Database Applications (15-415)

DBMS Internals- Part XIII
Lecture 24, April 16, 2015

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Today...

- Last Session:
  - Transaction Management

- Today’s Session:
  - Recovery Management

- Announcement:
  - PS3 grades are out
DBMS Layers

Queries

Query Optimization and Execution
Relational Operators
Files and Access Methods
Buffer Management
Disk Space Management

DB

Transaction Manager
Lock Manager
Recovery Manager
Outline

- The ACID Properties
- The Steal, No-Force Approach
- Logging and the WAL Protocol
- The Log
The ACID Properties

- Four properties must be ensured in the face of concurrent accesses and system failures:
  - **Atomicity**: Either all actions of a transaction are carried out or none at all
  - **Consistency**: Each transaction (run by itself with no concurrent execution) must preserve the consistency of the database
  - **Isolation**: Execution of one transaction is isolated (or protected) from the effects of other concurrently running transactions
  - **Durability**: If a transaction commits, its effects persist (even of the system crashes before all its changes are reflected on disk)
The ACID Properties

Four properties must be ensured in the face of concurrent accesses and system failures:

- **Atomicity**: The Responsibility of the Recovery Manager
- **Consistency**: The Responsibility of the User
- **Isolation**: The Responsibility of the Transaction Manager
- **Durability**: The Responsibility of the Recovery Manager
Ensuring Atomicity and Durability

- How can the recovery manager ensure atomicity and durability (in case of a failure)?
  - It can ensure atomicity by *undoing* the actions of transactions that did not commit
  - It can ensure durability by *redoing* (all) the actions of committed transactions

Desired Behavior after the system restarts:
- T1, T2 & T3 should be durable
- T4 & T5 should be rolled back
Stealing Frames and Forcing Pages

- To realize what it takes to implement a recovery manager, it is necessary to understand what happens during normal execution
  - Can the changes made to an object $O$ in the buffer pool by a transaction $T$ be written to disk before $T$ commits?
    - Yes, if another transaction steals $O$'s frame (a steal approach is said to be in place)
    - No, if stealing is not allowed (a no-steal approach is said to be in place)
  - When $T$ commits, must we ensure that all its changes are immediately forced to disk?
    - Yes, if a force approach is used
    - No, if a no-force approach is used
Steal vs. No-Steal and Force vs. No-Force Approaches

- What if a no-steal approach is used?
  - We do not have to *undo* the changes of an aborted transaction (+)
  - But this assumes that all pages modified by ongoing transactions can be accommodated in the buffer pool (-)

- What if a force approach is used?
  - We do not have to *redo* the changes of a committed transaction (+)
  - But this results in excessive page I/O costs (e.g., when a highly used page is updated in succession by 20 transactions, it would be written to disk 20 times!) (-)
Steal vs. No-Steal and Force vs. No-Force Approaches (Cont’d)

- We indeed have four alternatives that we can employ:

<table>
<thead>
<tr>
<th></th>
<th>No-Steal</th>
<th>Steal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force</td>
<td>Trivial, but undesired</td>
<td>High I/O cost, but modified pages need not fit in the buffer pool</td>
</tr>
<tr>
<td>No-Force</td>
<td>Low I/O cost, but modified pages need to fit in the buffer pool</td>
<td>Low I/O cost, and modified pages need not fit in the buffer pool</td>
</tr>
</tbody>
</table>

- Most DBMSs use a steal, no-force approach
Outline

- The ACID Properties
- The Steal, No-Force Approach
- Logging and the WAL Protocol
- The Log
Logging and the WAL Property

- In order to recover from failures, the recovery manager maintains a log of all modifications to the database on stable storage (which should survive crashes).

- After a failure, the DBMS “replays” the log to:
  - Redo committed transactions
  - Undo uncommitted transactions

- Caveat: A log record describing a change must be written to stable storage before the change is made
  - This is referred to as the Write-Ahead Log (WAL) property
The WAL Protocol

- WAL is the fundamental rule that ensures that a record of every change to the database is available after a crash.

- What if a transaction made a change, committed, then a crash occurred (i.e., no log is kept “before” the crash)?
  - The *no-force approach* entails that this change may not have been written to disk before the crash.
  - Without a record of this change, there would be no way to ensure that the committed transaction survives the crash.
  - Hence, durability cannot be guaranteed!

To guarantee *durability*, a record for every change must be written to stable storage *before the change is made*.
The WAL Protocol (Cont’d)

- WAL is the fundamental rule that ensures that a record of every change to the database is available after a crash.

- What if a transaction made a change, was progressing, and a crash occurred?
  - The *steal approach* entails that this change may have been written to disk before the crash.
  - Without a record of this change, there would be no way to ensure that the transaction can be rolled back (i.e., its effects would be unseen).
  - Hence, atomicity cannot be guaranteed!

To guarantee **atomicity**, a record for every change must be written to stable storage **before the change is made**.
Outline

The ACID Properties

The Steal, No-Force Approach

Logging and the WAL Protocol

The Log
The Log

- The log is *a file of records* stored in stable storage.

- Every log record is given a unique id called the Log Sequence Number (LSN).
  - LSNs are assigned in a monotonically increasing order (this is required by the ARIES recovery algorithm - *later*).

- Every page contains the LSN of the *most recent* log record, which describes a change to this page.
  - This is called the pageLSN.
The Log (Cont’d)

- The most recent portion of the log, called the *log tail*, is kept in main memory and *forced* periodically to disk.

- The DBMS keeps track of the maximum LSN flushed to disk so far.
  - This is called the *flushedLSN*.

- As per the WAL protocol, before a page is written to disk, \( \text{pageLSN} \leq \text{flushedLSN} \).
When to Write Log Records?

- A log record is written after:
  - **Updating a Page**
    - An *update log record* is appended to the log tail
    - The pageLSN of the page is set to the LSN of the update log record
  - **Committing a Transaction**
    - A *commit log record* is appended to the log tail
    - The log tail is written to stable storage, up to and including the commit log record
  - **Aborting a Transaction**
    - An *abort log record* is appended to the log tail
    - An undo is initiated for this transaction
When to Write Log Records?

- A log record is written after:
  - Ending (After Aborting or Committing) a Transaction:
    - Additional steps are completed \( \text{(later)} \)
    - An end log record is appended to the log tail
  - Undoing an Update
    - When the action (described by an update log record) is undone, a compensation log record (CLR) is appended to the log tail
    - CLR describes the action taken to undo the action recorded in the corresponding update log record
Log Records

The fields of a log record are usually as follows:

- Fields common to all log records:
  - Update Log Records
  - Commit Log Records
  - Abort Log Records
  - End Log Records
  - Compensation Log Records

- Can be used to *redo* and *undo* the changes!
Other Recovery-Related Structures

- In addition to the log, the following two tables are maintained:
  - The Transaction Table
    - One entry $E$ for each **active** transaction
    - $E$ fields are:
      - Transaction ID
      - Status, which can be “Progress”, “Committed” or “Aborted”
      - $lastLSN$, which is the most recent log record for this transaction
  - The Dirty Page Table
    - One entry $E'$ for each **dirty** page in the buffer pool
    - $E'$ fields are:
      - Page ID
      - $recLSN$, which is the LSN of the first log record that caused the page to become dirty
### An Example

#### Dirty Page Table

<table>
<thead>
<tr>
<th>PageID</th>
<th>recLSN</th>
</tr>
</thead>
<tbody>
<tr>
<td>P500</td>
<td></td>
</tr>
<tr>
<td>P600</td>
<td></td>
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#### Transaction Table

<table>
<thead>
<tr>
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<tr>
<td>T1000</td>
<td></td>
</tr>
<tr>
<td>T2000</td>
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#### LOG

<table>
<thead>
<tr>
<th>prevLSN</th>
<th>transID</th>
<th>Type</th>
<th>pageID</th>
<th>Length</th>
<th>Offset</th>
<th>Before-Image</th>
<th>After-Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1000</td>
<td>Update</td>
<td>P500</td>
<td>3</td>
<td>21</td>
<td></td>
<td>ABC</td>
<td>DEF</td>
</tr>
<tr>
<td>T2000</td>
<td>Update</td>
<td>P600</td>
<td>3</td>
<td>41</td>
<td></td>
<td>HIJ</td>
<td>KLM</td>
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