CSE 444: Database Internals

Lecture 25
Replication

References

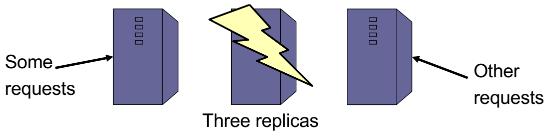
- Ullman Book Chapter 20.6
- **Database management systems.**
  Ramakrishnan and Gehrke.
  Third Ed. **Chapter 22.11**

Outline

- Goals of replication
- Three types of replication
  - Synchronous (aka eager) replication
  - Asynchronous (aka lazy) replication
  - Two-tier replication

Goals of Replication

- Goal 1: availability
- Goal 2: performance



- But, it's easy to build a replicated system that reduces performance and availability

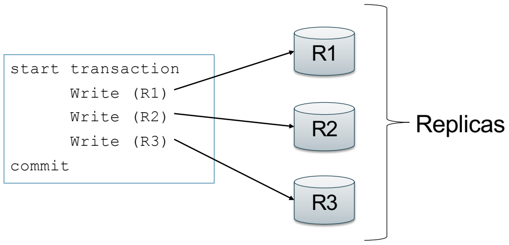
Types of Replication

	Master	Group
Synchronous	✓	
Asynchronous		

Synchronous Replication

- Also called eager replication
- All updates are applied to all replicas (or to a majority) as part of a single transaction (need two phase commit)
- Main goal: as if there was only one copy
  - Maintain **consistency**
  - Maintain **one-copy serializability**
  - I.e., execution of transactions has same effect as an execution on a non-replicated db
- Transactions must acquire global locks

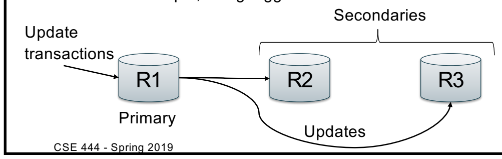
Synchronous Replication



```
start transaction
      Write (R1)
      Write (R2)
      Write (R3)
commit
```

Synchronous Master Replication

- One master for each object holds primary copy
  - The "Master" is also called "Primary"
  - To update object, transaction must acquire a lock at the master
  - Lock at the master is global lock
- Master propagates updates to replicas synchronously
  - Updates propagate as part of the same distributed transaction
    - Need to run 2PC at the end
  - For example, using triggers



Crash Failures

- What happens when a secondary crashes?
  - Nothing happens
  - When secondary recovers, it catches up
- What happens when the master/primary fails?
  - Blocking would hurt availability
  - Must chose a new primary: run election

Network Failures

- Network failures can cause trouble...
  - Secondaries think that primary failed
  - Secondaries elect a new primary
  - But primary can still be running
  - Now have two primaries!

Majority Consensus

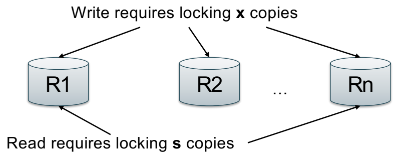
- To avoid problem, only majority partition can continue processing at any time
- In general,
  - Whenever a replica fails or recovers...
  - a set of communicating replicas must determine...
  - whether they have a majority before they can continue

Types of Replication

	Master	Group
Synchronous	✓	✓
Asynchronous		

Synchronous Group Replication

- With n copies
  - Exclusive lock on x copies is global exclusive lock
  - Shared lock on s copies is global shared lock
  - Must have: $2x > n$ and $s + x > n$
  - Version numbers serve to identify current copy



Write requires locking **x** copies

Read requires locking **s** copies

Synchronous Group Replication

- Majority locking
  - $s = x = \lceil (n+1)/2 \rceil$
  - No need to run any reconfiguration algorithms
- Read-locks-one, write-locks-all
  - s=1 and x = n, high read performance
  - Need to make sure algo runs on quorum of computers

Synchronous Replication Properties

- Favours consistency over availability
  - Only majority partition can process requests
  - There appears to be a single copy of the db
- High runtime overhead
  - Must lock and update at least majority of replicas
  - Two-phase commit
  - Runs at pace of slowest replica in quorum
  - So overall system is now slower
  - Higher deadlock rate (transactions take longer)

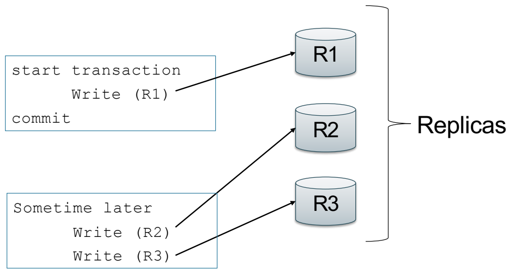
Types of Replication

	Master	Group
Synchronous	✓	✓
Asynchronous	✓	

Asynchronous Replication

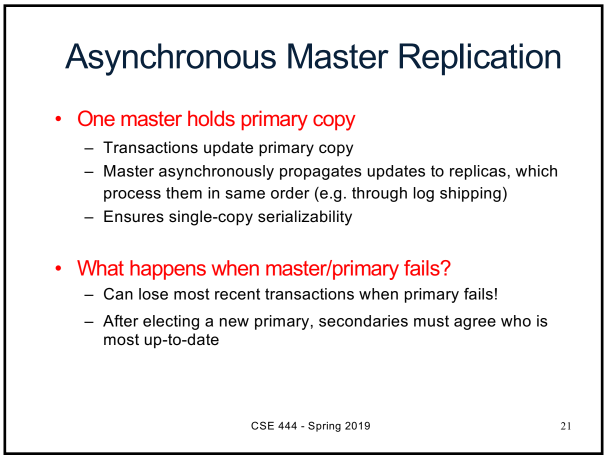
- Also called lazy replication
- Also called optimistic replication
- Main goals: availability and performance
- Approach
  - One replica updated by original transaction
  - Updates propagate asynchronously to other replicas

Asynchronous Replication



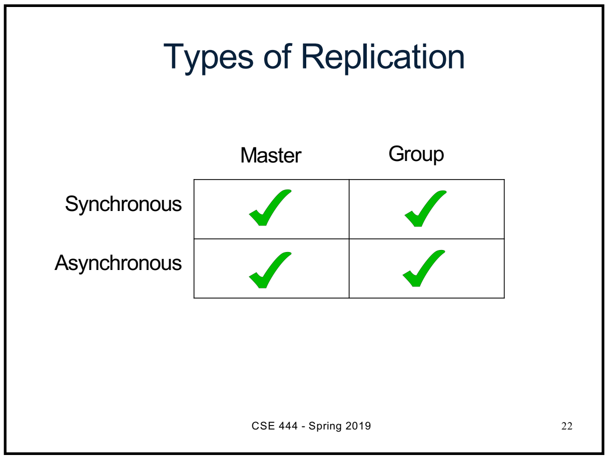
```
start transaction
        Write (R1)
commit
```

```
Sometime later
        Write (R2)
        Write (R3)
```



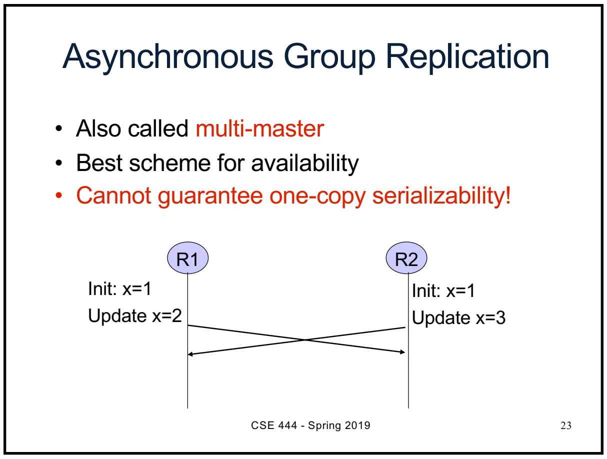
Asynchronous Master Replication

- One master holds primary copy
  - Transactions update primary copy
  - Master asynchronously propagates updates to replicas, which process them in same order (e.g. through log shipping)
  - Ensures single-copy serializability
- What happens when master/primary fails?
  - Can lose most recent transactions when primary fails!
  - After electing a new primary, secondaries must agree who is most up-to-date



Types of Replication

	Master	Group
Synchronous	✓	✓
Asynchronous	✓	✓



Asynchronous Group Replication

- Also called multi-master
- Best scheme for availability
- Cannot guarantee one-copy serializability!

R1

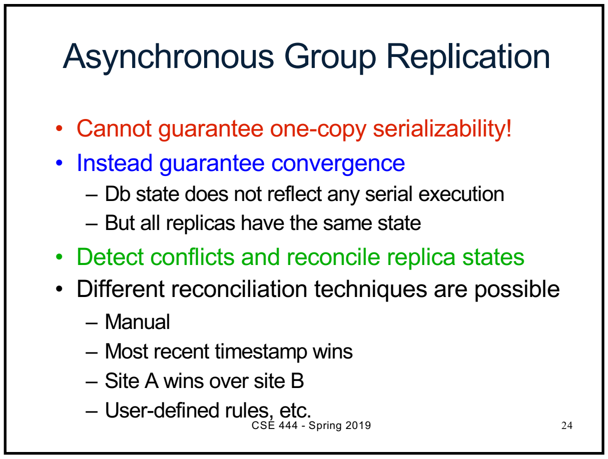
Init: x=1

Update x=2

R2

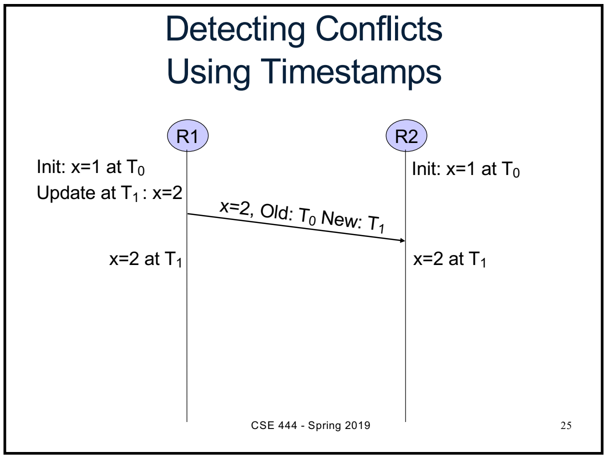
Init: x=1

Update x=3



Asynchronous Group Replication

- Cannot guarantee one-copy serializability!
- Instead guarantee convergence
  - Db state does not reflect any serial execution
  - But all replicas have the same state
- Detect conflicts and reconcile replica states
- Different reconciliation techniques are possible
  - Manual
  - Most recent timestamp wins
  - Site A wins over site B
  - User-defined rules, etc.



Detecting Conflicts Using Timestamps

R1

Init: x=1 at T_0

Update at T_1 : x=2

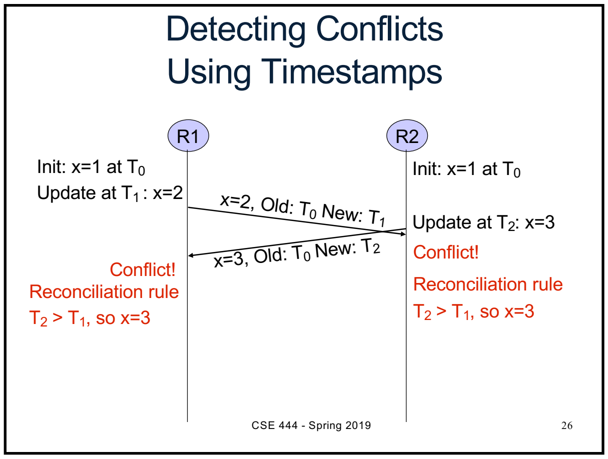
x=2 at T_1

$x=2$, Old: T_0 New: T_1

R2

Init: x=1 at T_0

x=2 at T_1



Detecting Conflicts Using Timestamps

R1

Init: x=1 at T_0

Update at T_1 : x=2

$x=2$, Old: T_0 New: T_1

$x=3$, Old: T_0 New: T_2

Conflict!

Reconciliation rule

$T_2 > T_1$, so x=3

R2

Init: x=1 at T_0

Update at T_2: x=3

Conflict!

Reconciliation rule

$T_2 > T_1$, so x=3

Vector Clocks

- An extension of Multiversion Concurrency Control (MVCC) to multiple servers
- Standard MVCC:
  each data item X has a timestamp t:
  X_4, X_9, X_{10}, X_{14}, …, X_t
- Vector Clocks:
  X has set of [server, timestamp] pairs
  X([s1,t1], [s2,t2],…)

Vector Clocks: Conflict or not?

Data 1	Data 2	Conflict ?
([SX,3],[SY,6])	([SX,3],[SZ,2])	

Vector Clocks: Conflict or not?

Data 1	Data 2	Conflict ?
([SX,3],[SY,6])	([SX,3],[SZ,2])	Yes

Vector Clocks: Conflict or not?

Data 1	Data 2	Conflict ?
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([SX,3])	([SX,5])	

Vector Clocks: Conflict or not?

Data 1	Data 2	Conflict ?
([SX,3],[SY,6])	([SX,3],[SZ,2])	Yes
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Vector Clocks: Conflict or not?

Data 1	Data 2	Conflict ?
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([SX,3])	([SX,5])	No
([SX,3],[SY,6])	([SX,3],[SY,6],[SZ,2])	No

Vector Clocks: Conflict or not?

Data 1	Data 2	Conflict ?
([SX,3],[SY,6])	([SX,3],[SZ,2])	Yes
([SX,3])	([SX,5])	No
([SX,3],[SY,6])	([SX,3],[SY,6],[SZ,2])	No
([SX,3],[SY,10])	([SX,3],[SY,20],[SZ,2])	No

Asynchronous Group Replication Properties

- Favours availability over consistency
  - Can read and update any replica
  - High runtime performance
- Weak consistency
  - Conflicts and reconciliation

Outline

- Goals of replication
- Three types of replication
  - Synchronous (aka eager) replication
  - Asynchronous (aka lazy) replication
  - Two-tier replication

Two-Tier Replication

- Benefits of lazy master and lazy group
- Each object has a master with primary copy
- When disconnected from master
  - Secondary can only run tentative transactions
- When reconnects to master
  - Master reprocesses all tentative transactions
  - Checks an acceptance criterion
  - If passes, we now have final commit order
  - Secondary undoes tentative and redoes committed

Conclusion

- Replication is a very important problem
  - Fault-tolerance (various forms of replication)
  - Caching (lazy master)
  - Warehousing (lazy master)
  - Mobility (two-tier techniques)
- Replication is complex, but basic techniques and trade-offs are **very well known**
  - Synchronous or asynchronous replication
  - Master or quorum