Database Design & Applications

Backup and Recovery

Objectives

- Failure Classification
- Storage Structure
- Recovery and Atomicity
- Log-Based Recovery
- Shadow Paging
- Recovery With Concurrent Transactions
- Buffer Management

Failure

- **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
- **Recovery algorithms have two parts:**
  - Actions taken during normal transaction processing to ensure enough information exists to recover from failures
  - 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

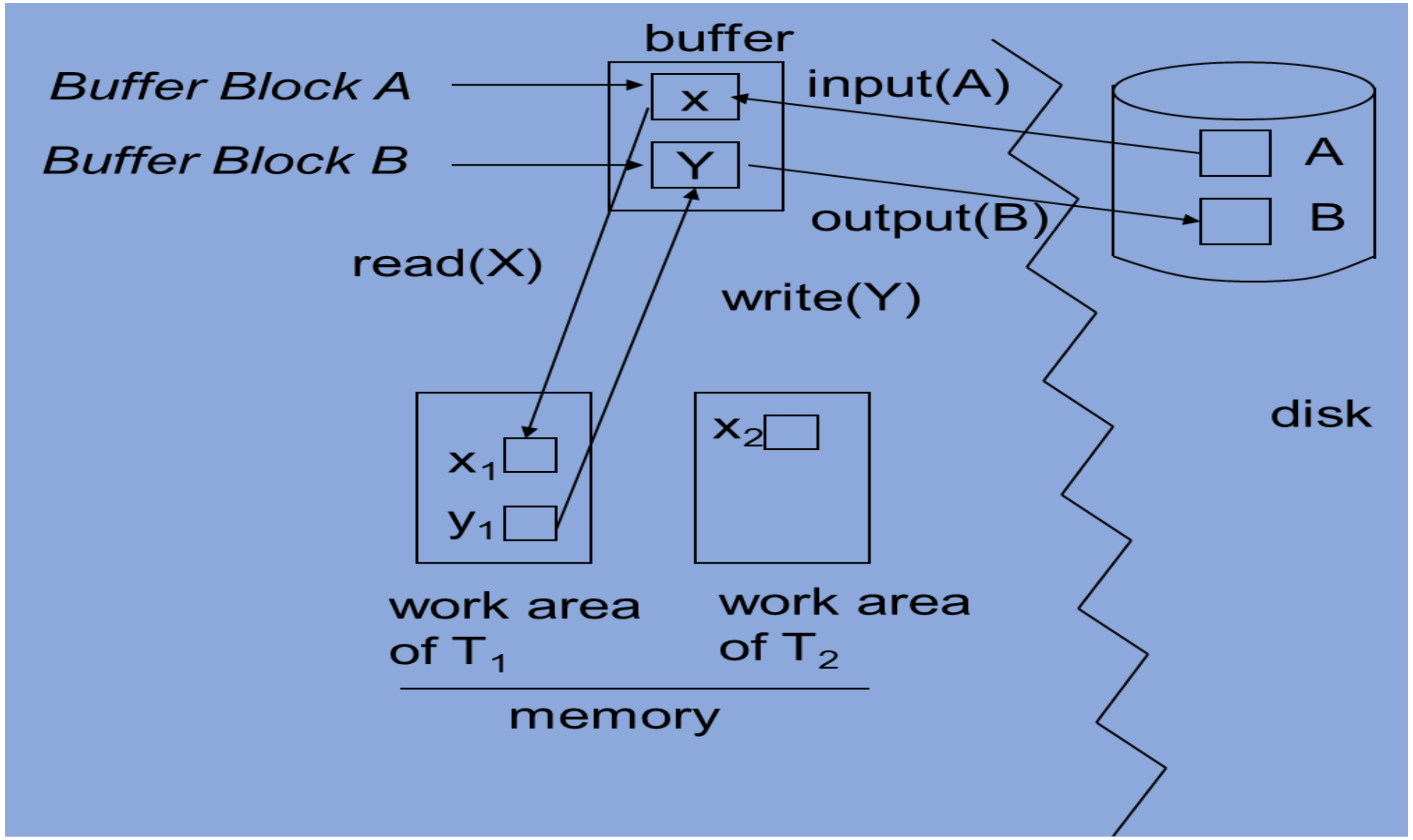
Data Access

- 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 Ti has its private work-area in which local copies of all data items accessed and updated by it are kept.
  - Ti'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 xi.
  - write(X) assigns the value of local variable xi to data item {X} in the buffer block.
  - Both these commands may necessitate the issue of an input(BX) instruction before the assignment, if the block BX 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(BX) 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 Ti that transfers $50 from account A to account B; goal is either to perform all database modifications made by Ti or none at all.
- Several output operations may be required for Ti (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.
- **Two main approaches are:**
  - log-based recovery
  - shadow-paging
- We assume (initially) that transactions run serially, that is, one after the other.

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 Ti starts, it registers itself by writing a

  <Ti start> log record
- Before Ti executes write(X), a log record <Ti, X, V1, V2> is written, where V1 is the value of X before the write, and V2 is the value to be written to X.
  - Log record notes that Ti has performed a write on data item Xj Xj had value V1 before the write, and will have value V2 after the write.
- When Ti finishes it last statement, the log record <Ti commit> 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 **<Ti start>** record to log.
- A **write(X)** operation results in a log record **<Ti, X, V>** 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 **Ti** partially commits, **<Ti commit>** 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 **<Ti start>** and **<Ti commit>** are there in the log.
- Redoing a transaction **Ti (redo Ti)** 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 **T0** and **T1** (T0 executes before T1):

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 (Cont.)

- 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$>$
$<T_0, A, 950>$	$<T_0, A, 950>$	$<T_0, A, 950>$
$<T_0, B, 2050>$	$<T_0, B, 2050>$	$<T_0, B, 2050>$
	$<T_0$ commit$>$	$<T_0$ commit$>$
	$<T_1$ start$>$	$<T_1$ start$>$
	$<T_1, C, 600>$	$<T_1, C, 600>$
		$<T_1$ commit$>$

- 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 **$<T_i$ 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
<T_0 **start**>		
<T_0, A, 1000, 950>		
T_o, 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

- 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 **<T_i start>,** but does not contain the record **<T_i commit>.**
  - Transaction T_i needs to be redone if the log contains both the record <T_i **start**> and the record **<T_i commit>.**
- 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 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>
(a)	(b)	(c)

- **Recovery actions in each case above are:**
  a) undo (T_0): B is restored to 2000 and A to 1000.
  b) undo (T_1) and redo (T_0): C is restored to 700, and then *A* and *B* are 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

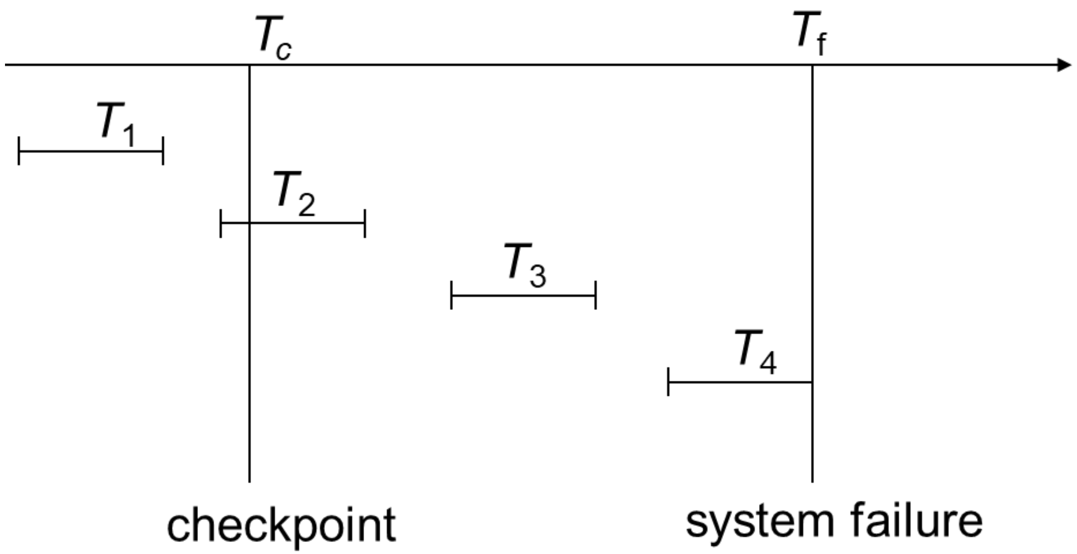
Checkpoints

- **Problems in recovery procedure as discussed earlier :**
  1. Searching the entire log is time-consuming
  2. We might unnecessarily redo transactions which have already
  3. Output their updates to the database.
- Streamline recovery procedure by periodically performing **checkpointing**
  1. Output all log records currently residing in main memory onto stable storage.
  2. Output all modified buffer blocks to the disk.
  3. Write a log record < **checkpoint**> onto stable storage.

Checkpoints (Cont.)

- During recovery we need to consider only the most recent transaction **Ti** that started before the checkpoint, and transactions that started after **Ti**.
- Scan backwards from end of log to find the most recent <checkpoint> record
- Continue scanning backwards till a record **<Ti start>** is found.
- Need only consider the part of log following above start record. Earlier part of log can be ignored during recovery, and can be erased whenever desired.
- For all transactions (starting from **Ti** or later) with no <**Ti commit**>, execute undo(**Ti**). (Done only in case of immediate modification.)
- Scanning forward in the log, for all transactions starting from Ti or later with a <**Ti commit**>, execute redo(**Ti**).

Example of Checkpoints

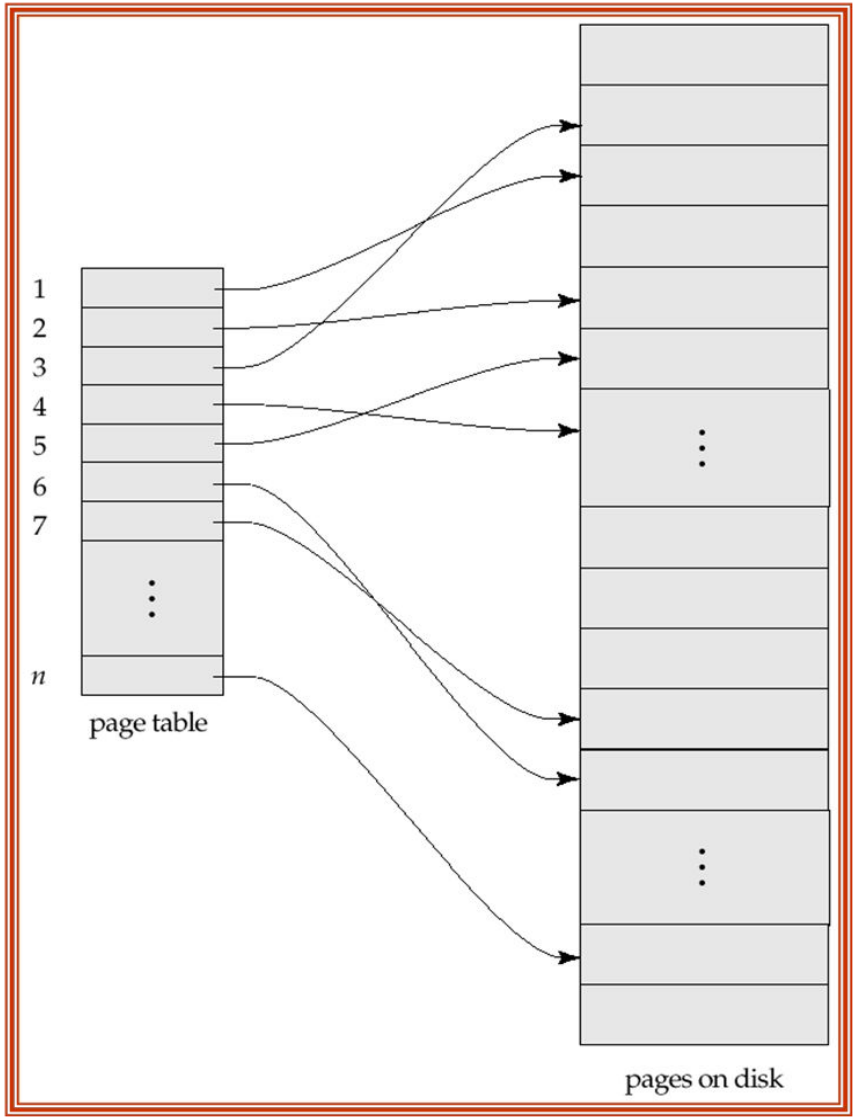


- T_1 can be ignored (updates already output to disk due to checkpoint)
- T_2 and T_3 redone.
- T_4 undone

Shadow Paging

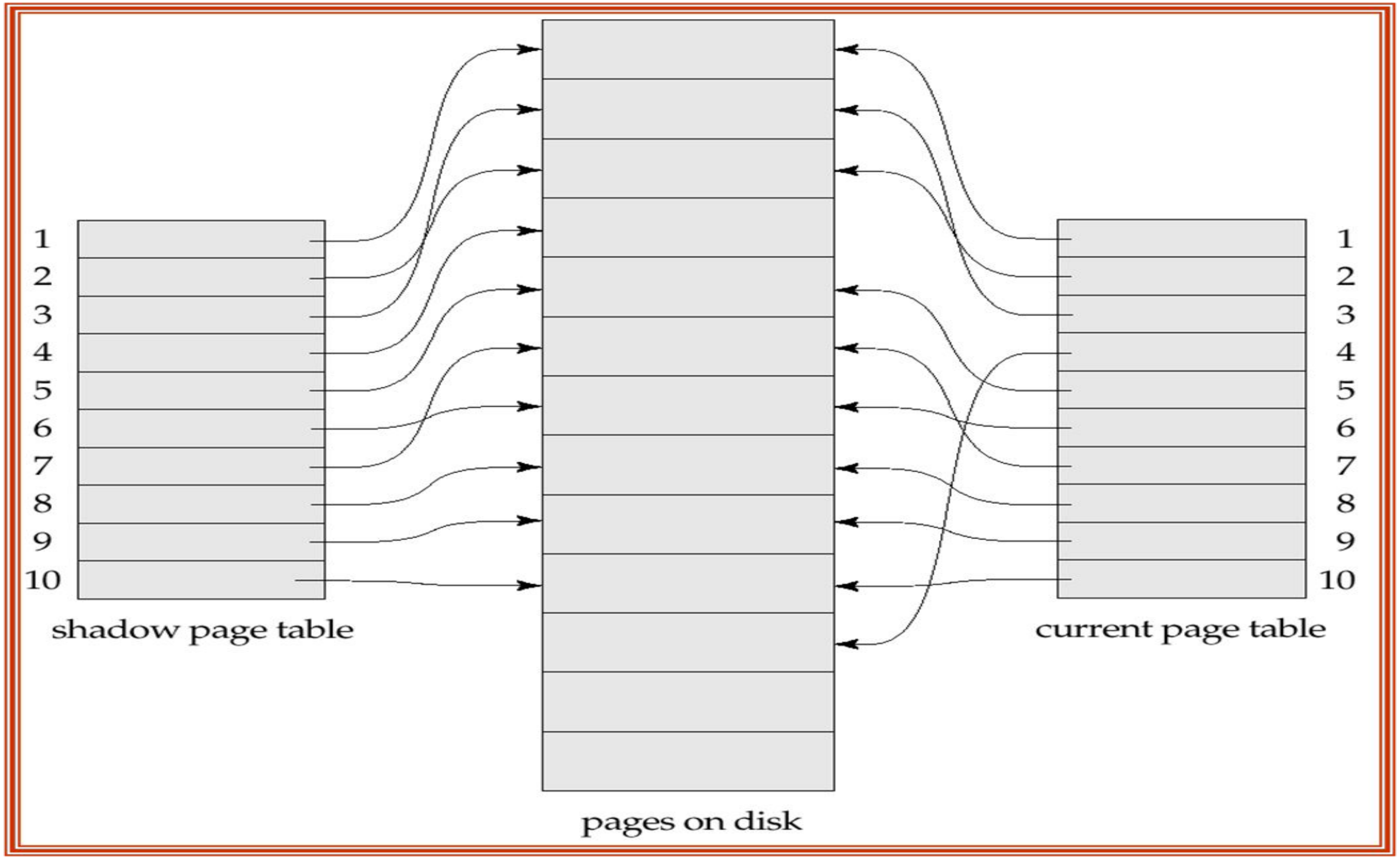
- **Shadow paging** is an alternative to log-based recovery; this scheme is useful if transactions execute serially
- **Idea:** maintain two page tables during the lifetime of a transaction –the **current page table**, and the **shadow page table**
- Store the shadow page table in nonvolatile storage, such that state of the database prior to transaction execution may be recovered.
  - Shadow page table is never modified during execution
- To start with, both the page tables are identical. Only current page table is used for data item accesses during execution of the transaction.
- Whenever any page is about to be written for the first time
  - A copy of this page is made onto an unused page.
  - The current page table is then made to point to the copy
  - The update is performed on the copy

Sample Page Table



Example of Shadow Paging

- Shadow and current page tables after write to page 4



Shadow Paging (Cont.)

- **To commit a transaction :**

1. Flush all modified pages in main memory to disk
2. Output current page table to disk
3. Make the current page table the new shadow page table, as follows:
   - keep a pointer to the shadow page table at a fixed (known) location on disk.
   - to make the current page table the new shadow page table, simply update the pointer to point to current page table on disk

- Once pointer to shadow page table has been written, transaction is committed.
- No recovery is needed after a crash — new transactions can start right away, using the shadow page table.
- Pages not pointed to from current/shadow page table should be freed (garbage collected).

Shadow Paging (Cont.)

- **Advantages of shadow-paging over log-based schemes**
  - no overhead of writing log records
  - recovery is trivial
- **Disadvantages :**
  - Copying the entire page table is very expensive
    - Can be reduced by using a page table structured like a B^+-tree
    - No need to copy entire tree, only need to copy paths in the tree that lead to updated leaf nodes
  - Commit overhead is high even with above extension
    - Need to flush every updated page, and page table
  - Data gets fragmented (related pages get separated on disk)
  - After every transaction completion, the database pages containing old versions of modified data need to be garbage collected
  - Hard to extend algorithm to allow transactions to run concurrently
    - Easier to extend log based schemes

THANK YOU!