Transaction Management

CS 564 - Spring 2025

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WHAT IS THIS LECTURE ABOUT?

- Transaction (TXN) management
- **ACID** properties
  - atomicity
  - consistency
  - isolation
  - durability
- Logging
- Scheduling & locking

TRANSACTIONS

DBMS MEMORY MODEL

Local: each process in a DBMS has its own local memory, where it stores values that only it "sees"

Global: each process can read from / write to shared data in main memory

Disk: global memory can read from / flush to disk

TRANSACTION

A **<u>transaction</u>** is a collection of *operations* that form a single *atomic* logical unit

```
BEGIN TRANSACTION ;
  {SQL}
COMMIT ;
```

- Operations: `READ / WRITE`
- In the real world, a TXN either happens completely or not at all

TRANSACTION EXAMPLES

- Bank transfer of money between two accounts
- Purchase a group of products online
- Register for a class (either waitlist or allocated)

TRANSACTIONS IN SQL

In SQL, multiple statements can be grouped together as a transaction:

```
BEGIN TRANSACTION ;
  UPDATE account
    SET balance = balance – 1000
    WHERE account_no = 1;
  UPDATE account
    SET balance = balance + 1000
    WHERE account_no = 2;
COMMIT ;
```

WHY TRANSACTIONS?

Grouping user actions (reads/writes) into *transactions* helps with two goals:

<u>Recovery & Durability</u>: keeping the DBMS data consistent and durable in the face of crashes, aborts, system shutdowns, etc.

<u>Concurrency</u>: achieving better performance by parallelizing TXNs *without* inconsistencies

RECOVERY & DURABILITY

- Data must be durable in the face of:
  - system crashes
  - TXN aborts by the user

IDEA:

- make sure that TXNs are either *durably stored in full, or not at all*
- keep *log* to be able to *roll-back* TXNs

RECOVERY & DURABILITY: EXAMPLE

What can happen if the system crashes after the first SQL query is executed?

```
UPDATE account
  SET balance = balance – 1000
  WHERE account_no = 1;
UPDATE account
  SET balance = balance + 1000
  WHERE account_no = 2;
```

CONCURRENCY

Concurrent execution of user programs is essential for good DBMS performance

- better utilization: CPU/IO overlap
- avoids the situation where long running queries starve other queries
- provides the users with an illusion of a single-user system, called **isolation**
- maintains **consistency** during the concurrent execution

CONCURRENCY: EXAMPLE

What can happen if the two SQL queries are executed at the same time?

```
1: UPDATE account
   SET balance = balance – 1000
   WHERE account_no = 1;
2: UPDATE account
   SET balance = balance * 1.5
   WHERE account_no = 1;
```

THE ACID PROPERTIES

ACID PROPERTIES

Atomicity: all actions in the TXN happen, or none happen

Consistency: a database in a consistent state will remain in a consistent state after the TXN

Isolation: the execution of one TXN is isolated from other (possibly interleaved) TXNs

Durability: once a TXN commits, its effects must persist

ACID: ATOMICITY

Atomicity: All actions in the transaction happen, or none happen

- Two possible outcomes for a TXN
  - **commit**: all the changes are made
  - **abort**: no changes are made

ACID: CONSISTENCY

Consistency: a database in a consistent state will remain in a consistent state after the transaction

- Examples*:*
  - account number is unique
  - stock amount can't be negative
- How consistency is achieved:
  - the *programmer* makes sure a TXN takes a consistent state to a consistent state
  - the *DBMS* makes sure that the TXN is **atomic**

ACID: ISOLATION

Isolation: the execution of one transaction is isolated from other (possibly interleaved) transactions

Example:

- if T1, T2 are interleaved, the result should be the same as executing first T1 then T2, or first T2 then T1

ACID: DURABILITY

Durability: if a transaction commits, its effects must persist

- for example, if the system crashes after a commit, the effects must remain
- essentially, this means that we have to write to disk

CHALLENGES FOR ACID

- power failures (but not media failures)
- users may abort the program: need to “rollback the changes”
  - we need to *log* what happened!
- many users can execute concurrently
  - *locking* (we’ll see this next lecture!)

all these must be done while keeping performance in mind!

LOGGING

WHY LOGGING?

- Can we just write the modified pages to disk **only** once whole TXN is complete?
  - if abort/crash and the TXN is not complete, it has no effect: atomicity + durability!

- However, we need to **log** partial results of TXNs:
  - memory constraints (the buffer pool may want to write pages to disk earlier!)
  - time constraints (what if one TXN takes very long?)

LOGGING

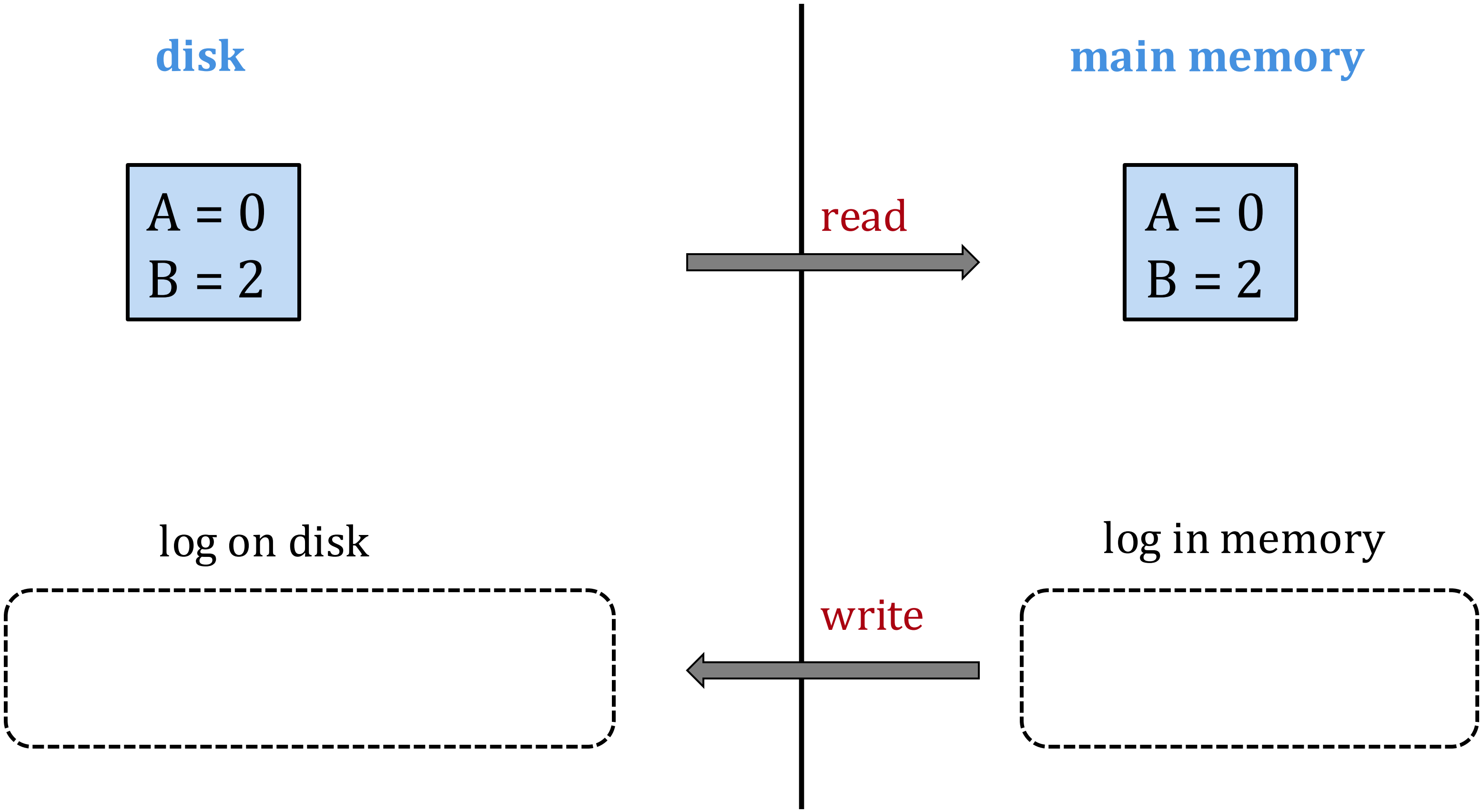
The **log** is a list of modifications

- it records **REDO/UNDO** information for every update
  - only minimal info (diff) written to log
- it is *duplexed* and *archived* on stable storage (disk)
- it can **force** pages to disk

- it consists of an *ordered list* of actions of the form

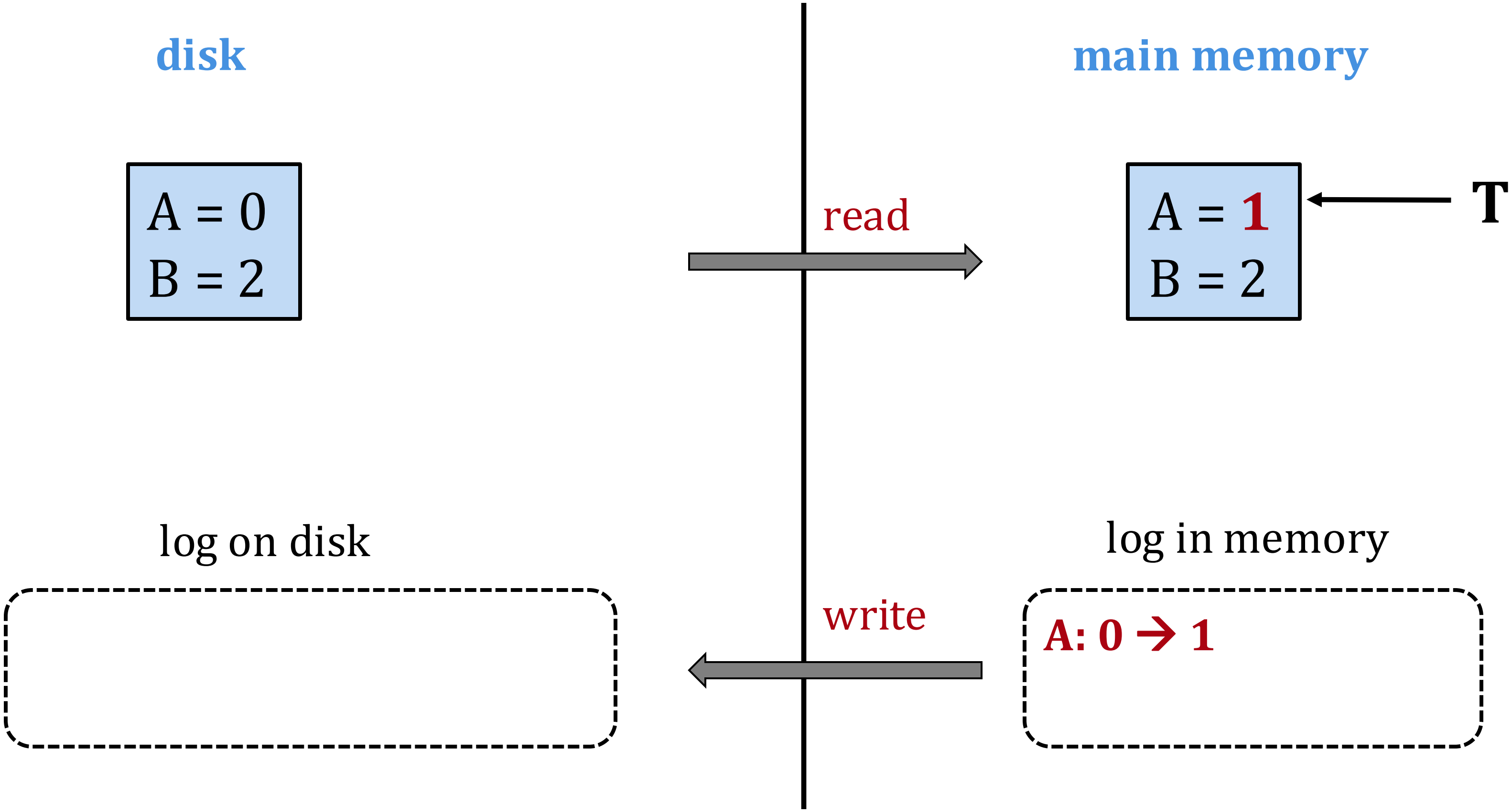
  `<TXNID, location, old-data, new-data>`

LOGGING: EXAMPLE



T: Read(A), Write(A)

LOGGING: EXAMPLE



The log records the operation in the main memory!

T: Read(A), Write(A)

HOW DO WE WRITE THIS TO DISK?

- We will see the Write-Ahead Logging (WAL) protocol
- WAL guarantees atomicity & durability
- We will also see why other ideas don’t work!

WRITE-AHEAD LOGGING

1. we force the log record for an update to disk before the corresponding page goes to disk

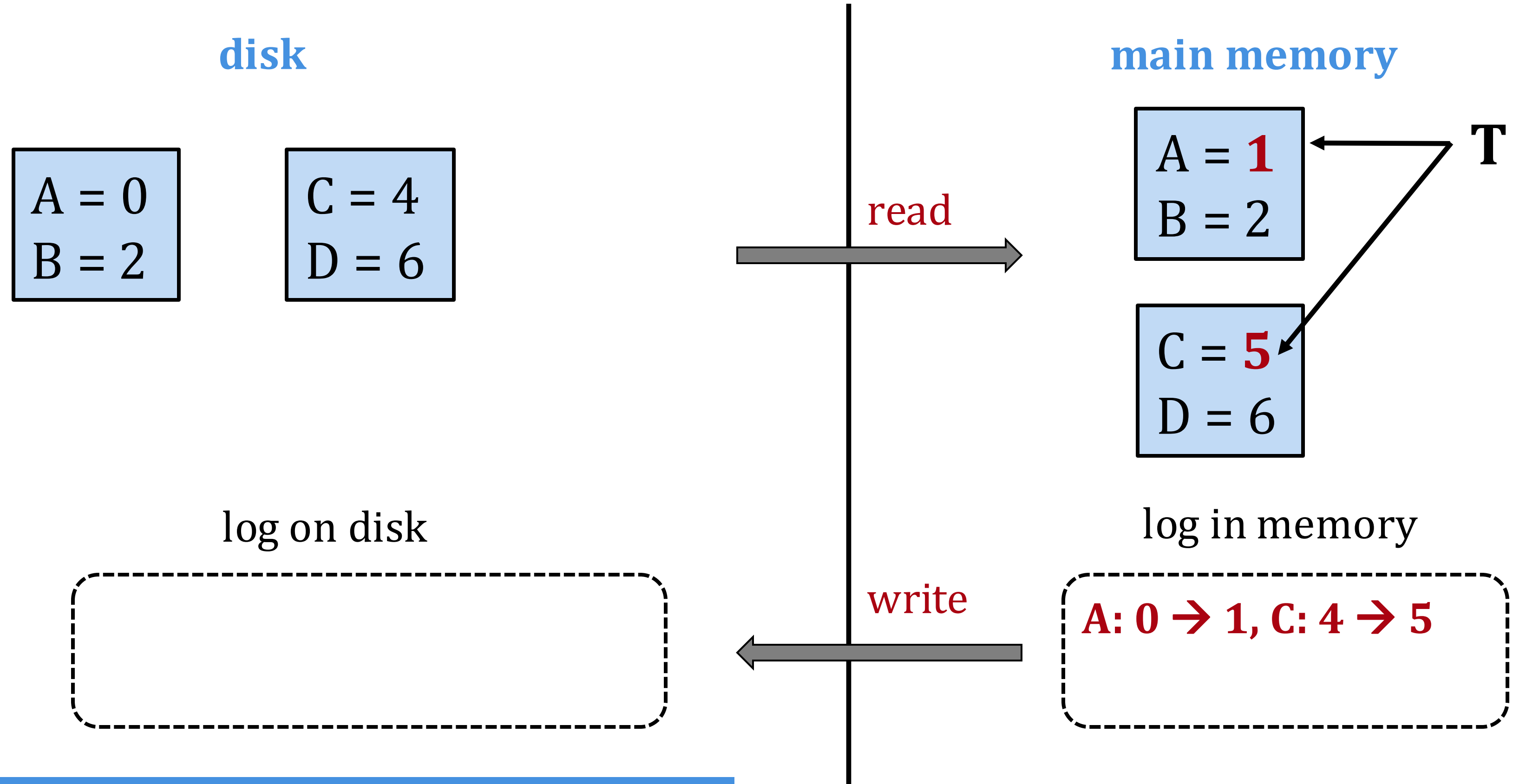
ATOMICITY

2. we write to disk all log records for a TXN before commit

DURABILITY

Note: WAL does not record any reads, only updates!

LOGGING: BAD PROTOCOLS #1

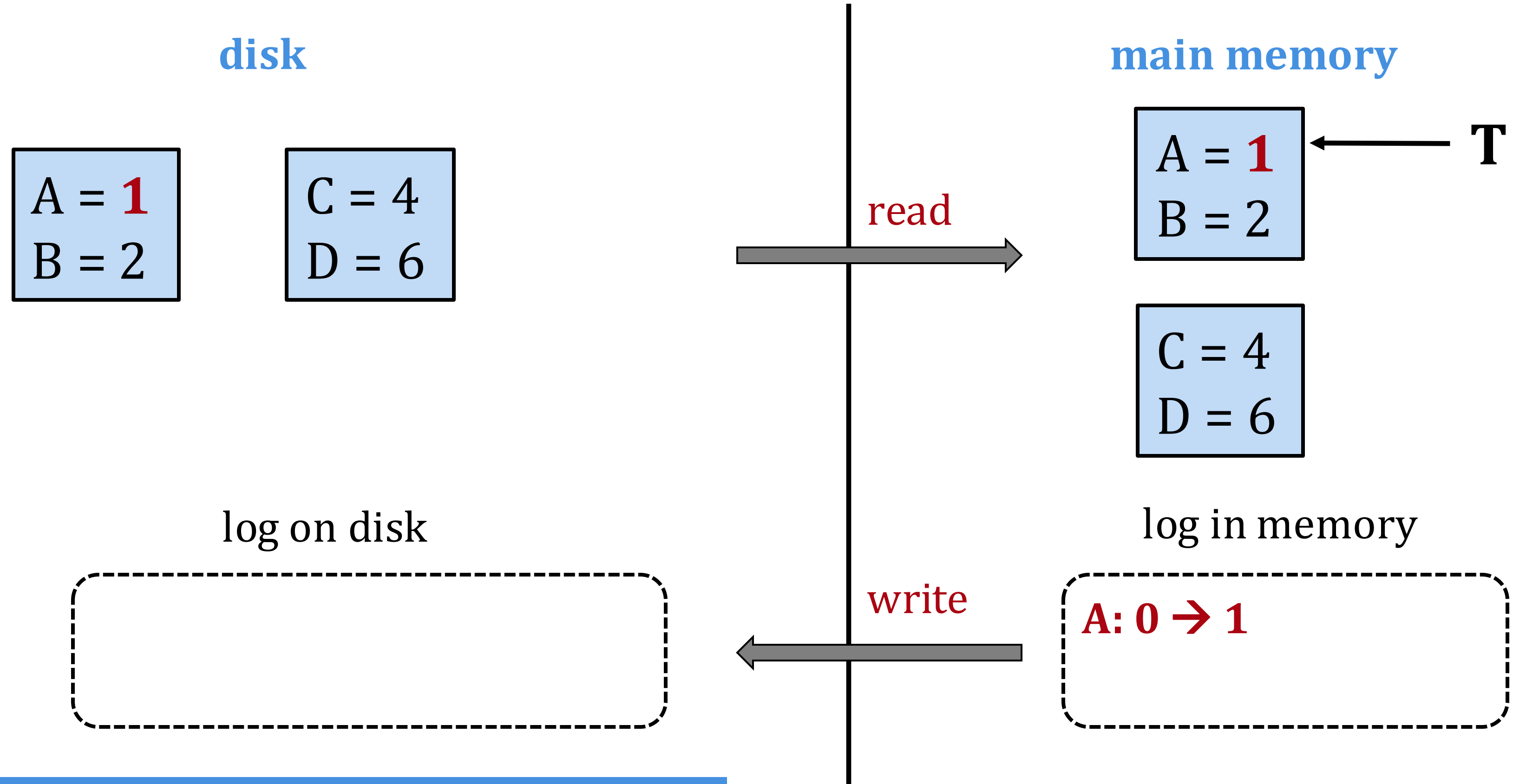


What happens if we commit the TXN before writing page/log to disk?

- if crash, not durable!

T: Write(A), Write(C)

LOGGING: BAD PROTOCOLS #2

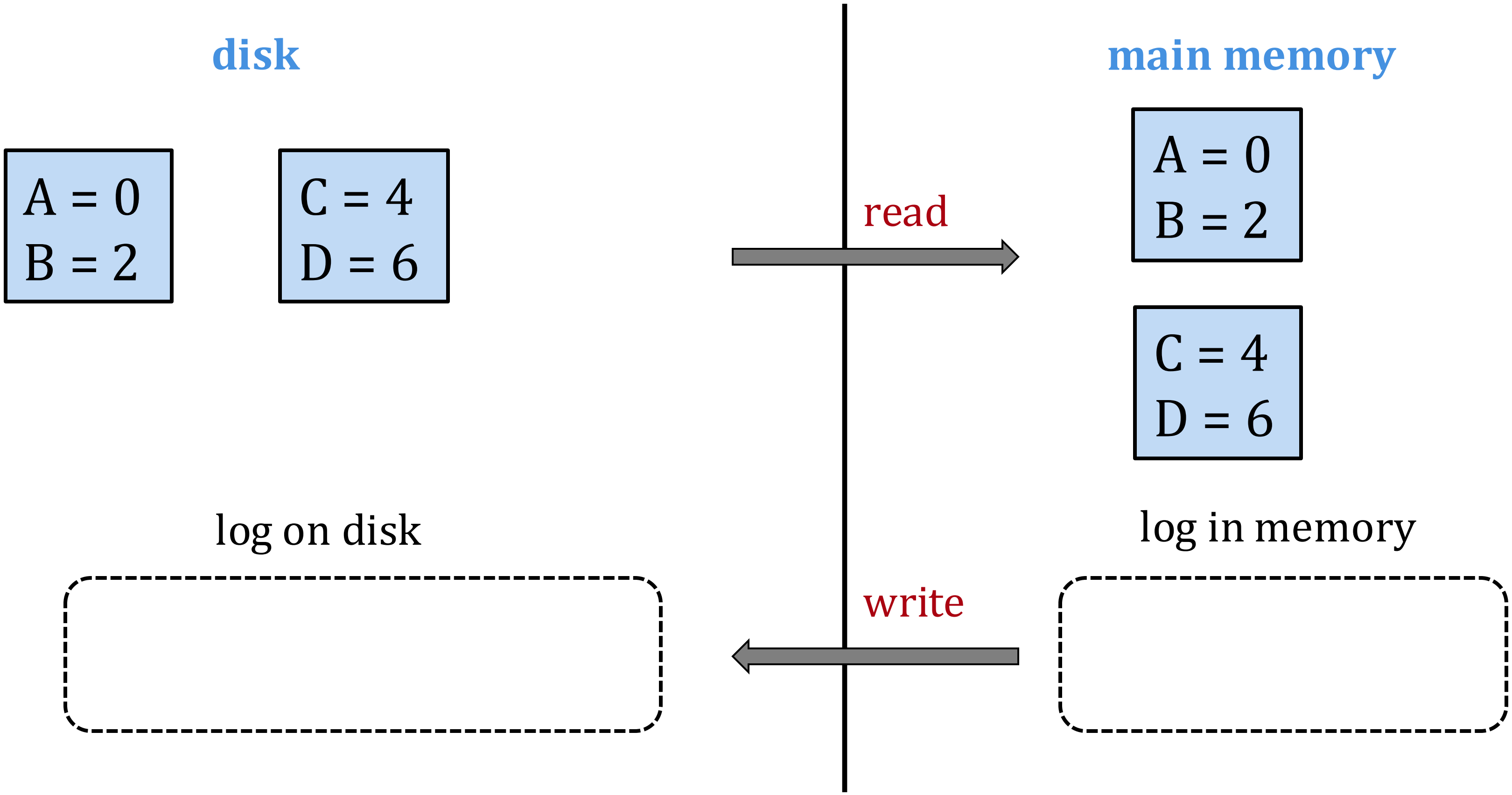


What happens if we write the page to disk before the log writes to disk?

- if crash/abort, not atomicity!

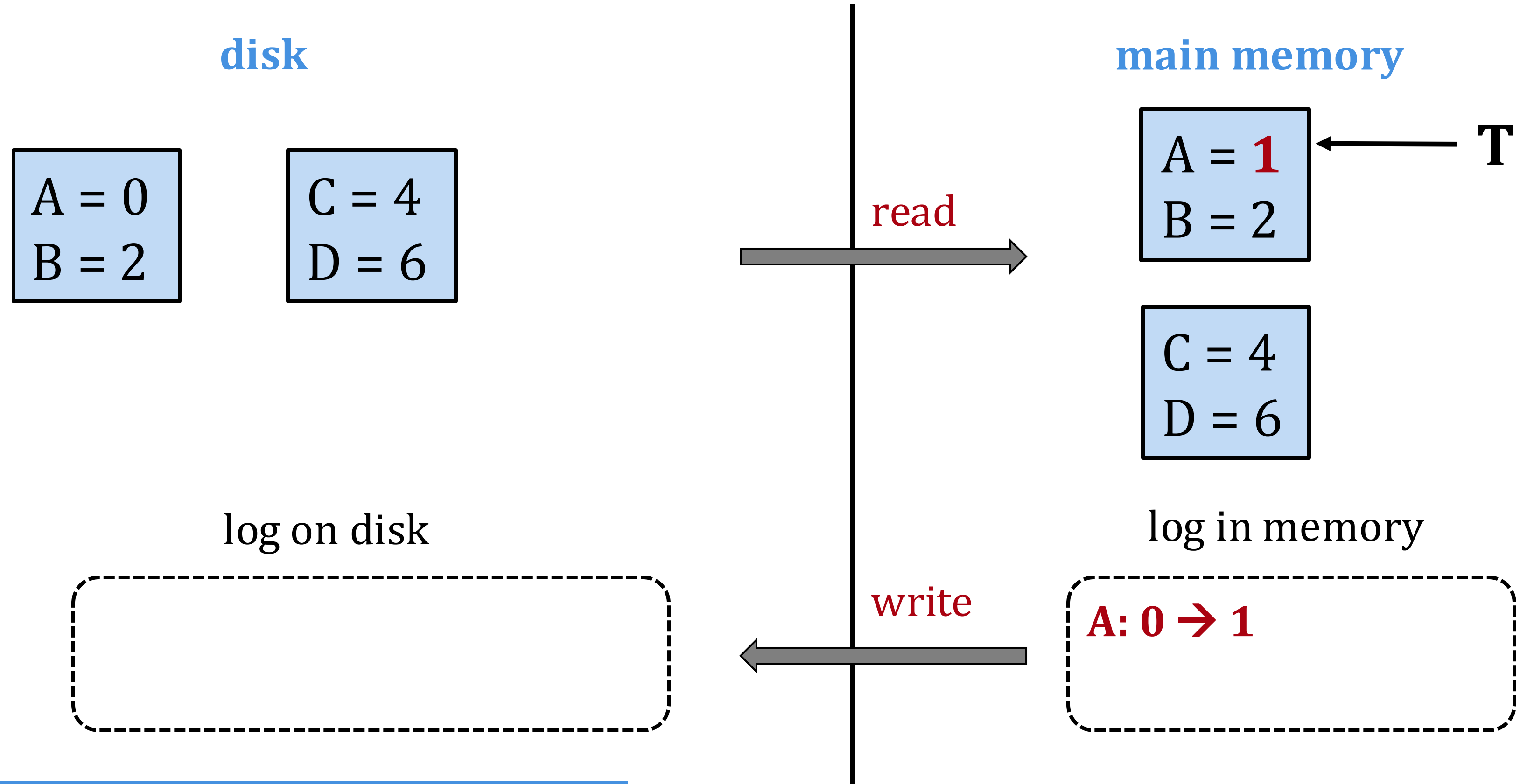
T: Write(A), Write(C)

LOGGING: WAL PROTOCOL



T: Write(A), Write(C)

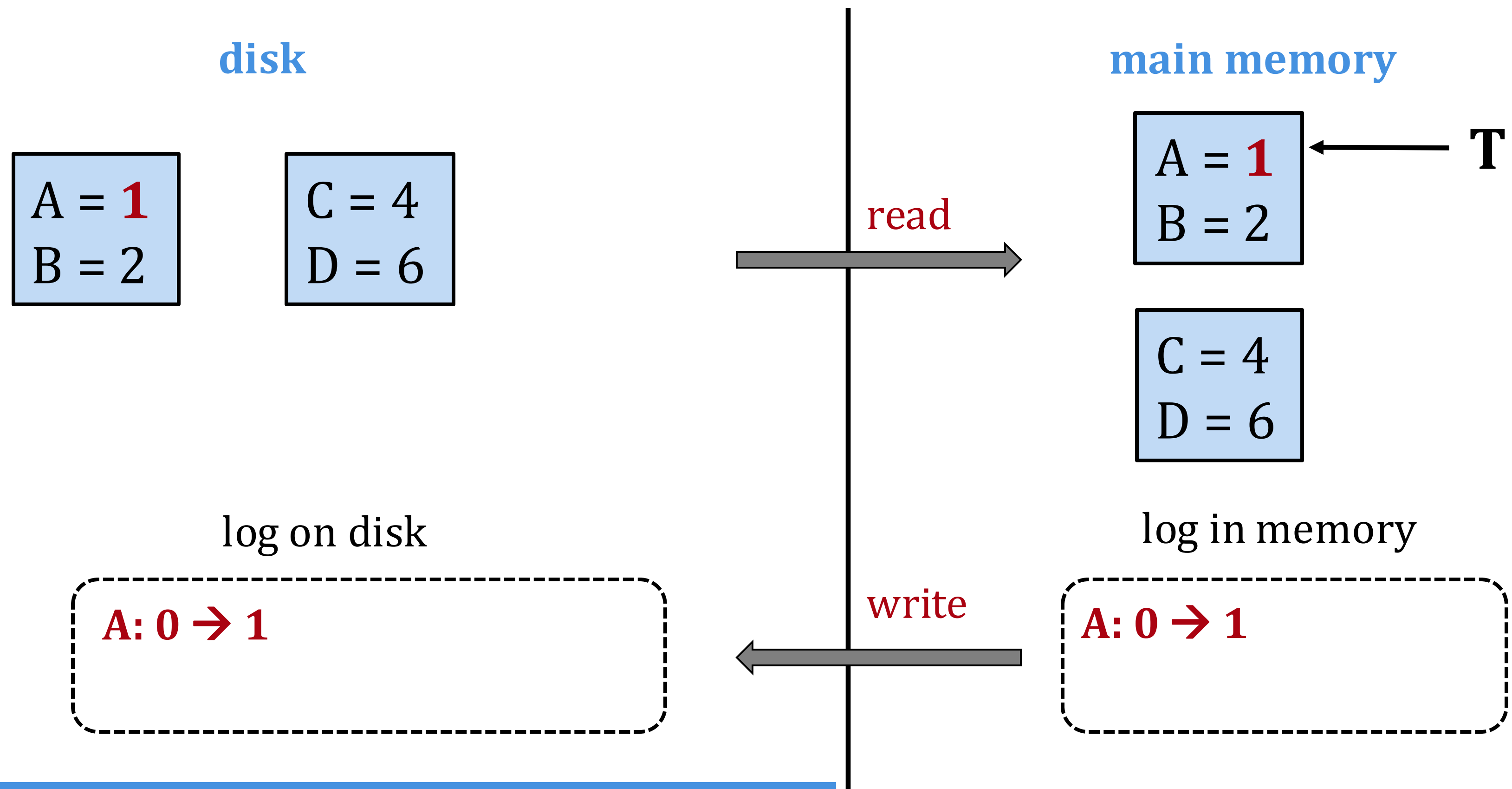
LOGGING: WAL PROTOCOL



So far no writing to disk.
If crash/abort now, we are fine!

T: Write(A), Write(C)

LOGGING: WAL PROTOCOL

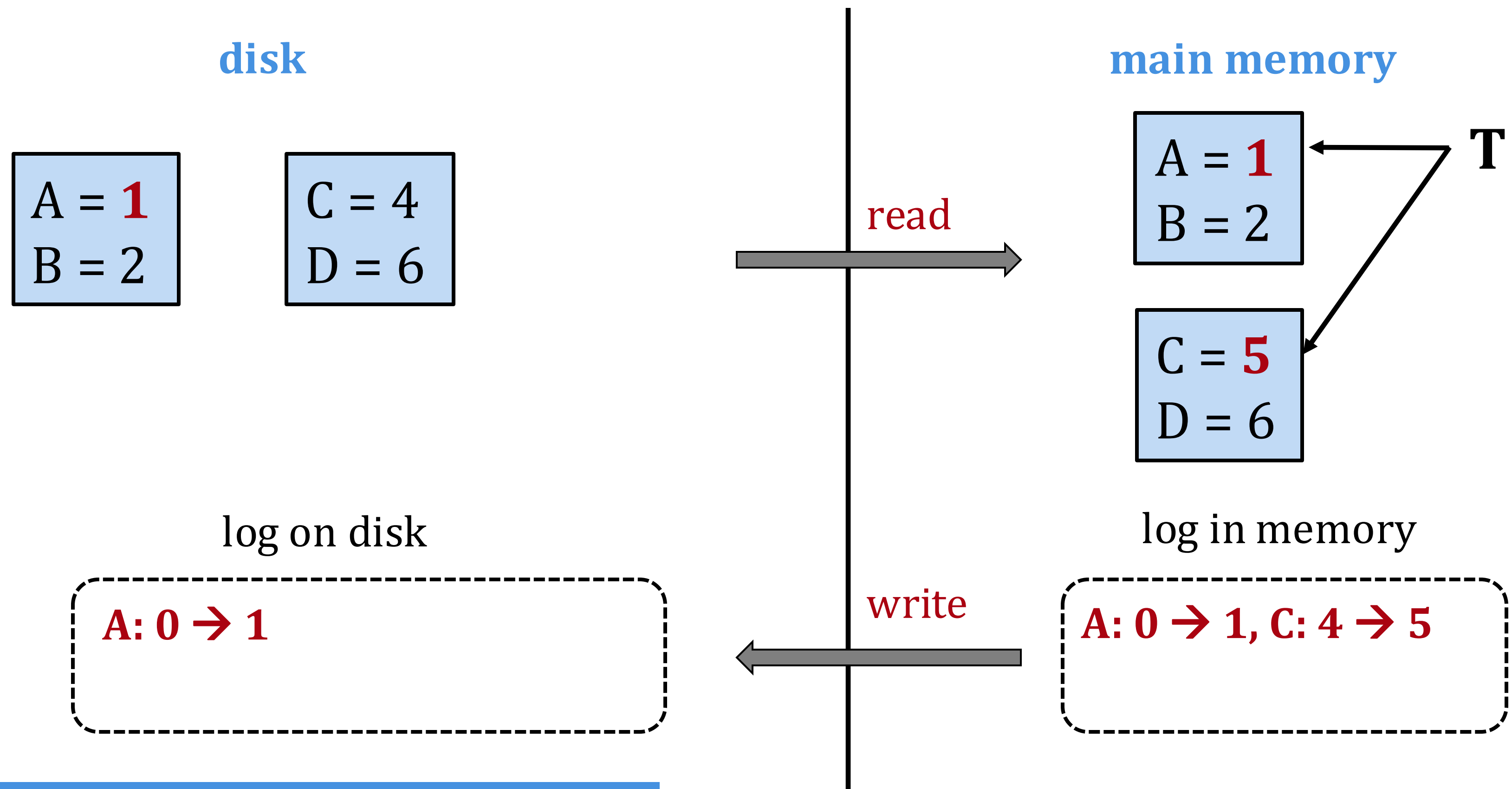


If the buffer decides to write to disk, we must write the log before!

- if crash/abort, we can UNDO using log

T: Write(A), Write(C)

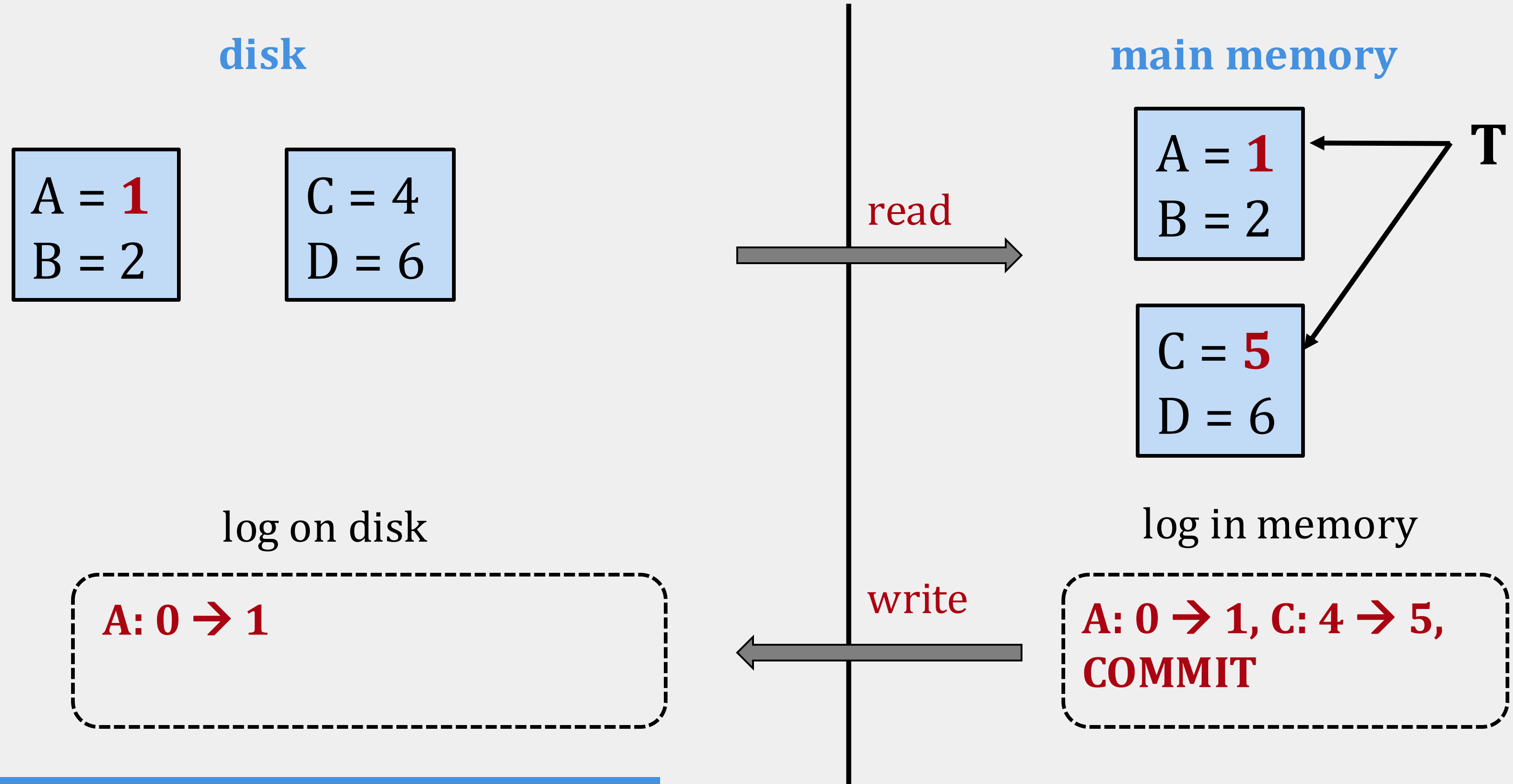
LOGGING: WAL PROTOCOL



We don't write to disk right away

T: Write(A), Write(C)

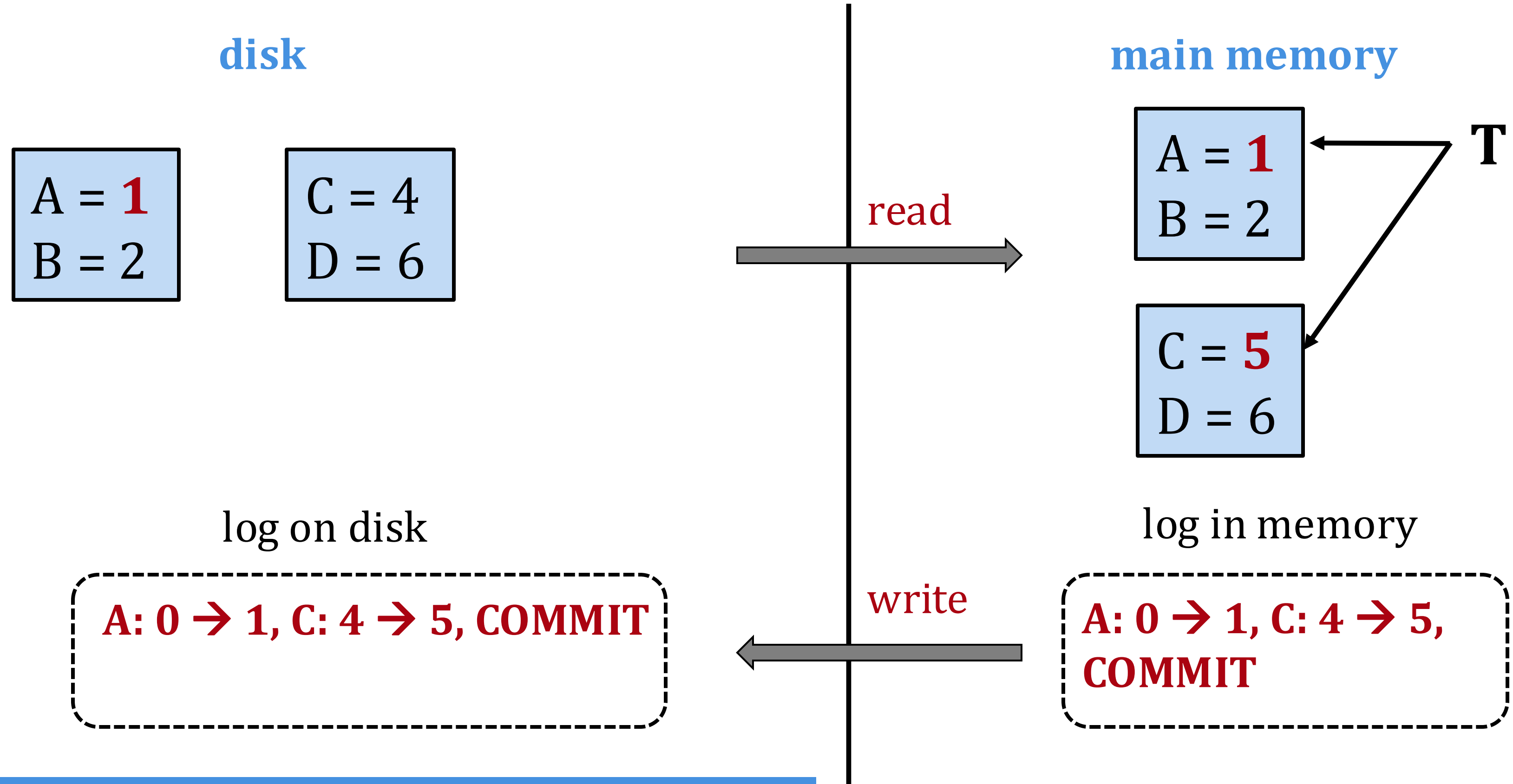
LOGGING: WAL PROTOCOL



We don’t write to disk right away

T: Write(A), Write(C)

LOGGING: WAL PROTOCOL



Upon commit of the TXN, we force write the log to disk!

- the page does not need to be written!

T: Write(A), Write(C)

LOGGING: WAL PROTOCOL

disk

main memory

A = **1**
B = 2

C = 4
D = 6

read

CRASH!

log on disk

A: 0 → 1, C: 4 → 5, COMMIT

write

Upon crash, we can use the log to reconstruct (REDO) the modified pages

T: Write(A), Write(C)

ARIES

- The WAL protocol still has to force multiple pages to disk, which can limit performance
- ARIES is a (very) complex recovery algorithm that improves performance and has 3 phases:
  - Analysis
  - UNDO (rollback)
  - REDO (replay)

- For more on crashes and recovery, take CS 764!