ARIES (& Logging)

Database Systems: The Complete Book

Ch 17

Transaction Correctness

- Reliability in database transactions guaranteed by ACID
- A - Atomicity (“Do or Do Not, there is nothing like try”) - usually ensured by logs
- C - Consistency (“Within the framework of law”) - usually ensured by integrity constraints, validations, etc.
- I - Isolation (“Execute in parallel or serially, the result should be same”) - usually ensured by locks
- D - Durability (“once committed, remain committed”) - usually ensured at hardware level

What does it mean for a transaction to be committed?

commit
returns
successfully

=

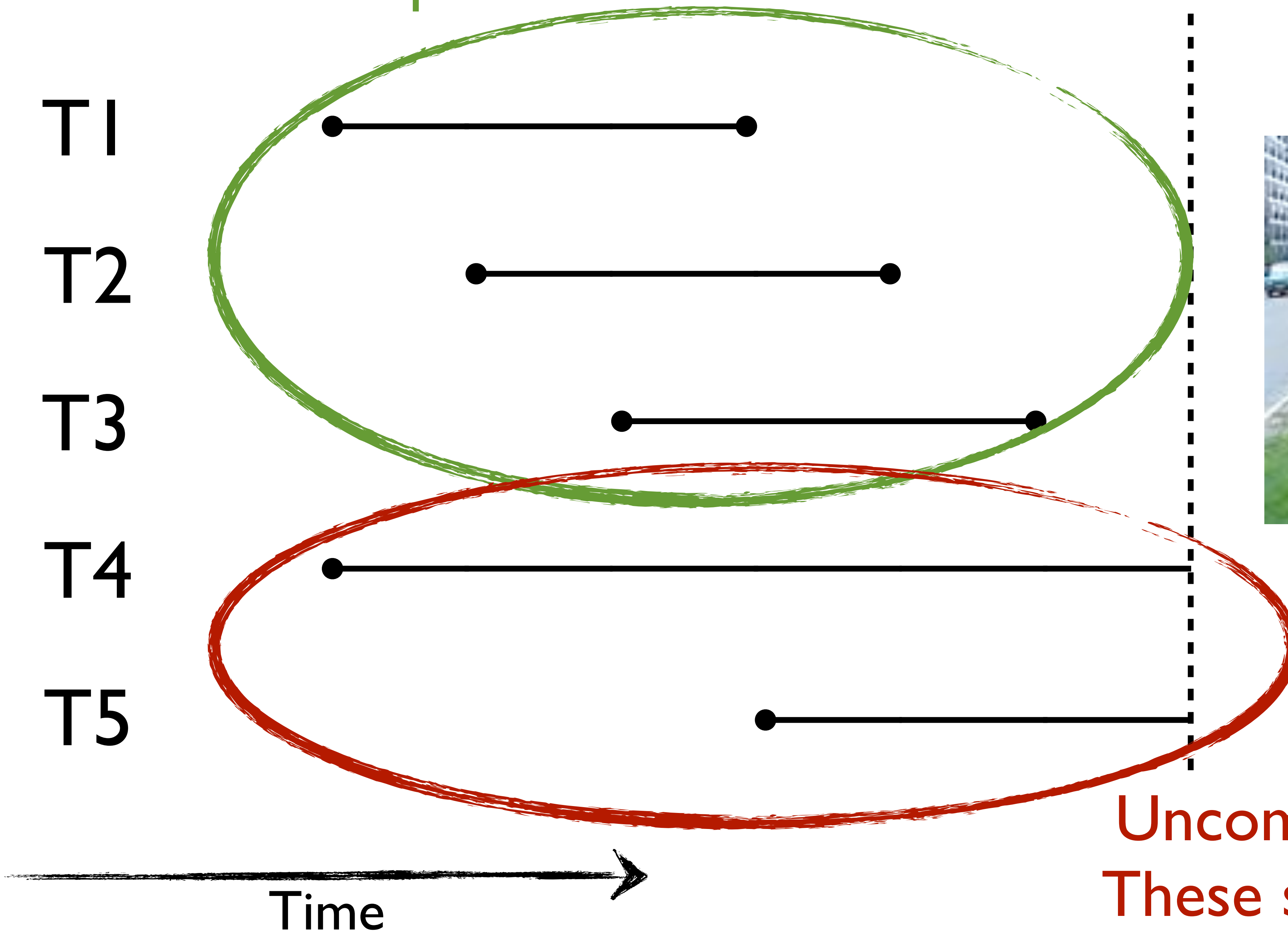
the xact's
effects
are visible
<u>forever</u>

commit returns successfully = the xact's effects are visible <u>forever</u>

commit called but doesn't return = the xact's effects <u>may</u> be visible

Motivation

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



Uncommitted Transactions.
These should leave no trace

- How do we guarantee durability under failures?

- How do aborted transactions get rolled back?

- How do we guarantee atomicity under failures?

Problem 1: Providing durability under failures.

Simplified Model

When a write succeeds, the data is completely written

Problems

- A crash occurs part-way through the write.

- A crash occurs before buffered data is written.

Write-Ahead Logging

Before writing to the database, first write what you plan to write to a log file…

Log

`W(A:10)`

A	8
B	12
C	5
D	18
E	16

Write-Ahead Logging

Once the log is safely on disk you can write the database

A	~~8~~ 10
B	12
C	5
D	18
E	16

Log

`W(A:10)`

Write-Ahead Logging

Log is append-only,
so writes are always
efficient

<u>Log</u>

```
W(A:10)
W(C:8)
W(E:9)
```

A	~~8~~ 10
B	12
C	5
D	18
E	16

Write-Ahead Logging

…allowing random writes
to be safely batched

Log

```
W(A:10)
W(C:8)
W(E:9)
```

A	~~8~~ 10
B	12
C	~~5~~ 8
D	18
E	~~16~~ 9

Problem 2: Providing rollback.

Single DB Model

Txn 1

```
A = 20
B = 14
COMMIT
```

Txn 2

```
E = 19
B = 15
ABORT
```

A	8
B	12
C	5
D	18
E	16

Single DB Model

Txn 1

```
A = 20
B = 14
COMMIT
```

Txn 2

```
E = 19
B = 15
ABORT
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A	~~8~~ 20
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A	~~8~~ 20
B	~~12~~
C	5
D	18
E	~~16~~ 19

Single DB Model

Txn 1	Txn 2
A = 20	E = 19
B = 14	B = 15
COMMIT	ABORT

A	~~8~~ 20
B	~~12~~ 14
C	5
D	18
E	~~16~~ 19

Single DB Model

Txn 1

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A = 20
B = 14
COMMIT
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Txn 2

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E = 19
B = 15
ABORT
```

A	~~8~~ 20
B	~~12~~ ~~14~~ 15
C	5
D	18
E	~~16~~ 19

Staged DB Model

<u>Txn 1</u>

```
A = 20
B = 14
COMMIT
```

<u>Txn 2</u>

```
E = 19
B = 15
ABORT
```

A	8
B	12
C	5
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A	8
B	12
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Staged DB Model

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A	~~8~~ 20
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E	16

A	8
B	~~12~~ 15
C	5
D	18
E	~~16~~ 19

Staged DB Model

Txn 1

```
A = 20
B = 14
COMMIT
```

Txn 2

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ABORT
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A	~~8~~ 20
B	~~12~~ 14
C	5
D	18
E	16

Is staging always possible?

- Staging takes up more memory.
- Merging after-the-fact can be harder.
- Merging after-the-fact introduces more latency!

for the single database model

Problem 2: Providing rollback.

UNDO Logging

Store both the “old” and the “new” values of the record being replaced

A	~~8~~ 10
B	12
C	~~5~~ 8
D	18
E	~~16~~ 9

Log

W(A:8→10)
W(C:5→8)
W(E:16→9)

UNDO Logging

A	~~8~~ 10
B	12
C	~~5~~ 8
D	18
E	~~16~~ 9

Active Xacts

Xact:1, Log: 45

Xact:2, Log: 32

Log

```
43: W(A:8→10)
44: W(C:5→8)
45: W(E:16→9)
```

UNDO Logging

A	~~8~~ 10
B	12
C	~~5~~ 8
D	18
E	~~16~~ 9

Active Xacts

Xact:1, Log: 45

ABORT

Xact:2, Log: 32

Log

```
43: W(A:8→10)
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UNDO Logging

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UNDO Logging

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B	12
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Active Xacts

ABORT

Xact:1, Log: 45

Xact:2, Log: 32

Log

43: W(A:8→10)

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45: W(E:16→9)

UNDO Logging

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Active Xacts

Xact:1, Log: 45

ABORT

Xact:2, Log: 32

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43: W(A:8→10)
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```
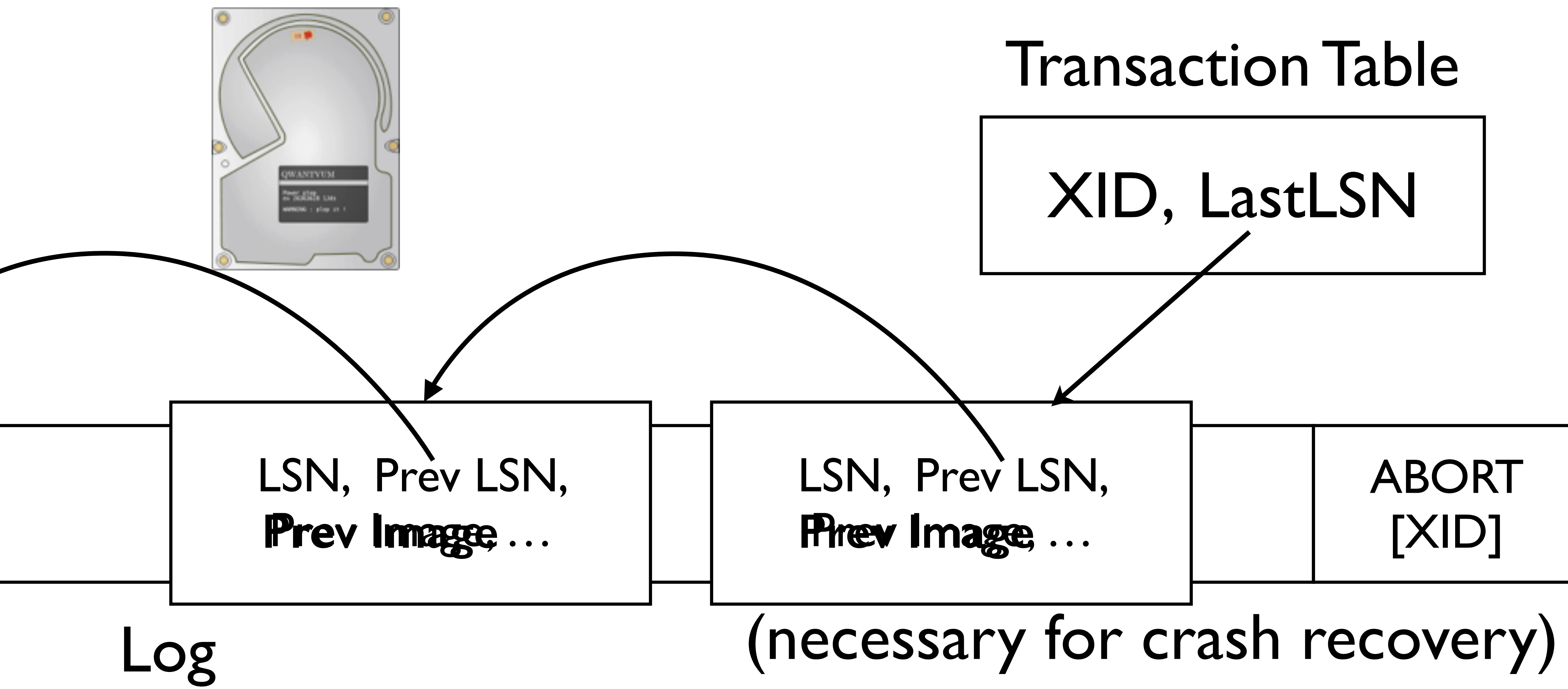

Log Sequence Number Linked Lists



Problem 3: Providing atomicity.

Goal: Be able to reconstruct all state at the time of the DB's crash (minus all running xacts)

What state is relevant?

DB State

On-Disk (or rebuildable)

A	~~8~~ 10
B	12
C	~~5~~ 8
D	18
E	~~16~~ 9

In-Memory Only!

<u>Active Xacts</u>

Xact:1, Log: 45

Xact:2, Log: 32

On-Disk

<u>Log</u>

```
43: W(A:8→10)
44: W(C:5→8)
45: W(E:16→9)
```

Rebuilding the Xact Table

Log every COMMIT
(replay triggers commit process)

Log every ABORT
(replay triggers abort process)

New message: END
(replay removes Xact from Xact Table)

What about BEGIN?
(when does an Xact get added to the Table?)

Transaction Commit

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

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?)

Rebuilding the Xact Table

Optimization: Write the Xact Table to the log periodically. (checkpointing)

ARIES Crash Recovery

- Start from checkpoint stored in master record.
- Analysis: Rebuild the Xact Table
- Redo: Replay operations from all live Xacts (even uncommitted ones).
- Undo: Revert operations from all uncommitted/aborted Xacts.