

# Recovery Management



# Introduction

- ▶ Failure Classification
- ▶ Storage Structure
- ▶ Recovery and Atomicity
- ▶ Log-Based Recovery
- ▶ Shadow Paging
- ▶ Recovery With Concurrent Transactions
- ▶ Buffer Management
- ▶ Failure with Loss of Nonvolatile Storage
- ▶ Advanced Recovery Techniques
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- ▶ Remote Backup Systems

# 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 (e.g., 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 by 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

- ▶ Recovery algorithms are techniques to ensure database consistency and transaction atomicity and durability despite failures
  - Focus of this chapter
- ▶ Recovery algorithms have two parts
  1. Actions taken during normal transaction processing to ensure enough information exists to recover from failures
  2. Actions taken after a failure to recover the database contents to a state that ensures atomicity, consistency and durability

# 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

## ▶ **Stable storage:**

- a mythical form of storage that survives all failures
- approximated by maintaining multiple copies on distinct nonvolatile 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):
    1. Write the information onto the first physical block.
    2. When the first write successfully completes, write the same information onto the second physical block.
    3. The output is completed only after the second write successfully completes.

# Stable Storage Implementation (Cont.)

- ▶ 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:
  1. First find inconsistent blocks:
    1. *Expensive solution*: Compare the two copies of every disk block.
    2. *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
  2. 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

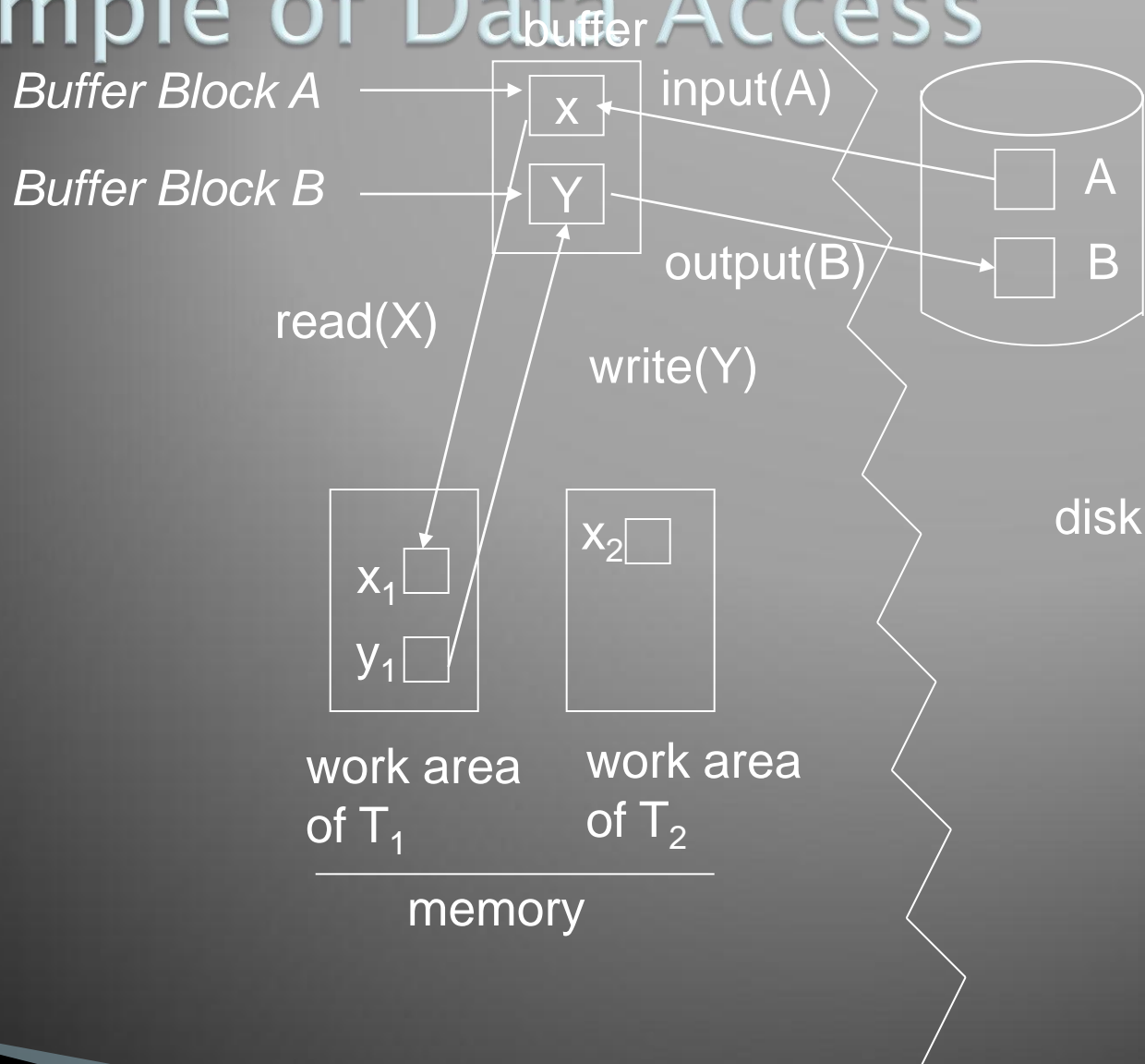
- ▶ **Physical blocks** are those blocks residing on the disk.
- ▶ **Buffer blocks** are the blocks residing temporarily in main memory.
- ▶ Block movements between disk and main memory are initiated through the following two operations:
  - **input( $B$ )** transfers the physical block  $B$  to main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



# Data Access (Cont.)

- ▶ Transaction transfers data items between system buffer blocks and its private work-area using the following operations :
  - **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.
  - both these commands may necessitate the issue of an **input( $B_x$ )** instruction before the assignment, if the block  $B_x$  in which  $X$  resides is not already in memory.
- ▶ Transactions
  - Perform **read( $X$ )** while accessing  $X$  for the first time;
  - All subsequent accesses are to the local copy.
  - After last access, transaction executes **write( $X$ )**.
- ▶ **output( $B_x$ )** need not immediately follow **write( $X$ )**. System can perform the **output** operation when it deems fit.

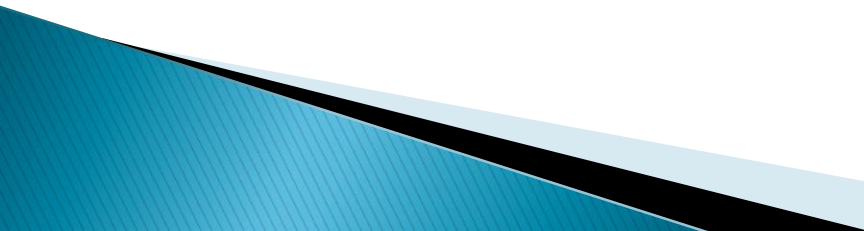
# Example of Data Access



# Recovery and Atomicity

- ▶ Modifying the database without ensuring that the transaction will commit may leave the database in an inconsistent state.
- ▶ Consider transaction  $T_i$  that transfers \$50 from account  $A$  to account  $B$ ; goal is either to perform all database modifications made by  $T_i$  or none at all.
- ▶ Several output operations may be required for  $T_i$  (to output  $A$  and  $B$ ). A failure may occur after one of these modifications have been made but before all of them are made.

# Recovery and Atomicity (Cont.)

- ▶ To ensure atomicity despite failures, we first output information describing the modifications to stable storage without modifying the database itself.
  - ▶ We study two approaches:
    - log-based recovery, and
    - shadow-paging
  - ▶ We assume (initially) that transactions run serially, that is, one after the other.
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# Log-Based Recovery

- ▶ A log is kept on stable storage.
  - The log is a sequence of **log records**, and maintains a record of update activities on the database.
- ▶ When transaction  $T_i$  starts, it registers itself by writing a  $\langle T_i \text{ start} \rangle$  log record
- ▶ *Before*  $T_i$  executes  $\text{write}(X)$ , a log record  $\langle T_i, X, V_1, V_2 \rangle$  is written, where  $V_1$  is the value of  $X$  before the write, and  $V_2$  is the value to be written to  $X$ .
  - Log record notes that  $T_i$  has performed a write on data item  $X_j$ .  $X_j$  had value  $V_1$  before the write, and will have value  $V_2$  after the write.
- ▶ When  $T_i$  finishes its last statement, the log record  $\langle T_i \text{ commit} \rangle$  is written.
- ▶ We assume for now that log records are written directly to stable storage (that is, they are not buffered)
- ▶ Two approaches using logs
  - Deferred database modification
  - Immediate database modification

# Deferred Database Modification

- ▶ The **deferred database modification** scheme records all modifications to the log, but defers all the writes to after partial commit.
- ▶ Assume that transactions execute serially
- ▶ Transaction starts by writing  $\langle T_i, \textit{start} \rangle$  record to log.
- ▶ A **write( $X$ )** operation results in a log record  $\langle T_i, X, V \rangle$  being written, where  $V$  is the new value for  $X$ 
  - Note: old value is not needed for this scheme
- ▶ The write is not performed on  $X$  at this time, but is deferred.
- ▶ When  $T_i$  partially commits,  $\langle T_i, \textit{commit} \rangle$  is written to the log
- ▶ Finally, the log records are read and used to actually execute the previously deferred writes.

# Deferred Database Modification

(Cont.)

- ▶ During recovery after a crash, a transaction needs to be redone if and only if both  $\langle T_i \text{ start} \rangle$  and  $\langle T_i \text{ commit} \rangle$  are there in the log.
- ▶ Redoing a transaction  $T_i$  (**redo  $T_i$** ) sets the value of all data items updated by the transaction to the new values.
- ▶ Crashes can occur while
  - the transaction is executing the original updates, or
  - while recovery action is being taken
- ▶ example transactions  $T_0$  and  $T_1$  ( $T_0$  executes before  $T_1$ ):

$T_0$ : read (A)  
A: - A - 50  
Write (A)  
read (B)  
B: - B + 50  
write (B)

$T_1$ : read (C)  
C: - C - 100  
write (C)



# Deferred Database Modification

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

< $T_0$  start>

< $T_0$ , A, 950>

< $T_0$ , B, 2050>

(a)

< $T_0$  start>

< $T_0$ , A, 950>

< $T_0$ , B, 2050>

< $T_0$  commit>

< $T_1$  start>

< $T_1$ , C, 600>

(b)

< $T_0$  start>

< $T_0$ , A, 950>

< $T_0$ , B, 2050>

< $T_0$  commit>

< $T_1$  start>

< $T_1$ , C, 600>

< $T_1$  commit>

(c)

- ▶ If log on stable storage at time of crash is as in case:

(a) No redo actions need to be taken

(b) redo( $T_0$ ) must be performed since < $T_0$  commit> is present

(c) redo( $T_0$ ) must be performed followed by redo( $T_1$ ) since  
< $T_0$  commit> and < $T_1$  commit> are present

# Immediate Database Modification

- ▶ The **immediate database modification** scheme allows database updates of an uncommitted transaction to be made as the writes are issued
  - since undoing may be needed, update logs must have both old value and new value
- ▶ Update log record must be written *before* database item is written
  - We assume that the log record is output directly to stable storage
  - Can be extended to postpone log record output, so long as prior to execution of an **output( $B$ )** operation for a data block  $B$ , all log records corresponding to items  $B$  must be flushed to stable storage
- ▶ Output of updated blocks 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.

# Immediate Database Modification Example

Log	Write	Output
$\langle T_0 \text{ start} \rangle$		
$\langle T_0, A, 1000, 950 \rangle$		
$T_0, B, 2000, 2050$		
	$A = 950$	
	$B = 2050$	
$\langle T_0 \text{ commit} \rangle$		
$\langle T_1 \text{ start} \rangle$		
$\langle T_1, C, 700, 600 \rangle$		
	$C = 600$	
		$B_B, B_C$
$\langle T_1 \text{ commit} \rangle$		$B_A$

- ▶ Note:  $B_X$  denotes block containing  $X$ .

# Immediate Database Modification

## (Cont.)

- ▶ Recovery procedure has two operations instead of one:
  - **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  $T_i$
  - **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  $T_i$
- ▶ Both operations must be **idempotent**
  - That is, even if the operation is executed multiple times the effect is the same as if it is executed once
    - Needed since operations may get re-executed during recovery
- ▶ When recovering after failure:
  - Transaction  $T_i$  needs to be undone if the log contains the record  $\langle T_i, \text{start} \rangle$ , but does not contain the record  $\langle T_i, \text{commit} \rangle$ .
  - Transaction  $T_i$  needs to be redone if the log contains both the record  $\langle T_i, \text{start} \rangle$  and the record  $\langle T_i, \text{commit} \rangle$ .
- ▶ Undo operations are performed first, then redo operations.

# Immediate DB Modification Recovery Example

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

< $T_0$  start>

< $T_0$ , A, 1000, 950>

< $T_0$ , B, 2000, 2050>

(a)

< $T_0$  start>

< $T_0$ , A, 1000, 950>

< $T_0$ , B, 2000, 2050>

< $T_0$  commit>

< $T_1$  start>

< $T_1$ , C, 700, 600>

(b)

< $T_0$  start>

< $T_0$ , A, 1000, 950>

< $T_0$ , B, 2000, 2050>

< $T_0$  commit>

< $T_1$  start>

< $T_1$ , C, 700, 600>

< $T_1$  commit>

(c)

set to 950 and 2050 respectively.

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