CPS216: Data-intensive Computing Systems

Failure Recovery

Shivnath Babu

Key problem Unfinished transaction

Example Constraint: A=B

T_1: $A \leftarrow A \times 2$

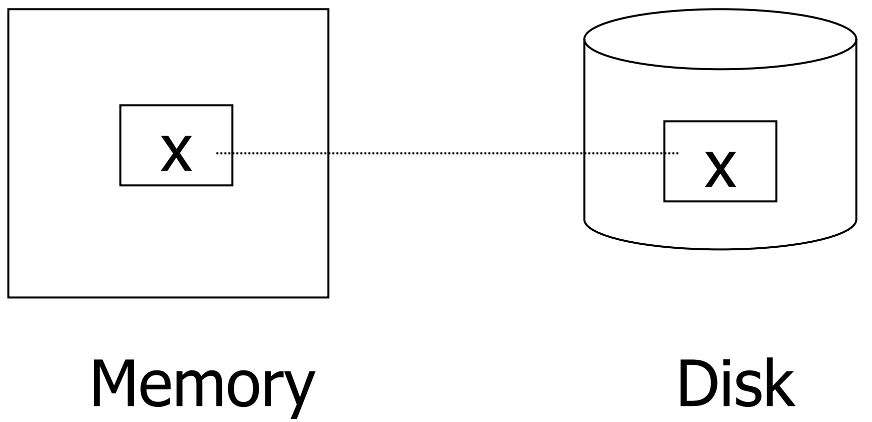
$B \leftarrow B \times 2$

Unexpected Events:

Examples:

- Power goes off
- Software bugs
- Disk data is lost
- Memory lost without CPU halt
- CPU misbehaves (overheating)

Storage hierarchy



Operations:

- Input (x): block containing x $\rightarrow$ memory
- Output (x): block containing x $\rightarrow$ disk

- Read (x,t): do input(x) if necessary
  t $\leftarrow$ value of x in block
- Write (x,t): do input(x) if necessary
  value of x in block $\leftarrow$ t

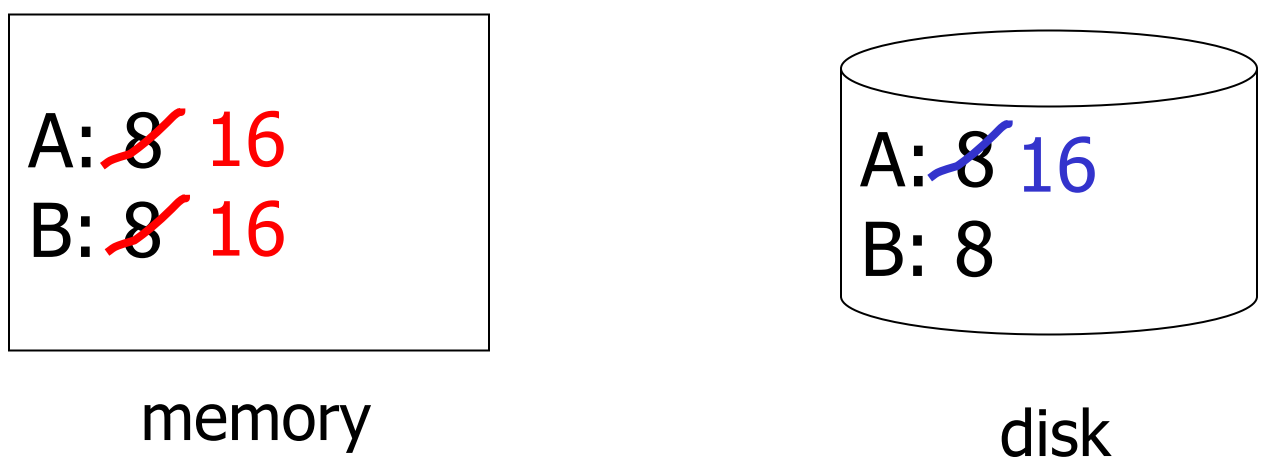
<u>Key problem</u> Unfinished transaction

Example Constraint: A=B

T_1: $A \leftarrow A \times 2$

$B \leftarrow B \times 2$

T_1: Read (A,t); $t \leftarrow t \times 2$
Write (A,t);
Read (B,t); $t \leftarrow t \times 2$
Write (B,t);
Output (A);
failure!
Output (B);



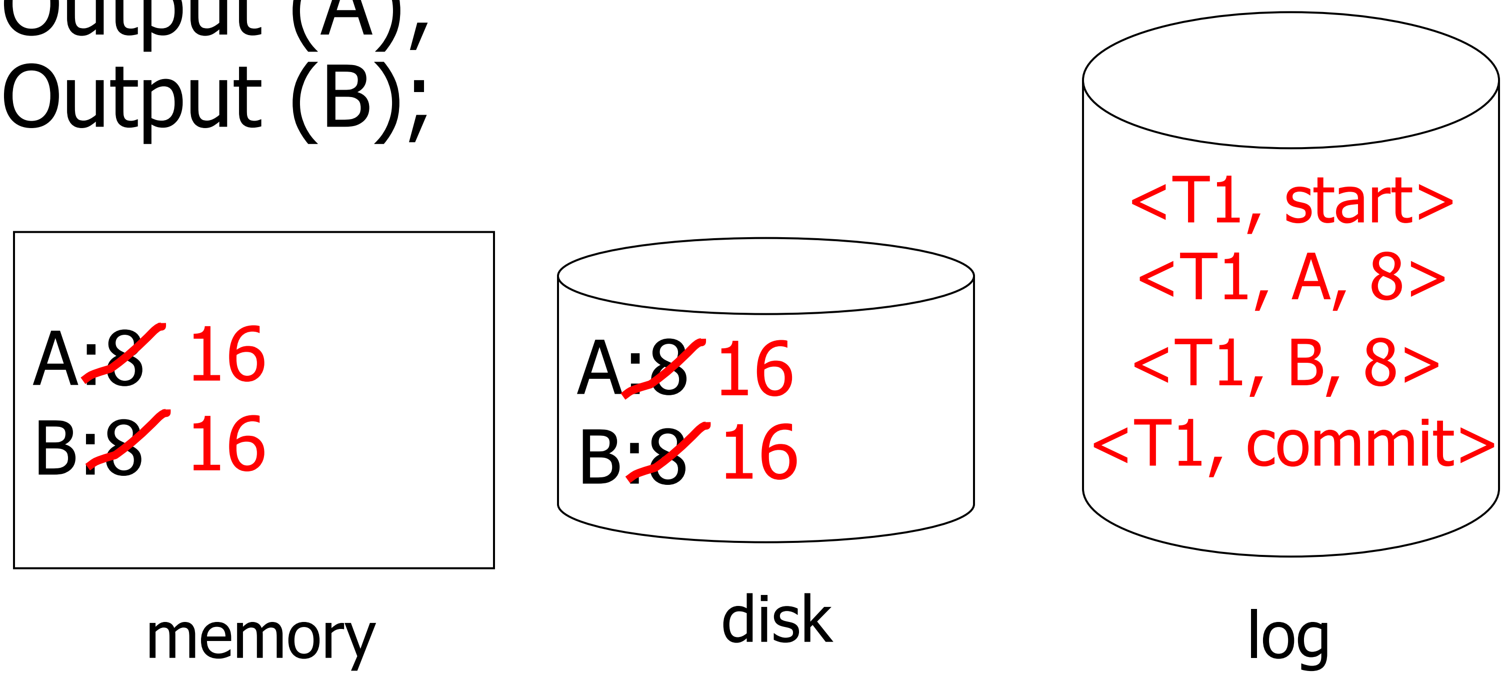
- Need atomicity: execute all actions of a transaction or none at all

One solution: undo logging (immediate modification)

due to: Hansel and Gretel, 782 AD

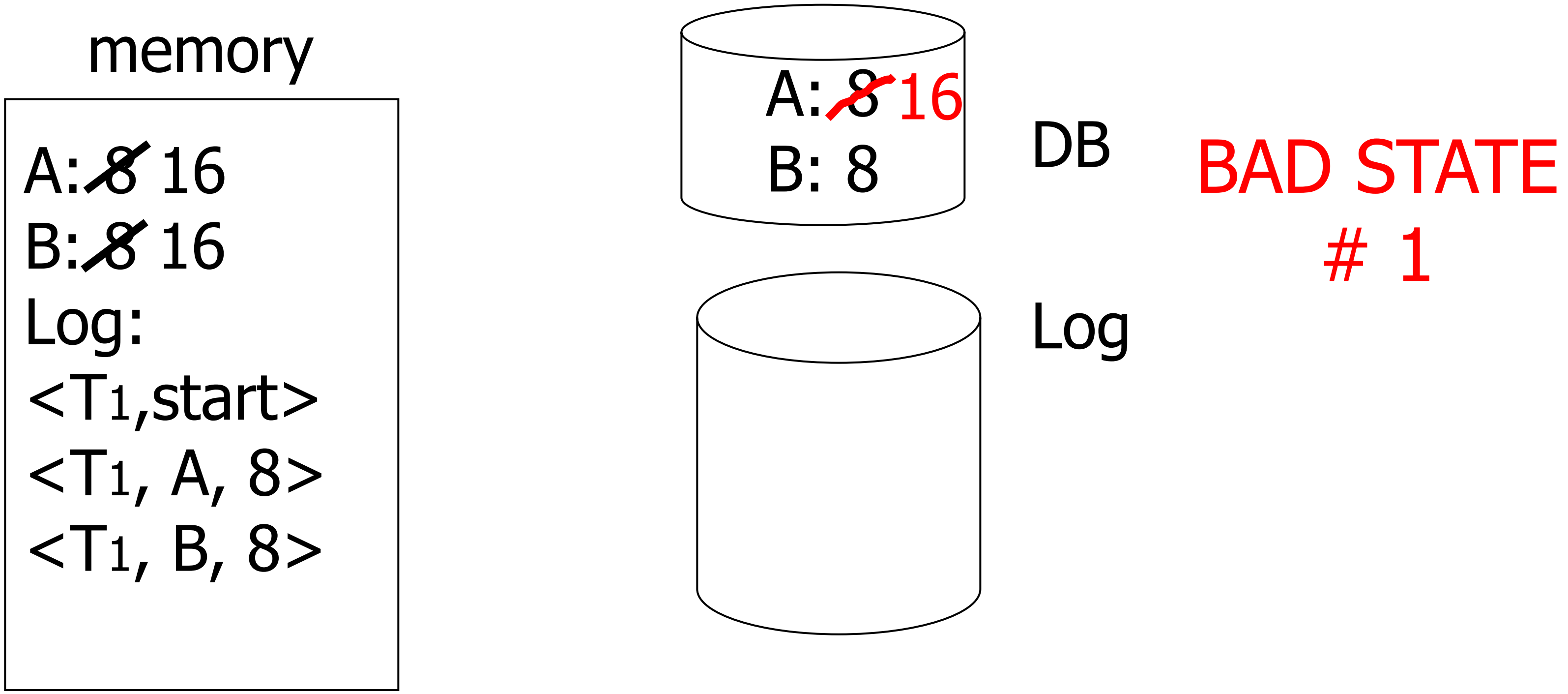
Undo logging (Immediate modification)

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



One "complication"

- Log is first written in memory
- Not written to disk on every action



One "complication"

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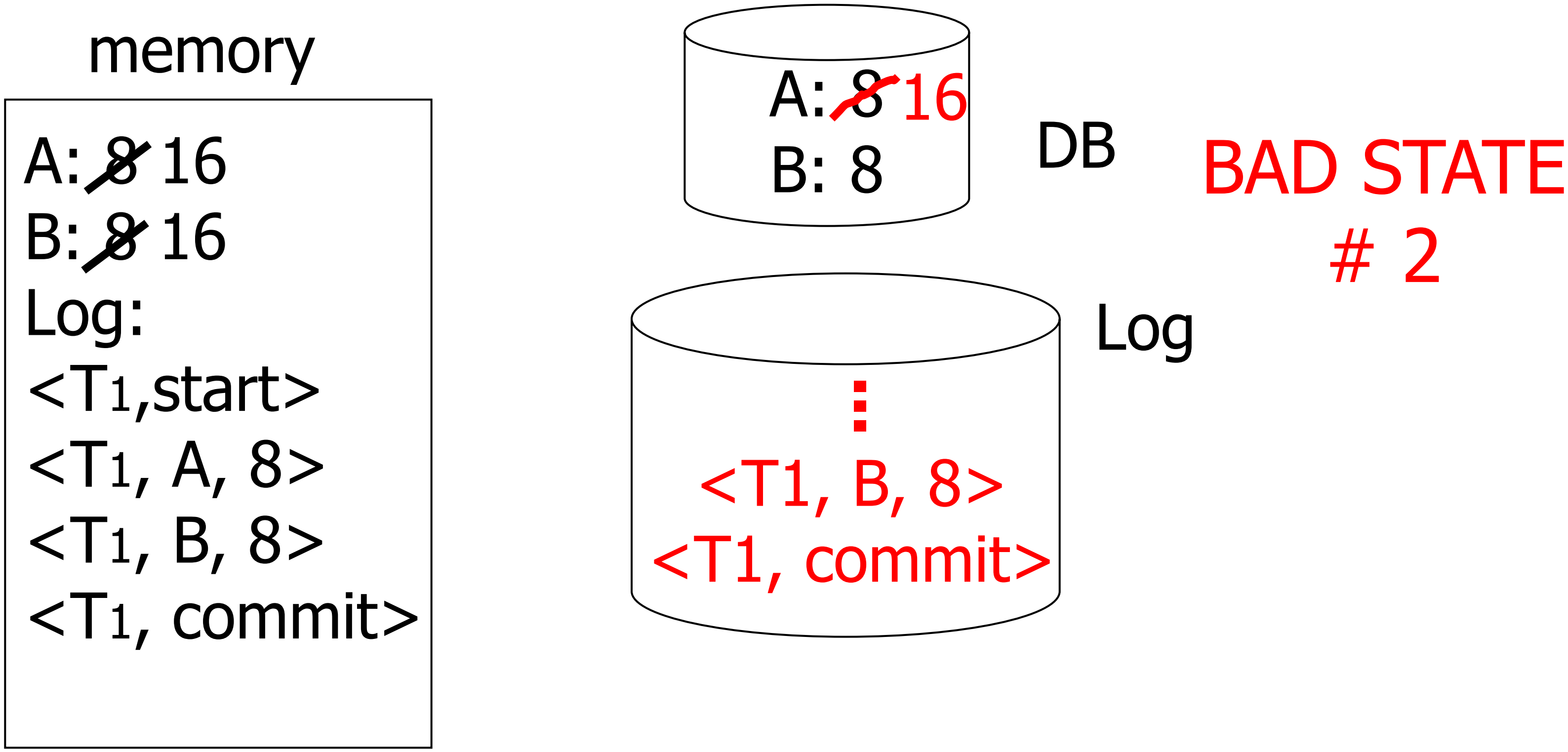


Undo logging rules

(1) For every action generate undo log record (containing old value)

(2) Before *x* is modified on disk, log records pertaining to *x* must be on disk (write ahead logging: WAL)

(3) Before commit is flushed to log, all writes of transaction must be reflected on disk

Recovery rules for Undo logging

- For every Ti with <Ti, start> in log:
  - Either: Ti completed ➔

    <Ti,commit> or <Ti,abort> in log
  - Or: Ti is incomplete

  Undo incomplete transactions

Recovery rules for Undo Logging (contd.)

(1) Let S = set of transactions with

<Ti, start> in log, but no

<Ti, commit> or <Ti, abort> record in log

(2) For each <Ti, X, v> in log,

in reverse order (latest $\rightarrow$ earliest) do:

- if Ti $\in$ S then { - write (X, v)
  - output (X) }

(3) For each Ti $\in$ S do

- write <Ti, abort> to log

What if failure during recovery?

No problem: Undo is idempotent

To discuss:

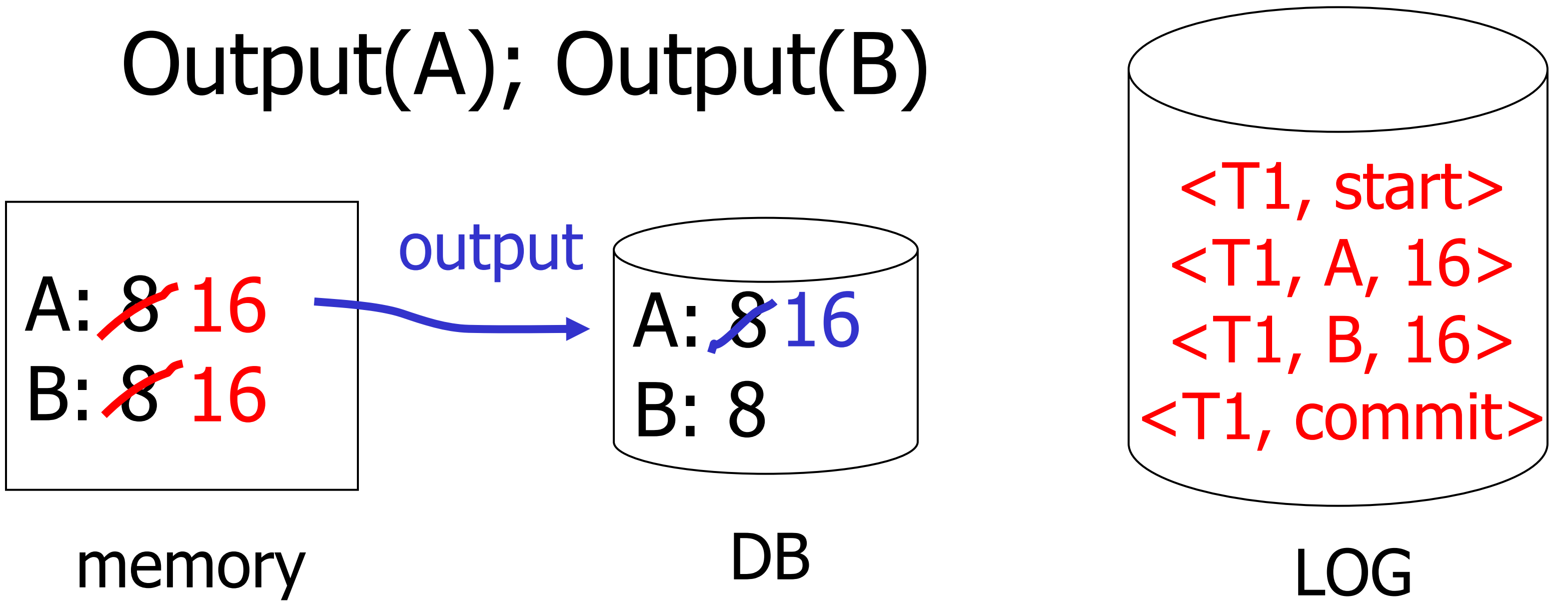
- Redo logging
- Undo/redo logging, why both?
- Real world actions
- Checkpoints
- Media failures

Redo logging (deferred modification)

T_1: Read(A,t); $t \leftarrow t \times 2$; write (A,t);

Read(B,t); $t \leftarrow t \times 2$; write (B,t);

Output(A); Output(B)



Redo logging rules

(1) For every action, generate redo log record (containing new value)

(2) Before X is modified on disk (DB), all log records for transaction that modified X (including commit) must be on disk

(3) Flush log at commit

Recovery rules: Redo logging

- For every Ti with <Ti, commit> in log:
  - For all <Ti, X, v> in log:

    Write(X, v)
    Output(X)

☒IS THIS CORRECT??

Recovery rules: Redo logging

(1) Let S = set of transactions with
<Ti, commit> in log

(2) For each <Ti, X, v> in log, in forward order (earliest $\rightarrow$ latest) do:

- if Ti $\in$ S then { Write(X, v)
  Output(X) ← optional

Key drawbacks:

- *Undo logging:* cannot bring backup DB copies up to date
- *Redo logging:* need to keep all modified blocks in memory until commit

Solution: undo/redo logging!

Update $\Rightarrow$ <Ti, Xid, New X val, Old X val>
page X

Rules

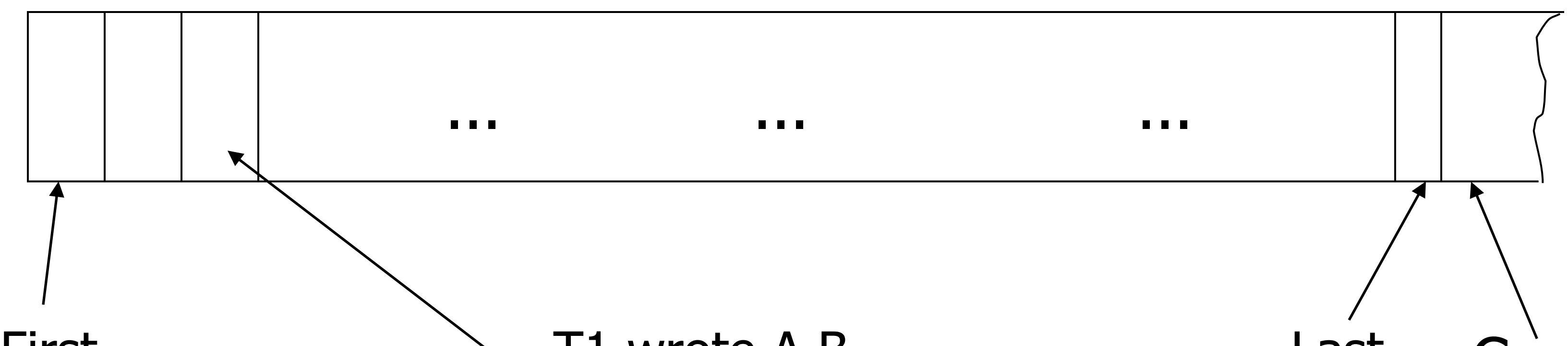
- Page X can be flushed before or after Ti commit
- Log record flushed before corresponding updated page (WAL)

Recovery Rules

- Identify transactions that committed
- Undo uncommitted transactions
- Redo committed transactions

Recovery is very, very SLOW !

Redo log:



First Record (1 year ago)

T1 wrote A,B Committed a year ago

Last Record

Crash

--> STILL, Need to redo after crash!!

Solution: Checkpoint (simple version)

Periodically:

(1) Do not accept new transactions

(2) Wait until all transactions finish

(3) Flush all log records to disk (log)

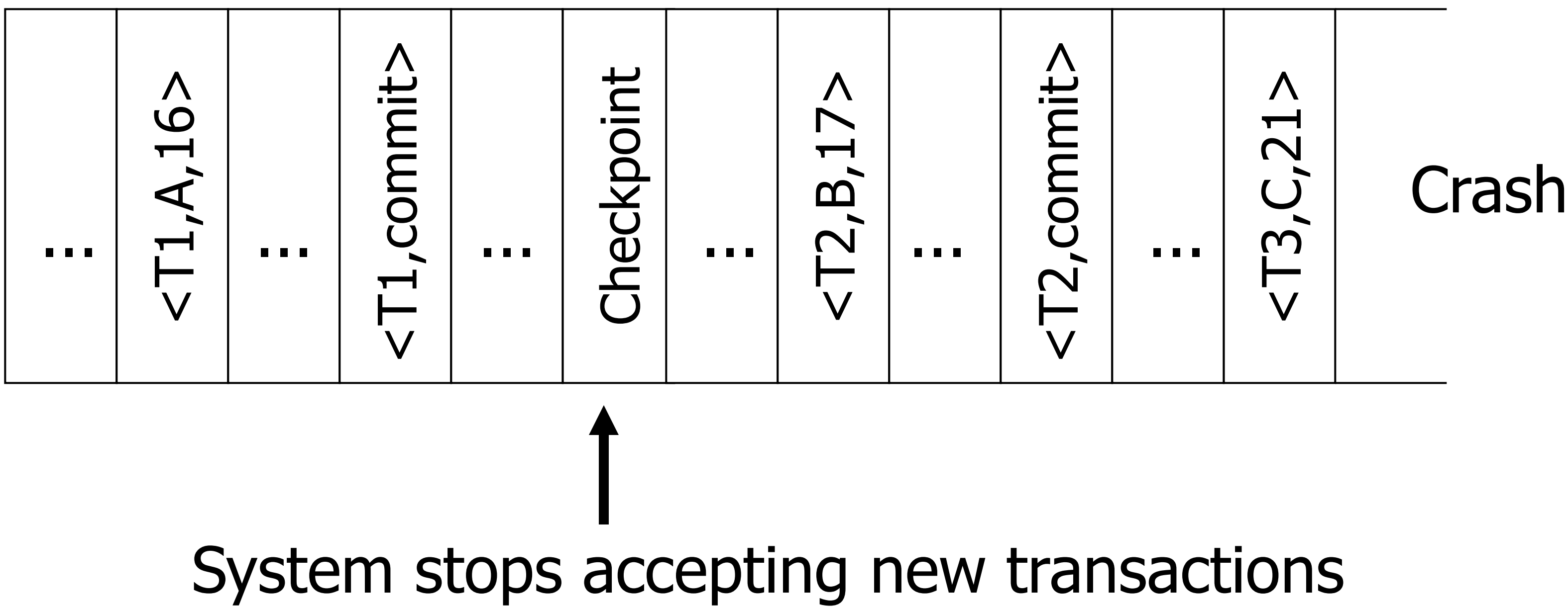
(4) Flush all buffers to disk (DB) (do not discard buffers)

(5) Write "checkpoint" record on disk (log)

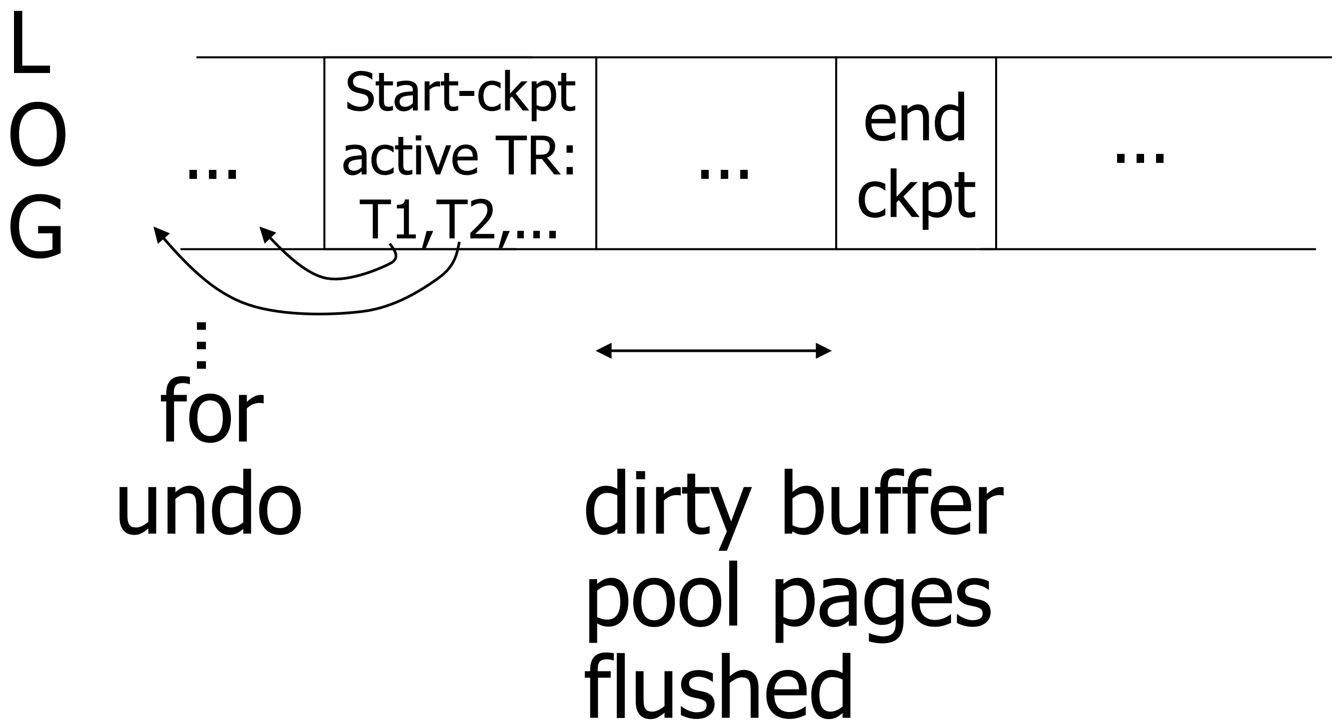
(6) Resume transaction processing

Example: what to do at recovery?

Redo log (disk):



Non-quiescent checkpoint for Undo/Redo logging

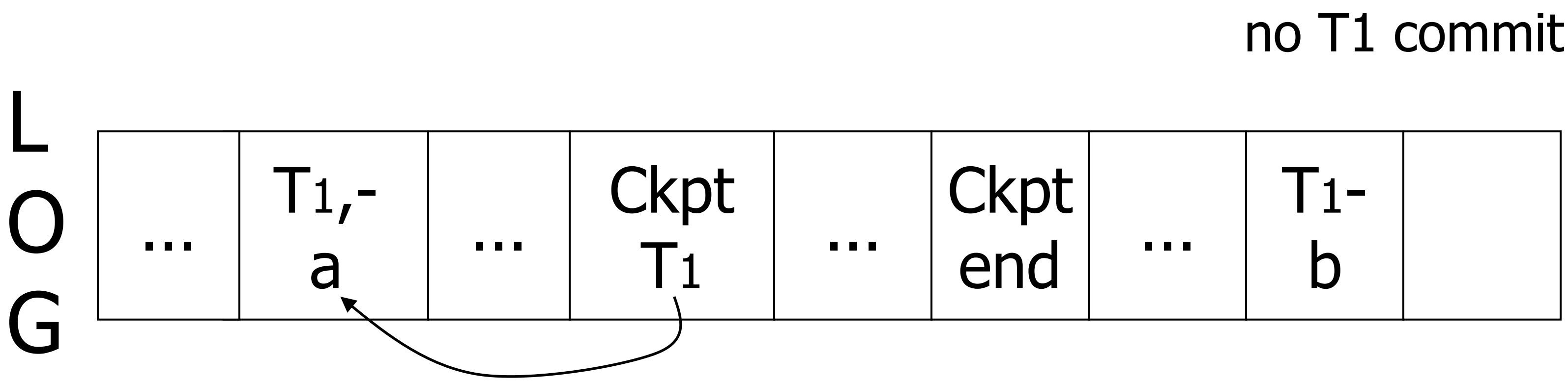


Example: Undo/Redo + Non Quiescent Chkpt.

<start T1>
<T1,A,4,5>
<start T2>
<commit T1>
<T2,B,9,10>
<start chkpt(T2)>
<T2,C,14,15>
<start T3>
<T3,D,19,20>
<end checkpt>
<commit T2>
<commit T3>

1. Flush log
2. Flush all dirty buffers. May start new transactions
3. Write <end checkpt>. Flush log

Examples what to do at recovery time?



- Undo T_1 (undo a,b)

Example

L
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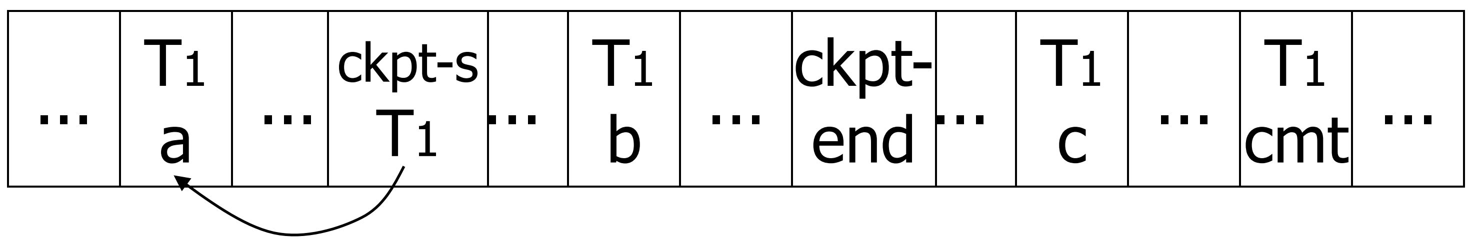
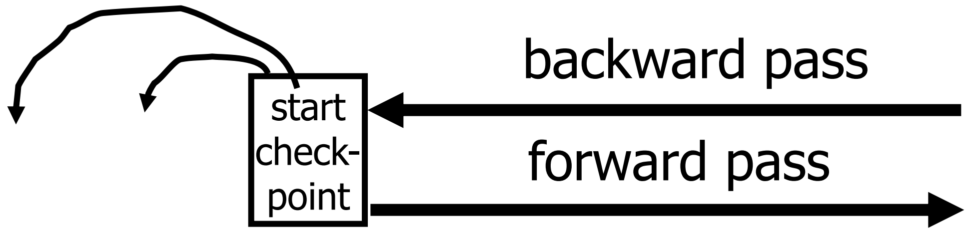


- Redo T1: (redo b,c)

Recovery process:

- Backwards pass (end of log ➲ latest checkpoint start)
  - construct set S of committed transactions
  - undo actions of transactions not in S
- Undo pending transactions
  - follow undo chains for transactions in (checkpoint active list) - S
- Forward pass (latest checkpoint start ➲ end of log)
  - redo actions of S transactions



Example: Redo + Non Quiescent Chkpt.

<start T1>
<T1,A,5>
<start T2>
<commit T1>
<T2,B,10>
<start chkpt(T2)>
<T2,C,15>
<start T3>
<T3,D,20>
<end chkpt>
<commit T2>
<commit T3>

1. Flush log
2. Flush data elements written by transactions that committed before <start chkpt>. May start new transactions.
3. Write <end chkpt>. Flush log

Example: Undo + Non Quiescent Chkpt.

<start T1>
<T1,A,5>
<start T2>
<T2,B,10>
<start chkpt(T1,T2)>
<T2,C,15>
<start T3>
<T1,D,20>
<commit T1>
<T3,E,25>
<commit T2>
<end checkpt>
<T3,F,30>

1. Flush log
2. Wait for active transactions to complete. New transactions may start
3. Write <end checkpt>. Flush log

Real world actions

E.g., dispense cash at ATM

$Ti = a_1\, a_2 \ldots\ldots\, a_j \ldots\ldots\, a_n$

↓

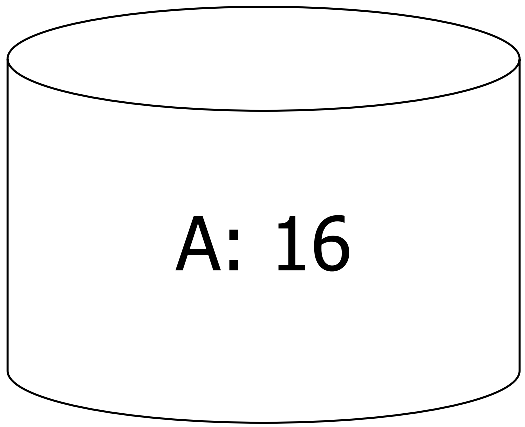
$

Solution

(1) execute real-world actions after commit

(2) try to make idempotent

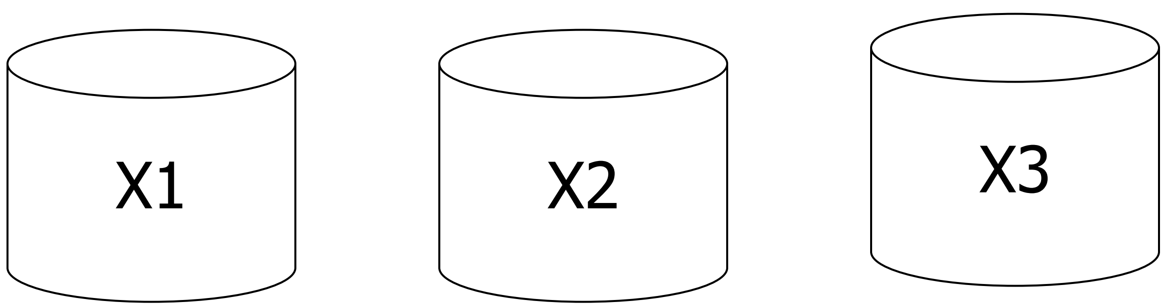
Media failure (loss of non-volatile storage)



Solution: Make copies of data!

Example 1 Triple modular redundancy

- Keep 3 copies on separate disks
- Output(X) --> three outputs
- Input(X) --> three inputs + vote

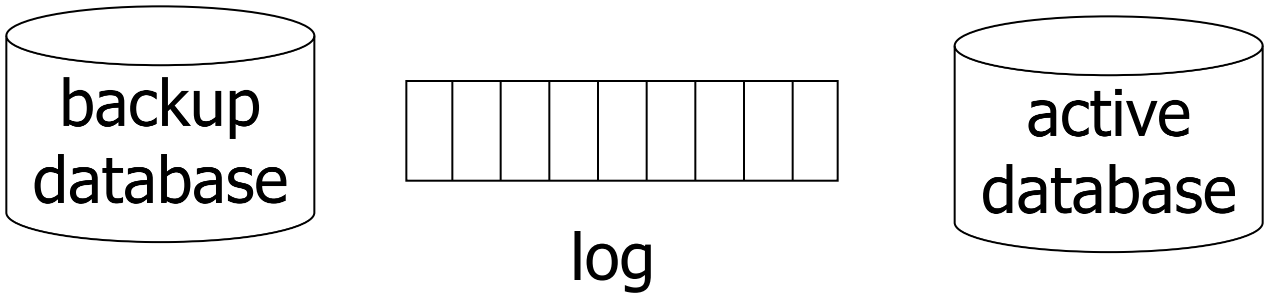


Example #2 Redundant writes, Single reads

- Keep N copies on separate disks
- Output(X) --> N outputs
- Input(X) --> Input one copy
  - if ok, done
  - else try another one

⇔ Assumes bad data can be detected

Example #3: DB Dump + Log



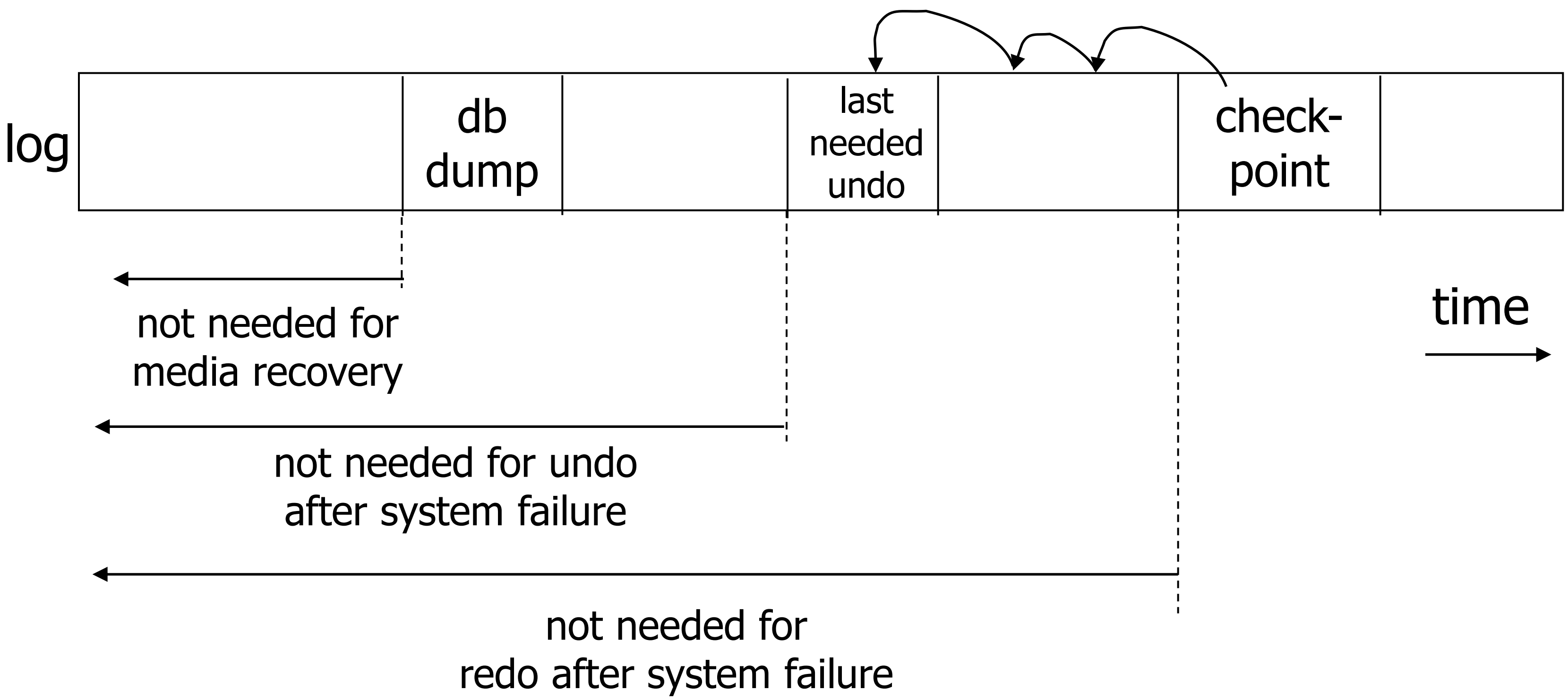
- If active database is lost,
  - restore active database from backup
  - bring up-to-date using redo entries in log

Non-quiescent Archiving

- Log may look like:

  <start dump>
  <start checkpt(T1,T2)>
  <T1,A,1,3>
  <T2,C,3,6>
  <commit T2>
  <end checkpt>
  Dump completes
  <end dump>

When can log be discarded?



Summary

- Consistency of data
- One source of problems: failures
    - Logging
    - Redundancy
- Another source of problems:
  Data Sharing..... next