CSE 444: Database Internals

Section 8:

Transactions - Recovery

Review in this section

1. UNDO logging

1. REDO logging

1. Updating ARIES Data Structures

Undo Logging

- Two Rules:
  - 1. If a transaction writes element **X**, then the log record of this update **<T,X,v>** must be written to disk before the new value of **X** is written to disk.
  - 2. If a transaction commits, then the **COMMIT** must be written to disk only after all elements changed by the transaction have been written to disk.

UNDO LOG RULES

1. <T, X, v> before OUTPUT(X)
2. OUTPUT(X) before <COMMIT>

Action				Disk A	Disk B	Log
						<START T>
INPUT(A				8	8	
READ(A,t)	8	8		8	8	
t:=t*2	16	8		8	8	
WRITE(A,t)	16	16		8	8	<T,A,8>
INPUT(B)	16	16	8	8	8	
READ(B,t)	8	16	8	8	8	
t:=t*2	16	16	8	8	8	
WRITE(B,t)	16	16	16	8	8	<T,B,8>
OUTPUT(A)	16	16	16	16	8	
OUTPUT(B)	16	16	16	16	16	
COMMIT						<COMMIT T>

When recovering (with UNDO logging)…

- We can not simply ignore the log before a recent commit
  - Many transactions interleave at once. If we truncate before a commit for a transaction, any information about those unfinished transactions would be lost.

- Instead, we can use checkpoint the log periodically…

Review: Checkpointing

- **Checkpointing (naïve)**
  - Write a <START CKPT(T1,…,Tk)>. Flush log to disk
  - **<u>Stop accepting new transactions</u>**
  - Wait until all active transactions abort/commit
  - Write <CKPT>. Flush log to disk.
  - <u>Resume</u> accepting transactions

- **Nonquiescent Checkpointing**
  - Write a <START CKPT(T1,…,Tk)>. Flush log to disk
  - <u>Continue normal operation</u>
  - When all of T1,…,Tk have completed, write <END CKPT>. Flush log to disk
  - **<u>More efficient, system does not seem to be stalled</u>**

Problem 1. UNDO Logging

```
LSN1     <START T1>
LSN2     <T1 X 5>
LSN3     <START T2>
LSN4     <T1 Y 7>
LSN5     <T2 X 9>
LSN6     <START T3>
LSN7     <T3 Z 11>
LSN8     <COMMIT T1>
LSN9     <START CKPT(T2,T3)>
LSN10    <T2 X 13>
LSN11    <T3 Y 15>
      *CRASH*
```

1.
Show how far back in the recovery manager needs to read the log

(which LSN do we need to read up to?)

UNDO: How far to scan log from the end?

- **Case 1**: See **<END CKPT>** first
  - All incomplete transactions began after <START CKPT…>
- **Case 2:** See **<START CKPT(T1..TK)>** first
  - Incomplete transactions began after <START CKPT…> or incomplete ones among T1.. TK
  - Find the earliest <START Ti> among them
  - At most we have to go until the previous <START CKPT>…<END CKPT>

```
LSN1      <START T1>
LSN2      <T1 X 5>
LSN3      <START T2>
LSN4      <T1 Y 7>
LSN5      <T2 X 9>
LSN6      <START T3>
LSN7      <T3 Z 11>
LSN8      <COMMIT T1>
LSN9      <START CKPT(T2,T3)>
LSN10     <T2 X 13>
LSN11     <T3 Y 15>
      *CRASH*
```

Problem 1. UNDO Logging

```
LSN1     <START T1>
LSN2     <T1 X 5>
LSN3     <START T2>
LSN4     <T1 Y 7>
LSN5     <T2 X 9>
LSN6     <START T3>
LSN7     <T3 Z 11>
LSN8     <COMMIT T1>
LSN9     <START CKPT(T2,T3)>
LSN10    <T2 X 13>
LSN11    <T3 Y 15>
      *CRASH*
```

1.
Show how far back in the recovery manager needs to read the log

(write the earliest LSN)

LSN3
(start of the earliest transaction among incomplete transactions)

Problem 1. UNDO Logging

```
LSN1     <START T1>
LSN2     <T1 X 5>
LSN3     <START T2>
LSN4     <T1 Y 7>
LSN5     <T2 X 9>
LSN6     <START T3>
LSN7     <T3 Z 11>
LSN8     <COMMIT T1>
LSN9     <START CKPT(T2,T3)>
LSN10    <T2 X 13>
LSN11    <T3 Y 15>
      *CRASH*
```

2.
Show the actions of the recovery manager during recovery.

Problem 1. UNDO Logging

```
LSN1     <START T1>
LSN2     <T1 X 5>
LSN3     <START T2>
LSN4     <T1 Y 7>
LSN5     <T2 X 9>
LSN6     <START T3>
LSN7     <T3 Z 11>
LSN8     <COMMIT T1>
LSN9     <START CKPT(T2,T3)>
LSN10    <T2 X 13>
LSN11    <T3 Y 15>
      *CRASH*
```

2.
Show the actions of the recovery manager during recovery.

Y = 15
X = 13
Z = 11
X = 9

Redo Logging

- One Rule:
  - 1. Before modifying any element X on disk, all log records pertaining to this modification (<T,X,v> and the <COMMIT T>), must appear on disk.

REDO LOG RULE

Both <T, X, v> and <COMMIT >
before OUTPUT(X)
v = new value

Action	T				sk B	Log
						<START T>
READ(A,t)	8				8	
t:=t*2	16				8	
WRITE(A,t)	16	16		8	8	<T,A,16>
READ(B,t)	8	16	8	8	8	
t:=t*2	16	16	8	8	8	
WRITE(B,t)	16	16	16	8	8	<T,B,16>
						<COMMIT T>
OUTPUT(A)	16	16	16	16	8	
OUTPUT(B)	16	16	16	16	16	

Problem 2: REDO Logging

1. < START T1 >
2. < T1, A, 10 >
3. < START T2 >
4. < T2, B, 5 >
5. < T1, C, 7 >
6. < START T3 >
7. < T3, D, 12 >
8. < COMMIT T1 >
9. < START CKPT ???? >
10. < START T4 >
11. < T2, E, 5 >
12. < COMMIT T2 >
13. < T3, F, 1 >
14. < T4, G, 15 >
15. < END CKPT >
16. < COMMIT T3 >
17. < START T5 >
18. < T5, H, 3 >
19. < START CKPT ???? >
20. < COMMIT T5 >

*** CRASH ***

1\.
What are the correct values of the two <START CKPT ????> records?

Problem 2: REDO Logging

1. < START T1 >
2. < T1, A, 10 >
3. < START T2 >
4. < T2, B, 5 >
5. < T1, C, 7 >
6. < START T3 >
7. < T3, D, 12 >
8. < COMMIT T1 >
9. < START CKPT ???? >
10. < START T4 >
11. < T2, E, 5 >
12. < COMMIT T2 >
13. < T3, F, 1 >
14. < T4, G, 15 >
15. < END CKPT >
16. < COMMIT T3 >
17. < START T5 >
18. < T5, H, 3 >
19. < START CKPT ???? >
20. < COMMIT T5 >

1\. What are the correct values of the two <START CKPT ????> records?

First START CKPT:
< START CKPT (T2, T3) >

Second START CKPT:
< START CKPT (T4, T5) >

Problem 2: REDO Logging **(Checkpoint)**

1. < START T1 >
2. < T1, A, 10 >
3. < START T2 >
4. < T2, B, 5 >
5. < T1, C, 7 >
6. < START T3 >
7. < T3, D, 12 >
8. < COMMIT T1 >
9. **< START CKPT T2,T3 >**
10. < START T4 >
11. < T2, E, 5 >
12. < COMMIT T2 >
13. < T3, F, 1 >
14. < T4, G, 15 >
15. **< END CKPT >**
16. < COMMIT T3 >
17. < START T5 >
18. < T5, H, 3 >
19. < START CKPT T4,T5 >
20. < COMMIT T5 >

NOTE:

<Commit T3> after <END CKPT>

What are we CKPTing?

The transactions that committed before **<START CKPT>**

REDO: How far to scan log from the start?

- **Identify committed transactions**

- Case 1: See <END CKPT> first
  - All committed transactions before <START CKPT (T1.. TK)> are written
  - Consider T1.. Tk, or transactions that started after <START CKPT…>, trace back until earliest <START Ti>

<START T_1>
<$T_1, A, 5$>
<START T_2>
<COMMIT T_1>
<$T_2, B, 10$>
<START CKPT (T_2)>
<$T_2, C, 15$>
<START T_3>
<$T_3, D, 20$>
<END CKPT>
<COMMIT T_2>
<COMMIT T_3>

REDO: How far to scan log from the start?

- **Identify committed transactions**

- Case 1: See <END CKPT> first
  - All committed transactions before <START CKPT (T1.. TK)> are written
  - Consider T1.. Tk, or transactions that started after <START CKPT…>, trace back until earliest <START Ti>

- Case 2: See <START CKPT(T1..TK)> first
  - Committed transactions before START CKPT might not have been written
  - Find previous <END CKPT>, its matching <START CKPT(S1, … Sm)>
  - Redo committed transactions that started after <START CKPT T1..Tk> or S1.. Sm

Problem 2: REDO Logging

1. < START T1 >
2. < T1, A, 10 >
3. < START T2 >
4. < T2, B, 5 >
5. < T1, C, 7 >
6. < START T3 >
7. < T3, D, 12 >
8. < COMMIT T1 >
9. < START CKPT T2,T3 >
10. < START T4 >
11. < T2, E, 5 >
12. < COMMIT T2 >
13. < T3, F, 1 >
14. < T4, G, 15 >
15. < END CKPT >
16. < COMMIT T3 >
17. < START T5 >
18. < T5, H, 3 >
19. < START CKPT T4,T5 >
20. < COMMIT T5 >

2.
What fragment of the log does the recovery manager need to read?

Problem 2: REDO Logging

1. < START T1 >
2. < T1, A, 10 >
3. **< START T2 >**
4. < T2, B, 5 >
5. < T1, C, 7 >
6. **< START T3 >**
7. < T3, D, 12 >
8. < COMMIT T1 >
9. **< START CKPT T2,T3>**
10. < START T4 >
11. < T2, E, 5 >
12. **< COMMIT T2 >**
13. < T3, F, 1 >
14. < T4, G, 15 >
15. < END CKPT >
16. **< COMMIT T3 >**
17. < START T5 >
18. < T5, H, 3 >
19. **< START CKPT T4,T5>**
20. < COMMIT T5 >

2.
What fragment of the log does the recovery manager need to read?

- We know there was a commit for T5.
- In the previous START CKPT, T2 and T3 were the two active transactions. Both transactions committed and must thus be redone.
- T2 was the earliest one

Problem 2: REDO Logging

1. < START T1 >
2. < T1, A, 10 >
3. < START T2 >
4. < T2, B, 5 >
5. < T1, C, 7 >
6. < START T3 >
7. < T3, D, 12 >
8. < COMMIT T1 >
9. < START CKPT T2,T3 >
10. < START T4 >
11. < T2, E, 5 >
12. < COMMIT T2 >
13. < T3, F, 1 >
14. < T4, G, 15 >
15. < END CKPT >
16. < COMMIT T3 >
17. < START T5 >
18. < T5, H, 3 >
19. < START CKPT T4,T5 >
20. < COMMIT T5 >

3.
Which elements are recovered by the redo recovery manager? compute their values after recovery.

Problem 2: REDO Logging

1. < START T1 >
2. < T1, A, 10 >
3. < START T2 >
4. **< T2, B, 5 >**
5. < T1, C, 7 >
6. < START T3 >
7. **< T3, D, 12 >**
8. < COMMIT T1 >
9. < START CKPT T2,T3 >
10. < START T4 >
11. **< T2, E, 5 >**
12. < COMMIT T2 >
13. **< T3, F, 1 >**
14. < T4, G, 15 >
15. < END CKPT >
16. < COMMIT T3 >
17. < START T5 >
18. **< T5, H, 3 >**
19. < START CKPT T4,T5 >
20. < COMMIT T5 >

3. Which elements are recovered by the redo recovery manager? compute their values after recovery.

All changes by T2, T3, T5 (committed)

B=5
D=12
E=5
F=1
H=3

Comparison Undo/Redo

- Undo logging:
  - OUTPUT must be done early
  - If <COMMIT T> is seen, T definitely has written all its data to disk (hence, don't need to redo) – inefficient

Steal/Force

- Redo logging
  - OUTPUT must be done late
  - If <COMMIT T> is not seen, T definitely has not written any of its data to disk (hence there is not dirty data on disk, no need to undo) – inflexible

No-Steal/No-Force

- Would like more flexibility on when to OUTPUT: undo/redo logging (next)

Steal/No-Force

ARIES Data Structures

Dirty page table

pageID	recLSN

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101						

Transaction table

transID	lastLSN	status

Buffer Pool

P500 PageLSN= - A = abc D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Disk

P500 PageLSN= - A = abc D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

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

Review: ARIES Data Structures (UNDO/REDO Logging)

Example.

1. **T_{1000}** changes the value of **A from “abc” to “def”** on **page P500**
2. **T_{2000}** changes the value of **B from “hij” to “klm”** on **page P600**
3. **T_{2000}** changes the value of **D from “mnp” to “qrs”** on **page P500**
4. **T_{1000}** changes the value of **C from “tuv” to “wxy”** on **page P505**
5. **T_{2000}** commits and the end log record is written
6. **T_{1000}** changes the value of **E from “pq” to “rs”** on **page P700**
7. **P600** is flushed to disk
8. **Crash!!**

ARIES Data Structures

Dirty page table

pageID	recLSN

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101						

Transaction table

transID	lastLSN	status

Buffer Pool

P500 PageLSN= - A = abc D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Disk

P500 PageLSN= - A = abc D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

First operation:

1. T_{1000} changes the value of **A from "abc" to "def"** on **page P500?**

Dirty page table

pageID	recLSN

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101						

Transaction table

transID	lastLSN	status

Buffer Pool

P500 PageLSN= - A = abc D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Disk

P500 PageLSN= - A = abc D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Changes

1. T_{1000} changes the value of **A from "abc" to "def"** on **page P500**

Dirty page table

pageID	recLSN
P500	101

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A "abc" -> "def"	Update	-

Transaction table

transID	lastLSN	status
T_{1000}	101	Running

Buffer Pool

P500 **PageLSN= 101** **A = def** D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Disk

P500 PageLSN= - A = abc D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Next:

2. T_{2000} changes the value of **B from "hij" to "klm"** on **page P600 ?**

Dirty page table

pageID	recLSN
P500	101

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A "abc" -> "def"	Update	-

Transaction table

transID	lastLSN	status
T_{1000}	101	Running

Buffer Pool

P500 **PageLSN= 101** **A = def** D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Disk

P500 PageLSN= - A = abc D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Changes:

2. T_{2000} changes the value of **B from "hij" to "klm"** on **page P600 ?**

Dirty page table

pageID	recLSN
P500	101
P600	**102**

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A "abc" -> "def"	Update	-
102	-	T_{2000}	P600	Write B "hij" -> "klm"	Update	

Transaction table

transID	lastLSN	status
T_{1000}	101	Running
T_{2000}	**102**	**Running**

Buffer Pool

P500 PageLSN= 101 A = def D = mnp	**P600** **PageLSN= 102** **B = klm**
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Disk

P500 PageLSN= - A = abc D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Next:

3. T_{2000} changes the value of D from “mnp” to “qrs” on page P500?

Dirty page table

pageID	recLSN
P500	101
P600	102

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A “abc” -> “def”	Update	-
102	-	T_{2000}	P600	Write B “hij” -> “klm”	Update	

Transaction table

transID	lastLSN	status
T_{1000}	101	Running
T_{2000}	102	Running

Buffer Pool

P500 PageLSN= 101 A = def D = mnp	**P600** PageLSN= 102 B = klm
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Disk

P500 PageLSN= - A = abc D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Changes:

3. T_{2000} changes the value of D from “mnp” to “qrs” on page P500

Dirty page table

pageID	recLSN
P500	101
P600	102

Transaction table

transID	lastLSN	status
T_{1000}	101	Running
T_{2000}	103	Running

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A “abc” -> “def”	Update	-
102	-	T_{2000}	P600	Write B “hij” -> “klm”	Update	-
103	102	T_{2000}	P500	Write D “mnp” -> “qrs”	Update	-

Buffer Pool

P500 PageLSN= 103 A = def D = qrs	**P600** PageLSN= 102 B = klm
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Disk

P500 PageLSN= - A = abc D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Next:

4. T_{1000} changes the value of C from “tuv” to “wxy” on page P505?

Dirty page table

pageID	recLSN
P500	101
P600	102

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A “abc” -> “def”	Update	-
102	-	T_{2000}	P600	Write B “hij” -> “klm”	Update	-
103	102	T_{2000}	P500	Write D “mnp” -> “qrs”	Update	-

Transaction table

transID	lastLSN	status
T_{1000}	101	Running
T_{2000}	103	Running

Buffer Pool

P500 PageLSN= 103 A = def D = qrs	**P600** PageLSN= 102 B = klm
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Disk

P500 PageLSN= - A = abc D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Changes:

4. T_{1000} changes the value of C from "tuv" to "wxy" on page P505?

Dirty page table

pageID	recLSN
P500	101
P600	102
P505	**104**

Transaction table

transID	lastLSN	status
T_{1000}	**104**	**Running**
T_{2000}	103	Running

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A "abc" -> "def"	Update	-
102	-	T_{2000}	P600	Write B "hij" -> "klm"	Update	-
103	102	T_{2000}	P500	Write D "mnp" -> "qrs"	Update	-
104	101	T_{1000}	P505	Write C "tuv" -> "wxy"	Update	-

Buffer Pool

P500 PageLSN= 103 A = def D = qrs	**P600** PageLSN= 102 B = klm
P505 **PageLSN= 104** **C = wxy**	**P700** PageLSN= - E = pq

Disk

P500 PageLSN= - A = abc D = mnp	**P600** PageLSN= - B = hij
P505 PageLSN= - C = tuv	**P700** PageLSN= - E = pq

Next:

5. T_{2000} commits and the end log record is written

Dirty page table

pageID	recLSN
P500	101
P600	102
P505	**104**

Transaction table

transID	lastLSN	status
T_{1000}	**104**	**Running**
T_{2000}	103	Running

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A "abc" -> "def"	Update	-
102	-	T_{2000}	P600	Write B "hij" -> "klm"	Update	-
103	102	T_{2000}	P500	Write D "mnp" -> "qrs"	Update	-
104	101	T_{1000}	P505	Write C "tuv" -> "wxy"	Update	-

Buffer Pool

P500 PageLSN= 103 A = def D = qrs	**P600** PageLSN= 102 B = klm
P505 **PageLSN= 104** **C = wxy**	**P700** PageLSN= - E = pq

Disk

PageLSN= -

A = abc D = mnp

B = hij

P505

PageLSN= -

C = tuv

P700

PageLSN= -

E = pq

Changes:

5. T_{2000} commits and the end log record is written --- step 1

Dirty page table

pageID	recLSN
P500	101
P600	102
P505	104

Transaction table

transID	lastLSN	status
T_{1000}	104	Running
T_{2000}	103	Committed

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A “abc” -> “def”	Update	-
102	-	T_{2000}	P600	Write B “hij” -> “klm”	Update	-
103	102	T_{2000}	P500	Write D “mnp” -> “qrs”	Update	-
104	101	T_{1000}	P505	Write C “tuv” -> “wxy”	Update	-
105	103	T_{2000}			Commit	
106	105	T_{2000}			End	

Buffer Pool

PageLSN= 103

A = def D = qrs

PageLSN= 102

B = klm

P505

PageLSN= 104

C = wxy

P700

PageLSN= -

E = pq

Disk

PageLSN= -

A = abc D = mnp

B = hij

P505

PageLSN= -

C = tuv

P700

PageLSN= -

E = pq

Changes:

5. T_{2000} commits and the end log record is written --- step 2

T2000 removed from transaction table

Dirty page table

pageID	recLSN
P500	101
P600	
P505	104

Transaction table

transID	lastLSN	status
T_{1000}	104	Running
~~T_{2000}~~	~~103~~	~~Committed~~

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A “abc” -> “def”	Update	-
			P600	Write B “hij” -> “klm”	Update	-
	102	T_{2000}	P500	Write D “mnp” -> “qrs”	Update	-
104	101	T_{1000}	P505	Write C “tuv” -> “wxy”	Update	-
105	103	T_{2000}			Commit	
106	105	T_{2000}			End	

Buffer Pool

PageLSN= 103

A = def D = qrs

PageLSN= 102

B = klm

P505

PageLSN= 104

C = wxy

P700

PageLSN= -

E = pq

Disk

PageLSN= -

A = abc D = mnp

B = hij

P505

PageLSN= -

C = tuv

P700

PageLSN= -

E = pq

Changes:

5. T_{2000} commits and the end log record is written --- step 2

Dirty page table

pageID	recLSN
P500	101
P600	102
P505	104

Transaction table

transID	lastLSN	status
T_{1000}	104	Running
T_{2000}	103	Committed

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A “abc” -> “def”	Update	-
102	-	T_{2000}	P600	Write B “hij” -> “klm”	Update	-
103	102	T_{2000}	P500	Write D “mnp” -> “qrs”	Update	-
104	101	T_{1000}	P505	Write C “tuv” -> “wxy”	Update	-
105	103	T_{2000}			Commit	
106	105	T_{2000}			End	

Buffer Pool

PageLSN= 103

A = def   D = qrs

PageLSN= 102

B = klm

P505
PageLSN= 104

C = wxy

P700
PageLSN= -

E = pq

Disk

Log written to disk
Note: no force = not the dirty pages changed by T_{2000}!

A = abc   D = mnp

B = hij

P505
PageLSN= -

C = tuv

P700
PageLSN= -

E = pq

Whenever a transaction commits,
log is flushed to the disk == the log-tail is written to disk

NOTE:
1. The “Commit” record is <u>required</u> to be flushed (i.e. all logs up to and including that commit record)
2. The “End” record is <u>not required</u> to be flushed, in this case we are only assuming that it has been flushed as well (so that we have a good example while doing recovery ☺️)

Next:

6. T_{1000} changes the value of E from “pq” to “rs” on page P700

Dirty page table

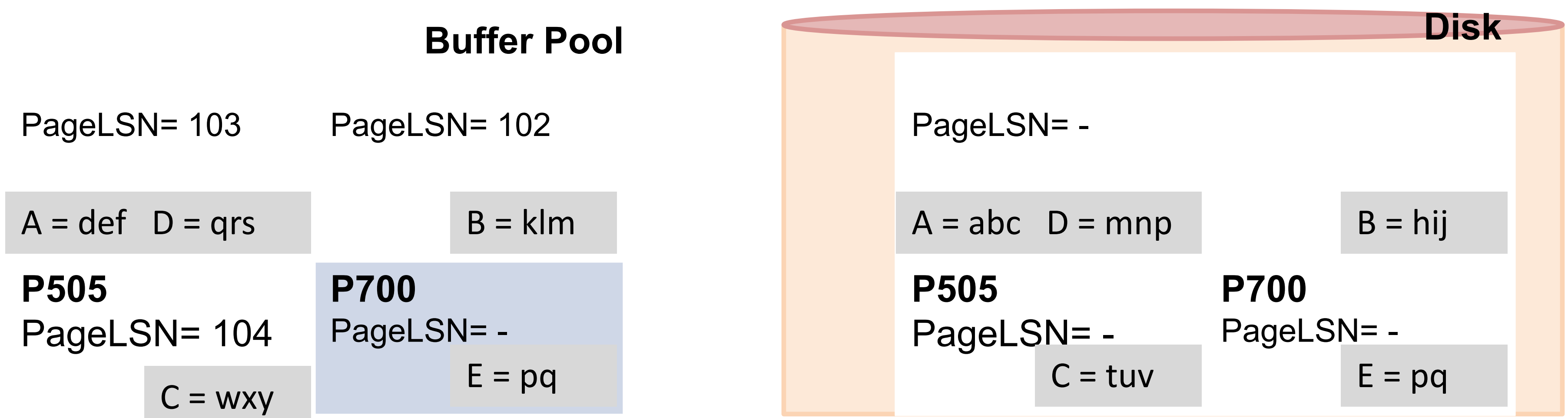
pageID	recLSN
P500	101
P600	102
P505	104

Transaction table

transID	lastLSN	status
T_{1000}	104	Running

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A “abc” -> “def”	Update	-
102	-	T_{2000}	P600	Write B “hij” -> “klm”	Update	-
103	102	T_{2000}	P500	Write D “mnp” -> “qrs”	Update	-
104	101	T_{1000}	P505	Write C “tuv” -> “wxy”	Update	-
105	103	T_{2000}			Commit	
106	105	T_{2000}			End	



Changes:

6. T_{1000} changes the value of E from “pq” to “rs” on page P700

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A “abc” -> “def”	Update	-
102	-	T_{2000}	P600	Write B “hij” -> “klm”	Update	-
103	102	T_{2000}	P500	Write D “mnp” -> “qrs”	Update	-
104	101	T_{1000}	P505	Write C “tuv” -> “wxy”	Update	-
105	103	T_{2000}			Commit	
106	105	T_{2000}			End	
107	104	T_{1000}	P700	Write E “pq” -> “rs”	Update	-

Dirty page table

pageID	recLSN
P500	101
P600	102
P505	104
P700	**107**

Transaction table

transID	lastLSN	status
T_{1000}	**107**	**Running**

Buffer Pool

PageLSN= 103

A = def D = qrs

PageLSN= 102

B = klm

P505

PageLSN= 104

C = wxy

P700

PageLSN= 107

E = rs

Disk

PageLSN= -

A = abc D = mnp

B = hij

P505

PageLSN= -

C = tuv

P700

PageLSN= -

E = pq

Next:

7. Page P600 is flushed to disk

Dirty page table

pageID	recLSN
P500	101
P600	102
P505	104
P700	107

Transaction table

transID	lastLSN	status
T_{1000}	107	Running

Log

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A “abc” -> “def”	Update	-
102	-	T_{2000}	P600	Write B “hij” -> “klm”	Update	-
103	102	T_{2000}	P500	Write D “mnp” -> “qrs”	Update	-
104	101	T_{1000}	P505	Write C “tuv” -> “wxy”	Update	-
105	103	T_{2000}			Commit	
106	105	T_{2000}			End	
107	104	T_{1000}	P700	Write E “pq” -> “rs”	Update	-

Buffer Pool

PageLSN= 103
A = def D = qrs

PageLSN= 102
B = klm

P505
PageLSN= 104
C = wxy

P700
PageLSN= 107
E = rs

Disk

PageLSN= -
A = abc D = mnp

B = hij

P505
PageLSN= -
C = tuv

P700
PageLSN= -
E = pq

Next:

7. Page P600 is flushed to disk – Step 1

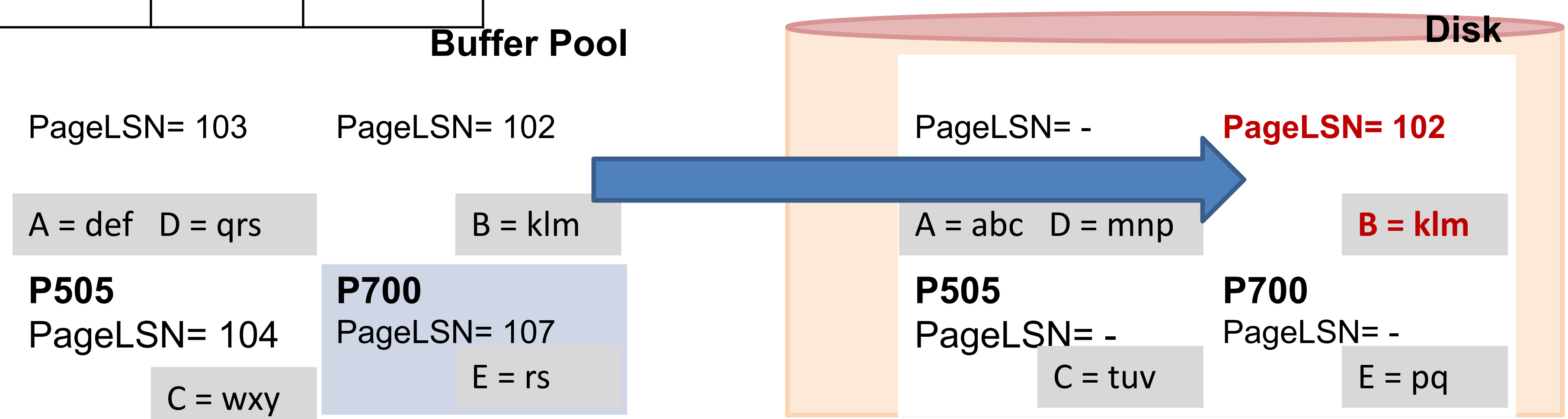
Dirty page table

pageID	recLSN
P500	101
~~P600~~	~~102~~
P505	104
P700	107

Transaction table

transID	lastLSN	status
T_{1000}	107	Running

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A "abc" -> "def"	Update	-
102	-	T_{2000}	P600	Write B "hij" -> "klm"	Update	-
103	102	T_{2000}	P500	Write D "mnp" -> "qrs"	Update	-
104	101	T_{1000}	P505	Write C "tuv" -> "wxy"	Update	-
105	103	T_{2000}			Commit	
106	105	T_{2000}			End	
107	104	T_{1000}	P700	Write E "pq" -> "rs"	Update	-



Next:

7. Page P600 is flushed to disk – Step 2

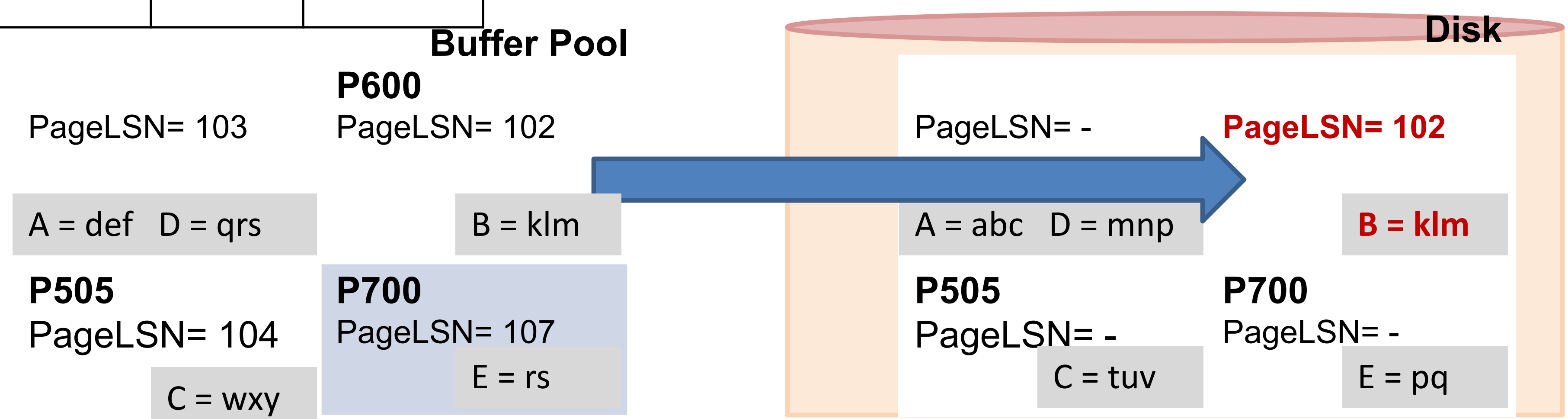
Dirty page table

pageID	recLSN
P500	101
P505	104
P700	107

Transaction table

transID	lastLSN	status
T_{1000}	107	Running

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A “abc” -> “def”	Update	-
102	-	T_{2000}	P600	Write B “hij” -> “klm”	Update	-
103	102	T_{2000}	P500	Write D “mnp” -> “qrs”	Update	-
104	101	T_{1000}	P505	Write C “tuv” -> “wxy”	Update	-
105	103	T_{2000}			Commit	
106	105	T_{2000}			End	
107	104	T_{1000}	P700	Write E “pq” -> “rs”	Update	-



8. CRASH!!

8. Crash!! ---- These are gone from memory

LSN	prevLSN	tID	pID	Log entry	Type	undoNextLSN
101	-	T1000	P500	Write A "abc" -> "def"	Update	-
102	-	T_{2000}	P600	Write B "hij" -> "klm"	Update	-
103	102	T_{2000}	P500	Write D "mnp" -> "qrs"	Update	-
104	101	T_{1000}	P505	Write C "tuv" -> "wxy"	Update	-
105	103	T_{2000}			Commit	
106	105	T_{2000}			End	
107						

Dirty pa ble

P700	

Transaction table

transID	lastLSN	status
		ig

Buffer Pool

PageLSN= 103

A = def

P505

PageLSN

C = wxy

N= 107

E = rs

Disk

PageLSN= -

A = abc D = mnp

B = klm

P505

PageLSN= -

C = tuv

P700

PageLSN= -

E = pq