ARIES

A Transaction Recovery Method

Outline

- **What's the problem ?**
- Terminology
- ARIES in action
  - Normal processing
  - System crash

ACID

- **Atomicity**: Either all actions in the transaction occur, or none occur
- **Consistency**: If each transaction is consistent and the DB starts in a consistent state, then the DB ends up being consistent.
- **Isolation**: The execution of one Transaction is isolated from that of other transactions
- **Durability**: The result of a committed transaction is stored persistently.

Discussion

- How much of the success of a database management system depends on reliable and efficient transaction management?
- Given that relational database management systems have been very successful, do you believe relational model has made the design of transaction management algorithms easier and more efficient? Why or why not?

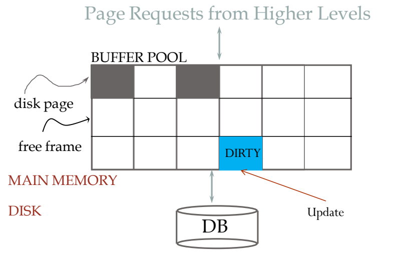
What is ARIES good for ?

- Problem: How to ensure the Atomicity and Durability if a transaction gets aborted or a media or device failure occurs?
  - Unroll transaction
  - redo transactions
- ARIES supports methods to deal with the problem
- ARIES features: fine granularity locking
  1. OO systems make users think in small objects
  2. "Object-oriented system users may tend to have many terminal interactions during …"
  3. More system use → more hotspots → need less tuning
  4. Metadata is accessed often; cannot all be locked at once

Goals

1. Simplicity (Concurrency & recovery are complex)
2. Operation Logging (higher concurrency level)
3. Flexible storage management (avoid offline reorganization of data --> garbage collect)
4. Partial rollbacks (faster than total rollback)
5. Flexible buffer management (↑ concurrency ↓I/O)
6. Recovery independence (selective recovery+ image copy at different granularities e.g. page oriented)
7. Logical undo (concurrency)
8. Parallelism and fast recovery (multiprocessors, normal processing while recovery)
9. Minimal overhead (min log data, min CPU usage)

Excursus: Buffer management



Q: When should a updated page be written to disc? → Need for a policy

Handling the buffer pool → Policies

- **Force:** make sure that every update is on disk before commit
  - Durability without REDO logging
  - Bad performance ← Transaction has to wait for the disk
- **no Steal:** don't allow buffer-pool frames with uncommitted updates to overwrite committed data on disk.
  - Atomicity without UNDO logging
  - Bad performance

	No Steal	Steal
No Force		Fastest
Force	Slowest	

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

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 (difference) 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).

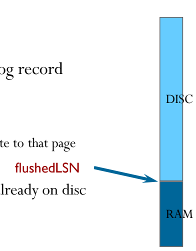
Write-Ahead Logging (WAL)

- The Write-Ahead Logging Protocol:
  ① Must force 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.
  - With UNDO info (ARIES: logical undo, concurrency)
- #2 guarantees Durability.
  - With REDO info (ARIES: physical REDO, simplicity, independency)

Note: Now we can implement Steal/No-force

Log in WAL

- LSN: log sequence number for every log record
  - Always increasing
- **pageLSN**:
  - LSN of the most recent *log record* for an update to that page
- Part of the log is in RAM another part is already on disc



- Following the WAL-Protocol requires that **flushedLSN >= pageLSN**
- Otherwise there would be an updated page which isn't registered in the log on stable storage

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The Big Picture: What's Stored Where

LogRecords
LSN
prevLSN
XID
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

Log Records

LogRecord fields:

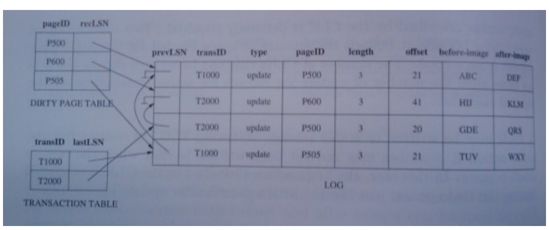
prevLSN
transID
type
update records only: pageID, length, offset, before-image, after-image
CLR only: UndoNxtLSN

Possible log record types:

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

before and after image are the data before and after the update.

Dirty page & Transaction table



DIRTY PAGE TABLE

pageID	recLSN
P500	
P600	
P505	

TRANSACTION TABLE

transID	lastLSN
T1000	
T2000	

LOG

prevLSN	transID	type	pageID	length	offset	before-image	after-image
	T1000	update	P500	3	21	ABC	DEF
	T2000	update	P600	3	41	HIJ	KLM
	T2000	update	P500	3	20	GDE	QRS
	T1000	update	P505	3	21	TUV	WXY

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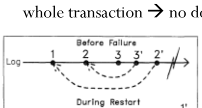
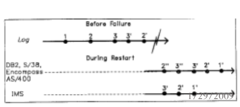
Normal processing

- Updating / forward processing
  - Adding records the log file
- Checkpoints (→ next Slide)
- Total/partial rollback
  - If transaction is aborted. Rollback to the last savepoint or the whole transaction → no double UNDO





Checkpoints

- Motivation: reduce the amount of recovery work after a System crash
- Idea: make a fuzzy snapshot of the DPT and TAT
  - 1st log entry: begin_ckp
  - 2nd log entry end_ckp. Save DPT and TAT on stable storage
  - Write begin_ckp LSN to a save place (master record)
- Fuzzy, because there might be transaction between begin_ckp and end_ckp
- No attempt to force dirty pages to disk
  - effectiveness of checkpoint limited by oldest unwritten change to a dirty page

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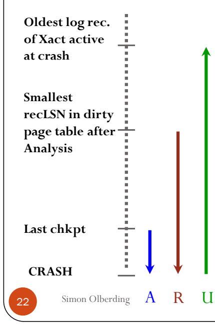
Crash Recovery: Big Picture



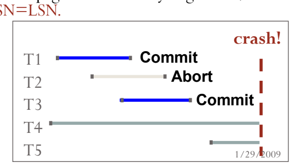
- ❖ Start from a checkpoint (found via master record).
- ❖ Three phases. Need to do:
  - Analysis - Figure out which Xacts committed since checkpoint, which failed.
  - REDO ***all*** actions. (repeat history)
  - UNDO effects of failed Xacts.

Analysis Phase

- Recreate Transaction & Dirtypage table using the checkpoint
- Follow the log data from the checkpoint until the last LSN (like normal processing)
  - 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.

Result: TAT says which Xacts were active at time of crash.

DPT says which dirty pages *MIGHT NOT* have made it to disk



Redo pass

- Motivation: Repeat history to reconstruct state at crash
- Reapply all updates, also updates of looser transactions
- Procedure
  - Start at the log with the smallest recLSN
  - Redo all actions of log record or CLR unless
    - Affected Pages is not in the DPT or
    - Affected page is in DPT and (recLSN > LSN or
    - pageLSN >= LSN) (requires I/O, therefore last check)
  - Redo = apply action + set pageLSN = LSN
  - At the end of REDO, and End record is inserted in the log for each transaction with status C which is removed from Xact table.

UNDO Pass

- Motivation: remove looser transactions

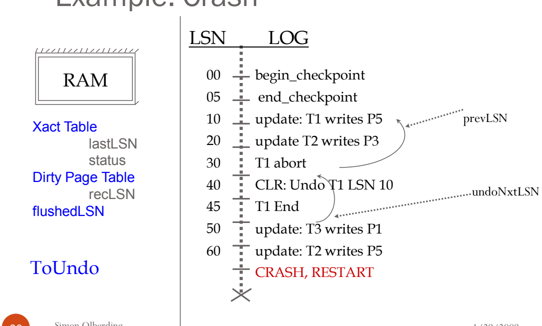
ToUndo = { *l* | *l* a lastLSN of a "loser" Xact}

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: Crash



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

undonextLSN

Analysis+Redo: P1(50), P3(20) P5(10)
T2(60), T3(50)

Discussion

- **Goals of ARIES:** Simplicity, operation logging, flexible storage management, partial rollbacks, flexible buffer management, recovery independence, logical undo, parallelism and fast recovery, minimal overhead
- The authors claim that the system is simple and efficient. Do you agree or disagree with each claim? Why or why not? Do you think all of these goals are among the primary requirements of every transaction management system?

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Xact Table
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	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

Analysis+Redo: P1(50), P3(20) P5(10)
T2(70) → DPT same as before

Limit the recovery work

- 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.

Sources

- Mohan, C., Haderle, D., Lindsay, B., Pirahesh, H., and Schwarz, P. 1992. ARIES: a transaction recovery method supporting fine-granularity locking and partial rollbacks using write-ahead logging. *ACM Trans. Database Syst.* 17, 1 (Mar. 1992), 94-162. DOI= http://doi.acm.org/10.1145/128765.128770
- Slides Crash Recovery by Robert VanNatta
- Slides ARIES: Database Logging and Recovery by Zachary G. Ives
- Slides ARIES: A Transaction Recovery Method by Rachel Pottinger
- Slides "Buffer Management Notes" by Amol Deshpande
- R. Ramakrishnan and J. Gehrke, Database Management Systems, McGraw-Hill, 3rdEd., 2003