Transaction Processing

Introduction to Databases
CompSci 316 Fall 2015
Announcements (Tue., Nov. 24)

• Homework #4 due next Tuesday
• Project demos coming up—please sign up!
  • Early in-class demos on 12/3
• Final exam Wed. Dec. 9 7-10pm
  • Open-book, open-notes
  • Comprehensive, but with strong emphasis on the second half of the course
Review

• ACID
  • Atomicity: TX’s are either completely done or not done at all
  • Consistency: TX’s should leave the database in a consistent state
  • Isolation: TX’s must behave as if they are executed in isolation
  • Durability: Effects of committed TX’s are resilient against failures

• SQL transactions
  -- Begins implicitly
  SELECT ...;
  UPDATE ...;
  ROLLBACK  |  COMMIT;
Concurrency control

• Goal: ensure the “I” (isolation) in ACID

\[ T_1: \]
read(A);
write(A);
read(B);
write(B);
commit;

\[ T_2: \]
read(A);
write(A);
read(C);
write(C);
commit;

Diagram:

- A
- B
- C

Transactions proceed in parallel.
Good versus bad schedules

<table>
<thead>
<tr>
<th></th>
<th>Good!</th>
<th>Bad!</th>
<th>Good! (But why?)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_1$</td>
<td>$T_2$</td>
<td>$T_1$</td>
</tr>
<tr>
<td>r(A)</td>
<td></td>
<td></td>
<td>r(A)</td>
</tr>
<tr>
<td>w(A)</td>
<td></td>
<td></td>
<td>w(A)</td>
</tr>
<tr>
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<td></td>
<td></td>
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</tr>
<tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td>r(C)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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Read 400
Write 400 – 100
Read 400
Write 400 – 50
Serial schedule

- Execute transactions in order, with no interleaving of operations
  - $T_1.r(A), T_1.w(A), T_1.r(B), T_1.w(B), T_2.r(A), T_2.w(A), T_2.r(C), T_2.w(C)$
  - $T_2.r(A), T_2.w(A), T_2.r(C), T_2.w(C), T_1.r(A), T_1.w(A), T_1.r(B), T_1.w(B)$

  Isolation achieved by definition!

- Problem: no concurrency at all

- Question: how to reorder operations to allow more concurrency
Conflicting operations

• Two operations on the *same* data item **conflict** if at least one of the operations is a write
  • r(X) and w(X) conflict
  • w(X) and r(X) conflict
  • w(X) and w(X) conflict
  • r(X) and r(X) do not conflict
  • r/w(X) and r/w(Y) do not conflict

• Order of conflicting operations matters
  • E.g., if $T_1.r(A)$ precedes $T_2.w(A)$, then conceptually, $T_1$ should precede $T_2$
Precedence graph

- A **node** for each transaction
- A **directed edge** from $T_i$ to $T_j$ if an operation of $T_i$ precedes and conflicts with an operation of $T_j$ in the schedule

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**Good:** no cycle

**Bad:** cycle
Conflict-serializable schedule

• A schedule is conflict-serializable iff its precedence graph has no cycles

• A conflict-serializable schedule is equivalent to some serial schedule (and therefore is “good”)
  • In that serial schedule, transactions are executed in the topological order of the precedence graph
  • You can get to that serial schedule by repeatedly swapping adjacent, non-conflicting operations from different transactions
Locking

• Rules
  • If a transaction wants to read an object, it must first request a shared lock (S mode) on that object
  • If a transaction wants to modify an object, it must first request an exclusive lock (X mode) on that object
  • Allow one exclusive lock, or multiple shared locks

<table>
<thead>
<tr>
<th>Mode of lock(s) currently held by other transactions</th>
<th>Mode of the lock requested</th>
<th>Grant the lock?</th>
</tr>
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<tbody>
<tr>
<td>S</td>
<td>S</td>
<td>Yes</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>No</td>
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Compatibility matrix
Basic locking is not enough

Add 1 to both A and B (preserve A=B)
Read 100
Write 100+1
unlock(A)

Possible schedule under locking

But still not conflict-serializable!

lock-X(A)
lock-X(B)

Possible schedule under locking

Multiply both A and B by 2 (preserves A=B)
Read 101
Write 101*2
unlock(A)

lock-X(A)
lock-X(B)

Read 100
Write 100*2
unlock(B)

A ≠ B!
Two-phase locking (2PL)

- All lock requests precede all unlock requests
  - Phase 1: obtain locks, phase 2: release locks

\[
\begin{align*}
T_1 & \quad T_2 \\
\text{lock-X}(A) & \quad \text{lock-X}(A) \\
r(A) & \quad r(A) \\
w(A) & \quad w(A) \\
\text{lock-X}(B) & \\
\text{unlock}(A) & \\
\text{unlock}(B) & \\
r(B) & \\
w(B) & \\
\end{align*}
\]

2PL guarantees a conflict-serializable schedule

\[
\begin{align*}
T_1 & \quad T_2 \\
r(A) & \quad r(A) \\
w(A) & \quad w(A) \\
r(B) & \\
w(B) & \\
\end{align*}
\]

Cannot obtain the lock on B until \( T_1 \) unlocks
Problem of 2PL

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- $T_2$ has read uncommitted data written by $T_1$
- If $T_1$ aborts, then $T_2$ must abort as well
- **Cascading aborts** possible if other transactions have read data written by $T_2$

- Even worse, what if $T_2$ commits before $T_1$?
  - Schedule is **not recoverable** if the system crashes right after $T_2$ commits
Strict 2PL

• Only release locks at commit/abort time
  • A writer will block all other readers until the writer commits or aborts

• Used in many commercial DBMS
  • Oracle is a notable exception
Recovery

• Goal: ensure “A” (atomicity) and “D” (durability)
Execution model

To read/write X

• The disk block containing X must be first brought into memory
• X is read/written in memory
• The memory block containing X, if modified, must be written back (flushed) to disk eventually
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)?
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: 
  \( \langle T_i, X, old\_value\_of\_X, new\_value\_of\_X \rangle \)
  - \( T_i \) is transaction id and \( X \) identifies the data item
- A transaction \( T_i \) is committed when its commit log record 
  \( \langle T_i, commit \rangle \) 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;

Steal: can flush before commit
No force: can flush after commit
No restriction (except WAL) on when memory blocks can/should be flushed
Checkpointing

• Where does recovery start?

Naïve approach:

• To checkpoint:
  • Stop accepting new transactions *(lame!)*
  • Finish all active transactions
  • Take a database dump

• To recover:
  • Start from last checkpoint
Fuzzy checkpointing

• Determine $S$, the set of (ids of) currently active transactions, and log $\langle$ begin-checkpoint $S$ $\rangle$

• Flush all blocks (dirty at the time of the checkpoint) at your leisure

• Log $\langle$ end-checkpoint begin-checkpoint_location $\rangle$

• 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 $\langle$ start-checkpoint $S \rangle$

• Initially, let $U$ be $S$

• Scan forward from that start-checkpoint to end of the log
  • For a log record $\langle T, \text{start} \rangle$, add $T$ to $U$
  • For a log record $\langle T, \text{commit} \mid \text{abort} \rangle$, remove $T$ from $U$
  • For a log record $\langle T, X, \text{old}, \text{new} \rangle$, issue write($X$, new)

$\triangleright$ Basically repeats history!
Recovery: undo phase

• Scan log **backward**
  • Undo the effects of transactions in $U$
  • That is, for each log record $\langle T, X, \text{old}, \text{new} \rangle$ where $T$ is in $U$, issue write($X$, old), and log this operation too (part of the “repeating-history” paradigm)
  • Log $\langle T, \text{abort} \rangle$ 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
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 (backward)