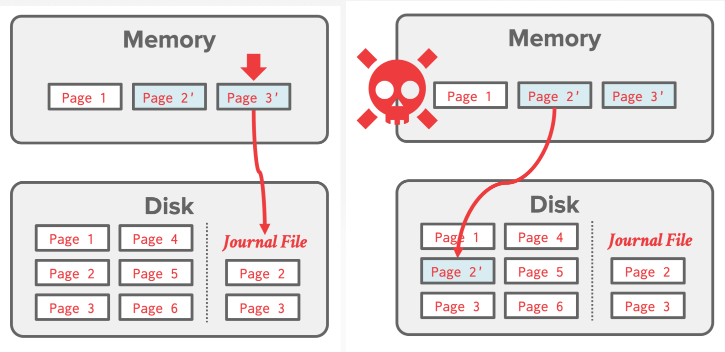
SQLITE (PRE-2010)



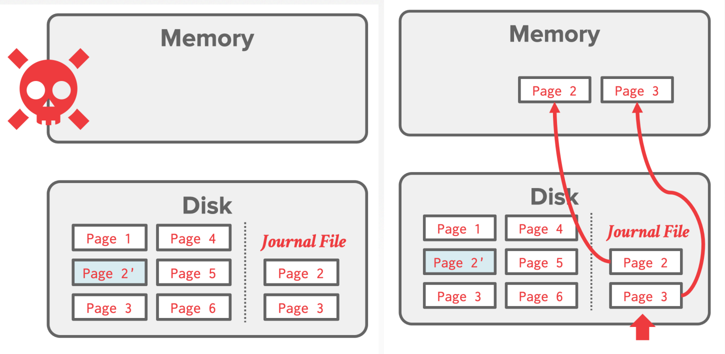


Georgia Tech

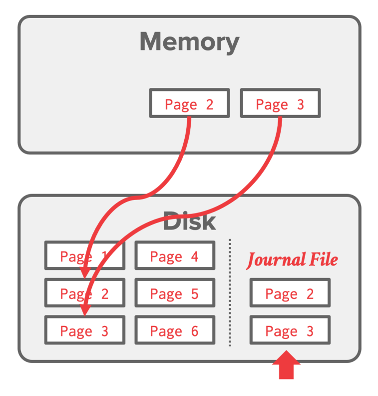
SQLITE (PRE-2010)



SQLITE (PRE-2010)



SQLITE (PRE-2010)



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.

Conclusion

Parting Thoughts

- 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.
- Three types of failures: transaction, system, and hardware failures
- Buffer policies: NO-STEAL + FORCE

Next Class

- Write Ahead Logging