Transaction Processing: Recovery

CPS 216

Advanced Database Systems

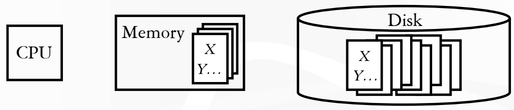
Announcements (April 28)

- Homework #4 due today
  - Sample solution will be emailed to you by tomorrow morning
- Project demo period: April 28 – May 1
  - Remember to email me to sign up for a 30-minute slot
- Final exam on Monday, May 2, 2-5pm
  - 3 hours—no time pressure!
  - Open book, open notes
  - Comprehensive, but with emphasis on the second half of the course and materials exercised in homework
- Solution to sample final available

Review

- ACID
  - Atomicity → Recovery
  - 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:
- ❖ 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:

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

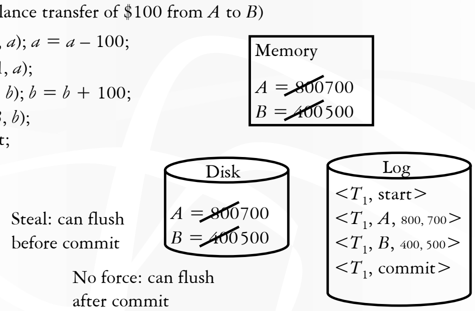
Undo/redo logging rules

- Record values before and after each modification: $\langle T_i, X, old\_value\_of\_X, new\_value\_of\_X \rangle$
- A transaction T_i is committed when its commit log record $\langle T_i, \text{commit} \rangle$ is written to disk
- Write-ahead logging (WAL): Before X is modified on disk, the log record pertaining to X must be flushed
  - Without WAL, system might crash after X is modified on disk but before its log record is written to disk—no way to undo
- No force: A transaction can commit even if its modified memory blocks have not be written to disk (since redo information is logged)
- Steal: Modified memory blocks can be flushed to disk anytime (since undo information is logged)

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);
commit;



No restriction on when memory blocks can/should be flushed

Checkpointing

- Naïve approach:
  - Stop accepting new transactions (lame!)
  - Finish all active transactions
  - Take a database dump
  - Now safe to truncate the log
- Fuzzy checkpointing
  - Determine S, the set of currently active transactions, and log ⟨ begin-checkpoint S ⟩
  - Flush all modified memory blocks at your leisure
  - 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*)
  - ☞ Basically 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

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

Summary

- Concurrency control
  - Serial schedule: no interleaving
  - Conflict-serializable schedule: no cycles in the precedence graph; equivalent to a serial schedule
  - 2PL: guarantees a conflict-serializable schedule
  - Strict 2PL: also guarantees recoverability
- Recovery: undo/redo logging with fuzzy checkpointing
  - Normal operation: write-ahead logging, no force, steal
  - Recovery: first redo (forward), and then undo (backword)

Review: XML

- Data model: tree or graph (with ID/IDREF)
  - DTD (schema) is optional
- Query languages: XPath (building blocks for other languages: path expressions), XQuery (SQL-like), XSLT (structural recursion)
- XML-relational mapping: schema-oblivious (nodes/edges; intervals; label-paths; Dewey order) vs. schema-aware
- XML query processing: navigational (equality joins) vs. structural (containment joins)

  → Path expression processing boils down to joins!
- XML indexing: nodes/edges; intervals; paths; sequences; structural

Review: query optimization or "goodification"?

- Heuristics: push selections down; smaller joins first

  → Reduce the size of intermediate results
- Cost-based
  - Query rewrite: merge blocks to get a bigger search space
  - Cost estimation: use statistics (e.g., histograms)
  - Search algorithm: dynamic programming (+ interesting orders), randomized search, genetic programming, etc.

Review: transaction processing

- ACID properties
- Concurrency control
  - Locking-based: strict 2PL; handling deadlocks; multiple-granularity locking; index and predicate locking
  - Validation-based, timestamp-based, multi-version

  → Trade-off: blocking versus aborts and restarts
- Recovery
  - Steal: requires undo logging
  - No force: requires redo logging
  - WAL (log holds the truth)