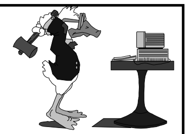


Crash Recovery

15-415 Spring 2003, Lecture 23
R &G - Chapter 18

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.

Robert VanNatta,
Logging History of Columbia County

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).
- **Can you think of a <u>simple</u> scheme (requiring no logging) to guarantee Atomicity & Durability?**
  – What happens during normal execution (what is the minimum lock granularity)?
  – What happens when a transaction commits?
  – What happens when a transaction aborts?

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.
- Question: which ones does the Recovery Manager help with?

Atomicity & Durability (and also used for Consistency-related rollbacks)

Buffer Mgmt Plays a Key Role

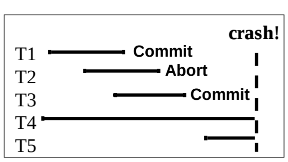
- **Force policy – make sure that every update is on disk before commit.**
  – Provides durability without REDO logging.
  – But, can cause poor performance.
- **No Steal policy – don't allow buffer-pool frames with <u>uncommited</u> updates to overwrite <u>committed</u> data on disk.**
  – Useful for ensuring atomicity without UNDO logging.
  – But can cause poor performance.

Of course, there are some nasty details for getting Force/NoSteal to work…

Motivation

- **Atomicity:**
  – Transactions may abort ("Rollback").
- **Durability:**
  – What if DBMS stops running? (Causes?)

❖ Desired state after system restarts:
– T1 & T3 should be durable.
– T2, T4 & T5 should be aborted (effects not seen).



Preferred Policy: Steal/No-Force

- This combination is most complicated but allows for highest performance.
- <u>NO FORCE</u> **(complicates enforcing Durability)**
  – What if system crashes before a modified page written by a committed transaction makes it to disk?
  – Write as little as possible, in a convenient place, at commit time, to support REDOing modifications.
- <u>STEAL</u> **(complicates enforcing Atomicity)**
  – What if the Xact that performed udpates aborts?
  – What if system crashes before Xact is finished?
  – Must remember the old value of P (to support UNDOing the write to page P).

Buffer Management summary

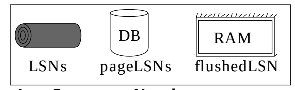
	No Steal	Steal
No Force		Fastest
Force	Slowest	

Performance Implications

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

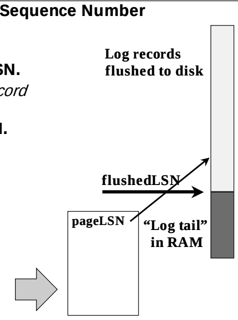
Logging / Recovery Implications

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: For a page i to be written must flush log at least to the point where:**

  $pageLSN_i \le flushedLSN$



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).

Log Records

LogRecord fields:

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

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

prevLSN is the LSN of the previous log record written by *this* Xact (so records of an Xact form a linked list backwards in time)

Possible log record types:

- Update, Commit, Abort
- Checkpoint **(for log maintenance)**
- **Compensation Log Records (CLRs)**
  - for UNDO actions
- End **(end of commit or abort)**

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 force all log records for a Xact *before commit*. (alt. transaction is not committed until all of its log records including its "commit" record are on the stable log.)
- **#1 (with UNDO info) helps guarantee Atomicity.**
- **#2 (with REDO info) helps guarantee Durability.**
- **This allows us to implement Steal/No-Force**

- **Exactly how is logging (and recovery!) done?**
  - We'll look at the ARIES algorithms from IBM.

Other Log-Related State

- **Two in-memory tables:**
- **Transaction Table**
  - One entry per currently active Xact.
    - entry removed when Xact commits or aborts
  - Contains XID, status (running/committing/aborting), and lastLSN (most recent LSN written by Xact).
- **Dirty Page Table:**
  - One entry per dirty page currently 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 disk write is atomic.
    - In practice, additional details to deal with non-atomic writes.
- **Strict 2PL.**
- **STEAL, NO-FORCE buffer management, with Write-Ahead Logging.**

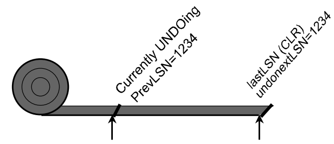
Transaction Commit

- **Write commit record to log.**
- **All log records up to Xact's commit record are flushed to disk.**
  - 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.**

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.
  - Write a "CLR" (compensation log record) for each undone operation.
  - Write an *Abort* log record before starting to rollback operations.

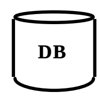
Abort, cont.



- **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 CLR:**
  - You continue logging while you UNDO!!
  - CLR has one extra field: undonextLSN
    - 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.**

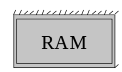
The Big Picture: What's Stored Where

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



Data pages
each with a pageLSN

master record
LSN of most recent checkpoint



Xact Table
lastLSN
status

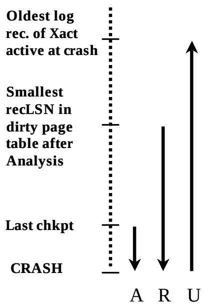
Dirty Page Table
recLSN

flushedLSN

Checkpointing

- **Conceptually, keep log around for all time. Obviously this has performance/implemenation problems...**
- **Periodically, the DBMS creates a <u>checkpoint</u>, 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.
  - Store LSN of most recent chkpt record in a safe place (*master* record).

Crash Recovery: Big Picture



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

Recovery: The Analysis Phase

- **Re-establish knowledge of state at checkpoint.**
  - via transaction table and dirty page table stored in the checkpoint
- **Scan log forward from checkpoint.**
  - End record: Remove Xact from Xact table.
  - All Other records: Add Xact to Xact table, set lastLSN=LSN, change Xact status on commit.
  - 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 says which xacts were active at time of crash.
  - DPT says which dirty pages *__might not__* have made it to disk

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 rec containing smallest recLSN in DPT.** Q: why start here?
- **For each update log record 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 (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. Undo the update, write a CLR, add prevLSN to ToUndo.

Until ToUndo is empty.

Example of Recovery

RAM

Xact Table
lastLSN
status
Dirty Page Table
recLSN
flushedLSN

ToUndo

LSN	LOG
00	begin_checkpoint
05	end_checkpoint
10	update: T1 writes P5
20	update T2 writes P3
30	T1 abort
40	CLR: Undo T1 LSN 10
45	T1 End
50	update: T3 writes P1
60	update: T2 writes P5
	CRASH, RESTART

prevLSNs

Example: Crash During Restart!

RAM

Xact Table
lastLSN
status
Dirty Page Table
recLSN
flushedLSN

ToUndo

LSN	LOG
00,05	begin_checkpoint, end_checkpoint
10	update: T1 writes P5
20	update T2 writes P3
30	T1 abort
40,45	CLR: Undo T1 LSN 10, T1 End
50	update: T3 writes P1
60	update: T2 writes P5
	CRASH, RESTART
70	CLR: Undo T2 LSN 60
80,85	CLR: Undo T3 LSN 50, T3 end
	CRASH, RESTART
90	CLR: Undo T2 LSN 20, T2 end

undonextLSN

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!**