Road Map

- Lecture 1: Isolation levels
- Lecture 2: Safe Use of Low Isolation
- Lecture 3: Replication Management
  - The key principle (R any, W all)
  - Global concurrency control
  - The main design choices
  - Serializable systems with lazy propagation
  - Using SI in replication
  - Limited divergence

Definition

- Replication is when the value of some data item is stored in more than one place
  - Typically in different databases at different physical locations
  - Similar issues arise with cached copies
- Eg keep a copy of the part-list at each warehouse

Motivation

- Performance
  - Each reader can find a copy close-by
    - Less latency to access the data
  - More parallelism, load-sharing
    - Improved throughput
- Fault-tolerance
  - Failure of some site doesn’t halt all activities
  - Graceful degradation

Key principle

- Read any copy
  - Preferably near to the client
- For unchanging data, this is wonderful! But what if the data item value sometimes changes (i.e. some transactions write the data)?
  - Write all the copies
  - This damages performance and fault-tolerance!
  - Thus replication is best for data where reads dominate over updates

Global transaction issues

- For now, ignore replication and just think about a system with multiple databases, and transactions that access them
- How to get global atomicity?
  - Use Two-phase commit
  - But this reduces performance markedly, especially during periods where some nodes are not available

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Global serializability

- How to get serializable behavior?
- It is not enough for each db to provide serializable operation locally
- If each db uses 2PL, then global execution is serializable
  - All conflicts are compatible with the Commit order
- If you’re not sure each db uses 2PL, and you want global serializability, you can
  - keep global serialization graph
  - introduce conflicts at every site through “ticket” updates

The main design choices

- There are many design choices for a system with replicated data. In the next slides, we present some of these, with sketches of the trade-offs involved.

Where to replicate?

- Everywhere
  - “total replication”
  - All dbs have identical contents
  - Any read can be done locally, with no cross-network communication
- Simple system design
- Performance may suffer

- Not everywhere
  - “partial replication”
  - Need to manage information about replica locations, and choose location for reads
  - Need to make choices about placement
- Complicated system design
- Performance may be improved

If partial, what to replicate?

- Complete tables
  - Each db has some of the tables
  - Easy to decide whether local copy exists for some data
  - Easy to reuse standard dbms engine for query optimization and processing
- Relatively simpler system design

- Fragments of tables
  - Keep copy of some rows, perhaps based on values in particular columns
  - Keep copy of some columns
  - Copy can be seen as a view of underlying global table
- Complex system design

How consistent?

- “Always” consistent
  - At least, apps shouldn’t observe difference from using single dbms
    - “transparent replication”
    - Formal definition for “1 copy serializable (abbreviated as 1-SR)”
    - Some systems propose “1-copy SI”

- Eventually consistent
  - “convergent”
  - If updates cease for long enough, all copies will reach a common value
  - Intermediate approach: limited divergence

How to propagate writes?

- Capture SQL statements, and execute at replicas
  - Difficulties if state is not the same as when originally executed

- Capture values written/inserted, and perform at replicas
  - Use triggers to capture information
  - Or access logs kept by each dbms
When to propagate writes?

- **Eager**
  - Update all replicas inside the original transaction
  - Requires two-phase commit
- **Good for consistency**
- **Bad for performance**
- **Hybrid approach:** do some remote activity, but not the updates themselves

- **Lazy**
  - “asynchronous”
  - Update one copy of each item inside original txn, then apply those writes that are relevant to replicas at a given site in a separate “copier” txn
  - Original txn may be entirely local at one site
- **Good for performance**
- **May be bad for consistency**

Is there a master?

- **Primary copy**
  - “master-slave”
  - One replica of each item is authoritative
  - It is always updated first
  - If lazy propagation, this either restricts transaction content, or forces non-local execution
- **Bad for flexibility**
  - **Group**
  - “multimaster” or “update anywhere”
  - Different txns can update replicas in different orders
  - If eager propagation, then deadlock is very common;
  - If lazy propagation, then need conflict resolution to ensure convergence
- **Good for flexibility**

System architecture

- **Middleware**
  - Applications go through a veneer that manages global issues and then passes operations to local dbs
  - Middleware may not have enough information eg internal conflicts, risk of distributed deadlocks
  - No need to modify apps if they use JDBC or similar API
  - No need to modify engines
  - More practical in most cases

- **Engine-based**
  - Modify each dbms to know about replication
  - No need to modify applications
  - Need to modify engines
  - Hard to do except with open-source dbms, or if you work for one of the vendors!
  - Unlikely to work with heterogeneous engines

Communication platform?

- **Point-to-point messages**
  - Eg socket programming
  - Always present on any platform
  - Programmer needs to deal with failures, and with out-of-order deliveries
  - Can get good raw performance

- **Group communication services**
  - Eg Spread, Transis, etc
  - Deliver to all members of the group
  - Sender can require guarantees on order etc
  - Much easier system design
  - Performance may suffer

Design space summary

- **In practice, want performance and simple system design**
  - lazy propagation and primary copy
- **In theory, want consistency and application generality**
  - eager propagation, multi-master

Isolation and lazy propagation?

- **If multi-master, then even convergence is hard to enforce**
  - Need timestamps to recognize out-of-order updates
- **So, assume primary copy**
- **Without restrictions on data and applications, reads can see old data**
  - If a txi’s reads are not all at same site, it might even see inconsistently old data
Example

• X has primary copy at A, replica at B
• Y has primary copy at B, replica at A
• T1 runs at A: r[X] r[Y] w[X]
  – Later copier T3 propagates write of X to B
• T2 runs at B: r[X] r[Y] w[Y]
  – Later copier T4 propagates write of Y to A

• At A: r1[Xa] r1[Ya] w1[Xa] c1 w4[Ya] c4
• At B: r2[Xb] r2[Yb] w2[Yb] c2 w3[Xb] c3
• Neither T1 nor T2 sees the other’s changes

Example II

• X has primary copy at A, replica at B and C
• Y has primary copy at B, replica at C
• T1 runs at A: r[X] w[X]
  – Later copier T4 propagates write of X to B
  – Copier T5 propagates write of X to C
• T2 runs at B: r[X] r[Y] w[Y]
  – Later copier T6 propagates write of Y to C
• T3 runs at C: r[X] r[Y]

• At A: r1[Xa] w1[Xa] c1
• At B: w1[Xa] c1 r1[Xa] r[Ya] w2[Ya] c2
• At C: w2[Ya] c1 r1[Xa] r[Yc] w6[Yc] c6
• T2 sees T1, T3 sees T2 on Y (hence knows about T1) but does not see T1 on X

Restrictions

• Most work on serialization with lazy updates assumes a restricted model of data and apps
• We limit application logic so that each original transaction can run at one site
  – It accesses data with copies at that site
  – It only updates data whose primary copy is at that site
• Call this the “data ownership” assumption
  – This is common in practice, since app is usually focused on modifying data which “belongs” to the organisation or suborg which wrote the app
  – But it may read data which belongs elsewhere

The copy graph

• Nodes are the sites where databases are located
• Edge from Ni to Nj if
  – There is an item X whose primary copy is located at Ni and which is replicated at Nj

Strongly Acyclic Copy graph

• CRR96 showed:
  – Assume data ownership model
  – Assume each db uses 2PL
  – Allow arbitrary execution of copier transactions,
  – then the overall execution is 1-copy serializable if and only if the undirected image of the copy graph has no cycles

Combining OLTP and OLAP

• A special case has been widely used, where copy graph is a star
• Have one site which has the primary copy for all items (OLTP node)
• Other sites just run read-only queries (OLAP nodes)
• Eg RBSS’02, PA’04
Acyclic Copy Graph

- BKRSS99 introduced algorithms that work if directed copy graph has no cycle
- Key idea: ensure that copiers update nodes in a consistent order
  - Based on a tree
  - Or using timestamps
  - Could also be done with totally ordered multicast to carry each txn’s copiers

Use of SI in Replication

- Because SI is now so common (Oracle, PostgreSQL), there is recently a lot of interest in replication using SI rather than 2PL
- SW’00 shows how to ensure 1-SR using ticket or graph techniques
- WK’05, LKPJ’05 show how to get 1-SI
  - Without data ownership hypothesis
  - Using totally-ordered multicast

Combining local SI to 1-SI

- Assume each txn runs at a single site
- Then reading is determined by consistent snapshot
- But how to test for concurrent writes?
- Solution: deliver writeset info to other sites within the txn
  - But defer actually applying them
- Important to use db info so conflicts are checked at tuple not table granularity

Extensions

- LKPJ’05 also deals with many practical issues such as handling message failures, preventing deadlocks, detecting some conflicts early using the local SI properties
- Overall message: they get quite scalable performance

Relaxed Currency

- 1-SR allows read-only queries which run on out-of-date values
  - Some applications want limits on how old data might be
- RBSS’02 allows app to specify bound on staleness
- GLRG’04 provides SQL extension
  - And builds checks into query optimisation

Relaxed Consistency

- 1-SR and 1-SI both require all items read by txn T to come from a consistent view
  - This is easy if each txn runs at a single site
  - But it is hard if txn’s reads can be spread around, for performance or because replication is not total
- Some applications may be willing to see data which were valid at slightly different times
- Much theory about controlling timing of updates to limit divergence of data values
  - Exp work on real-time databases
- GLRG’04 introduced SQL syntax to capture apps requirements
  - Focus on allocating reads to sites, rather than controlling divergence of sites
Future Work

• Replication across WANS
  – Order-enforcing group communication costs are very high here
• Limited divergence (QoS guarantees)
  – Integrating system mechanisms with application requirements

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