Crash Recovery
Chapter 20

If you are going to be in the logging business, one of the things that you have to do is to learn about heavy equipment.

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Logging History of Columbia County

Review: The ACID properties
❖ Atomicity: All actions in the Xact happen, or none happen.
❖ Consistency: If each Xact is consistent, and the DB starts consistent, it ends up consistent.
❖ Isolation: Execution of one Xact is isolated from that of other Xacts.
❖ Durability: If a Xact commits, its effects persist.
❖ The Recovery Manager guarantees Atomicity & Durability.

Motivation
❖ Atomicity:
  – Transactions may abort ("Rollback").
❖ Durability:
  – What if DBMS stops running? (Causes?)
❖ Desired Behavior after system restarts:
  – T1, T2 & T3 should be durable.
  – T4 & T5 should be aborted (effects not seen).

Assumptions
❖ Concurrency control is in effect.
  – Strict 2PL, in particular.
❖ Updates are happening “in place”.
  – i.e. data is overwritten on (deleted from) the disk.
❖ A simple scheme to guarantee Atomicity & Durability?

Handling the Buffer Pool
❖ Force every write to disk?
  – Poor response time.
  – But provides durability.
❖ Steal buffer-pool frames from uncommitted Xacts?
  – If not, poor throughput.
  – If so, how can we ensure atomicity?

More on Steal and Force
❖ STEAL (why enforcing Atomicity is hard)
  – To steal frame F: Current page in F (say P) is written to disk; some Xact holds lock on P.
    • What if the Xact with the lock on P aborts?
    • Must remember the old value of P at steal time (to support UNDOing the write to page P).
❖ NO FORCE (why enforcing Durability is hard)
  – What if system crashes before a modified page is written to disk?
  – Write as little as possible, in a convenient place, at commit time, to support REDOing modifications.
Basic Idea: Logging

❖ Record REDO and UNDO information, for every update, in a log.
  – Sequential writes to log (put it on a separate disk).
  – Minimal info (diff) written to log, so multiple updates fit in a single log page.
❖ Log: An ordered list of REDO/UNDO actions
  – Log record contains:
    <XID, pageID, offset, length, old data, new data>
  – and additional control info (which we’ll see soon).

Write-Ahead Logging (WAL)

❖ The Write-Ahead Logging Protocol:
  1. Must force the log record for an update before the corresponding data page gets to disk.
  2. Must write all log records for a Xact before commit.
❖ #1 guarantees Atomicity.
❖ #2 guarantees Durability.
❖ Exactly how is logging (and recovery!) done?
  – We’ll study the ARIES algorithms.

WAL & the Log

❖ Each log record has a unique Log Sequence Number (LSN).
  – LSNs always increasing.
❖ Each data page contains a pageLSN.
  – The LSN of the most recent log record for an update to that page.
❖ System keeps track of flushedLSN.
  – The max LSN flushed so far.
❖ WAL: Before a page is written, pageLSN ≤ flushedLSN

Log Records

Possible log record types:
❖ Update
❖ Commit
❖ Abort
❖ End (signifies end of commit or abort)
❖ Compensation Log Records (CLRs)
  – for UNDO actions

Other Log-Related State

❖ Transaction Table:
  – One entry per active Xact.
  – Contains XID, status (running/committed/aborted), and lastLSN.
❖ Dirty Page Table:
  – One entry per dirty page in buffer pool.
  – Contains recLSN – the LSN of the log record which first caused the page to be dirty.

Normal Execution of an Xact

❖ Series of reads & writes, followed by commit or abort.
  – We will assume that write is atomic on disk.
    • In practice, additional details to deal with non-atomic writes.
❖ Strict 2PL.
❖ STEAL, NO-FORCE buffer management, with Write-Ahead Logging.
Checkpointing

- Periodically, the DBMS creates a checkpoint, in order to minimize the time taken to recover in the event of a system crash. Write to log:
  - begin_checkpoint record: Indicates when chkpt began.
  - end_checkpoint record: Contains current Xact table and dirty page table. This is a "fuzzy checkpoint":
    - Other Xacts continue to run, so these tables accurate only as of the time of the begin_checkpoint record.
    - No attempt to force dirty pages to disk; effectiveness of checkpoint limited by oldest unwritten change to a dirty page. (So it’s a good idea to periodically flush dirty pages to disk!)
  - Store LSN of chkpt record in a safe place (master record).

The Big Picture: What’s Stored Where

- Log
  - LogRecords
    - prevLSN
    - XID
    - length
    - offset
    - before-image
    - after-image
- DB
  - Data pages
    - each with a pageLSN
  - master record
- RAM
  - Dirty Page Table
    - recLSN
    - flushedLSN

Simple Transaction Abort

- For now, consider an explicit abort of a Xact.
  - No crash involved.
- We want to “play back” the log in reverse order, UNDOing updates.
  - Get lastLSN of Xact from Xact table.
  - Can follow chain of log records backward via the prevLSN field.
  - Before starting UNDO, write an Abort log record.
    - For recovering from crash during UNDO!

Abort, cont.

- To perform UNDO, must have a lock on data!
  - No problem!
- Before restoring old value of a page, write a CLR:
  - You continue logging while you UNDO!!
  - CLR has one extra field: undoneLSN
    - Points to the next LSN to undo (i.e. the prevLSN of the record we’re currently undoing).
  - CLRs never Undone (but they might be Redone when repeating history: guarantees Atomicity!)
- At end of UNDO, write an “end” log record.

Transaction Commit

- Write commit record to log.
- All log records up to Xact’s lastLSN are flushed.
  - Guarantees that flushedLSN ≥ lastLSN.
  - Note that log flushes are sequential, synchronous writes to disk.
  - Many log records per log page.
- Commit() returns.
- Write end record to log.

Crash Recovery: Big Picture

- Start from a checkpoint (found via master record).
- Three phases. Need to:
  - Figure out which Xacts committed since checkpoint, which failed (Analysis).
  - REDO all actions.
    - (repeat history)
  - UNDO effects of failed Xacts.
Recovery: The Analysis Phase

- Reconstruct state at checkpoint.
  - via end_checkpoint record.
- Scan log forward from checkpoint.
  - End record: Remove Xact from Xact table.
  - Other records: Add Xact to Xact table, set lastLSN=LSN, change Xact status on commit.
  - Update record: If P not in Dirty Page Table,
    - Add P to D.P.T., set its recLSN=LSN.

Recovery: The REDO Phase

- We repeat History to reconstruct state at crash:
  - Reapply all updates (even of aborted Xacts!), redo CLRs.
  - Scan from log rec containing smallest recLSN in D.P.T. For each CLR or update log rec LSN, REDO the action unless:
    - Affected page is not in the Dirty Page Table, or
    - Affected page is in D.P.T., but has recLSN > LSN, or
    - pageLSN (in DB) ≥ LSN.
  - To REDO an action:
    - Reapply logged action.
    - Set pageLSN to LSN. No additional logging!

Recovery: The UNDO Phase

ToUndo={ l | l a lastLSN of a “loser” Xact }

Repeat:
  - Choose largest LSN among ToUndo.
  - If this LSN is a CLR and undonextLSN==NULL
    - Write an End record for this Xact.
  - If this LSN is a CLR, and undonextLSN != NULL
    - Add undonextLSN to ToUndo
  - Else this LSN is an update. Undo the update, write a CLR, add prevLSN to ToUndo.

Until ToUndo is empty.

Example of Recovery

Additional Crash Issues

- What happens if system crashes during Analysis? During REDO?
- How do you limit the amount of work in REDO?
  - Flush asynchronously in the background.
  - Watch “hot spots”!
- How do you limit the amount of work in UNDO?
  - Avoid long-running Xacts.
Summary of Logging/Recovery

❖ Recovery Manager guarantees Atomicity & Durability.
❖ Use WAL to allow STEAL/NO-FORCE w/o sacrificing correctness.
❖ LSNs identify log records; linked into backwards chains per transaction (via prevLSN).
❖ pageLSN allows comparison of data page and log records.

Summary, Cont.

❖ Checkpointing: A quick way to limit the amount of log to scan on recovery.
❖ Recovery works in 3 phases:
  – Analysis: Forward from checkpoint.
  – Redo: Forward from oldest recLSN.
  – Undo: Backward from end to first LSN of oldest Xact alive at crash.
❖ Upon Undo, write CLRs.
❖ Redo “repeats history”: Simplifies the logic!