UNIVERSITY of VIRGINIA

# CS4740
# CLOUD COMPUTING

## Transaction

Prof. Chang Lou, UVA CS, Fall 2025

# CONTEXT

- We'll dive into more advanced topics: agreement, consensus..
- But before continuing DS, today we discuss how some DS challenges are solved in simpler, single-node systems.
  - Then we come back to distributed settings.

- Today: Transaction
  - How transaction helps solving key system challenges
  - Implement transaction: Part I

# CHALLENGES OF DISTRIBUTED SYSTEMS

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- Two common challenges of building a distributed system (e.g., database):
  - Handling **failures**: failures are inevitable but they create the potential for partial computations and correctness of computations after restart.
  - Handling **concurrency**: concurrency is vital for performance (e.g., I/O is slow so need to overlap with computation), but it creates races. Need to use some form of synchronization to avoid those.

They are not unique to distributed systems!

# CHALLENGES OF SINGLE-NODE SYSTEMS

- Two common challenges of building a single-node system (e.g., database):
  - Handling **failures**: servers may crash or operations may abort anytime.
  - Handling **concurrency**: single-node systems handle concurrent requests to improve throughput.
- Let's start from what we left last class: RPC

# EXAMPLE: FLIGHT BOOKING

— Client code:

```
x = server.getFlightAvailability(ABC, 123, date);   // read(ABC, 123, date)
if (x > 0)
    y = server.bookTicket(ABC, 123, date);          // write(ABC, 123, date)
server.putSeat(y, “aisle”);
```

# FAILURE: ABORTION

**Client 1**
x = getSeats(ABC123);
y = getSeats(ABC789);
write(x-1, ABC123);

write(y+1, ABC789);

crash/abort!

new ticket was
booked but old ticket
was not returned!

# CONCURRENCY: 1. LOST UPDATE PROBLEM

**Client 1**

```
x = getSeats(ABC123);
  // x = 10
if(x > 1)
  x = x – 1;
write(x, ABC123);
```

**Client 2**

```
x = getSeats(ABC123);
if(x > 1) //x = 10


  x = x – 1;
write(x, ABC123);
```

At Server: seats = 10

C1's or C2's update was lost!

seats = 9

seats = 9

# CONCURRENCY: 2. INCONSISTENT RETRIEVAL PROBLEM

**Client 1**

```
x = getSeats(ABC123);
y = getSeats(ABC789);
write(x-5, ABC123);
  // ABC123 = 5 now

write(y+5, ABC789);
```

**Client 2**

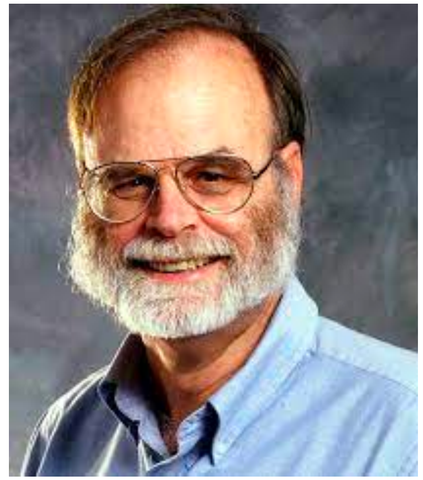
```
x = getSeats(ABC123);
y = getSeats(ABC789);
  // x = 5, y = 15
print("Total:" x+y);
  // Prints "Total: 20"
```

At Server:
ABC123 = 10
ABC789 = 15

C2's sum is the wrong value! Should have been "Total: 25"

# TRANSACTION

- Turing-award-winning idea.
- Abstraction provided to programmers that encapsulates a unit of work against a database.
- Guarantees that the unit of work is executed atomically in the face of failures and is isolated from concurrency.



Jim Gray (1944-2012)

# TRANSACTION API

- Simple but very powerful:

```
txID = Begin()          // Starts a transaction. Returns a unique ID for the
                        // transaction.
```

```
outcome= Commit(txID)   // Attempts to commit a transaction; returns
                        // whether or not the commit was successful. If
                        // successful, all operations in the transaction
                        // have been applied to the DB. If unsuccessful,
                        // none of them has been applied.
```

```
Abort(txID)             // Cancels all operations of a transaction and erases
                        // their effects on the DB. Can be invoked by the
                        // programmer or by the database engine itself.
```

# SEMANTICS

- By wrapping a set of accesses in a transaction, the database can hide failures and concurrency under meaningful guarantees.
- One such set of guarantees is ACID:
  - Atomicity: Either all operations in the transaction will complete successfully (commit outcome), or none of them will (abort outcome), regardless of failures.
  - Isolation: A transaction's behavior is not impacted by the presence of concurrently executing transactions.
  - Durability: The effects of committed transactions survive failures.

hide failures

hide concurrency

# EXAMPLE

**Transaction T1**
begin
x = getSeats(ABC123);
y = getSeats(ABC789);
write(x-1, ABC123);
write(y+1, ABC789);

commit

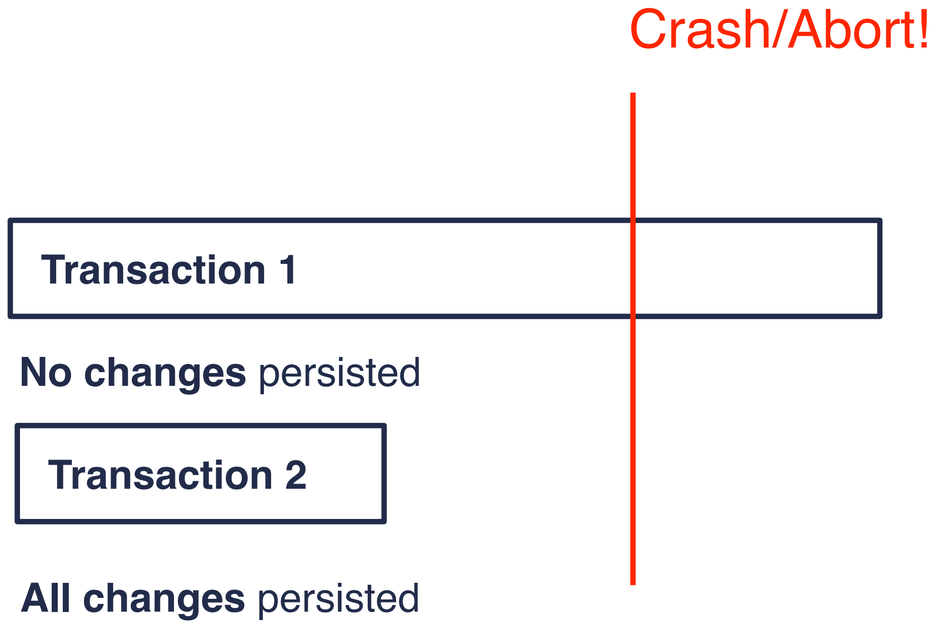
Atomicity: both writes succeed, or neither

Durability: writes are persisted and recoverable after failures

Isolation: T1 don't get affected by other transactions

# HOW TO IMPLEMENT TRANSACTIONS?

- Atomicity and Durability
  - Key mechanism: **write-ahead logging**
- Isolation



# HOW TO MAKE UPDATES DURABLE

**Transaction T1**
begin
x = getSeats(ABC123);
y = getSeats(ABC789);
write(x-1, ABC123);
write(y+1, ABC789);

commit

x = 10

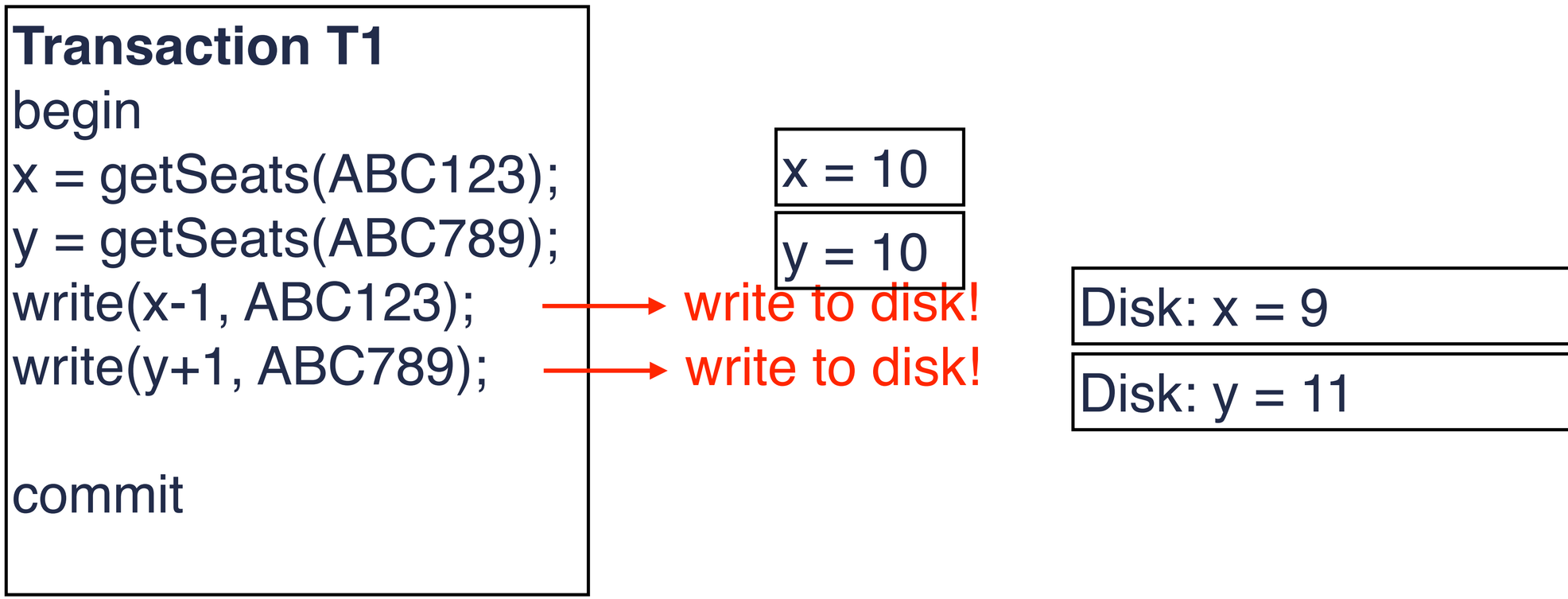
y = 10

Disk: x = 9

Disk: y = 11

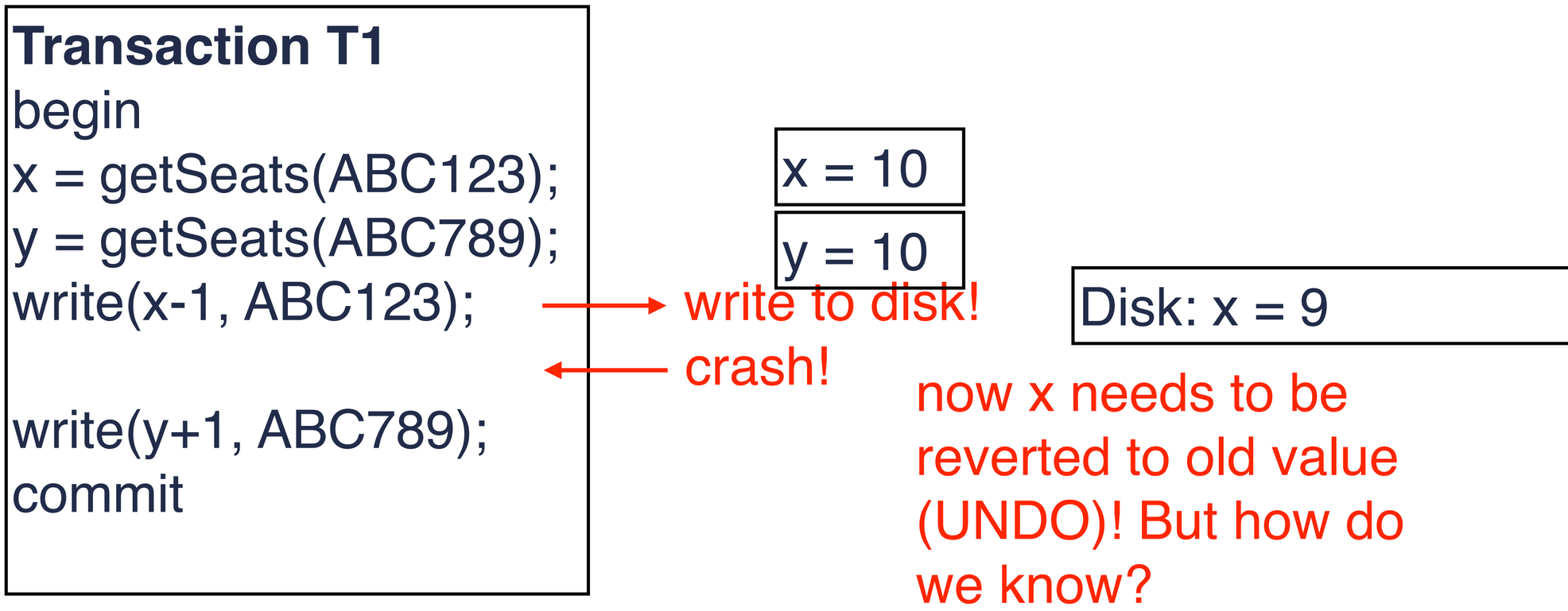
# HOW TO MAKE UPDATES DURABLE

— Write updates to disk!



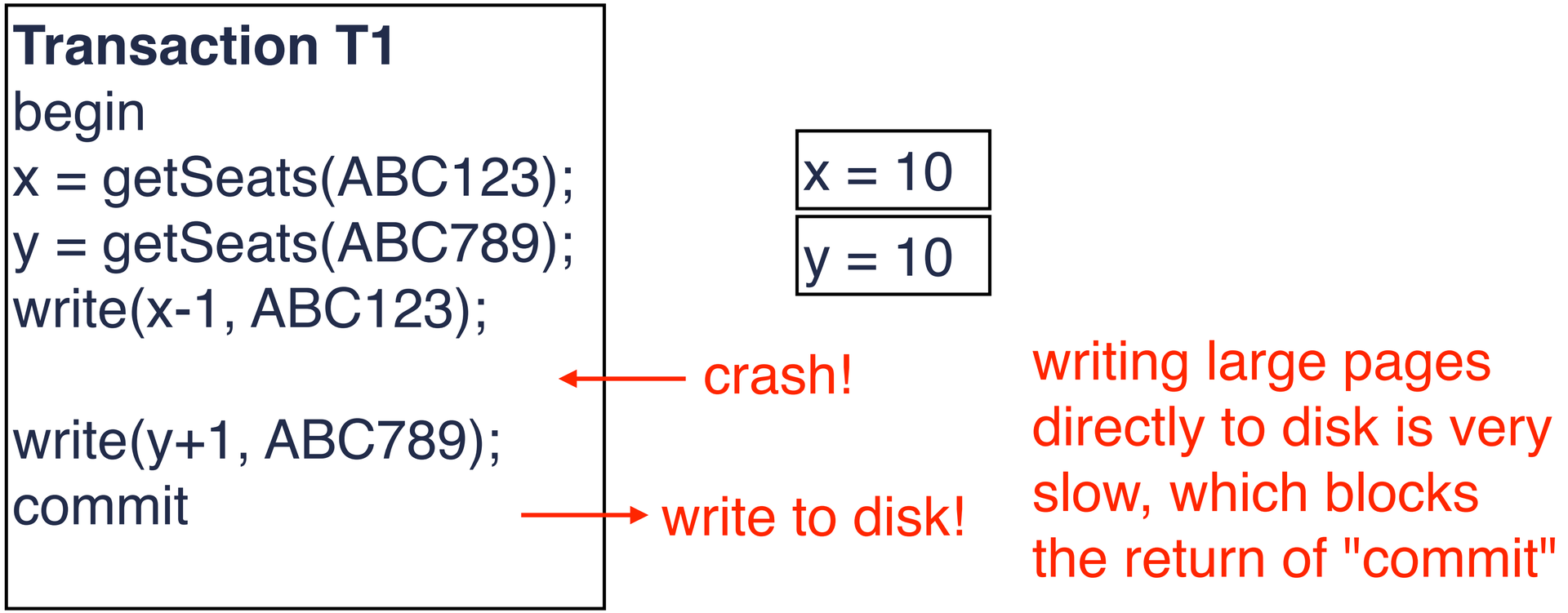
# HOW TO MAKE UPDATES ATOMIC

— Write updates to disk!



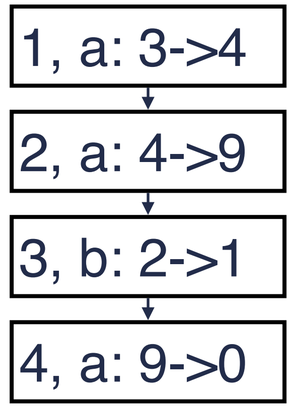
# HOW ABOUT WRITING DATA TO DISK WHEN COMMITTING

— Write updates to disk!



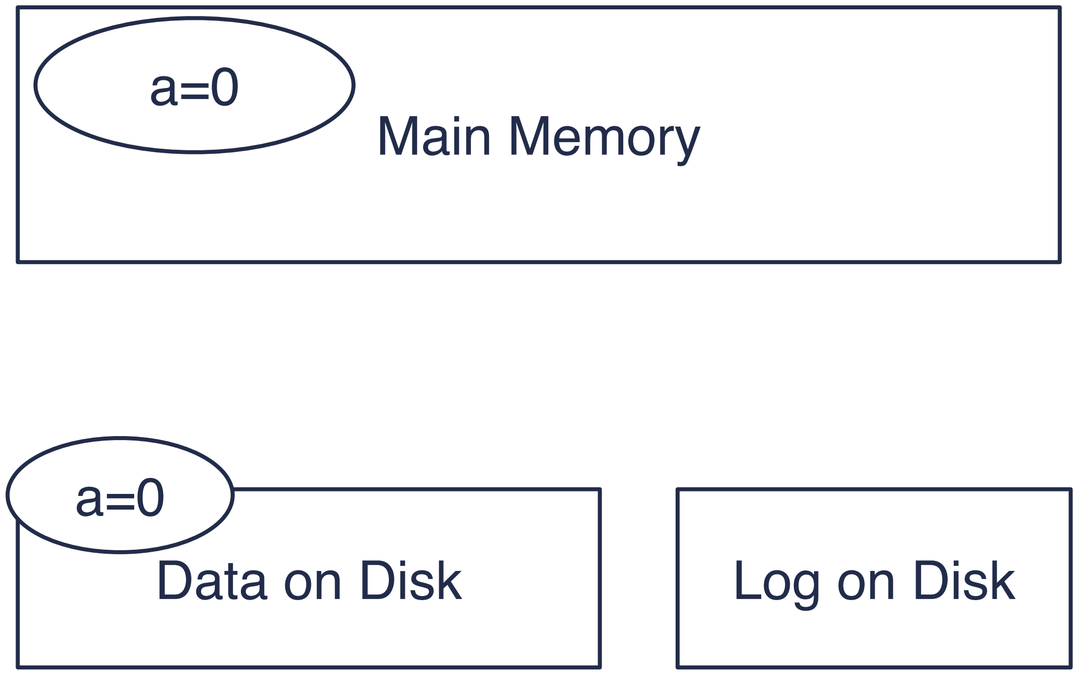
# BASIC IDEA: LOGGING

- Record UNDO/REDO information, for every update, in a log
  - Sequential writes to log (put in one a separate disk)
  - Minimal diff written to log, so multiple updates fit in a single log page
- Log: An ordered list of UNDO/REDO actions
  - Log record: <XID, location, old data, new data>

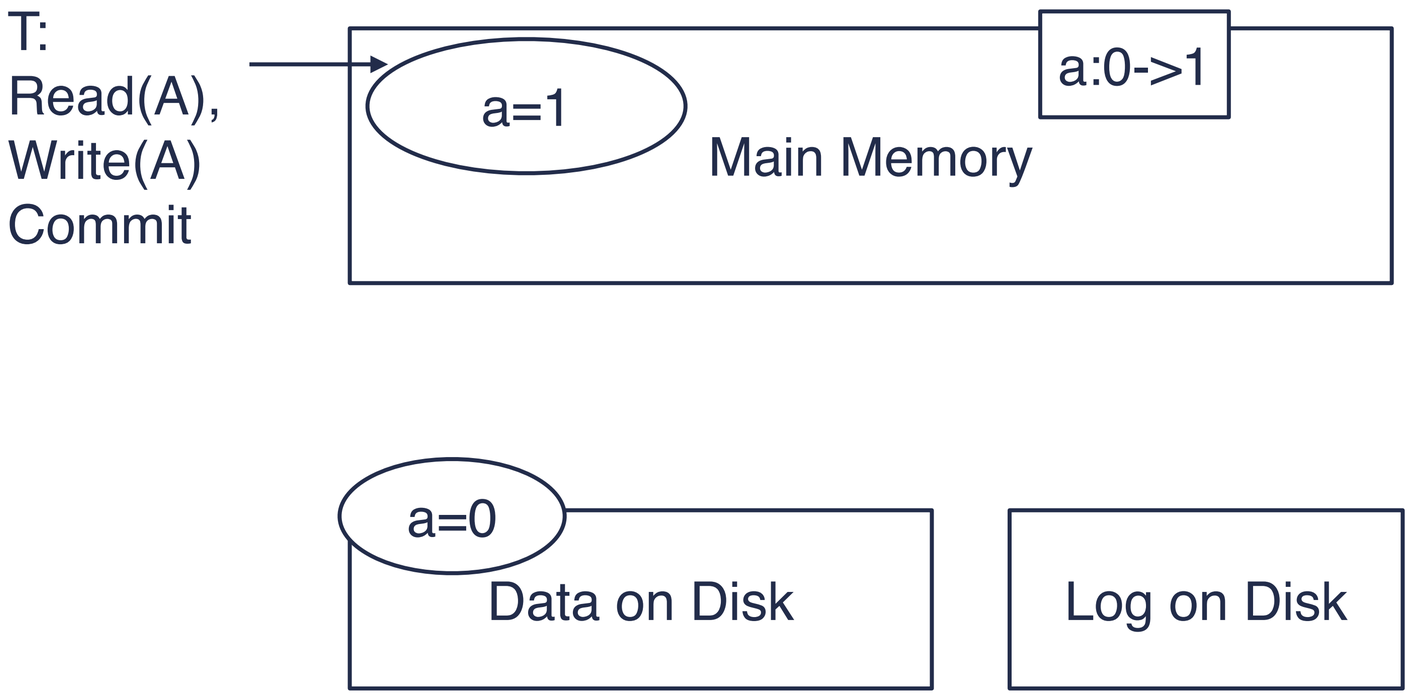



logs

# WHY SIMPLE LOGGING NOT WORKING?

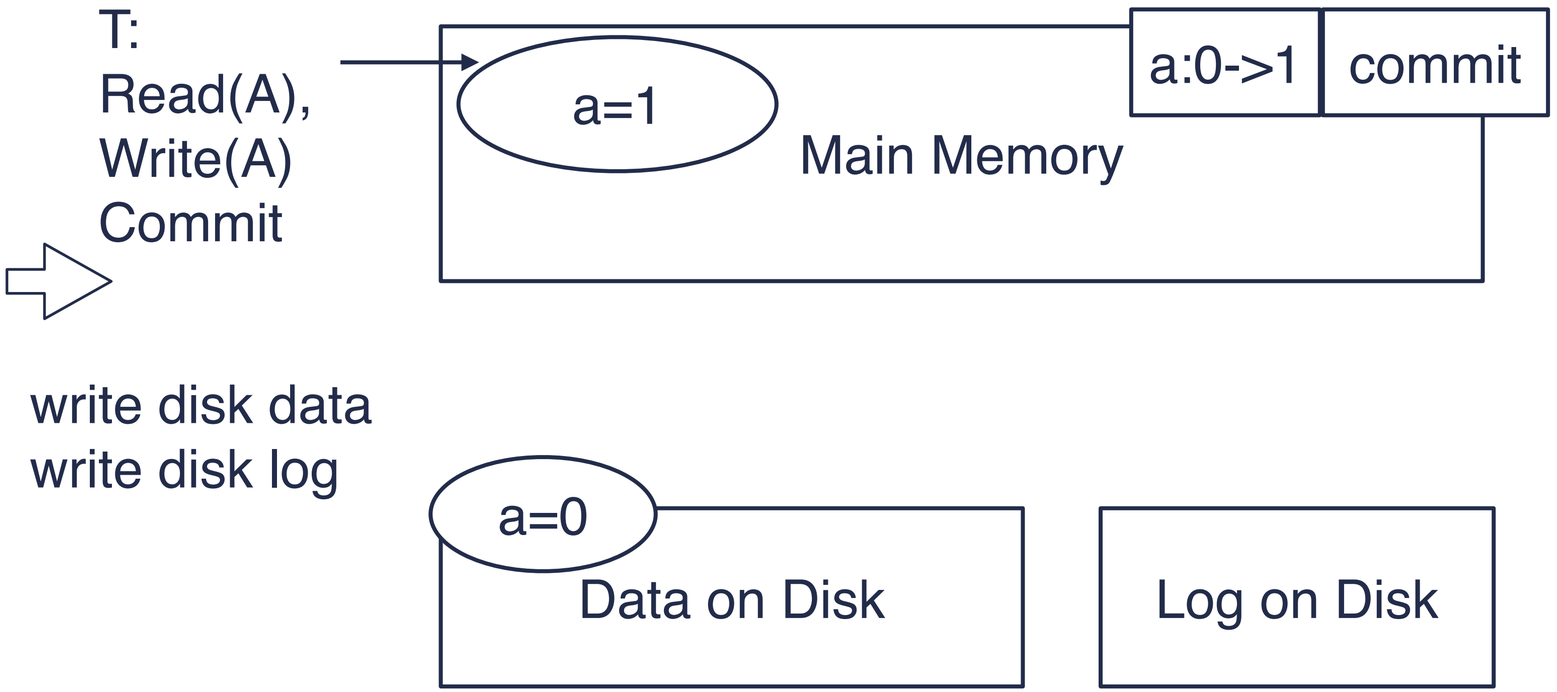


# WHY SIMPLE LOGGING NOT WORKING?




Option1: committing **before** we've written either data or log to disk…

# WHY SIMPLE LOGGING NOT WORKING?



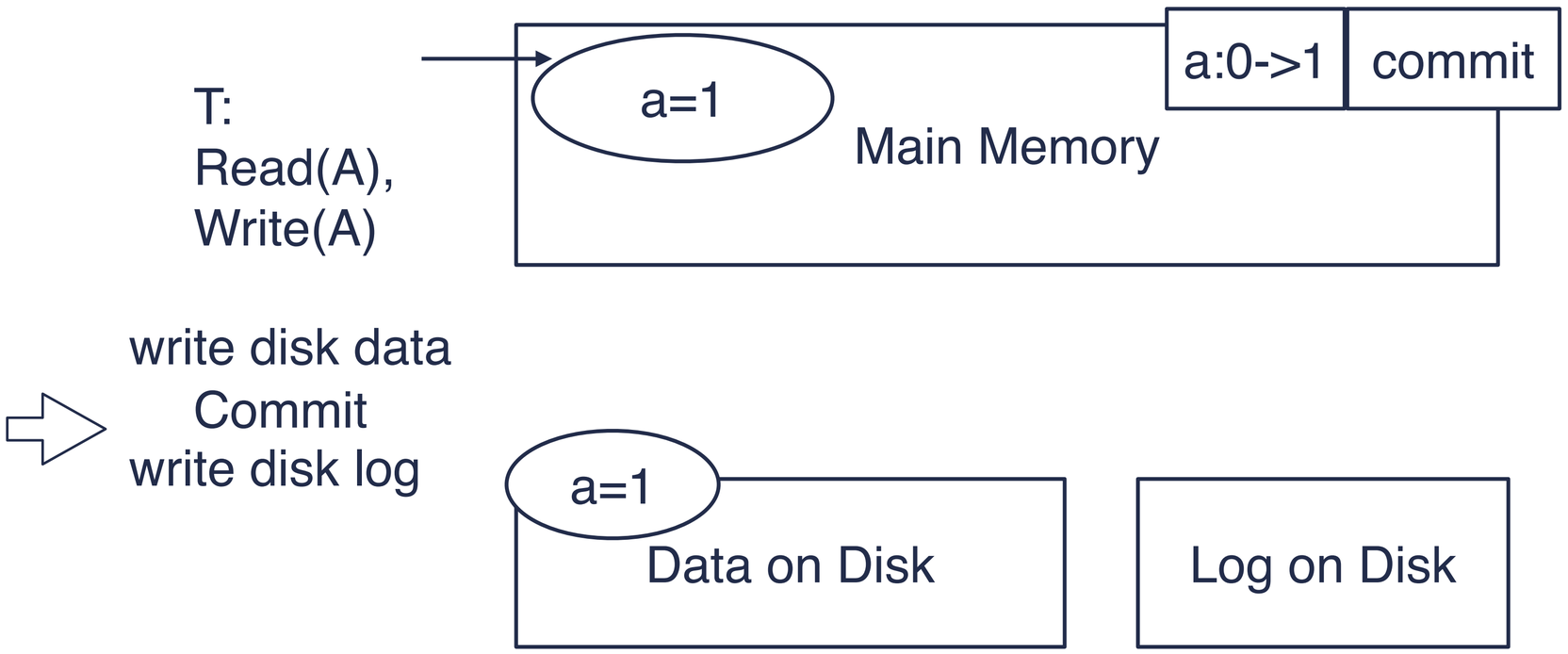

Option1: committing **before** we've written either data or log to disk…

crash!

what happened?

Lost T's update!

# WHY SIMPLE LOGGING NOT WORKING?




Option2: committing **after** we've written data but **before** we've written log to disk…

crash!

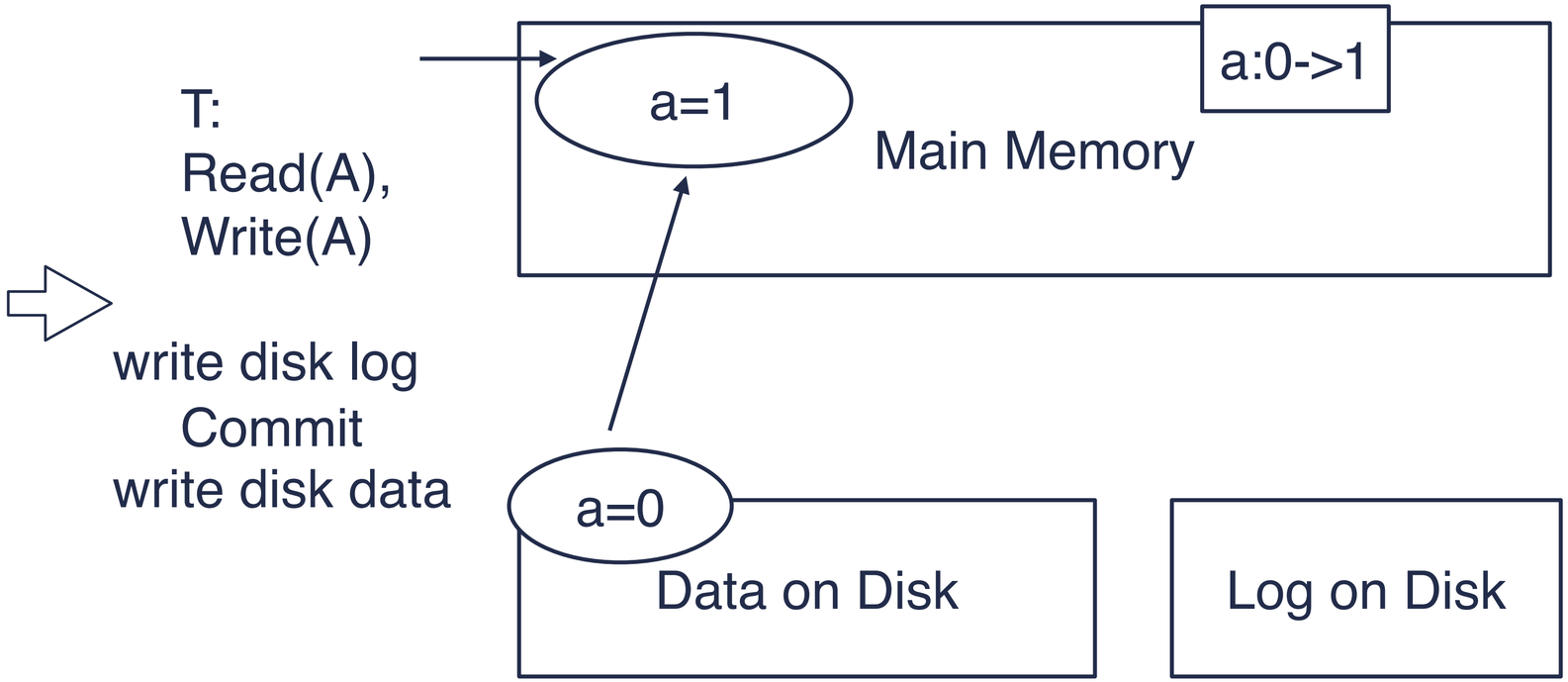
what happened?

How do we know whether T was committed??

# WRITE-AHEAD LOGGING (WAL)

- The Write-Ahead Logging Protocol:
  - Write logs to disk and return to the client
  - Write the data to disk asynchronously

# WRITE-AHEAD LOGGING (WAL)




WAL: committing **after** we've written log to disk but **before** we've written data to disk

crash!

what happened?

read data from disk

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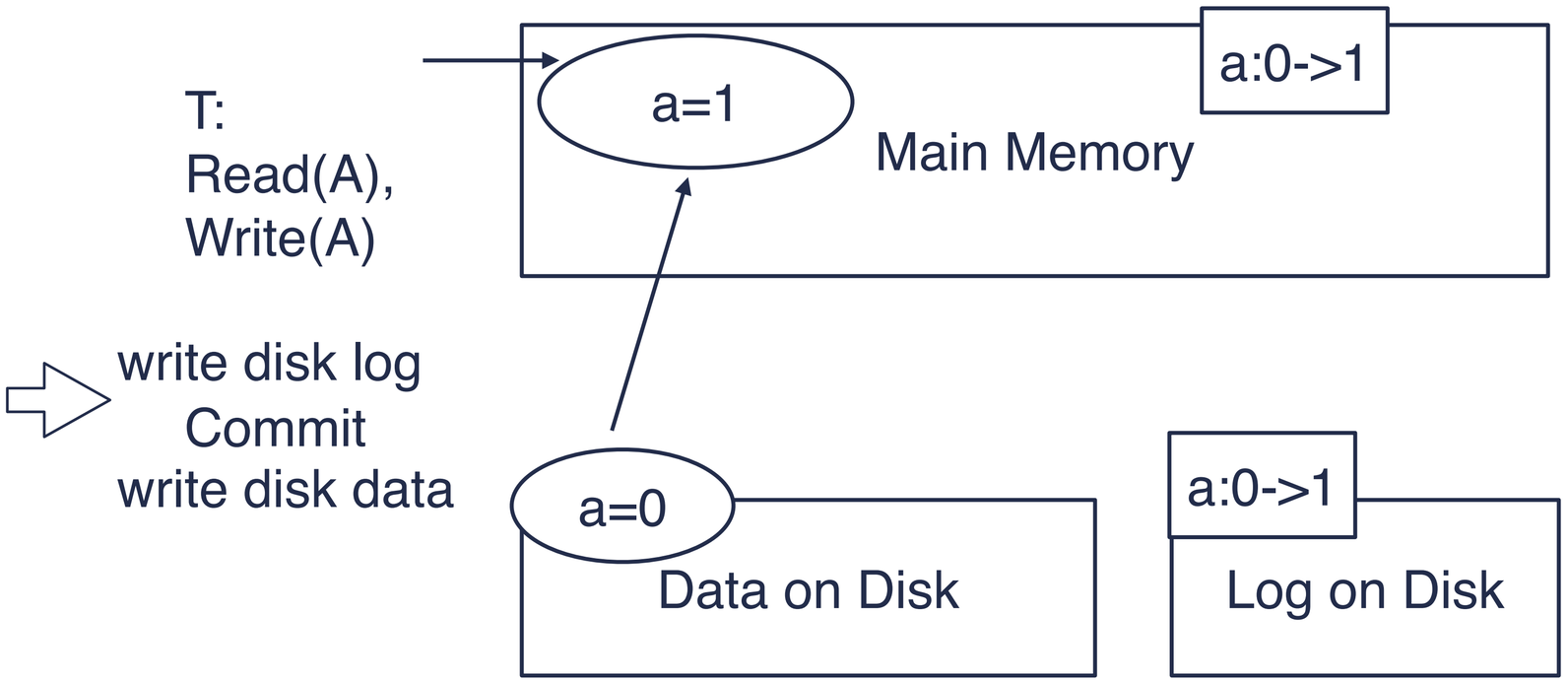


WAL: committing **after** we've written log to disk but **before** we've written data to disk

crash!

what happened?

read data from disk

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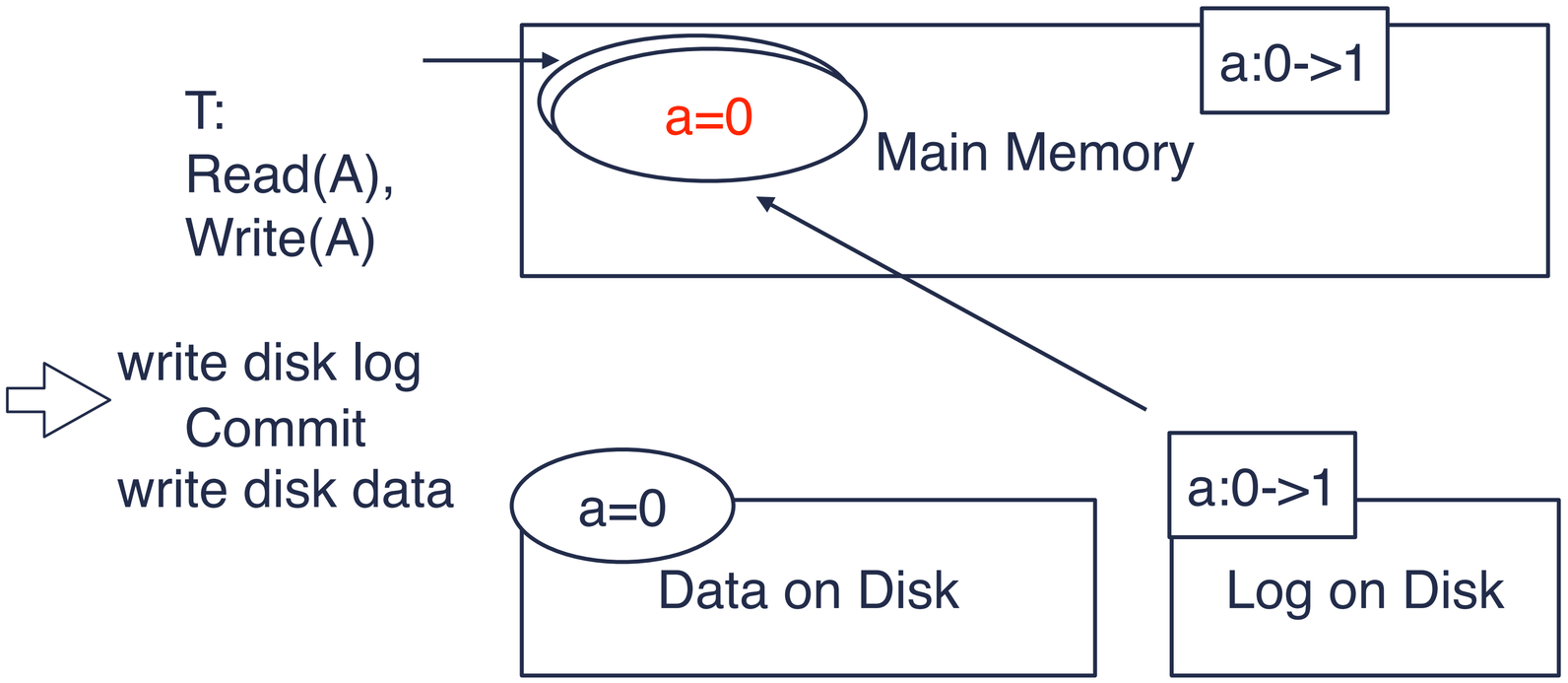


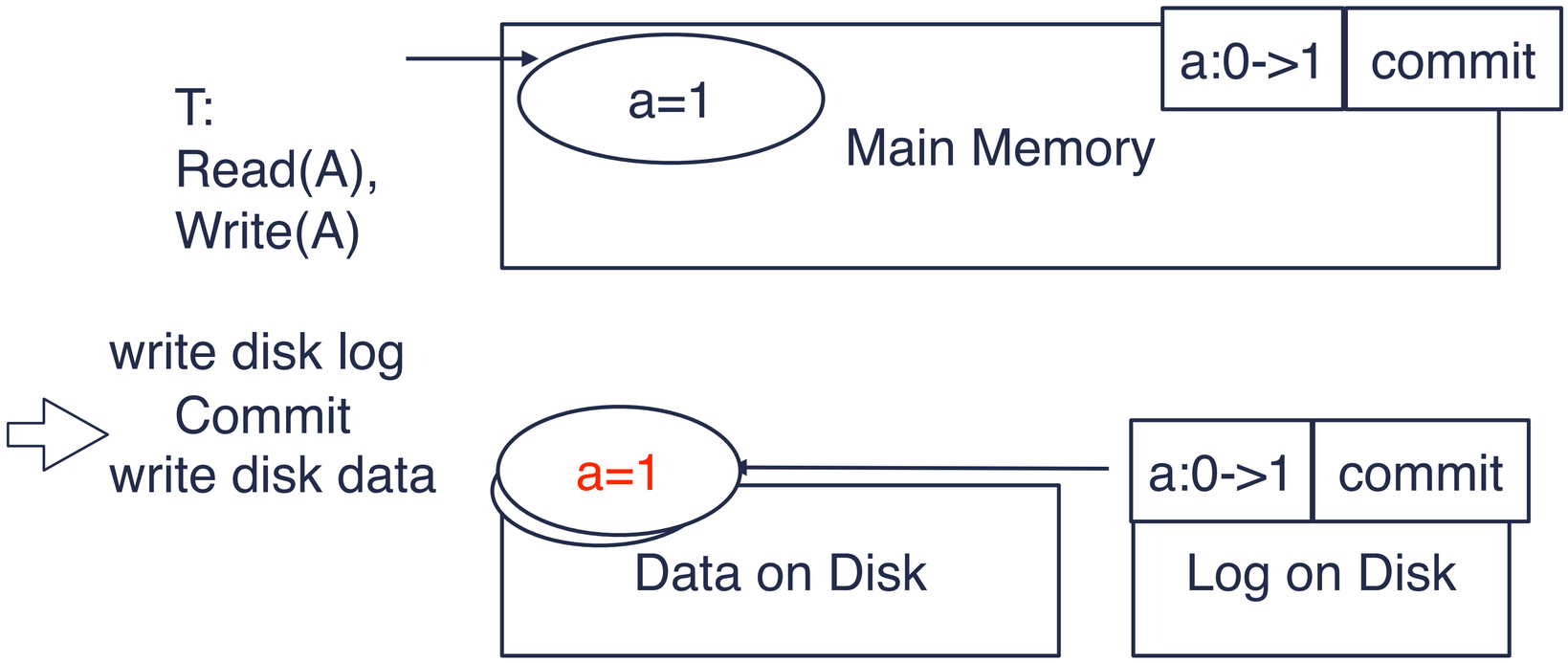

WAL: committing **after** we've written log to disk but **before** we've written data to disk

abort!

what happened?

Just UNDO the log

# WRITE-AHEAD LOGGING (WAL)



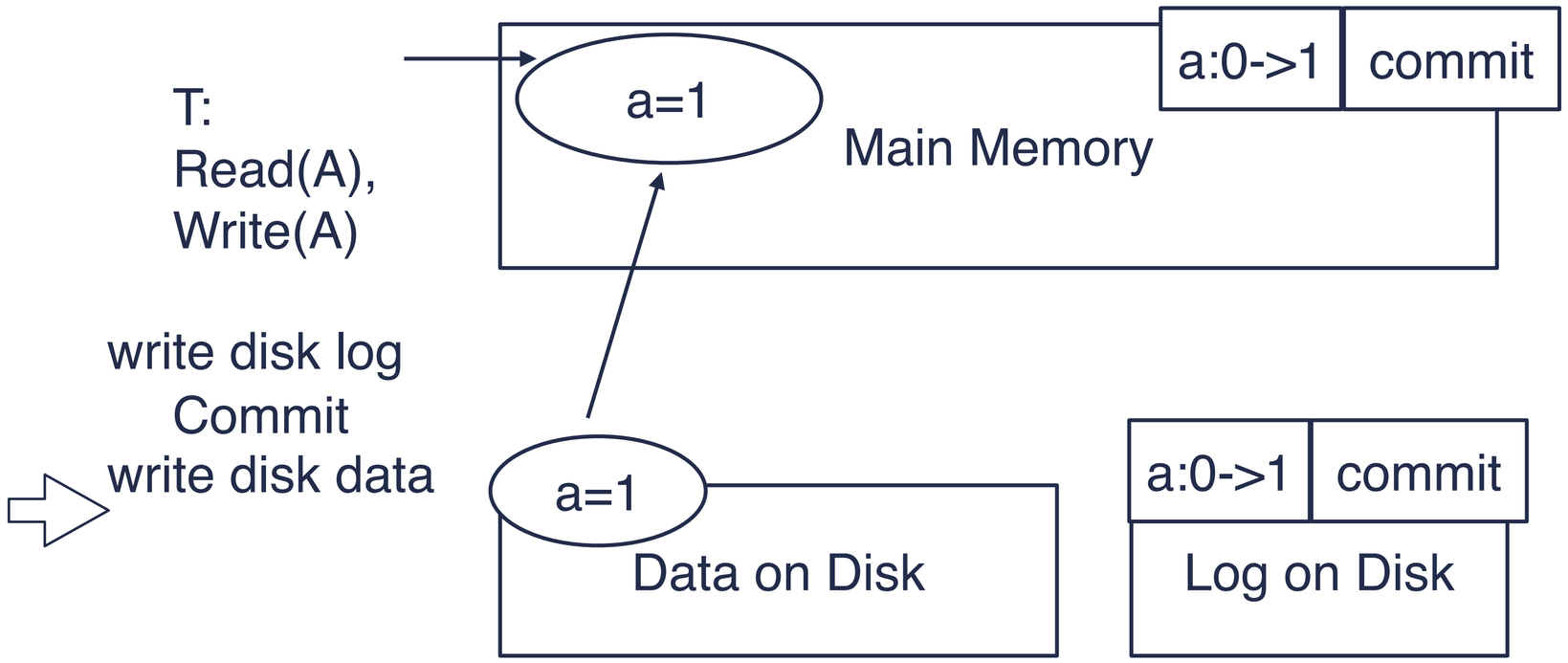

WAL: committing **after** we've written log to disk but **before** we've written data to disk

crash!

what happened?

Just REDO the log

# WRITE-AHEAD LOGGING (WAL)




WAL: committing **after** we've written log to disk but **before** we've written data to disk

crash!

what happened?

read data from disk

# RECOVERING FROM SIMPLE FAILURES

- e.g., system crash
  - For now, assume we can read the log
- “Analyze” the log
- Redo all (usually) transactions (forward)
  - Repeating history!
- Undo uncommitted transactions (backward)

# WHY WRITE-AHEAD LOGGING (WAL)

- The Write-Ahead Logging Protocol:
  - Must enforce the log record for an update before the corresponding data page gets to disk (where the name of protocol comes from)
  - Must write all log records for a Xact before commit
- #1 guarantees Atomicity
- #2 guarantees Durability

# THE PERFORMANCE OF WAL

- Why performance is good?
  - This decouples writing a transaction's dirty pages to database on disk from committing the transaction.
  - We only need to write its corresponding log records.
  - If a txn updates a 100 tuples stored in 100 pages, we only need to write 100 log records (which could be a few pages) instead of 100 dirty pages.

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# TAKEAWAYS

- Systems need dealing with failures and concurrency
- Transactions provide Atomicity, Durability, Isolation
  - How? **Write-Ahead Logging**
- Next class: Transaction (contd.)
  - We'll discuss concurrency control techniques such as **locking**


# ACKNOWLEDGEMENT

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