CS522 Advanced Database Systems
Concurrency Control

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Overview

- Serializability
- Scheduling schemes
  - Locking
  - Timestamp
  - Validation
- Recoverability
- Distributed Databases and 2PC

Transaction

- A collection of database operations that should be treated as a whole
  - Atomicity (ACID)
    - commit
    - abort (rollback)
  - Isolation (ACID)

Consistent States

- Database *elements*
  - relations, tuples, disk pages ...
- State – a "snapshot" of all elements
- Consistent state (ACID)
  - Explicit constraints
  - Implicit constraints

Correctness Assumption

- Each transaction, executed in isolation from other transactions, brings a database from one consistent state to another consistent state.
  - consistent *before* and *after*
  - not necessarily *during*

Interleaving of Transactions

- Why do we want to do that??
- Notations
  - r(X,t)
  - w(X,t)

Transactions Example ...

- Consistency constraint: A = B

T_1:

r(A,t) t=t+10 w(A,t) r(B,t) t=t+10 w(B,t)

T_2:

r(A,t) t=2*t w(A,t) r(B,t) t=t*2 w(B,t)

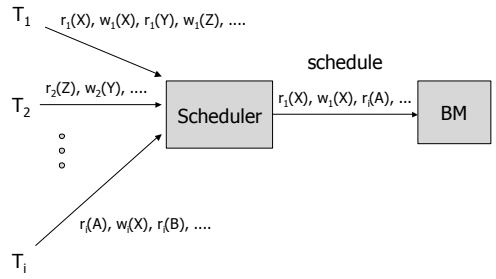
... Transactions Example

- T_1T_2
- T_2T_1
- Interleaving T_1 and T_2

Further Abstraction

- What if T2 multiply A and B by 1 instead of 2??
- Omit local operations (a.k.a. what could go wrong will go wrong)
  - T_i
  - $r_i(X)$, $w_i(Y)$

Scheduling



Serial Schedules

- What is a correct schedule??
- Serial schedules
  - If *any* action of T proceeds *any* action of T', *all* actions of T proceed *all* actions of T'

Serializable Schedules

- A serializable schedule has the same effect on the database as *some* serial schedule

serial:

$r_1(x),w_1(x),r_2(x),w_2(x),r_2(y),w_2(y)$

serializable:

??

Conflicts

- Consider action $a_i(E)$ from T_i and action $a_j(E')$ from T_J, assuming $i \neq j$
  - action could be either *r* or *w*
  - E and E' could be same or different
- When can we interchange the order of $a_i(E), a_j(E')$ to $a_j(E'), a_i(E)$??

Conflicts Table

a_i	E	a_j	E'	conflict??
r_i	X	r_j	X	
r_i	X	w_j	X	
w_i	X	r_j	X	
w_i	X	w_j	X	

Conflict-Serializability

- Conflict-equivalent
- Conflict-serializable schedule
  - A schedule that is conflict-equivalent to a serial schedule
  - Example: $r_1(a), w_1(a), r_2(a), w_2(a), r_1(b), w_1(b), r_2(b), w_2(b)$

Conflict-serializable vs. Serializable

Conflict-serializable schedule

?? ↓ ↑ ??

Serializable schedule

$w_1(Y), w_2(Y), w_2(X), w_1(X), w_3(X)$

Precedence Graph for a Schedule S

- The nodes of the graph are transactions T_i
- There's an arc from node T_i to node T_j if T_i takes precedence of T_j, or $T_i <_s T_j$
  - There is an action a_i proceed an action a_j in S
  - a_i and a_j operate on the same database element
  - At least one of a_i and a_j is a write

Precedence Graph Examples

- $r_2(a), r_1(b), w_2(a), r_3(a), w_1(b), w_3(a), r_2(b), w_2(b)$
- $r_2(a), r_1(b), w_2(a), r_2(b), r_3(a), w_1(b), w_3(a), w_2(b)$

Precedence Graph Test

- Acyclic graph → conflict-serializable
  - Proof

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Locking Mechanisms

- Lock
  - request a lock on a db element: $l_i(e)$
  - release a lock on a db element: $u_i(e)$
- Transaction
  - a transaction can only access an element if it's holding a lock on that element
  - after a transaction locks an element, it must unlock it *later*.

Scheduling with Exclusive Locks

- Scheduling
  - Lock table
  - No two transactions can hold the lock for the same element at the same time
- Lock-based scheduling is *not* enough

Two-Phase Locking (2PL)

- In every transaction, all lock requests proceed all unlock requests
- 2PL transactions

2PL Transactions + Lock-based Scheduling

Conflict-serializable schedule

Why 2PL Works

- Example: $r_1(a),w_2(b),w_1(b)$
  - Add an action from T_2 to make the schedule non-conflict-serializable??
  - Why it is not possible with 2PL??
- Proof

Shared Locks

- We need locks to reads; concurrent read should be allowed
  - Shared lock (read lock): $sl_i(e)$, $u_i(e)$
  - Exclusive lock (write lock): $xl_i(e)$, $u_i(e)$
- Compatibility matrix

		lock requested S	lock requested X
lock held	S	Y	N
lock held	X	N	N

Lock Upgrading

- Acquire shared lock first, then only upgrade it to exclusive lock when necessary
- Why do we want to do it??
- Why do we not want to do it??

Update Lock

- Update lock: $ul_i(e)$
  - read privilege
  - can be upgraded to exclusive lock, while shared locks cannot

	S	X	U
S	Y	N	
X	N	N	
U			

Increment Action and Increment Lock

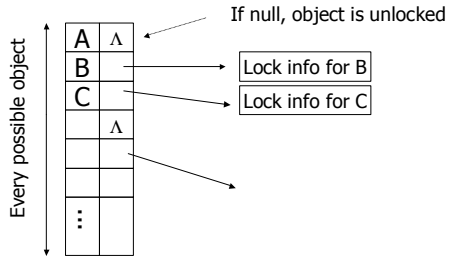
- Increment action: $inc_i(e)$
- Increment lock: $il_i(e)$

	S	X	U	I
S	Y	N		
X	N	N		
U				
I				

Lock-based Scheduler

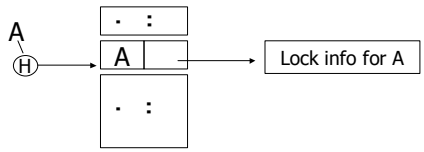
- Insert locking and unlocking operations into transactions
- Accept or delay operations according to a *lock table*

Conceptual Lock Table



HGM Notes

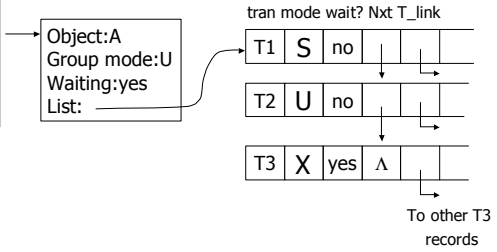
Implementation with a Hash Table



If object not found in hash table, it is unlocked

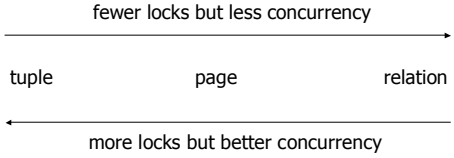
HGM Notes

Lock Table Example

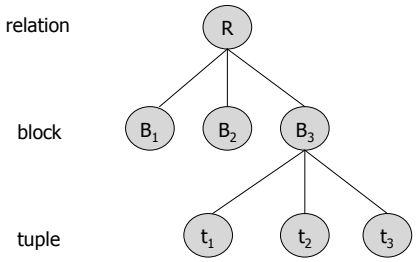


HGM Notes

Lock Granularity



DB Elements in a Hierarchy



Intension Locks

- Called *Warning Locks* in the textbook
- IS – "intend to acquire a shared lock"
- IX – "intend to acquire a exclusive lock"

Multi-Granularity Locking

- Always start at the root node and work downward
- Place an intension lock on each node along the path
- Place an lock on the target node

Compatibility Matrix with Intension Locks

	IS	IX	S	X
IS				
IX				
S			Y	N
X			N	N

Tree Index Locking

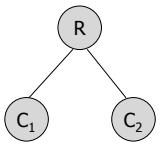
- Why the hierarchical locking scheme does *not* work for tree indexes??
- How to make tree locking more efficient
  - locking does not have to start with the root node
  - does not have to be strictly 2PL

Tree Protocol

- First lock may be any node
- Can only lock child node when there's a lock on the parent node
- Can Unlock at any time
- Cannot re-lock a node

Tree Protocol Example

- $T_1, T_2, \ldots, T_{10}$
- Exclusive lock only
- Lock order
  - R: T_1, T_2, T_3
  - C_1: $T_4, T_1, T_5, T_2, T_6, T_3, T_7$
  - C_2: $T_8, T_2, T_9, T_{10}, T_3$
- Give a serial schedule based on the locking order



Optimistic Concurrency Control

- No locks
- Just let the transactions run ...
- ... until something bad happens, then we abort and restart the transaction

Timestamp-based Scheduler

- Each transaction is given a *timestamp* TS(T)
  - hardware clock
  - software counter
- For each db element X, maintain
  - RT(X) – latest timestamp of read
  - WT(X) – latest timestamp of write
  - C(X) – latest write has committed

Timestamp Example

- $r_2(x), r_1(x), r_1(y), w_1(y), c_1, w_2(y), c_2$

Physically Unrealizable

- Serialize transactions by timestamp
- Unserializable behavior is called physically unrealizable
  - read too late
  - write too late

Timestamp-based Scheduling

	$R_i(X)$	$W_i(X)$
TS(Ti) < RT(X)		
TS(Ti) < WT(X)		
...		

Multi-version Timestamps

- Why do we want to do it??
- How do we do it??
  - When can older versions be removed??

Validation-based Scheduler

- Transaction
  - Read set RS(T)
  - Write set WS(T)
- Scheduling
  - Read
  - Validate
  - Write

Transaction Sets

- START
  - transactions that have started but not validated
  - start(T)
- VAL
  - transactions that are validated but have to finished writing
  - start(T), val(T)
- FIN
  - trasnactions that have finished
  - start(T), val(T), and fin(T)

Validation Example

- Validate T
  - U in VAL
  - U is not finished
  - RS(T)∩WS(U)≠∅, or WS(T)∩WS(U) ≠∅

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The Recoverability Problem

- Serializability problem
  - Ensure correct execution of $T_1,...,T_k$ when *all transactions successfully commit*
- Recoverability problem
  - Ensure correct execution of $T_1,...,T_k$ when *some of the transactions abort*

"Seemingly" Unrecoverable Schedule

- Is the schedule serializable??
  - conflict-serializable??
- Are the transactions 2PL??
- Is the schedule recoverable??

$w_1(A),w_2(A),c_2,a_1$

<START T_1>
<T_1,A,v>
<START T_2>
<T_2,A,v>
<COMMIT T_2> failure

Unrecoverable Schedule

- Is the schedule serializable??
  - conflict-serializable??
- Are the transactions 2PL??
- Is the schedule recoverable??

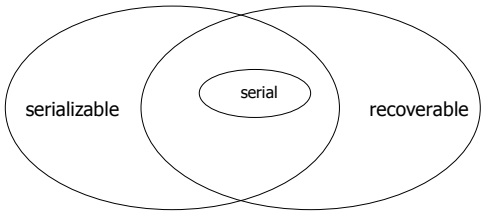
$w_1(A),r_2(A),w_2(A),c_2,a_1$

<START T_1>
<T_1,A,v>
<START T_2>
<T_2,A,v>
<COMMIT T_2> failure

Recoverable Schedule

- *Recoverable schedule*: each transaction commits only after each transaction from which it has read committed.
- Examples:
  - $w_1(A),w_1(B),w_2(A),r_2(B),c_1,c_2$
  - $w_2(a),w_1(B),w_1(A),r_2(B),c_1,c_2$

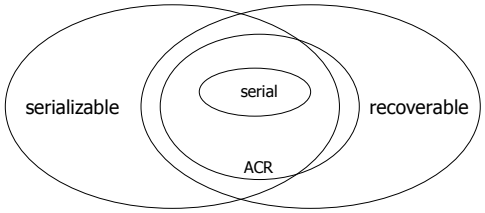
Serializable and Recoverable (I)



ACR Schedules

- Cascading rollback
  - w1(A),w1(B),w2(A),r2(B),a1
- A schedule *avoids cascading rollback* (ACR) if transactions only read values written by committed transactions
  - a.k.a. never read "dirty" data

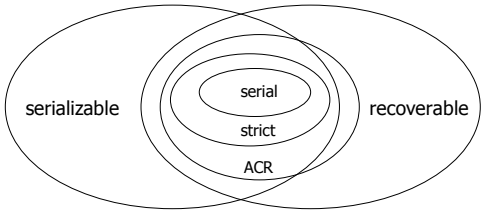
Serializable and Recoverable (II)



Scheduling Schemes That Enforce ACR

- Timestamp
- Validation
- Strict 2PL
  - 2PL
  - release any write-related lock (exclusive, update, increment ...) after <COMMIT T> or <ABORT T> is flushed to disk

Serializable and Recoverable (III)



Group Commit

- Relaxed *Strict 2PL*
  - release write-related locks after <COMMIT T> is written to memory buffer
  - ??

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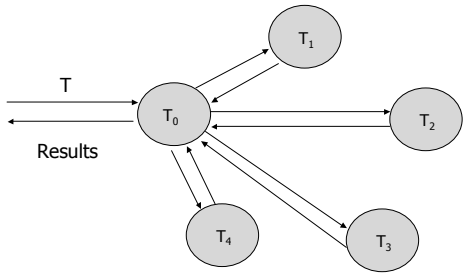
Distributed Databases

- Retail chains
- Bank branches
- ...
- Replicated databases for load balancing
  - Great for queries (reads)
  - Not so great for updates (writes)

Distributed Transaction Example

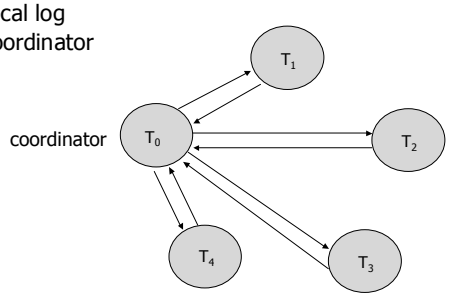


Issues in Distributed Transaction

- Commit/abort
- Serializability
  - distributed locking and timestamp
- Recovery
  - node failure
  - network failure
- Automicity
- ...

2 Phase Commit (2PC)

- Local log
- Coordinator



2PC – Phase One

- Coordinator
  - log <Prepare T>
  - send message [prepare T]
- Other
  - Commit
    - enter a *precommitted* state
    - <Ready T>, [Ready T]
  - Abort
    - <Don't commit T>, [Don't commit T]
    - Abort

2PC – Phase Two

- Coordinator
  - All [Ready T]
    - <Commit T>
    - [Commit T]
  - At least one [Don't commit T]
    - <Abort T>
    - [Abort T]
- Other
  - [Commit T] → <Commit T>
  - [Abort T] → <Abort T>

2PC Recovery When "Other" Fails

- When last log record is:
  - <Start T>
  - <Commit T>
  - <Abort T>
  - <Ready T>
  - <Don't Commit T>

2PC Recovery When Coordinator Fails

- New coordinator
  - At least one site has <Commit T>
  - At least one site has <Abort T>
  - At least one site has <Don't commit T>
  - All surviving sites have <Ready T>
  - All surviving sites have <Start T>