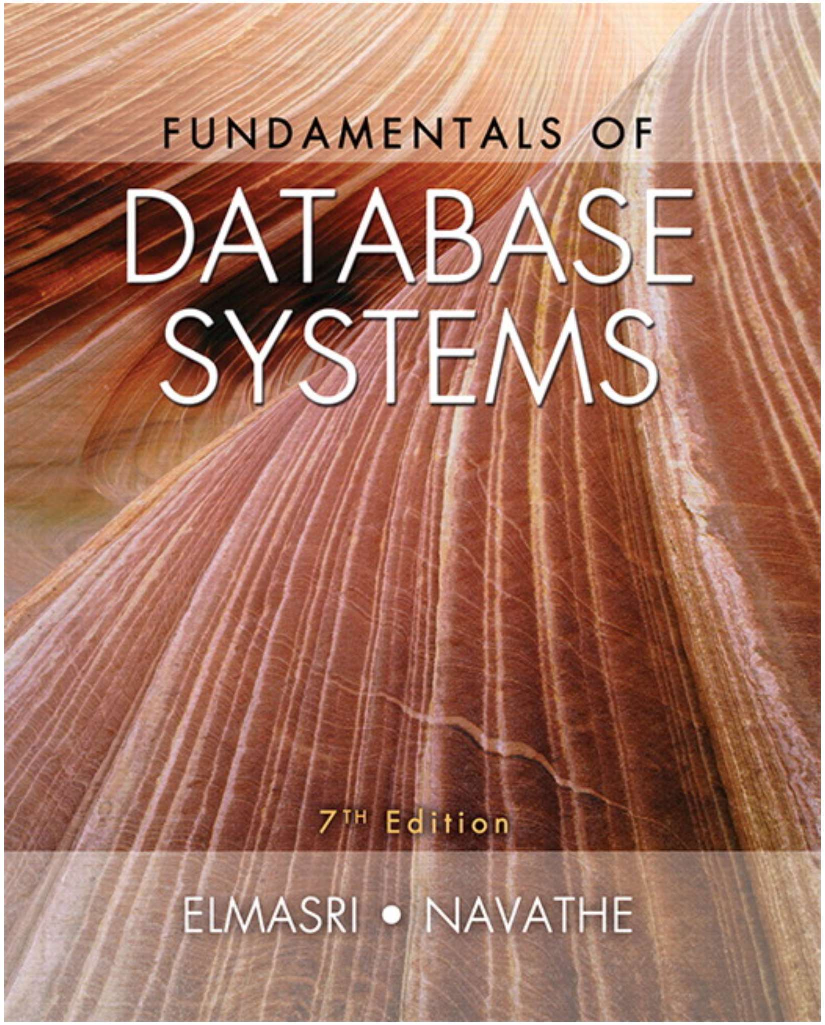

FUNDAMENTALS OF
DATABASE SYSTEMS
7TH Edition
ELMASRI • NAVATHE

CHAPTER 23

Distributed Database Concepts

Introduction

- Distributed computing system
  - Consists of several processing sites or nodes interconnected by a computer network
  - Nodes cooperate in performing certain tasks
  - Partitions large task into smaller tasks for efficient solving
- Big data technologies
  - Combine distributed and database technologies
  - Deal with mining vast amounts of data

23.1 Distributed Database Concepts

- What constitutes a distributed database?
  - Connection of database nodes over computer network
  - Logical interrelation of the connected databases
  - Possible absence of homogeneity among connected nodes
- Distributed database management system (DDBMS)
  - Software system that manages a distributed database

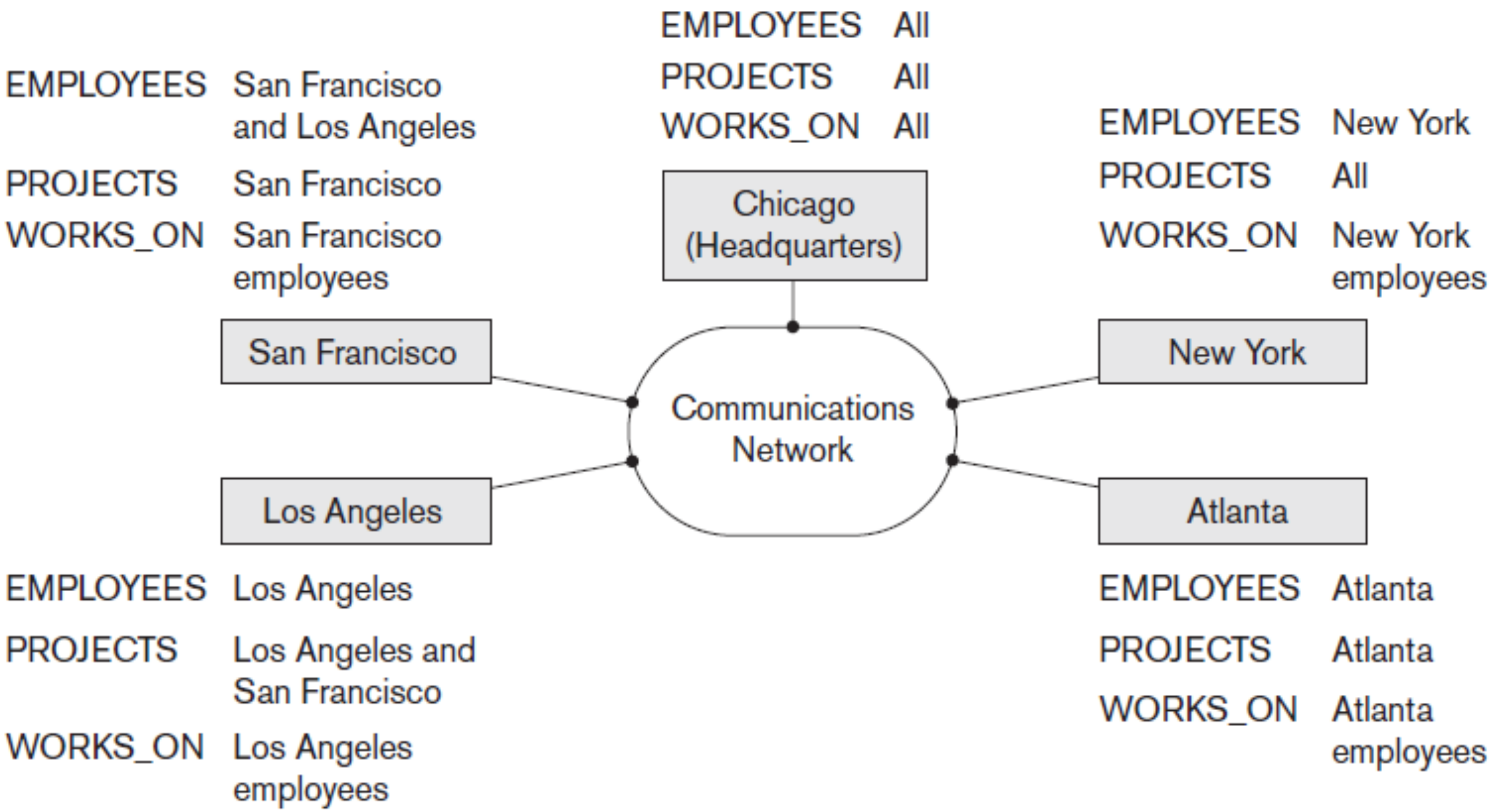
Distributed Database Concepts (cont'd.)

- Local area network
  - Hubs or cables connect sites
- Long-haul or wide area network
  - Telephone lines, cables, wireless, or satellite connections
- Network topology defines communication path
- Transparency
  - Hiding implementation details from the end user

Transparency

- Types of transparency
  - Data organization transparency
    - Location transparency
    - Naming transparency
  - Replication transparency
  - Fragmentation transparency
    - Horizontal fragmentation
    - Vertical fragmentation
  - Design transparency
  - Execution transparency

Distributed Databases



Chicago (Headquarters)

EMPLOYEES	All
PROJECTS	All
WORKS_ON	All

San Francisco

EMPLOYEES	San Francisco and Los Angeles
PROJECTS	San Francisco
WORKS_ON	San Francisco employees

Los Angeles

EMPLOYEES	Los Angeles
PROJECTS	Los Angeles and San Francisco
WORKS_ON	Los Angeles employees

New York

EMPLOYEES	New York
PROJECTS	All
WORKS_ON	New York employees

Atlanta

EMPLOYEES	Atlanta
PROJECTS	Atlanta
WORKS_ON	Atlanta employees

Figure 23.1 Data distribution and replication among distributed databases

Availability and Reliability

- Availability
  - Probability that the system is continuously available during a time interval
- Reliability
  - Probability that the system is running (not down) at a certain time point
- Both directly related to faults, errors, and failures
- Fault-tolerant approaches

Scalability and Partition Tolerance

- Horizontal scalability
  - Expanding the number of nodes in a distributed system
- Vertical scalability
  - Expanding capacity of the individual nodes
- Partition tolerance
  - System should have the capacity to continue operating while the network is partitioned

Autonomy

- Determines extent to which individual nodes can operate independently
- Design autonomy
  - Independence of data model usage and transaction management techniques among nodes
- Communication autonomy
  - Determines the extent to which each node can decide on sharing information with other nodes
- Execution autonomy
  - Independence of users to act as they please

Advantages of Distributed Databases

- Improved ease and flexibility of application development
  - Development at geographically dispersed sites
- Increased availability
  - Isolate faults to their site of origin
- Improved performance
  - Data localization
- Easier expansion via scalability
  - Easier than in non-distributed systems

23.2 Data Fragmentation, Replication, and Allocation Techniques for Distributed Database Design

- Fragments
  - Logical units of the database
- Horizontal fragmentation (sharding)
  - Horizontal fragment or shard of a relation is a subset of the tuples in that relation
  - Can be specified by condition on one or more attributes or by some other method
  - Groups rows to create subsets of tuples
    - Each subset has a certain logical meaning

Data Fragmentation (cont'd.)

- Vertical fragmentation
  - Divides a relation vertically by columns
  - Keeps only certain attributes of the relation
- Complete horizontal fragmentation
  - Apply UNION operation to the fragments to reconstruct relation
- Complete vertical fragmentation
  - Apply OUTER UNION or FULL OUTER JOIN operation to reconstruct relation

Data Fragmentation (cont’d.)

- Mixed (hybrid) fragmentation
  - Combination of horizontal and vertical fragmentations
- Fragmentation schema
  - Defines a set of fragments that includes all attributes and tuples in the database
- Allocation schema
  - Describes the allocation of fragments to nodes of the DDBS

Data Replication and Allocation

- Fully replicated distributed database
  - Replication of whole database at every site in distributed system
  - Improves availability remarkably
  - Update operations can be slow
- Nonredundant allocation (no replication)
  - Each fragment is stored at exactly one site

Data Replication and Allocation (cont'd.)

- Partial replication
  - Some fragments are replicated and others are not
  - Defined by replication schema
- Data allocation (data distribution)
  - Each fragment assigned to a particular site in the distributed system
  - Choices depend on performance and availability goals of the system

Example of Fragmentation, Allocation, and Replication

- Company with three computer sites
  - One for each department
  - Expect frequent access by employees working in the department and projects controlled by that department
- See Figures 23.2 and 23.3 in the text for example fragmentation among the three sites

23.3 Overview of Concurrency Control and Recovery in Distributed Databases

- Problems specific to distributed DBMS environment
  - Multiple copies of the data items
  - Failure of individual sites
  - Failure of communication links
  - Distributed commit
  - Distributed deadlock

Distributed Concurrency Control Based on a Distinguished Copy of a Data Item

- Particular copy of each data item designated as distinguished copy
  - Locks are associated with the distinguished copy
- Primary site technique
  - All distinguished copies kept at the same site
- Primary site with backup site
  - Locking information maintained at both sites
- Primary copy method
  - Distributes the load of lock coordination among various sites

Distributed Concurrency Control Based on Voting

- Voting method
  - No distinguished copy
  - Lock requests sent to all sites that contain a copy
  - Each copy maintains its own lock
  - If transaction that requests a lock is granted that lock by a majority of the copies, it holds the lock on all copies
  - Time-out period applies
  - Results in higher message traffic among sites

Distributed Recovery

- Difficult to determine whether a site is down without exchanging numerous messages with other sites
- Distributed commit
  - When a transaction is updating data at several sties, it cannot commit until certain its effect on every site cannot be lost
  - Two-phase commit protocol often used to ensure correctness

23.4 Overview of Transaction Management in Distributed Databases

- Global transaction manager
  - Supports distributed transactions
  - Role temporarily assumed by site at which transaction originated
    - Coordinates execution with transaction managers at multiple sites
  - Passes database operations and associated information to the concurrency controller
    - Controller responsible for acquisition and release of locks

Commit Protocols

- Two-phase
    - Coordinator maintains information needed for recovery
        - In addition to local recovery managers
- Three-phase
    - Divides second commit phase into two subphases
        - Prepare-to-commit phase communicates result of the vote phase
        - Commit subphase same as two-phase commit counterpart

23.5 Query Processing and Optimization in Distributed Databases

- Stages of a distributed database query
  - Query mapping
    - Refers to global conceptual schema
  - Localization
    - Maps the distributed query to separate queries on individual fragments
  - Global query optimization
    - Strategy selected from list of candidates
  - Local query optimization
    - Common to all sites in the DDB

Query Processing and Optimization in Distributed Databases (cont'd.)

- Data transfer costs of distributed query processing
  - Cost of transferring intermediate and final result files
- Optimization criterion: reducing amount of data transfer

Query Processing and Optimization in Distributed Databases (cont'd.)

- Distributed query processing using semijoin
  - Reduces the number of tuples in a relation before transferring it to another site
  - Send the joining column of one relation R to one site where the other relation S is located
  - Join attributes and result attributes shipped back to original site
  - Efficient solution to minimizing data transfer

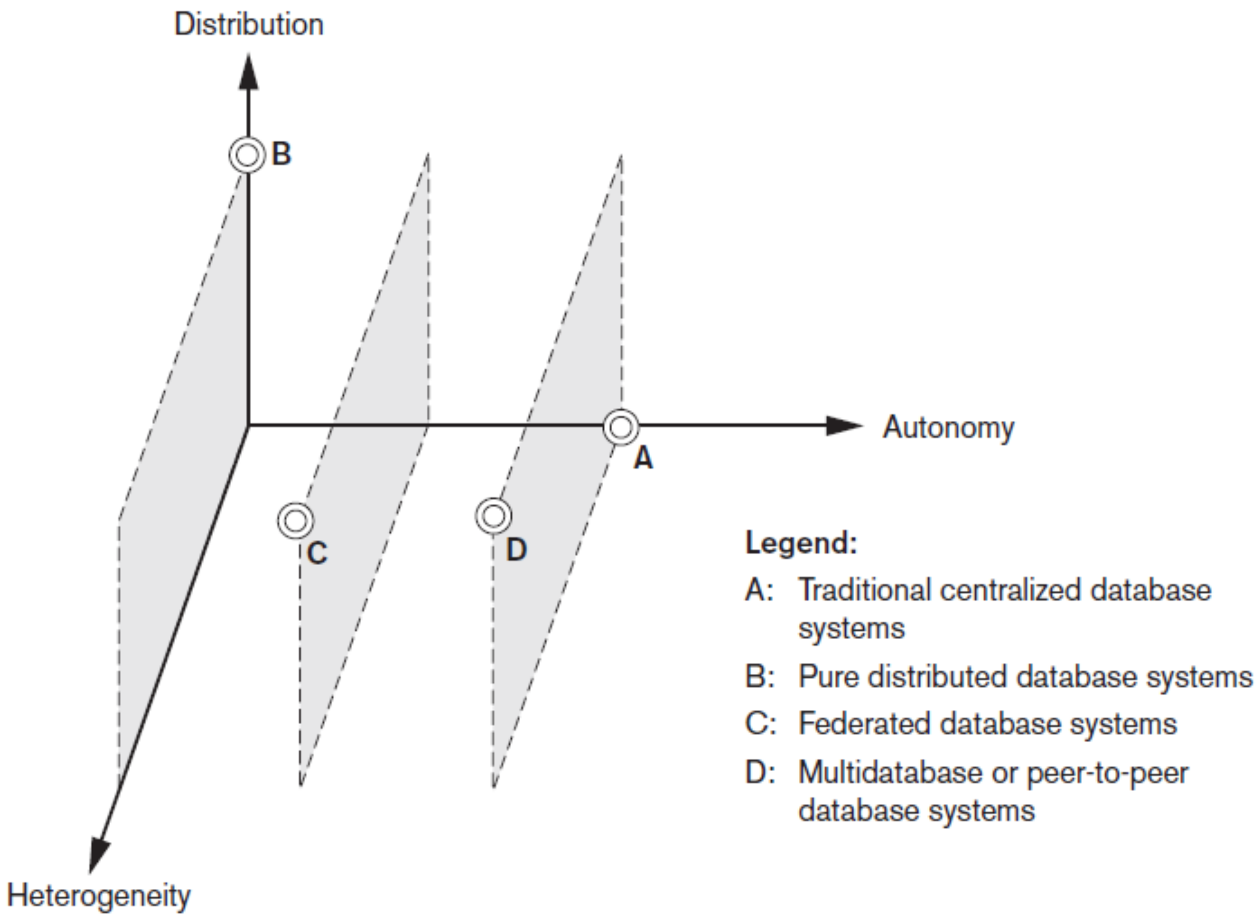
Query Processing and Optimization in Distributed Databases (cont'd.)

- Query and update decomposition
  - User can specify a query as if the DBMS were centralized
    - If full distribution, fragmentation, and replication transparency are supported
  - Query decomposition module
    - Breaks up a query into subqueries that can be executed at the individual sites
    - Strategy for combining results must be generated
  - Catalog stores attribute list and/or guard condition

23.6 Types of Distributed Database Systems

- Factors that influence types of DDBMSs
  - Degree of homogeneity of DDBMS software
    - Homogeneous
    - Heterogeneous
  - Degree of local autonomy
    - No local autonomy
    - Multidatabase system has full local autonomy
- Federated database system (FDBS)
  - Global view or schema of the federation of databases is shared by the applications

Classification of Distributed Databases



Legend:

- A: Traditional centralized database systems
- B: Pure distributed database systems
- C: Federated database systems
- D: Multidatabase or peer-to-peer database systems

Figure 23.6 Classification of distributed databases

Types of Distributed Database Systems (cont'd.)

- Federated database management systems issues
  - Differences in data models
  - Differences in constraints
  - Differences in query languages
- Semantic heterogeneity
  - Differences in meaning, interpretation, and intended use of the same or related data

Types of Distributed Database Systems (cont'd.)

- Design autonomy allows definition of the following parameters
  - The universe of discourse from which the data is drawn
  - Representation and naming
  - Understanding, meaning, and subjective interpretation of data
  - Transaction and policy constraints
  - Derivation of summaries

Types of Distributed Database Systems (cont'd.)

- Communication autonomy
  - Decide whether to communicate with another component DBS
- Execution autonomy
  - Execute local operations without interference from external operations by other component DBSs
  - Ability to decide order of execution
- Association autonomy
  - Decide whether and how much to share its functionality and resources

23.7 Distributed Database Architectures

- Parallel versus distributed architectures
- Types of multiprocessor system architectures
  - Shared memory (tightly coupled)
  - Shared disk (loosely coupled)
  - Shared-nothing

Database System Architectures

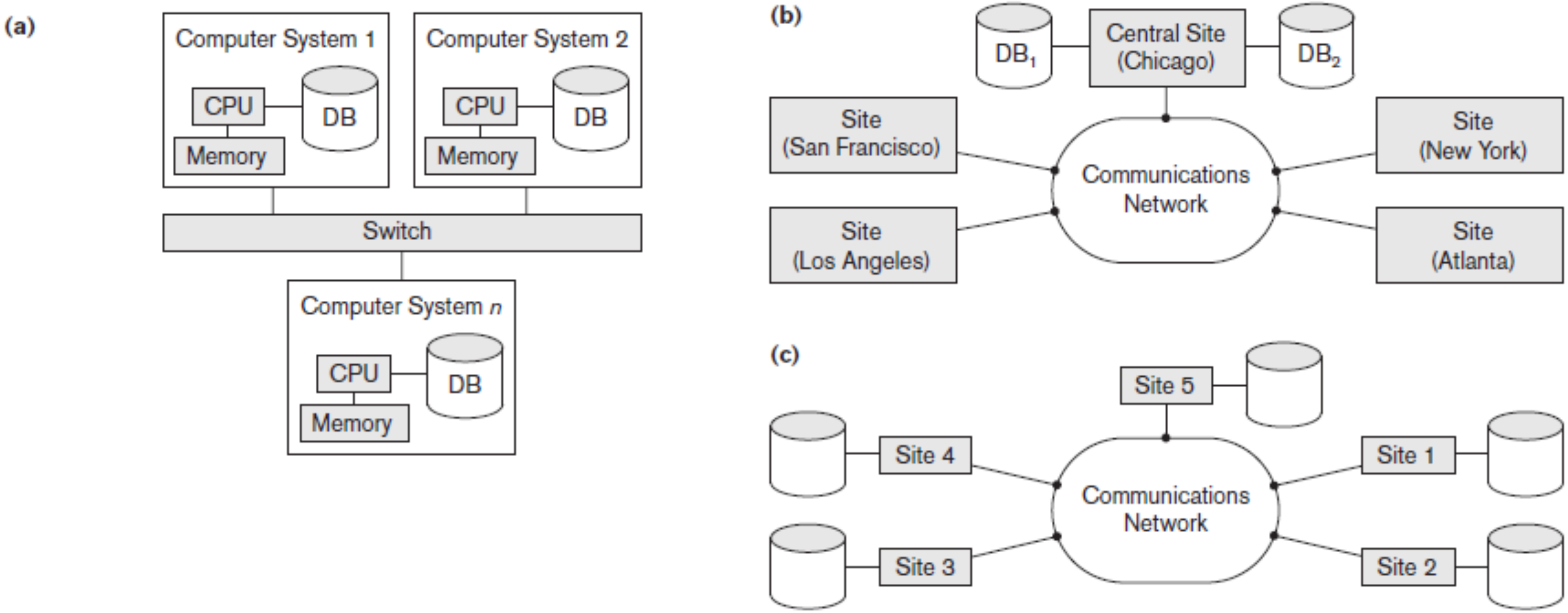


Figure 23.7 Some different database system architectures (a) Shared-nothing architecture (b) A networked architecture with a centralized database at one of the sites (c) A truly distributed database architecture

General Architecture of Pure Distributed Databases

- Global query compiler
  - References global conceptual schema from the global system catalog to verify and impose defined constraints
- Global query optimizer
  - Generates optimized local queries from global queries
- Global transaction manager
  - Coordinates the execution across multiple sites with the local transaction managers

Schema Architecture of Distributed Databases

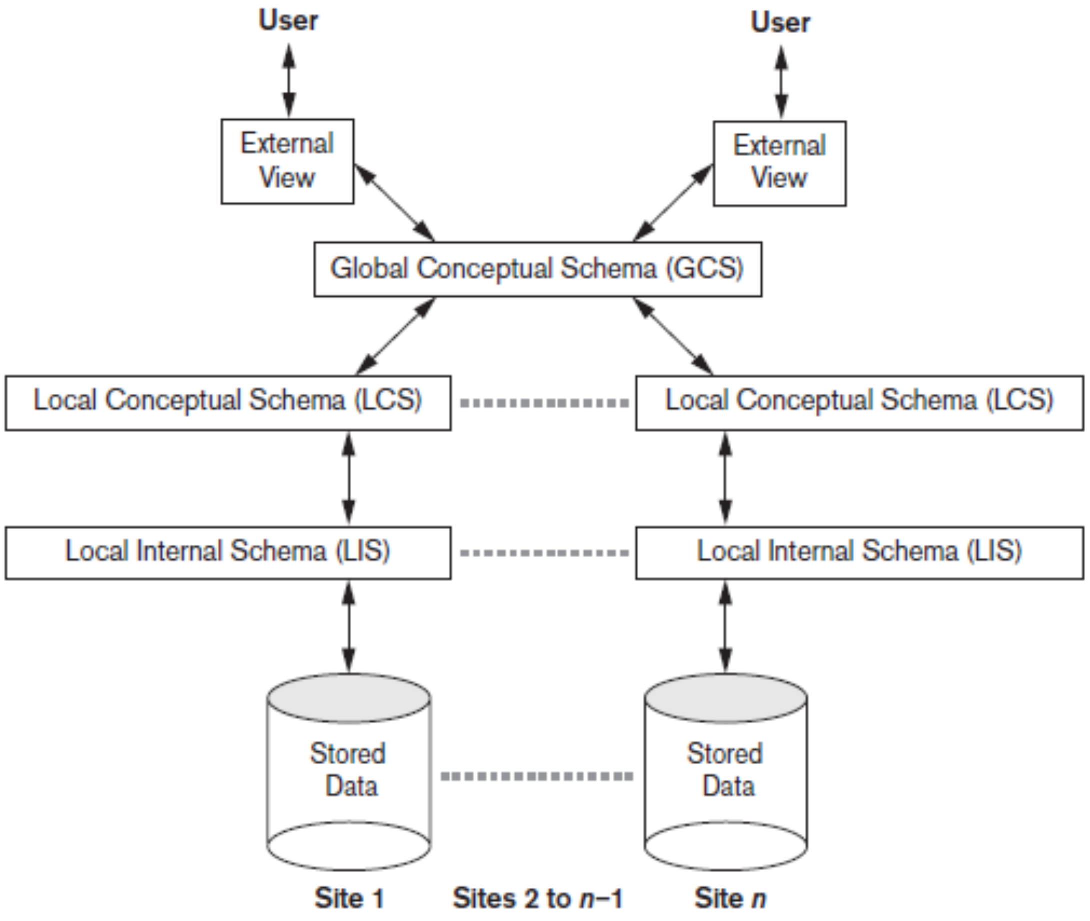

User
User
External View
External View
Global Conceptual Schema (GCS)
Local Conceptual Schema (LCS)
Local Conceptual Schema (LCS)
Local Internal Schema (LIS)
Local Internal Schema (LIS)
Stored Data
Stored Data
Site 1
Sites 2 to n–1
Site n

Figure 23.8 Schema architecture of distributed databases

Federated Database Schema Architecture

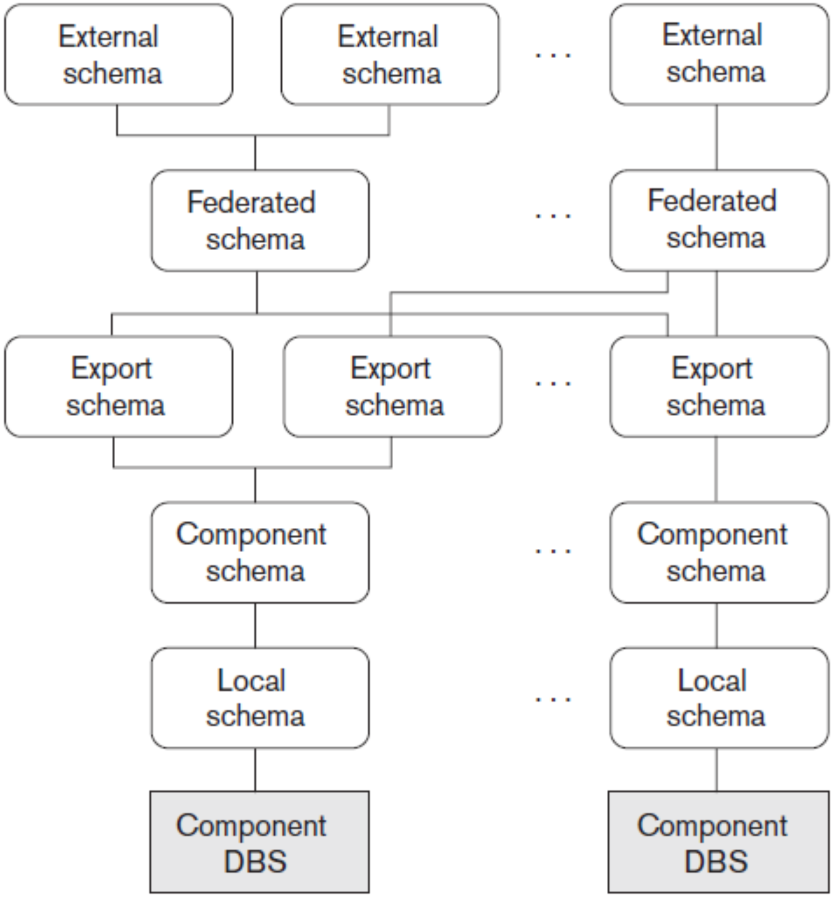


Figure 23.9 The five-level schema architecture in a federated database system (FDBS)

An Overview of Three-Tier Client/Server Architecture

- Division of DBMS functionality among the three tiers can vary

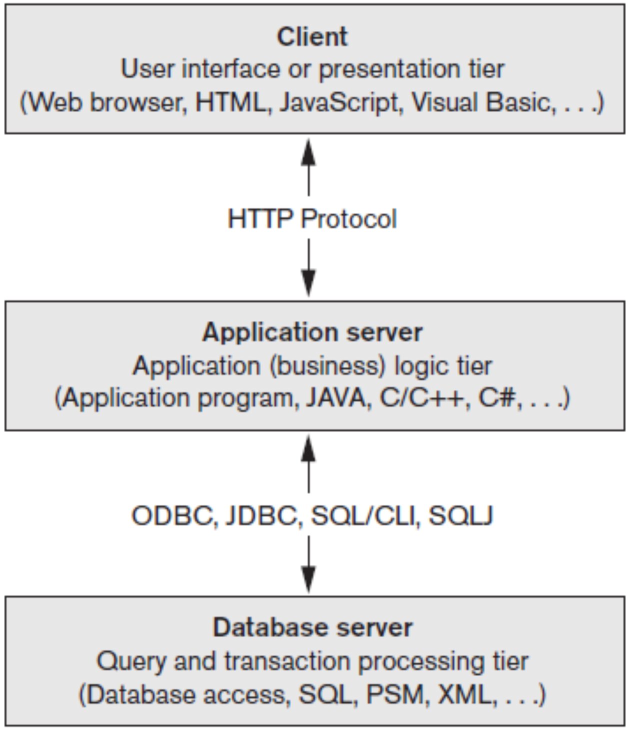

Client
User interface or presentation tier
(Web browser, HTML, JavaScript, Visual Basic, . . .)
HTTP Protocol
Application server
Application (business) logic tier
(Application program, JAVA, C/C++, C#, . . .)
ODBC, JDBC, SQL/CLI, SQLJ
Database server
Query and transaction processing tier
(Database access, SQL, PSM, XML, . . .)

Figure 23.10 The three-tier client/server architecture

23.8 Distributed Catalog Management

- Centralized catalogs
  - Entire catalog is stored at one single site
  - Easy to implement
- Fully replicated catalogs
  - Identical copies of the complete catalog are present at each site
  - Results in faster reads
- Partially replicated catalogs
  - Each site maintains complete catalog information on data stored locally at that site

23.9 Summary

- Distributed database concept
- Distribution transparency
- Fragmentation transparency
- Replication transparency
- Design issues
  - Horizontal and vertical fragmentation
- Concurrency control and recovery techniques
- Query processing
- Categorization of DDBMSs