ARIES Recovery Algorithm

ARIES: A Transaction Recovery Method Supporting Fine Granularity Locking and Partial Rollback Using Write-Ahead Logging
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Slides prepared by
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Recovery Scheme Metrics

- Concurrency
- Functionality
- Complexity
- Overheads:
  - Space and I/O (Seq and random) during Normal processing and recovery
- Failure Modes:
  - transaction/process, system and media/device

Key Features of Aries

- Physical Logging, and
- Operation logging
  - e.g. Add 5 to A, or insert K in B-tree B
- Page oriented redo
  - recovery independence amongst objects
- Logical undo (may span multiple pages)
- WAL + Inplace Updates

Key Aries Features (contd)

- Transaction Rollback
  - Total vs partial (up to a savepoint)
  - Nested rollback - partial rollback followed by another (partial/total) rollback
- Fine-grain concurrency control
  - supports tuple level locks on records, and key value locks on indices

More Aries Features

- Flexible storage management
  - Physiological redo logging:
    - logical operation within a single page
    - no need to log intra-page data movement for compaction
    - LSN used to avoid repeated redos (more on LSNs later)
- Recovery independence
  - can recover some pages separately from others
- Fast recovery and parallelism

Latches and Locks

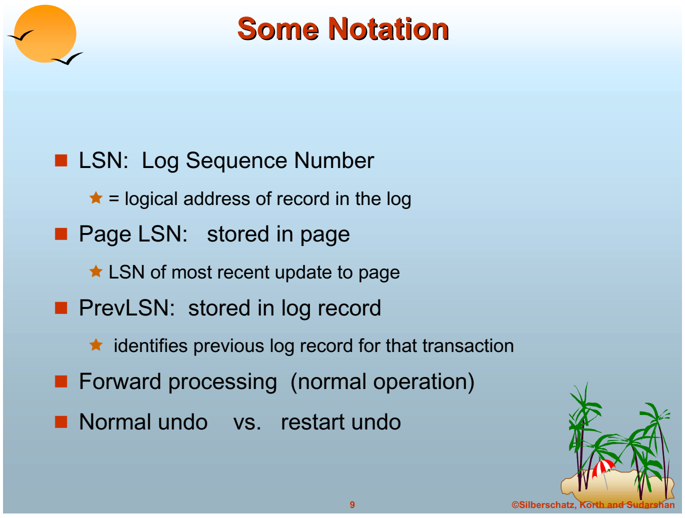
- Latches
  - used to guarantee physical consistency
  - short duration
  - no deadlock detection
  - direct addressing (unlike hash table for locks)
    - often using atomic instructions
    - latch acquisition/release is much faster than lock acquisition/release
- Lock requests
  - conditional, instant duration, manual duration, commit duration

Buffer Manager

- Fix, unfix and fix_new (allocate and fix new pg)
- Aries uses **steal policy** - uncommitted writes may be output to disk (contrast with **no-steal** policy)
- Aries uses **no-force** policy (updated pages need not be forced to disk before commit)
- dirty page: buffer version has updated not yet reflected on disk
  - dirty pages written out in a continuous manner to disk

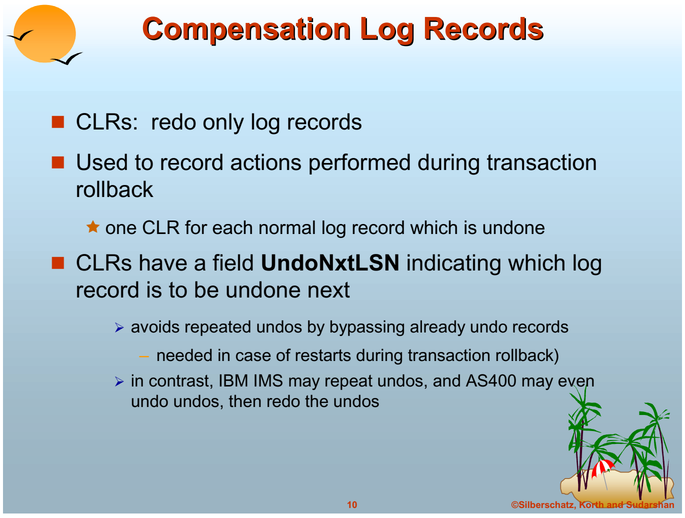
Buffer Manager (Contd)

- BCB: buffer control blocks
  - stores page ID, dirty status, latch, fix-count
- Latching of pages = latch on buffer slot
  - limits number of latches required
  - but page must be fixed before latching



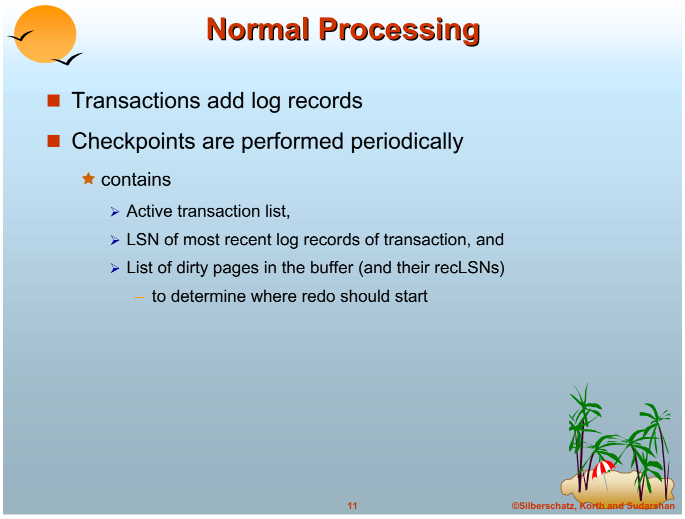
Some Notation

- LSN: Log Sequence Number
  - = logical address of record in the log
- Page LSN: stored in page
  - LSN of most recent update to page
- PrevLSN: stored in log record
  - identifies previous log record for that transaction
- Forward processing (normal operation)
- Normal undo vs. restart undo



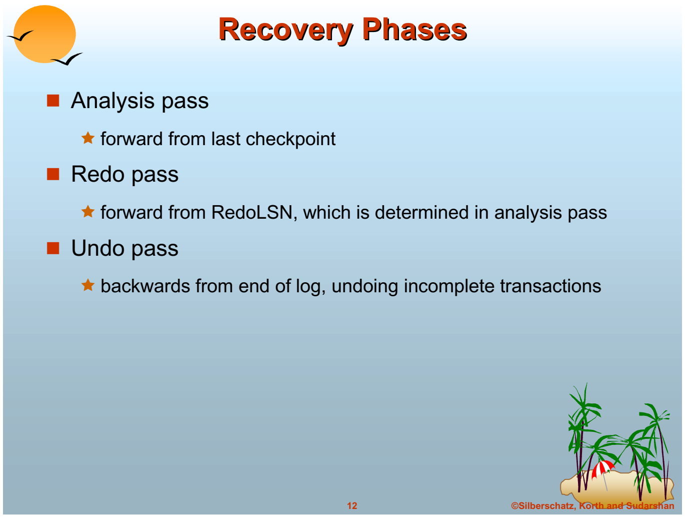
Compensation Log Records

- CLRs: redo only log records
- Used to record actions performed during transaction rollback
  - one CLR for each normal log record which is undone
- CLRs have a field **UndoNxtLSN** indicating which log record is to be undone next
  - avoids repeated undos by bypassing already undo records
    - needed in case of restarts during transaction rollback)
  - in contrast, IBM IMS may repeat undos, and AS400 may even undo undos, then redo the undos



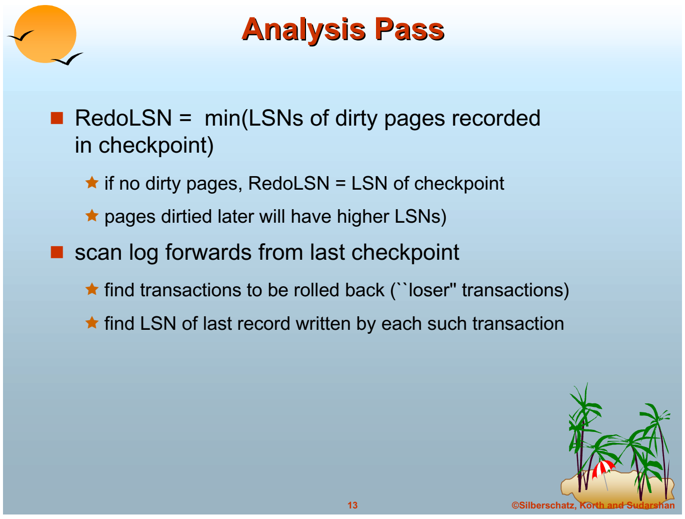
Normal Processing

- Transactions add log records
- Checkpoints are performed periodically
  - contains
    - Active transaction list,
    - LSN of most recent log records of transaction, and
    - List of dirty pages in the buffer (and their recLSNs)
      - to determine where redo should start



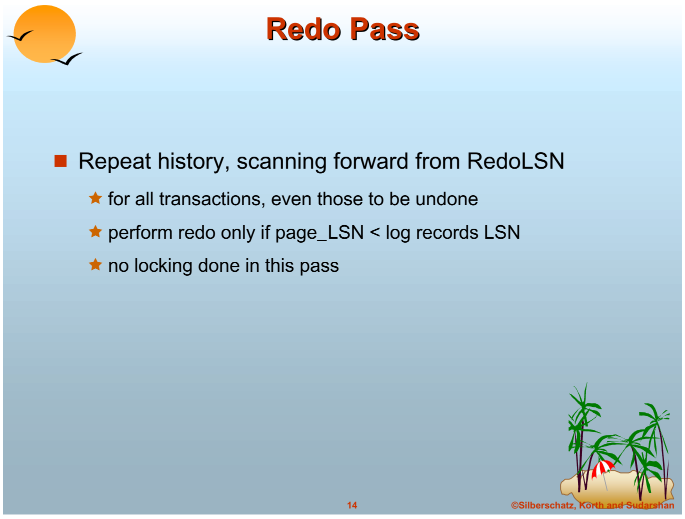
Recovery Phases

- Analysis pass
  - forward from last checkpoint
- Redo pass
  - forward from RedoLSN, which is determined in analysis pass
- Undo pass
  - backwards from end of log, undoing incomplete transactions



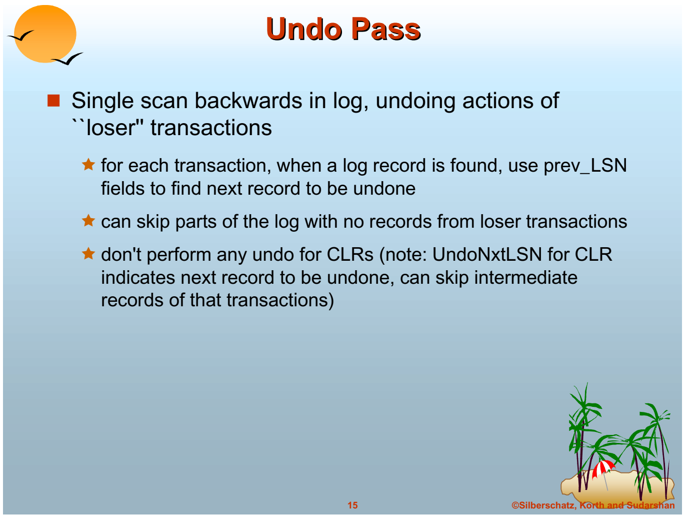
Analysis Pass

- RedoLSN = min(LSNs of dirty pages recorded in checkpoint)
  - if no dirty pages, RedoLSN = LSN of checkpoint
  - pages dirtied later will have higher LSNs)
- scan log forwards from last checkpoint
  - find transactions to be rolled back (``loser'' transactions)
  - find LSN of last record written by each such transaction



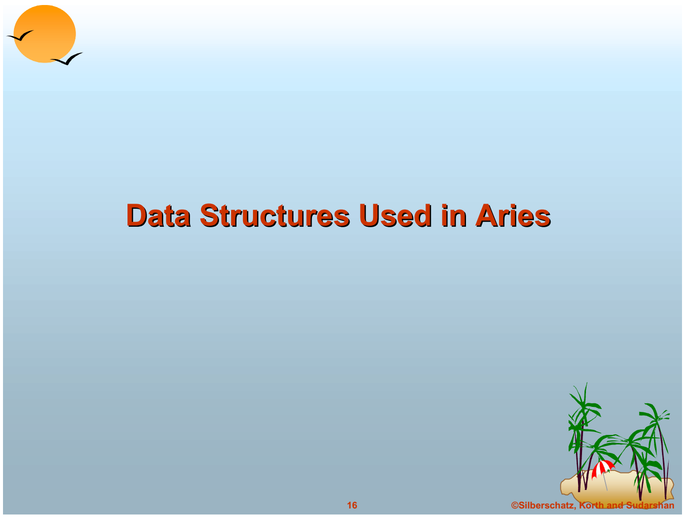
Redo Pass

- Repeat history, scanning forward from RedoLSN
  - for all transactions, even those to be undone
  - perform redo only if page_LSN < log records LSN
  - no locking done in this pass

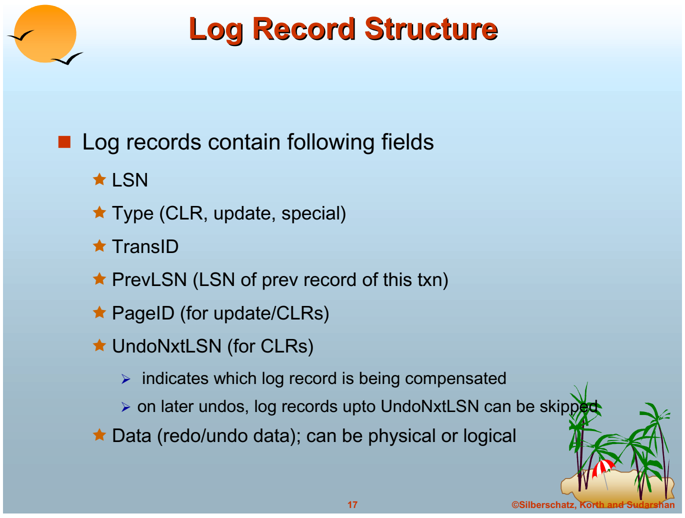


Undo Pass

- Single scan backwards in log, undoing actions of ``loser'' transactions
  - for each transaction, when a log record is found, use prev_LSN fields to find next record to be undone
  - can skip parts of the log with no records from loser transactions
  - don't perform any undo for CLRs (note: UndoNxtLSN for CLR indicates next record to be undone, can skip intermediate records of that transactions)

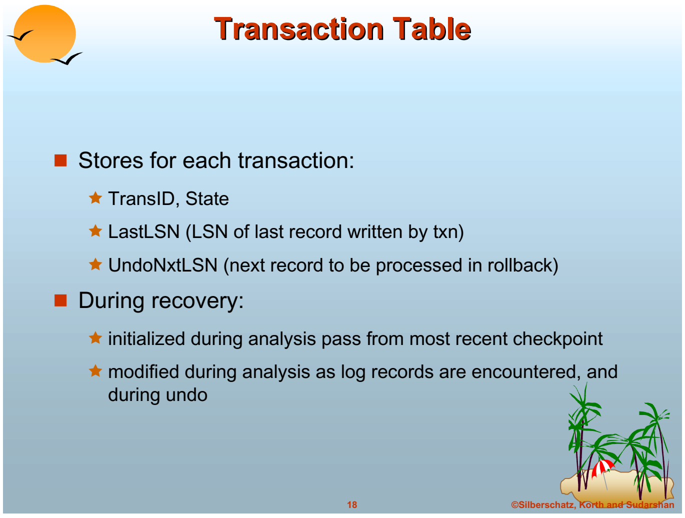


Data Structures Used in Aries



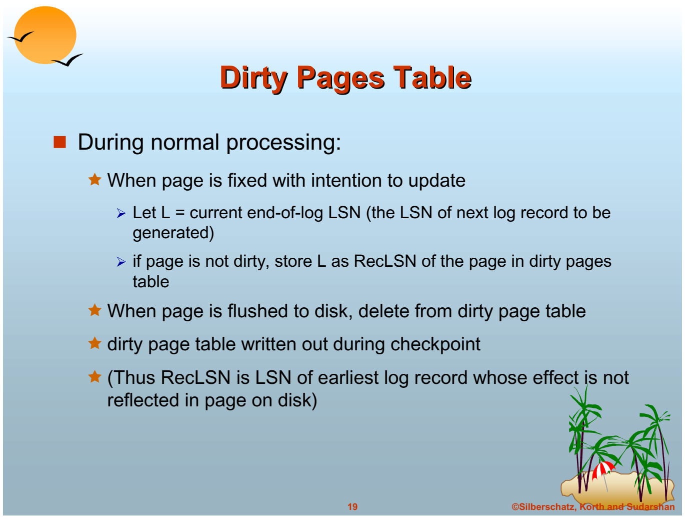
Log Record Structure

- Log records contain following fields
  - LSN
  - Type (CLR, update, special)
  - TransID
  - PrevLSN (LSN of prev record of this txn)
  - PageID (for update/CLRs)
  - UndoNxtLSN (for CLRs)
    - indicates which log record is being compensated
    - on later undos, log records upto UndoNxtLSN can be skipped
  - Data (redo/undo data); can be physical or logical



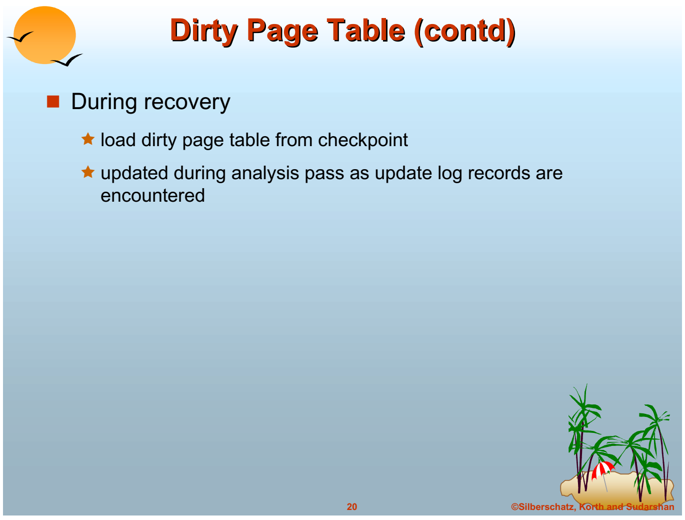
Transaction Table

- Stores for each transaction:
  - TransID, State
  - LastLSN (LSN of last record written by txn)
  - UndoNxtLSN (next record to be processed in rollback)
- During recovery:
  - initialized during analysis pass from most recent checkpoint
  - modified during analysis as log records are encountered, and during undo



Dirty Pages Table

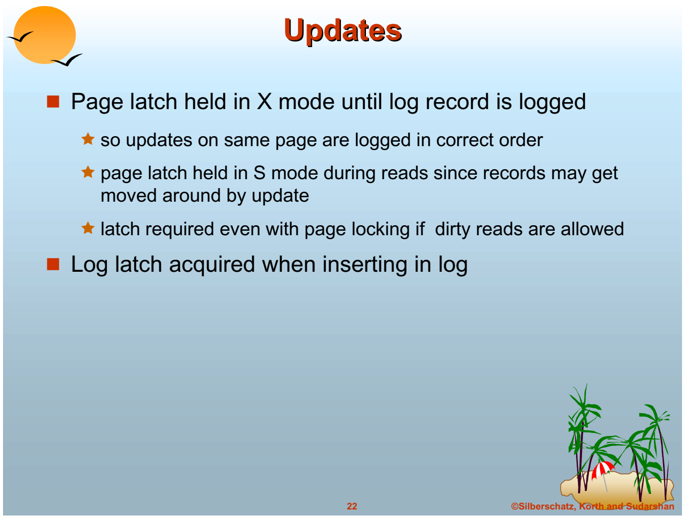
- During normal processing:
  - When page is fixed with intention to update
    - Let L = current end-of-log LSN (the LSN of next log record to be generated)
    - if page is not dirty, store L as RecLSN of the page in dirty pages table
  - When page is flushed to disk, delete from dirty page table
  - dirty page table written out during checkpoint
  - (Thus RecLSN is LSN of earliest log record whose effect is not reflected in page on disk)



Dirty Page Table (contd)

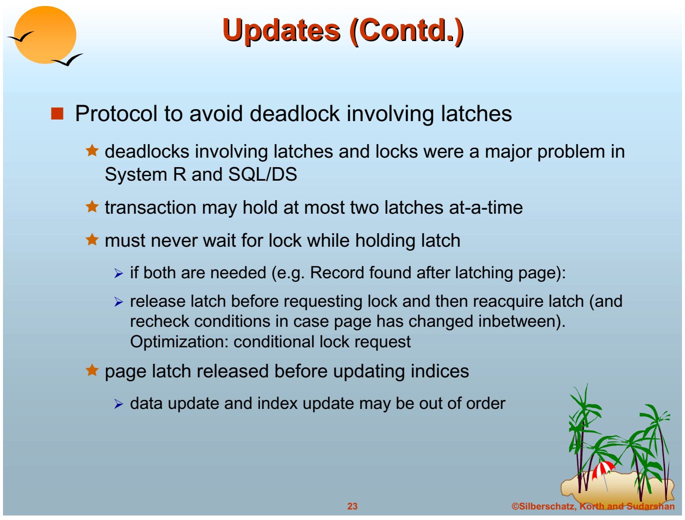
- During recovery
  - load dirty page table from checkpoint
  - updated during analysis pass as update log records are encountered

Normal Processing Details



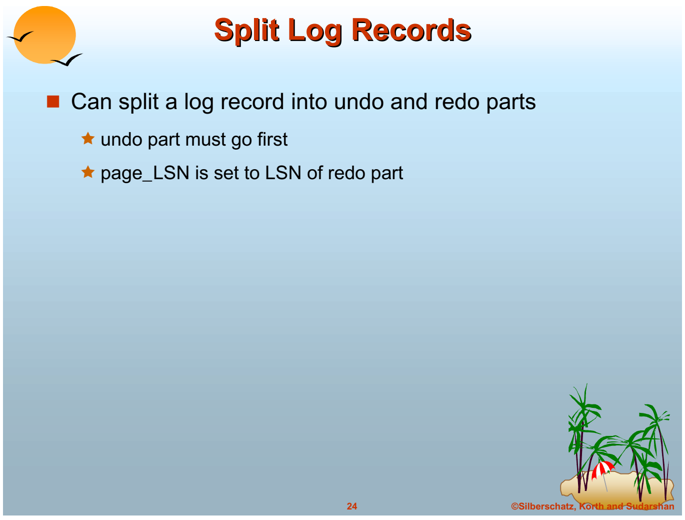
Updates

- Page latch held in X mode until log record is logged
  - so updates on same page are logged in correct order
  - page latch held in S mode during reads since records may get moved around by update
  - latch required even with page locking if dirty reads are allowed
- Log latch acquired when inserting in log



Updates (Contd.)

- Protocol to avoid deadlock involving latches
  - deadlocks involving latches and locks were a major problem in System R and SQL/DS
  - transaction may hold at most two latches at-a-time
  - must never wait for lock while holding latch
    - if both are needed (e.g. Record found after latching page):
    - release latch before requesting lock and then reacquire latch (and recheck conditions in case page has changed inbetween). Optimization: conditional lock request
  - page latch released before updating indices
    - data update and index update may be out of order



Split Log Records

- Can split a log record into undo and redo parts
  - undo part must go first
  - page_LSN is set to LSN of redo part

Savepoints

- Simply notes LSN of last record written by transaction (up to that point) - denoted by SaveLSN
- can have multiple savepoints, and rollback to any of them
- deadlocks can be resolved by rollback to appropriate savepoint, releasing locks acquired after that savepoint

Rollback

- Scan backwards from last log record of txn
  - (last log record of txn = transTable[TransID].UndoNxtLSN
  - if log record is an update log record
    - undo it and add a CLR to the log
  - if log record is a CLR
    - then UndoNxt = LogRec.UnxoNxtLSN
    - else UndoNxt = LogRec.PrevLSN
  - next record to process is UndoNxt; stop at SaveLSN or beginning of transaction as required

More on Rollback

- Extra logging during rollback is bounded
  - make sure enough log space is available for rollback in case of system crash, else BIG problem
- In case of 2PC, if in-doubt txn needs to be aborted, rollback record is written to log then rollback is carried out

Transaction Termination

- prepare record is written for 2PC
  - locks are noted in prepare record
- prepare record also used to handle non-undoable actions e.g. deleting file
  - these **pending actions** are noted in prepare record and executed only after actual commit
- end record written at commit time
  - pending actions are then executed and logged using special redo-only log records
- end record also written after rollback

Checkpoints

- begin_chkpt record is written first
- transaction table, dirty_pages table and some other file mgmt information are written out
- end_chkpt record is then written out
  - for simplicity all above are treated as part of end_chkpt record
- LSN of begin_chkpt is then written to **master** record in well known place on stable storage
- incomplete checkpoint
  - if system crash before end_chkpt record is written

Checkpoint (contd)

- Pages need not be flushed during checkpoint
  - are flushed on a continuous basis
- Transactions may write log records during checkpoint
- Can copy dirty_page table fuzzily (hold latch, copy some entries out, release latch, repeat)

Restart Processing

- Finds checkpoint begin using master record
- Do restart_analysis
- Do restart_redo
  - ... some details of dirty page table here
- Do restart_undo
- reacquire locks for prepared transactions
- checkpoint

Result of Analysis Pass

- Output of analysis
  - transaction table
    - including UndoNxtLSN for each transaction in table
  - dirty page table: pages that were potentially dirty at time of crash/shutdown
  - RedoLSN - where to start redo pass from
- Entries added to dirty page table as log records are encountered in forward scan
  - also some special action to deal with OS file deletes
- This pass can be combined with redo pass!

Redo Pass

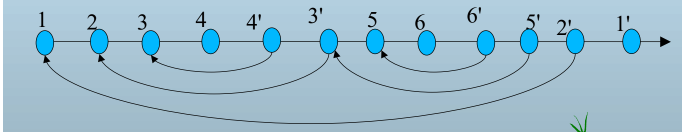
- Scan forward from RedoLSN
  - If log record is an update log record, AND is in dirty_page_table AND LogRec.LSN >= RecLSN of the page in dirty_page_table
  - then if pageLSN < LogRec.LSN then perform redo; else just update RecLSN in dirty_page_table
- Repeats history: redo even for loser transactions (some optimization possible)

More on Redo Pass

- Dirty page table details
  - dirty page table from end of analysis pass (restart dirty page table) is used and set in redo pass (and later in undo pass)
- Optimizations of redo
  - Dirty page table info can be used to pre-read pages during redo
  - Out of order redo is also possible to reduce disk seeks

Undo Pass

- Rolls back loser transaction in reverse order in single scan of log
  - stops when all losers have been fully undone
  - processing of log records is exactly as in single transaction rollback



Undo Optimizations

- Parallel undo
  - each txn undone separately, in parallel with others
  - can even generate CLRs and apply them separately , in parallel for a single transaction
- New txns can run even as undo is going on:
  - reacquire locks of loser txns before new txns begin
  - can release locks as matching actions are undone

Undo Optimization (Contd)

- If pages are not available (e.g media failure)
  - continue with redo recovery of other pages
    - once pages are available again (from archival dump) redos of the relevant pages must be done first, before any undo
  - for physical undos in undo pass
    - we can generate CLRs and apply later; new txns can run on other pages
  - for logical undos in undo pass
    - postpone undos of loser txns if the undo needs to access these pages - ``stopped transaction''
    - undo of other txns can proceed; new txns can start provided appropriate locks are first acquired for loser txns

Transaction Recovery

- Loser transactions can be restarted in some cases
  - e.g. Mini batch transactions which are part of a larger transaction

Checkpoints During Restart

- Checkpoint during analysis/redo/undo pass
  - reduces work in case of crash/restart during recovery
    - (why is Mohan so worried about this!)
  - can also flush pages during redo pass
    - RecLSN in dirty page table set to current last-processed-record

Media Recovery

- For archival dump
  - can dump pages directly from disk (bypass buffer, no latching needed) or via buffer, as desired
    - this is a fuzzy dump, not transaction consistent
  - begin_chkpt location of most recent checkpoint completed before archival dump starts is noted
    - called image copy checkpoint
    - redoLSN computed for this checkpoint and noted as media recovery redo point

Media Recovery (Contd)

- To recover parts of DB from media failure
  - failed parts if DB are fetched from archival dump
  - only log records for failed part of DB are reapplied in a redo pass
  - inprogress transactions that accessed the failed parts of the DB are rolled back
- Same idea can be used to recover from page corruption
  - e.g. Application program with direct access to buffer crashes before writing undo log record

Nested Top Actions

- Same idea as used in logical undo in our advanced recovery mechanism
  - used also for other operations like creating a file (which can then be used by other txns, before the creater commits)
  - updates of nested top action commit early and should not be undone
- Use dummy CLR to indicate actions should be skipped during undo