Transaction Processing: Recovery

CPS 216

Advanced Database Systems

Announcements

- Homework #4 due in 7 days (April 23)
- Recitation session this Friday (April 18)
  - Homework #4 Q&A
- Project demo period starting in 12 days (April 28)
  - Sign-up sheet will be available next Monday
- Final exam in 17 days (May 1, 2-5pm)
  - More details will be available next Monday

Review

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

Execution model

- Before it can be operated upon, disk-resident data must first be brought into memory
  - input(X): copy the disk block containing object X to memory
  - v = read(X): 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

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)?

Naïve approach

- Force: When a transaction commits, all writes of this transaction must be reflected on disk
  - Without force, if system crashes right after T commits, effects of T will be lost
  - ☞Problem: Lots of random writes hurt performance
- No steal: Writes of a transaction can only be flushed to disk at commit time
  - With steal, if system crashes before T commits but after some writes of T have been flushed to disk, there is no way to undo these writes
  - ☞Problem: Holding on to all dirty blocks requires lots of memory

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
- One change turns into two—bad for performance?
  - But writes are sequential (append to the end of log)
  - Can use dedicated disk(s) to improve performance

Undo logging

Basic idea

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

No steal?

- Not needed because we can undo; can flush dirty blocks before commit

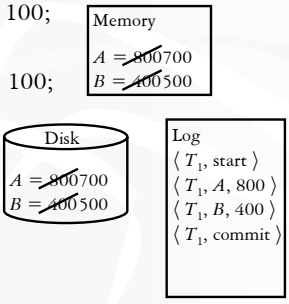
Force?

- Still needed; otherwise effects of committed transactions can be lost after crash

Undo logging example

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

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

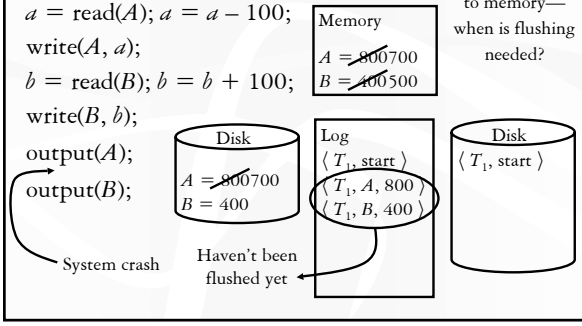


One technicality

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

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

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



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

Undo logging: normal operations

- For every write, generate an 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
- Also log ⟨ T_i, start ⟩, ⟨ T_i, commit ⟩, ⟨ T_i, abort ⟩
- WAL
- Force: before the commit log record of T_i is flushed, all writes of T_i must be reflected on disk

Undo logging: recovery

- Identify U, the set of active transactions at time of crash
  - Log contains $\langle T, \text{start} \rangle$, but neither $\langle T, \text{commit} \rangle$ nor $\langle T, \text{abort} \rangle$
- Process log backward (why?)
  - For each $\langle T, X, \textit{old\_value} \rangle$ where T is in U, issue write(X, *old_value*), output(X) (why flush?)
- For each T in U, append $\langle T, \text{abort} \rangle$ to the end of the log (why?)

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

Redo logging

Basic idea

- Every time something is modified on disk, record its new value in the log
- If system crashes, redo the writes of committed transactions and ignore those that did not commit

Force?

- Not needed because we can redo; commit does not trigger writing of dirty blocks

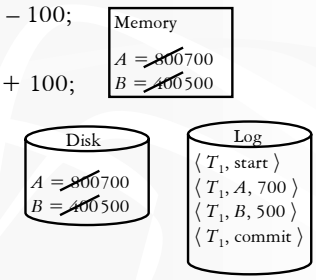
No steal?

- Still needed; otherwise there is no way to roll back changes made by incomplete transactions

Redo logging example

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

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



Redo logging: normal operations

- For every write, generate a redo log record containing the new value being written
  $\langle T_i, X, \textit{new\_value\_of\_X} \rangle$
- Also log $\langle T_i, \text{start} \rangle$, $\langle T_i, \text{commit} \rangle$, $\langle T_i, \text{abort} \rangle$
- WAL
- No steal
  - Before the commit log record of T_i is flushed, no writes of T_i can be flushed to disk
  - Requires keeping all dirty blocks in memory before commit

Redo logging: recovery

- Identify C, the set of all committed transactions (those with commit log records in log)
- Process log forward
  - For each $\langle T, X, \textit{new\_value} \rangle$ where T is in C, issue write(X, *new_value*) (output(X) is optional; why?)
- For each incomplete transaction T (with neither commit nor abort log record), append $\langle T, \text{abort} \rangle$ to the end of the log

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 …

Checkpointing

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

☞ Alternative: fuzzy checkpointing (more later)

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

Logging taxonomy

	No steal	Steal
Force	No logging	Undo logging
No force	Redo logging	Undo/redo logging

Next!

Undo/redo logging: normal operations

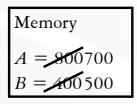
- Log both old and new values
  $\langle T_i, X, \textit{old\_value\_of\_}X, \textit{new\_value\_of\_}X \rangle$
- Also log $\langle T_i, \text{start} \rangle$, $\langle T_i, \text{commit} \rangle$, $\langle T_i, \text{abort} \rangle$
- WAL
- Steal: If chosen for replacement, modified memory blocks can be flushed to disk anytime
- No force: When a transaction commits, modified memory blocks are not forced to disk

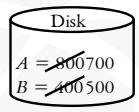
☞ Buffer manager has complete freedom!

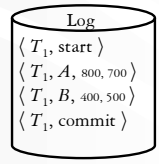
Undo/redo logging example

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

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







Steal: can flush before commit

No force: can flush after commit

No restriction on when memory blocks can/should be flushed

Fuzzy checkpointing

- Determine *S*, the set of currently active transactions, and log ⟨ begin-checkpoint *S* ⟩
- Write to disk all memory blocks currently dirty
  - Regardless whether they are written by committed or uncommitted transactions (but do follow WAL)
  - Blocks that become dirty after begin-checkpoint do not need to be flushed
- Log ⟨ end-checkpoint ⟩
- Between begin and end, continue processing old and new transactions

Undo/redo logging: recovery

- Scan log from the last ⟨ start-checkpoint *S* ⟩ with a matching ⟨ end-checkpoint ⟩ to find
  - *C*, the set of committed transactions since last checkpoint
  - *A*, the set of active transactions at the time of crash
  - ☞*C* and *A* may contain transactions that started after checkpoint
- Scan forward from that start-checkpoint to end of the log, and redo transactions in *C*
  - No need to look before start-checkpoint for redo (why?)
- Scan the log backward to undo transactions in *A*
  - May scan past start-checkpoint (why?)
  - Optimization: each log record stores a pointer to the previous log record for the same transaction; follow the pointer during undo
- Append ⟨ *T*, abort ⟩ to the log for each *T* in *A*

Physical vs. 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
  - ☞See solution offered by ARIES

ARIES

"ARIES: A Transaction Recovery Method Supporting Fine-Granularity Locking and Partial Rollbacks Using Write-Ahead Logging," by Mohan et al. *TODS* 1992

- Same basic ideas: steal, no force, WAL
- Three phases: analysis, redo, undo
  - Repeats history (redo even incomplete transactions)
- Better than our simple algorithm
  - CLR (Compensation Log Record) for transaction aborts
  - Redo/undo on an object is only performed when necessary → idempotency requirement lifted → logical logging supported
    - Each disk block records the LSN (log sequence number) of the last change
  - Can take advantage of a partial checkpoint
    - Recovery can start from any start-checkpoint, not necessarily one that corresponds to an end-checkpoint