CS 133: Databases

Fall 2019
Lec 24 – 12/05
Parallel and Distributed DBMSs

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Warm-up Exercise

(See exercise sheet. You can start before class.)

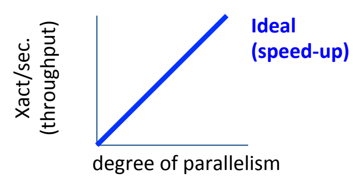
Performance, availability, more storage space to fit the data

Goals for Today

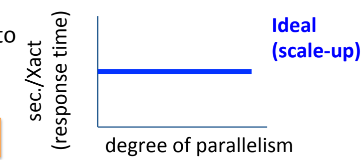
- Discuss distributing data and workload for increased performance in a DBMS
- Reason about DBMS concepts in parallel and distributed setting
  - How to achieve distributed ACID transactions
  - Data consistency across copies
- Understand why some of the disadvantages of distributed databases have led to some relaxation of consistency

Some Parallelism Terminology

- Throughput
  - Amount of work done per unit time
- Latency (response time)
  - Time to complete one unit work
- Speed-Up
  - More resources means less time for a given unit of work
    → do more units of work in same time



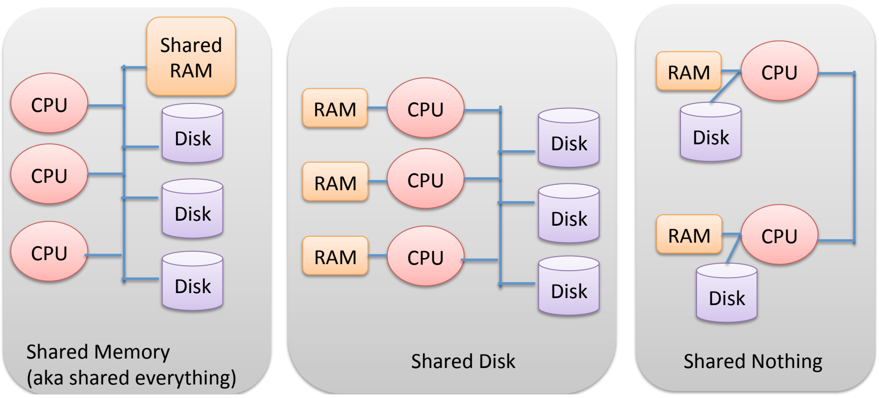
- Scale-Up
  - If resources increased in proportion to increase in units of work, time per unit is constant.



Resource contention impacts scale-up/speed-up

Parallel DBMS Architectures

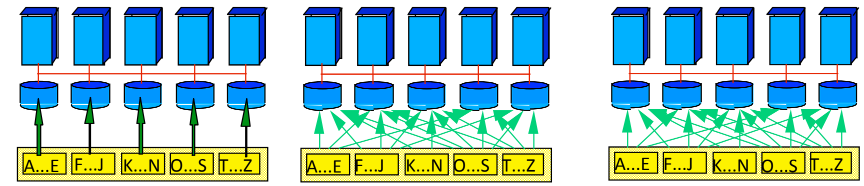
- Multiple processors (CPUs) can do work in parallel
  - How do they communicate about what work to do?
  - Three main parallel DB architectures:



Data Partitioning

Partitioning (aka *sharding* aka *horizontally fragmenting*) a table:

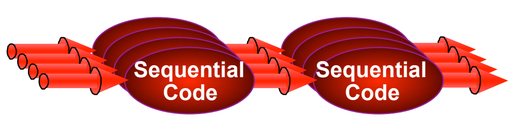
Range | Hash | Round Robin



Good for equijoins, range queries group-by | Good for equijoins | Good to spread load

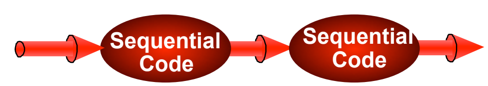
Different Types of DBMS Parallelism

- **Inter-query** parallelism: different queries run on different nodes
- **Intra-operator “partitioned” parallelism**
  - Multiple machines working together to execute an operator (e.g., scan, sort, join)
  - Machines work on disjoint partition of the data
- Parallelizing a relational operator: merge and split
  - Merge streams of output to serve as input to an operator
  - Split output of operator to be processed in parallel



Different Types of DBMS Parallelism

- Inter-operator **“pipelined” parallelism**
  - Each relational operator may run concurrently on a different machine
  - Output of first operator consumed on-the-fly as input to second operator



Could be limited by blocking operators such as sort or aggregation

Exercise 2

- (a) inter-query
- (b) intra-operator "partitioned" parallelism

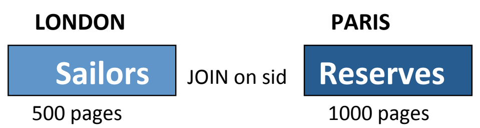
Distributed DBMS (Shared Nothing)

- Data is stored at several sites (geo-distributed), each managed by a DBMS that can run independently

Extends Physical and Logical Data Independence principles

- **Distributed Data Independence:** Users should not have to know where data is located
  - Note: **catalog** needs to keep track of where data is
- **Distributed Transaction Atomicity:** Users should be able to write Xacts accessing multiple sites just like local Xacts

Distributed Query Processing: Joins

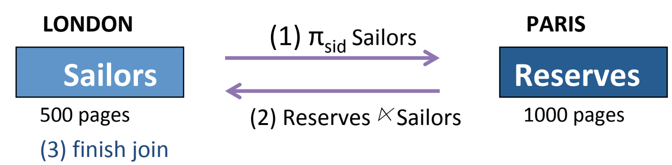


- **Approach 1 -- Fetch as Needed**: Page NLJ, Sailors as outer (query submitted at London):
  - **D** is cost to read/write page; **S** is cost to ship page
  - **Cost:** 500 D + 500 * 1000 (D+S) = 500,500 D + 500,000 S
  - If query not submitted at London, must add cost of shipping result to query site
- **Approach 2 -- Ship to One Site**: Ship *Reserves* to London
  - Cost: 1000 (D+S) + 500 D + 500*1000 D = 501,500 D + 1000 S

Could also consider other single-site join methods

Semijoin

- Why ship all of *Reserves* to London?
  - Some of these tuples may not even end up being joined, so wasted communication cost
  - **Idea**: only ship the Reserves tuples that will match *Sailors* tuples



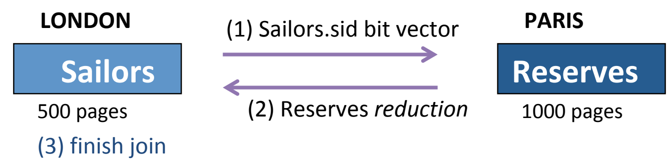
- Bottom line: Tradeoff the cost of computing and shipping projection for cost of shipping full Reserves relation.
- *Note*: Especially useful if there is a selection on Sailors, and then join selectivity is also high

An aside: Bloom Filter

- A **bloom filter** is a bit vector used to quickly determine whether an element belongs to a set
- Hash elements to one of ***k* buckets**

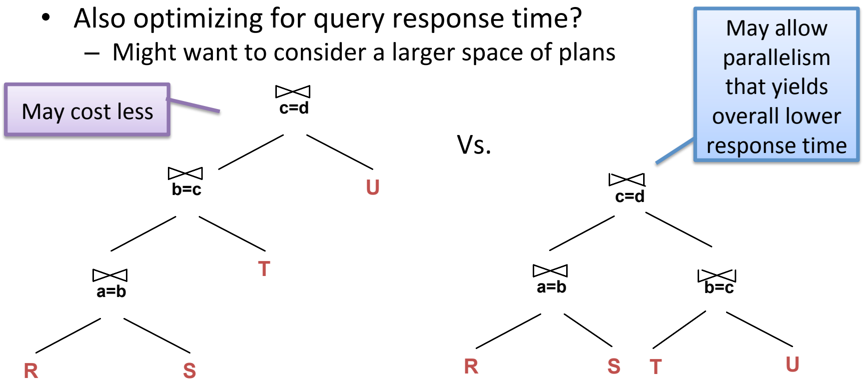
Refinement: Bloomjoin

- Idea: rather than shipping the join column, ship a more compact data structure that captures (almost) the same info
  - **Bloom filter** bit vector
  - Bit-vector cheaper to ship, almost as effective (false positives possible)
- Hash Sailors.sid values into range [0,k-1]
  - If tuple hashes to slot *i*, set bit *i* to 1
- Hash Reserves tuples into same range [0,k-1]
  - Discard tuples that hash to 0 in Sailors bit vector



Query Optimization

- New considerations for **cost-based approach**
  - **Communication** costs
  - New **distributed join methods**
- Also optimizing for query response time?
  - Might want to consider a larger space of plans



Exercise 3

- Concerns: correctness, deadlock, performance
- Some options:
  - All lock requests go through a central location
  - Lock requests distributed; request is sent to the site that holds the data that is desired

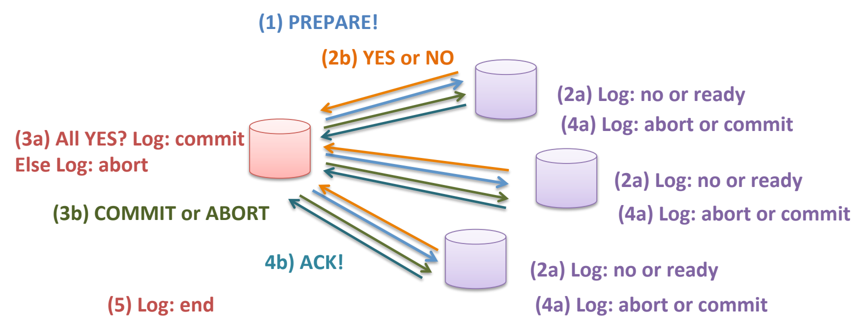
Distributed Transactions

- With data at distributed sites, a transaction may operate on data at multiple sites
  - xact broken down into **sub-xacts** that execute **at each site**
- Example: **read and update inventory at four sites** with horizontal partitions of the data
  - T: R(A), R(B), R(C), R(D), W(A), W(B), W(C), W(D), commit

- How do we guarantee atomicity??
  - Need a **commit protocol** (type of consensus protocol)
  - 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*
- Suppose xact wants to commit (normal execution):



2PC: Steps

- When a Xact wants to commit:

  ① Coordinator sends **prepare** msg to each subordinate.

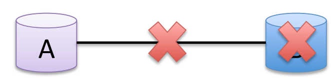
  ② Subordinate force-writes a **no** or **ready** log record and then sends a **no** or **yes** msg to coordinator.

  ③ 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.

  ④ Subordinates force-write **abort/commit** log rec based on msg they get, then send **ack** msg to coordinator.

  ⑤ Coordinator writes **end** log rec after getting all acks.

Site and Link Failures ☹



- If coordinator detects a subordinate failed, e.g., after timeout

  Exercise 4: when the failed subordinate site wakes up, can it tell if a global transaction committed or aborted?

- If coordinator for Xact T fails, subordinates who have voted **yes** cannot decide whether to commit or abort T until coordinator recovers
  - Xact T is **blocked**

Exercise 4

- Site that wakes up should interpret its log
  - (a) T committed! it should REDO actions for T
  - (b) T aborted! it should UNDO actions for T
  - (c) Can't tell... Needs to consult coordinator about what coordinator decided
  - (d) T aborted! it should write abort, and UNDO
    - Since it never even wrote ready, coordinator couldn't possibly have decided to commit (since it would have waited for the site to say yes)

Data Replication

- **Replication**: keep copies of data at different sites
- Benefits
  - Gives increased ***availability***
  - Faster query evaluation
- Flavors
  - Synchronous (eager) vs. Asynchronous (lazy)
    - Vary in how current copies are (i.e., how ***consistent*** they are)
- Can be used in addition to data partitioning
  - **Full replication**: copy of all data at every site (vs. partial)

Locking: on **primary copy** or **fully distributed**

Updating Distributed Data

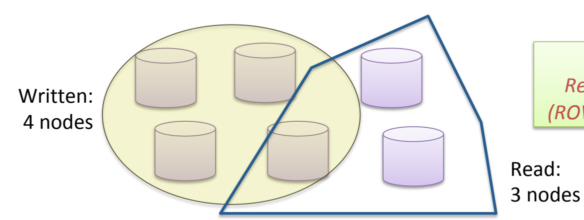
Not necessarily *all* copies!

- Synchronous (Eager) Replication: set of copies of a modified relation must be updated **before the modifying xact commits**
  - Exclusive locks on **all** the copies that are modified
  - Users/apps do not need to know data location(s)
- Asynchronous (Lazy) Replication: Copies of a modified relation are only periodically updated
  - **Different copies may get out of sync** in the meantime
  - Users/applications must be aware of data location(s)

Synchronous Replication: Majority

- Majority technique can guarantee data consistency:
  - Xact must **write a majority** of copies to modify an object
  - Each copy has version number for object
  - Xact must **read enough copies** to be sure of seeing at least one most recent copy
- Example: 6 copies of data

Impact on performance of READ queries??



Could use *Read-one-write-all (ROWA)* policy instead