Crash Recovery

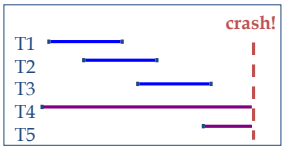
Chapter 18

Why Is This Important?

- Needed for achieving atomicity and durability
  - Need to abort transactions or restart them
  - Need to recover from crashes
- Crash recovery algorithms had major impact beyond databases
  - Algorithms are interesting in their own right
- Logging for crash recovery has significant impact on DBMS performance

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).



Handling the Buffer Pool

- Assumption: data on disk is durable
- Force every write to disk?
  - Poor response time.
  - But provides durability.
- Steal buffer-pool frames from uncommited Xacts?
  - If not, poor throughput.
  - If so, how can we ensure atomicity?

	No Steal	Steal
Force	Trivial	
No Force		Desired

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 page modified by a committed Xact is written to disk?
  - Write as little as possible, in a convenient place, at commit time, to support REDOing modifications.

Basic Idea: Logging

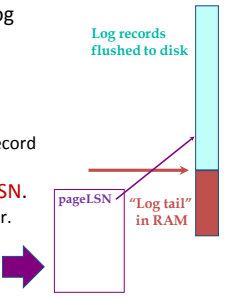
- Record REDO and UNDO information, for every update, in a log.
  - Write sequentially to log (put it on a separate disk).
  - Minimal info ("diff") written to log, so multiple updates fit in a single log page.
- Log: An ordered list of REDO/UNDO actions
  - Log record for update contains:
    - <XactID, 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:
  - Must force the log record for an update before the corresponding data page gets to disk.
    - Needed for atomicity
  - Must write all log records for a Xact before commit.
    - Needed for 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).
  - LSN is 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 to disk so far.
- WAL: Before a page is written,
  - pageLSN ≤ flushedLSN



Log Record Fields

- prevLSN: LSN of previous log record for the same transaction
- XactID: ID of transaction generating the log record
- type: Type of log record
- Update log records also contain
  - pageID: ID of modified page
  - length: number of bytes changed
  - offset: offset where change occurred
  - before-image: value of changed bytes before the change
  - after-image: value of changed bytes after the change

Actions Logged

- Page update
  - PageLSN set to LSN of log record
- Commit
  - Force-writes log record: appends record to log, flushes log up to this log record to stable storage
  - Xact is considered to have committed only after its commit log record is written to stable storage
- Abort
- End
  - Indicates that all additional steps required after writing a commit or abort log record are completed (e.g., undo of Xact)
- Undoing an update
  - Compensation log record (CLR), indicating that an action described by a log record is undone (important if database crashes again during recovery!)
  - Written just before the action is undone
  - Action described by CLR will never be undone, because decision to roll back Xact is final

Other Log-Related State

- Transaction Table:
  - One entry per active Xact.
  - Contains XactID, 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.
    - Earliest log record that might have to be redone for this page during restart from crash

Normal Execution of an Xact

- Series of reads and writes, followed by commit or abort.
  - We will assume that an individual 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 are 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 known safe place (master record).

The Big Picture: What's Stored Where

LogRecords
prevLSN
XactID
type
pageID
length
offset
before-image
after-image

Data pages
each
with a
pageLSN

master record

Xact Table
lastLSN
status

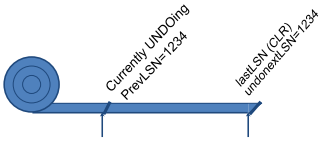
Dirty Page Table
recLSN

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.)

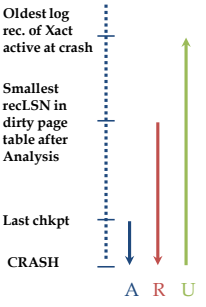


- To perform UNDO, must have a lock on data.
  - No problem!
- Before restoring old value of a page, write a CLR:
  - You continue logging while you UNDO!
  - CLR has one extra field: undoNextLSN
    - Points to the next LSN to undo (= the prevLSN of the record we're currently undoing).
  - CLRs never 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 and which failed since checkpoint (Analysis).
  - REDO all actions of committed Xacts.
  - UNDO effects of failed Xacts.

Recovery: The Analysis Phase

- Reconstruct state at latest checkpoint.
  - Get dirty page table and transaction table from end_checkpoint record.
- Scan log forward from begin_checkpoint.
  - End record: Remove Xact from Xact table.
  - Other records: Add new 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.
- After reaching end of log:
  - Know all Xacts that were active at time of crash
  - Know all dirty pages (maybe some false positives, but that's ok)
  - Know smallest recLSN of all dirty pages
    - That's where the REDO phase has to start

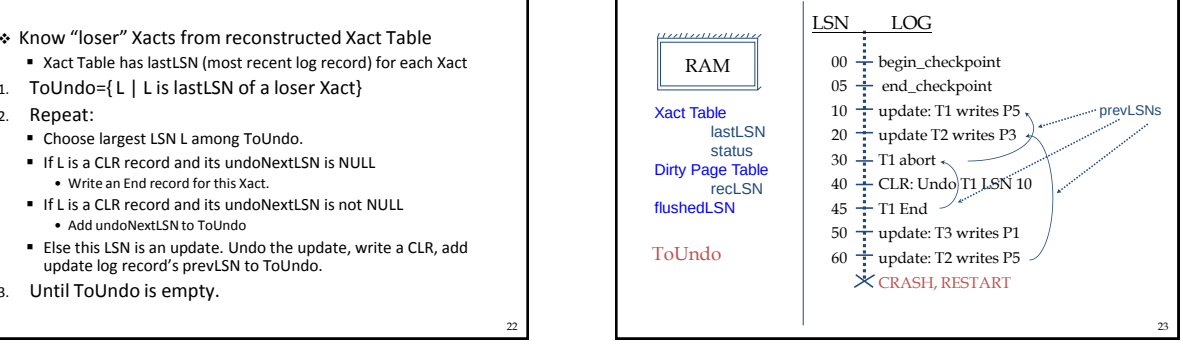
Recovery: The REDO Phase

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

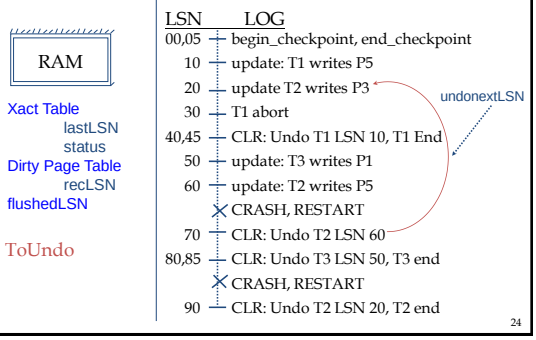
Recovery: The UNDO Phase

- Know "loser" Xacts from reconstructed Xact Table
  - Xact Table has lastLSN (most recent log record) for each Xact
1. ToUndo={ L | L is lastLSN of a loser Xact}
2. Repeat:
   - Choose largest LSN L among ToUndo.
   - If L is a CLR record and its undoNextLSN is NULL
     - Write an End record for this Xact.
   - If L is a CLR record and its undoNextLSN is not NULL
     - Add undoNextLSN to ToUndo
   - Else this LSN is an update. Undo the update, write a CLR, add update log record's prevLSN to ToUndo.
3. Until ToUndo is empty.

Example of Recovery



Example: Crash During Restart!



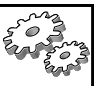
Additional Crash Issues

- Previous example showed crash during UNDO
- What happens if system crashes during Analysis?
  - Just start Analysis phase again
- What about crash during REDO?
  - Standard restart, but changes written to disk during partial REDO need not be performed again
- 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 and Durability.
- Use WAL to allow STEAL/NO-FORCE without 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 three phases:
  - Analysis: Forward from checkpoint.
  - Redo: Forward from oldest recLSN of dirty page.
  - Undo: Backward from log end to first LSN of oldest Xact alive at crash.
- Upon Undo, write CLRs.
- Redo "repeats history": Simplifies the logic!