Database Management Systems

Module 52: Backup & Recovery/2: Recovery/1

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Module Recap

- Learnt why having backup is essential
- Analysed different backup strategies and respective schedules
- Learnt how Hot backup of transaction log helps in recovering consistent database

Module Objectives

- We need to understand what are the possible sources for failure for transactions in a database
- Various types of storages are used for recovery from failures to ensure Atomicity, Consistency and Durability – these models need to be explored
- To understand recovery scheme based on logging
- To focus on single transactions only

Module Outline

- Failure Classification
- Storage Structure
- Log-Based Recovery

Failure Classification

Database System Recovery

- All database reads/writes are within a transaction
- Transactions have the “ACID” properties
    - Atomicity - all or nothing
    - Consistency - preserves database integrity
    - Isolation - execute as if they were run alone
    - Durability - results are not lost by a failure
- Concurrency Control guarantees I, contributes to C
- Application program guarantees C
- Recovery subsystem guarantees A & D, contributes to C

Failure Classification

- **Transaction failure**:
  - **Logical errors**: transaction cannot complete due to some internal error condition
  - **System errors**: the database system must terminate an active transaction due to an error condition (for example, deadlock)
- **System crash**: a power failure or other hardware or software failure causes the system to crash
  - **Fail-stop assumption**: non-volatile storage contents are assumed to not be corrupted as result of a system crash
    - ▷ Database systems have numerous integrity checks to prevent corruption of disk data
- **Disk failure**: a head crash or similar disk failure destroys all or part of disk storage
  - Destruction is assumed to be detectable
    - ▷ Disk drives use checksums to detect failures

Recovery Algorithms

- Consider transaction T_i that transfers \$50 from account A to account B
  - Two updates: subtract 50 from A and add 50 to B
- Transaction T_i requires updates to A and B to be output to the database
  - A failure may occur after one of these modifications have been made but before both of them are made
  - Modifying the database without ensuring that the transaction will commit may leave the database in an inconsistent state
  - Not modifying the database may result in lost updates if failure occurs just after transaction commits
- Recovery algorithms have two parts
  a) Actions taken during normal transaction processing to ensure enough information exists to recover from failures
  b) Actions taken after a failure to recover the database contents to a state that ensures atomicity, consistency and durability

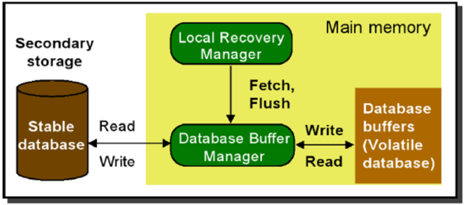
Storage Structure

Storage Structure

- **Volatile Storage**:
  - does not survive system crashes
  - examples: main memory, cache memory
- **Nonvolatile Storage**:
  - survives system crashes
  - examples: disk, tape, flash memory, non-volatile (battery backed up) RAM
  - but may still fail, losing data
- **Stable Storage**:
  - a mythical form of storage that survives all failures
  - approximated by maintaining multiple copies on distinct non-volatile media

Stable Storage Implementation

- Maintain multiple copies of each block on separate disks
  - copies can be at remote sites to protect against disasters such as fire or flooding
- Failure during data transfer can still result in inconsistent copies. Block transfer can result in
  - Successful completion
  - Partial failure: destination block has incorrect information
  - Total failure: destination block was never updated
- Protecting storage media from failure during data transfer (one solution):
  - Execute output operation as follows (assuming two copies of each block):
    - Write the information onto the 1^{st} physical block
    - When the 1^{st} write is successful, write the same information onto the 2^{nd} physical block
    - The output is completed only after the second write successfully completes



Stable Storage Implementation (2)

Protecting storage media from failure during data transfer (cont.):

- Copies of a block may differ due to failure during output operation
- To recover from failure:
  - First find inconsistent blocks:
    - *Expensive solution* : Compare the two copies of every disk block
    - *Better solution*:
      - Record in-progress disk writes on non-volatile storage (Non-volatile RAM or special area of disk)
      - Use this information during recovery to find blocks that may be inconsistent, and only compare copies of these
      - Used in hardware RAID systems
  - If either copy of an inconsistent block is detected to have an error (bad checksum), overwrite it by the other copy
  - If both have no error, but are different, overwrite the second block by the first block

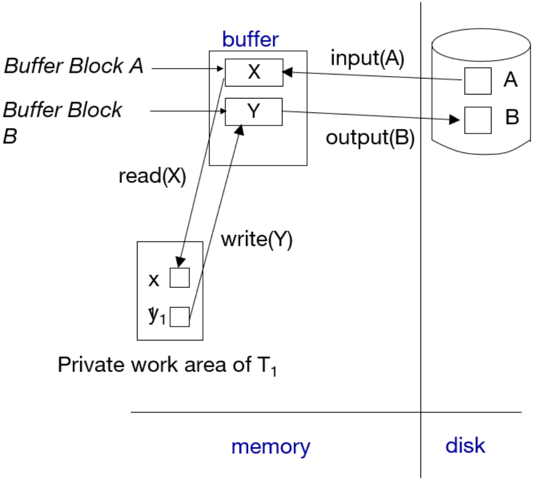
Data Access

- **Physical Blocks** are those blocks residing on the disk
- **System Buffer Blocks** are the blocks residing temporarily in main memory
- Block movements between disk and main memory are initiated through the following two operations:
  - **input(B)** transfers the physical block B to main memory
  - **output(B)** transfers the buffer block B to the disk, and replaces the appropriate physical block there
- We assume, for simplicity, that each data item fits in, and is stored inside, a single block

Data Access (2)

- Each transaction T_i has its private work-area in which local copies of all data items accessed and updated by it are kept
  - T_i's local copy of a data item X is denoted by x_i
  - B_X denotes block containing X
- Transferring data items between system buffer blocks and its private work-area done by:
  - **read(X)** assigns the value of data item X to the local variable x_i
  - **write(X)** assigns the value of local variable x_i to data item X in the buffer block
- Transactions
  - Must perform **read(X)** before accessing X for the first time (subsequent reads can be from local copy)
  - The **write(X)** can be executed at any time before the transaction commits
- Note that **output**(B_X) need not immediately follow **write(X)**. System can perform the **output** operation when it deems fit

Data Access (3): Example



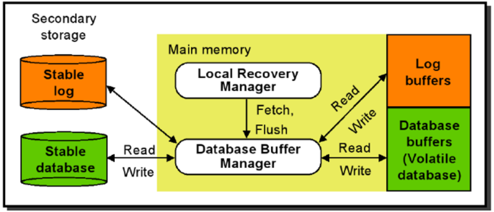
Recovery and Atomicity

- To ensure atomicity despite failures, we first output information describing the modifications to stable storage without modifying the database itself
- We study **Log-based Recovery Mechanisms**
  - We first present key concepts
  - And then present the actual recovery algorithm
- Less used alternative: **Shadow Paging**
- In this Module we assume serial execution of transactions
- In the next Module, we consider the case of concurrent transaction execution

Log-Based Recovery

Log-Based Recovery

- A **log** is kept on stable storage
  - The log is a sequence of **log records**, which maintains information about update activities on the database
- When transaction Ti starts, it registers itself by writing a record $< T_i$ **start** $>$ to the log
- Before Ti executes **write(X)**, a log record $< T_i, X, V_1, V_2 >$ is written, where V_1 is the value of X before the write (**old value**), and V_2 is the value to be written to X (**new value**)
- When T_i finishes its last statement, the log record $< T_i$ **commit** $>$ is written



Database Modification Schemes

- The **immediate-modification** scheme allows updates of an uncommitted transaction to be made to the buffer, or the disk itself, before the transaction commits
  - Update log record must be written *before* a database item is written
    - We assume that the log record is output directly to stable storage
  - Output of updated blocks to disk storage can take place at any time before or after transaction commit
  - Order in which blocks are output can be different from the order in which they are written
- The **deferred-modification** scheme performs updates to buffer/disk only at the time of transaction commit
  - Simplifies some aspects of recovery
  - But has overhead of storing local copy
- We cover here only the immediate-modification scheme

Transaction Commit

- A transaction is said to have committed when its commit log record is output to stable storage
  - All previous log records of the transaction must have been output already
- Writes performed by a transaction may still be in the buffer when the transaction commits, and may be output later

Immediate Database Modification Example

Log	Write	Output
<T_0 **start**>		
<T_0, A, 1000, 950>		
<T_0, B, 2000, 2050>		
	A = 950	
	B = 2050	
<T_0 **commit**>		
<T_1 **start**>		
<T_1, C, 700, 600>		
	C = 600	
		B_B , B_C
<T_1 **commit**>		
		B_A

B_C output before T_1 commits

B_A output after T_0 commits

- Note: B_X denotes block containing X

Undo and Redo Operations

- **Undo** of a log record $< T_i, X, V_1, V_2 >$ writes the **old** value V_1 to X
- **Redo** of a log record $< T_i, X, V_1, V_2 >$ writes the **new** value V_2 to X
- **Undo and Redo of Transactions**
  - **undo**(T_i) restores the value of all data items updated by T_i to their old values, going backwards from the last log record for T_i
    - Each time a data item X is restored to its old value V a special log record (called **redo-only**) $< T_i, X, V >$ is written out
    - When undo of a transaction is complete, a log record $< T_i$ **abort**$>$ is written out (to indicate that the undo was completed)
  - **redo**(T_i) sets the value of all data items updated by T_i to the new values, going forward from the first log record for T_i
    - No logging is done in this case

Undo and Redo Operations (2)

- The **undo** and **redo** operations are used in several different circumstances:
  - The **undo is** used for transaction rollback during normal operation
    - in case a transaction cannot complete its execution due to some logical error
  - The **undo** and **redo** operations are used during recovery from failure
- We need to deal with the case where during recovery from failure another failure occurs prior to the system having fully recovered

Undo and Redo on Normal Transaction Rollback

- Let T_i be the transaction to be rolled back
- Scan log backwards from the end, and for each log record of T_i of the form $< T_i, X_j, V_1, V_2 >$
  - Perform the undo by writing V_1 to X_j,
  - Write a log record $< T_i, X_j, V_1 >$
    - such log records are called **Compensation Log Records**
- Once the record $< T_i$ **start**$>$ is found stop the scan and write the log record $< T_i$ **abort**$>$

Undo and Redo on Recovering from Failure

- When recovering after failure:
  - Transaction T_i needs to be undone if the log
    - contains the record $< T_i$ **start**$>$,
    - but does not contain either the record $< T_i$ **commit**$>$ or $< T_i$ **abort**$>$
  - Transaction T_i needs to be redone if the log
    - contains the records $< T_i$ **start**$>$
    - and contains the record $< T_i$ **commit** $>$ or $< T_i$ **abort** $>$
  - It may seem strange to redo transaction T_i if the record $< T_i$ **abort**$>$ record is in the log
    - To see why this works, note that if $< T_i$ **abort**$>$ is in the log, so are the redo-only records written by the undo operation. Thus, the end result will be to undo T_i 's modifications in this case. This slight redundancy simplifies the recovery algorithm and enables faster overall recovery time
    - such a redo redoes all the original actions including the steps that restored old value – Known as **Repeating History**

Immediate Modification Recovery Example

Below we show the log as it appears at three instances of time.

(a)	(b)	(c)
$<T_0$ start$>$	$<T_0$ start$>$	$<T_0$ start$>$
$<T_0, A, 1000, 950>$	$<T_0, A, 1000, 950>$	$<T_0, A, 1000, 950>$
$<T_0, B, 2000, 2050>$	$<T_0, B, 2000, 2050>$	$<T_0, B, 2000, 2050>$
	$<T_0$ commit$>$	$<T_0$ commit$>$
	$<T_1$ start$>$	$<T_1$ start$>$
	$<T_1, C, 700, 600>$	$<T_1, C, 700, 600>$
		$<T_1$ commit$>$

Recovery actions in each case above are:

(a) undo (T_0): B is restored to 2000 and A to 1000, and log records $< T_0$, B, 2000 $>$, $< T_0$, A, 1000 $>$, $< T_0$, **abort**$>$ are written out

(b) redo (T_0) and undo (T_1): A and B are set to 950 and 2050 and C is restored to 700. Log records $< T_1$, C, 700 $>$, $< T_1$, **abort**$>$ are written out

(c) redo (T_0) and redo (T_1): A and B are set to 950 and 2050 respectively. Then C is set to 600.

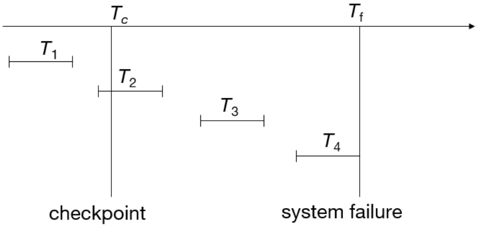
Checkpoints

- Redoing/undoing all transactions recorded in the log can be very slow
  - Processing the entire log is time-consuming if the system has run for a long time
  - We might unnecessarily redo transactions which have already output their updates to the database
- Streamline recovery procedure by periodically performing **checkpointing**
- All updates are stopped while doing checkpointing
  a) Output all log records currently residing in main memory onto stable storage
  b) Output all modified buffer blocks to the disk
  c) Write a log record $<$ **checkpoint** $L >$ onto stable storage where L is a list of all transactions active at the time of checkpoint

Checkpoints (2)

- During recovery we need to consider only the most recent transaction T_i that started before the checkpoint, and transactions that started after T_i
  - Scan backwards from end of log to find the most recent <**checkpoint** L > record
  - Only transactions that are in L or started after the checkpoint need to be redone or undone
  - Transactions that committed or aborted before the checkpoint already have all their updates output to stable storage
- Some earlier part of the log may be needed for undo operations
  - Continue scanning backwards till a record $<T_i$ **start**$>$ is found for every transaction T_i in L
  - Parts of log prior to earliest $<T_i$ **start**$>$ record above are not needed for recovery, and can be erased whenever desired

Checkpoints (3): Example



- Any transactions that committed before the last checkpoint should be ignored
  - T_1 can be ignored (updates already output to disk due to checkpoint)
- Any transactions that committed since the last checkpoint need to be redone
  - T_2 and T_3 redone
- Any transaction that was running at the time of failure needs to be undone and restarted
  - T_4 undone

Module Summary

- Failures may be due to variety of sources – each needs a strategy for handling
- A proper mix and management of volatile, non-volatile and stable storage can guarantee recovery from failures and ensure Atomicity, Consistency and Durability
- Log-based recovery is efficient and effective

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