Recovery

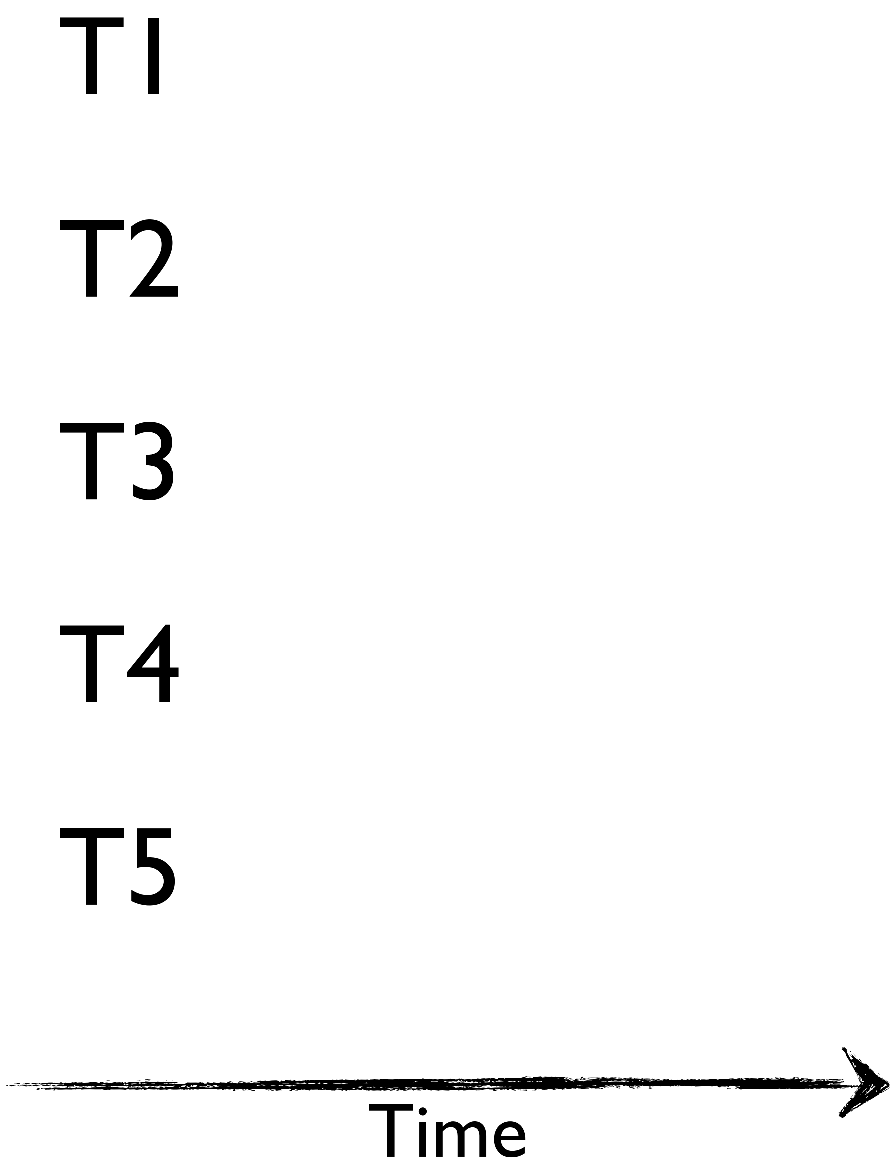
R&G Chapter 18

(slides adapted from content by J.Gehrke, J.Shanmugasundaram, and/or C.Koch)

A.C.I.D.

- **Atomicity**: All actions in a transaction happen, or none happen.
- **Consistency**: If the transaction maintains consistency, and the DB starts consistent, then the database ends consistent.
- **Isolation**: The execution of one transaction is isolated from all other transactions.
- **Durability**: If a transaction commits, its effects persist.

Motivation



T1

T2

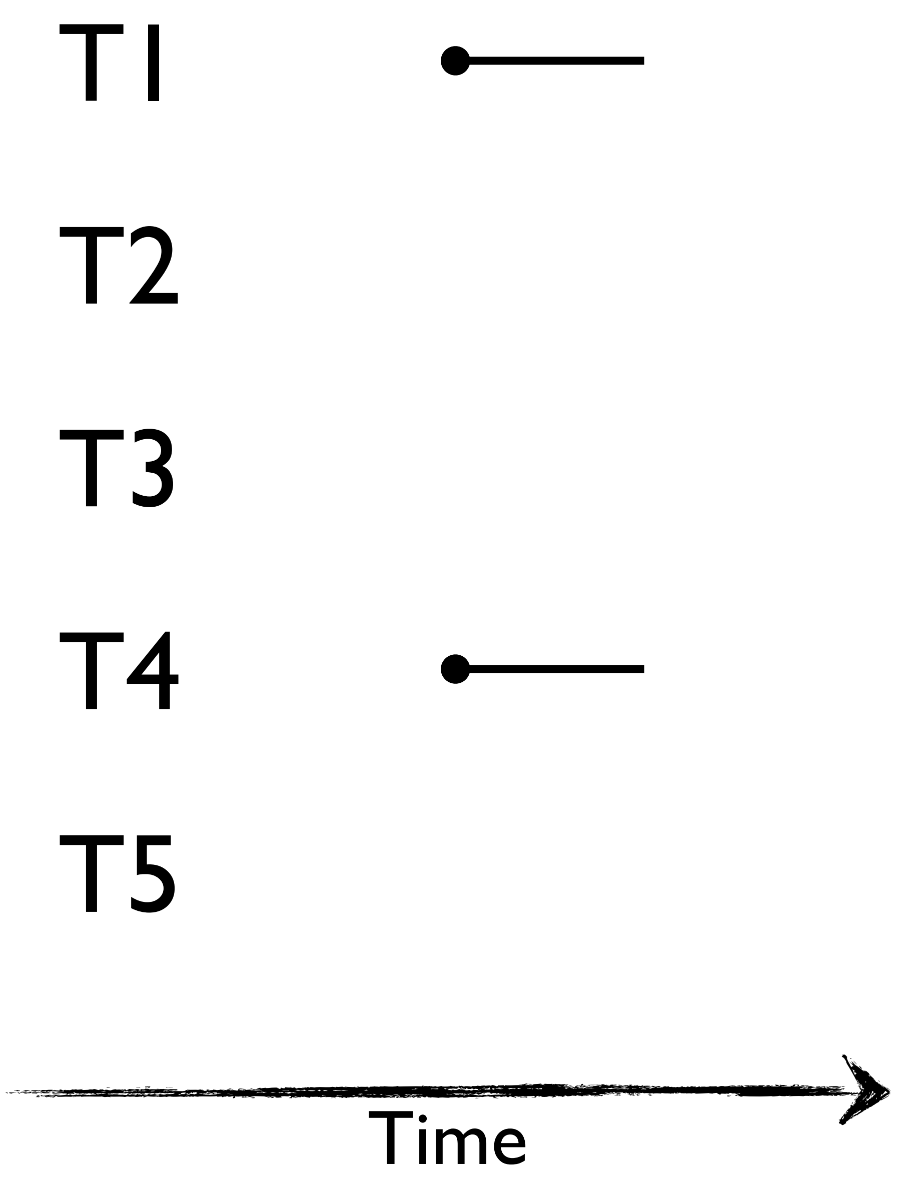
T3

T4

T5

Time

Motivation



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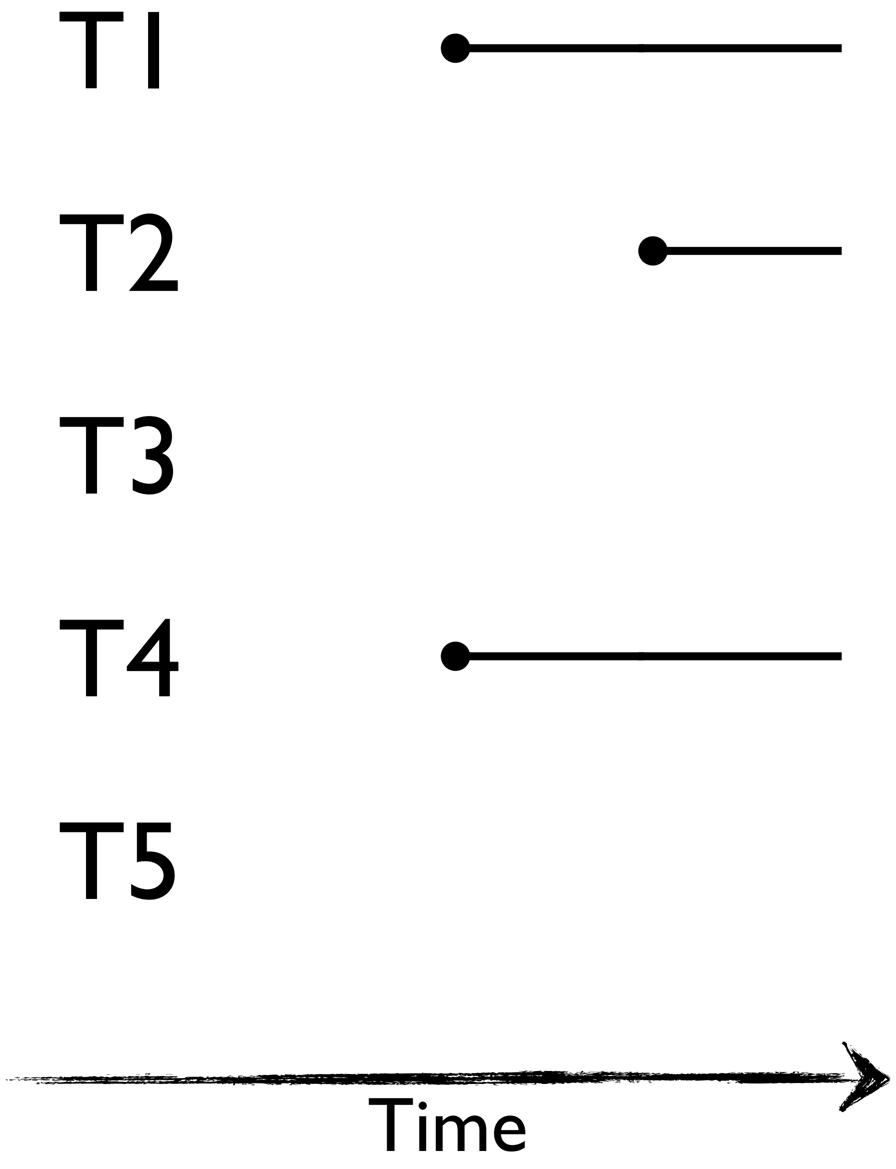
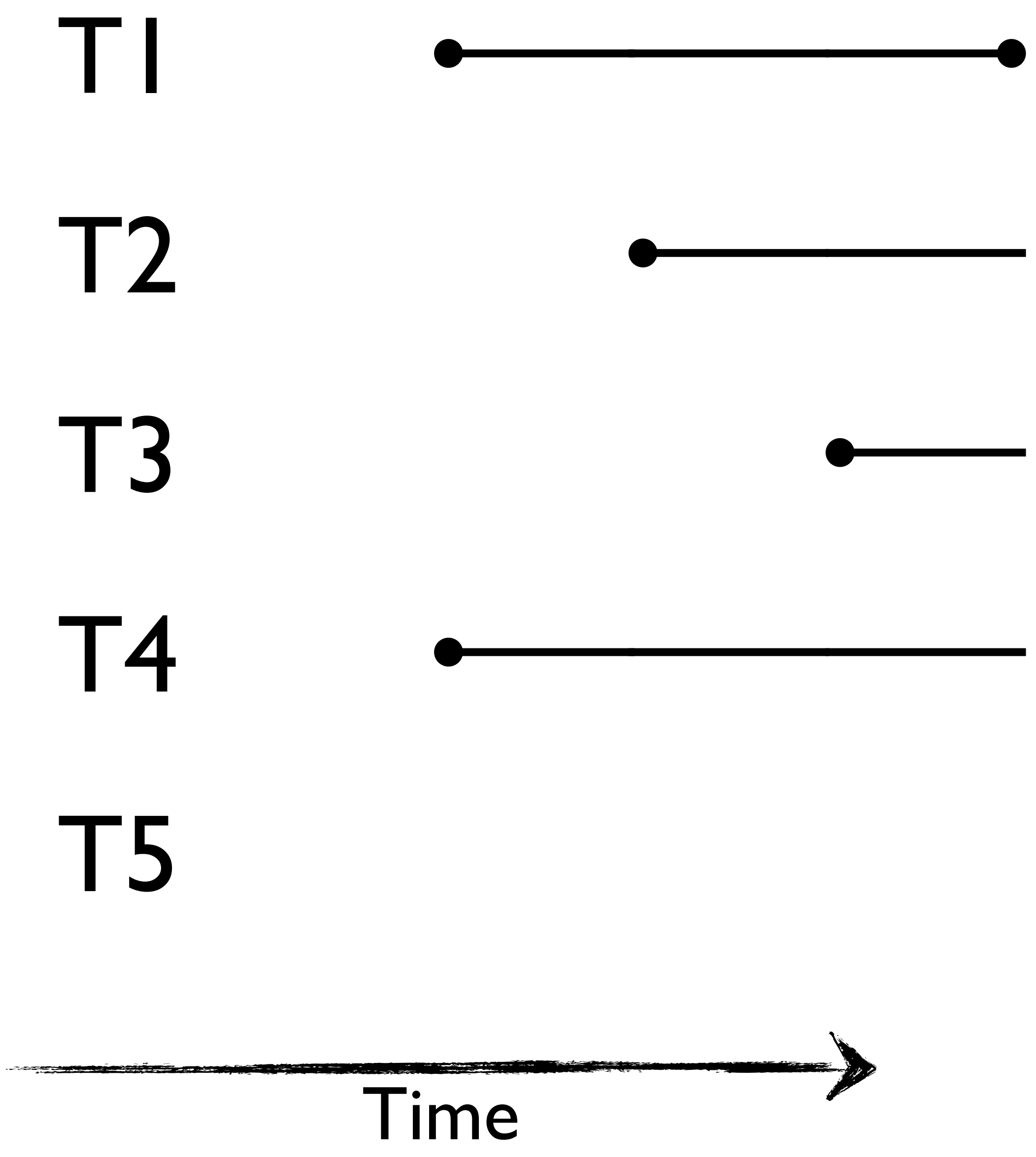


Motivation



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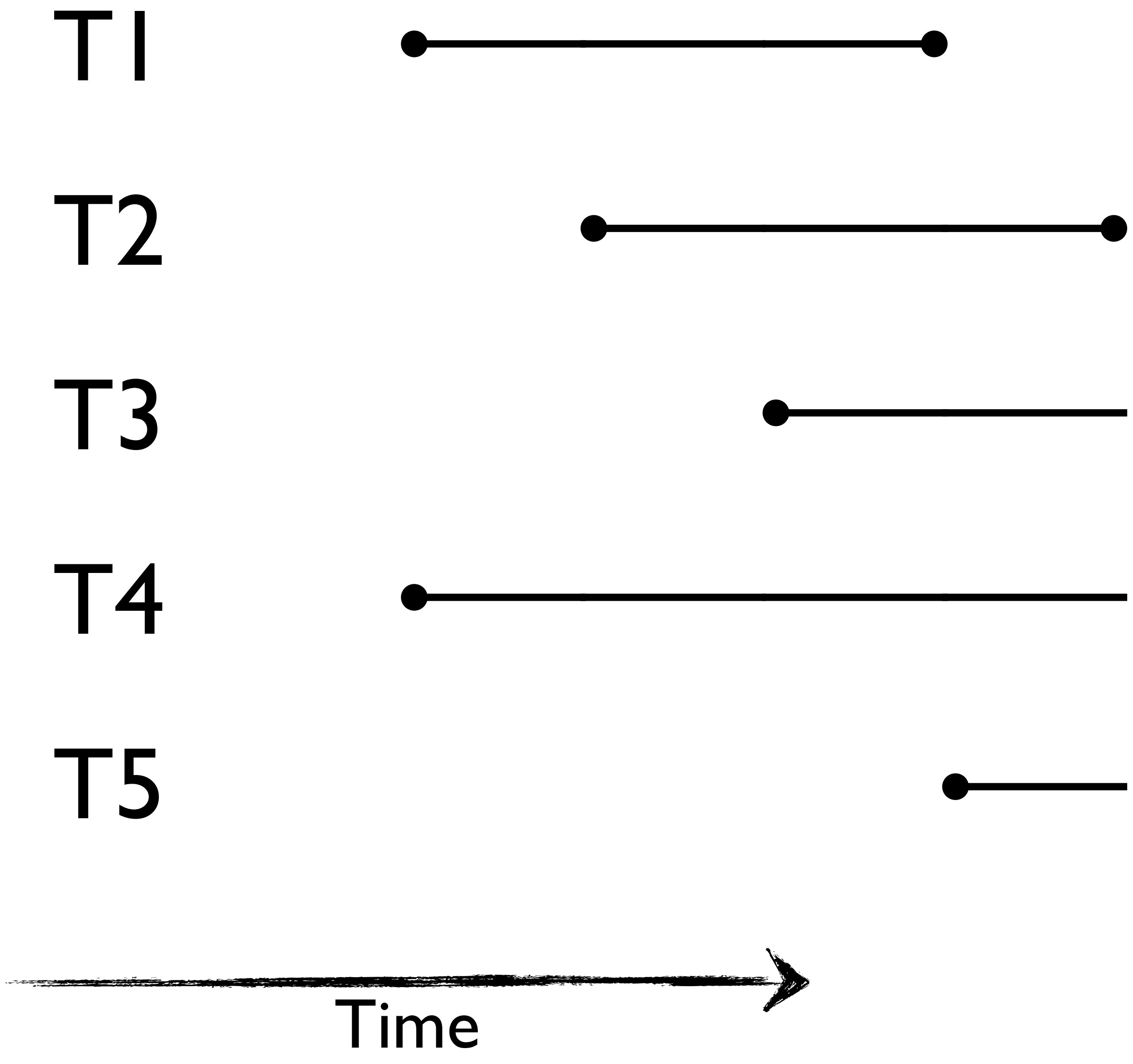

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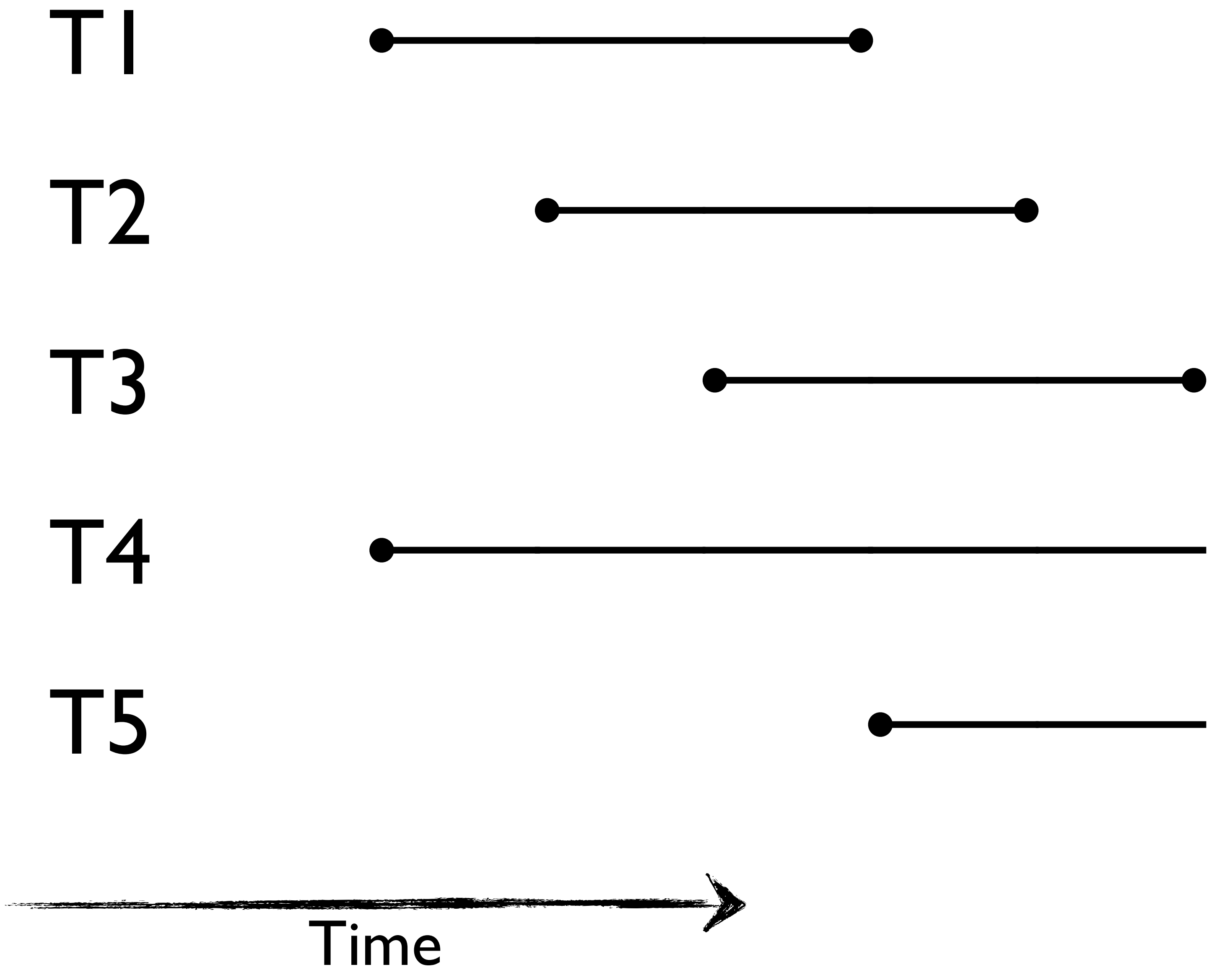

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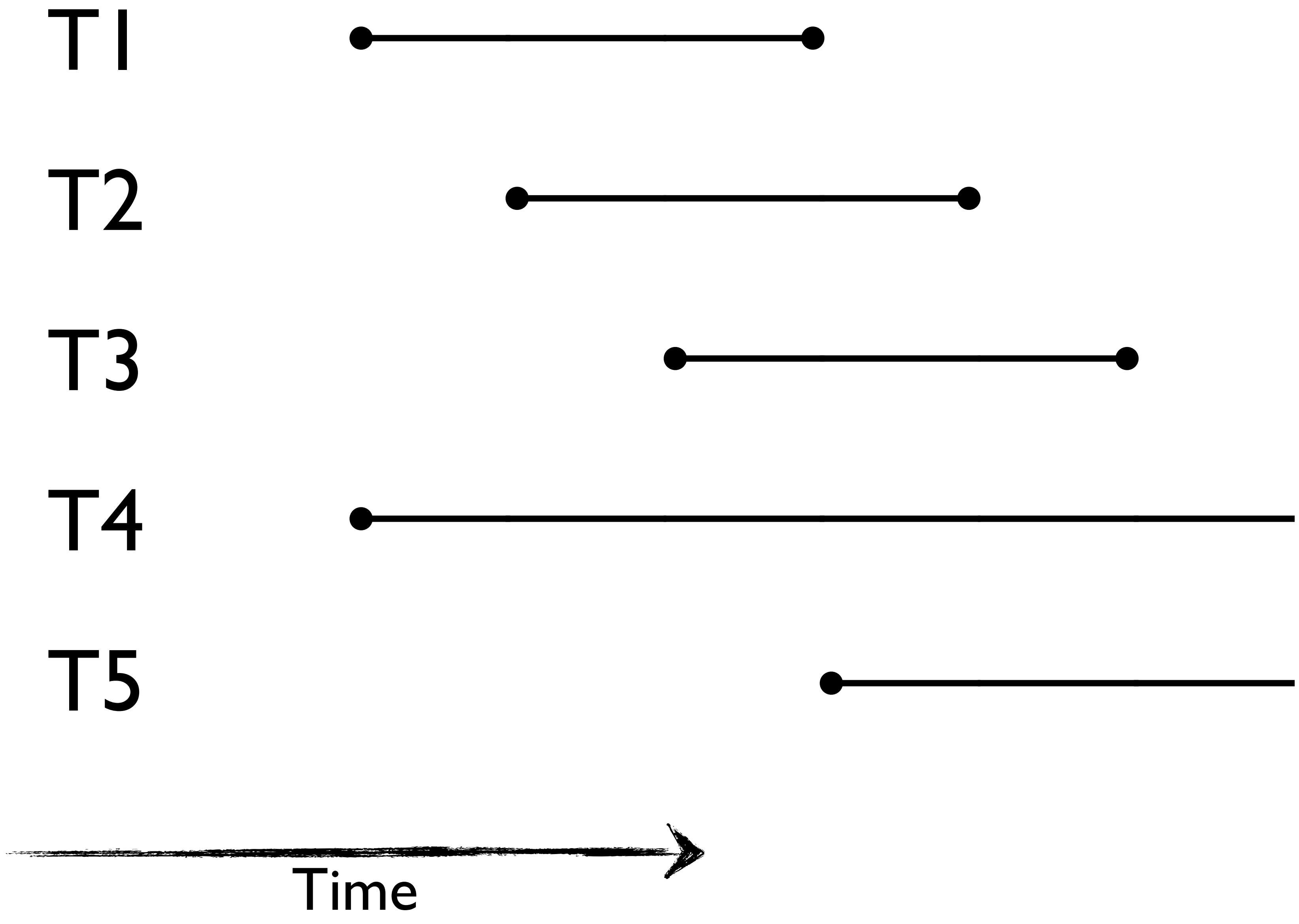
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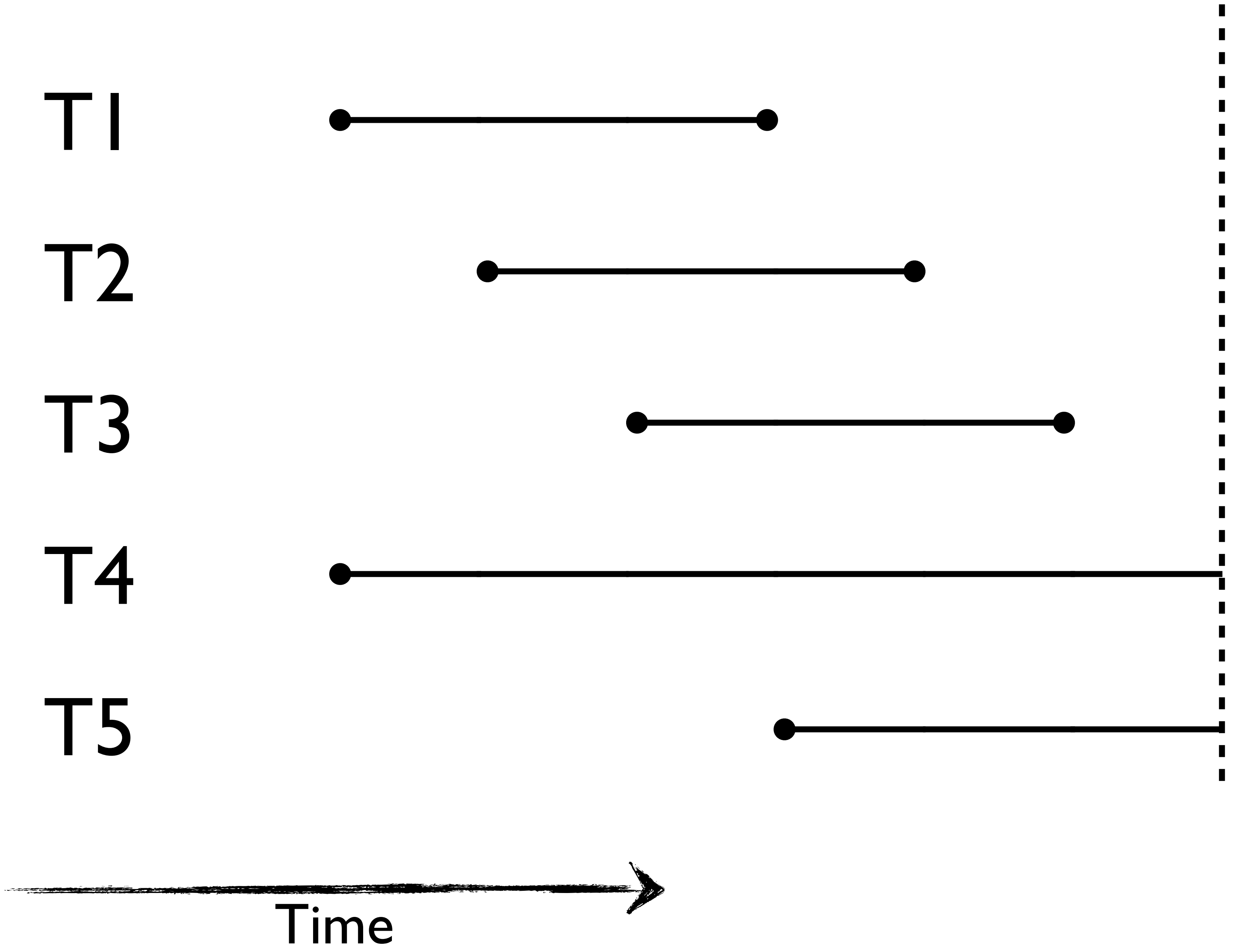

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T4

T5

Time

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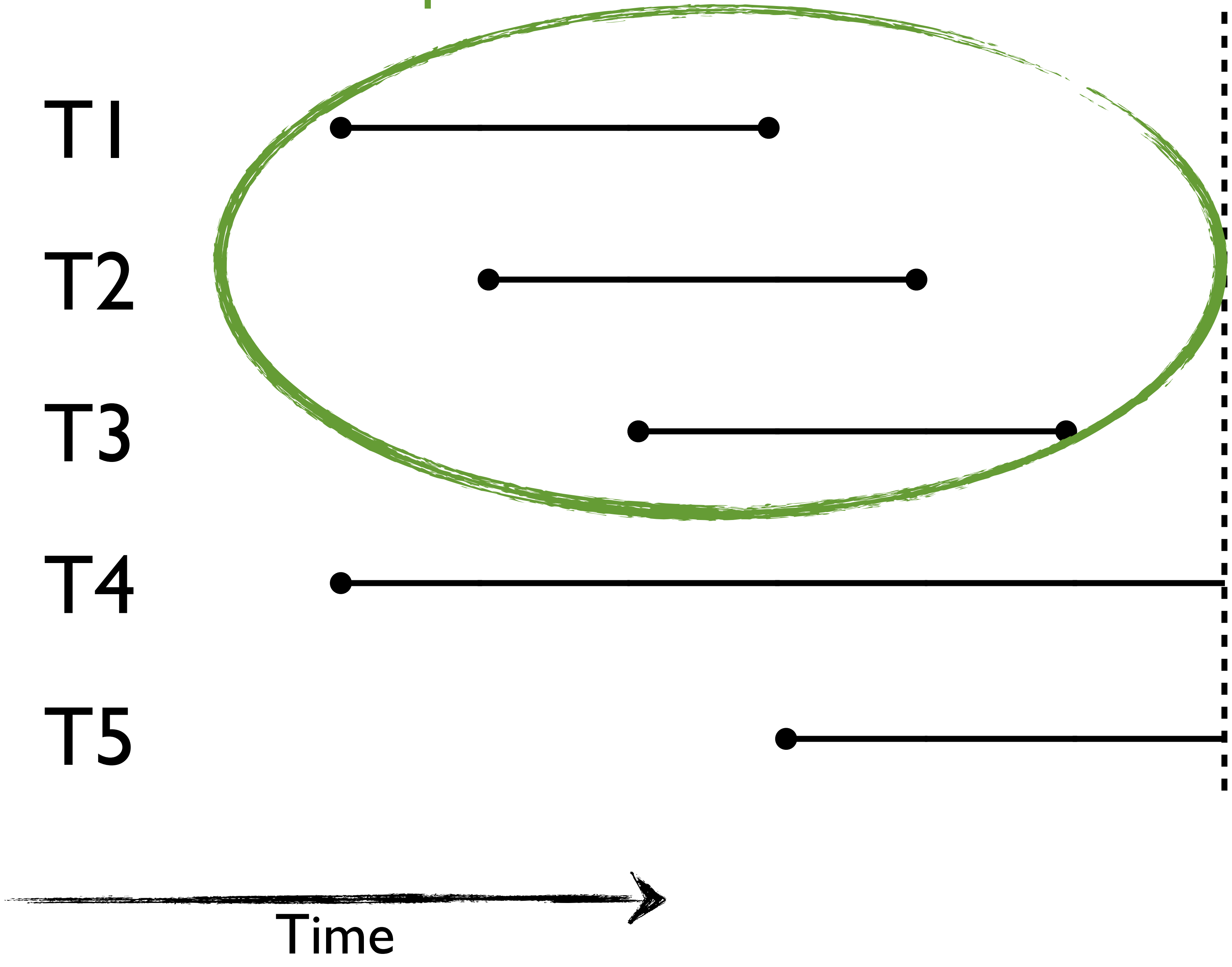
Motivation

Committed Transactions.
These should be present when the DB restarts.



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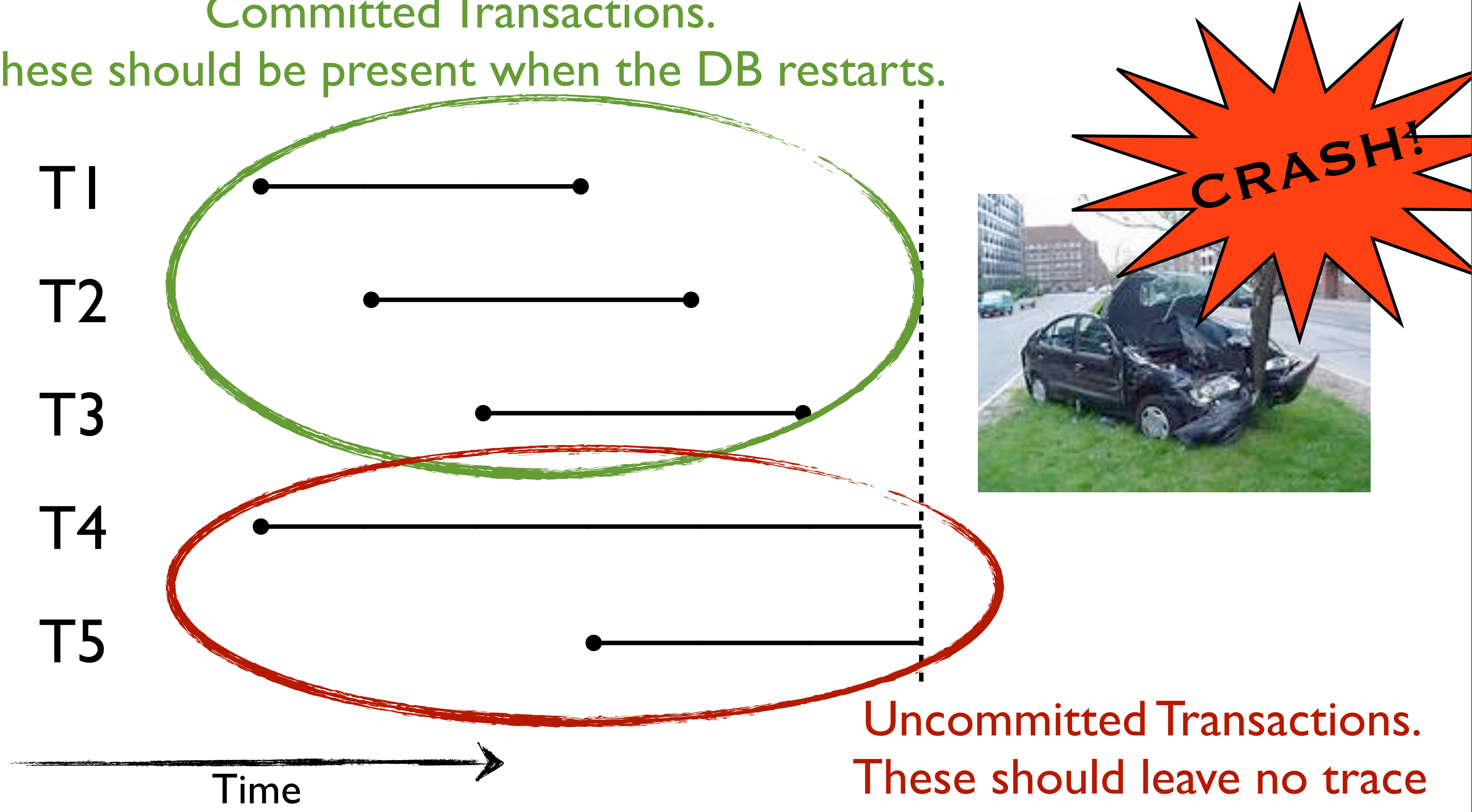
Motivation



Committed Transactions.
These should be present when the DB restarts.

Uncommitted Transactions.
These should leave no trace

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Goals

- Support recovery from crashes
- Ensure that the effects of committed transactions are recovered fully.
- Ensure that the effects of uncommitted transactions are discarded fully.
- We want a simple scheme to guarantee atomicity and durability.

Assumptions

- Concurrency control is in effect
  - Strict 2-Phase Locking Specifically
- Updates are happening "in place"
  - Updates are applied directly to the (single) on-disk copy of the data.

The Buffer Pool

- An intermediary between memory and disk.
- Challenges:
    - **Force**: Every write goes directly to disk?
        - Provides durability.
        - … but results in poor response time.

The Buffer Pool

- An intermediary between memory and disk.
- Challenges:
    - **Steal**: Allow buffer-pool frames to be stolen from uncommitted xacts?
        - If stealing not allowed, poor throughput.
        - If stealing allowed, atomicity not preserved.

The Buffer Pool

	No Steal	Steal
Force	Trivial!	
No Force		Desired

Steal

- Enforcing **atomicity** is hard
  - To steal frame F, the current page P in F is written to disk.
  - Some transaction T has written to P.
  - What if T aborts?
  - Need to be able to UNDO T's writes to P.

No Force

- Enforcing **durability** is hard
  - What if the system crashes before a modified page is written to disk?
  - What if the system crashes while writing several pages to disk?
  - Need to be able to REDO writes that haven’t been finalized yet.

Basic Idea: Logging

- Record all information needed to perform REDO and UNDO operations in a log.
  - Log accesses are all sequential writes.
  - Can use a separate disk for logs.
  - Minimal info (delta) is written to log, so can fit many updates in one page.

Example Log Record

- Transaction ID
- Page ID
- Offset
- Length
- Old Data
- New Data
- (Some extra control info that we'll see shortly)

Write-Ahead Logging

- The write-ahead logging protocol
  - Force the log record for an update before the corresponding data page is written.
    - Guarantees Atomicity (REDO).
  - Force all log records for a transaction before the transaction commits.
    - Guarantees Durability (UNDO).

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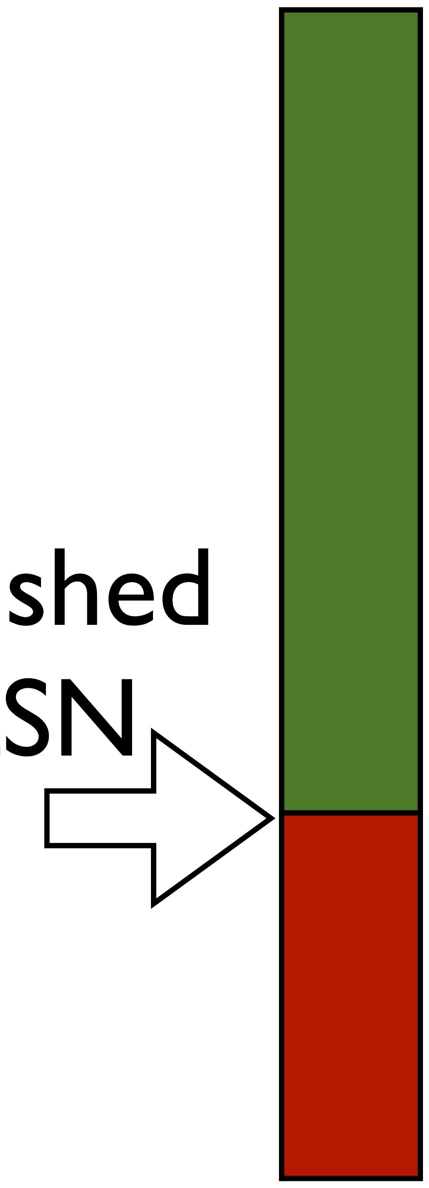
How would recovery be implemented?

WAL & The Log

- Each log record has a unique Log Sequence Number (LSN)
- Each data page contains a Page LSN.
- System keeps (in memory) the max Flushed LSN (max LSN forced to disk)
- Before a page is written, ensure that **Page LSN ≤ Flushed LSN**

Flushed Log Records



Flushed LSN

Tail (Ram Only)

Log Records

- Record Types
  - **Update**
  - **Commit**
  - **Abort**
  - **End** (of commit/abort)
  - CLRs

Log Record Fields

```
Prev LSN
XID
Record Type
Page ID
Length
Offset
Before-Image
After-Image
```

Only needed for **update**: Page ID, Length, Offset, Before-Image, After-Image

Other Log-Related State

- **Transaction Table**
  - One entry per active transaction
  - Contains XID, Transaction Status, LastLSN
- **Dirty Page Table**
  - One entry per dirty page in the buffer pool.
  - Contains **RecLSN**: LSN of the log record that first caused the page to be dirty.

Transaction Execution

- Normal execution:
  - A Series of reads and writes followed by a commit or an abort.
  - Strict 2-Phase Locking
  - Steal, No-Force buffer management with write-ahead logging.

The Big Picture

The Log

Log Records

- `Prev LSN`
- `XID`
- `Record Type`
- `Page ID`
- `Length`
- `Offset`
- `Before-Image`
- `After-Image`

The DB (Disk)

Data Pages

(each with a PageLSN)

Master Record

The DB (Ram)

Transaction Table

- `XID`
- `LastLSN`
- `Status`

Dirty Page Table

- `RecLSN`

Flushed LSN

Simple Transaction Abort (no crash involved)

“Play Back” the log in reverse order, UNDOing records

Transaction Table

Log

image credit: openclipart.org

Simple Transaction Abort (no crash involved)

“Play Back” the log in reverse order, UNDOing records

Transaction Table

ABORT [XID]

Log

(necessary for crash recovery)

image credit: openclipart.org

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Transaction Table

XID, LastLSN

ABORT [XID]

Log

(necessary for crash recovery)

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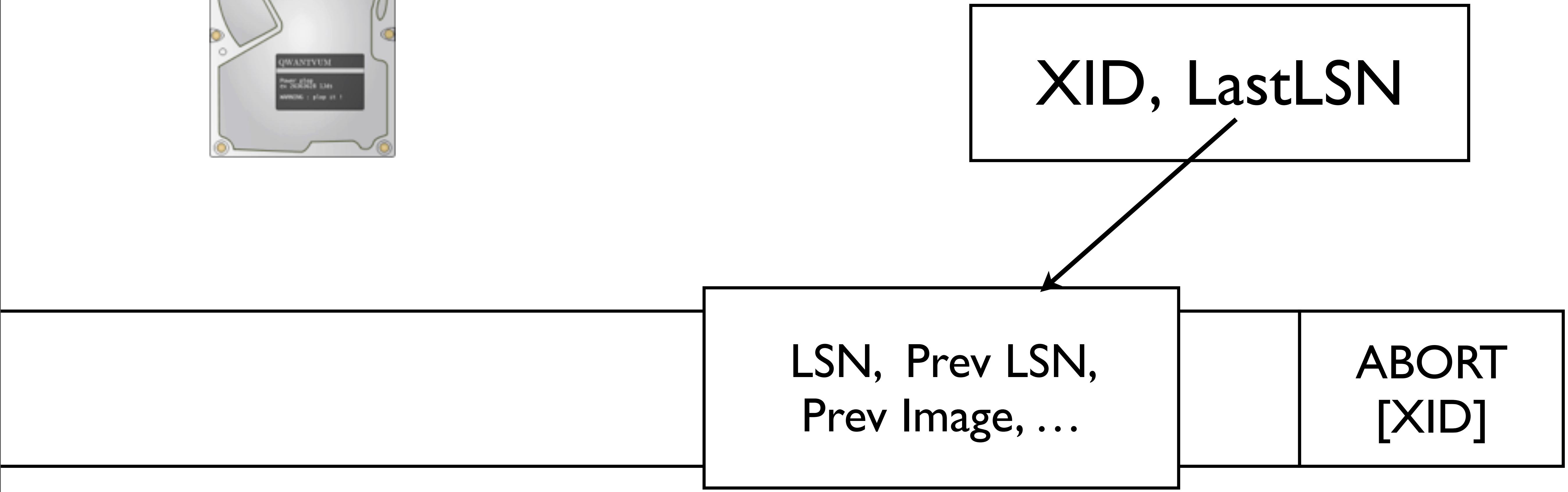
Transaction Table



XID, LastLSN

LSN, Prev LSN, Prev Image, …

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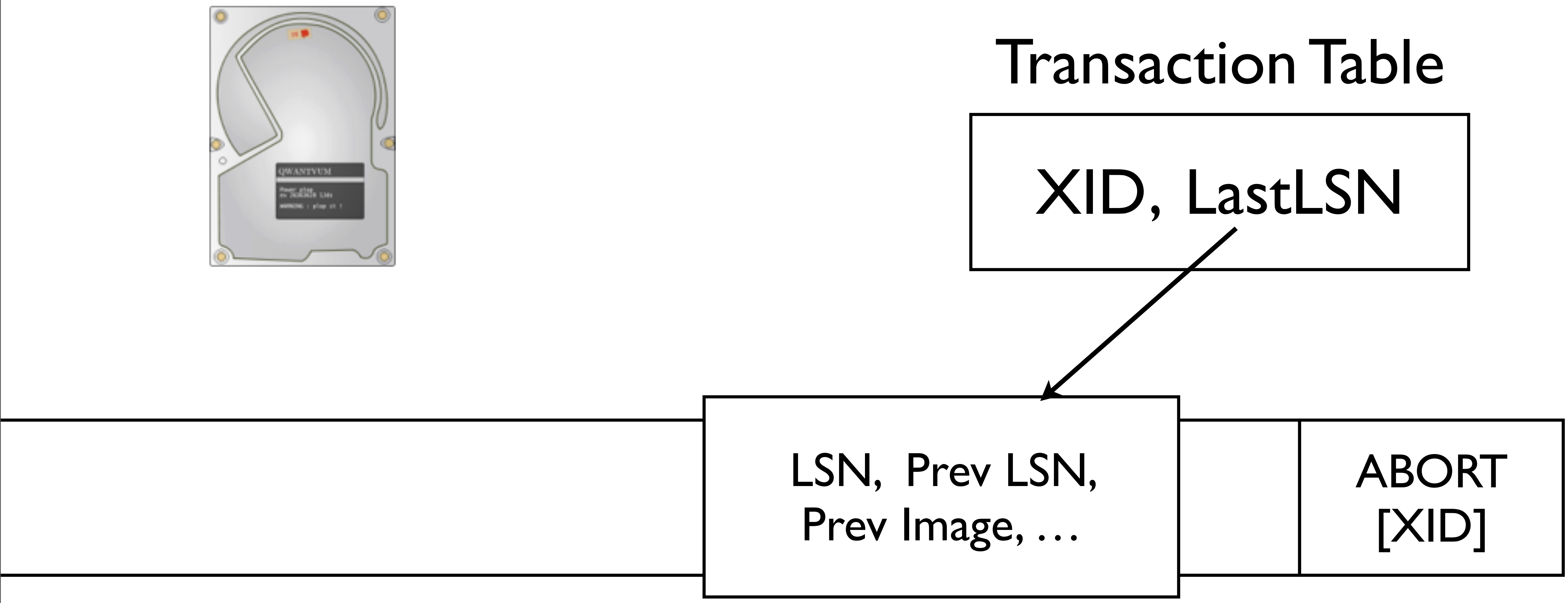

Transaction Table

XID, LastLSN

LSN, Prev LSN, Prev Image, …

ABORT [XID]

(necessary for crash recovery)

Log

image credit: openclipart.org

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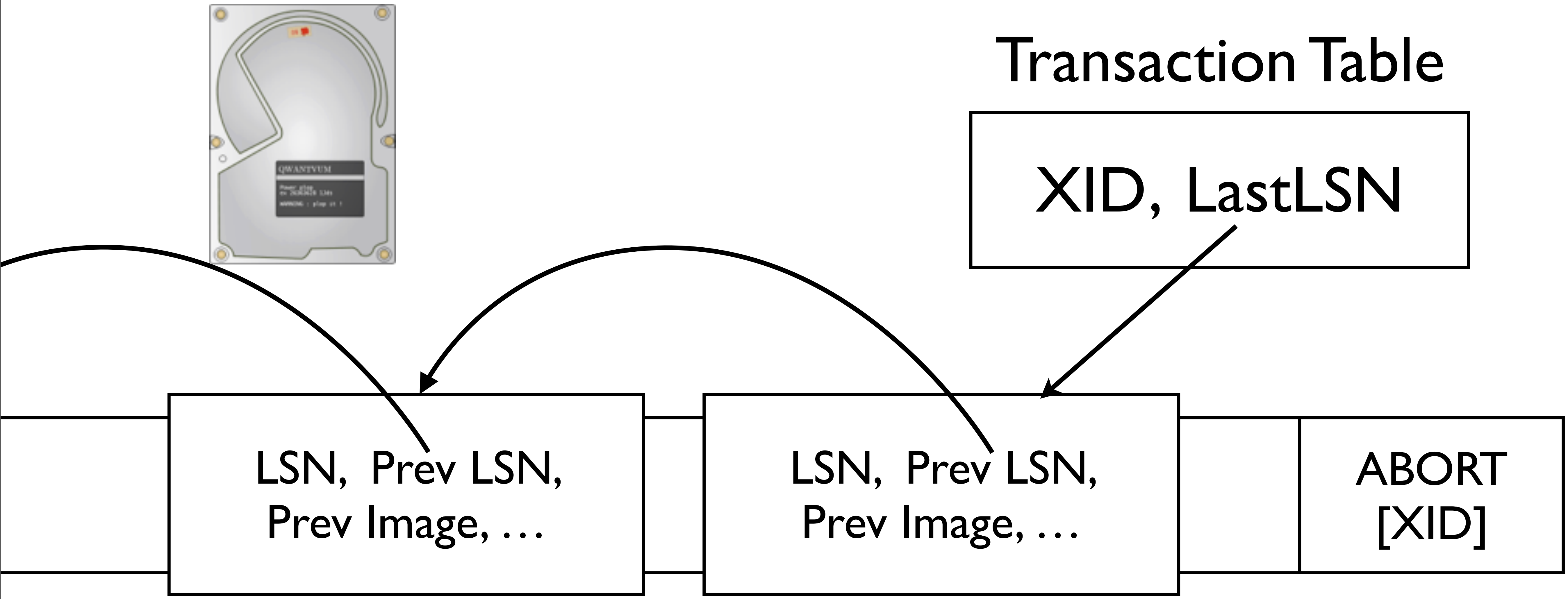

Transaction Table

XID, LastLSN

LSN, Prev LSN, Prev Image, …

LSN, Prev LSN, Prev Image, …

ABORT [XID]

Log

(necessary for crash recovery)

image credit: openclipart.org

Simple Transaction Abort (supporting crash recovery)

- Before restoring the old value of a page, write a Compensation Log Record (CLR).
  - Logging continues <u>during</u> UNDO processing.
  - CLR has an extra field: UndoNextLSN
    - Points to the next LSN to undo (the PrevLSN of the record currently being undone)
  - CLRs are never UNDOne.
    - But might be REDOne when repeating history.
    - (Why?)

Transaction Commit

- Write **Commit** Record to Log
- All Log records up to the transaction's LastLSN are flushed.
  - Guarantees that FlushedLSN ≥ LastLSN
  - Note that Log Flushes are Sequential, Synchronous Writes to Disk
- Commit() returns.
- Write **End** record to log.

Next week: Crash Recovery