CS 5614: (Big) Data Management Systems

B. Aditya Prakash

Lecture #8: Transactions 2: 2PL and Deadlocks
Review (last lecture)

- DBMSs support ACID Transaction semantics.
- Concurrency control and Crash Recovery are key components.
Review

- For Isolation property, serial execution of transactions is safe but slow
  - Try to find schedules equivalent to serial execution
- One solution for “conflict serializable” schedules is Two Phase Locking (2PL)
Outline

- 2PL/2PLC
- Lock Management
- Deadlocks
  - detection
  - Prevention
- Specialized Locking
Serializability in Practice

- DBMS does not test for conflict serializability of a given schedule
  - Impractical as interleaving of operations from concurrent Xacts could be dictated by the OS

- Approach:
  - Use specific protocols that are known to produce conflict serializable schedules
  - But may reduce concurrency
Solution?

- One solution for “conflict serializable” schedules is Two Phase Locking (2PL)
Answer

- (Full answer:) use locks; keep them until commit (‘strict 2 phase locking’)
- Let’s see the details
## Lost update problem - no locks

<table>
<thead>
<tr>
<th>T1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read(N)</td>
<td>Read(N)</td>
</tr>
<tr>
<td>N = N - 1</td>
<td>N = N - 1</td>
</tr>
<tr>
<td>Write(N)</td>
<td>Write(N)</td>
</tr>
</tbody>
</table>
Solution – part 1

- with locks:
- lock manager: grants/denies lock requests
Lost update problem – with locks

T1

lock(N)

Read(N)

N=N-1

Write(N)

Unlock(N)

time

T2

lock manager

grants lock

lock(N)

denies lock

T2: waits

grants lock to T2

Read(N) ...
Locks

- Q: I just need to read ‘N’ - should I still get a lock?
Solution – part 1

- Locks and their flavors
  - exclusive (or write-) locks
  - shared (or read-) locks
  - <and more ... >
- compatibility matrix

<table>
<thead>
<tr>
<th>T2 wants</th>
<th>S</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 has</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Solution – part 1

- Locks and their flavors
  - exclusive (or write-) locks
  - shared (or read-) locks
  - <and more ... >

- compatibility matrix

<table>
<thead>
<tr>
<th>T2 wants</th>
<th>S</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 has</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Solution – part 1

- transactions request locks (or upgrades)
- lock manager grants or blocks requests
- transactions release locks
- lock manager updates lock-table
locks are not enough – eg., the ‘inconsistent analysis’ problem
‘Inconsistent analysis’

T1
Read(A)
A = A - 10
Write(A)

Read(B)
B = B + 10
Write(B)

T2
Read(A)
Sum = A
Read(B)
Sum += B
‘Inconsistent analysis’ – w/ locks

<table>
<thead>
<tr>
<th>time</th>
<th>T1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L(A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Read(A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>...</td>
<td></td>
</tr>
<tr>
<td></td>
<td>U(A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L(A)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>....</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L(B)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>....</td>
</tr>
</tbody>
</table>

the problem remains!

T2 reads an inconsistent DB state

Solution??
General solution:

- Protocol(s)
- Most popular protocol: 2 Phase Locking (2PL)
2PL

X-lock version: transactions issue no lock requests, after the first ‘unlock’

THEOREM: if **ALL** transactions in the system obey 2PL --> all schedules are serializable
2PL – example

- ‘inconsistent analysis’ – how does 2PL help?
- how would it be under 2PL?
2PL – X/S lock version

transactions issue no lock/upgrade request, after the first unlock/downgrade

In general: ‘growing’ and ‘shrinking’ phase
2PL – X/S lock version

transactions issue no lock/upgrade request, after the first unlock/downgrade

In general: ‘growing’ and ‘shrinking’ phase

# locks

violation of 2PL

time
Two-Phase Locking (2PL), cont.

- 2PL on its own is sufficient to guarantee conflict serializability (i.e., schedules whose precedence graph is acyclic), but, it is subject to Cascading Aborts.
2PL

- Problem: Cascading Aborts
- Example: rollback of T1 requires rollback of T2!

| T1: R(A), W(A), R(B), W(B), Abort |
| T2: R(A), W(A) |

- Solution: Strict 2PL, i.e,
- keep all locks, until ‘commit’
Strict 2PL

- Allows only conflict serializable schedules, but it is actually stronger than needed for that purpose.

# locks held

acquisition phase

release all locks at end of xact

time
Strict 2PL == 2PLC (2PL till Commit)

- In effect, “shrinking phase” is delayed until
  - Transaction commits (commit log record on disk), or
  - Aborts (then locks can be released after rollback).

![Graph showing number of locks held over time]

- Acquisition phase: number of locks held over time.
- Release all locks at end of xact.
Non-2PL, $A = 1000$, $B = 2000$, Output = ?

<table>
<thead>
<tr>
<th>Lock_X(A)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Read(A)</td>
<td></td>
</tr>
<tr>
<td>$A = A - 50$</td>
<td></td>
</tr>
<tr>
<td>Write(A)</td>
<td></td>
</tr>
<tr>
<td>Unlock(A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lock_S(A)</td>
</tr>
<tr>
<td></td>
<td>Read(A)</td>
</tr>
<tr>
<td></td>
<td>Unlock(A)</td>
</tr>
<tr>
<td></td>
<td>Lock_S(B)</td>
</tr>
<tr>
<td></td>
<td>Read(B)</td>
</tr>
<tr>
<td></td>
<td>Unlock(B)</td>
</tr>
<tr>
<td></td>
<td>PRINT(A+B)</td>
</tr>
<tr>
<td>Lock_X(B)</td>
<td></td>
</tr>
<tr>
<td>Read(B)</td>
<td></td>
</tr>
<tr>
<td>$B = B + 50$</td>
<td></td>
</tr>
<tr>
<td>Write(B)</td>
<td></td>
</tr>
<tr>
<td>Unlock(B)</td>
<td></td>
</tr>
</tbody>
</table>
2PL, A = 1000, B = 2000, Output = ?

<table>
<thead>
<tr>
<th>Action</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lock_X(A)</td>
<td>Access X lock on A</td>
</tr>
<tr>
<td>Read(A)</td>
<td>Read A</td>
</tr>
<tr>
<td>A := A - 50</td>
<td>Subtract 50 from A</td>
</tr>
<tr>
<td>Write(A)</td>
<td>Write to A</td>
</tr>
<tr>
<td>Lock_X(B)</td>
<td>Access X lock on B</td>
</tr>
<tr>
<td>Unlock(A)</td>
<td>Release lock on A</td>
</tr>
<tr>
<td>Lock_S(A)</td>
<td>Access S lock on A</td>
</tr>
<tr>
<td>Read(A)</td>
<td>Read A</td>
</tr>
<tr>
<td>Read(B)</td>
<td>Read B</td>
</tr>
<tr>
<td>B := B + 50</td>
<td>Add 50 to B</td>
</tr>
<tr>
<td>Write(B)</td>
<td>Write to B</td>
</tr>
<tr>
<td>Unlock(B)</td>
<td>Release lock on B</td>
</tr>
<tr>
<td>Lock_S(B)</td>
<td>Access S lock on B</td>
</tr>
<tr>
<td>Unlock(A)</td>
<td>Release lock on A</td>
</tr>
<tr>
<td>Read(B)</td>
<td>Read B</td>
</tr>
<tr>
<td>Unlock(B)</td>
<td>Release lock on B</td>
</tr>
<tr>
<td>PRINT(A + B)</td>
<td>Output A + B</td>
</tr>
</tbody>
</table>
Strict 2PL, $A=1000$, $B=2000$, Output = ?

<table>
<thead>
<tr>
<th>Action</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lock_X(A)</td>
<td></td>
</tr>
<tr>
<td>Read(A)</td>
<td></td>
</tr>
<tr>
<td>$A: = A - 50$</td>
<td></td>
</tr>
<tr>
<td>Write(A)</td>
<td></td>
</tr>
<tr>
<td>Lock_X(B)</td>
<td></td>
</tr>
<tr>
<td>Read(B)</td>
<td></td>
</tr>
<tr>
<td>$B := B + 50$</td>
<td></td>
</tr>
<tr>
<td>Write(B)</td>
<td></td>
</tr>
<tr>
<td>Unlock(A)</td>
<td></td>
</tr>
<tr>
<td>Unlock(B)</td>
<td></td>
</tr>
<tr>
<td>Lock_S(A)</td>
<td></td>
</tr>
<tr>
<td>Read(A)</td>
<td></td>
</tr>
<tr>
<td>Lock_S(B)</td>
<td></td>
</tr>
<tr>
<td>Read(B)</td>
<td></td>
</tr>
<tr>
<td>PRINT(A+B)</td>
<td></td>
</tr>
<tr>
<td>Unlock(A)</td>
<td></td>
</tr>
<tr>
<td>Unlock(B)</td>
<td></td>
</tr>
</tbody>
</table>
Venn Diagram for Schedules

All Schedules

Conflict Serializable

Avoid Cascading Abort

Serial
Q: Which schedules does Strict 2PL allow?

- All Schedules
- Conflict Serializable
- Serial
- Avoid
- Cascading
- Abort
Q: Which schedules does Strict 2PL allow?

- All Schedules
- Conflict Serializable
- Avoid Cascading Abort
- Serial
Another Venn diagram

- Serializable schedules
- 2PL schedules
- 2PLC
- Serial sch’s
Outline

- 2PL/2PLC
- Lock Management
  - detection
  - Prevention
- Specialized Locking
Lock Management

- Lock and unlock requests handled by the Lock Manager (LM).
- LM contains an entry for each currently held lock.
- Q: structure of a lock table entry?
Lock Management

- Lock and unlock requests handled by the Lock Manager (LM).
- LM contains an entry for each currently held lock.
- Lock table entry:
  - Ptr. to list of transactions currently holding the lock
  - Type of lock held (shared or exclusive)
  - Pointer to queue of lock requests
Lock Management, cont.

- When lock request arrives see if any other xact holds a conflicting lock.
  - If not, create an entry and grant the lock
  - Else, put the requestor on the wait queue

- Lock upgrade: transaction that holds a shared lock can be upgraded to hold an exclusive lock
Lock Management, cont.

- Two-phase locking is simple enough, right?
- We’re not done. There’s an important wrinkle ...
Example: Output = ?

<table>
<thead>
<tr>
<th>Lock_X(A)</th>
<th>Lock_S(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Read(B)</td>
</tr>
<tr>
<td></td>
<td>Lock_S(A)</td>
</tr>
<tr>
<td>Read(A)</td>
<td></td>
</tr>
<tr>
<td>A: = A-50</td>
<td></td>
</tr>
<tr>
<td>Write(A)</td>
<td></td>
</tr>
<tr>
<td>Lock_X(B)</td>
<td></td>
</tr>
</tbody>
</table>
Example: Output = ?

<table>
<thead>
<tr>
<th>Lock_X(A)</th>
<th>Lock_S(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Read(B)</td>
</tr>
<tr>
<td></td>
<td>Lock_S(A)</td>
</tr>
<tr>
<td>Read(A)</td>
<td></td>
</tr>
<tr>
<td>A: = A-50</td>
<td></td>
</tr>
<tr>
<td>Write(A)</td>
<td></td>
</tr>
<tr>
<td>Lock_X(B)</td>
<td></td>
</tr>
</tbody>
</table>

lock mgr:
- grant
- grant
- wait
- wait
Outline

- Lock Management
- Deadlocks
  - detection
  - Prevention
- Specialized Locking
Deadlocks

- Deadlock: Cycle of transactions waiting for locks to be released by each other.
- Two ways of dealing with deadlocks:
  - Deadlock prevention
  - Deadlock detection
- Many systems just punt and use Timeouts
  - What are the dangers with this approach?
Deadlock Detection

- Create a waits-for graph:
  - Nodes are transactions
  - Edge from Ti to Tj if Ti is waiting for Tj to release a lock
- Periodically check for cycles in waits-for graph
Example:

T1: \( S(A), S(D), S(B) \)
T2: \( X(B) \)
T3: \( S(D), S(C), X(A) \)
T4: \( X(B) \)
Another example

- is there a deadlock?
- if yes, which xacts are involved?
Another example

- now, is there a deadlock?
- if yes, which xacts are involved?
Deadlock detection

- how often should we run the algo?
- how many transactions are typically involved?
Deadlock handling

• Q: what to do?
Deadlock handling

- Q0: what to do?
  - A: select a ‘victim’ & ‘rollback’
- Q1: which/how to choose?
Deadlock handling

• Q1: which/how to choose?
  • A1.1: by age
  • A1.2: by progress
  • A1.3: by # items locked already...
  • A1.4: by # xacts to rollback

• Q2: How far to rollback?
Deadlock handling

- Q2: How far to rollback?
  - A2.1: completely
  - A2.2: minimally
- Q3: Starvation??
Deadlock handling

• Q3: Starvation??
• A3.1: include #rollbacks in victim selection criterion.
Outline

- Lock Management
- Deadlocks
  - detection
  - Prevention
- Specialized Locking
Deadlock Prevention

- Assign priorities based on timestamps (older -> higher priority)
- We only allow ‘old-wait-for-young’
- (or only allow ‘young-wait-for-old’)
- and rollback violators. Specifically:
- Say Ti wants a lock that Tj holds - two policies:
  - Wait-Die: If Ti has higher priority, Ti waits for Tj; otherwise Ti aborts (ie., old wait for young)
  - Wound-wait: If Ti has higher priority, Tj aborts; otherwise Ti waits (ie., young wait for old)
Deadlock Prevention

**Wait-Die**

Ti wants

Tj has

**Wound-Wait**

Ti wants

Tj has

Priorities
Deadlock Prevention

- Q: Why do these schemes guarantee no deadlocks?
- A:
- Q: When a transaction restarts, what is its (new) priority?
- A:
Deadlock Prevention

- Q: Why do these schemes guarantee no deadlocks?
- A: only one ‘type’ of direction allowed.
- Q: When a transaction restarts, what is its (new) priority?
- A: its original timestamp. -- Why?
usually, conc. control is transparent to the user, but

LOCK <table-name> [EXCLUSIVE|SHARED]
Quiz:

- is there a serial schedule (= interleaving) that is not serializable?
- is there a serializable schedule that is not serial?
- can 2PL produce a non-serializable schedule? (assume no deadlocks)
Quiz - cont’d

- is there a serializable schedule that can not be produced by 2PL?
- a xact obeys 2PL - can it be involved in a non-serializable schedule?
- all xacts obey 2PL - can they end up in a deadlock?
Outline

- Lock Management
- Deadlocks
  - detection
  - Prevention
- Specialized Locking
Things we will not study

- We assumed till now DB objects are fixed and independent---not true in many cases!
- Multi-level locking
  - Lock db or file or pages or record?
- What about locking indexes?
  - E.g. B+-trees
  - Crabbing Algorithm
- What about dynamic databases?
  - ‘phantom’ problem
  - Solution: predicate locking
- Non-locking based Techniques
  - Timestamp based Concurrency Control
- All these are in the textbook though
Transaction Support in SQL-92

**SERIALIZABLE** – No phantoms, all reads repeatable, no “dirty” (uncommitted) reads.

- **REPEATABLE READS** – phantoms may happen.
- **READ COMMITTED** – phantoms and unrepeetable reads may happen
- **READ UNCOMMITTED** – all of them may happen.

Prakash 2014
Transaction Support in SQL-92

- **SERIALIZABLE**: obtains all locks first; plus index locks, plus strict 2PL
- **REPEATABLE READS**: as above, but no index locks
- **READ COMMITTED**: as above, but S-locks are released immediately
- **READ UNCOMMITTED**: as above, but allowing ‘dirty reads’ (no S-locks)
Transaction Support in SQL-92

- SET TRANSACTION ISOLATION LEVEL
  SERIALIZABLE READ ONLY

- Defaults:
  - SERIALIZABLE
  - READ WRITE

  isolation level

  access mode
Conclusions

- 2PL/2PL-C (=Strict 2PL): extremely popular
- Deadlock may still happen
  - detection: wait-for graph
  - prevention: abort some xacts, defensively
- philosophically: concurrency control uses:
  - locks
  - and aborts