Distributed Databases

Chapter 21, Part B

Introduction

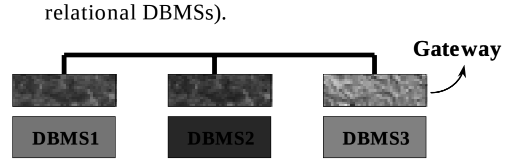
- Data is stored at several sites, each managed by a DBMS that can run independently.
- Distributed Data Independence: Users should not have to know where data is located (extends Physical and Logical Data Independence principles).
- Distributed Transaction Atomicity: Users should be able to write Xacts accessing multiple sites just like local Xacts.

Recent Trends

- Users have to be aware of where data is located, i.e., Distributed Data Independence and Distributed Transaction Atomicity are not supported.
- These properties are hard to support efficiently.
- For globally distributed sites, these properties may not even be desirable due to administrative overheads of making location of data transparent.

Types of Distributed Databases

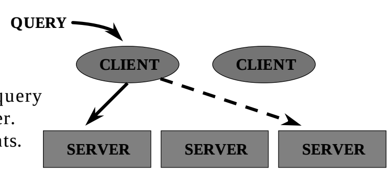
- Homogeneous: Every site runs same type of DBMS.
- Heterogeneous: Different sites run different DBMSs (different RDBMSs or even non-relational DBMSs).



Distributed DBMS Architectures

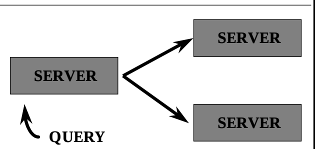
- Client-Server

Client ships query to single site. All query processing at server.
- *Thin* vs. *fat* clients.
- Set-oriented communication, client side caching.

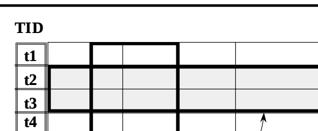


- Collaborating-Server

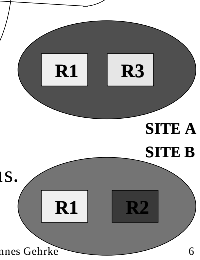
Query can span multiple sites.



Storing Data



- Fragmentation
  - Horizontal: Usually disjoint.
  - Vertical: Lossless-join; tids.
- Replication
  - Gives increased availability.
  - Faster query evaluation.
  - Synchronous vs. Asynchronous.
    - Vary in how current copies are.



Distributed Catalog Management

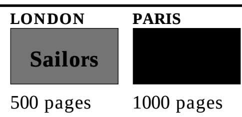
- Must keep track of how data is distributed across sites.
- Must be able to name each replica of each fragment. To preserve local autonomy:
  - <**local-name, birth-site**>
- Site Catalog: Describes all objects (fragments, replicas) at a site + Keeps track of replicas of relations created at this site.
  - To find a relation, look up its birth-site catalog.
  - Birth-site never changes, even if relation is moved.

Distributed Queries

```
SELECT AVG(S.age)
FROM Sailors S
WHERE S.rating > 3
  AND S.rating < 7
```

- Horizontally Fragmented: Tuples with rating < 5 at Shanghai, >= 5 at Tokyo.
  - Must compute SUM(age), COUNT(age) at both sites.
  - If WHERE contained just S.rating>6, just one site.
- Vertically Fragmented: *sid* and *rating* at Shanghai, *sname* and *age* at Tokyo, *tid* at both.
  - Must reconstruct relation by join on *tid*, then evaluate the query.
- Replicated: Sailors copies at both sites.
  - Choice of site based on local costs, shipping costs.

Distributed Joins



- Fetch as Needed, Page NL, Sailors as outer:
  - **Cost:** 500 D + 500 * 1000 (D+S)
  - **D** is cost to read / write page; **S** is cost to ship page.
  - If query was not submitted at London, must add cost of shipping result to query site.
  - Can also do INL at London, fetching matching Reserves tuples to London as needed.
- Ship to One Site: Ship Reserves to London.
  - Cost: 1000 S + 4500 D (SM Join; cost = 3*(500+1000))
  - If result size is very large, may be better to ship both relations to result site and then join them!

Semijoin

- At London, project Sailors onto join columns and ship this to Paris.
- At Paris, join Sailors projection with Reserves.
  - Result is called **reduction** of Reserves wrt Sailors.
- Ship reduction of Reserves to London.
- At London, join Sailors with reduction of Reserves.
- Idea: Tradeoff the cost of computing and shipping projection and computing and shipping projection for cost of shipping full Reserves relation.
- Especially useful if there is a selection on Sailors, and answer desired at London.

Bloomjoin

- At London, compute a bit-vector of some size k:
  - Hash join column values into range 0 to k-1.
  - If some tuple hashes to I, set bit I to 1 (I from 0 to k-1).
  - Ship bit-vector to Paris.
- At Paris, hash each tuple of Reserves similarly, and discard tuples that hash to 0 in Sailors bit-vector.
  - Result is called **reduction** of Reserves wrt Sailors.
- Ship bit-vector reduced Reserves to London.
- At London, join Sailors with reduced Reserves.
- Bit-vector cheaper to ship, almost as effective.

Distributed Query Optimization

- Cost-based approach; consider all plans, pick cheapest; similar to centralized optimization.
  - Difference 1: Communication costs must be considered.
  - Difference 2: Local site autonomy must be respected.
  - Difference 3: New distributed join methods.
- Query site constructs global plan, with suggested local plans describing processing at each site.
  - If a site can improve suggested local plan, free to do so.

Updating Distributed Data

- Synchronous Replication: All copies of a modified relation (fragment) must be updated before the modifying Xact commits.
  - Data distribution is made transparent to users.
- Asynchronous Replication: Copies of a modified relation are only periodically updated; different copies may get out of synch in the meantime.
  - Users must be aware of data distribution.
  - Current products follow this approach.

Synchronous Replication

- Voting: Xact must write a majority of copies to modify an object; must read enough copies to be sure of seeing at least one most recent copy.
  - E.g., 10 copies; 7 written for update; 4 copies read.
  - Each copy has version number.
  - Not attractive usually because reads are common.
- Read-any Write-all: Writes are slower and reads are faster, relative to Voting.
  - Most common approach to synchronous replication.
- Choice of technique determines *which* locks to set.

Cost of Synchronous Replication

- Before an update Xact can commit, it must obtain locks on all modified copies.
  - Sends lock requests to remote sites, and while waiting for the response, holds on to other locks!
  - If sites or links fail, Xact cannot commit until they are back up.
  - Even if there is no failure, committing must follow an expensive ***commit protocol*** with many msgs.
- So the alternative of *asynchronous replication* is becoming widely used.

Asynchronous Replication

- Allows modifying Xact to commit before all copies have been changed (and readers nonetheless look at just one copy).
  - Users must be aware of which copy they are reading, and that copies may be out-of-sync for short periods of time.
- Two approaches: Primary Site and Peer-to-Peer replication.
  - Difference lies in how many copies are ``updatable'' or ``master copies''.

Peer-to-Peer Replication

- More than one of the copies of an object can be a master in this approach.
- Changes to a master copy must be propagated to other copies somehow.
- If two master copies are changed in a conflicting manner, this must be resolved. (e.g., Site 1: Joe's age changed to 35; Site 2: to 36)
- Best used when conflicts do not arise:
  - E.g., Each master site owns a disjoint fragment.
  - E.g., Updating rights owned by one master at a time.

Primary Site Replication

- Exactly one copy of a relation is designated the primary or master copy. Replicas at other sites cannot be directly updated.
  - The primary copy is published.
  - Other sites subscribe to (fragments of) this relation; these are secondary copies.
- Main issue: How are changes to the primary copy propagated to the secondary copies?
  - Done in two steps. First, capture changes made by committed Xacts; then apply these changes.

Implementing the Capture Step

- Log-Based Capture: The log (kept for recovery) is used to generate a Change Data Table (CDT).
  - If this is done when the log tail is written to disk, must somehow remove changes due to subsequently aborted Xacts.
- Procedural Capture: A procedure that is automatically invoked (trigger; more later!) does the capture; typically, just takes a snapshot.
- Log-Based Capture is better (cheaper, faster) but relies on proprietary log details.

Implementing the Apply Step

- The Apply process at the secondary site periodically obtains (a snapshot or) changes to the CDT table from the primary site, and updates the copy.
  - Period can be timer-based or user/application defined.
- Replica can be a view over the modified relation!
  - If so, the replication consists of incrementally updating the materialized view as the relation changes.
- Log-Based Capture plus continuous Apply minimizes delay in propagating changes.
- Procedural Capture plus application-driven Apply is the most flexible way to process changes.

Data Warehousing and Replication

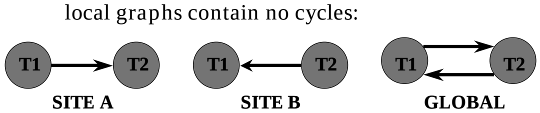
- A hot trend: Building giant "warehouses" of data from many sites.
  - Enables complex decision support queries over data from across an organization.
- Warehouses can be seen as an instance of asynchronous replication.
  - Source data typically controlled by different DBMSs; emphasis on "cleaning" data and removing mismatches ($ vs. rupees) while creating replicas.
- Procedural capture and application Apply best for this environment.

Distributed Locking

- How do we manage locks for objects across many sites?
  - Centralized: One site does all locking.
    - Vulnerable to single site failure.
  - Primary Copy: All locking for an object done at the primary copy site for this object.
    - Reading requires access to locking site as well as site where the object is stored.
  - Fully Distributed: Locking for a copy done at site where the copy is stored.
    - Locks at all sites while writing an object.

Distributed Deadlock Detection

- Each site maintains a local waits-for graph.
- A global deadlock might exist even if the local graphs contain no cycles:



- Three solutions: Centralized (send all local graphs to one site); Hierarchical (organize sites into a hierarchy and send local graphs to parent in the hierarchy); Timeout (abort Xact if it waits too long).

Distributed Recovery

- Two new issues:
  - New kinds of failure, e.g., links and remote sites.
  - If "sub-transactions" of an Xact execute at different sites, all or none must commit. Need a commit protocol to achieve this.
- A log is maintained at each site, as in a centralized DBMS, and commit protocol actions are additionally logged.

Two-Phase Commit (2PC)

- Site at which Xact originates is coordinator; other sites at which it executes are subordinates.
- When an Xact wants to commit:
  - ← Coordinator sends **prepare** msg to each subordinate.
  - ↑ Subordinate force-writes an **abort** or **prepare** log record and then sends a **no** or **yes** msg to coordinator.
  - → If coordinator gets unanimous yes votes, force-writes a **commit** log record and sends **commit** msg to all subs. Else, force-writes **abort** log rec, and sends **abort** msg.
  - ↓ Subordinates force-write **abort/commit** log rec based on msg they get, then send **ack** msg to coordinator.
  - ° Coordinator writes **end** log rec after getting all acks.

Comments on 2PC

- Two rounds of communication: first, voting; then, termination. Both initiated by coordinator.
- Any site can decide to abort an Xact.
- Every msg reflects a decision by the sender; to ensure that this decision survives failures, it is first recorded in the local log.
- All commit protocol log recs for an Xact contain Xactid and Coordinatorid. The coordinator's abort/commit record also includes ids of all subordinates.

Restart After a Failure at a Site

- If we have a commit or abort log rec for Xact T, but not an end rec, must redo/undo T.
  - If this site is the coordinator for T, keep sending **commit/abort** msgs to subs until **acks** received.
- If we have a prepare log rec for Xact T, but not commit/abort, this site is a subordinate for T.
  - Repeatedly contact the coordinator to find status of T, then write **commit/abort** log rec; redo/undo T; and write **end** log rec.
- If we don't have even a prepare log rec for T, unilaterally abort and undo T.
  - This site may be coordinator! If so, subs may send msgs.

Blocking

- If coordinator for Xact T fails, subordinates who have voted yes cannot decide whether to commit or abort T until coordinator recovers.
  - T is <u>blocked.</u>
  - Even if all subordinates know each other (extra overhead in prepare msg) they are blocked unless one of them voted no.

Link and Remote Site Failures

- If a remote site does not respond during the commit protocol for Xact T, either because the site failed or the link failed:
  - If the current site is the coordinator for T, should abort T.
  - If the current site is a subordinate, and has not yet voted yes, it should abort T.
  - If the current site is a subordinate and has voted yes, it is blocked until the coordinator responds.

Observations on 2PC

- Ack msgs used to let coordinator know when it can "forget" an Xact; until it receives all acks, it must keep T in the Xact Table.
- If coordinator fails after sending prepare msgs but before writing commit/abort log recs, when it comes back up it aborts the Xact.
- If a subtransaction does no updates, its commit or abort status is irrelevant.

2PC with Presumed Abort

- When coordinator aborts T, it undoes T and removes it from the Xact Table immediately.
  - Doesn't wait for **acks**; "presumes abort" if Xact not in Xact Table. Names of subs not recorded in **abort** log rec.
- Subordinates do not send acks on abort.
- If subxact does not do updates, it responds to prepare msg with reader instead of yes/no.
- Coordinator subsequently ignores readers.
- If all subxacts are readers, 2nd phase not needed.

Summary

- Parallel DBMSs designed for scalable performance. Relational operators very well-suited for parallel execution.
  - Pipeline and partitioned parallelism.
- Distributed DBMSs offer site autonomy and distributed administration. Must revisit storage and catalog techniques, concurrency control, and recovery issues.