CPS216: Data-intensive Computing Systems

Failure Recovery

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Integrity or correctness of data

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

EMP

Name	Age
White	52
Green	3421
Blue	1

Integrity or consistency constraints

- Predicates data must satisfy
- Examples:
  - x is key of relation R
  - $x \rightarrow y$ holds in R (functional dependency)
  - Domain(x) = {Red, Blue, Green}
  - α is valid index for attribute x of R
  - no employee should make more than twice the average salary

Definition:

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

Constraints (as we use here) may not capture "full correctness"

Example 1   Transaction constraints

- When salary is updated,
  new salary > old salary
- When account record is deleted,
  balance = 0

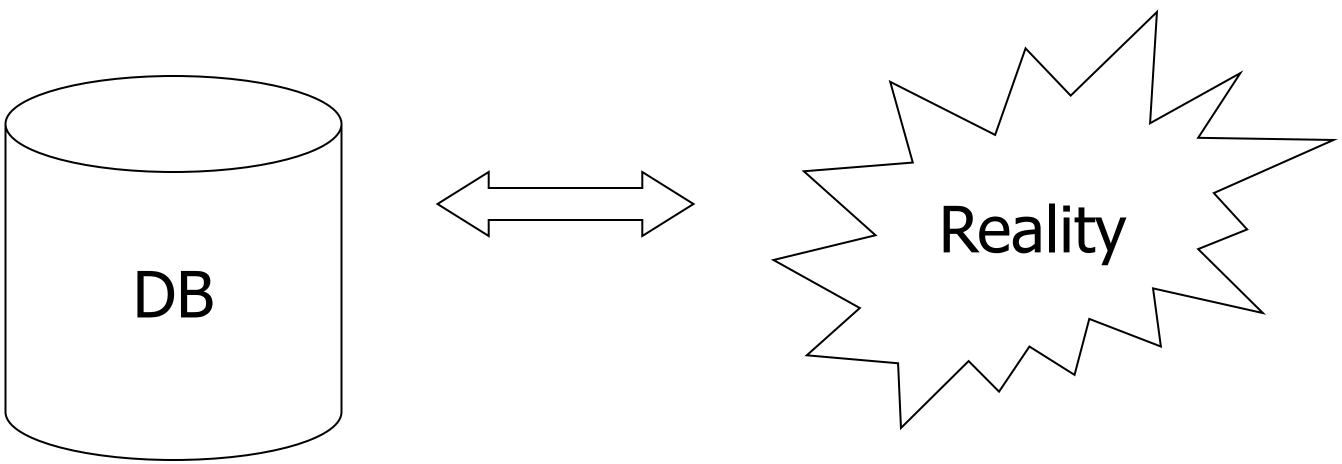
Note: could be "emulated" by simple constraints, e.g.,

account

Acct #	....	balance	deleted?

Constraints (as we use here) may not capture "full correctness"

Example 2 Database should reflect real world



☞ in any case, continue with constraints...

<u>Observation:</u> DB <u>cannot</u> be consistent always!

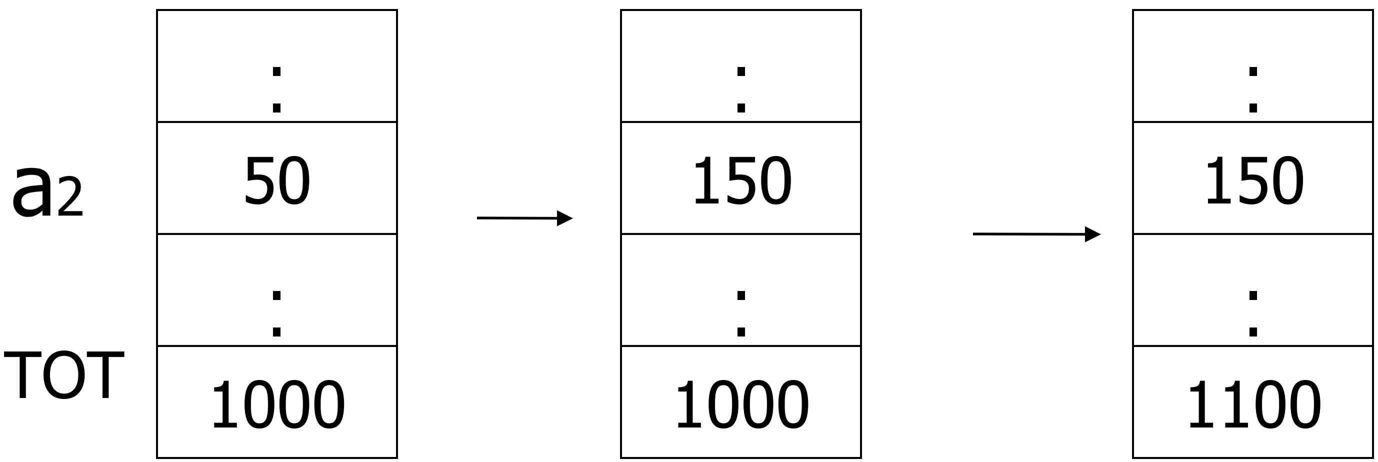
<u>Example:</u> $a_1 + a_2 + \ldots. a_n = TOT$ (constraint)

Deposit \$100 in a_2: $\begin{cases} a_2 \leftarrow a_2 + 100 \\ TOT \leftarrow TOT + 100 \end{cases}$

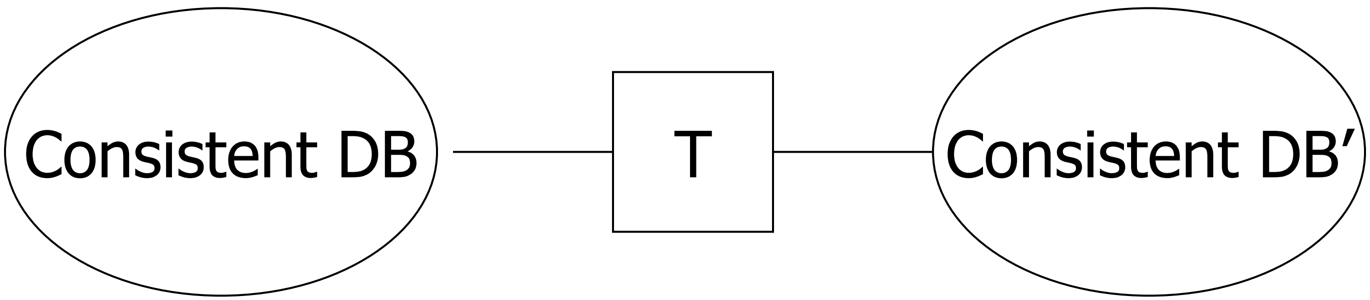
Example: $a_1 + a_2 + \ldots.\ a_n = TOT$ (constraint)

Deposit \$100 in a_2: $a_2 \leftarrow a_2 + 100$

$TOT \leftarrow TOT + 100$



Transaction: collection of actions that preserve consistency



Assumption:

If T starts with DB in consistent state +

T executes in isolation

$\Rightarrow$ T leaves DB in consistent state

Correctness (informally)

- If we stop running transactions,
  DB left consistent
- Each transaction sees a consistent DB

How can constraints be violated?

- Transaction bug
- DBMS bug
- Hardware failure

    e.g., disk crash alters balance of account

- Data sharing

  e.g.: T1: give 10% raise to programmers

    T2: change programmers $\Rightarrow$ systems analysts

How can we prevent/fix violations?

- Due to failures only
- Due to data sharing only
- Due to failures and sharing

Will not consider:

- How to write correct transactions
- How to write correct DBMS
- Constraint checking & repair

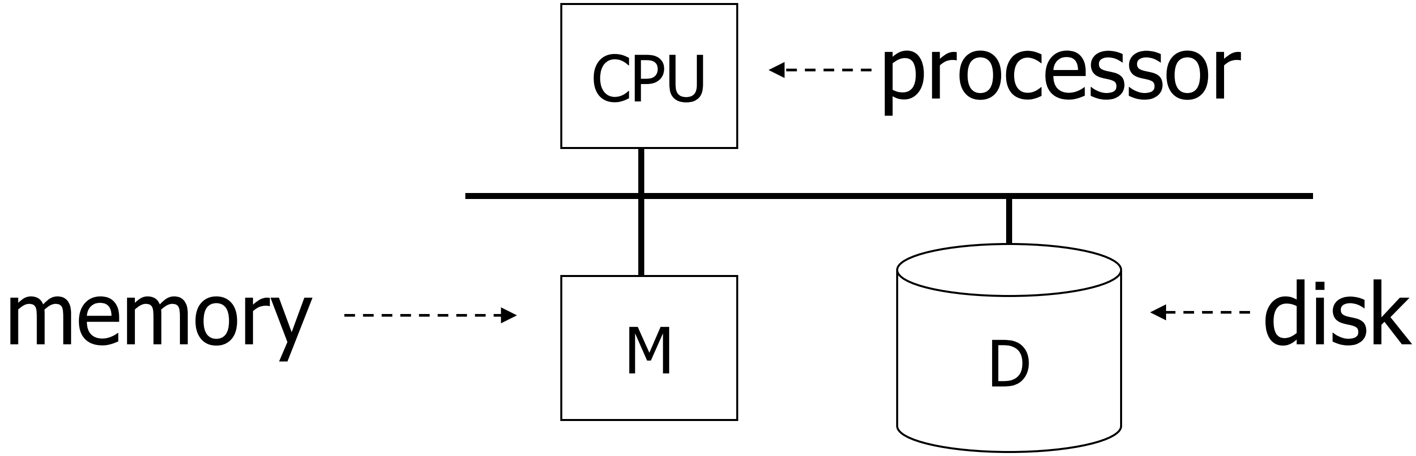
That is, solutions studied here do not need to know constraints

Recovery

- First order of business:
  Failure Model

- Events
  - Desired
  - Undesired
    - Expected
    - Unexpected

Our failure model



Desired events: see product manuals….

Undesired expected events:

System crash

- memory lost
- cpu halts, resets

that's it!!

Undesired Unexpected: Everything else!

<u>Undesired Unexpected:</u> Everything else!

Examples:

- Software bugs
- Disk data is lost
- Memory lost without CPU halt
- CPU implodes wiping out universe….

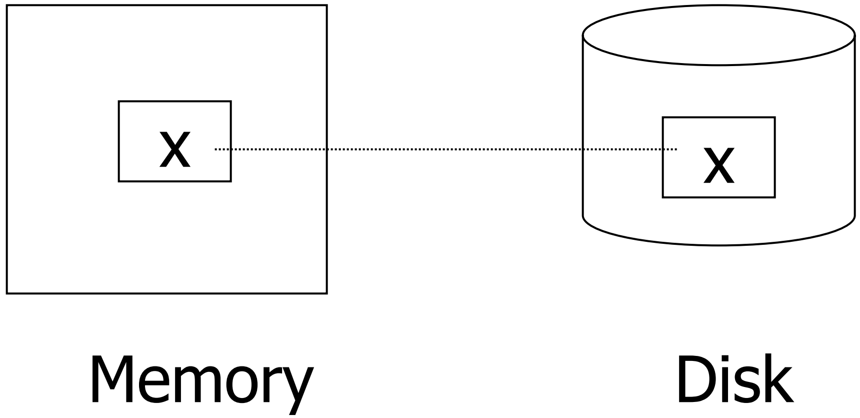
Is this model reasonable?

Approach: Add low level checks + redundancy to increase the probability that model holds

E.g.,
- Replicate disk storage (stable store)
- Memory parity
- CPU checks

Second order of business:

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

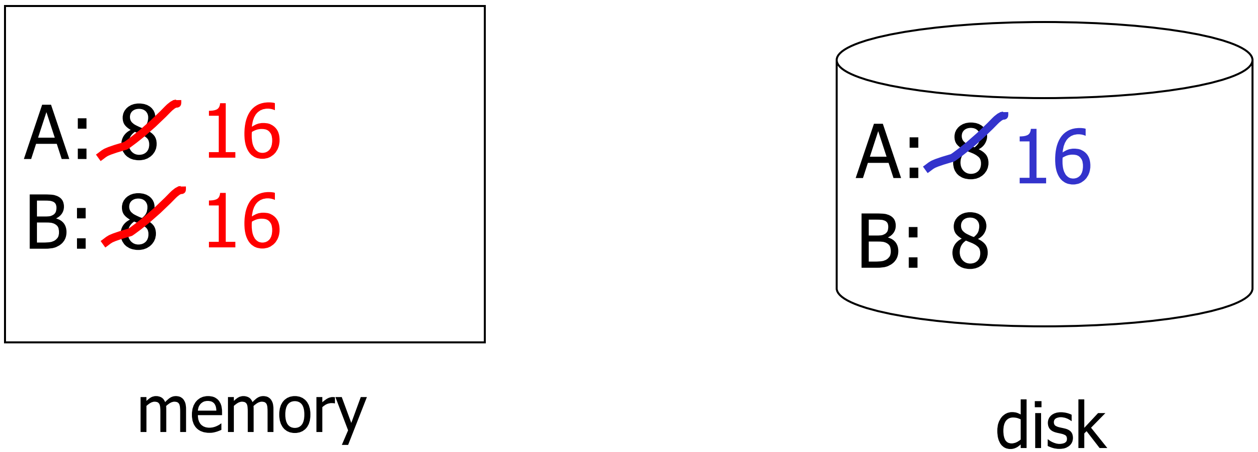
Key problem   Unfinished transaction

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);



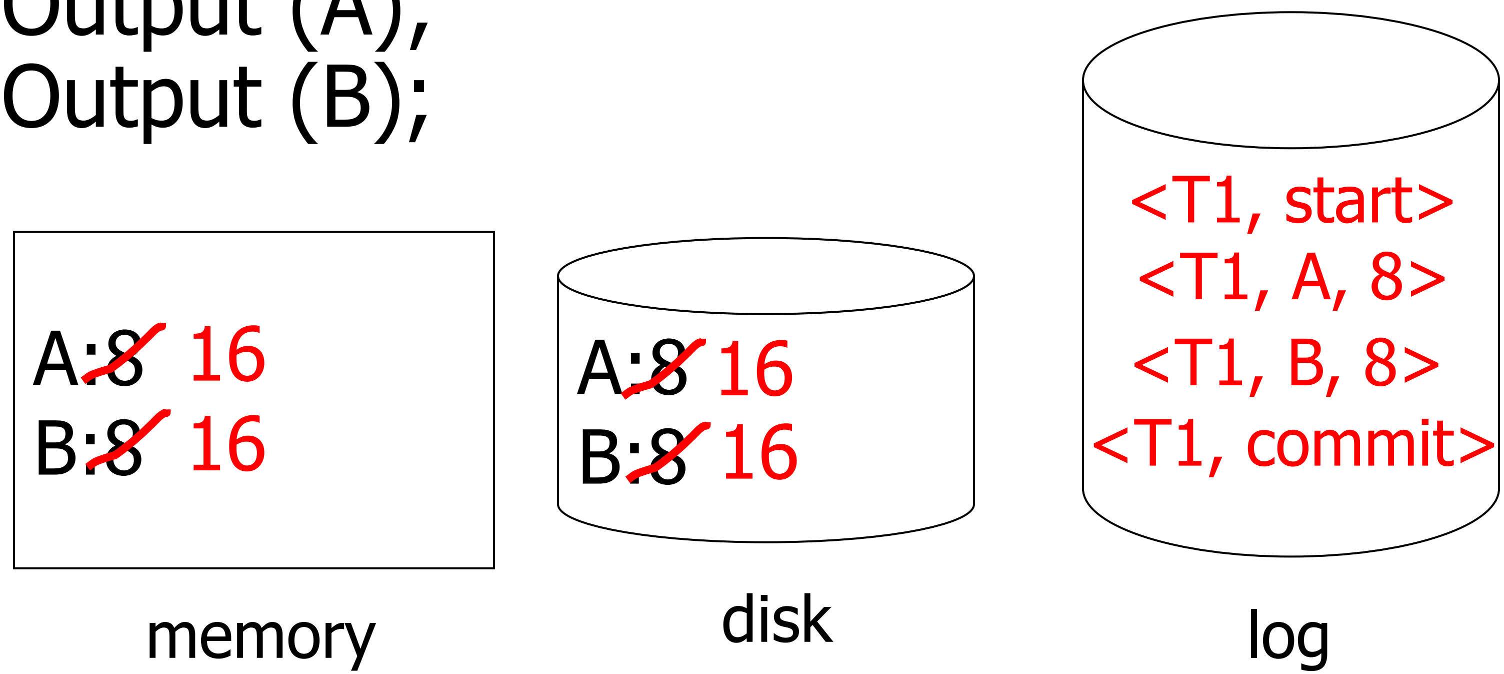
- Need atomicity: execute all actions of a transaction or none at all

<u>One solution:</u> undo logging (immediate modification)

due to: Hansel and Gretel, 782 AD

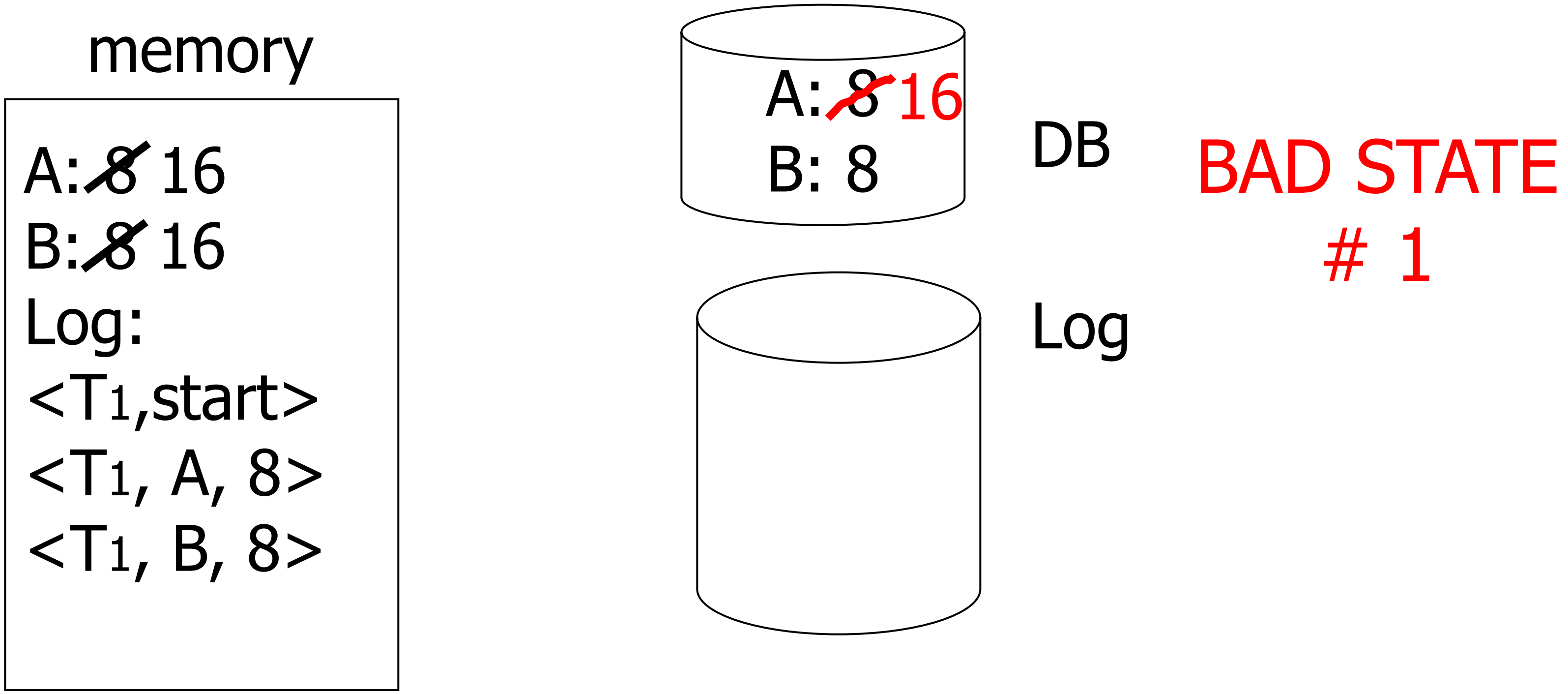
Undo logging (Immediate modification)

T_1: 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



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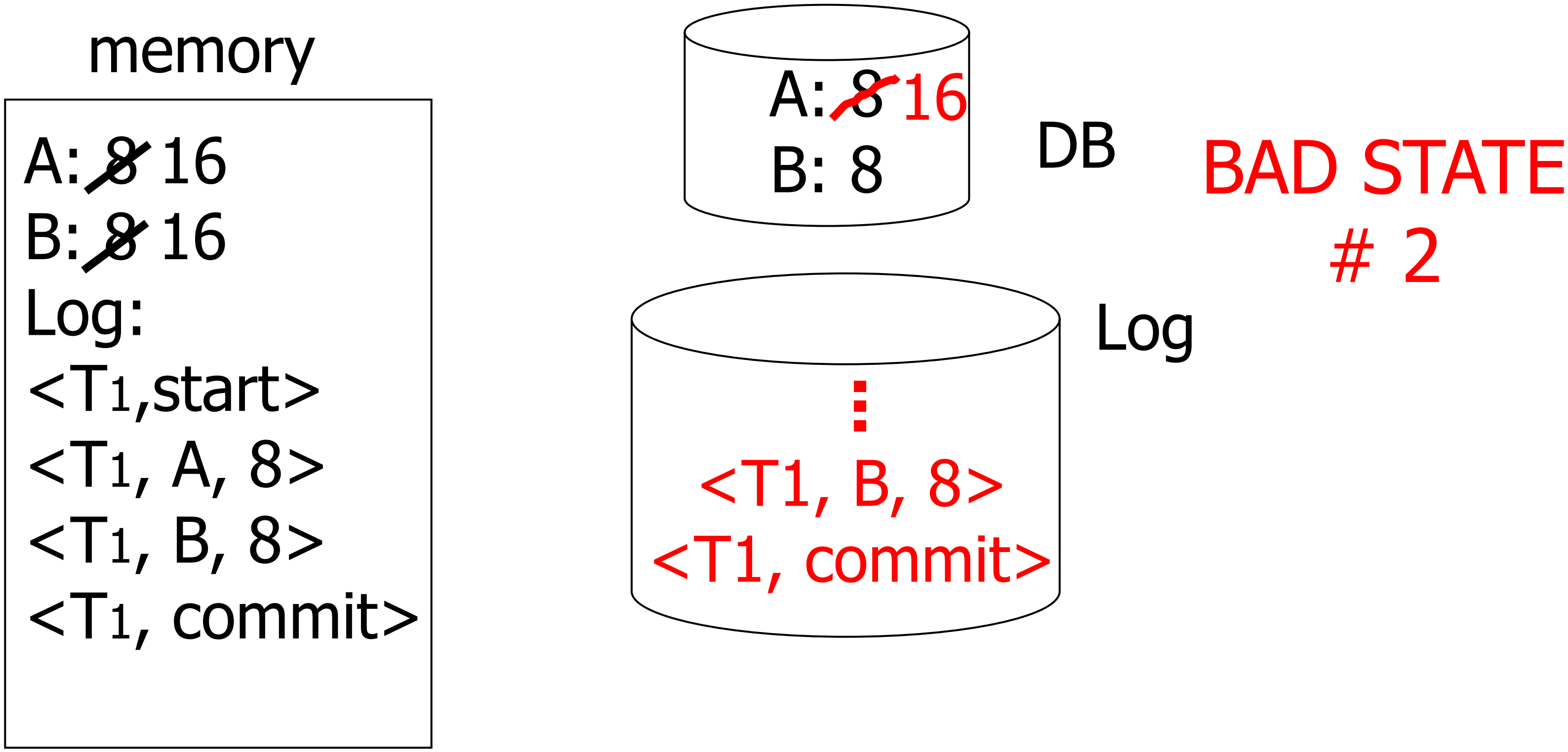


Undo logging rules

(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 $\begin{cases} \text{- write (X, v)} \\ \text{- output (X)} \end{cases}$

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

- write <Ti, abort> to log

<u>What if failure during recovery?</u>

No problem: Undo is idempotent

To discuss:

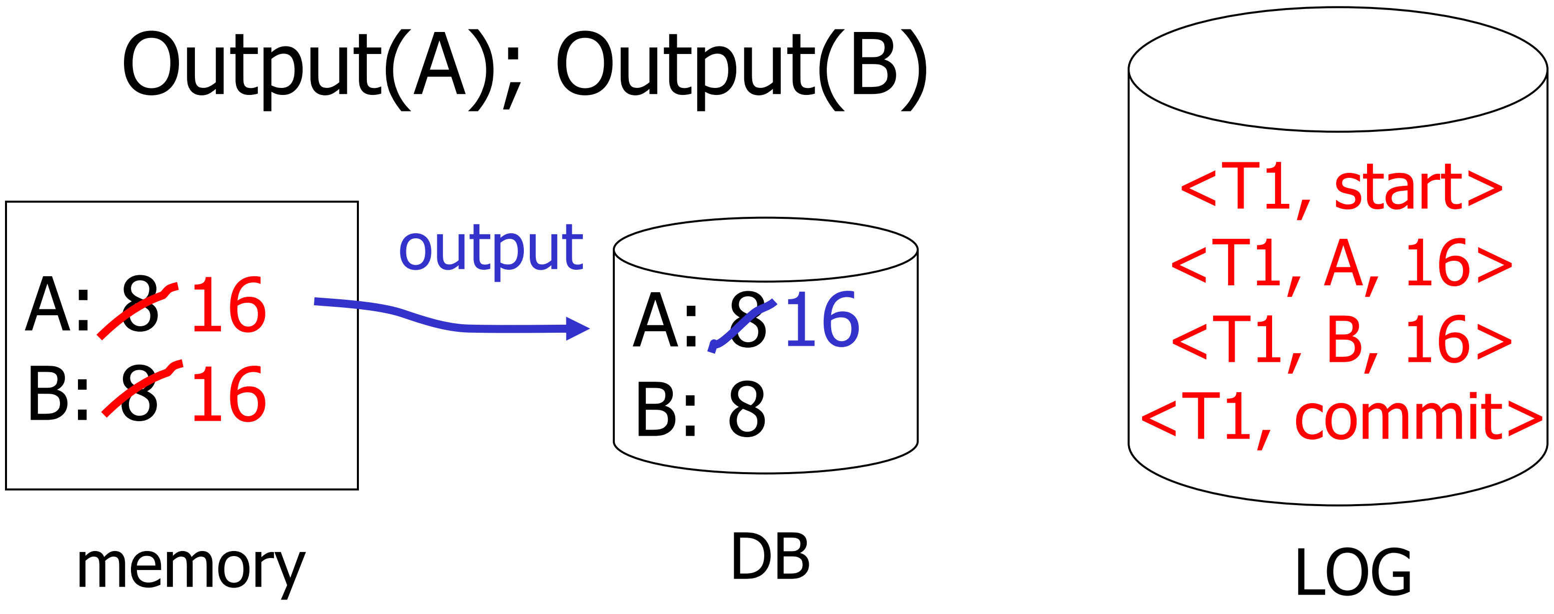
- Redo logging
- Undo/redo logging, why both?
- Real world actions
- Checkpoints
- Media failures

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

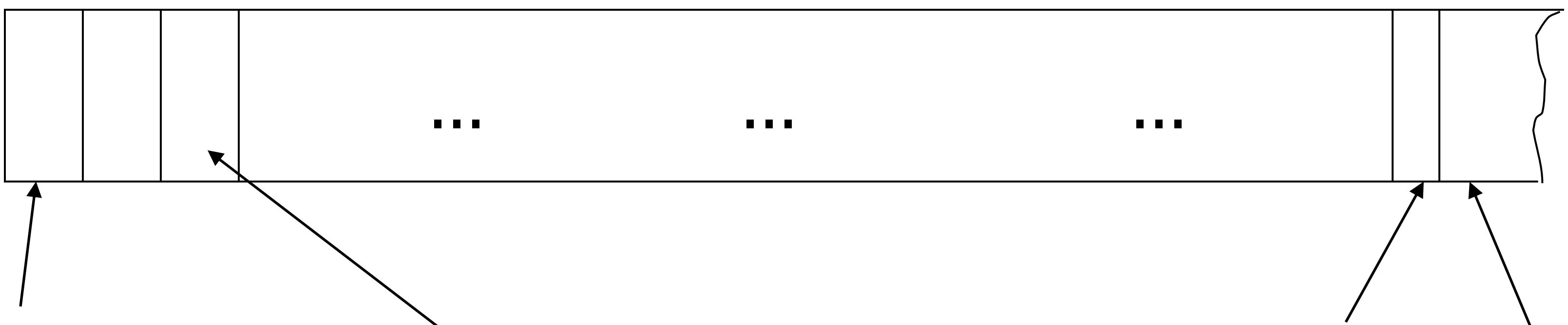
- Page X can be flushed before or after Ti commit
- Log record flushed before corresponding updated page (WAL)

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)

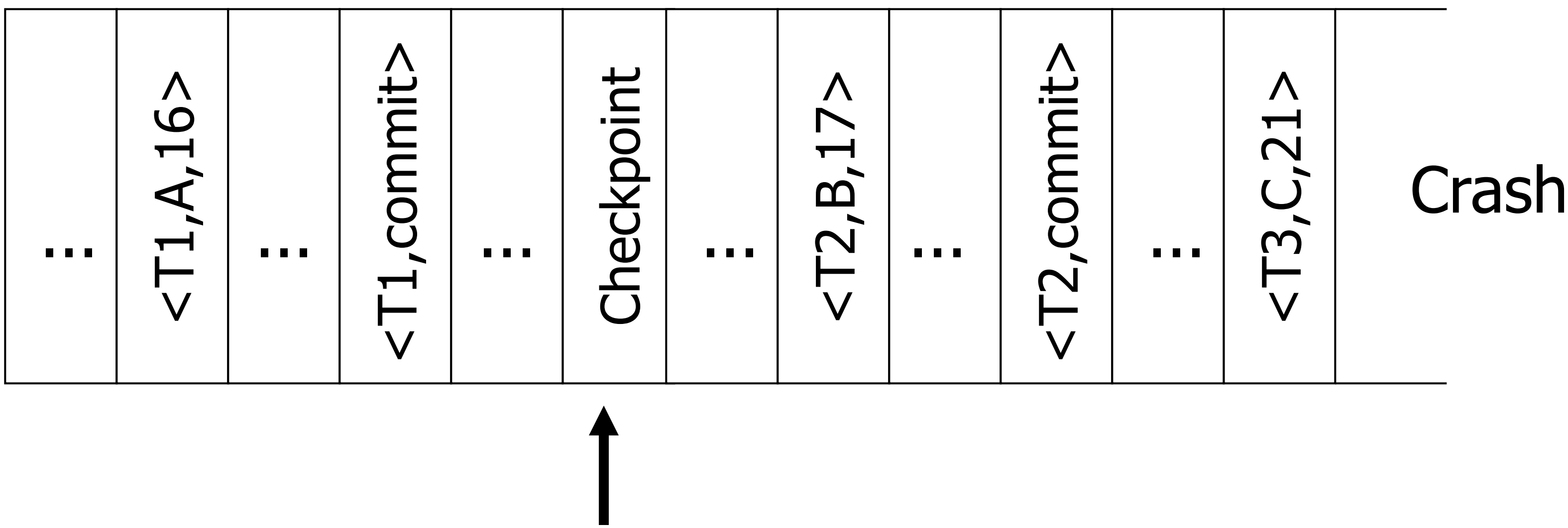
(4) Flush all buffers to disk (DB) (do not discard buffers)

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

(6) Resume transaction processing

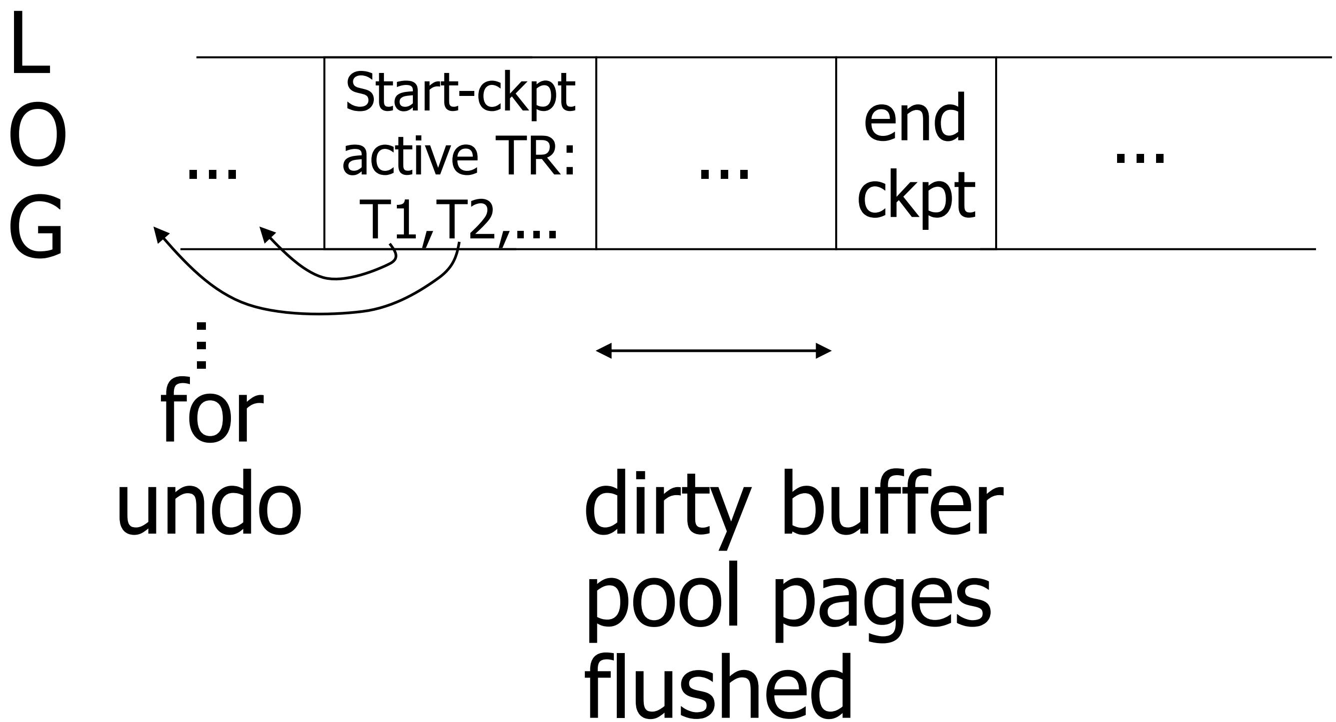
Example: what to do at recovery?

Redo log (disk):



System stops accepting new transactions

Non-quiescent checkpoint for Undo/Redo logging

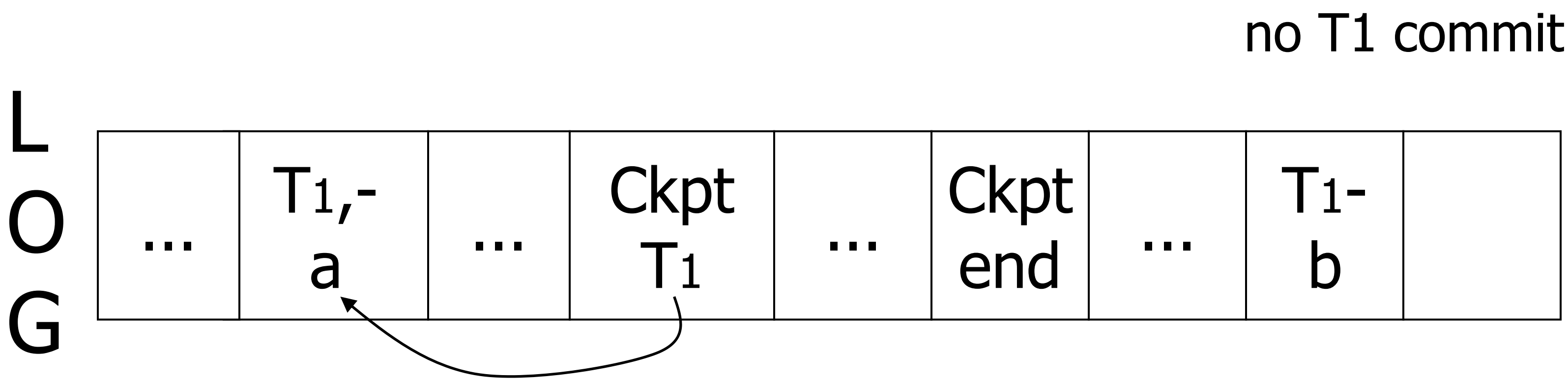


Example: Undo/Redo + Non Quiescent Chkpt.

<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>

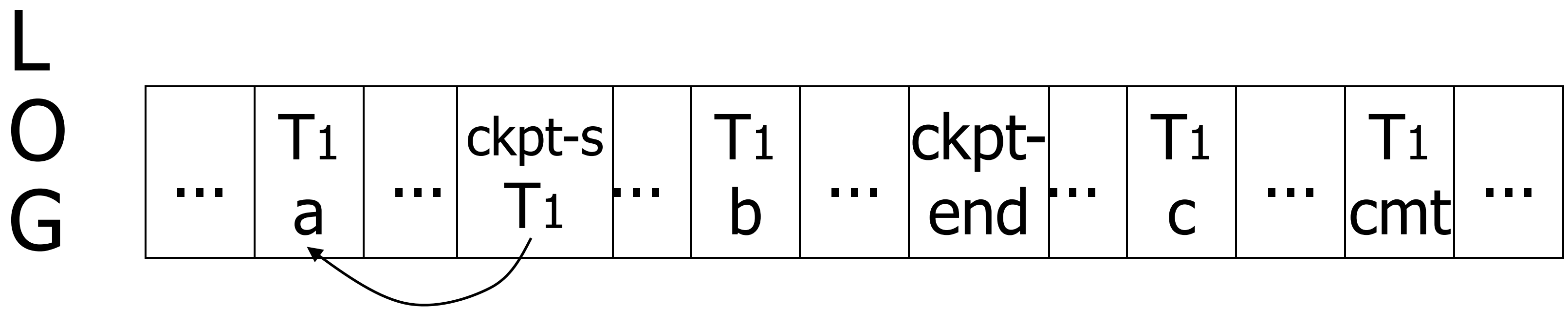
1. Flush log
2. Flush all dirty buffers. May start new transactions
3. Write <end checkpt>. Flush log

Examples what to do at recovery time?



☒ Undo T_1 (undo a,b)

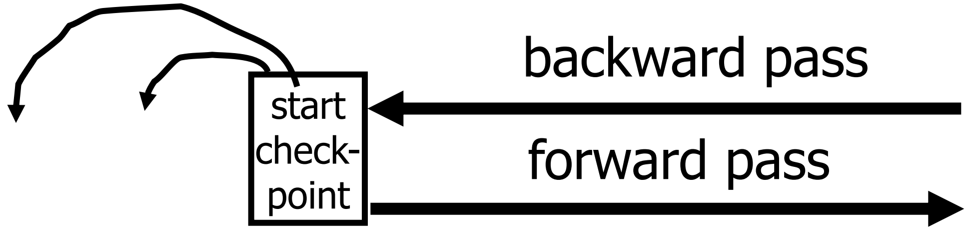
Example



- 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

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

$$\downarrow$$

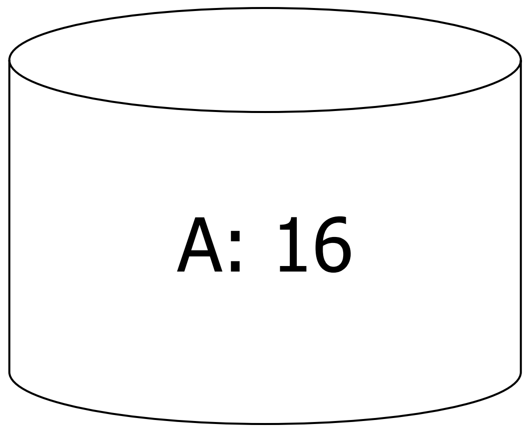
$

Solution

(1) execute real-world actions after commit

(2) try to make idempotent

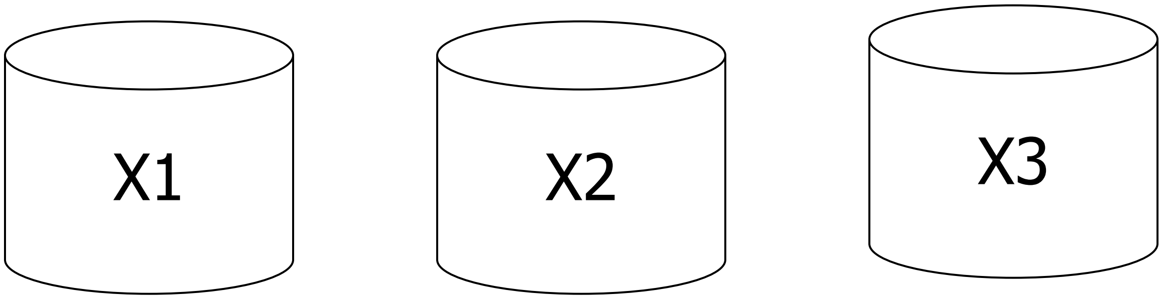
Media failure (loss of non-volatile storage)



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

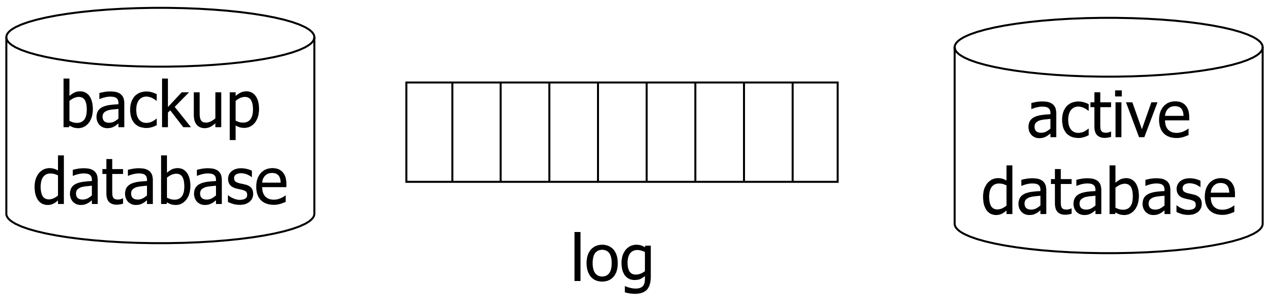


Example #2 Redundant writes, Single reads

- 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

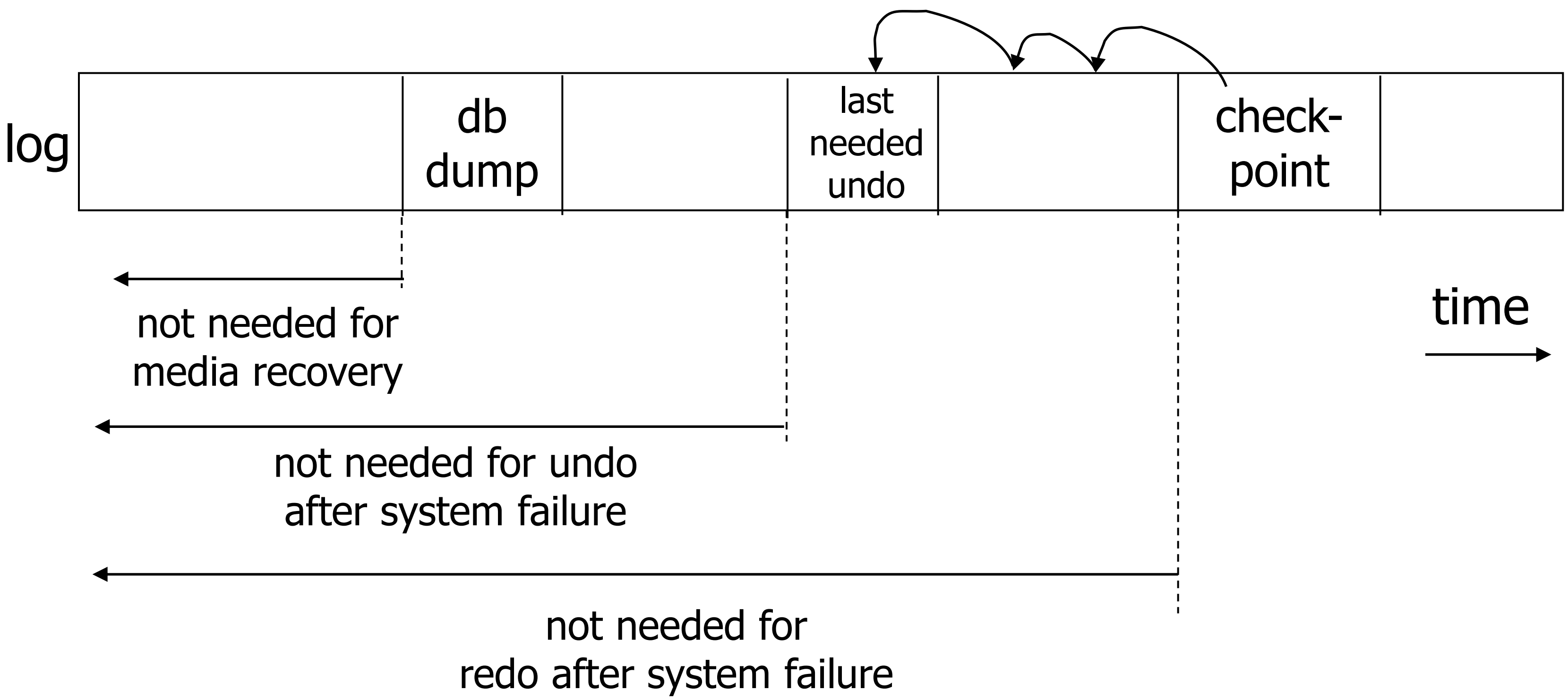


- If active database is lost,
  - restore active database from backup
  - bring up-to-date using redo entries in log

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