Crash Recovery Method

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CS 3200

Lecture 11

Outline

- Overview of the recovery manager
  - Data structures used by the recovery manager
- Checkpointing
- Crash recovery
  - Write ahead logging
  - ARIES (Algorithm for recovery and isolation exploiting semantics)

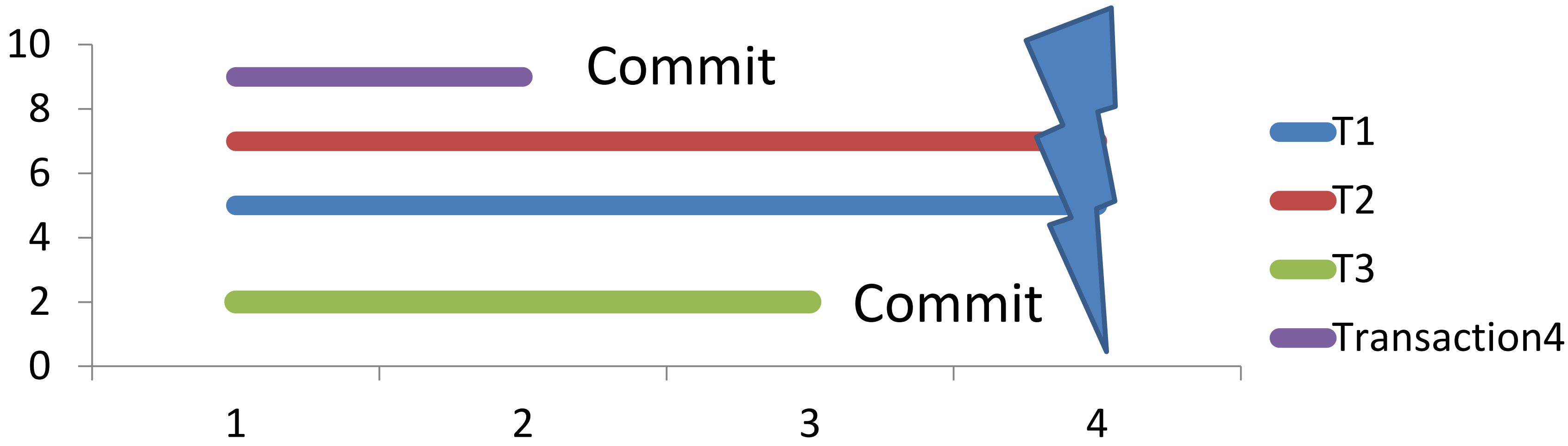
Review: ACID Properties

- **Atomicity**: either the entire set of operations happens or none of it does
- **Consistency**: the set of operations taken together should move the system for one consistent state to another consistent state.
- **Isolation**: each system perceives the system as if no other transactions were running concurrently (even though odds are there are other active transactions)
- **Durability**: results of a completed transaction must be permanent - even IF the system crashes

Recovery Manager

- Recovery manager ensures the ACID principles of atomicity and durability
  - Atomicity: either all actions are done or none
  - Durability: if a transaction is committed, changes persist within the database
- Desired behavior
  - keep actions of committed transactions
  - discard actions of uncommitted transactions

Keep the committed transactions



Throw away the active transactions work

- T3 and T4 actions should appear in the database
- T1 and T2 actions should not appear in the database

Challenges for the Recovery Manager

- Concurrency is in effect
  - Strict 2 phase locking
- Updates are happening in place
  - Overwrite of data
  - Deletion of records

Transaction

- 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
- Write-Ahead Logging

Handling of the buffer pool

- FORCE – every write to disk?
  - Poor performance (many writes clustered on same page)
  - At least this guarantees the persistence of the data
- STEAL – allow dirty pages to be written to disk?
  - If so, reading data from uncommitted transactions violates atomicity
  - If not, poor performance

	Force - every write to disk	**No Force – write when optimal**
Steal – use internal DB buffer for read		Desired but complicated
No Steal - always read only committed data	Easy but slow	

Complications from NO FORCE and STEAL

- NO FORCE
  - What if the system crashes before a modified page can be written to disk?
  - Write as little as possible to a convenient place at commit time to support **REDO**ing the data update
- STEAL
  - Current updated data can be flushed to disk but still locked by a transaction T1
    - What if T1 aborts?
    - Need to **UNDO** the data update done by T1

Solution: Logging

- Record REDO and UNDO information, for every update, in a *log.*
  - Sequential writes to log (put it on a separate disk).
  - Minimal information (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

Write-ahead Logging

- 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 transaction *before commit*.
  - #1 guarantees Atomicity.
  - #2 guarantees Durability.
- Example: ARIES algorithm.

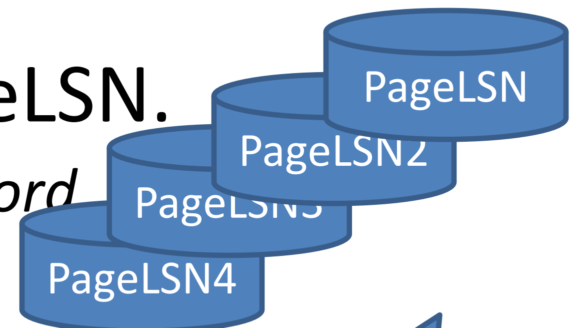
The Log

- Collection of records that represent the history of actions executed by the DBMS
  - Most recent portion of the log is called the log tail
  - Tail is in memory
  - Rest of the log stored of stable storage
- Actions recorded in the log:
  - Update a page
  - Commit
  - Abort
  - End
  - Undo an update

Sequencing events

- 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 maximum LSN flushed to disk.

- WAL: *Before* a page is written to disk LSN ≤ flushedLSN

Tracking operations with records

- Update a page
  - **UPDATE** record is appended to the log tail
  - Page LSN of the page is set to LSN of the update record
- Commit
  - **COMMIT** type record is appended to the log with transaction id
  - Log tail written to stable storage
- Abort
  - **ABORT** record is appended to the log with the transaction id
  - Undo is initiated for this transaction
- End
  - After all actions are finished to complete a transaction, an **END** record is appended to the log
- Undo an update
  - When a transaction is rolled-back, its updates are undone
  - When the 'undone' actions are complete a compensation log record or **CLR** is written

Data structures associated with the log

Log sequence record

- prevLSN (links actions)
- TransactionID
- Type of action
- Length of data
- pageID
- Offset on page
- Initial value
- Final Value

Update Action

Linking log to transactions

- **Transaction Table:**
  - One entry per active transaction
  - Contains Transaction ID, status (running/commited/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.

Log sequence numbers

- Every record in a log has a log sequence number to uniquely identify it **LSN**
- References to log sequence numbers in other records
  - Previous log sequence number **prevLSN**
    - Links together the log records for a transaction in the log record
  - Last sequence number **lastLSN**
    - Most recent log record for this transaction
  - Undo next sequence number **undonextLSN**
    - Found in a compensation log record (undo the operations associated with a transaction)
  - Page Log Sequence Number **pageLSN**
    - Stored in the database, one per page – it is the most recent log sequence number that changed the page
  - Recovery Log sequence Number **recLSN**
    - Stored in the dirty page table contains the first log record that caused this page to be dirty and be stored in the dirty page table

Example of Log, Dirty Page and Transaction Table

Transaction Table	
TRANSId	lastLSN
T1000	3
T2000	4

Dirty Page Table	
PageId	recLSN
P500	1
P600	2
P505	4

LOG								
LSN	Prev LSN	TRANS ID	type	pageId	length	offset	before	After
1	NULL	T1000	UPDATE	P500	3	21	ABC	DEF
2	NULL	T2000	UPDATE	P600	3	41	HIJ	KLM
3	2	T2000	UPDATE	P500	3	20	GDE	QRS
4	1	T1000	UPDATE	P505	3	21	TUV	WXY

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 transactions 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 checkpoint record in a safe place (*master* record).

Abort a transaction

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

UNDO

- 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 (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.

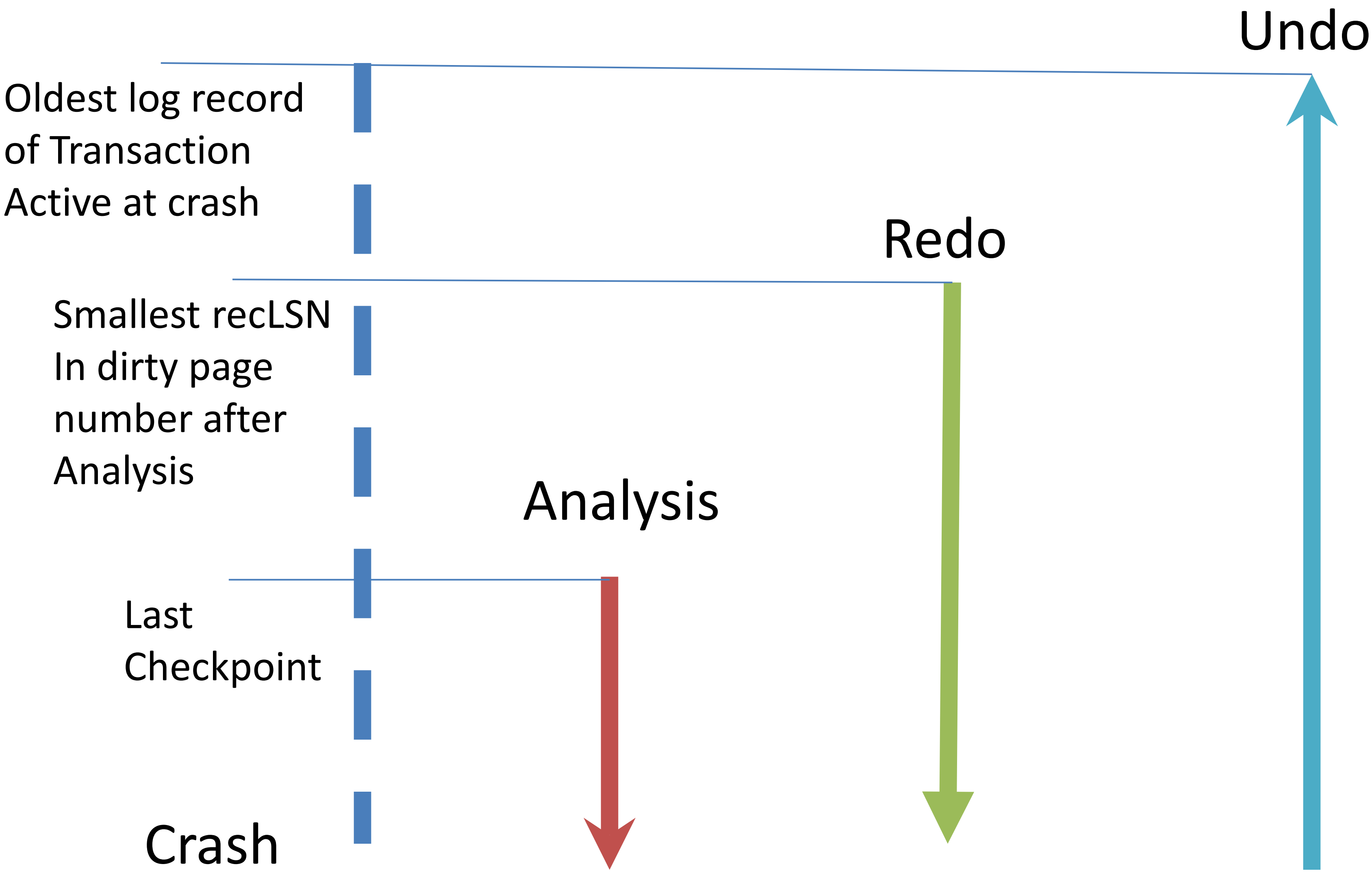
COMMIT

- 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.
- Write end record to log.

Crash recovery

- Start from a checkpoint (found via master record).
- Three phases. Need to:
  - **ANALYSIS** Determine which transactions committed since checkpoint and which ones failed
  - **REDO** ***all*** actions.
    - (repeat history)
  - **UNDO** effects of uncommitted transactions (the active transactions at the time of the crash)

Crash Recovery Phases



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 transaction from transaction table.
  - Other records: Add new transaction to transaction table, set lastLSN=LSN, change transaction status on commit.
  - Update record: If P not in Dirty Page Table,
    - Add P to DIRTY PAGE TABLE, set its recLSN=LSN.

At the end of the Analysis Phase

- When Analysis phase reaches the end of log:
  - Know all transactions 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
- REDO phase has the information it needs to do its job

REDO Phase

- We repeat History to reconstruct state at crash:
  - Reapply all updates (even aborted transactions), redo CLRs (compensation log record).
  - 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 Dirty Page Table, 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!

Undo Algorithm

- 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, addupdate log record’s prevLSN to ToUndo.
- 3. Until ToUndo is empty.

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.

Example

First write for page?
Have all dirty pages?
Identified all active X?

Log Sequence Number

(LSN)	LOG
00	begin_checkpoint
05	end_checkpoint
10	update: T1 writes P5
15	update T2 writes P3
20	T1 abort
25	CLR: Undo T1 LSN 10
30	T1 End
35	update: T3 writes P1
40	update: T2 writes P5
45	CRASH, RESTART

Log, Dirty Page and Transaction Table

Transaction Table		
TRANSId	lastLSN	Status
T1	30	Aborted
T2	40	Progress
T3	35	Progress

Dirty Page Table	
PageId	recLSN
P5	10
P3	15
P1	35

LOG								
LSN	Prev LSN	TRANS ID	type	pageId	length	offset	before	After
10	NULL	T1	UPDATE	P5	3	21	ABC	DEF
15	NULL	T2	UPDATE	P3	3	41	HIJ	KLM
20	10	T1	ABORT					
25	20	T1	UNDO					
30	25	T1	END					
35	NULL	T3	UPDATE	P1	3	41	DEF	HHH
40	15	T2	UPDATE	P5	3	48	SED	AWK
45	NULL		RESTART					

Analysis Phase Example

First write for page?
Have all dirty pages?
Identified all active X?

Start

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Active Transactions
T2
T3

Dirty Pages
P5 10 T1
P3 15 T2
P1 35 T3

RecLSN?

Redo Phase Example

First write for page?
Have all dirty pages?
Identified all active X?

Active Transactions
T2
T3

Dirty Pages
P5 10 T1
P3 15 T2
P1 35 T3

RecLSN?

Log Sequence Number

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Undo Phase Example

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Log
Sequence
Number

Active Transactions
T2
T3

Dirty Pages
P5 10 T1
P3 15 T2
P1 35 T3

Start

Summary: Recovery Manager

- 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

- Checkpointing: A quick way to limit the amount of log to scan on recovery.
- Recovery works in 3 phases:
  – Analysis: Walks forward from checkpoint.
  – Redo: Walks forward from oldest recLSN.
  – Undo: Walks backward from end to first LSN of oldest transaction still active at crash.