PA152: Efficient Use of DB
11. Failure Recovery

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Integrity or correctness of data

- Would like data to be "accurate" or "correct" at all times

Employee

Name	Age
Novák	52
Starý	3421
Svoboda	1

Integrity or correctness of data

- Integrity constraint
  - Main approach to consistency of DB
  - Predicates that data must satisfy
- Examples:
  - Domain(x) = {red, blue, green}
  - *x* is a key of relation *R*
  - A valid value for attribute *x* of *R* (foreign key)
  - Functional dependency: $x \rightarrow y$

Integrity or correctness of data

- Consistent state
  - satisfies all constraints
- Consistent DB
  - DB in consistent state

Limits of integrity constraints

- May not capture “full correctness”
- Examples: (Transaction constraints)
  - No employee should make more than twice the average salary.
  - When salary is updated,
    new salary > old salary
  - When account record is deleted,
    balance = 0

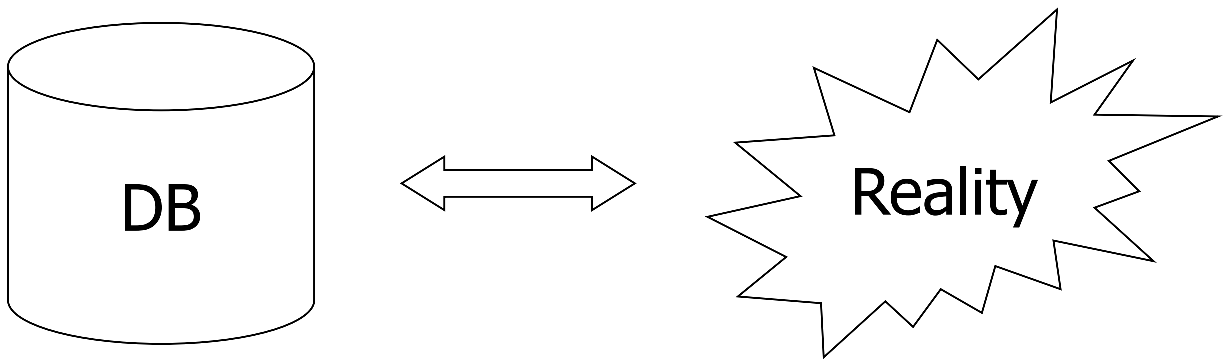
Limits of integrity constraints

- Some could be “emulated” by simple constraints
  - Deletion of account replaced with deletion flag

account	acc.no.	...	balance	deleted

Limits of integrity constraints

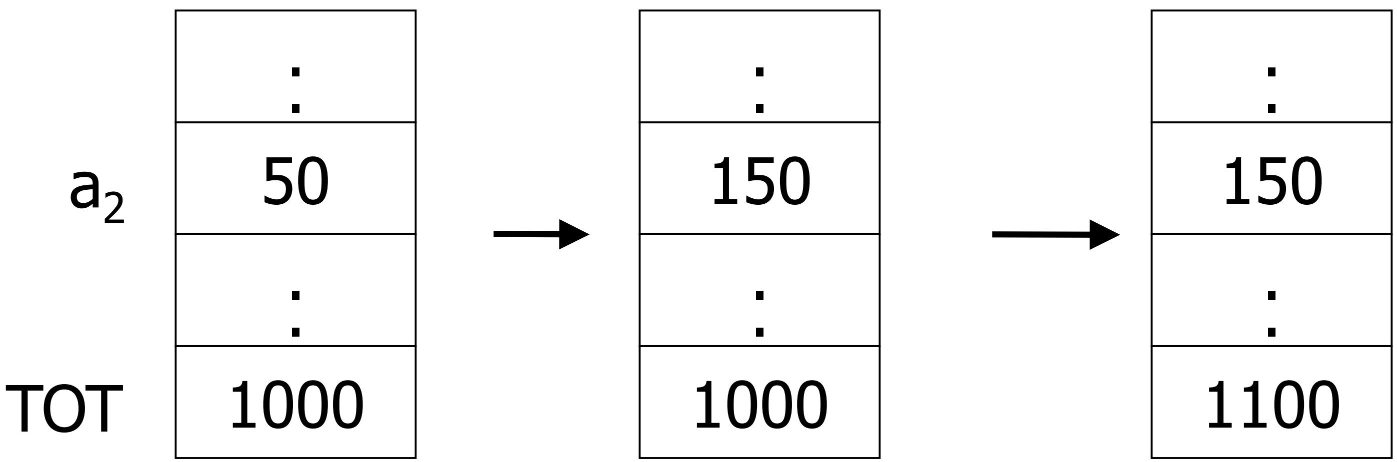
- Database should reflect real world.



- Continue with constraints
  - even though some part of "reality" cannot be defined as constraint or DB does not mirror reality
- Observation
  - DB cannot always be consistent.

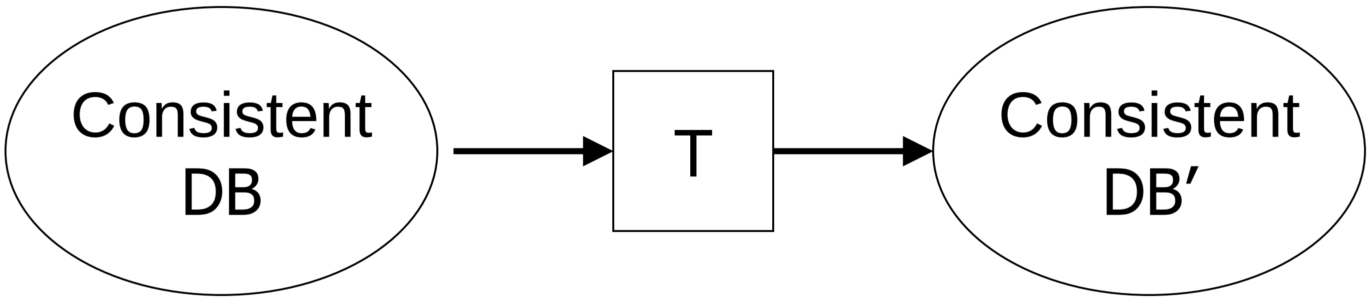
Example of inconsistent state

- Constraint example:
  - $a_1 + a_2 + \ldots.\ a_n = TOT$
- Money transfer of 100 CZK to account a_2
  - $a_2 \leftarrow a_2 + 100$
  - $TOT \leftarrow TOT + 100$



Solving inconsistencies

- Transaction
  - Collection of actions (updating data) that preserve consistency



Transaction Processing

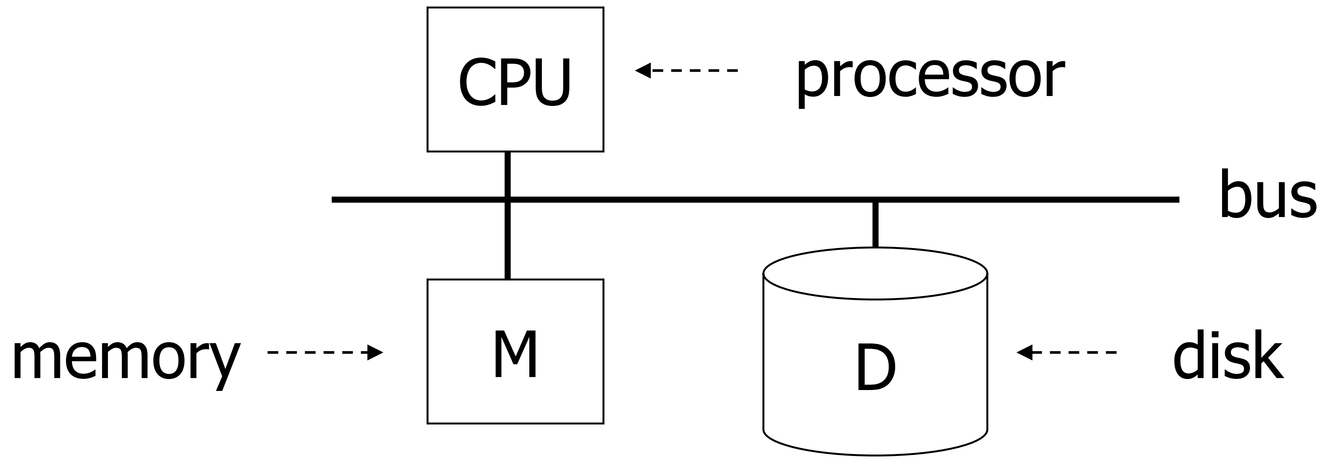
- Assumption
  - If T starts with consistent state and T executes in isolation
  - $\rightarrow$ T leaves DB in a consistent state
- Correctness
  - If we stop running transactions, DB is left consistent
  - Each transaction sees a consistent DB

Consistency Violation

- Causes
  - Transaction bug
  - DBMS bug
  - Hardware failure
    - E.g., a disk crash alters balance of account
  - Data sharing
    - E.g., T1: give 10% raise to programmers
      T2: change programmers → systems analysts

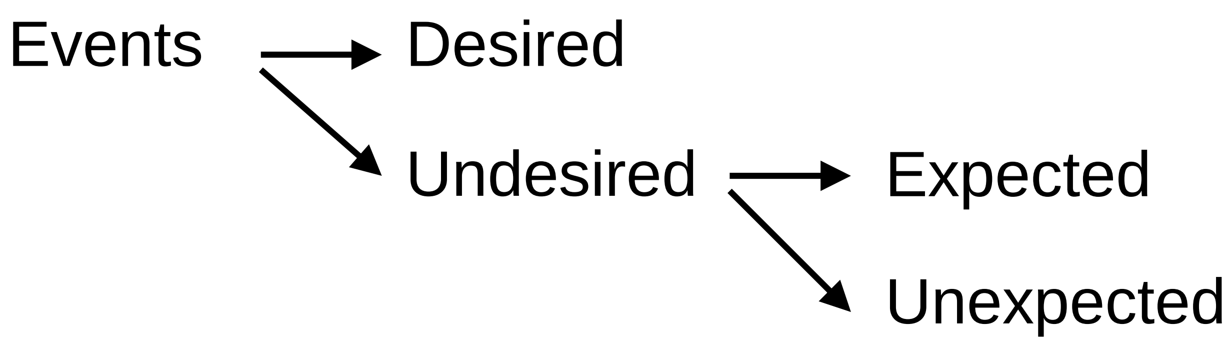
Prevent Consistency Violations

- Failure model
  - Identify possible risks
  - Handle individual component failures



Prevent Consistency Violations

- Failure model
  - Categorize risks



Prevent Consistency Violations

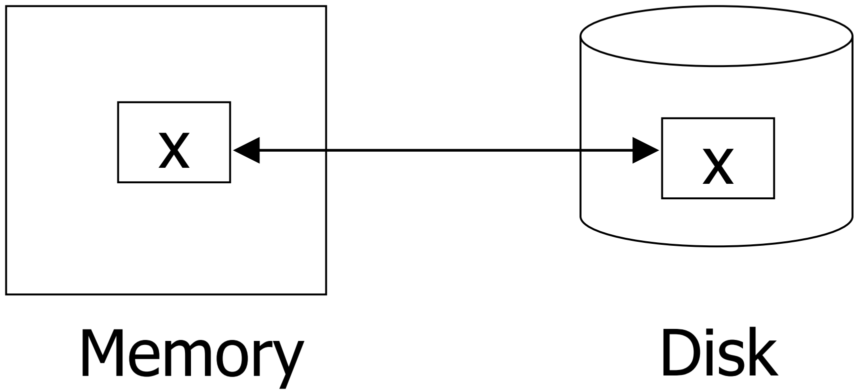
- Events
  - Desired
    - See product manuals… ☺
  - Undesired expected
    - Memory lost
    - CPU halts, resets
    - Forcible shutdown
  - Undesired Unexpected (Everything else)
    - Disk data is lost
    - Memory lost without CPU halt
    - Disaster – fire, flooding, …

Failure Model

- Approach:
  - Add low-level checks
  - Redundancy to increase probability model holds
- E.g.,
  - Replicate disk storage (stable store, RAID)
  - Memory parity, ECC
  - CPU checks

Failure Model

- Focusing on memory



- Key problem
  - Unfinished transactions
  - E.g.,

Constraint: $A=B$

Transaction T1: $A \leftarrow A \cdot 2$

$B \leftarrow B \cdot 2$

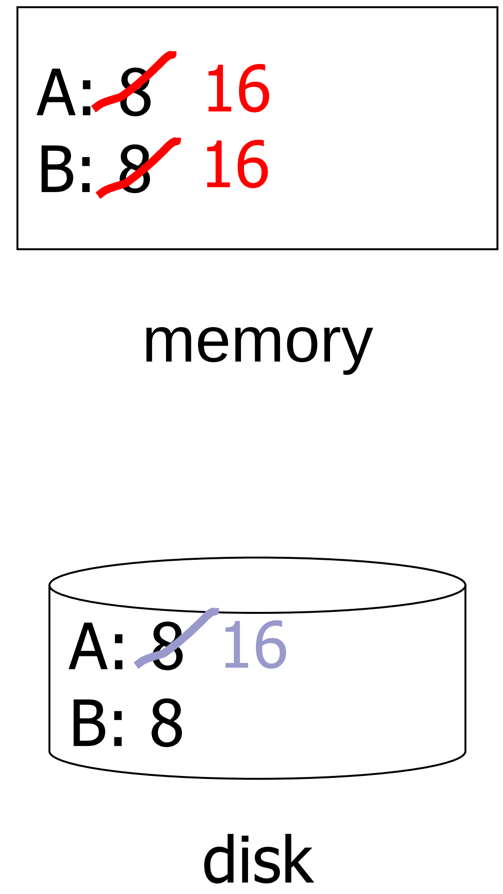
Transaction

- Elementary operations
  - Input (x): block containing x $\rightarrow$ memory
  - Read (x,t): a. *Input(x)*, if necessary,
    b. t $\leftarrow$ value of x in block
  - Write (x,t): a. *Input(x)*, if necessary,
    b. value of x in block $\leftarrow$ t
  - Output (x): block containing x $\rightarrow$ disk

Example: Transaction T1

T1: Read (A,t);
$t \leftarrow t \cdot 2$;
Write (A,t);
Read (B,t);
$t \leftarrow t \cdot 2$;
Write (B,t);
Output (A);
Output (B);

Failure!



Transaction

- Atomicity
  - Solution to unfinished transactions
  - Execute all actions of a transaction or none at all

- How to implement?
  - Logging changes done to data
    - i.e., create a journal (file with records about changes)

Logging

- Transaction produces records of changes into journal
  - Start, End, Output, Write, …
- Use
  - System failure$\rightarrow$ redo/undo changes following the journal
  - Recovery from backup $\rightarrow$ redo changes following the journal

Logging

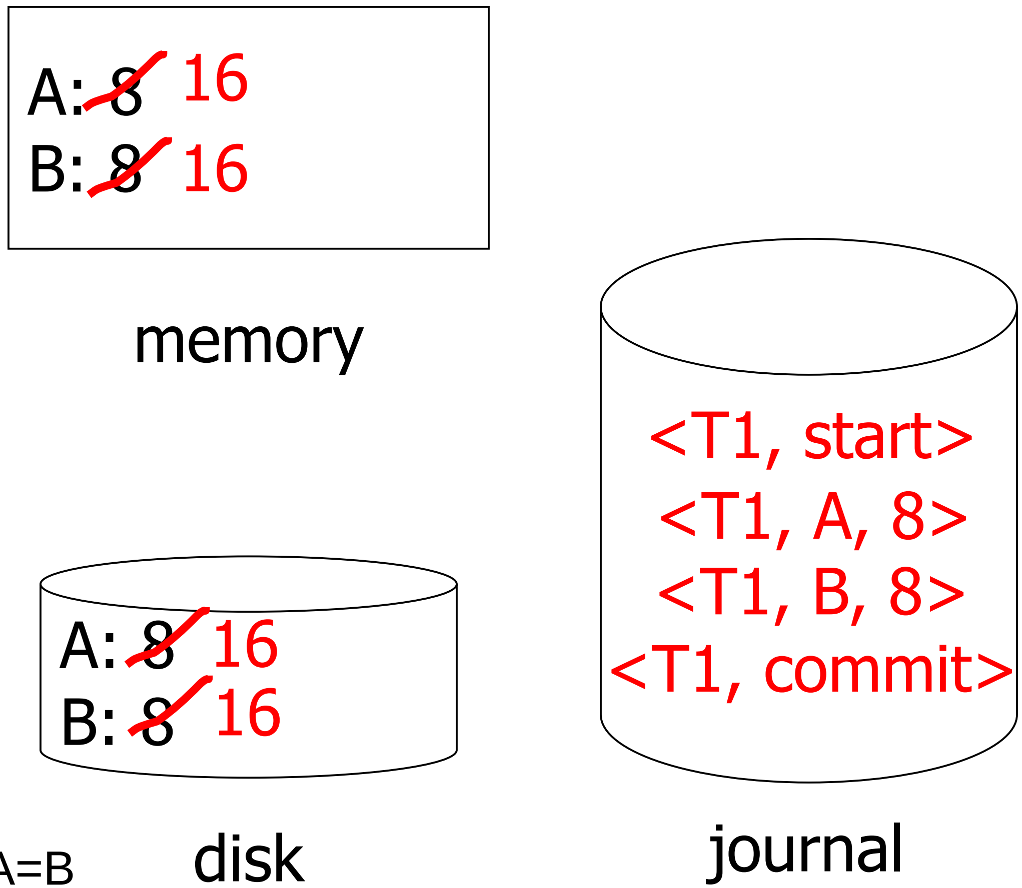
- During recovery after system failure
  - Some transactions are done again
    - REDO
  - Some transactions are aborted
    - UNDO

Undo logging

- Property
  - Changes done in transaction are immediately propagated to disk
  - Original (previous) value is logged.
- If not sure (100%) about storing of changes done during finished transaction
  - Undo the changes in the data from journal
    - i.e. recover last consistent DB
  - $\rightarrow$ Transaction has not ever been executed

Undo logging: Transaction T1

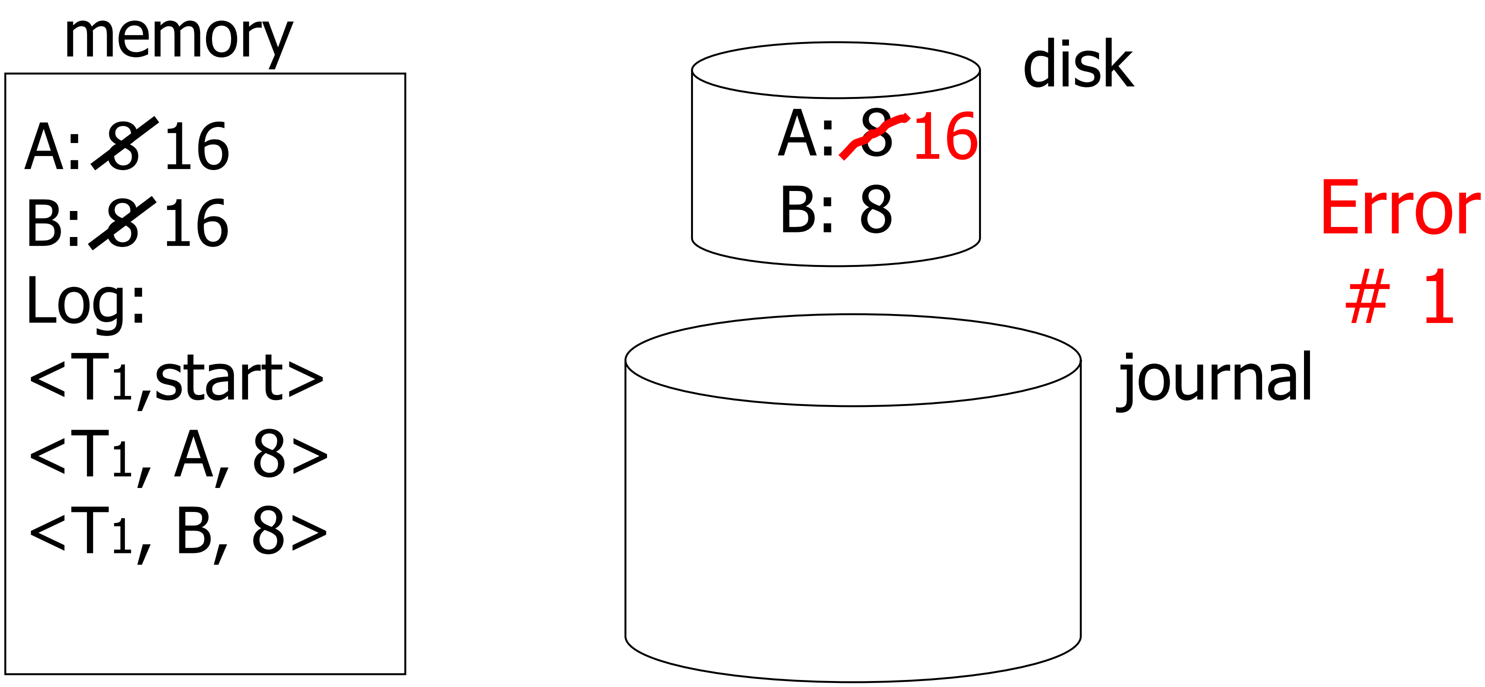
T1:
Read (A,t);
$t \leftarrow t \cdot 2$;
Write (A,t);
Read (B,t);
$t \leftarrow t \cdot 2$;
Write (B,t);
Output (A);
Output (B);



Remark: requiring validity of A=B

Undo logging

- Inconvenience
  - Logging uses buffer manager too → accumulated in memory, stored to disk later.



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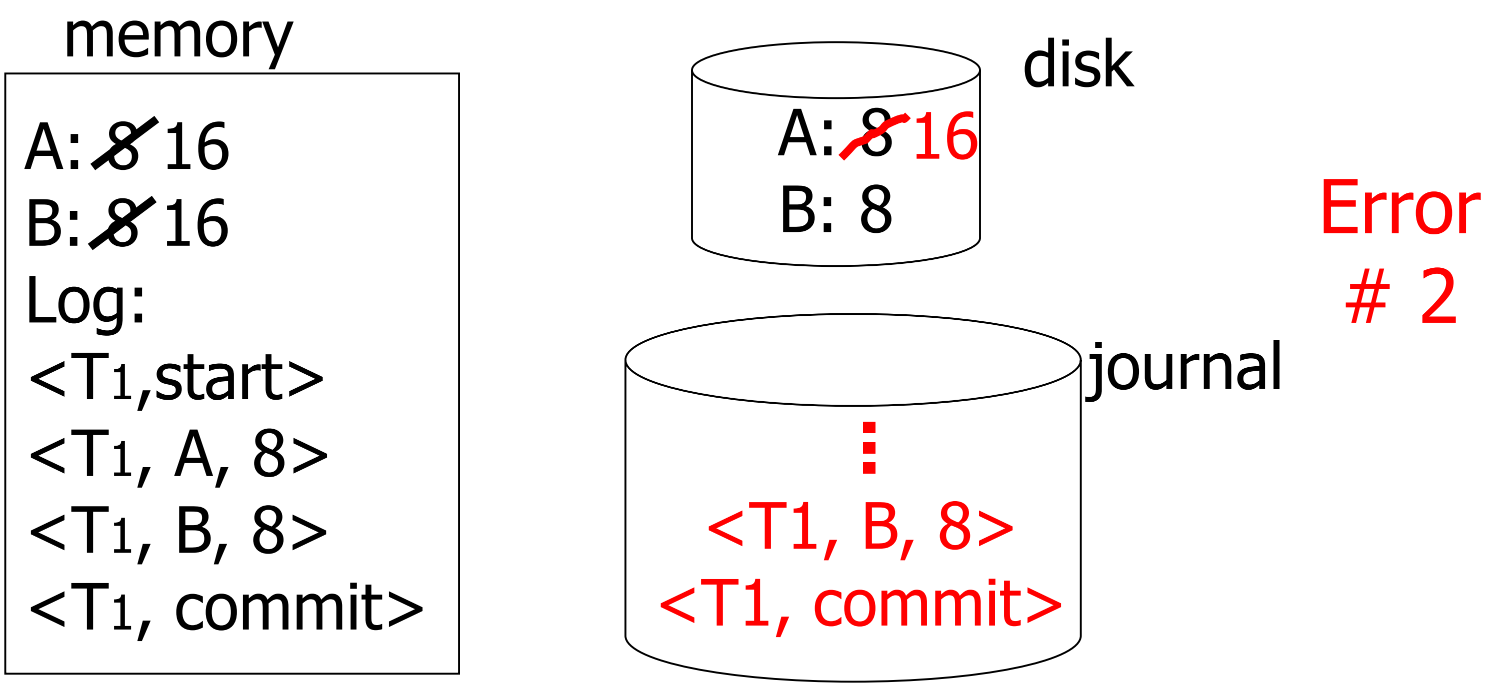


Undo logging

- Rules
  1. For every action **write**(X,t), generate undo log record containing old value of *X*
  2. Before *X* is modified on disk (**output**(X)), log records pertaining to *X* must be on disk
     - i.e., *write-ahead logging* (WAL)
  3. Before commit is flushed to log, all writes of transaction must be reflected on disk.

Undo logging – recovery after failure

- For every T_i with <T_i, start> in journal:
  - If <T_i, commit> or <T_i, abort> is in log, do nothing
  - Else for every <T_i, X, v> in journal:
    - write(X, v)
    - output(X)
    - write <T_i, abort> to journal

Is it correct?

Undo logging – recovery after failure

1. S = set of transactions
   - with <T_i, start> in log,
   - but no <T_i, commit> or <T_i, abort> in log
2. For each <T_i, X, v> in log
   - in the reverse order do (latest $\rightarrow$ earliest)
   - If $T_i \in S$, then write(X, v) and output (X)
3. For each $T_i \in S$
   - write <T_i, abort> to log
     - after successful writing all output(X) to disk

Undo logging – recovery after failure

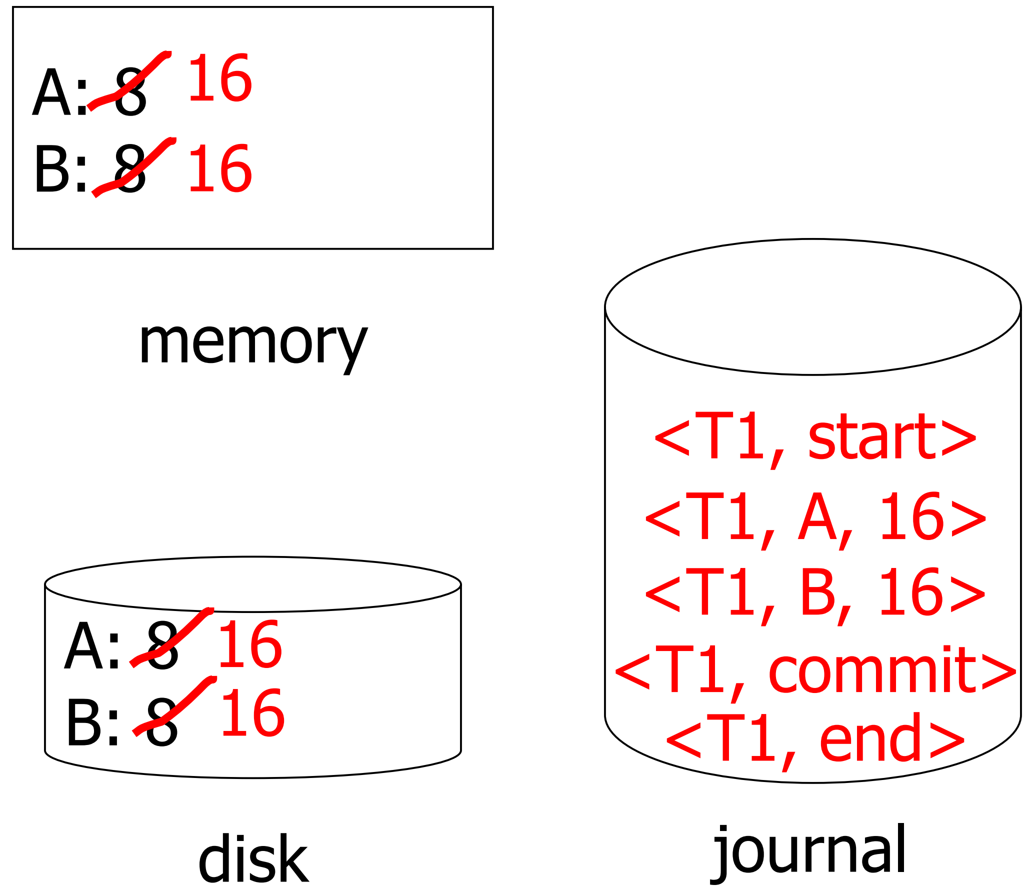
- Failure during recovery
  - No problem
    - UNDO can be done repeatedly (is idempotent)
    - Done for unfinished transactions

Redo logging

- Properties
  - Logging of new (updated) values
  - Changes done by transaction are *stored later*
    - → after transaction's commit
    - May save some intermediate writes to disk
    - i.e., requires storing log records before any change is done to DB.
  - Unfinished transactions are skipped during recovery

Redo logging: Transaction T1

T1:
Read (A,t);
t ← t · 2;
Write (A,t);
Read (B,t);
t ← t · 2;
Write (B,t);
Output (A);
Output (B);



Redo logging

- Rules
  1. For every action **write**(X,t), generate log record containing a new value of *X*
  2. Before *X* is modified on disk (in DB) (**output**(X)), all log records that modified X (including commit) must be on disk.
  3. For transaction modifying *X*
     1. Flush log records to disk
     2. Write updated blocks to disk
     3. Write *end* to journal

Redo logging – recovery after failure

- For every T_i with <T_i, commit> in log, do:
  - For all <T_i, X, v> in log:
    - write(X, v)
    - output(X)

Is it correct?

Redo logging – recovery after failure

1. S = set of transactions
   - with <T_i, commit > in log,
   - but <u>no</u> <T_i, end>
2. For each <T_i, X, v> in log
   - Do in forward order (earliest $\rightarrow$ latest)
   - If $T_i \in S$, then write(X, v) and output (X)
3. For each $T_i \in S$
   - write <T_i, end> to log

Combining <Ti, end> Records

- Want to delay DB flushes for hot objects

Say X is branch balance:
T1: ... update X...
T2: ... update X...
T3: ... update X...
T4: ... update X...

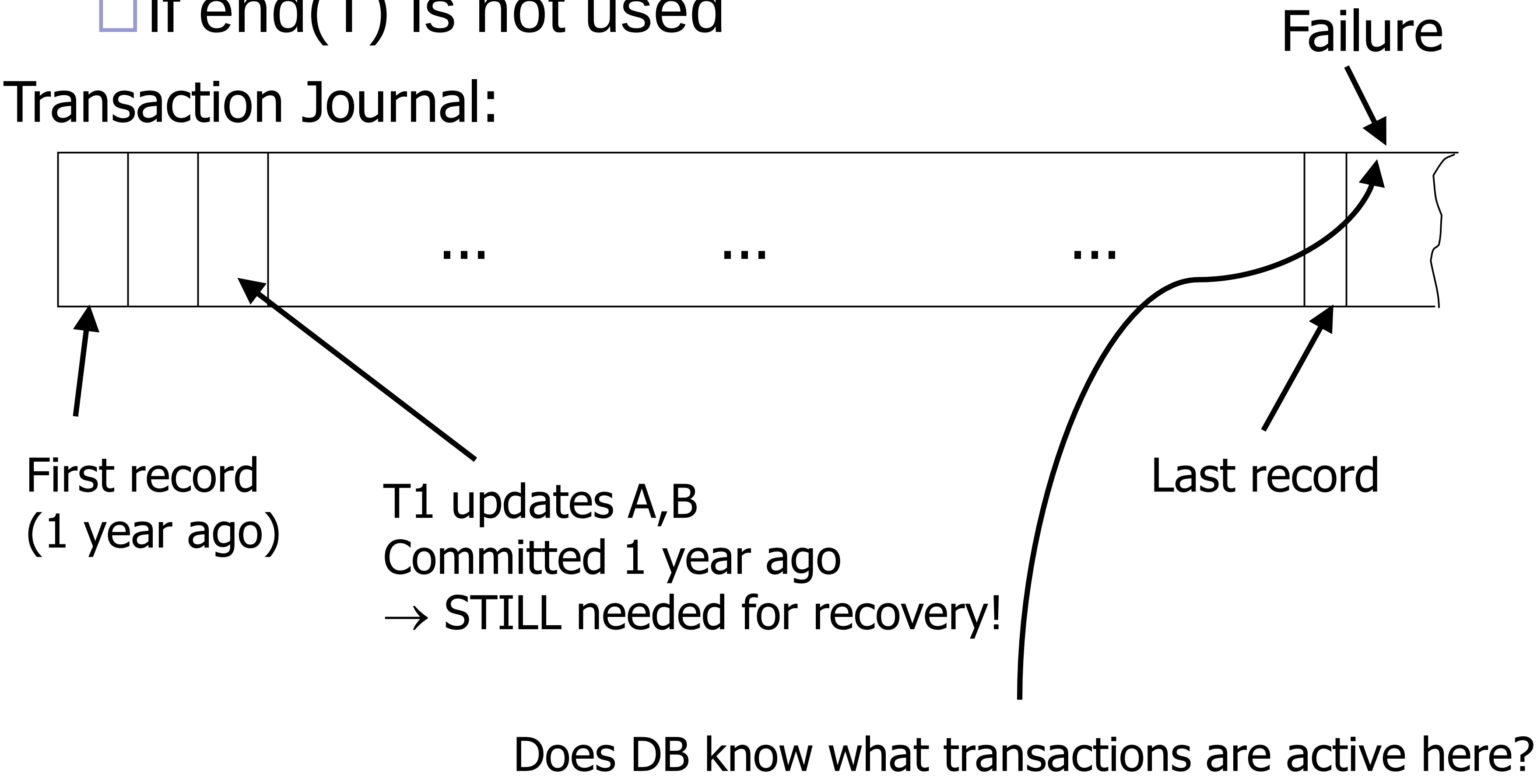
Log actions:
write X, v_1
~~output X~~
write X , v_2
~~output X~~
write X , v_3
~~output X~~
write X , v_4
output X
combined <end> (checkpoint)

Redo logging – recovery after failure

- Storing changes by output(X)
  - If there are more transactions changing X,
  - then output(X) can be done for the last log record <T_i, X, v> only
  - *end* can also be combined for multiple transactions

Redo logging – recovery after failure

- Recovery is very slow
  - if end(T) is not used

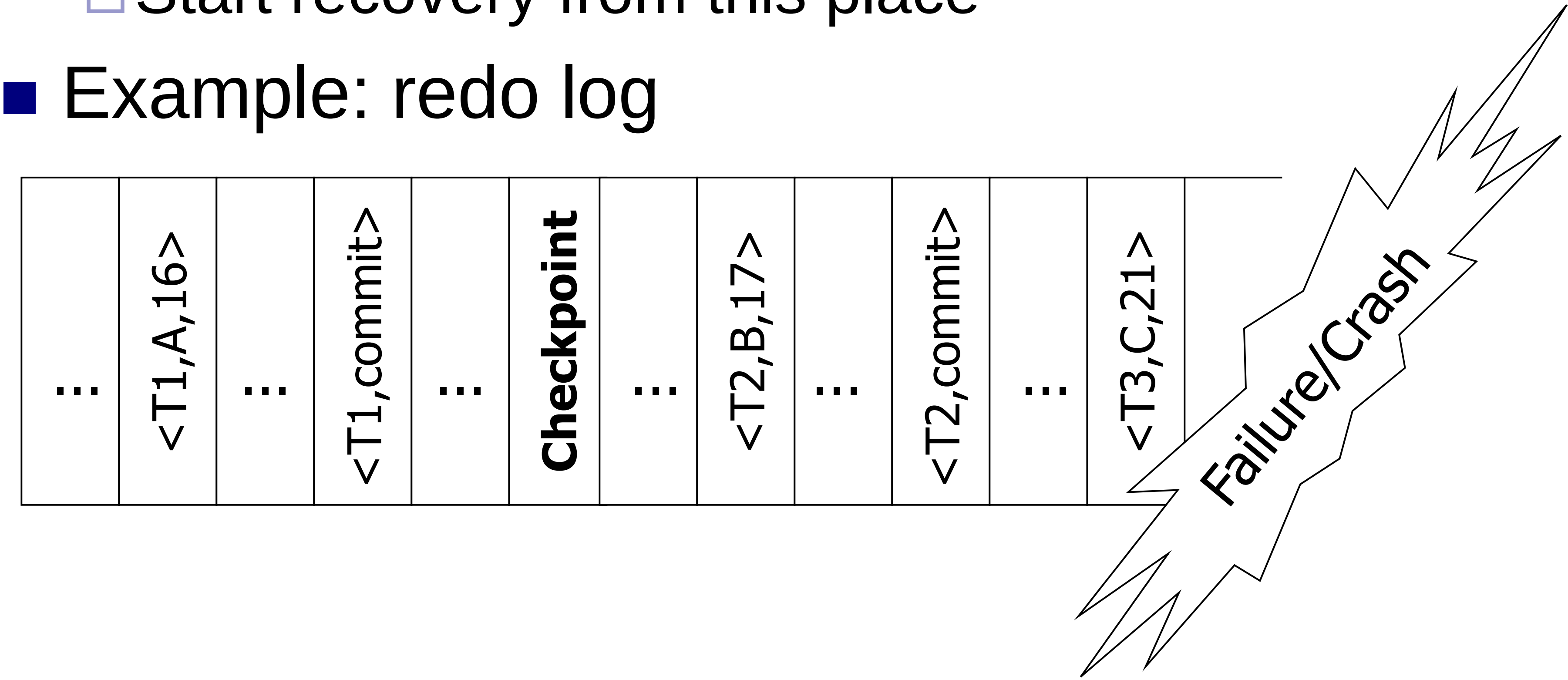


Logging – recovery after failure

- Solution to slowness
  $\rightarrow$ checkpoints
- Periodically do:
  1. Do not accept new transactions
  2. Wait until all transactions finish
  3. Flush all log records to disk (log)
  4. Flush all buffers to disk (DB)
  5. Write “checkpoint” record on disk (log)
  6. Resume transaction processing

Logging – recovery after failure

- Procedure during recovery
  - Locate last checkpoint
  - Start recovery from this place
- Example: redo log



Logging

- Key drawbacks
  - Undo logging
    - cannot bring backup DB copies up to date
  - Redo logging
    - need to keep all modified blocks in memory until commit
  - Writes to disk are controlled by logging rules and not be accesses to data
- Solution: Undo/Redo logging
  - Log record contains old and new value of X: $<T_i$, x, new X val, old X val$>$

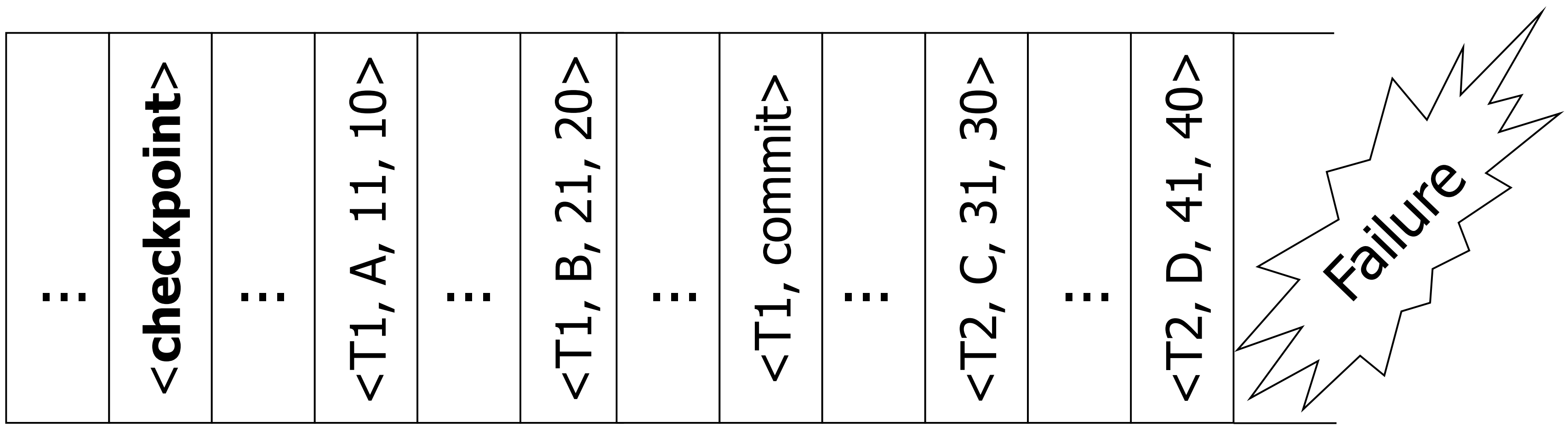
Undo/Redo logging

- Rules
  - Page *X* can be flushed before or after T_i *commit*
  - Log record flushed before corresponding updated page (WAL)
  - Flush log records at commit

- Recovery
  - Finished (committed) transactions are re-done from beginning
  - Unfinished transactions are rolled back (un-done) from end

Undo/Redo logging – recovery

- Example of undo/redo log:

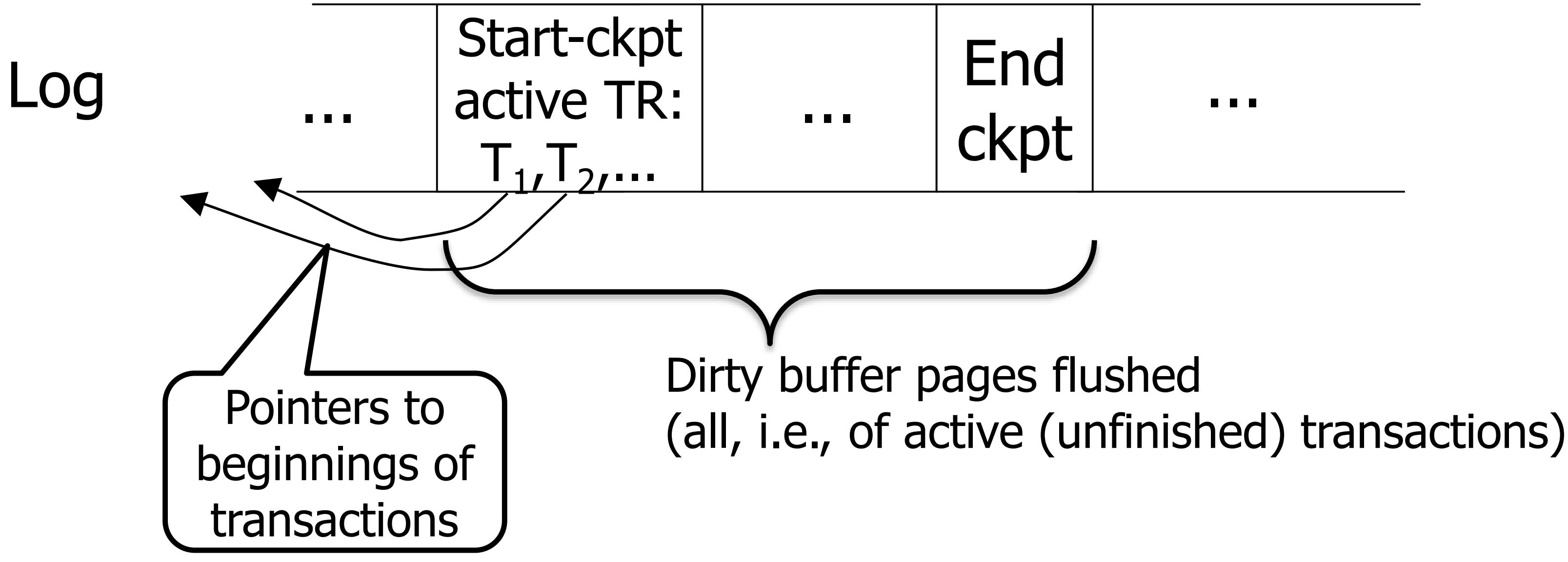


Checkpoints

- Simple checkpoint
  - No transaction can be active during creating checkpoint
  - Transaction throughput considerably lowered!
- Solution
  - Non-quiescent Checkpoint
    - Register active transactions
    - UNDO/REDO logging:
      - all modified pages (blocks) are flushed to disk

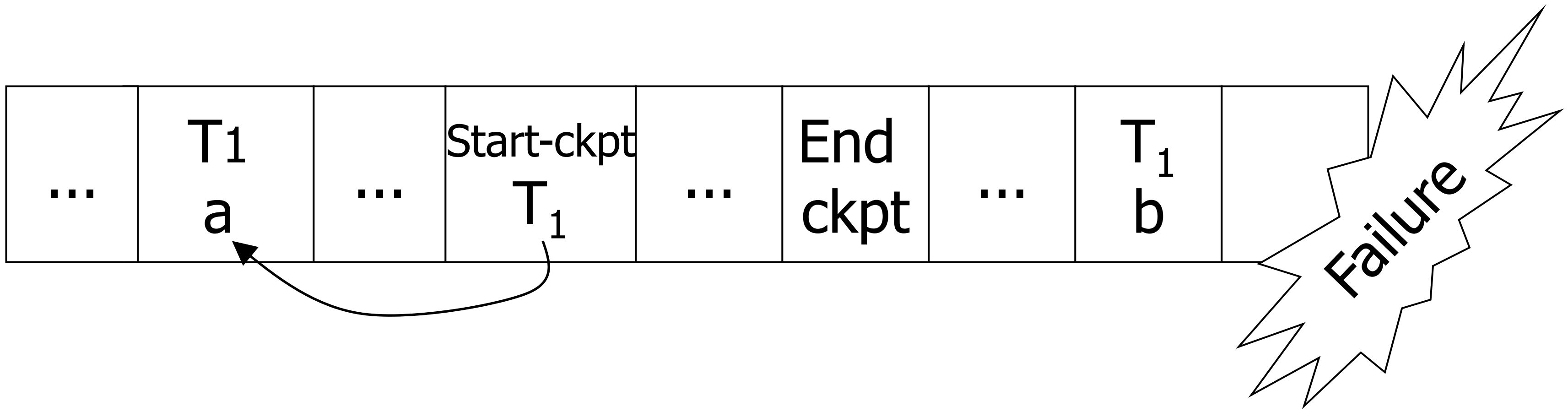
Non-quiescent Checkpoint

- Store start and end of checkpoint



Non-quiescent Checkpoint

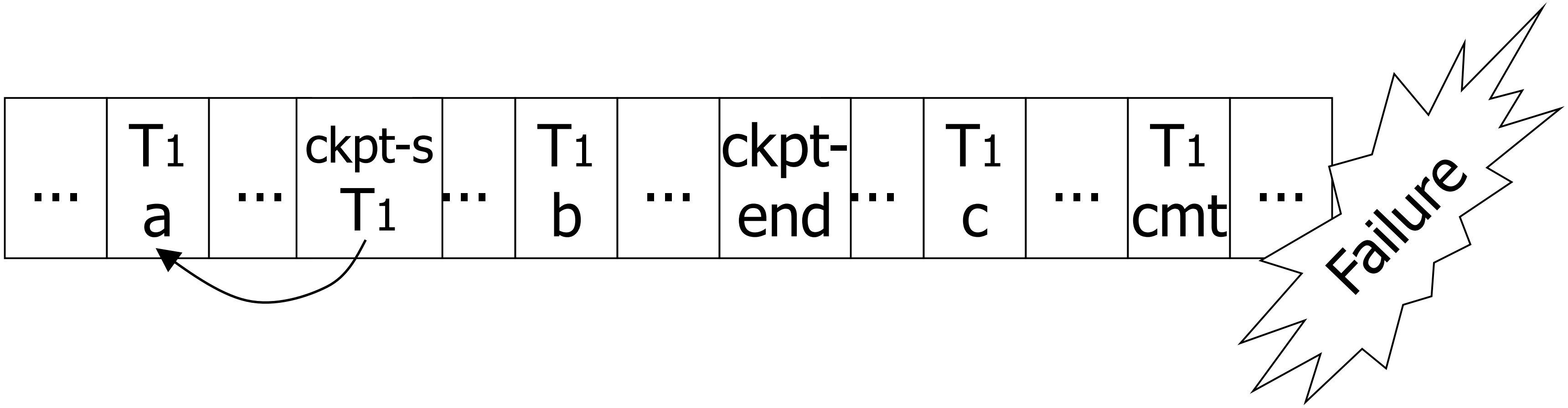
- Recovery 1



- T_1 has not been committed → Undo T_1 (undo changes to *b*, *a*)

Non-quiescent Checkpoint

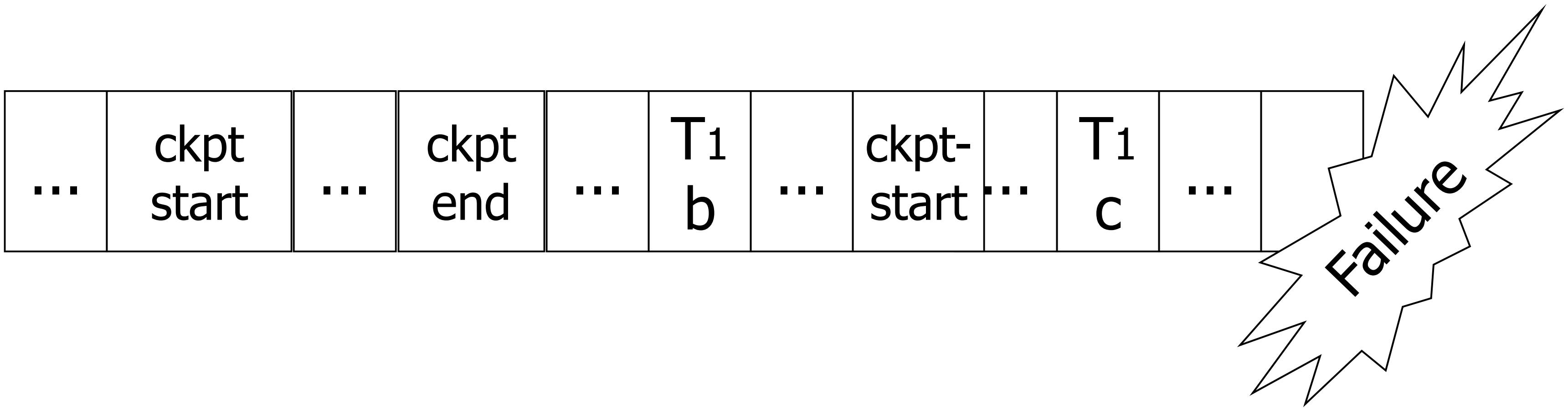
- Recovery 2



- T_1 has been committed → Redo T_1 (redo *b*,*c*)

Non-quiescent Checkpoint

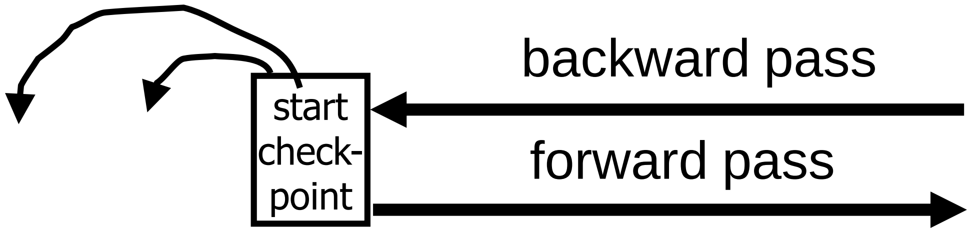
- Recovery 3



- Unfinished checkpoint
  → Locate last *finished* checkpoint
  - Start undo/redo of transactions

Recovery process

- Backwards pass
  (end of log → latest valid checkpoint start)
  1. construct set S of committed transactions
  2. undo actions of transactions not in S
- Remark: Undo pending transactions
  - Follow undo chains for transactions in checkpoint active list
- Forward pass
  (latest checkpoint start → end of log)
  - redo actions of S transactions (without *end*)

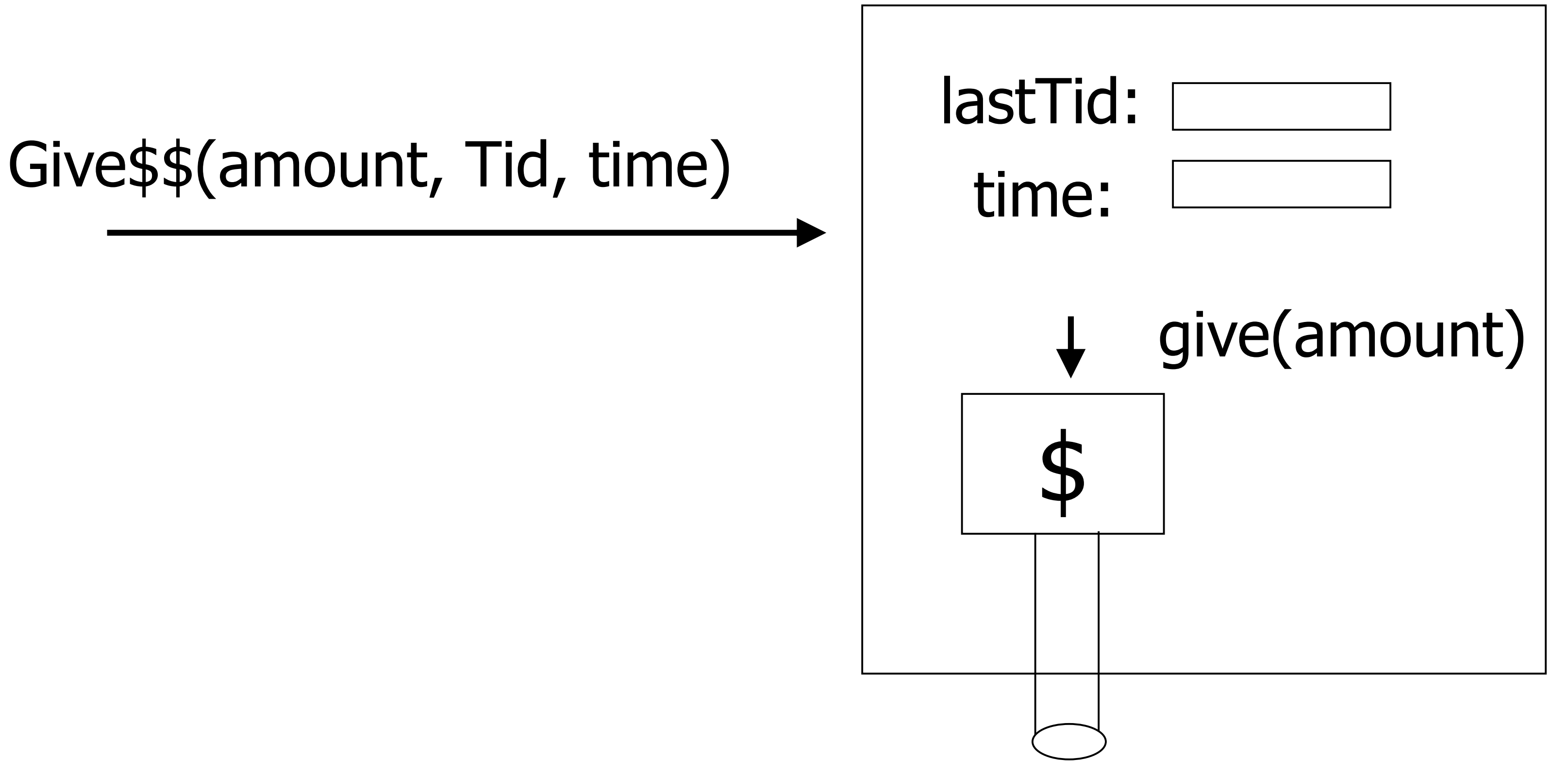


Real world transaction

- Withdraw cash from ATM
  - Info about bank accounts
  - HW of ATM
- Implementation
  - Transaction in DB
  - Dispense money
- Procedure
  - Do DB transaction, money dispensing after commit.
  - Dispensing should be made idempotent.

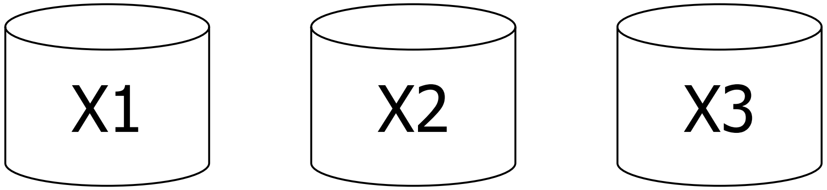
Real world transaction

- After DB transaction, a “signal“ for money dispensing is sent



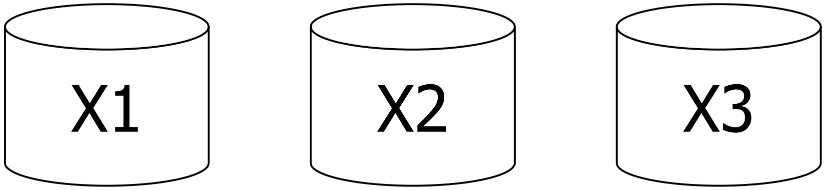
Media Failure

- RAID
- Make copies of data
  - E.g.,
    - Keep 3 copies
    - Output(X) → three outputs
    - Input(X) → three inputs + voting



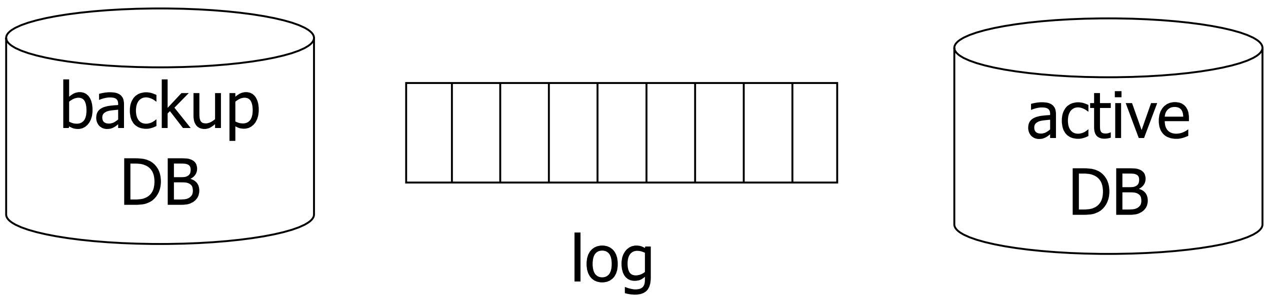
Media Failure

- Make copies of data
  - Other solution
    - Keep 3 copies
    - Output(X)
      $\rightarrow$ three outputs
    - Input(X)
      $\rightarrow$ read from first (if ok, continue)
      $\rightarrow$ read from second, …
    - Assumption
      - bad data can be detected



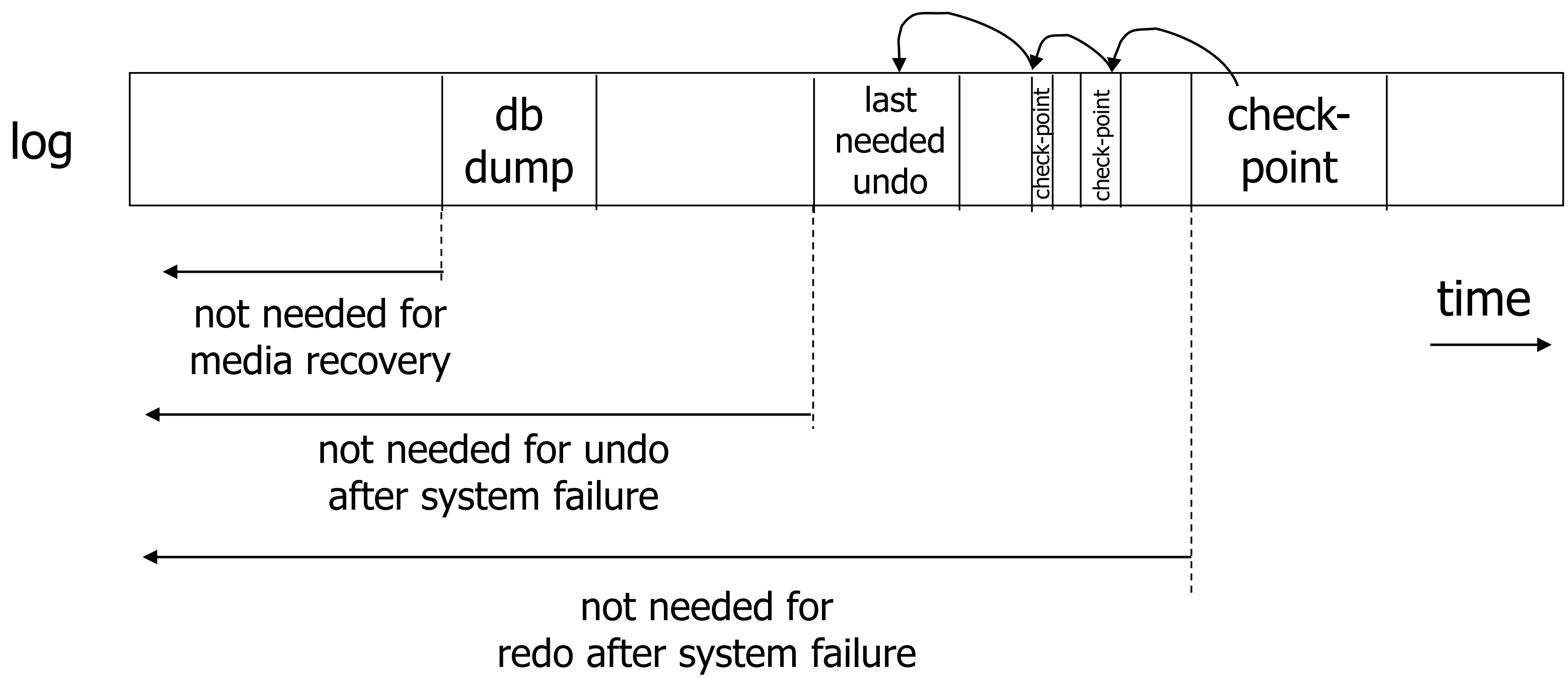
Media Failure

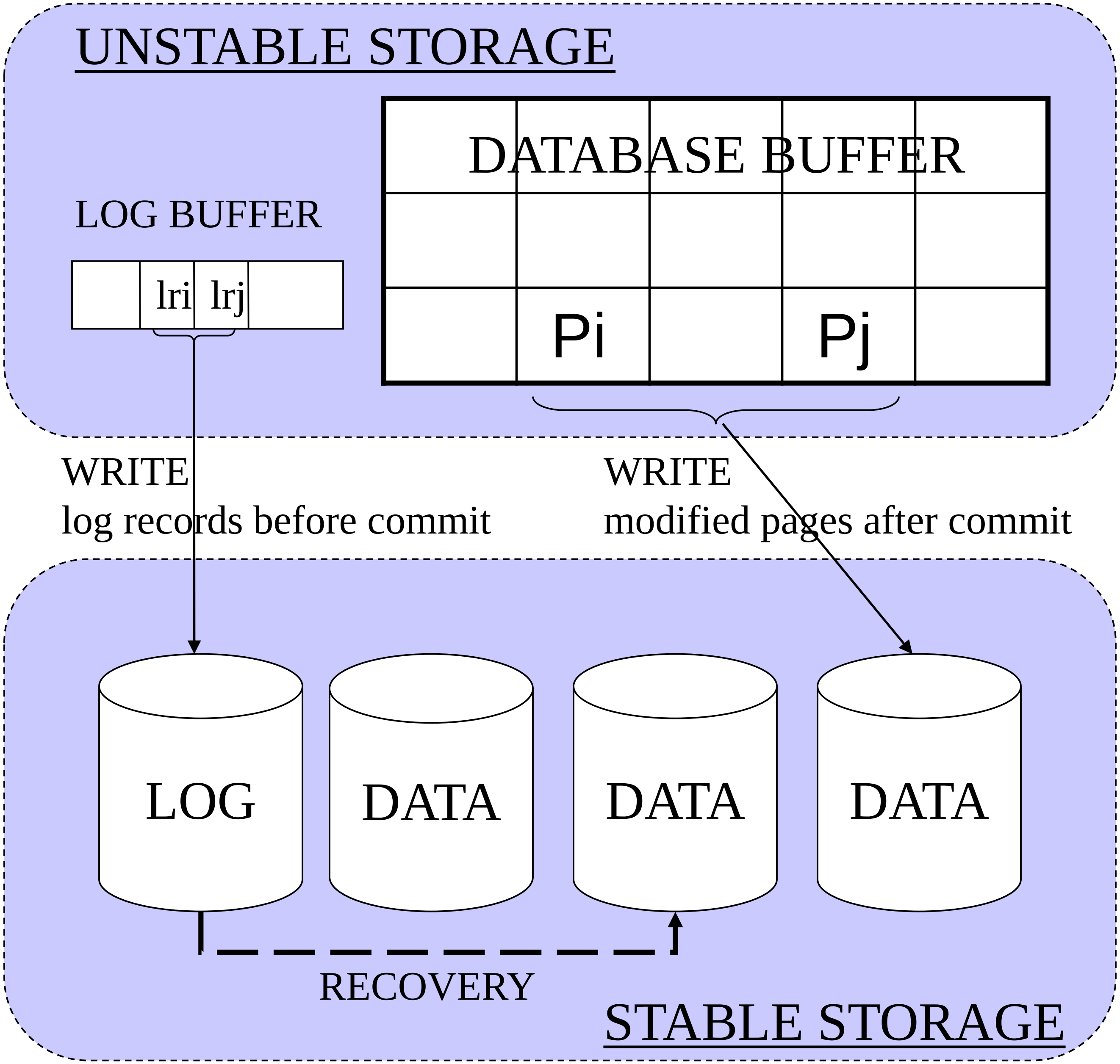
- DB backup (dump)
  - Recover DB backup
  - Apply log
    - Use redo entries of each transaction not finished at the backup time



Discarding Log

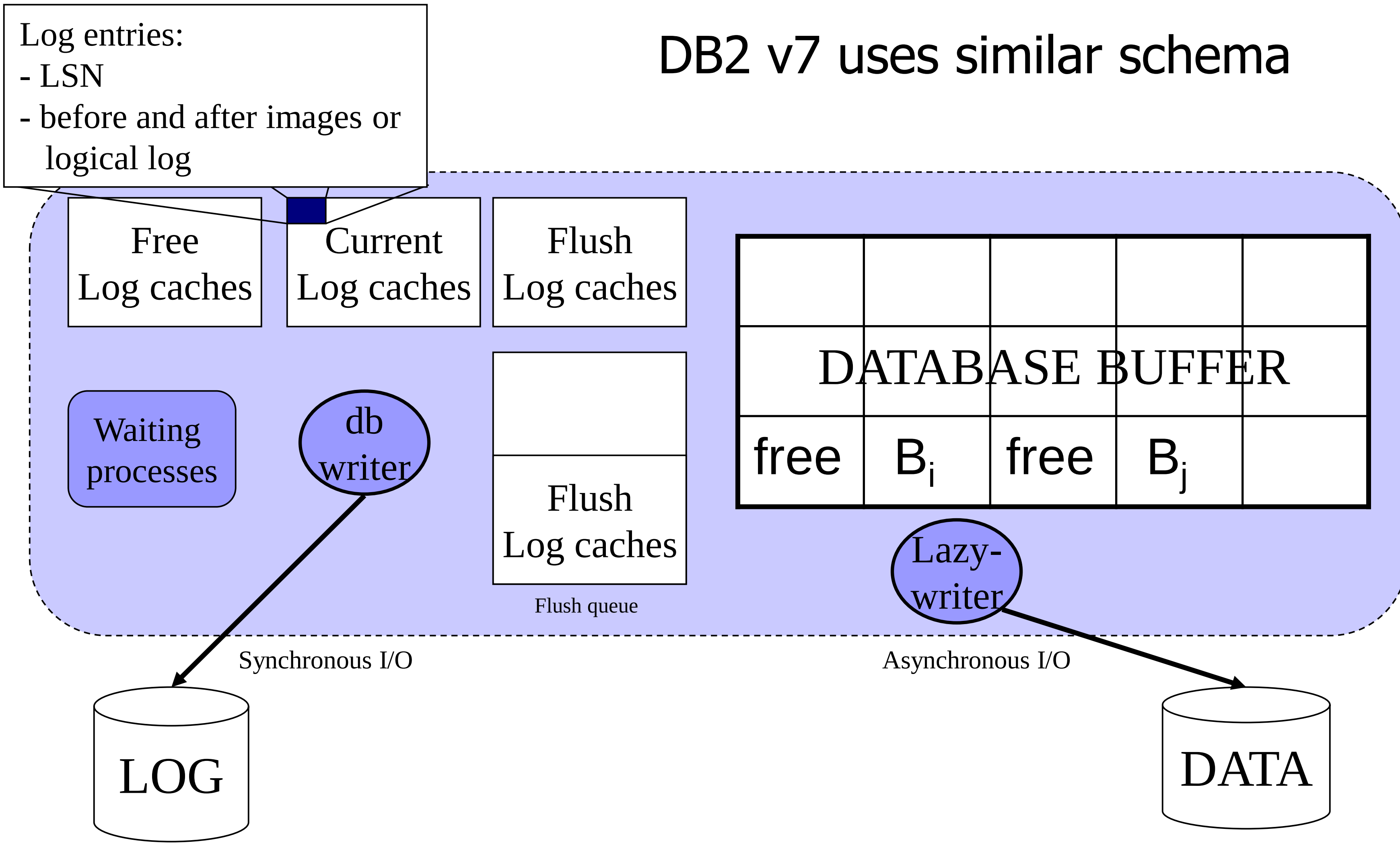
- When can log be discarded?
  - In case of UNDO/REDO logging



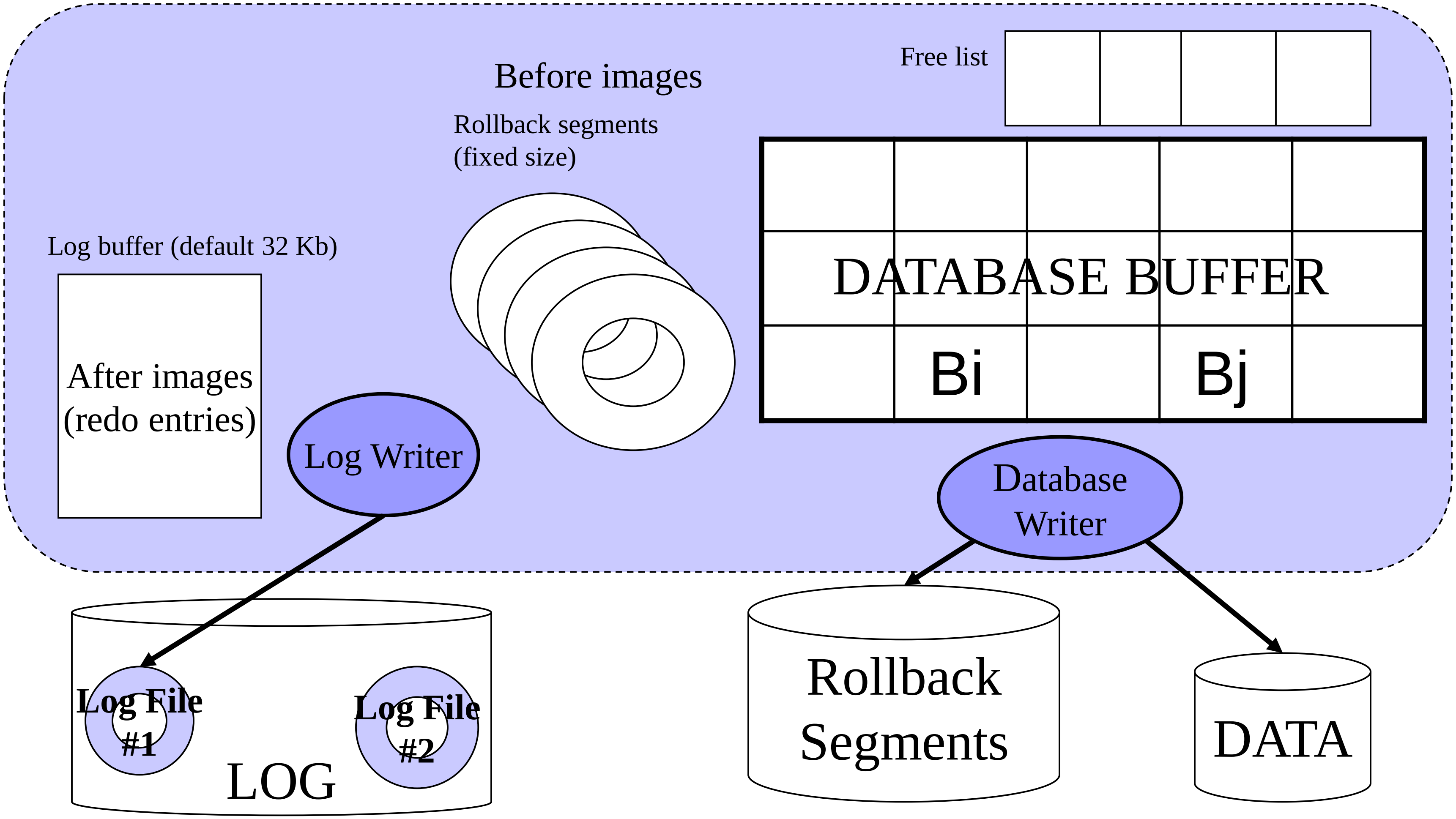

UNSTABLE STORAGE
DATABASE BUFFER
LOG BUFFER
lri
lrj
Pi
Pj
WRITE
log records before commit
WRITE
modified pages after commit
LOG
DATA
DATA
DATA
RECOVERY
STABLE STORAGE

Logging in SQLServer 2000

DB2 v7 uses similar schema



Logging in Oracle 8i

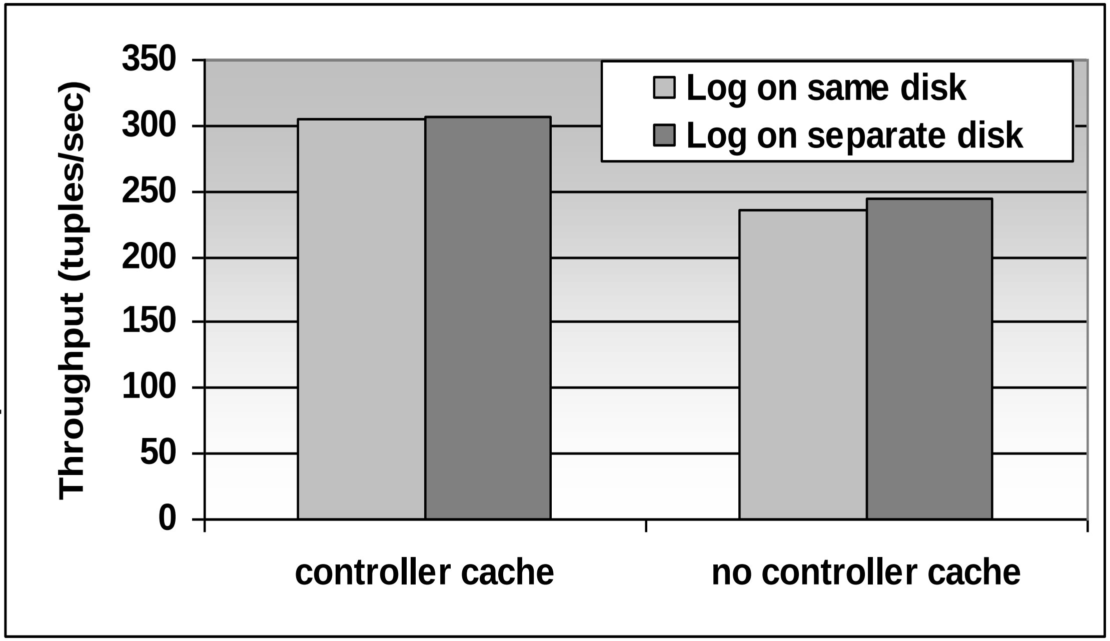


Storing Log

- On dedicated disk
- Log records are stored sequentially
- Sequential writes are much faster than random once (on a magnetic disk)

Disk for logging should not store any other data
+ sequential I/O
+ loss of log is not dependent on loss of DB

Storing Log



300 000 transactions
Each transaction = 1x INSERT

DB2 v7.1 server
5% improvement when log stored on dedicated disk

Controller Cache diminishes negative impact of non-dedicated disk
HW: middle server, Adaptec RAID controller (80Mb RAM), 2x18Gb disk.

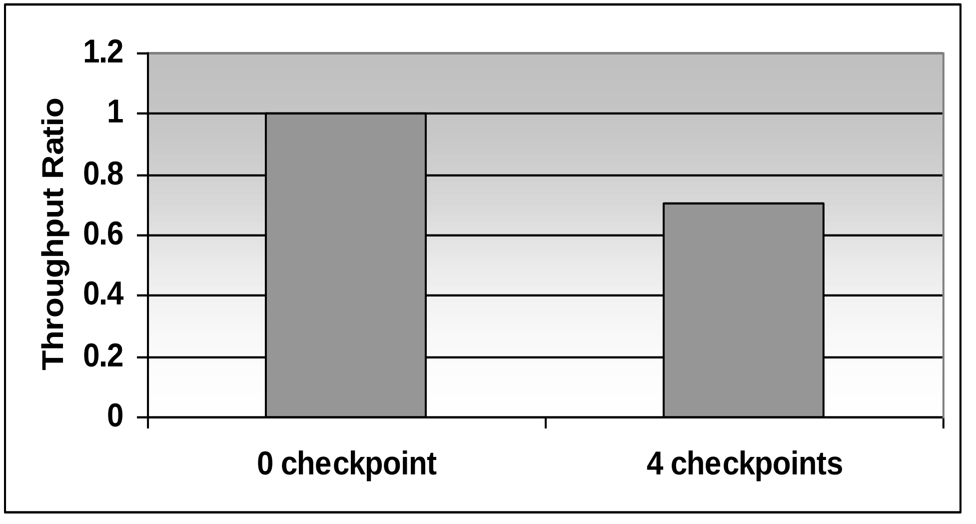
Flushing Buffers

- Flushing dirty page
  - When a threshold of modified pages is reached (Oracle 8)
  - When the ratio of free pages drops below a threshold (less than 3% in SQLServer 7)
  - After checkpoint
  - Periodically

Creating Checkpoints

Performance influence (decreased throughput)
Reduces size of log
Shortens time to recover after failure

300 000 transactions
Each transaction = one INSERT command
    Oracle 8i, Windows 2000



Summary & Takeaways

- Data consistency
  - One source of problems: failures
    - Solutions: (i) logging; (ii) redundancy
  - Another source of problems: data sharing
    - Solution: (i) Locking data during transactions
      - Not done in this course…
- Logging
  - Know principles and limitations
  - Understand checkpoints
  - Be able to do recovery

Lecture Takeaways

- …