Database Systems II

Lecture 11

Distributed Database Systems

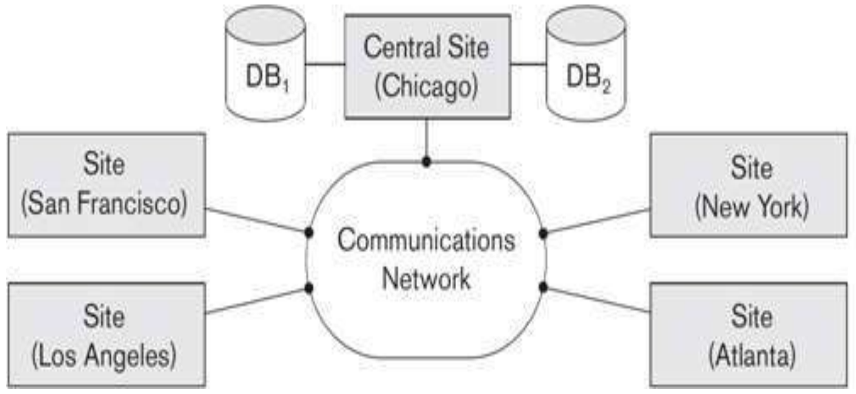
Lecture Outline

- What is a Distributed Database?
    - Centralized Vs DDBs
    - Parallel Vs DDBs
- Distributed Data Design
- Types of DDBs
- Advantages of DDBs

What is a Distributed Database?

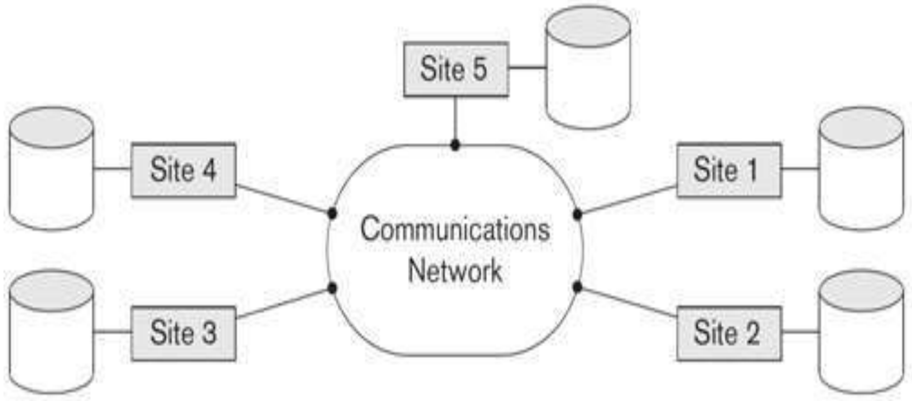
- A collection of multiple logically related database distributed over a computer network.
  - Database whose relations *reside* on different sites
  - Database whose relations are *split* between different sites
  - Database whose some of its relations are *replicated* at different sites
- A *Distributed Database Management System (DDBMS)* is the software system that manages a distributed database and makes the distribution *transparent* to the user.

Centralized Vs. Distributed Databases



In centralized database

- Data is located in one place (one server)
- All DBMS functionalities are done by that server



In Distributed Databases

- Data is stored in multiple places (each is running a DBMS)
- DBMS functionalities are distributed over many machines

Why Might Data be Distributed

- To minimize communication costs or response time.
- Maintain control and security.
- To increase its availability in the event of failure.
- Data is too large.

Parallel VS. Distributed Databases

In Parallel Database System (To improve performance through parallelization)

- DBMS running across *multiple processors and disks* that is designed to execute operations in parallel, whenever possible, in order to improve performance.
- Distributed processing usually imply *parallel processing* (not distribution of data)
- Can have parallel processing on a single machine

In Distributed Database System (To increased availability)

- Data is physically stored across *several sites*, and each site is managed by a DBMS capable of running independent of the other sites.
- In contrast to parallel databases, *sharing data is the key* of a DDBs

Different Architectures

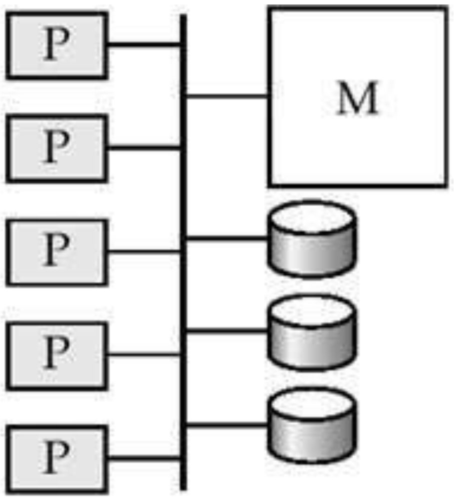
Three possible architectures for passing and processing data:

a) **Shared memory** -- processors share a common memory

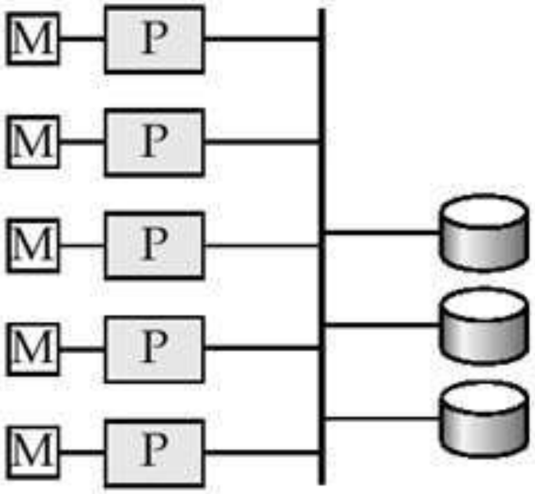
b) **Shared disk** -- processors share a common disk

c) **Shared nothing** -- processors share neither a common memory nor common disk

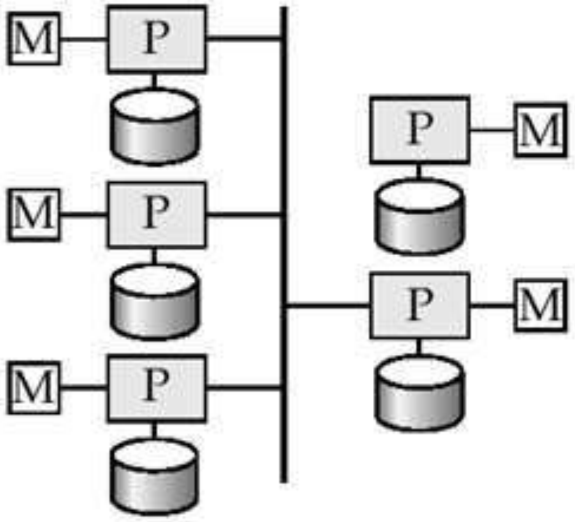
Different Architectures



(a) shared memory



(b) shared disk



(c) shared nothing

Parallel VS. Distributed Databases

In Parallel Databases

- Machines are physically *close to each* other, e.g., same server room
- Machines connects with dedicated high-speed LANs and switches
- Communication cost is assumed to be small.
- Can *shared-memory*, *shared-disk*, or *shared-nothing* architecture

In Distributed Databases

- Machines can be *far from each other*, e.g., in different continent
- Can be connected using public-purpose network, e.g., Internet
- Communication cost and problems cannot be ignored.
- *Usually shared-nothing architecture.*

Distributed Database Design

- **Three key issues:**

I. Fragmentation

Relation may be divided into a number of sub-relations, which are then distributed.

II. Allocation

Each fragment/replica is stored at site with "optimal" distribution.

III. Replication

Copy of fragment may be maintained at several sites.

Distributed Data Design: Fragmentation

I. Data Fragmentation

- Split a relation into logically related parts. A relation can be fragmented in three ways:
  - Horizontal Fragmentation
  - Vertical Fragmentation
  - Mixed (Hybrid) fragmentation

Distributed Data Design: Fragmentation

Horizontal Fragmentation

- It is a horizontal subset of a relation which contain tuples that satisfy a selection conditions.
- Consider the Employee relation with selection condition (DNO = 5). All tuples satisfy this condition will create a subset which will be a horizontal fragment of Employee relation.
- To reconstruct R from horizontal fragments a UNION is applied.

Distributed Data Design: Fragmentation

Horizontal fragmentation

PROJ

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
P2	Database Develop.	135000	New York
P3	CAD/CAM	250000	New York
P4	Maintenance	310000	Paris
P5	CAD/CAM	500000	Boston

$PROJ_1$

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
P2	Database Develop.	135000	New York

$PROJ_2$

PNO	PNAME	BUDGET	LOC
P3	CAD/CAM	250000	New York
P4	Maintenance	310000	Paris
P5	CAD/CAM	500000	Boston

Distributed Data Design: Fragmentation

- Horizontal Fragmentation Example:

$$P_1 = \sigma_{Dno='5'}(Employee) \rightarrow \text{Site 1}$$

$$P_2 = \sigma_{Dno='7'}(Employee) \rightarrow \text{Site 2}$$

To reconstruct Employee relation:

$$P_1 \cup P_2$$

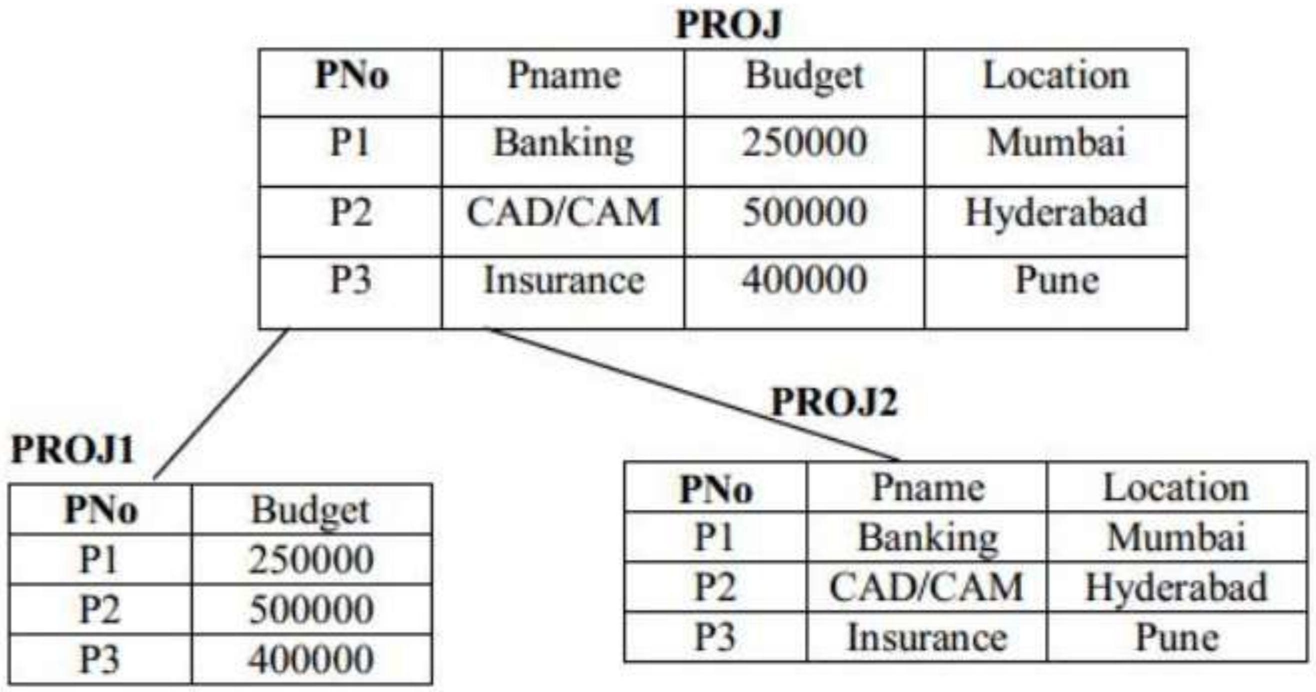
Distributed Data Design: Fragmentation

Vertical Fragmentation

- It is a subset of a relation which is created by a subset of columns. There is no selection condition used in vertical fragmentation.
- Consider the Employee relation. A vertical fragment can be created by projecting (π) the values of Name, DoB, and Address.
- Because there is no condition for creating a vertical fragment, *each fragment must include the primary key attribute of the parent relation* Employee. In this way all vertical fragments of a relation are connected.
- To reconstruct R from complete vertical fragments a OUTER JOIN is applied.

Distributed Data Design: Fragmentation

- Vertical Fragmentation



PROJ

PNo	Pname	Budget	Location
P1	Banking	250000	Mumbai
P2	CAD/CAM	500000	Hyderabad
P3	Insurance	400000	Pune

PROJ1

PNo	Budget
P1	250000
P2	500000
P3	400000

PROJ2

PNo	Pname	Location
P1	Banking	Mumbai
P2	CAD/CAM	Hyderabad
P3	Insurance	Pune

Distributed Data Design: Fragmentation

- Vertical Fragmentation Example:

$$S_1 = \Pi_{\text{staffNo, position, DOB, salary}}(\text{Staff})$$
$$S_2 = \Pi_{\text{staffNo, fName, lName, branchNo}}(\text{Staff})$$

To reconstruct Staff relation:

$$S_1 \bowtie S_2$$

Distributed Data Design: Fragmentation

Correctness of Fragmentation *(Three Rules)*

- **Completeness:**

  If relation *R* is decomposed into fragments R_1, R_2, ... R_n, each data item that can be found in *R* must appear in at least one fragment.

- **Reconstruction:**

  - Must be possible to define a relational operation that will reconstruct R from the fragments.

  -Reconstruction for horizontal fragmentation is Union operation and Outer Join for vertical .

- **Disjointness:**

  If data item d_i appears in fragment R_i, then it should not appear in any other fragment. Exception: vertical fragmentation, where primary key attributes must be repeated to allow reconstruction.

Distributed Data Design: Replication

II. Data Replication

- In *full replication* the entire database is replicated and in *partial (selective) replication* some selected parts are replicated to some of the sites.
- *Synchronous* and *asynchronous* replication.

Distributed Data Design: Replication

Advantages of Replication

- **Availability**: failure of site containing relation *r* does not result in unavailability of *R* is replicas exist.
- **Parallelism**: queries on *R* may be processed by several nodes in parallel.
- **Reduced data transfer**: relation *R* is available locally at each site containing a replica of *R*.

Distributed Data Design: Replication

Disadvantages of Replication

- Increased cost of updates: each replica of relation *r* must be updated.
- Increased complexity of concurrency control: concurrent updates to distinct replicas may lead to inconsistent data unless special concurrency control mechanisms are implemented.

Distributed Data Design

- **Fragmentation schema**
  - It describes all set of fragments (horizontal, vertical, or mixed) that includes all attributes and tuples in the database that satisfies the condition so that the whole database can be reconstructed when needed.
- **Allocation schema**
  - It describes the distribution of fragments to sites of distributed databases. It can be fully or partially replicated or can be partitioned.

Comparison of Strategies for Data Distribution

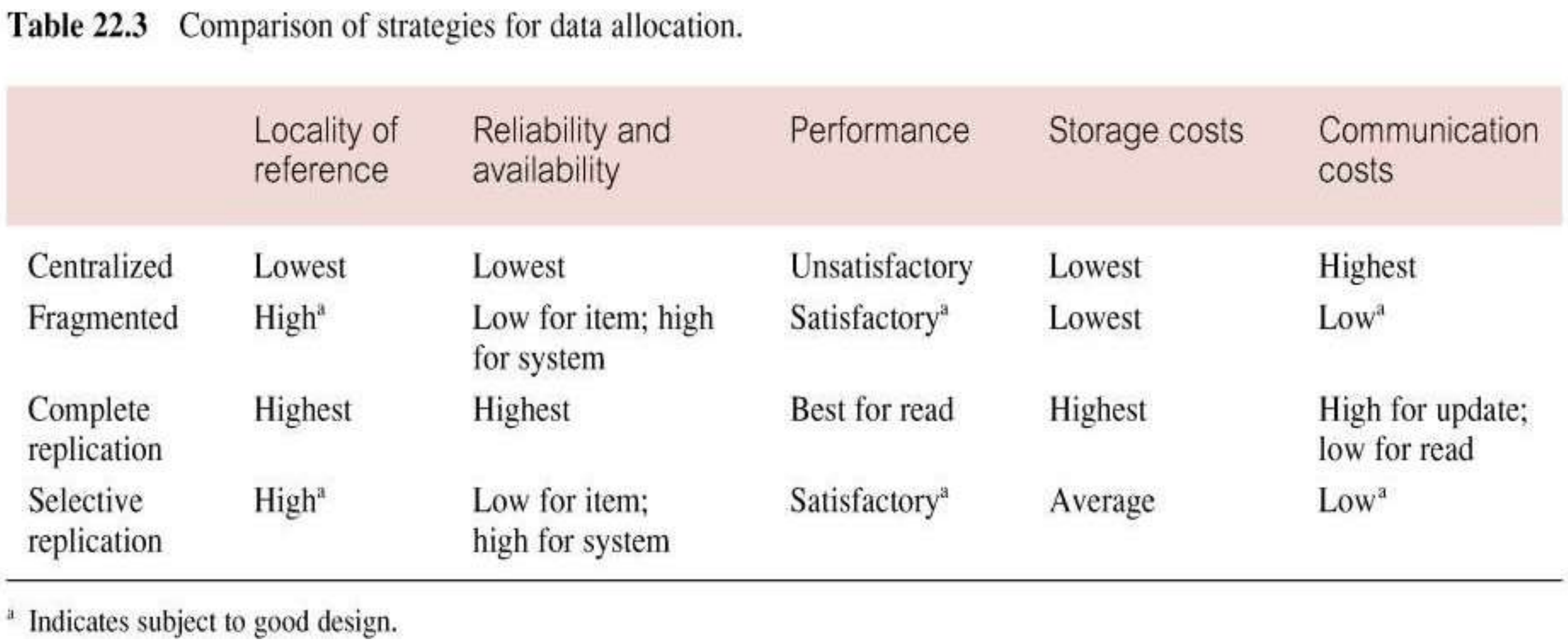


Table 22.3 Comparison of strategies for data allocation.

	Locality of reference	Reliability and availability	Performance	Storage costs	Communication costs
Centralized	Lowest	Lowest	Unsatisfactory	Lowest	Highest
Fragmented	High[a]	Low for item; high for system	Satisfactory[a]	Lowest	Low[a]
Complete replication	Highest	Highest	Best for read	Highest	High for update; low for read
Selective replication	High[a]	Low for item; high for system	Satisfactory[a]	Average	Low[a]

[a] Indicates subject to good design.

Types of Distributed Database Systems

- Three main factors are used to differentiate between different types of DDBMSs.
  - **Autonomy**
  - **Distribution**
  - **Heterogeneity**

Autonomy

- Autonomy refers to the ***distribution of control*** not of data
- It indicates the degree to which individual DBMS can operate independently (*self control*).
- Autonomy is a function of number of factors like:
  - whether the component systems exchange Info,
  - whether they can independently execute transactions, and
  - whether one is allowed to modify them.

Distribution

- Autonomy refers to distribution of control while Distribution refers to the taxonomy of data.
- Here we consider physical distribution of data over multiple sites.
- The user sees data as one logical pool.
- Three levels:
  - non-distributed option (centralized).
  - client-server distribution
  - peer –to – peer distribution(Full)

Distribution

- The client/ server distribution concentrates data management duties at servers while the client focuses on providing the application environment including the user interface.
- In peer to peer system, there is no distinction of client machines and server. Each machine has full DBMS functionality and can communicate with other machines to execute queries and transactions.

Heterogeneity

- Heterogeneity may occur in various forms in distributed systems from hardware heterogeneity and differences in networking protocols to variation in data managers.
- The important ones are related to data models, query languages and transaction management protocols.
- Representing data with different data modeling tools creates heterogeneity because of inherent expressive powers and limitations of individual data models.

Architectural Models for DDBMS

- Autonomy(A): Controller

  0 – Right Integration

  1 – Semi-autonomous System

  2 - Isolation

- Heterogeneity(H):

  0- Homogeneous

  1- Heterogeneous

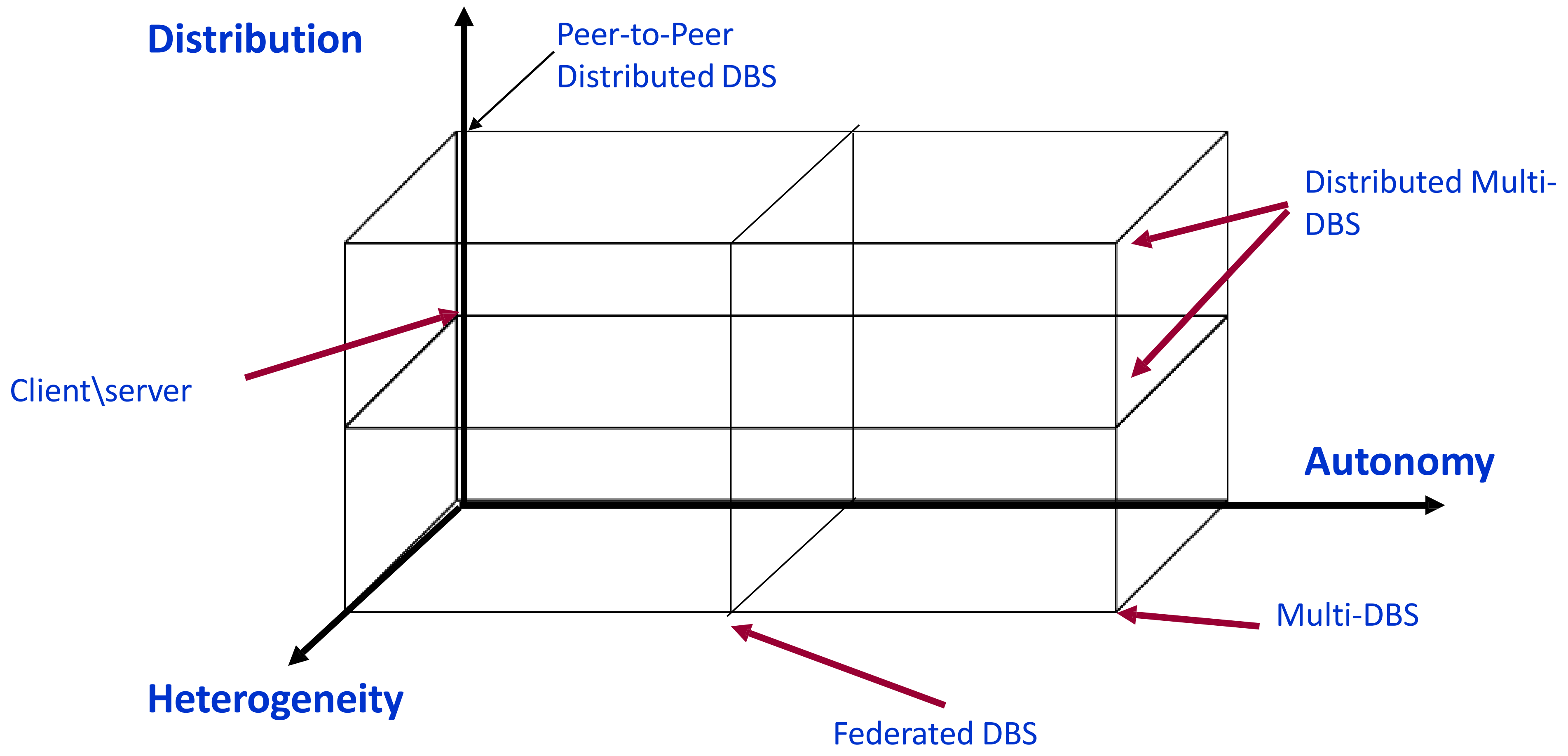
- Distribution(D): Data Management

  0 – No Distribution

  1 – Client – serve Architecture

  2 – Peer-to-peer Architecture

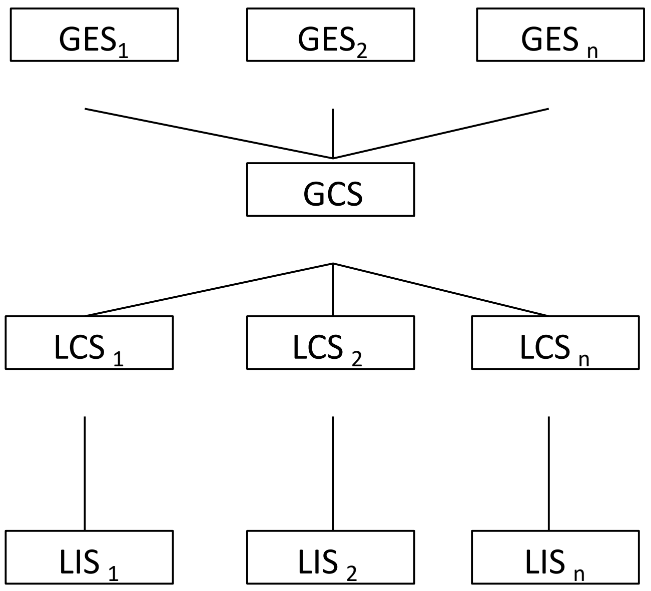
Classification of DDBMS



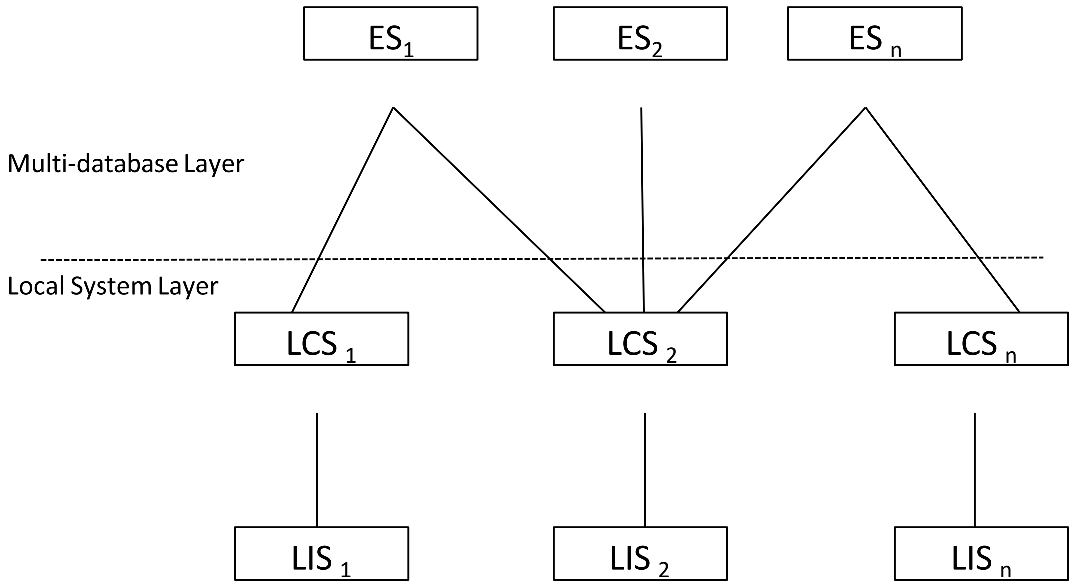
Heterogeneous Distributed Databases

- **Federated:** Each site may run different database system but the data access is managed through a single conceptual schema.
  - This implies that the degree of local autonomy is minimum. Each site must adhere to a centralized access policy. There may be a global schema.
- **Multi-database:** There is no one conceptual global schema. For data access a schema is constructed dynamically as needed by the application software.

Reference Architecture for DDBMS



DDBMS Architecture with a GCS



DDBMS Architecture without a GCS

Distributed Database System Advantages

- **Increased reliability and availability**:
  - Reliability refers to system live time, that is, system is running efficiently most of the time.
  - Availability is the probability that the system is continuously available (usable or accessible) during a time interval.

Distributed Database System Advantages

- **Improved performance**:
  - A distributed DBMS fragments the database to keep data closer to where it is needed most.
  - This reduces data management (access and modification) time significantly.
- **Easier expansion (scalability) !!!!!**
  - Allows new nodes (computers) to be added anytime without chaining the entire configuration.