Transaction Processing: Recovery

CPS 216

Advanced Database Systems

Review

- ACID
  - Atomicity → Recovery
  - Consistency
  - Isolation → Concurrency control
  - Durability → Recovery

2

Execution model

- input(*X*): copy the disk block containing object *X* to memory
- read(*X*, *v*): read the value of *X* into a local variable *v* (execute input(*X*) first if necessary)
- write(*X*, *v*): write value *v* to *X* in memory (execute input(*X*) first if necessary)
- output(*X*): write the memory block containing X to disk

Issued by transactions

Issued by DBMS

3

Failures

- System crashes in the middle of a transaction *T*; partial effects of *T* were written to disk
  - How do we undo *T* (atomicity)?
- System crashes right after a transaction *T* commits; not all effects of *T* were written to disk
  - How do we complete *T* (durability)?
- Media fails; data on disk corrupted
  - How do we reconstruct the database (durability)?

4

Logging

- Log
  - Sequence of log records, recording all changes made to the database
  - Written to stable storage (e.g., disk) during normal operation
  - Used in recovery
- Hey, one change turns into two!
  - Isn't it bad for performance?
  - But writes are sequential (append to the end of log)
  - Can use dedicated disk(s) to improve performance

5

Undo logging

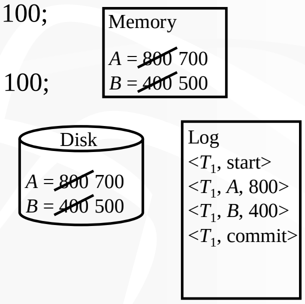
- Basic idea
  - Every time you modify something on disk, record its old value in the log
  - If system crashes, undo the writes of partially executed transactions by restoring the old values

6

Undo logging example

T_1 (balance transfer of \$100 from A to B)

read(A, a); $a = a - 100$;
write(A, a);
read(B, b); $b = b + 100$;
write(B, b);
output(A);
output(B);



7

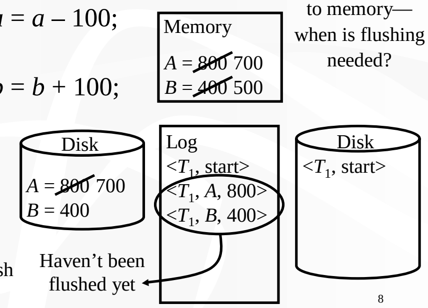
One technicality

T_1 (balance transfer of \$100 from A to B)

Log is first written to memory—when is flushing needed?

read(A, a); $a = a - 100$;
write(A, a);
read(B, b); $b = b + 100$;
write(B, b);
output(A);
output(B);

System crash



8

WAL

- Recap of the situation to be avoided
  - T_1 has not completed yet
  - A is modified on disk already
  - But there is no log record for A
  - Cannot undo the modification of A!
- Solution: WAL (Write-Ahead Logging)
  - Before any database object X is modified on disk, the log record pertaining to X must be flushed

9

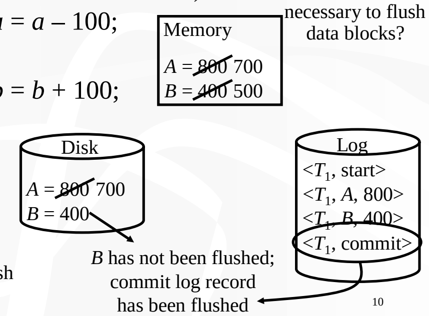
Another technicality

T_1 (balance transfer of \$100 from A to B)

When is it necessary to flush data blocks?

read(A, a); $a = a - 100$;
write(A, a);
read(B, b); $b = b + 100$;
write(B, b);
output(A);
output(B);

System crash



10

Force

- Recap of the situation to be avoided
  - T_1 has committed (the log says so)
  - Not all effects of T_1 have been flushed disk
  - Because there is no redo information in the log, we cannot redo the rest of T_1
    - So perhaps we should try redo logging?
- Solution: force
  - Before the commit record of a transaction is flushed to log, all writes of this transaction must be reflected on disk

11

Undo logging rules

- For every write, generate undo log record containing the old value being overwritten
  <T_i, X, *old_value_of_X*>
  - Typically (assuming physical logging)
    - T_i: transaction id
    - X: physical address of X (block id, offset)
    - *old_value_of_X*: bits
- WAL
- Force

12

Recovery with an undo log

- Identify U, the set of active transactions at time of crash
  - Log contains <T, start>, but neither <T, commit> nor <T, abort>
- Process log backward Why?
  - For each <T, X, *old_value*> where T is in U, issue write(X, *old_value*), output(X) Why?
- For each T in U, append <T, abort> to the end of the log

13

Additional issues with undo logging

- Failure during recovery?
  - No problem, run recovery procedure again
  - Undo is idempotent!
- Can you truncate log?
  - Yes, after a successful recovery
  - Or, truncate any prefix that contain no log records for active transactions

14

Redo logging

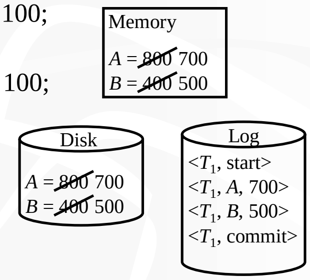
- Basic idea
  - Every time you modify something on disk, record its new value (which you are writing)
  - If system crashes, redo the writes of committed transactions and ignore those that did not commit

15

Redo logging example

T_1 (balance transfer of $100 from A to B)

read(A, a); $a = a - 100$;
write(A, a);
read(B, b); $b = b + 100$;
write(B, b);
output(A);
output(B);



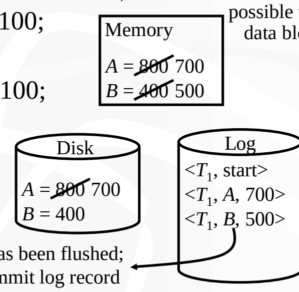
16

One technicality

T_1 (balance transfer of $100 from A to B)

When is it possible to flush data blocks?

read(A, a); $a = a - 100$;
write(A, a);
read(B, b); $b = b + 100$;
write(B, b);
output(A);
output(B);



System crash

A has been flushed; commit log record has not been written yet

17

No steal

- Recap of the situation to be avoided
  - T_1 has not completed yet
  - A is modified on disk already
  - There is a log record for A (i.e., WAL is followed)
  - Because there is no undo information in that log record, we cannot undo the modification of A!
    - Maybe undo/redo combined?
- Solution: no steal
  - Writes can be flushed only at commit time
  - Requires keeping all dirty blocks in memory—other transactions cannot steal any memory blocks

18

Redo logging rules

- For every write, generate redo log record containing the new value being written
  - <T_i, *X*, *new_value_of_X*>
- Do not modify any database objects on disk before you have flushed all log records for this transaction (including the commit record)
  - – That is, WAL and no steal

19

Recovery with a redo log

- Identify *C*, the set of all committed transactions (those with commit log record)
- Process log forward Why?
  - – For each <*T*, *X*, *new_value*> where *T* is in *C*, issue write(*X*, *new_value*) Why is output(*X*) unnecessary here?
- For each incomplete transaction *T* (with neither commit nor abort log record), append <*T*, abort> to the end of the log

20

Additional issues with redo logging

- Failure during recovery?
  - – No problem—redo is idempotent!
- Extremely slow recovery process!
  - – I transferred the balance last year…
- Can you truncate log?
  - – No, unless…

21

Checkpointing

- Naïve approach:
  - – Stop accepting new transactions (lame!)
  - – Finish all active transactions
  - – Take a database dump
  - – Now safe to truncate the redo log

➢ Fuzzy checkpointing
  - – Example later

22

Summary of redo and undo logging

- Undo logging—immediate write
  - – Force
    - Excessive disk I/Os
    - Imagine many small transactions updating the same block!
- Redo logging—deferred write
  - – No steal
    - High memory requirement
    - Imagine a big transaction updating many blocks

23

Logging taxonomy

Assuming each transaction modifies just one block and locking is at the block level

	no steal	steal
force	no logging!	undo logging
no force	redo logging	undo/redo logging

Next!

24

Undo/redo logging

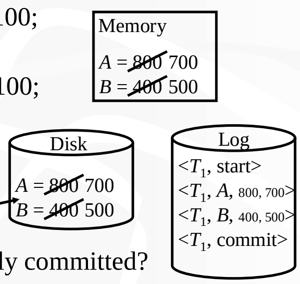
- Log both old and new values
  <T_i, *X*, *old_value_of_X*, *new_value_of_X*>
- WAL
- Steal: If chosen for replacement, modified memory blocks can be flushed to disk anytime
- No-force: When a transaction commits, modified memory blocks are not forced to disk

➢ Buffer manager has complete freedom!

Undo/redo logging example

T_1 (balance transfer of \$100 from *A* to *B*)

read(*A*, *a*); *a* = *a* – 100;
write(*A*, *a*);
read(*B*, *b*); *b* = *b* + 100;
write(*B*, *b*);



No output operations here—they are up to the buffer manager!

Anytime after corresponding log records are flushed

- So when is T_1 really committed?
  – When its commit log record is flushed to disk

Fuzzy checkpointing

- Determine *S*, the set of currently active transactions, and log <begin-checkpoint *S*>
- Flush all modified memory blocks at your leisure
  – Regardless whether they are written by committed or uncommitted transactions (but do follow WAL)
- Log <end-checkpoint *begin-checkpoint_location*>
- Between begin and end, continue processing old and new transactions

Recovery: analysis and redo phase

- Need to determine *U*, the set of active transactions at time of crash
- Scan log backward to find the last end-checkpoint record and follow the pointer to find the corresponding <start-checkpoint *S*>
- Initially, let *U* be *S*
- Scan forward from that start-checkpoint to end of the log
  – For a log record <*T*, start>, add *T* to *U*
  – For a log record <*T*, commit | abort>, remove *T* from *U*
  – For a log record <*T*, *X*, *old*, *new*>, issue write(*X*, *new*)
  – Repeats history!

Recovery: undo phase

- Scan log backward
  – Undo the effects of transactions in *U*
  – That is, for each log record <*T*, *X*, *old*, *new*> where *T* is in *U*, issue write(*X*, *old*), and log this operation too (part of the repeating-history paradigm)
  – Log <*T*, abort> when all effects of *T* have been undone
- An optimization
  – Each log record stores a pointer to the previous log record for the same transaction; follow the pointer chain during undo
- Is it possible that undo overwrites the effect of a committed transaction?
  – Not if strict 2PL!

Physical versus logical logging

- Physical logging (what we have assumed so far)
  – Log before and after images of data
- Logical logging
  – Log operations (e.g., insert a row into a table)
  – Smaller log records
    - An insertion could cause rearrangement of things on disk
    - Or trigger hundreds of other events
  – Sometimes necessary
    - Assume row-level rather than page(block)-level locking
    - Data might have moved to another block at time of undo!
  – Much harder to make redo/undo idempotent

Selective redo?

- Possible optimization for our recovery procedure:
  - Selectively redo only committed transactions
  - Lots of algorithms do it (some even undo before redo)
- What is the catch?
  - $T_1.op_1$, $T_2.op_1$, $T_1.op_2$ (T_1.commit)
  - Repeating history: $T_1.op_1$, $T_2.op_1$, $T_1.op_2$, undo($T_2.op_1$)
    - Exactly the same as normal transaction abort
  - Selective redo: $T_1.op_1$, $T_1.op_2$, undo($T_2.op_1$)
    - What if $T_2.op_1$ produced some side effects that $T_1.op_2$ relies on?
    - Not possible with page-level locking and physical logging
    - In general hard to guarantee

31

ARIES

- Same basic ideas: steal, no force, WAL
- Three phases: analysis, redo, undo
  - Repeats history
- CLR (Compensation Log Record) for transaction aborts
- More efficient than our simple algorithm
  - Redo/undo on an object is only performed when necessary
    - Each disk block records the last writer
  - Can take advantage of a partial checkpoint
    - Recovery can start from any start-checkpoint, not necessarily one that corresponds to an end-checkpoint

32