Database Management Systems

Module 58: RDBMS Performance & Architecture

Partha Pratim Das

Department of Computer Science and Engineering
Indian Institute of Technology, Kharagpur

ppd@cse.iitkgp.ac.in

Module Recap

- Understood the basic issues for optimizing queries
- For every relational expression, usually there are a number of equivalent expressions that can be created by simple transformations
- Final execution plan can be created by choose the estimated least cost expression from the alternates

Module Objectives

- To evaluate RDBMS, especially with reference to performance and scalability, as a backbone for data-intensive application development
- To understand the role of system and database architecture in performance
- To understand options for Scaling Databases

Module Outline

- RDBMS Performance and Scalability
- RDBMS Architecture
- Scaling Databases

RDBMS Performance and Scalability

What do DBMS Applications Need?

- **Throughput**, **Response Time**, & **Availability**
  - *Throughput is transactions / second (tps)*
  - *Response Time is the delay from submission of transaction to return of result*
  - *Availability is the mean time to failure*
  - At Transaction Level
    - ▷ Concurrency Control
    - ▷ Query Optimization
  - At System Level
    - ▷ System Architecture
    - ▷ Database Architecture
    - ▷ Performance Tuning
      - — *Hardware*: disks to speed up I/O, memory to increase buffer hits, move to a faster processor
      - — *Database System Parameters*: set buffer size to avoid paging, set checkpointing to limit log size
      - — *Higher level database design*: schema, indices and transactions
- **Correctness**
  - *Any given database transaction must change affected data only in allowed ways*
  - ACID Properties
- **Scalability**
  - *Ability to scale up a database to allow it to hold increasing amounts of data without sacrificing performance*
  - Should be able to scale with volume of data, number of users, diversity of services, geographic expanse, etc.
  - Scalability can be achieved by
    - ▷ System Architecture
    - ▷ Database Architecture
    - ▷ Scale expectations with scale of the system
    - ▷ Alternate Data Models
    - ▷ Accommodate Hybrid Systems
  - ...

RDBMS Architecture

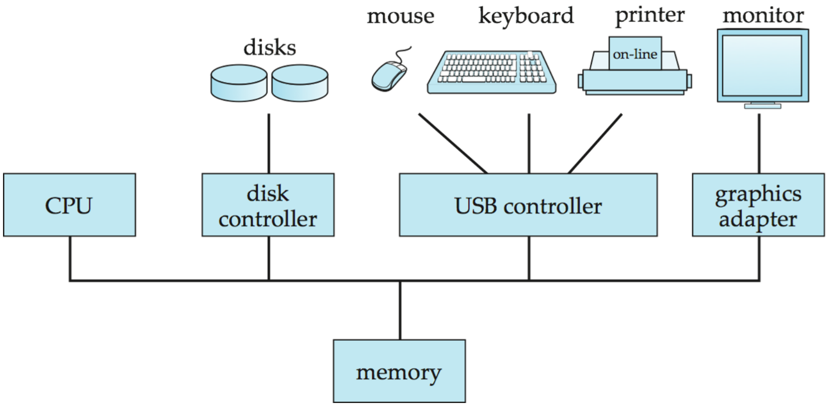
RDBMS Architecture

- Centralized and Client-Server Systems
- Server System Architectures
- Parallel Systems
- Distributed Systems
- Network Types

RDBMS Architecture: Centralized & Client-Server

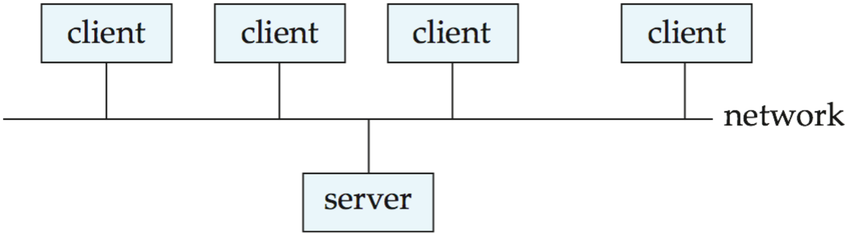
- **Centralized Architecture**
  - Run on a single computer system and do not interact with other computer systems
  - General-purpose computer system:
    - One to a few CPUs and a number of device controllers that are connected through a common bus that provides access to shared memory
  - Single-user system (for example, personal computer or workstation):
    - desk-top unit, single user, usually has only one CPU and one or two hard disks
    - the OS may support only one user
  - Multi-user system:
    - more disks, more memory, multiple CPUs, and a multi-user OS
    - Serve a large number of users who are connected to the system vie terminals
    - Often called server systems

RDBMS Architecture: Centralized & Client-Server



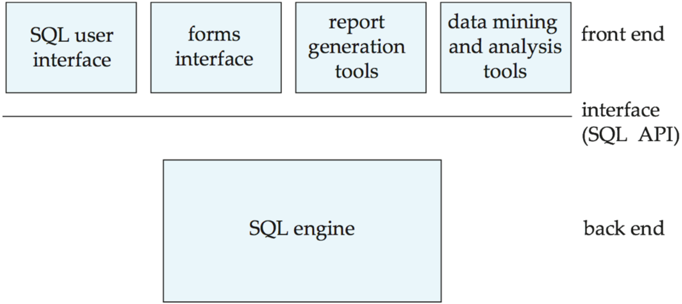
RDBMS Architecture: Centralized & Client-Server

- Server systems satisfy requests generated at m client systems



RDBMS Architecture: Centralized & Client-Server

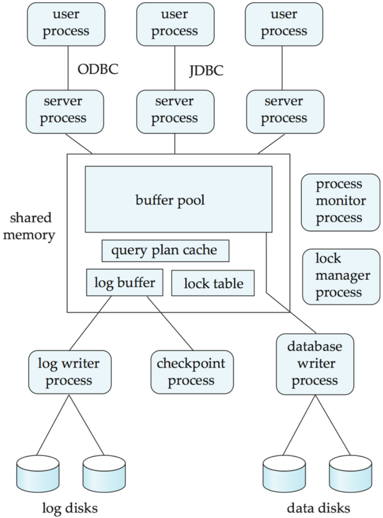
- Database functionality can be divided into:
  - **Back-end**: manages access structures, query evaluation and optimization, concurrency control and recovery
  - **Front-end**: consists of tools such as forms, report-writers, and graphical user interface facilities
- The interface between the front-end and the back-end is through SQL or through an application program interface



RDBMS Architecture: Server Systems

- **Transaction or Query servers** which are widely used in relational database systems
  - A typical transaction cycle is:
    - Clients send requests to the server
    - Transactions are executed at the server
    - Results are shipped back to the client
  - Requests are specified in SQL, and communicated to the server through a remote procedure call (RPC) mechanism
  - Transactional RPC allows many RPC calls to form a transaction.
  - ODBC / JDBC used to connect
- **Data servers**, used in object-oriented database systems
  - Used in high-speed LANs, in cases where
    - The clients are comparable in processing power to the server
    - The tasks to be executed are compute intensive
  - Issues:
    - Page-Shipping versus Item-Shipping
    - Locking
    - Data Caching
    - Lock Caching

RDBMS Architecture: Server Systems



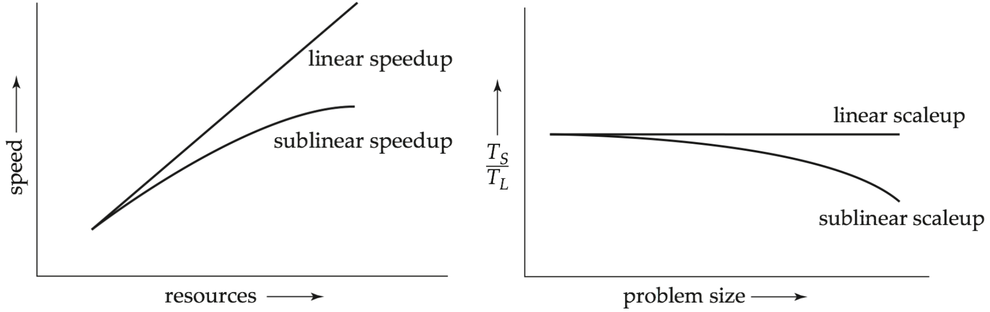
RDBMS Architecture: Parallel Systems

- Parallel database systems consist of multiple processors and multiple disks connected by a fast interconnection network
- A **coarse-grain parallel** machine consists of a small number of powerful processors
- **A massively parallel or fine grain parallel** machine utilizes thousands of smaller processors
- Two main performance measures:
  - **throughput**: the number of tasks that can be completed in a given time interval
  - **response time** the amount of time it takes to complete a single task from the time it is submitted

RDBMS Architecture: Parallel Systems

- **Speedup**: a fixed-sized problem executing on a small system is given to a system which is N-times larger
  - Measured by:
    - ▷ Speedup $= \frac{small\ \ system\ \ elapsed\ \ time}{large\ \ system\ \ elapsed\ \ time}$
  - Speedup is linear if equation equals N
  - Speedup Percentage $= \frac{Speedup}{N} * 100\%$
- **Scaleup**: increase the size of both the problem and the system N-times larger system used to perform N-times larger job
  - Measured by:
    - ▷ Scaleup $= \frac{small\ \ system\ \ small\ \ problem\ \ elapsed\ \ time}{big\ \ system\ \ big\ \ problem\ \ elapsed\ \ time}$
  - Scale up is linear if equation equals 1

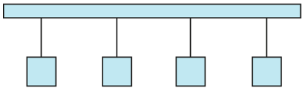
RDBMS Architecture: Parallel Systems: Speedup and Scaleup

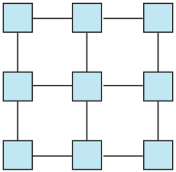


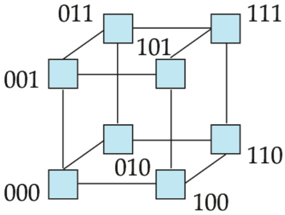
- Speedup and Scaleup are often sublinear due to:
  - **Startup costs**: Cost of starting up multiple processes may dominate computation time, if the degree of parallelism is high
  - **Interference**: Processes accessing shared resources (e.g., system bus, disks, or locks) compete with each other, thus spending time waiting on other processes, rather than performing useful work
  - **Skew**: Increasing the degree of parallelism increases the variance in service times of parallely executing tasks. Overall execution time determined by slowest of parallely executing tasks

RDBMS Architecture: Parallel Systems: Interconnect

- **Bus**: Components send data on and receive data from a single communication bus
  - Does not scale well with increasing parallelism
- **Mesh**: Components are arranged as nodes in a grid, and each component is connected to all adjacent components
  - Communication links grow with growing number of components, and so scales better
  - But may require $2\sqrt{n}$ hops to send message to a node ($\sqrt{n}$ with wraparound connections at edge)
- **Hypercube**: Components are numbered in binary; components are connected to one another if their binary representations differ in exactly one bit
  - n components are connected to $\log n$ other components and can reach each other via at most $\log n$ links; reduces communication delays

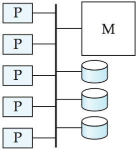




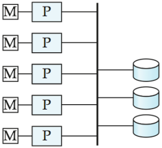


RDBMS Architecture: Parallel Systems

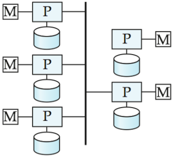
- **Shared memory**: processors share a common memory
- **Shared disk**: processors share a common disk
- **Shared nothing**: processors share neither a common memory nor common disk
- **Hierarchical**: hybrid of the above architectures



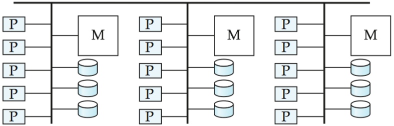
(a) shared memory



(b) shared disk



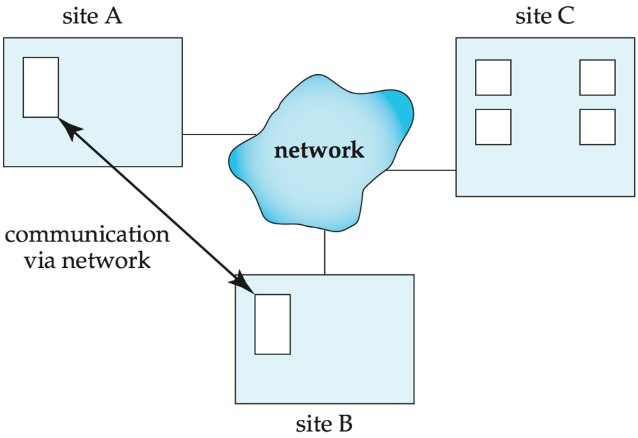
(c) shared nothing



(d) hierarchical

RDBMS Architecture: Distributed Systems

- Data spread over multiple machines (**sites** or **nodes**)
- Network interconnects the machines
- Data shared by users on multiple machines



RDBMS Architecture: Distributed Systems

- **Homogeneous** distributed databases
  - Same software/schema on all sites, data may be partitioned among sites
  - **Goal**: provide a view of a single database, hiding details of distribution
- **Heterogeneous** distributed databases
  - Different software/schema on different sites
  - **Goal**: integrate existing databases to provide useful functionality
- Differentiate between local and global transactions
  - A **local transaction** accesses data in the single site at which the transaction was initiated
  - A **global transaction** either accesses data in a site different from the one at which the transaction was initiated or accesses data in several different sites

RDBMS Architecture: Distributed Systems

- **Advantages**
  - **Sharing data**: users at one site able to access the data residing at some other sites
  - **Autonomy**: each site is able to retain a degree of control over data stored locally
  - **Higher system availability through redundancy**: data can be replicated at remote sites, and system can function even if a site fails
- **Disadvantages**
  - Added complexity required to ensure proper coordination among sites
    - Software development cost
    - Greater potential for bugs
    - Increased processing overhead

Scaling Databases

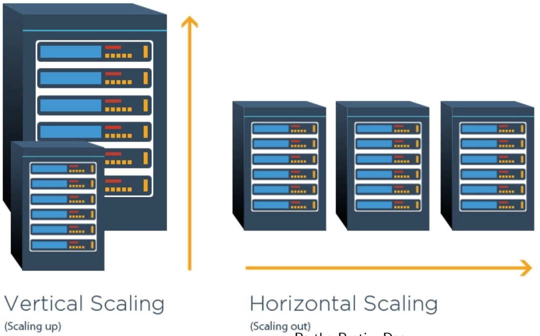
Scaling RDBMS

- Relational databases → mainstay of business
- Web-based applications caused spikes explosion of social media sites (Facebook, Twitter) with large data needs rise of cloud-based solutions such as Amazon S3 (simple storage solution)
- Hooking RDBMS to web-based application becomes trouble
- *Issues with Scaling Up*
  - Best way to provide ACID and rich query model is to have the dataset on a *single m/c*
  - Limits to scaling up (*vertical scaling*: make a "single" machine more powerful) → dataset is just too big!
  - Scaling out (*horizontal scaling*: adding more smaller/cheaper servers) is a better
  - Different approaches for horizontal scaling (multi-node database):
    - Master/Slave
    - Sharding (partitioning)

Source: *Introduction to NOSQL Databases, SlidePlayer*

Horizontal Vs. Vertical Scaling

- **What Is Horizontal Scaling?**
  - Horizontal scaling (aka scaling out) is adding additional nodes to infrastructure
  - This adds complexity of your operation. You must decide which machine does what and how your new machines work with your old machines
- **What Is Vertical Scaling?**
  - Vertical scaling (aka scaling up) describes adding additional resources to a system
  - It adds more power to your current machines



Horizontal Vs. Vertical Scaling (2)

Horizontal Scaling	Vertical Scaling
Advantages	
• Scaling is easier from a hardware perspective • Fewer periods of downtime • Increased resilience and fault tolerance • Increased performance	• Cost-effective • Less complex process communication • Less complicated maintenance • Less need for software changes
Disadvantages	
• Increased complexity of maintenance and operation • Increased Initial costs	• Higher possibility for downtime • Single point of failure • Upgrade limitations

Source: *Horizontal Vs. Vertical Scaling: How Do They Compare?*

Scaling out RDBMS

- **Master/Slave**
  - All writes are written to the master
  - All reads performed against the replicated slave databases
  - Critical reads may be incorrect as writes may not have been propagated down
  - Large datasets can pose problems as master needs to duplicate data to slaves
- **Sharding (Partitioning)**
  - Scales well for both reads and writes
  - Not transparent, application needs to be partition-aware
  - Can no longer have relationships/joins across partitions
  - Loss of referential integrity across shards
- **Other Options**
  - Multi-Master replication
  - INSERT only, not UPDATES/DELETES
  - No JOINs, thereby reducing query time $\rightarrow$ This involves de-normalizing data
  - In-memory databases

Source: *Introduction to NOSQL Databases, SlidePlayer*

Module Summary

- Evaluated RDBMS, especially with reference to performance and scalability, as a backbone for data-intensive application development
- Understood the role of system and database architecture in performance
- Understood the options for scaling databases

Slides used in this presentation are borrowed from http://db-book.com/ with kind permission of the authors.
Edited and new slides are marked with "PPD".