Supplemental Notes: Practical Aspects of Transactions

THIS MATERIAL IS NOT COVERED IN THE BOOK

Buffer Manager Policies

- **STEAL or NO-STEAL**
  – Can an update made by an uncommitted transaction overwrite the most recent committed value of a data item on disk?
- **FORCE or NO-FORCE**
  – Should all updates of a transaction be forced to disk before the transaction commits?
- Easiest for recovery: NO-STEAL/FORCE
- Highest performance: STEAL/NO-FORCE

Write-Ahead Log

- Enables the use of STEAL and NO-FORCE
- **Log: append-only file containing log records**
- For every update, commit, or abort operation
  - Write physical, logical, physiological log record
  - Note: multiple transactions run concurrently, log records are interleaved
- After a system crash, use log to:
  - Redo some transaction that did commit
  - Undo other transactions that didn't commit

Write-Ahead Log

- All log records pertaining to a page are written to disk before the page is overwritten on disk

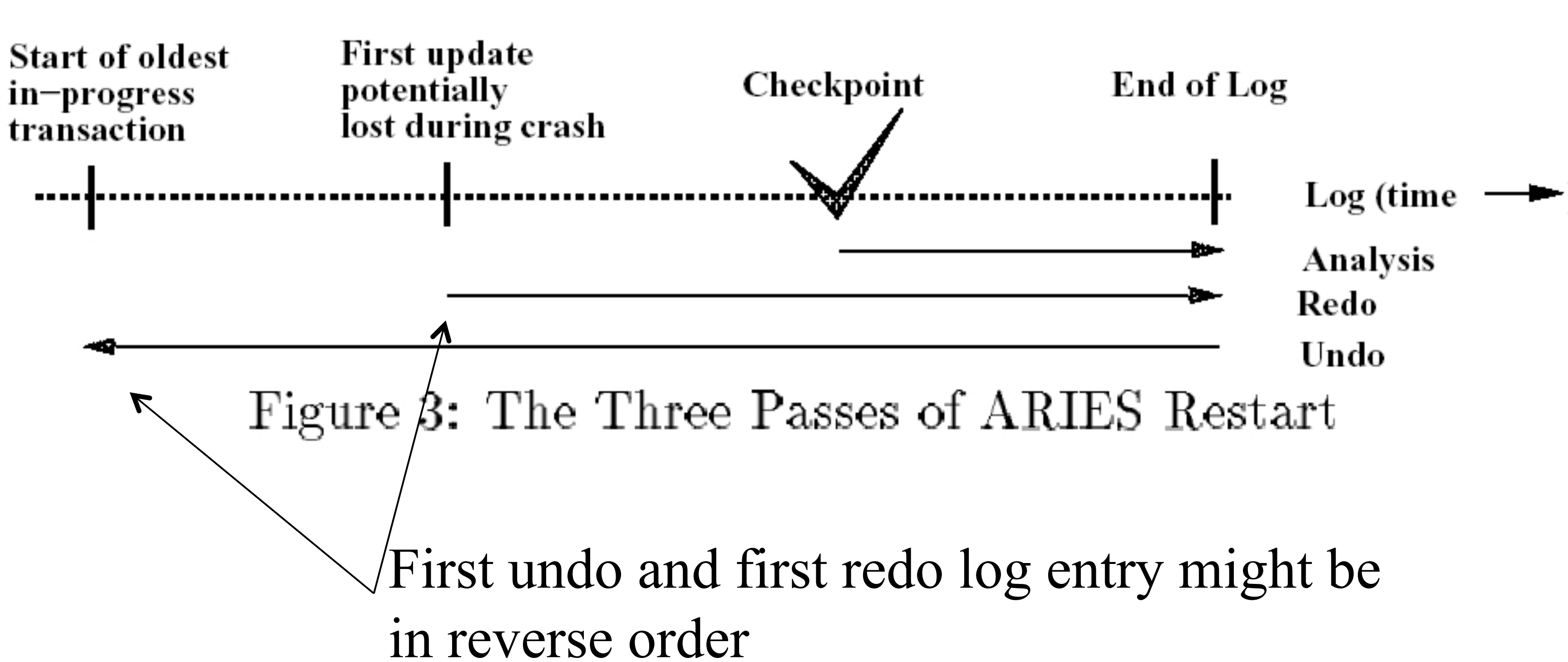
- All log records for transaction are written to disk before the transaction is considered committed
  - Why is this faster than FORCE policy?

- **Committed transaction**: transactions whose commit log record has been written to disk

ARIES Method

1. **Analysis pass**
   – Figure out what was going on at time of crash
   – List of dirty pages and active transactions
2. **Redo pass (repeating history principle)**
   – Redo all operations, even for transactions that will not commit
   – Get back to state at the moment of the crash
3. **Undo pass**
   – Remove effects of all uncommitted transactions
   – Log changes during undo in case of another crash during undo

ARIES Method Illustration



[Figure 3 from Franklin97]

ARIES Method Elements

- Each page contains a **pageLSN**
  - **Log Sequence Number** of log record for latest update to that page
  - Will serve to determine if an update needs to be redone
- Physiological logging
  - page-oriented REDO
    - Possible because will always redo all operations in order
  - logical UNDO
    - Needed to undo only one transaction

ARIES Data Structures

- Active Transactions Table
  - Lists all running transactions (active transactions)
  - For each txn: lastLSN = most recent update by transaction
- Dirty Page Table
  - Lists all dirty pages
  - For each dirty page: recoveryLSN (recLSN)= first LSN that caused page to become dirty
- Write Ahead Log contains log records
  - LSN, prevLSN = previous LSN for same transaction
  - other attributes

ARIES Data Structures

Dirty pages

pageID	recLSN
P5	102
P6	103
P7	101

Log

LSN	prevLSN	transID	pageID	Log entry
101	-	T100	P7	
102	-	T200	P5	
103	102	T200	P6	
104	101	T100	P5	

Active transactions

transID	lastLSN
T100	104
T200	103

Buffer Pool

P5 PageLSN=104	P6 PageLSN=103	P7 PageLSN=101

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ARIES Method Details

- Steps under normal operations
  - Add log record
  - Update transactions table
  - Update dirty page table
  - Update pageLSN

Checkpoints

Write into the log

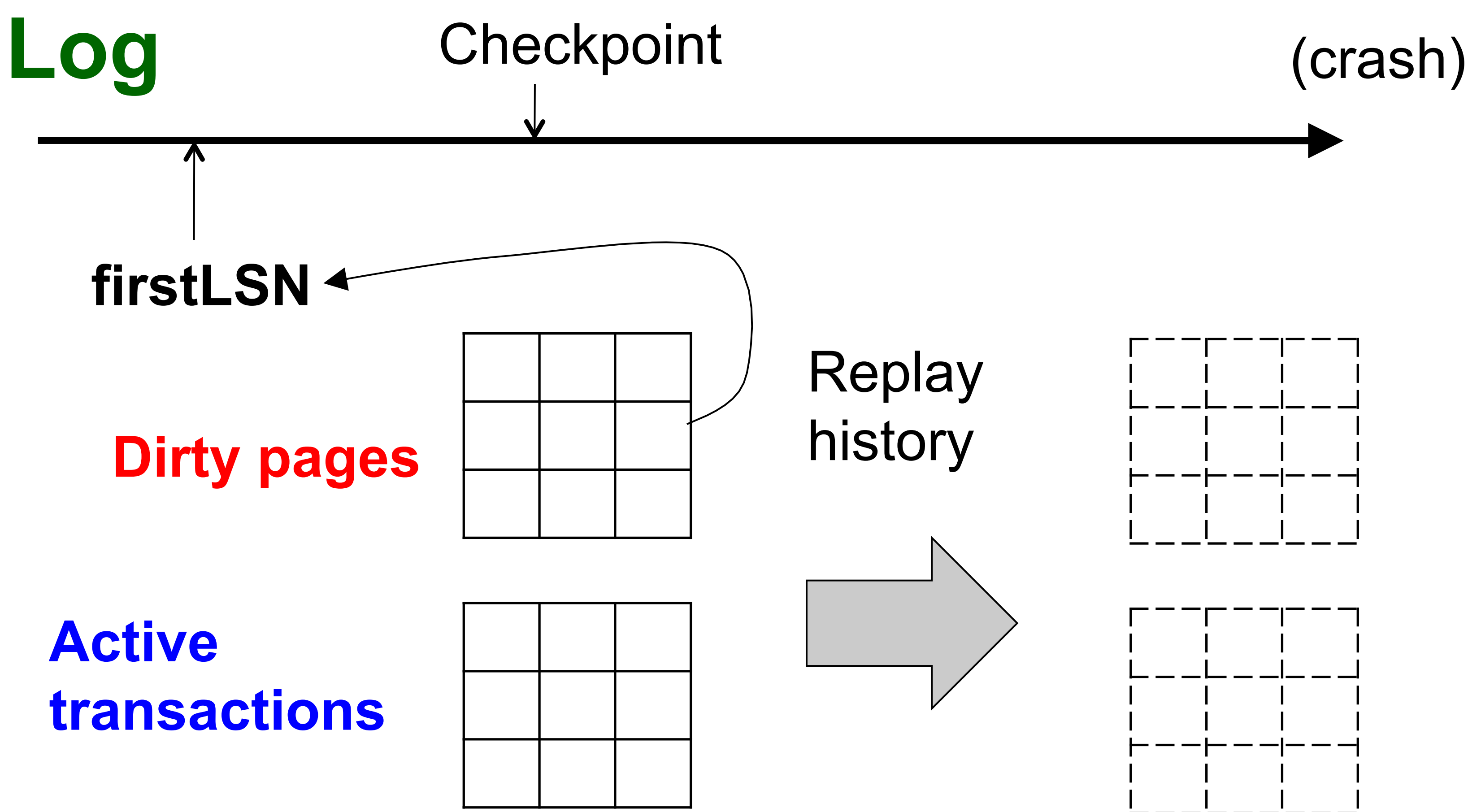
- Entire active transactions table
- Entire dirty pages table

1. Analysis Phase

- Goal
  - Determine point in log where to start REDO
  - Determine set of dirty pages when crashed
    - Conservative estimate of dirty pages
  - Identify active transactions when crashed

- Approach
  - Rebuild active transactions table and dirty pages table
  - Reprocess the log from the beginning (or checkpoint)
    - Only update the two data structures
  - Compute: **firstLSN** = smallest of all recoveryLSN

1. Analysis Phase



2. Redo Phase

Main principle: replay history

- Process Log forward, starting from **firstLSN**
- Read every log record, sequentially
- Redo actions are not recorded in the log
- Needs the Dirty Page Table

2. Redo Phase: Details

For each Log entry record LSN

- If affected page is not in Dirty Page Table then **do not update**
- If recoveryLSN > LSN, then **no update**
- Read page from disk;
  If **pageLSN** > LSN, then **no update**
- Otherwise perform update

3. Undo Phase

Main principle: “logical” undo

- Start from the end of the log, move backwards
- Read only affected log entries
- Redo actions *are* written in the Log as special entries: CLR (Compensating Log Records)
- CLRs are redone, but never undone

3. Undo Phase: Details

- "Loser transactions" = uncommitted transactions in Active Transactions Table
- **ToUndo** = set of lastLSN of loser transactions
- While **ToUndo** not empty:
  - Choose most recent (largest) LSN in **ToUndo**
  - If LSN = regular record: undo; write a CLR where CLR.undoNextLSN = LSN.prevLSN
  - If LSN = CLR record: (don't undo !) insert CLR.**undoNextLSN** in **ToUndo**

Handling Crashes during Undo

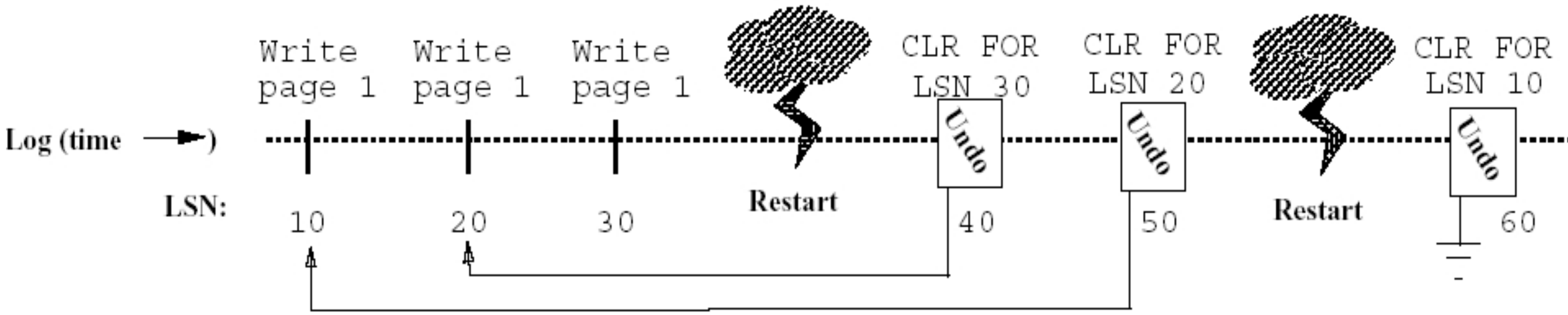


Figure 4: The Use of CLRs for UNDO

[Figure 4 from Franklin97]

Implementation: Locking

- Can serve to enforce serializability
- Two types of locks: **Shared and Exclusive**
- Also need **two-phase locking (2PL)**
  - Rule: once transaction releases lock, cannot acquire any additional locks!
  - So two phases: growing then shrinking
- Actually, need **strict 2PL**
  - Release all locks when transaction commits or aborts

Phantom Problem

- A "phantom" is a tuple that is invisible during part of a transaction execution but not all of it.
- Example:
  - T0: reads list of books in catalog
  - T1: inserts a new book into the catalog
  - T2: reads list of books in catalog
    - New book will appear!
- Can this occur?
- Depends on locking details (eg, granularity of locks)
- To avoid phantoms needs **predicate locking**

Deadlocks

- Two or more transactions are waiting for each other to complete

- **Deadlock avoidance**
  - Acquire locks in pre-defined order
  - Acquire all locks at once before starting

- **Deadlock detection**
  - Timeouts
  - Wait-for graph (this is what commercial systems use)

Degrees of Isolation

- Isolation level "serializable" (i.e. ACID)
  - Golden standard
  - Requires strict 2PL and predicate locking
  - But often too inefficient
  - Imagine there are few update operations and many long read operations
- Weaker isolation levels
  - Sacrifice correctness for efficiency
  - Often used in practice (often **default**)
  - Sometimes are hard to understand

Degrees of Isolation

- **Four levels of isolation**
  – All levels use **long-duration exclusive locks**
  – READ UNCOMMITTED: no read locks
  – READ COMMITTED: short duration read locks
  – REPEATABLE READ:
    - Long duration read locks on individual items
  – SERIALIZABLE:
    - All locks long duration and lock predicates
- **Trade-off: consistency vs concurrency**
- Commercial systems give choice of level

Lock Granularity

- Fine granularity locking (e.g., tuples)
  - High concurrency
  - High overhead in managing locks
- Coarse grain locking (e.g., tables)
  - Many false conflicts
  - Less overhead in managing locks
- Alternative techniques
  - **Hierarchical locking (and intentional locks)**
  - **Lock escalation**

The Tree Protocol

- An alternative to 2PL, for tree structures
- E.g. B-trees (the indexes of choice in databases)
- Because
  - Indexes are hot spots!
  - 2PL would lead to great lock contention

The Tree Protocol

Rules:

- The first lock may be any node of the tree
- Subsequently, a lock on a node A may only be acquired if the transaction holds a lock on its parent B
- Nodes can be unlocked in any order (no 2PL necessary)
- "Crabbing"
  - First lock parent then lock child
  - Keep parent locked only if may need to update it
  - Release lock on parent if child is not full

- The tree protocol is NOT 2PL, yet ensures conflict-serializability !

Other Techniques

- DB2 and SQL Server use strict 2PL
- Multiversion concurrency control (Postgres)
  - Snapshot isolation (also available in SQL Server 2005)
  - Read operations use old version without locking
- Optimistic concurrency control
  - Timestamp based
  - Validation based (Oracle)
  - Optimistic techniques **abort** transactions instead of blocking them when a conflict occurs

Summary

- Transactions are a useful abstraction
- They simplify application development
- DBMS must be careful to maintain ACID properties in face of
  – Concurrency
  – Failures