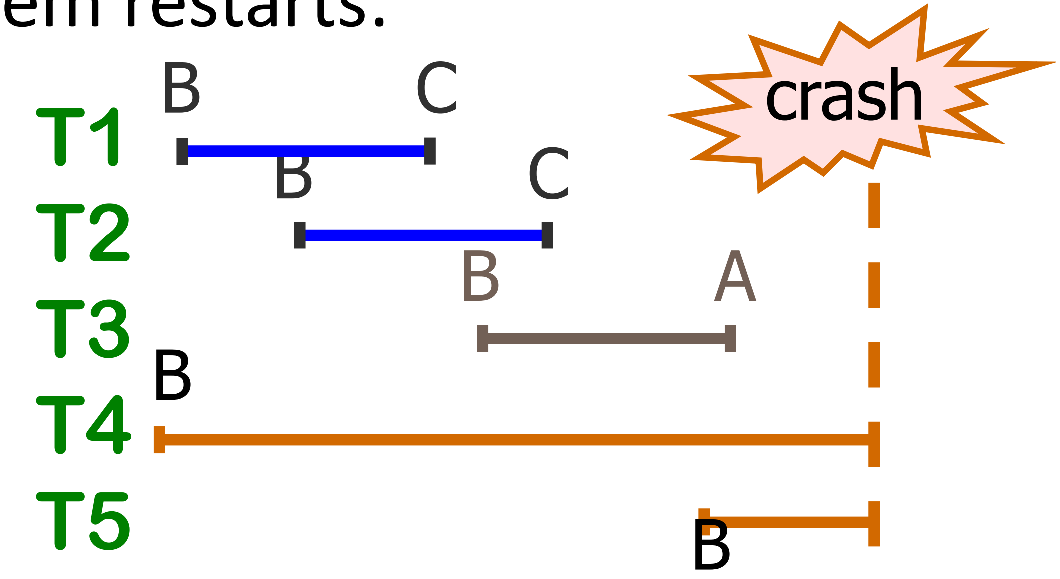
Fall 2019

LOGGING AND RECOVERY

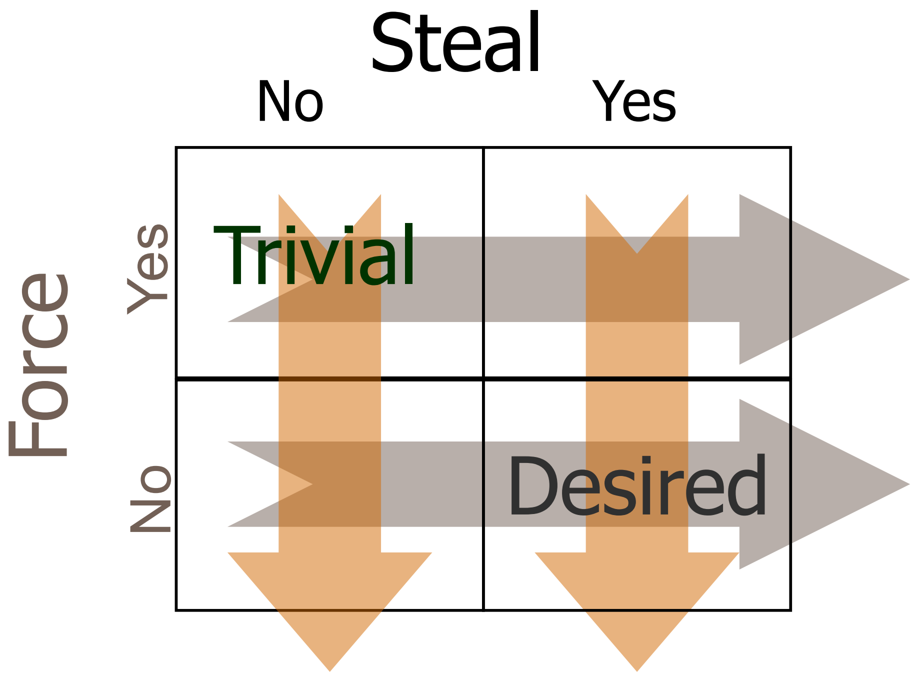
[CH 18]

Motivation

- Atomicity:
  - Transactions may abort (“Rollback”).
- Durability:
  - What if DBMS stops running? (Causes?)
- Desired Behavior after system restarts:
  - T1, T2 & T3 should be durable.
  - T4 & T5 should be aborted



Buffer Pool: Sharing & Writing



Force	Steal: No	Steal: Yes
Yes	Trivial	
No		Desired

Force

- *Poor response time, but durable*

No Force

- Crash before a page is flushed to disk
- Soln: Force a short summary @ commit (logs). Use this to REDO

No Steal

Poor throughput, but works

Steal

- Page being stolen (and flushed) was modified by an uncommitted Xact T
- If T aborts, how is atomicity enforced?
- Soln: Remember old value (logs). Use this to UNDO

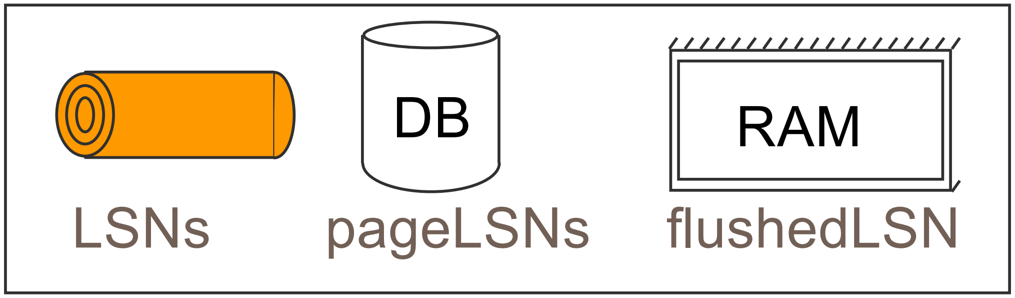
Basic Idea: Logging

- Record information, for every change, in a *log*.
  - Sequential writes to log (put it on a separate disk).
  - Stored in stable storage to survive system crash
    - disk mirroring
  - Each record has a log sequence number (LSN)
  - Log record contains:
    - <prevLSN, XID, type, … >
    - and additional control info (which we'll see soon)
    - Note: the log records for a transaction are chained by prevLSN

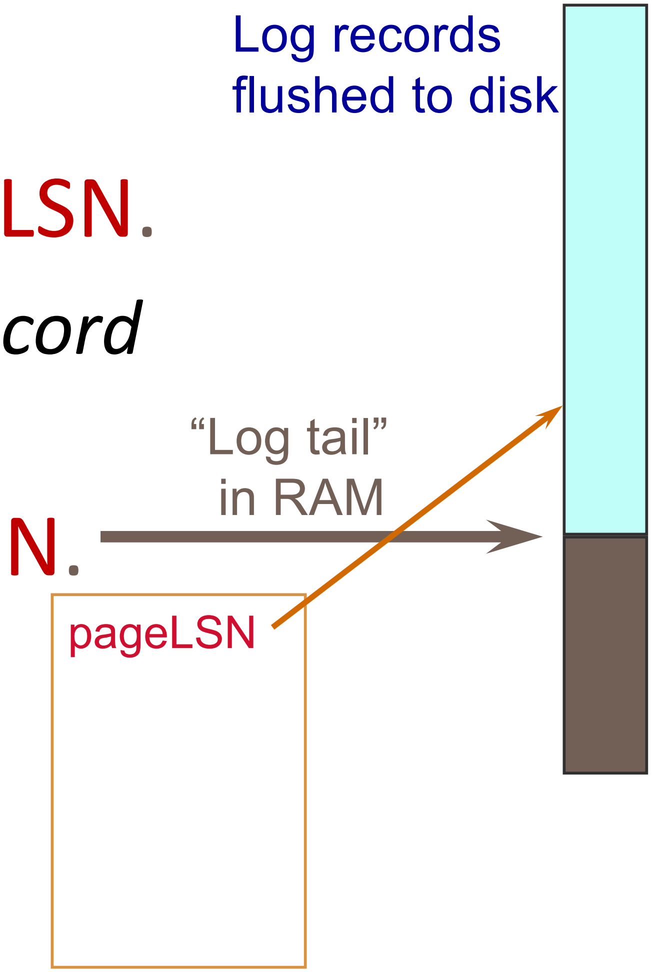
Write-Ahead Logging (WAL)

- The Write-Ahead Logging Protocol:
  1. Must force the log record for an update *before* the corresponding data page gets to disk.
  2. Must write all log records for a Xact *before commit*.
- #1 guarantees Atomicity.
- #2 guarantees Durability.
- Exactly how is logging (and recovery!) done?
  - We'll study the ARIES algorithms
    - breakthrough in recovery algorithms!
    - repeating history paradigm
    - fine-granularity locking and logical logging

WAL & the Log



- Log Sequence Number (LSN).
  - Unique and always increasing.
- Each *data page* contains a pageLSN.
  - The LSN of the most recent *log record* that updated the page
- System keeps track of flushedLSN.
  - The max LSN flushed so far.
- WAL: *Before* a page is written,
  - pageLSN ≤ flushedLSN



Log Records

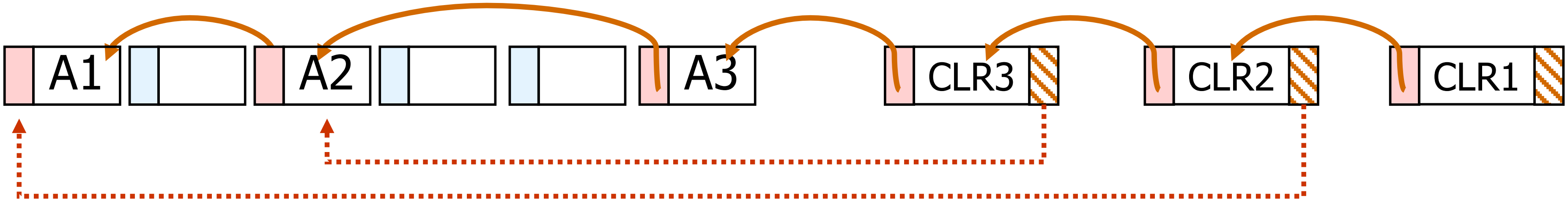
LogRecord fields:

prevLSN
XID
type
pageID
length
offset
before-image
after-image
…

update records only (pageID, length, offset, before-image, after-image)

Possible log record types:

- **Update**
- **Commit**
- **Abort**
- **End** (end of commit or abort)
- **Compensation Log Rec. (CLRs)**
  - For UNDO actions. When?
  - Contains undoNextLSN
    - Reverse chain of update logs
  - Contains before-image



Other Log-Related State

- Transaction Table: One entry per active Xact.
  - Contains
    - XID: Transaction identifier
    - status: running/commited/aborted
    - lastLSN: LSN of the most recent log rec. for this Xact.
- Dirty Page Table: One entry per dirty page in BP
  - Contains recLSN:- LSN of the log record that ***first*** caused the page to be dirty.
    - Starting point for REDO

Checkpointing

- Checkpoint: Snapshot of the database
  - Minimize recovery time
- Write to log:
  - begin_checkpoint record: Indicates when chkpt began.
  - end_checkpoint record:
    - Record Xact table and D.P.T.
    - Tables accurate only as of the time of the begin_checkpoint record
    - No attempt to force dirty pages to disk
    - This is a fuzzy checkpoint
  - Store LSN of chkpt record in a safe place (*master* record).

Normal Execution of an Xact

- Series of reads & writes, followed by commit or abort.
  - Updates are “in place”: i.e., data on disk is overwritten
  - We will assume that write is atomic on disk.
    - In practice, additional details to deal with non-atomic writes.
- Strict 2PL.
- STEAL, NO-FORCE buffer management, with Write-Ahead Logging.

The Big Picture: What's Stored Where

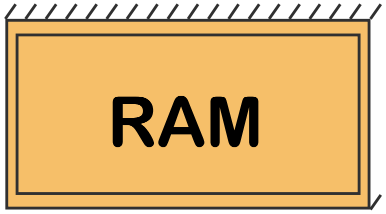
LogRecords

prevLSN
XID
type
pageID
length
offset
before-image
after-image

Data pages

each
with a
pageLSN

master record



Xact Table

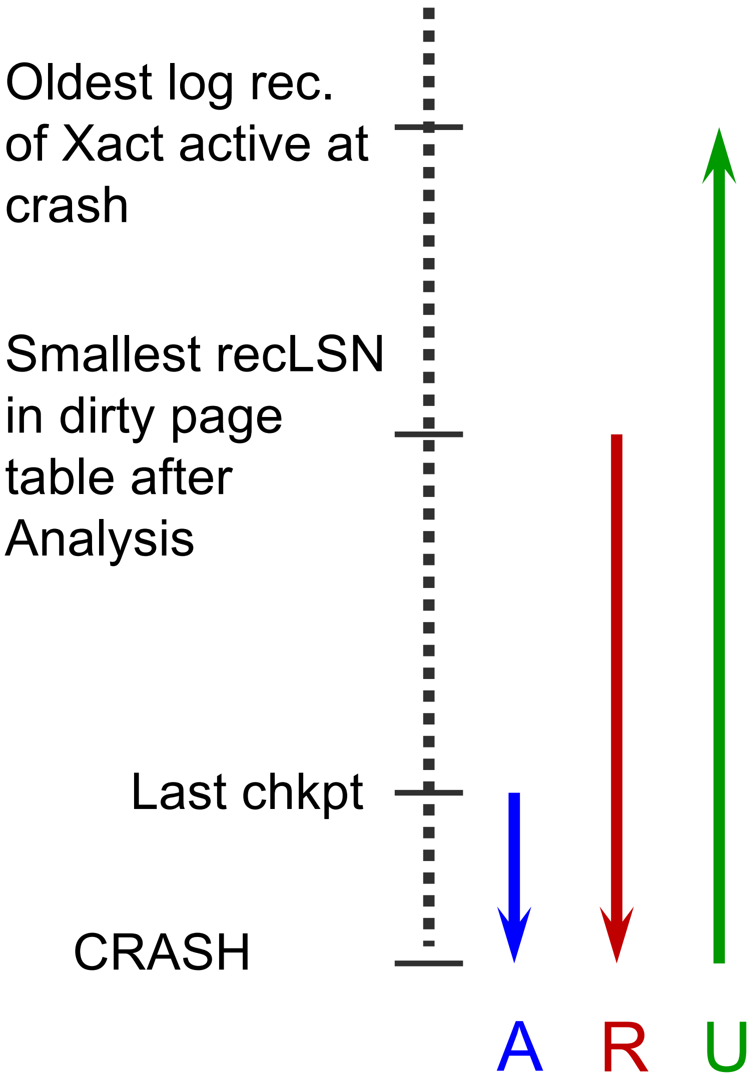
lastLSN
status

Dirty Page Table

recLSN

flushedLSN

Crash Recovery: Big Picture

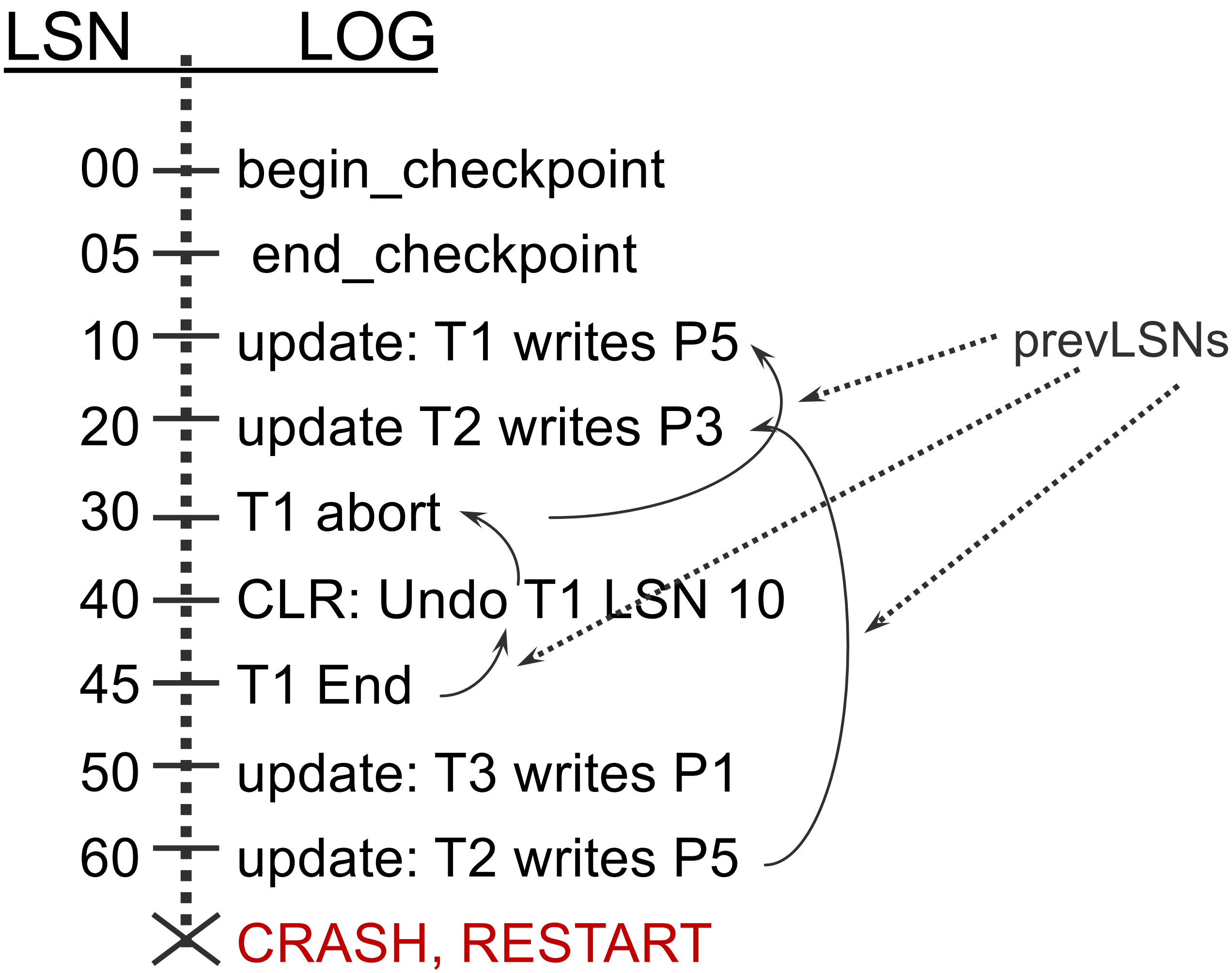

Oldest log rec. of Xact active at crash
Smallest recLSN in dirty page table after Analysis
Last chkpt
CRASH
A
R
U

- Start from a checkpoint (found via master record).
- Three phases:
  - Analysis: Since checkpoint, find
    - Xacts that must be aborted (losers)
    - dirty pages at time of crash (conservative estimate)
  - REDO *all* actions.
    - repeat history
  - UNDO effects of losers

Recovery: The Analysis Phase

- Compute
  - Set of dirty pages (conservative)
  - Uncommitted transactions at the crash point
- Scan log forward from checkpoint.
  - End record: Remove Xact from Xact table.
  - Other records: Add Xact to Xact table, set lastLSN=LSN
  - Commit record: change Xact status to commit.
  - Update or CLR record: If P not in Dirty Page Table,
    - Add P to D.P.T., set its recLSN=LSN.

Recovery: The Analysis Phase



LSN	LOG
00	begin_checkpoint
05	end_checkpoint
10	update: T1 writes P5
20	update T2 writes P3
30	T1 abort
40	CLR: Undo T1 LSN 10
45	T1 End
50	update: T3 writes P1
60	update: T2 writes P5
	CRASH, RESTART

prevLSNs

Transaction Table

XACT	LastLSN
T2	60
T3	50

D. P. T.

Page	recLSN
P1	50
P3	20
P5	10

Recovery: The REDO Phase

- *Repeat History* to reconstruct state at crash:
  - Reapply *all* updates (even of aborted Xacts!), redo CLRs
  - Bring the database to the same state as @ crash
- Scan forward from log record containing smallest recLSN in D.P.T.

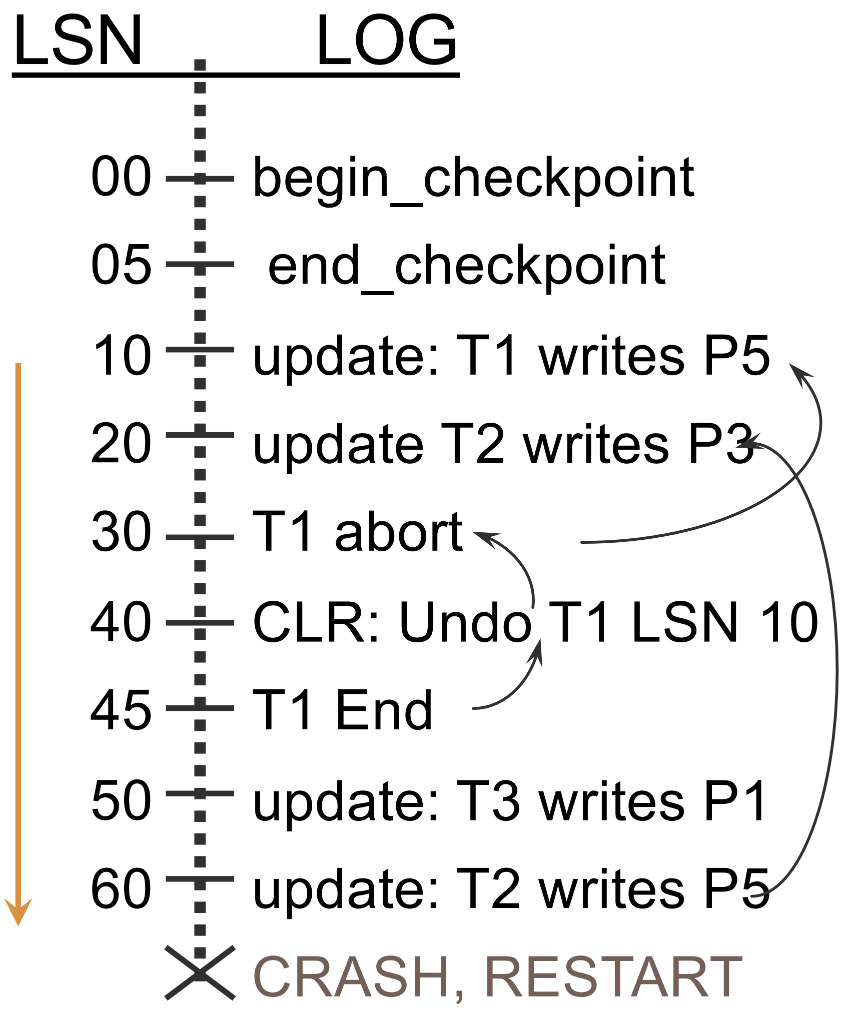
  For each update log record or CLR, REDO the action unless we can verify that the change has already been written to disk:

  - Affected page is not in the Dirty Page Table, or
  - Affected page is in D.P.T., but LSN < recLSN, or
    - update was propagated to disk
  - LSN ≤ pageLSN (in DB)
    - requires fetching the page

To REDO An Action

- Reapply logged action.
- Set pageLSN to LSN. No additional logging!
- Use of CLRs ensures that no change is ever carried out twice on the disk copy of an object.
  - For every “DO” there is one and only one “UNDO”
- At the end of REDO
  - Write END log recs for all commited Xacts.
  - Remove committed Xacts from the Xact table.

Recovery: The REDO Phase



LSN LOG

00 begin_checkpoint

05 end_checkpoint

10 update: T1 writes P5

20 update T2 writes P3

30 T1 abort

40 CLR: Undo T1 LSN 10

45 T1 End

50 update: T3 writes P1

60 update: T2 writes P5

CRASH, RESTART

Transaction Table

XACT	LastLSN
T2	60
T3	50

D. P. T.

Page	recLSN
P1	50
P3	20
P5	10

Recovery: The UNDO Phase

Abort: special case of UNDO

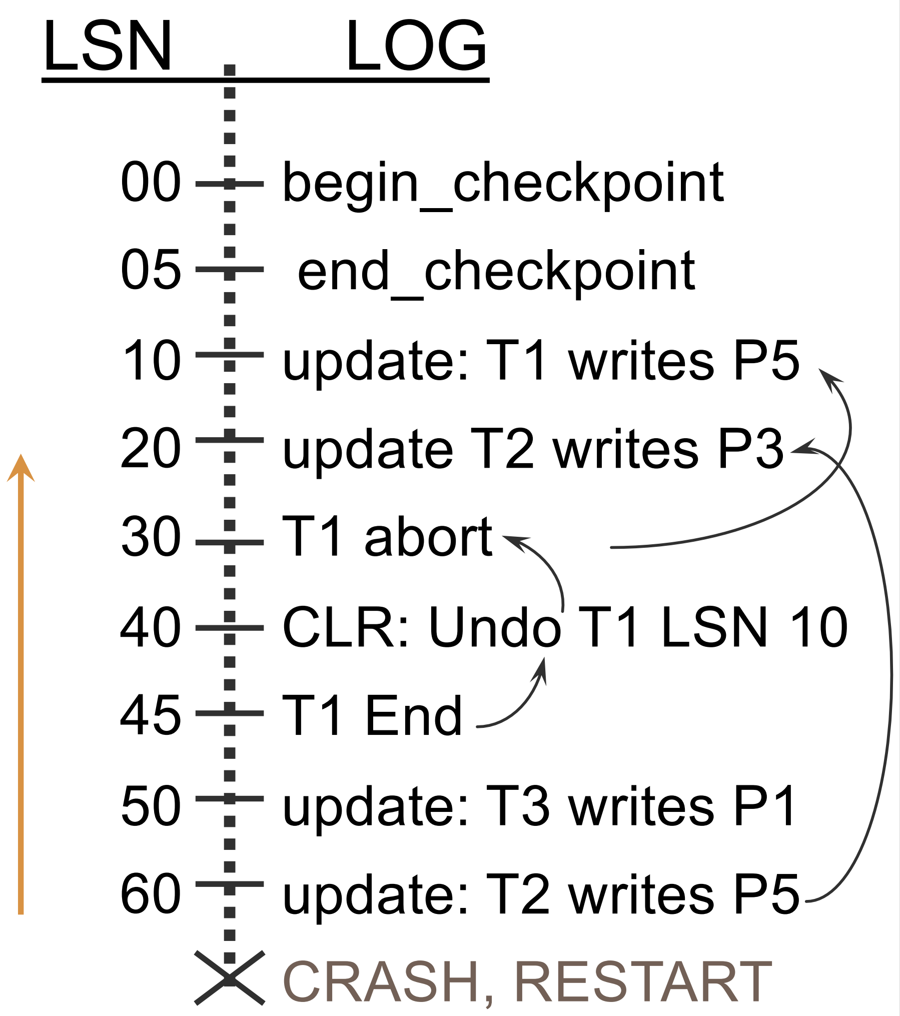
ToUndo = {lastLSNs of all “loser” Xact}

Repeat:

- Choose largest LSN among ToUndo.
- If this LSN is a CLR and undonextLSN==NULL
  - Write an End record for this Xact.
- If this LSN is a CLR, and undonextLSN != NULL
  - Add undonextLSN to ToUndo
- Else this LSN is an update. Undo the update, write a CLR, add prevLSN to ToUndo.

Until ToUndo is empty.

Recovery: The UNDO Phase



LSN	LOG
00	begin_checkpoint
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10	update: T1 writes P5
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30	T1 abort
40	CLR: Undo T1 LSN 10
45	T1 End
50	update: T3 writes P1
60	update: T2 writes P5
	CRASH, RESTART

XACT	LastLSN
T2	60
T3	50

Page	recLSN
P1	50
P3	20
P5	10

LSN	LOG	(undoNextLSN)
70	CLR: Undo T2, LSN 60,	(20)
80	CLR: Undo T3, LSN 50,	(null)
85	T3 End	
90	CLR: Undo T2, LSN 20,	(null)
95	T2 End	

Example: Crash During Restart!

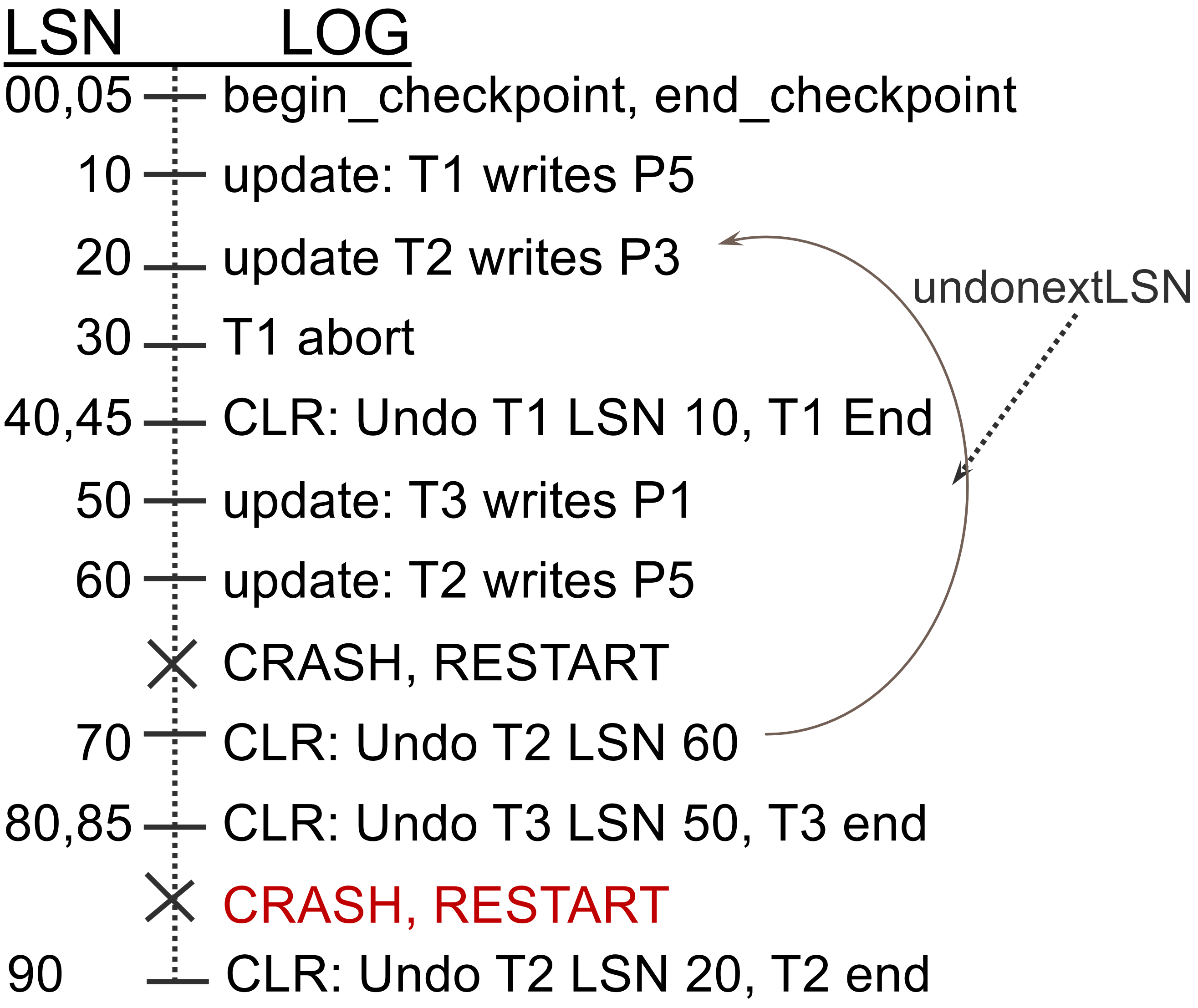
XACT	LastLSN
T2	70

Page	recLSN
P1	50
P3	20
P5	10

REDO: 10 to 85

UNDO:

- Undo 70, CLR
- Undo 20
- Take a ckpt



LSN	LOG
00,05	begin_checkpoint, end_checkpoint
10	update: T1 writes P5
20	update T2 writes P3
30	T1 abort
40,45	CLR: Undo T1 LSN 10, T1 End
50	update: T3 writes P1
60	update: T2 writes P5
	CRASH, RESTART
70	CLR: Undo T2 LSN 60
80,85	CLR: Undo T3 LSN 50, T3 end
	CRASH, RESTART
90	CLR: Undo T2 LSN 20, T2 end

Additional Crash Issues

- How do you limit the amount of work in REDO?
  - Flush asynchronously in the background.
  - Watch “hot spots”!
- How do you limit the amount of work in UNDO?
  - Avoid long-running Xacts.

Media Recovery

- Used for disaster recovery.
- Based on periodically making a copy of the database
  - similar to a fuzzy checkpoint
- Apply logs to the copy of the object in the media to bring it up-to-date

Summary of Logging/Recovery

- Atomicity & Durability.
- WAL to allow STEAL/NO-FORCE
- Checkpointing: A quick way to limit the amount of log to scan on recovery.
- Recovery works in 3 phases:
  - Analysis: Forward from checkpoint.
  - Redo: Forward from oldest recLSN.
  - Undo: Backward from end to first LSN of oldest Xact alive at crash.
- Upon Undo, write CLRs.
- Redo "repeats history": Simplifies the logic!
- **Interested in the history of ARIES:**
  - **http://www.sigmod.org/publications/ds-collection/discs-new/2000.1/out/slides/vldb/repeatinghistorc/index.pdf**