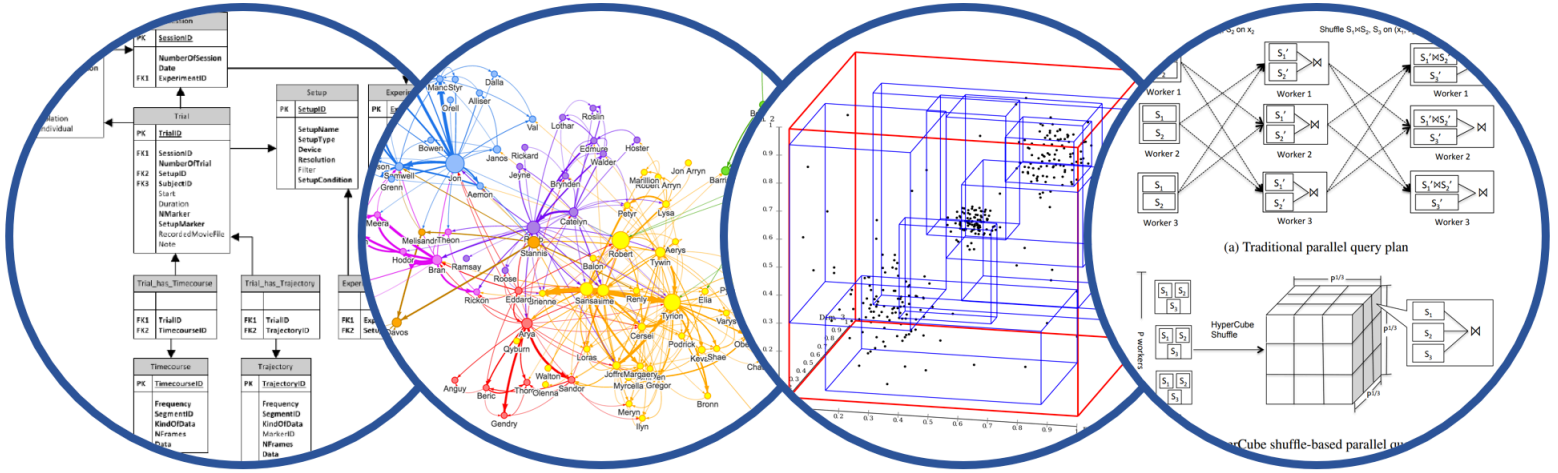


Database System Internals

Transactions: Recovery (part 3)

Paul G. Allen School of Computer Science and Engineering
University of Washington, Seattle

Announcements

- 544 reviews due tonight
- HW4 due on Monday
- Lab 3 due next Friday

ARIES

Undo/Redo protocol

Aries

- ARIES pieces together several techniques into a comprehensive algorithm
- Developed at IBM Almaden, by Mohan
- IBM botched the patent, so everyone uses it now
- Several variations, e.g. for distributed transactions

ARIES Recovery Manager

Log entries:

- <START T> – when T begins
- Update: <T,X,u,v>
  - T updates X, *old* value=u, *new* value=v
  - Logical description of the change
- <COMMIT T> or <ABORT T> then <END>
- <CLR> – we'll talk about them later.

ARIES Recovery Manager

Rule:

- If T modifies X, then <T,X,u,v> must be written to disk before OUTPUT(X)

We are free to OUTPUT early or late w.r.t commits

LSN = Log Sequence Number

- **LSN** = identifier of a log entry
  - Log entries belonging to the same TXN are linked with extra entry for previous LSN

- Each page contains a **pageLSN**:
  - LSN of log record for latest update to that page

ARIES Data Structures

- **Active Transactions Table**
  - Lists all active TXN's
  - For each TXN: lastLSN = its most recent update LSN
- **Dirty Page Table**
  - Lists all dirty pages
  - For each dirty page: recoveryLSN (recLSN)= first LSN that caused page to become dirty
- **Write Ahead Log**
  - LSN, prevLSN = previous LSN for same txn

$W_{T100}(P7)$
$W_{T200}(P5)$
$W_{T200}(P6)$
$W_{T100}(P5)$

Data Structures

Dirty pages

pageID	recLSN
P5	102
P6	103
P7	101

Log (WAL) - tail of the log may be in memory

LSN	prevLSN	transID	pageID	Log entry
101	-	T100	P7	
102	-	T200	P5	
103	102	T200	P6	
104	101	T100	P5	

Active transactions

transID	lastLSN
T100	104
T200	103

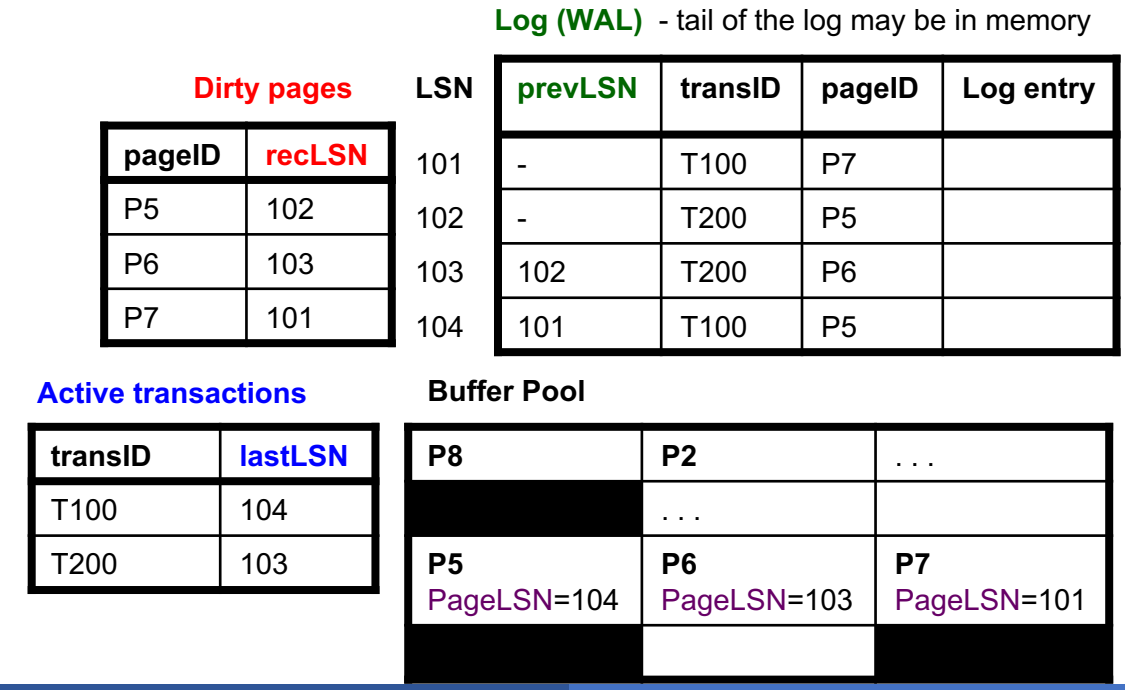
Buffer Pool

P8	**P2**	. . .
	. . .	
P5 PageLSN=104	**P6** PageLSN=103	**P7** PageLSN=101

ARIES Normal Operation

T writes page P

- What do we do ?



ARIES Normal Operation

T writes page P

- What do we do ?

- Write **<T,P,u,v>** in the **Log** – no need to flush to disk yet
- **pageLSN=LSN**
- **prevLSN=lastLSN**
- **lastLSN=LSN**
- **recLSN**=if isNull then **LSN**

Log (WAL) - tail of the log may be in memory

LSN	prevLSN	transID	pageID	Log entry
101	-	T100	P7	
102	-	T200	P5	
103	102	T200	P6	
104	101	T100	P5	

Dirty pages

pageID	recLSN
P5	102
P6	103
P7	101

Active transactions

transID	lastLSN
T100	104
T200	103

Buffer Pool

P8	**P2**	. . .
	. . .	
P5 PageLSN=104	**P6** PageLSN=103	**P7** PageLSN=101

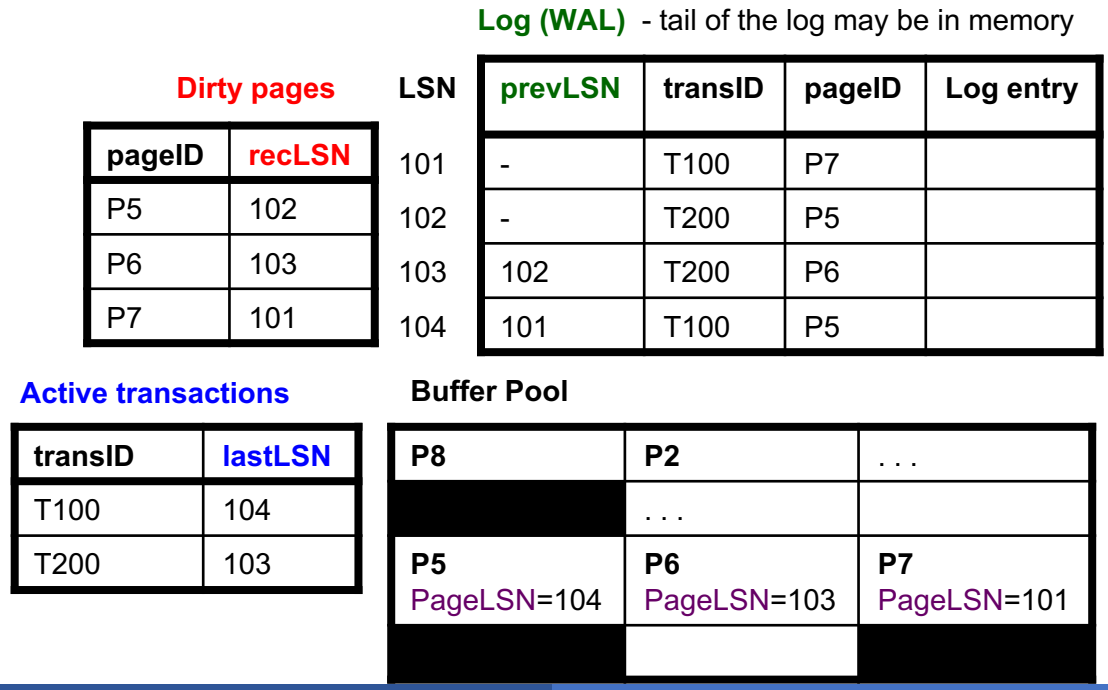
ARIES Normal Operation

Buffer manager wants to OUTPUT(P)

- What do we do ?

Buffer manager wants INPUT(P)

- What do we do ?



ARIES Normal Operation

Buffer manager wants to OUTPUT(P)

- Flush **log** up to **pageLSN**
- Remove P from **Dirty Pages** table

Buffer manager wants INPUT(P)

- What do we do ?

Log (WAL) - tail of the log may be in memory

Dirty pages

pageID	recLSN
P5	102
P6	103
P7	101

LSN	prevLSN	transID	pageID	Log entry
101	-	T100	P7	
102	-	T200	P5	
103	102	T200	P6	
104	101	T100	P5	

Active transactions

transID	lastLSN
T100	104
T200	103

Buffer Pool

P8	**P2**	. . .
	. . .	
P5 PageLSN=104	**P6** PageLSN=103	**P7** PageLSN=101

ARIES Normal Operation

Buffer manager wants to OUTPUT(P)

- Flush **log** up to **pageLSN**
- Remove P from **Dirty Pages** table

Buffer manager wants INPUT(P)

- Create entry in **Dirty Pages** table
  recLSN = NULL

Log (WAL) - tail of the log may be in memory

LSN	prevLSN	transID	pageID	Log entry
101	-	T100	P7	
102	-	T200	P5	
103	102	T200	P6	
104	101	T100	P5	

Dirty pages

pageID	recLSN
P5	102
P6	103
P7	101

Active transactions

transID	lastLSN
T100	104
T200	103

Buffer Pool

P8	**P2**	. . .
	. . .	
P5 PageLSN=104	**P6** PageLSN=103	**P7** PageLSN=101

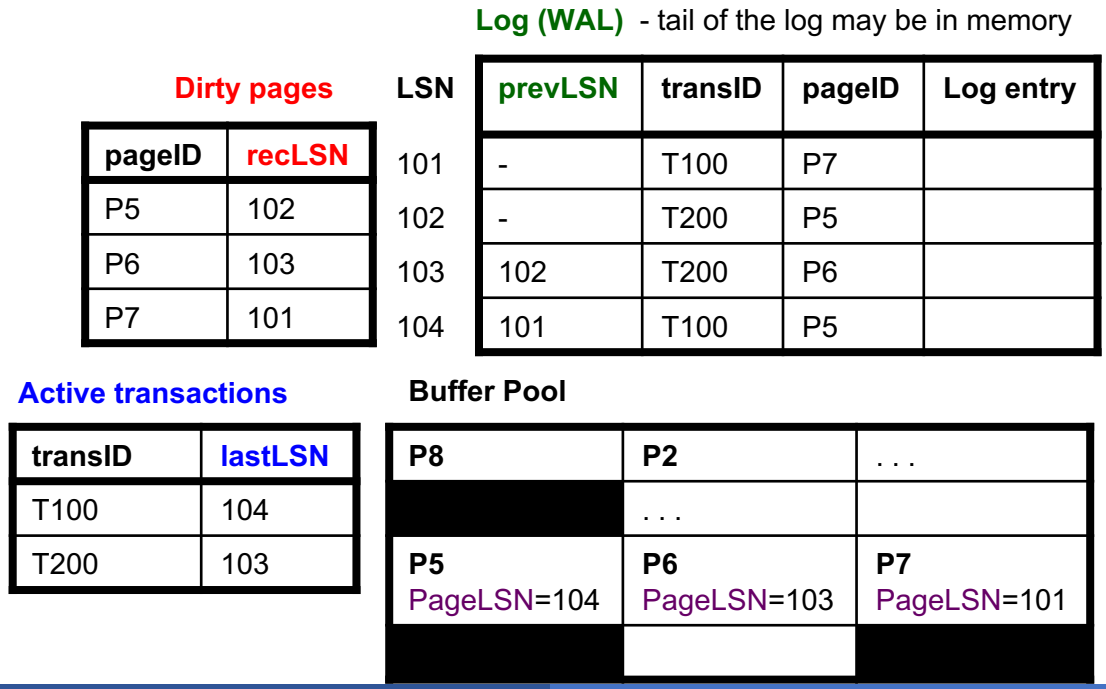
ARIES Normal Operation

Transaction T starts

- What do we do ?

Transaction T commits/aborts

- What do we do ?



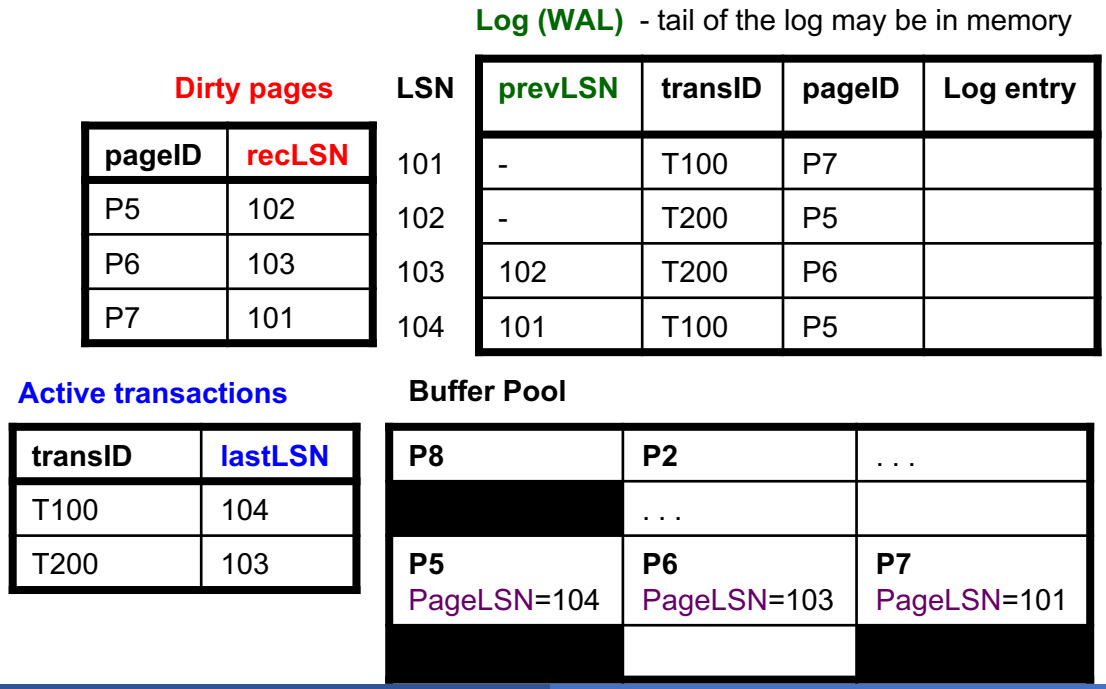
ARIES Normal Operation

Transaction T starts

- Write **<START T>** in the **log**
- New entry T in Active TXN; lastLSN = null

Transaction T commits

- What do we do ?



ARIES Normal Operation

Transaction T starts

- Write **<START T>** in the **log**
- New entry T in Active TXN; lastLSN = null

Transaction T commits

- Write **<COMMIT T>** in the **log**
- Flush **log** up to this entry
- Write **<END>**

Log (WAL) - tail of the log may be in memory

LSN	prevLSN	transID	pageID	Log entry
101	-	T100	P7	
102	-	T200	P5	
103	102	T200	P6	
104	101	T100	P5	

Dirty pages

pageID	recLSN
P5	102
P6	103
P7	101

Active transactions

transID	lastLSN
T100	104
T200	103

Buffer Pool

P8	**P2**	. . .
	. . .	
P5 PageLSN=104	**P6** PageLSN=103	**P7** PageLSN=101

Checkpoints

Write into the log

- Entire Active Transactions Table
- Entire Dirty Pages Table

Recovery always starts by analyzing latest checkpoint

Background process periodically flushes dirty pages to disk

ARIES Recovery

1. **Analysis pass**
   - Figure out what was going on at time of crash
   - List of dirty pages and active transactions
2. **Redo pass (repeating history principle)**
   - Redo all operations, even for transactions that will not commit
   - Get back to state at the moment of the crash
3. **Undo pass**
   - Remove effects of all uncommitted transactions
   - Log changes during undo in case of another crash during undo

ARIES Method Illustration

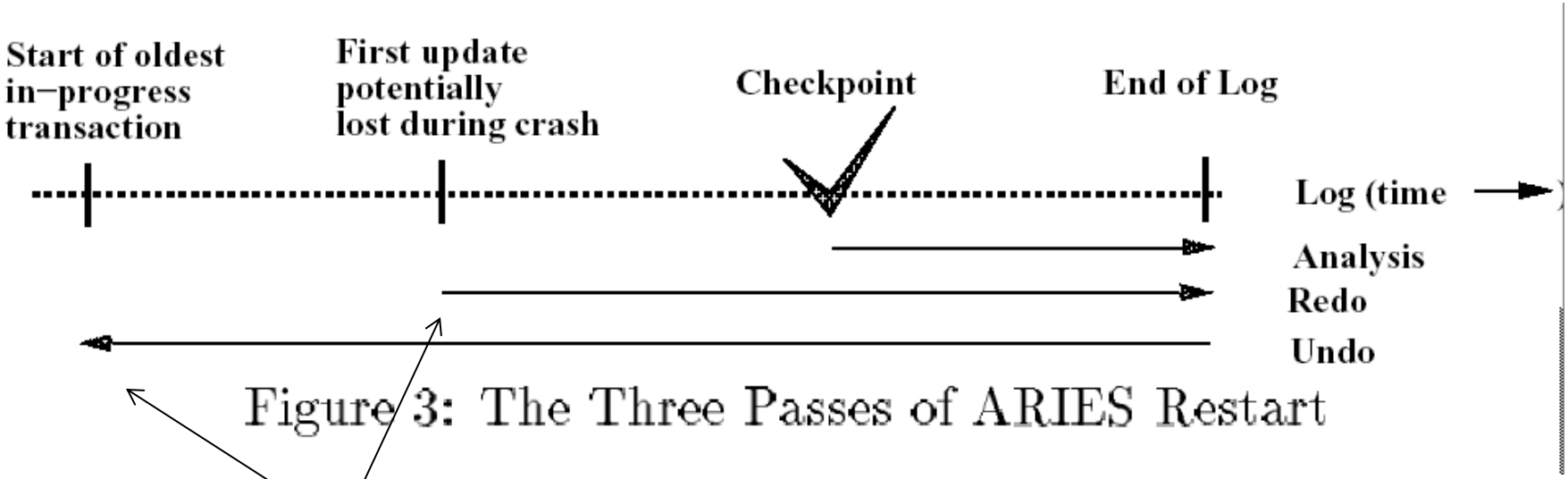


Figure 3: The Three Passes of ARIES Restart

First undo and first redo log entry might be in reverse order

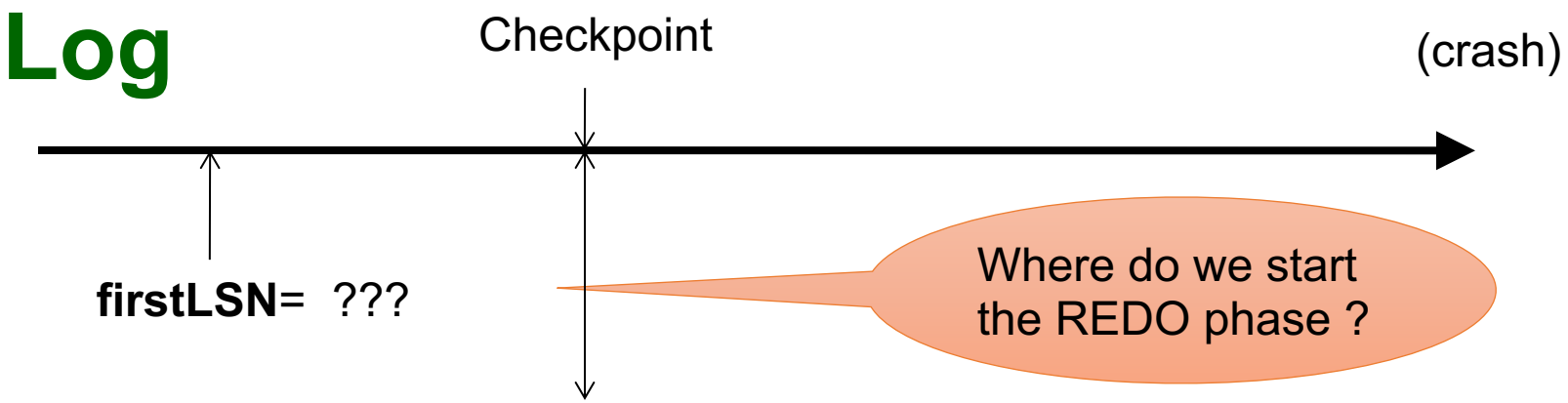
[Figure 3 from Franklin97]

1. Analysis Phase

- Goal
  - Determine point in log where to start REDO
  - Determine set of dirty pages when crashed
    - Conservative estimate of dirty pages
  - Identify active transactions when crashed

- Approach
  - Rebuild active transactions table and dirty pages table
  - Reprocess the log from the checkpoint
    - Only update the two data structures
  - Compute: **firstLSN** = smallest of all recoveryLSN

1. Analysis Phase



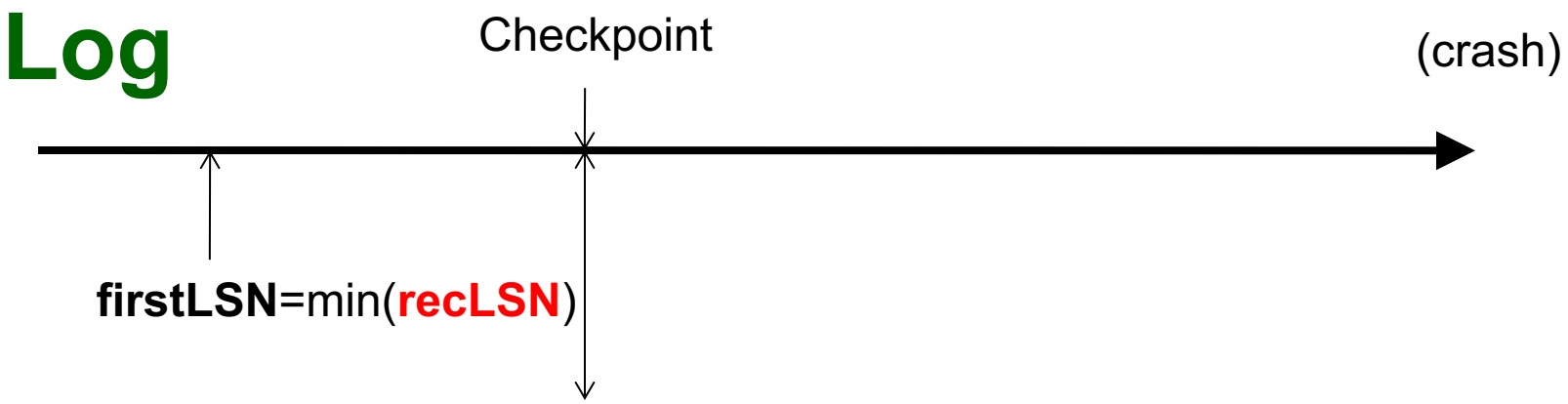
Dirty pages

pageID	recLSN

Active txn

transID	lastLSN

1. Analysis Phase



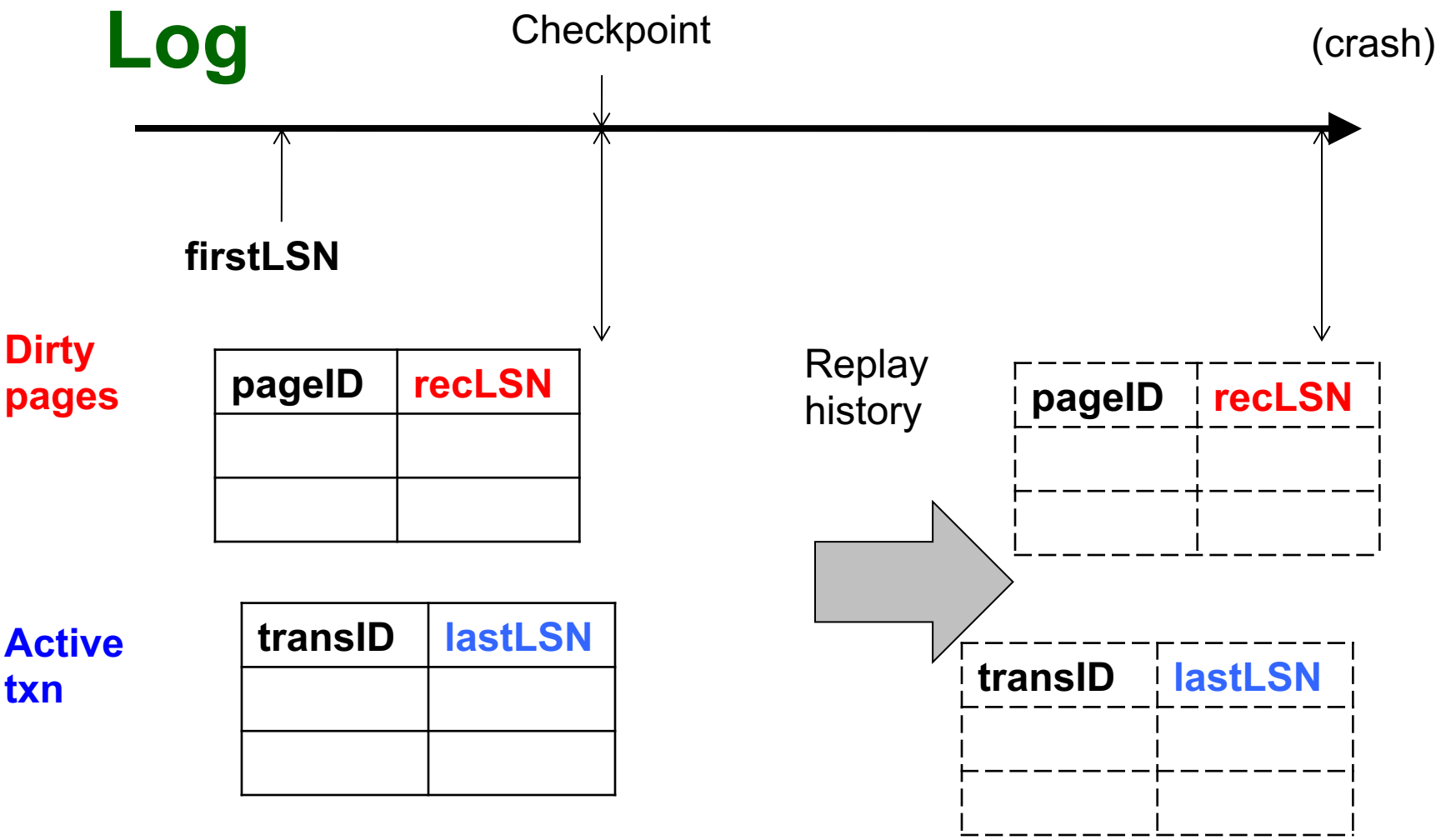
Dirty pages

pageID	recLSN

Active txn

transID	lastLSN

1. Analysis Phase



2. Redo Phase

Main principle: replay history

- Process Log forward, starting from **firstLSN**
- Read every log record, sequentially
- Redo actions are not recorded in the log
- Needs the Dirty Page Table

2. Redo Phase: Details

For each Log entry record LSN: **<T,P,u,v>**

- Redo the action P=u and WRITE(P)
- Only redo actions that need to be redone

2. Redo Phase: Details

For each Log entry record LSN: **<T,P,u,v>**

- If P is not in Dirty Page then **no update**
- If recLSN > LSN, then **no update**
- Read page from disk:
  If **pageLSN** >= LSN, then **no update**
- Otherwise perform update

2. Redo Phase: Details

What happens if system crashes during REDO ?

2. Redo Phase: Details

What happens if system crashes during REDO ?

We REDO again ! REDO is idempotent.

3. Undo Phase

- We could "unplay" history the same way as we "replay" history
- However, we cannot do this selectively, for one transactions that wants to ROLLBACK
- Reason 1:
  - TXN T1 updates one record on page X
  - TXN T2 updates another record on same page X
  - TXN T2 commits
  - TXN T1 wants to ROLLBACK: cannot restore X
- Reason 2: indexes; similar issue
- Explanation: limits of our abstract model…

Discussion

- Abstraction used for transactions:
  Database = a collection of elements: X, Y, Z, …
- WRITE/UNDO of X has no effect on Y

- This abstraction has limits
- When an element = a block, then:
  - Updating a record affects other records on same page
  - Updating a B^+-tree affects a path from root to leaf
- Solution:
  - For locking: tree protocol (see book)
  - For ARIES: logical UNDO

3. Undo Phase

Main principle: "logical" undo

- Start from end of Log, move backwards
- Read only affected log entries
- UNDO is not idempotent!
- Solution: log the UNDO's as special log entries: CLR (Compensating Log Records)
- CLRs are redone, but never undone

3. Undo Phase: Details

- "Loser transactions" = uncommitted transactions in Active Transactions Table

- **ToUndo** = set of lastLSN of loser transactions

3. Undo Phase: Details

While **ToUndo** not empty:

- Choose most recent (largest) LSN in **ToUndo**
- If LSN = regular record **<T,P,u,v>**:
  - Write a CLR where CLR.undoNextLSN = LSN.prevLSN
  - Undo v
- If LSN = CLR record:
  - Don't undo !
- if CLR.**undoNextLSN** not null, insert in **ToUndo** otherwise, write **<END>** in log

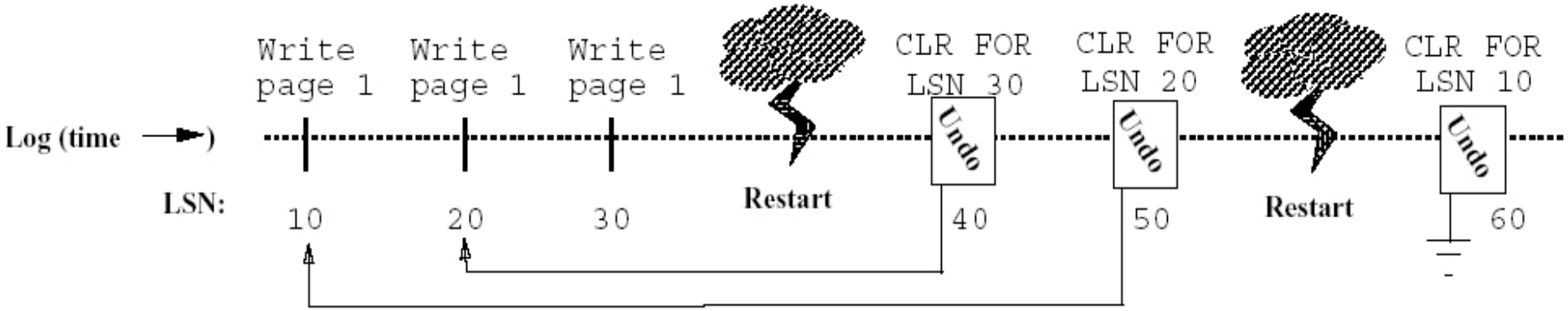


Figure 4: The Use of CLRs for UNDO

[Figure 4 from Franklin97]

3. Undo Phase: Details

What happens if system crashes during UNDO ?

3. Undo Phase: Details

What happens if system crashes during UNDO ?

We do not UNDO again ! Instead, each CLR is a REDO record: we simply redo the undo

Example

LSN	Log Entry	prevLSN	undoNextLSN
10	<T,X,a,b>	0	
20	<T,X,b,c>	10	
30	<T,X,c,d>	20	
	CRASH/RESTART		

Example

ToUndo = {30} from the Active TXN table

LSN	Log Entry	**prevLSN**	**undoNextLSN**
10	<T,X,a,b>	0	
20	<T,X,b,c>	10	
30	<T,X,c,d>	20	
	CRASH/RESTART		

Example

ToUndo = {~~30~~,20}

LSN	Log Entry	prevLSN	undoNextLSN
10	<T,X,a,b>	0	
20	<T,X,b,c>	10	
30	<T,X,c,d>	20	
	CRASH/RESTART		
40	CLR(T,X,c)		20

Example

ToUndo = {~~30~~,~~20~~,10}

LSN	Log Entry	prevLSN	undoNextLSN
10	<T,X,a,b>	0	
20	<T,X,b,c>	10	
30	<T,X,c,d>	20	
	CRASH/RESTART		
40	CLR(T,X,c)		20
50	CLR(T,X,b)		10

Example

LSN	Log Entry	prevLSN	undoNextLSN
10	<T,X,a,b>	0	
20	<T,X,b,c>	10	
30	<T,X,c,d>	20	
	CRASH/RESTART		
40	CLR(T,X,c)		20
50	CLR(T,X,b)		10
	CRASH/RESTART		

Example

Redo phase: update X=b, X=c, X=d, X=c, X=b

LSN	Log Entry	prevLSN	undoNextLSN
10	<T,X,a,b>	0	
20	<T,X,b,c>	10	
30	<T,X,c,d>	20	
	CRASH/RESTART		
40	CLR(T,X,c)		20
50	CLR(T,X,b)		10
	CRASH/RESTART		

Note: during REDO the CLR's are like regular update entries

Example

ToUndo = {50} this is the new LastLSN of T

LSN	Log Entry	**prevLSN**	**undoNextLSN**
10	<T,X,a,b>	0	
20	<T,X,b,c>	10	
30	<T,X,c,d>	20	
	CRASH/RESTART		
40	CLR(T,X,c)		20
50	CLR(T,X,b)		10
	CRASH/RESTART		

Example

ToUndo = {50}

LSN	Log Entry	**prevLSN**	**undoNextLSN**
10	<T,X,a,b>	0	
20	<T,X,b,c>	10	
30	<T,X,c,d>	20	
	CRASH/RESTART		
40	CLR(T,X,c)		20
50	CLR(T,X,b)		10
	CRASH/RESTART		

LSN 50 is a CLR; we do nothing, instead follow **undoNextLSN**

Example

ToUndo = {~~50~~,0} DONE!

LSN	Log Entry	prevLSN	undoNextLSN
10	<T,X,a,b>	0	
20	<T,X,b,c>	10	
30	<T,X,c,d>	20	
	CRASH/RESTART		
40	CLR(T,X,c)		20
50	CLR(T,X,b)		10
	CRASH/RESTART		
60	CLR(T,X,a)		0