CS 133: Databases

Fall 2019
Lec 19 – 11/14
Recovery
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Warm-up Exercise

(See exercise sheet. You can start before class.)

The page is evicted from buffer pool, so is flushed first

Goals for Today

- Consider the implications of the buffer manager's strategy for flushing pages on consistency
- Understand the role of the ***recovery manager*** in achieving xact Atomicity and Durability
- Reason about Write-Ahead-Logging and the ARIES recovery algorithm

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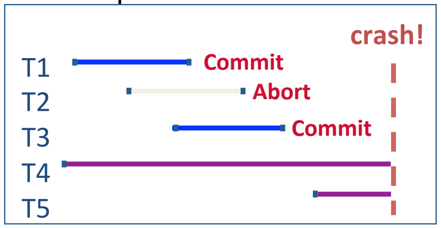
Review: The ACID properties

- 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.

Recovery Manager helps with Atomicity and Durability!

Recovery Manager: Motivation

- Atomicity:
  - Transactions may abort and “roll back” their changes.
- Durability:
  - What if DBMS stops running and data in memory is lost?
- Example:



Desired state after system restarts:

- **T1** & **T3** should be **durable**
- **T2**, **T4** & **T5** should be **aborted** (effects not seen)

Use a log of actions to help **UNDO** and **REDO** changes to data on disk

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Assumptions

- Concurrency control is in effect
  Strict 2PL, in particular
- Updates are happening “in place”
  - i.e., data is overwritten on (deleted from) the actual page copies (not private copies)
  - ***Writing a page to disk is atomic***
- Simple approach for atomicity and durability that requires no undoing or redoing (and thus no logging needed)?

Handling the Buffer Pool

- Force every write to disk at xact commit time?
  - Poor response time
  - But provides **durability**
- Steal buffer-pool frames from uncommitted xacts?
  - If not, hurts concurrency
  - If so, how can we ensure **atomicity**?

	No Steal	**Steal**
No Force		**Desired**
Force	**Easy!**	

Buffer Management Summary

	No Steal	**Steal**
No Force		**Fastest**
Force	**Slowest**	

Performance Implications

	No Steal	**Steal**
No Force		
Force		

Exercise 2

Logging/Recovery Implications

Buffer Management Summary

	No Steal	Steal
No Force		Fastest
Force	Slowest	

Performance Implications

	No Steal	Steal
No Force	No UNDO REDO	UNDO REDO
Force	No UNDO No REDO	UNDO No REDO

Logging/Recovery Implications

Preferred Policy: Steal/No-Force

- This combination is most complicated but allows for highest flexibility/performance
- NO FORCE (complicates enforcing Durability)
  - **Dirty pages *not forced to disk* when xact commits**
  - What if system crashes ***after*** a transaction commits but ***before*** a modified page written by that transaction makes it to disk?

REDO info: Write just the changes in a safe place at commit time, just in case need to redo those modifications.

Preferred Policy: Steal/No-Force

- STEAL (complicates enforcing Atomicity)
  - **Dirty pages could be written to disk before transaction commits or aborts**
  - What if transaction that performed updates aborts?
  - What if system crashes before transaction is finished?

UNDO info: just in case, remember the old value of a page to undo the changes

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Basic Idea: Logging

- Record REDO and UNDO information, for every update, in a ***log***.
- Log: An ordered list of REDO/UNDO actions
  - Log record contains:

    < xactID, pageID, offset, length, old data, new data >

    In our examples we'll simplify this to records like "*update: T1 writes P2*"
  - 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.

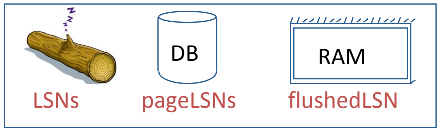
     UNDO → Atomicity despite STEAL

  2) Must force all log records for a Xact *before commit*. (transaction is not committed until all of its log records including its "commit" record are on the stable log.)

     REDO → Durability despite NO FORCE

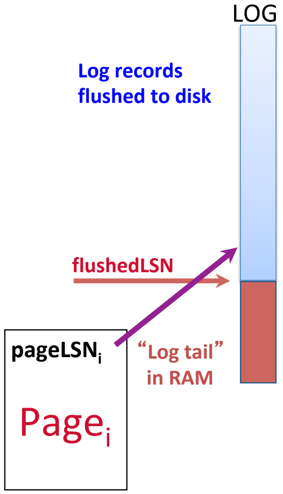
*We'll be looking at the **ARIES** algorithm from IBM*

WAL & the Log



- Each log record has a unique Sequence Number (LSN)
  - LSNs always increasing
- System keeps track of **flushedLSN**
  - max LSN flushed to stable log so far.
- Each *data page* contains a **pageLSN**.
  - The LSN of the most recent *log record* for an update to that page.
- WAL (rule 1): For a page *i* to be written, must flush log at least to the point where:

  $pageLSN_i <= flushedLSN$



Log Records

LogRecord fields:

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

for **update** records only: pageID, length, offset, before-image, after-image

prevLSN is the LSN of the previous log record written by *this xact*

the records for a xact form a linked list backwards in time

Possible log record types:

- Update, Commit, Abort
- End
  - After commit or abort
  - Bookkeeping only, means clean-up is finished
- Checkpoint (for log maintenance)
- Compensation Log Records (CLRs)
  - for UNDO actions

Other Log-Related State (in RAM)

- Transaction Table
  - One entry per currently active transaction
  - Entry removed when Xact ends (after commit or abort)

XactID	Status	lastLSN

Status: Running, Committing, or Aborting

lastLSN: Most recent update/CLR LSN written by this xact

- Dirty Page Table
  - One entry per dirty page currently in buffer pool
  - Entry removed when page flushed to disk

PageID	recLSN

recLSN: LSN of log record that **FIRST** dirtied this page

Exercise 3

(a)No. DPT thinks first LSN that dirtied page 5 was LSN 50

(b)Yup. Page 2 is not in dirty page table. It could have been flushed to disk due to STEAL policy

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Checkpointing

- Conceptually, keep log around for all time
  - this has performance/implementation issues…
- Periodically, the DBMS creates a checkpoint
  - Minimize time taken to recover if system crashes
  - Write to log:
    - **begin_checkpoint** record: Indicates when chkpt began.
    - **end_checkpoint** record: Contains current *Xact table* and *dirty page table*.
  - After end_checkpoint, log flushed
- Note: this is a **'fuzzy checkpoint'**:
  - Xacts continue to run; tables accurate only as of the time of the **begin_checkpoint** record.

After a system crash, will checkpoint entry always be last entry in log?

Store LSN of most recent checkpoint record in a safe place (*master* record).

Example Log: Normal Execution

Trans	lastLSN	Stat
T1	~~10~~20	~~R~~C
T2	~~30~~50	R

PageId	recLSN
P2	10
P4	20
P3	30

LSN	Log	prevLSN
10	**Update: T1 write P2**	null
20	**Update: T1 write P4**	10
30	**Update: T2 write P3**	null
40	**T1 commit**	20
50	**Update: T2 write P4**	30
60	**T1 end** (xact entry removed, not shown)	40

Log tail forced to disk on commit. Ensure **flushedLSN >= 40** (*WAL Rule #2*)

Assumptions: Strict 2PL, WAL, Steal/No-Force

Example Log: Normal Execution (cntd)

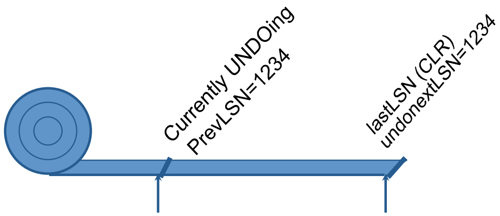
Trans	lastLSN	Stat
T1	~~10~~20	~~R~~C
T2	~~30~~~~50~~~~80~~ 90	~~R~~A

PageId	recLSN
P2	10
P4	20
P3	30

LSN	Log	prevLSN
10	**Update: T1 write P2**	null
20	**Update: T1 write P4**	10
30	**Update: T2 write P3**	null
40	**T1 commit**	20
50	**Update: T2 write P4**	30
60	**T1 end** (xact entry removed, not shown)	40
70	**T2 abort**	50
80	**CLR: Undo 50, UndoNext = 30**	70
90	**CLR: Undo 30, UndoNext = null**	80
100	**T2 end** (xact entry removed, not shown)	90

Must UNDO changes from T2 !

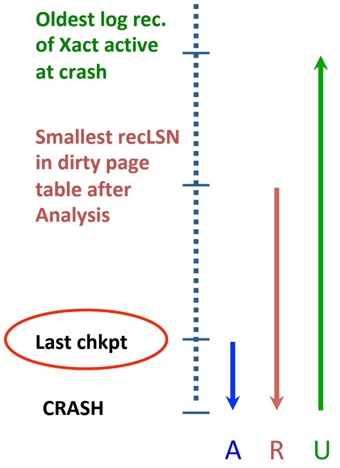
More on Abort



- To perform UNDO, must have a lock on data!
  - No problem (we're doing Strict 2PL)!
- *Before* restoring old value of a page, write a **compensation log record** (CLR):
  - CLR has one extra field: undoNextLSN
  - CLRs are *never* Undone (but they might be Redone when repeating history: guarantees Atomicity!)
- At end of UNDO, write an end log record

Continue logging while UNDOing

Crash Recovery: Big Picture



- Start from a checkpoint (on disk)
- Three phases:
  1. **Analysis** – Determine dirty pages and active xacts at time of crash → *updates* tables from checkpoint:
     - **XactTable**: which Xacts were active at time of crash.
     - **Dirty Page Table**: which pages *might* have been dirty in the buffer pool at time of crash.
  2. **REDO** ***all*** actions to restore state at time of crash
  3. **UNDO** effects of failed Xacts

Phase 1: Analysis Phase

- Re-establish knowledge of state at checkpoint
  - Via Xact table and Dirty Page Table stored in the checkpoint
- Scan log forward from checkpoint:
  - For **End** record: Remove Xact from Xact table.
  - For **Commit/Abort** records: update Xact status
  - All other records: Add Xact to Xact table, set lastLSN=LSN, Also, for **Update** records: If page P not in Dirty Page Table, Add P to DPT, set its recLSN=LSN
- At end of Analysis…
  - Transaction table has which xacts were active at time of crash.
  - Dirty page table has which dirty pages *might not* be on disk

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Phase 2: 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 containing smallest recLSN in dirty pages table
- For each redoable log record (update or CLR) with a given 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 (on actual page in DB) > LSN. (this last case requires I/O)
- To REDO an action:
  - Reapply logged action.
  - Set pageLSN to LSN. No additional logging, no forcing

Phase 3: The UNDO Phase

ToUndo= {lastLSNs of all Xacts in the Trans Table}

Repeat:

- Choose (and remove) 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. Write a CLR, undo the update,, add prevLSN to ToUndo.

Until ToUndo is **empty**.

Exercise 4

(a)Xacts: T1, T3, T4, T5,
DPT: P5, P1, P3, P2

(b)Note: start REDO at LSN 40 (smallest in DPT)
so redo: 40, 50, 60, 90, 110, 130, 160, 180
(don’t need to redo 70 since Page 2’s recLSN > 70)