# Distributed DB architectures: An Introduction

Data Management for Big Data

2018-2019 (spring semester)

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These slides are a modified version of the slides provided with the book

Özsu and Valduriez, *Principles of Distributed Database Systems* (3rd Ed.), 2011

The original version of the slides is available at: extras.springer.com

# Outline (today)

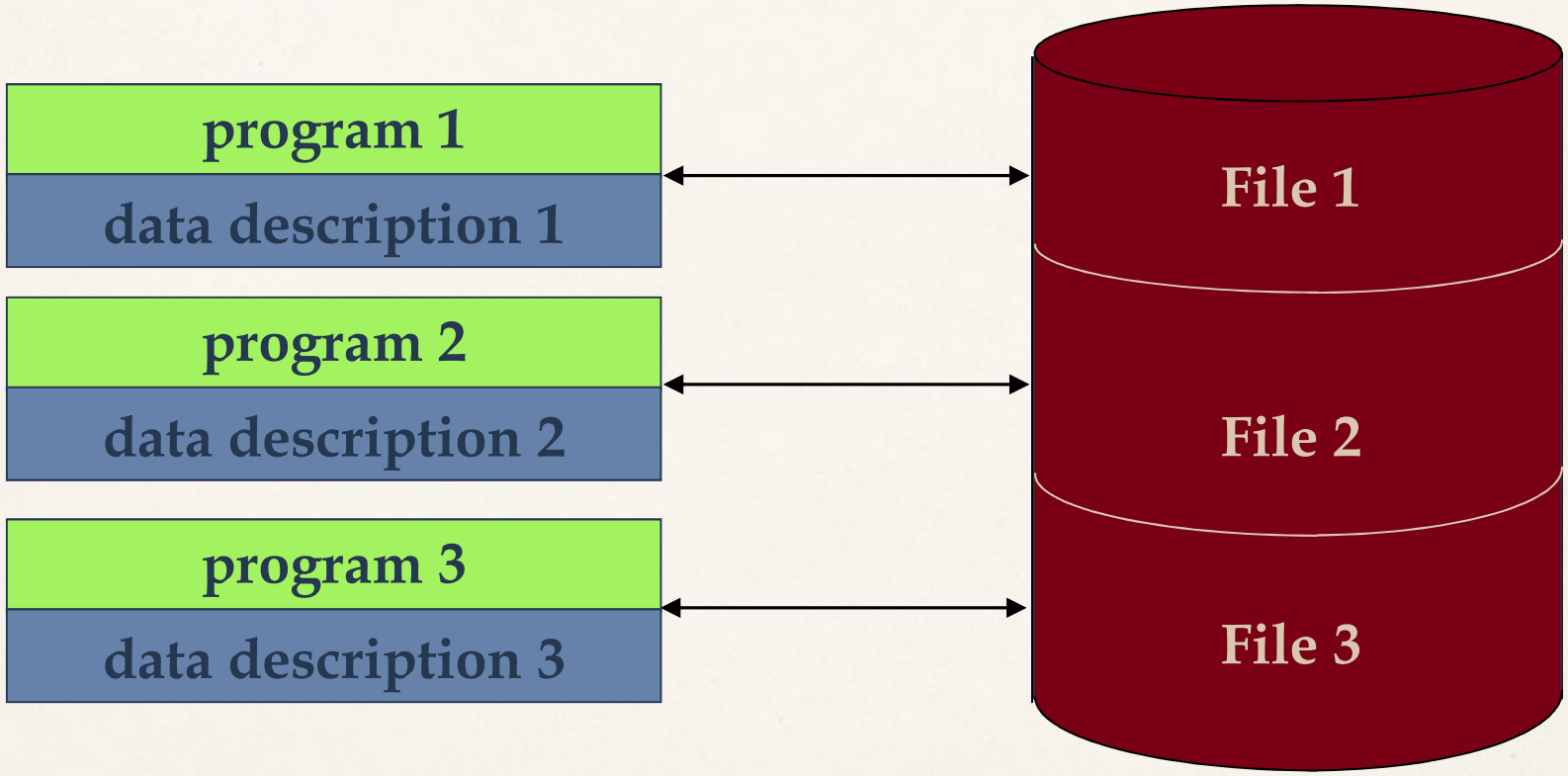
- Introduction (Ch. 1) *
  - Introduction to distributed processing
  - What is (not) a Distributed Database System (DDBS)
  - Data delivery alternatives
  - Promises of DDBS
    - Transparency and its levels
    - Reliability (introduction to the problem of distributed transactions)
    - Improved performances
    - Easier system expansion
  - Design issues (deriving for the promises)
  - Classification of Distributed DBMS (D-DBMS)
    - Dimensions of the classification (autonomy, distribution, heterogeneity)
    - Different D-DBMS Architectures

* Özsu and Valduriez, *Principles of Distributed Database Systems* (3rd Ed.), 2011

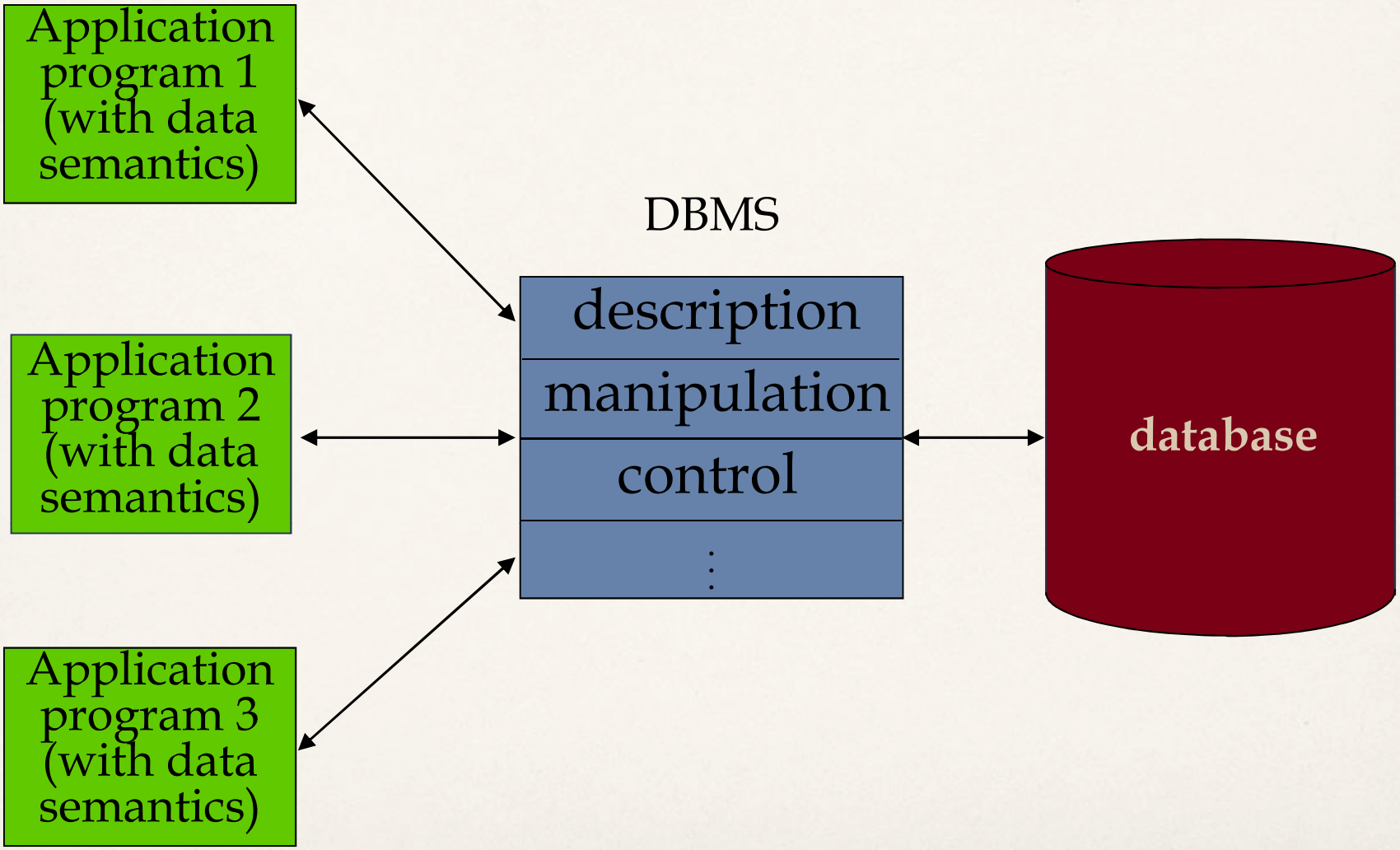
# Centralization, distribution, integration

- Database philosophy
  - Separation between application logic and data
  - Centralization (integration) of data
  - Transparency, data independence, access control
- Computer network
  - Distributed applications
  - Distribution of data (big data)
  - Concurrency, redundancy (backup), localization/proximity
- Distributed databases
  - Centralization data is logical
  - Distribution of data is physical
  - Integration

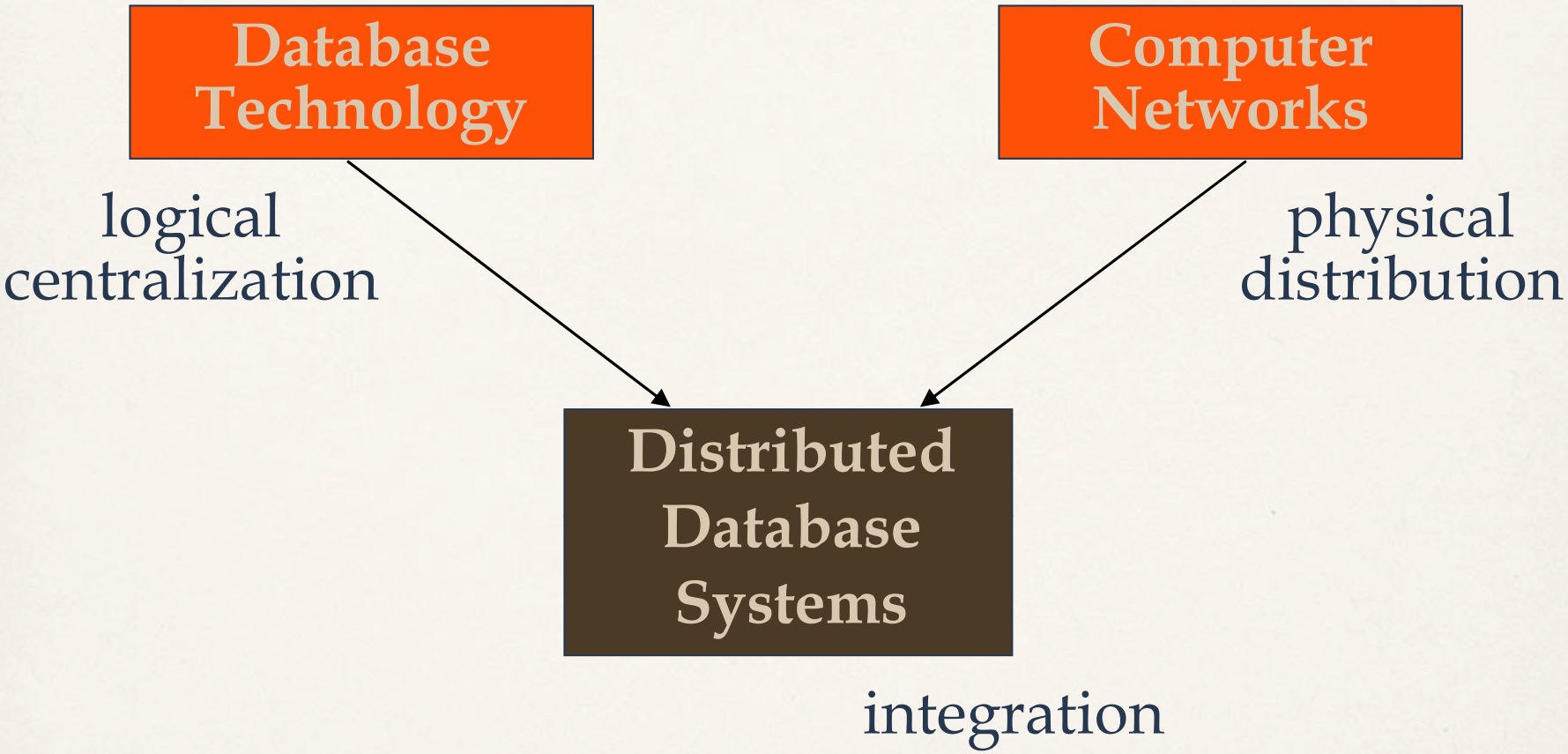
# File Systems



# Database Management



# Motivation




**integration ≠ centralization**

# Distributed Computing

- Some forms of distributed processing are everywhere (CPU vs. I/O, parallel computation, multi-processor, multi-core)
- **Definition (distributed computing).** A number of autonomous processing elements (not necessarily homogeneous) that are interconnected by a computer network and that cooperate in performing their assigned tasks

# Distribution: what and why?

- What is being distributed?
  - Processing logic (pieces of computations)
  - Function (tasks that are specific to a piece of hardware or software)
  - Data
  - Control
- Why to distribute?
  - Widely distributed (physically) enterprises
  - Reliability
  - More responsive systems
  - More importantly: nowadays applications are intrinsically distributed and so is the data (web-based, e-commerce, social)
  - In one word (actually two): big data → divide-et-impera (divide-and-conquer)

distr. DB systems : distr. processing = DB systems : centr. processing

# What is a Distributed Database System?

A distributed database (DDB) is a collection of multiple, *logically interrelated* databases distributed over a *computer network*.

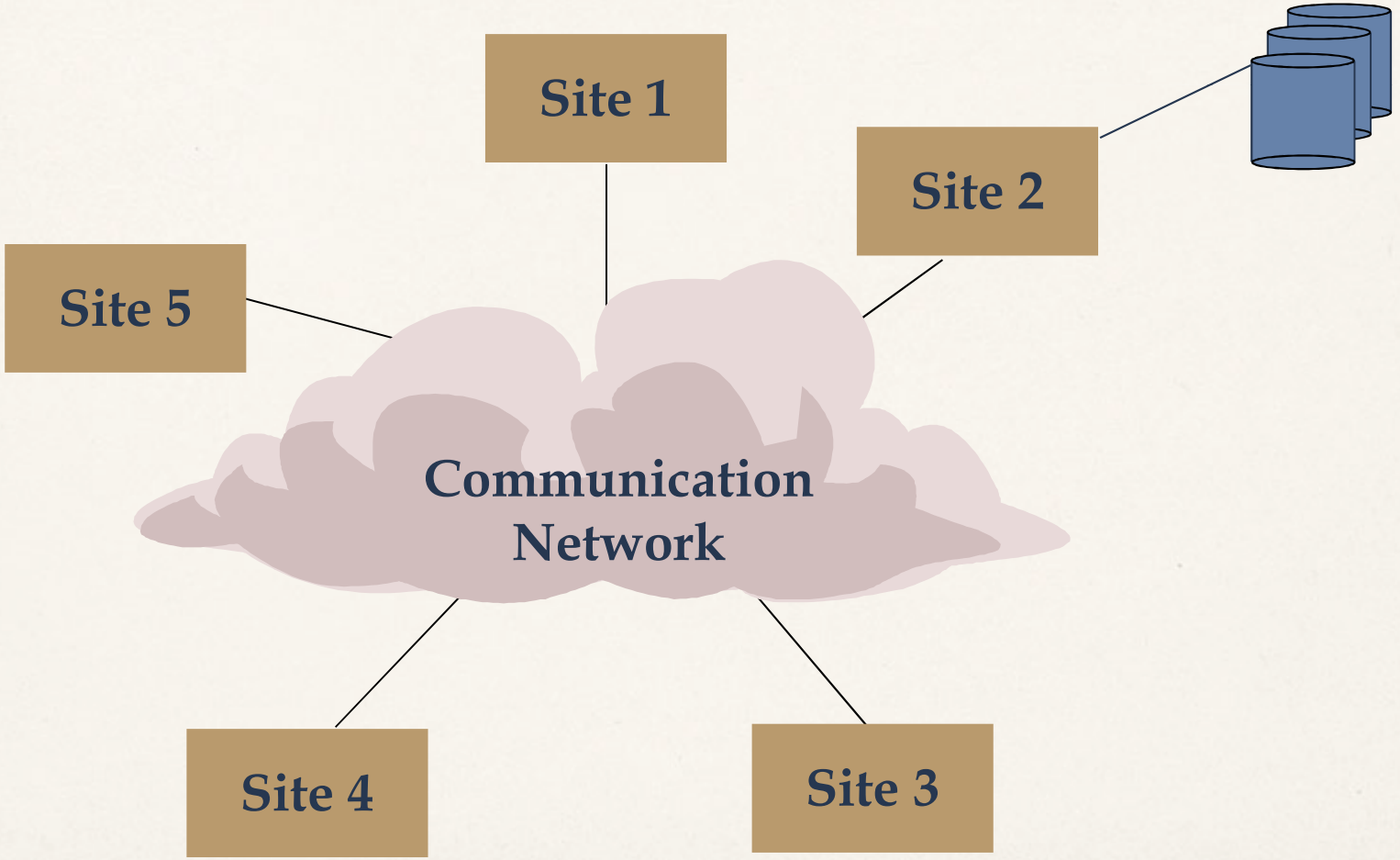
A distributed database management system (D–DBMS) is the software that manages the DDB and provides an access mechanism that makes this distribution transparent to the users.

Distributed database system (DDBS) = DDB + D–DBMS

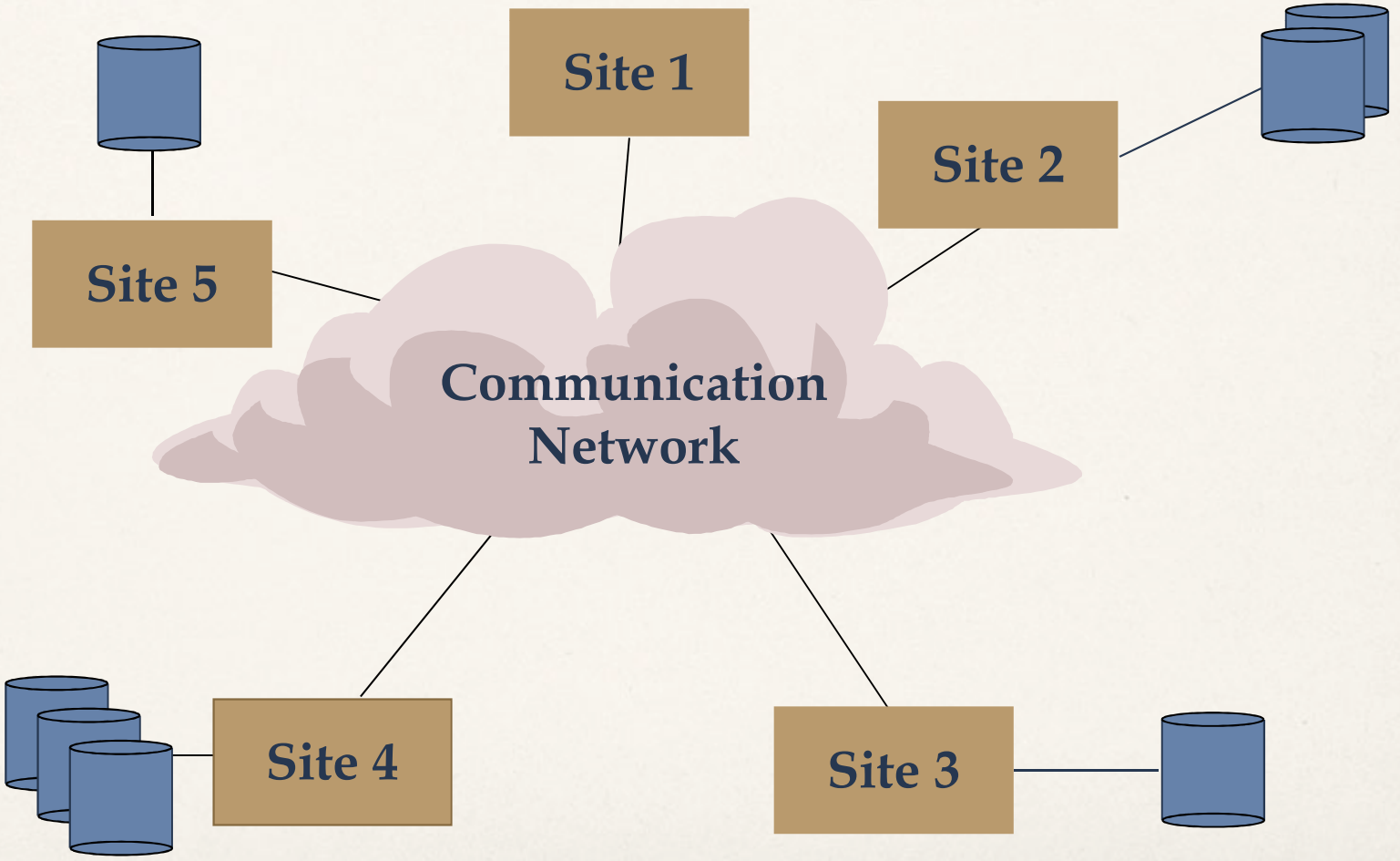
# What is not a DDBS?

- Files distributed over a network (missing structure and common logical access interface) → logical interrelation
- A number of related DB that reside on the same system → physical distribution (not necessarily over a wide area, network communication)
- A loosely coupled multiprocessor system → even though communication issues are similar to the one over network (no disk or memory shared), they are not enough heterogeneous (identical processors and OS's) → **parallel DB systems**
- A database system which resides at one of the nodes of a network of computers - this is a centralized database on a network node → multiple DB → **client/server DB systems**

# Centralized DBMS on a Network



# Distributed DBMS Environment



# Implicit Assumptions

- Data stored at a number of sites → each site *logically* consists of a single processor.
- Processors at different sites are interconnected by a computer network → not a multiprocessor system
  - ➡ Parallel database systems
- Distributed database is a database, not a collection of files → data logically related as exhibited in the users' access patterns
  - ➡ Relational data model
- D-DBMS is a full-fledged DBMS
  - ➡ Not remote file system, not a TP system

# Data Delivery Alternatives

- Delivery modes
  - ➡ Pull-only
  - ➡ Push-only
  - ➡ Hybrid
- Frequency
  - ➡ Periodic
  - ➡ Conditional
  - ➡ Ad-hoc or irregular
- Communication Methods
  - ➡ Unicast
  - ➡ One-to-many
- Note: not all combinations make sense

# Distributed DBMS Promises

1. Transparent management of distributed, fragmented, and replicated data
2. Improved reliability/availability through distributed transactions (tolerance to, e.g., network communication failure and concurrent access)
3. Improved performance
4. Easier and more economical system expansion

# Transparency

- Transparency is the separation of the higher level semantics of a system from the lower level implementation issues
- 4 types of transparency. Fundamental issue is to provide

  **data independence**

  in the distributed environment

  - Network transparency (or distribution transparency)
    - Location transparency
    - Naming transparency
  - Replication transparency
  - Fragmentation transparency
    - horizontal fragmentation: selection
    - vertical fragmentation: projection
    - hybrid

# Example

EMP

| ENO | ENAME | TITLE |
|---|---|---|
| E1 | J. Doe | Elect. Eng |
| E2 | M. Smith | Syst. Anal. |
| E3 | A. Lee | Mech. Eng. |
| E4 | J. Miller | Programmer |
| E5 | B. Casey | Syst. Anal. |
| E6 | L. Chu | Elect. Eng. |
| E7 | R. Davis | Mech. Eng. |
| E8 | J. Jones | Syst. Anal. |

ASG

| ENO | PNO | RESP | DUR |
|---|---|---|---|
| E1 | P1 | Manager | 12 |
| E2 | P1 | Analyst | 24 |
| E2 | P2 | Analyst | 6 |
| E3 | P3 | Consultant | 10 |
| E3 | P4 | Engineer | 48 |
| E4 | P2 | Programmer | 18 |
| E5 | P2 | Manager | 24 |
| E6 | P4 | Manager | 48 |
| E7 | P3 | Engineer | 36 |
| E8 | P3 | Manager | 40 |

PROJ

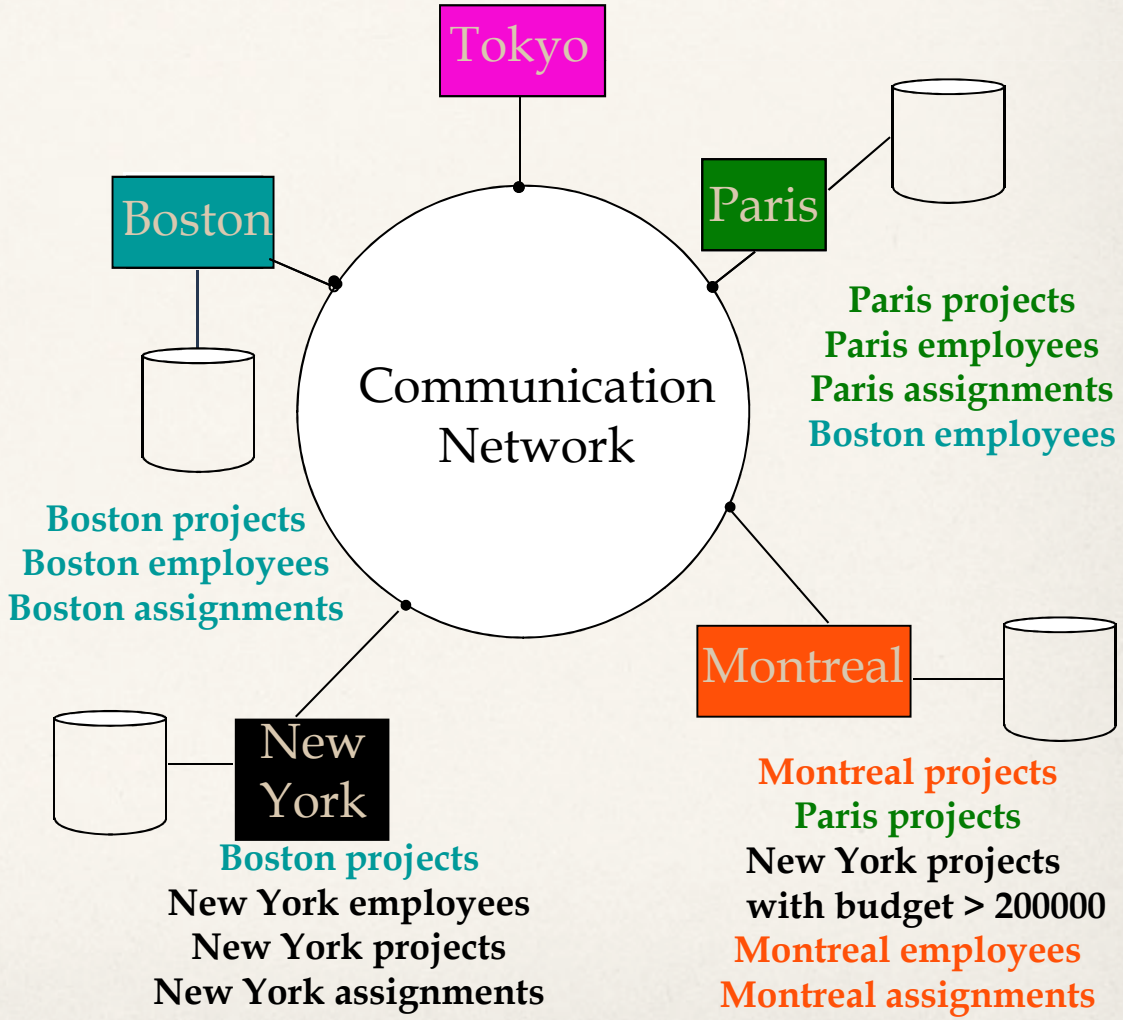
| PNO | PNAME | BUDGET |
|---|---|---|
| P1 | Instrumentation | 150000 |
| P2 | Database Develop. | 135000 |
| P3 | CAD/CAM | 250000 |
| P4 | Maintenance | 310000 |

PAY

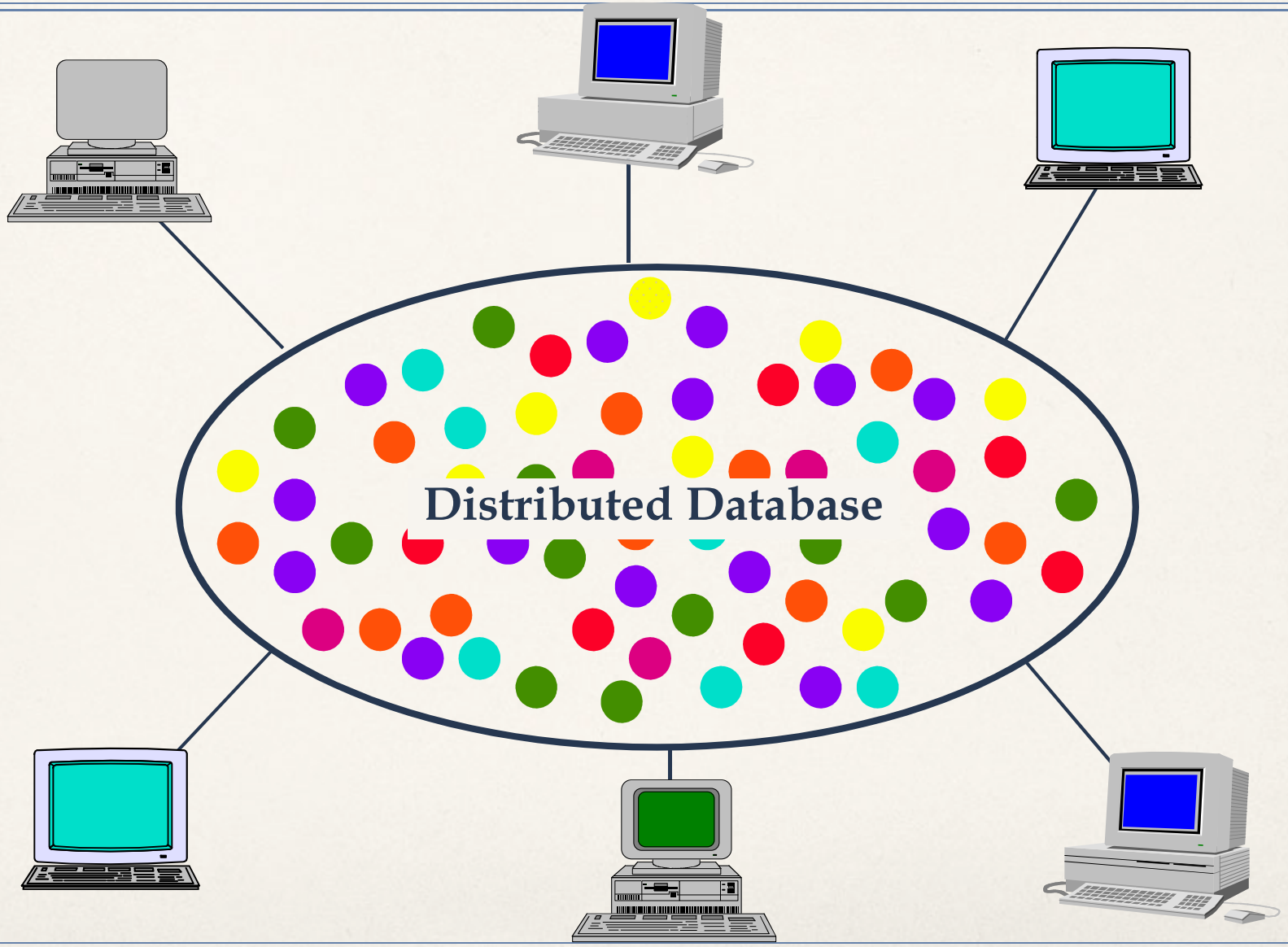
| TITLE | SAL |
|---|---|
| Elect. Eng. | 40000 |
| Syst. Anal. | 34000 |
| Mech. Eng. | 27000 |
| Programmer | 24000 |

# Transparent Access

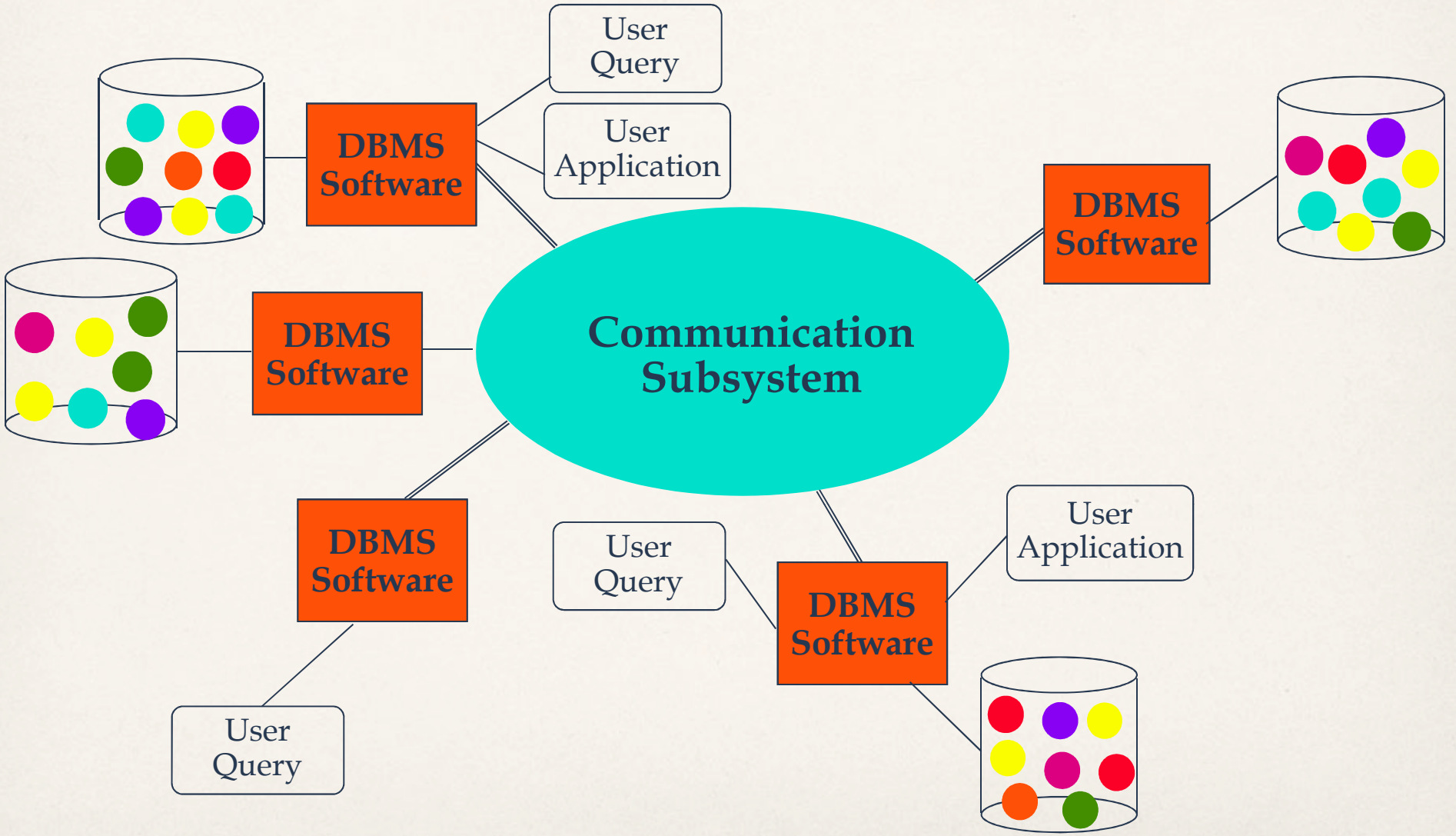
```
SELECT ENAME,SAL
FROM   EMP,ASG,PAY
WHERE  DUR > 12
AND    EMP.ENO = ASG.ENO
AND    PAY.TITLE = EMP.TITLE
```



# Distributed Database - User View



# Distributed DBMS - Reality



# Reliability Through Transactions

- Replicated components and data should make distributed DBMS more reliable
- Transactions: sequences of DB operations executed as atomic actions
- (Distributed) transactions provide
  - ➡ Consistency: bring the DB from a consistent state to another consistent one
  - ➡ Reliability: Concurrency transparency, Failure atomicity
- Distributed transaction support requires implementation of
  - ➡ Distributed concurrency control protocols
  - ➡ Commit protocols
- Data replication (we will not deal with it)
  - ➡ Great for read-intensive workloads, problematic for updates
  - ➡ Replication protocols

# Distributed systems are intrinsically problematic

**CAP Theorem** states that it is impossible for a distributed DB (where data is fragmented and replicated) to provide simultaneously:

- Consistency (always the updated data is read)
- Availability (every request receives a response)
- Partition tolerance (tolerance to network communication failures)

# Potentially Improved Performance

- Proximity of data to its points of use
  - ➡ Requires some support for fragmentation and replication
- Parallelism in execution
  - ➡ Inter-query parallelism
  - ➡ Intra-query parallelism

# Parallelism Requirements

- Have as much of the data required by *each* application at the site where the application executes
  - ➡ Full replication
- How about updates?
  - ➡ Mutual consistency
  - ➡ Freshness of copies

# Easier System Expansion

- Issue is database scaling
- Expansion: as easy as adding a new node in the network (with its own DBMS)
  - ➡ Easy thanks to transparency
- Expanding a centralized DBMS is more difficult than adding a new one

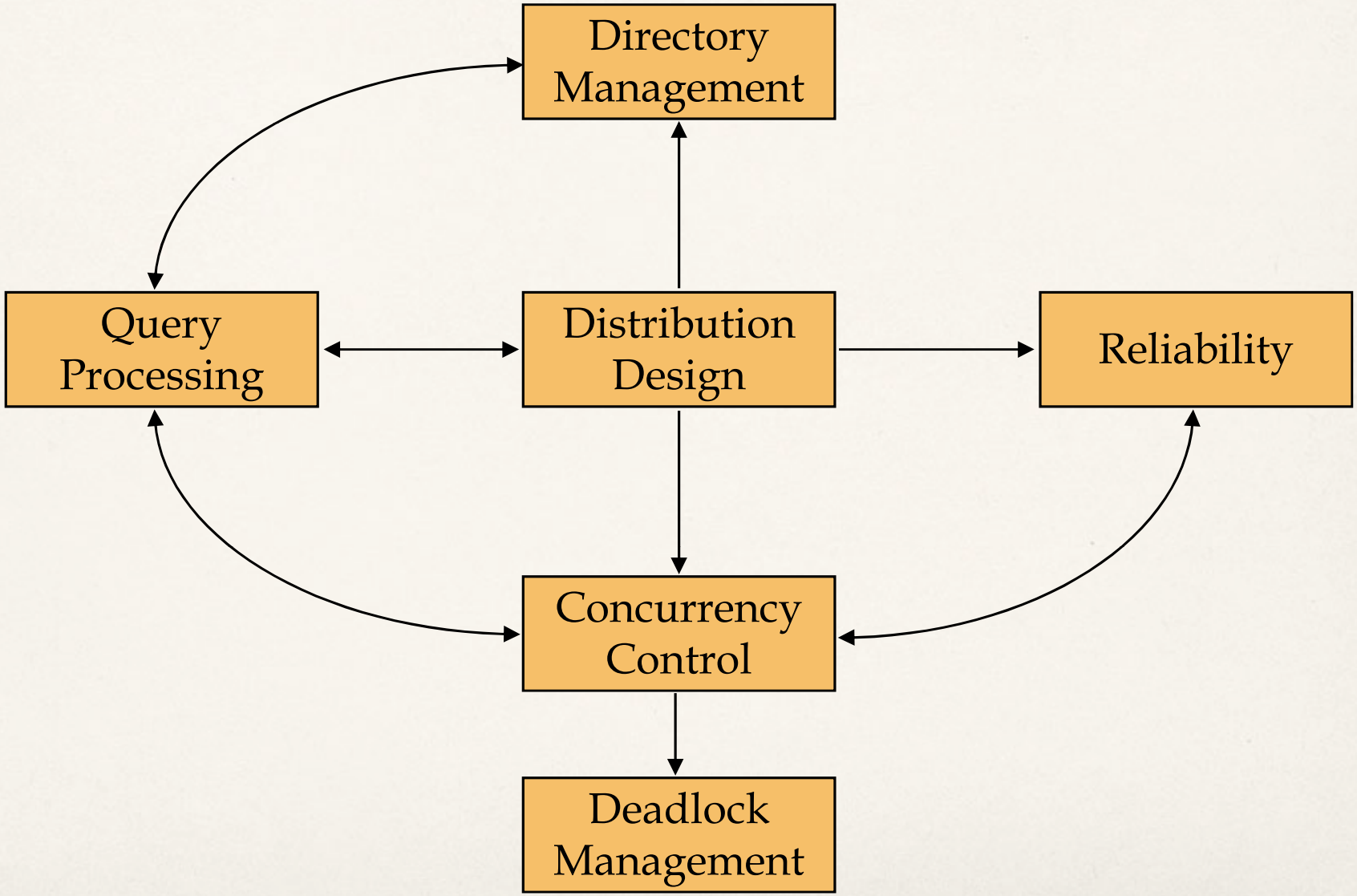
# Distributed DBMS Issues

- **Distributed Database Design**
  - How to distribute the database
  - Replicated & non-replicated database distribution
  - A related problem in **directory management**
- **Query Processing**
  - Convert user transactions to data manipulation instructions
  - Optimization problem
    - min{cost = data transmission + local processing}
  - General formulation is NP-hard

# Distributed DBMS Issues

- **Concurrency Control**
  - ➡ Synchronization of concurrent accesses
  - ➡ Consistency and isolation of transactions' effects
- **Distributed Deadlock management**
  - ➡ Prevention, avoidance, detection/recovery techniques
- **Reliability**
  - ➡ How to make the system resilient to failures
  - ➡ Atomicity and durability
- **Replication**
  - ➡ Consistency of the information (eager and lazy protocols)

# Relationship Between Issues



# Recent Developments

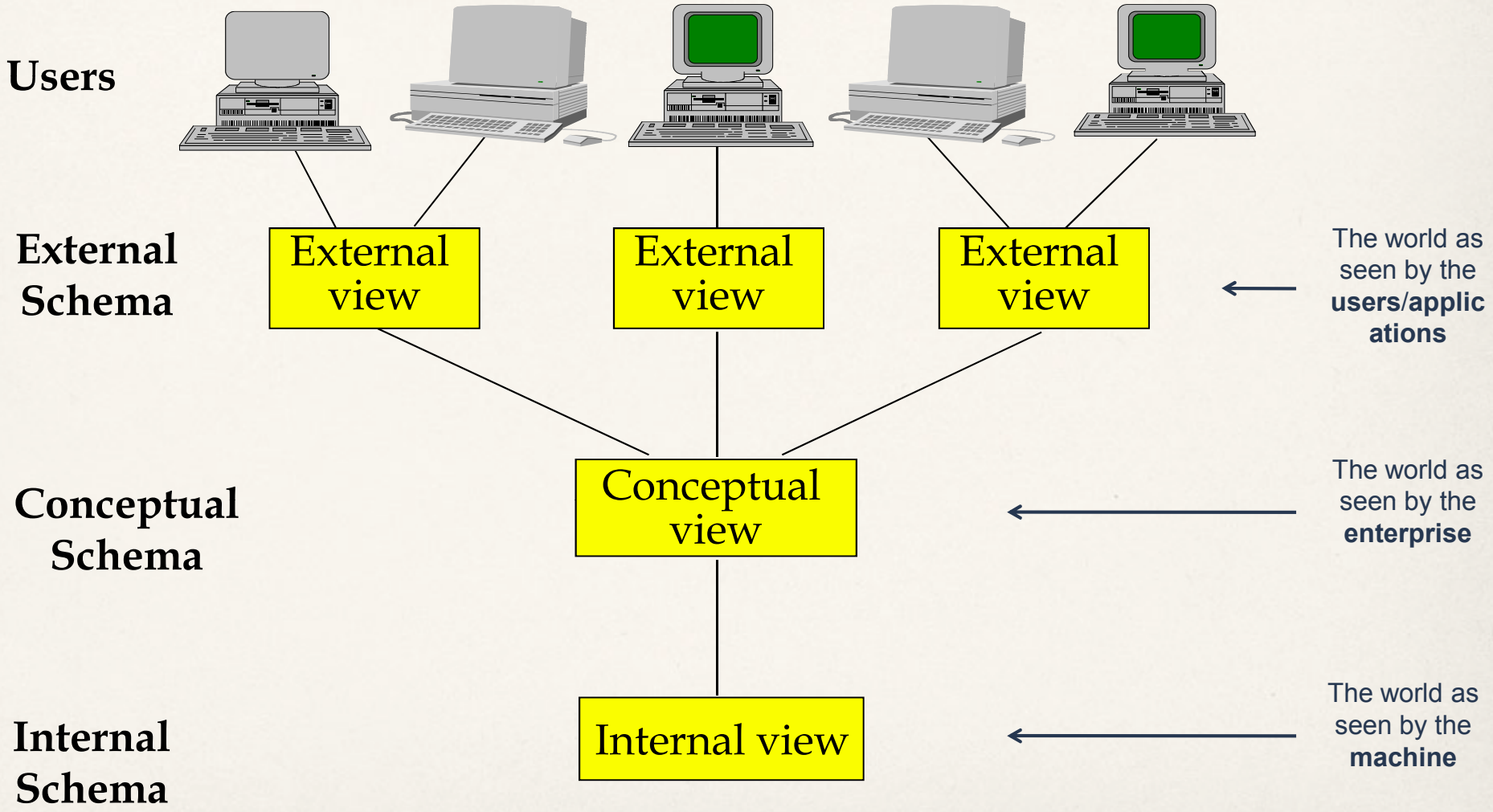
- So far, and in the rest of the course: focus on "traditional" DDBS
- Recent directions
  - **Multidatabase systems**, aka federated databases, aka data integration systems - *not in this course (Ch. 1.10, 4, 9)* *
    - Heterogeneity of data source
  - **Peer-to-peer** "reloaded" **and web data management** - *not in this course (Ch. 16, 17 )* *
    - Rethinking of an old architecture, oriented to needs of data sharing over the web
  - **Parallel databases** – *maybe at the end of the course (Ch. 14 )* *
    - Specific issues (not really distributed)

* Özsu and Valduriez, *Principles of Distributed Database Systems* (3rd Ed.), 2011

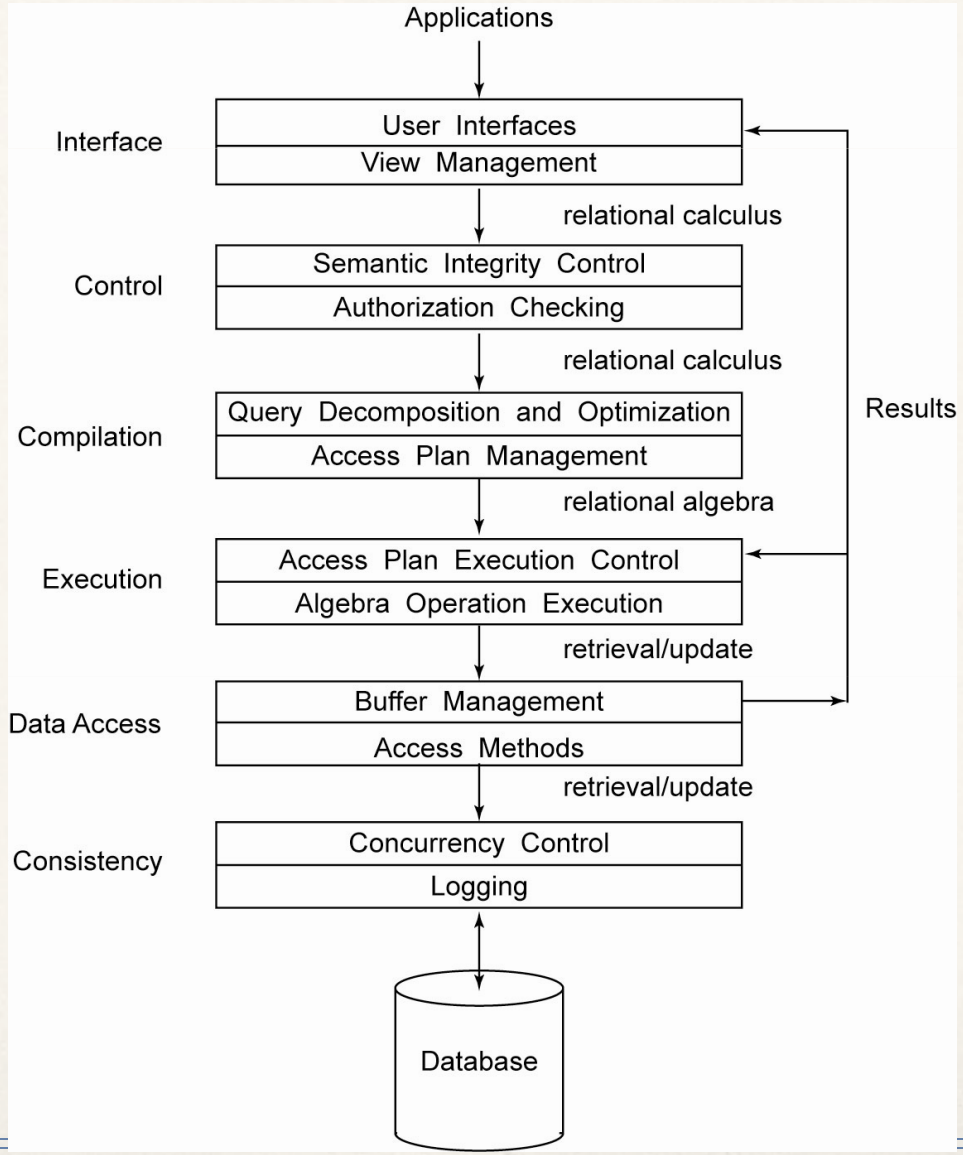
# Architecture

- Defines the structure of the system
  - ➡ components identified
  - ➡ functions of each component defined
  - ➡ interrelationships and interactions between components defined

# ANSI/SPARC Architecture



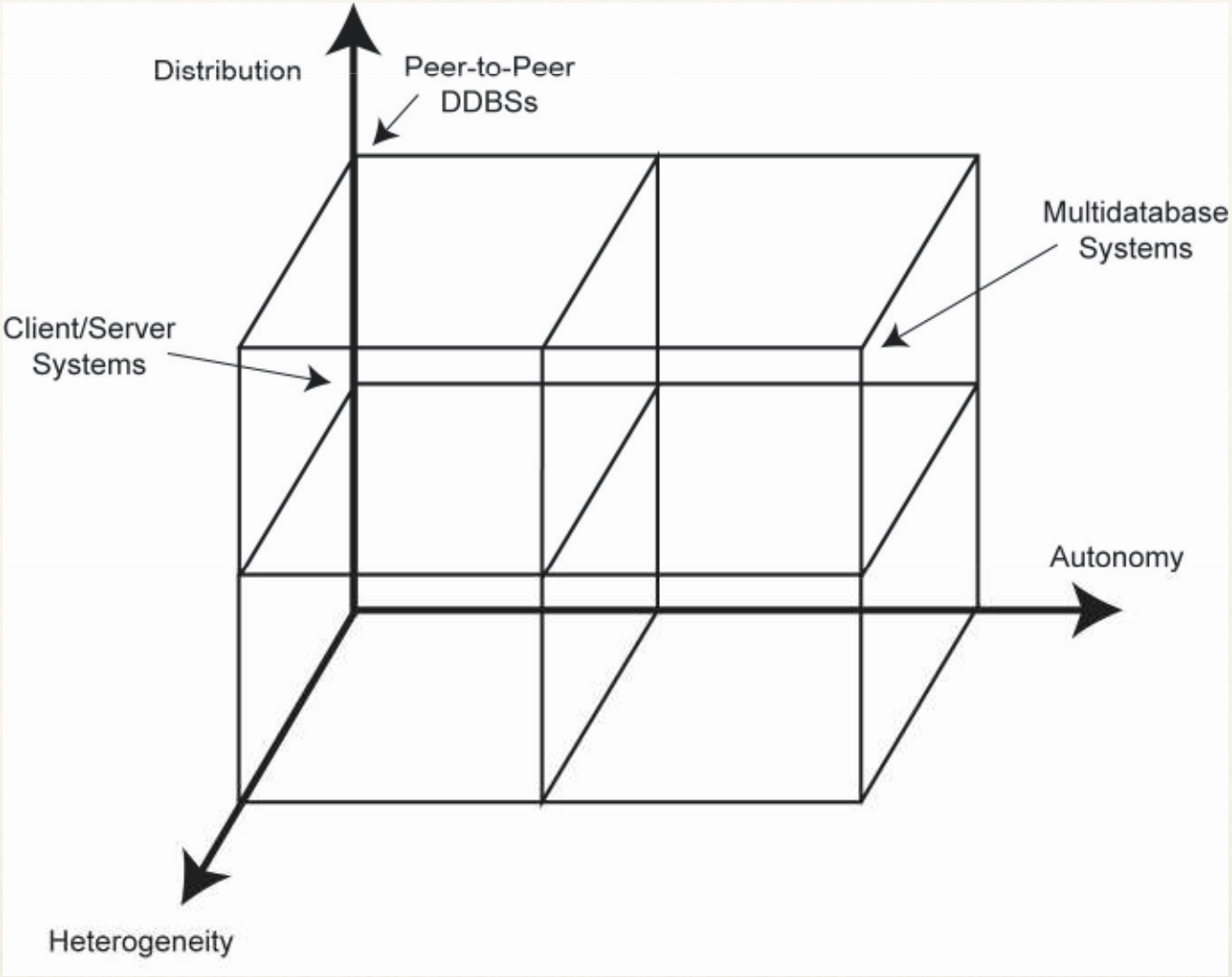
# Generic DBMS Architecture



# Dimensions of the Problem

- Distribution (of data)
  - Whether the components of the system are located on the same machine or not
    - Non-distributed/*client-server*/***fully distributed*** (peer-to-peer)
- Heterogeneity
  - Hardware, communications, **data model**, **query language**, **transaction management**
- Autonomy (distribution of control)
  - Various versions
    - Design autonomy: ability of a component DBMS to decide on issues related to its own design.
    - Communication autonomy: ability of a component DBMS to decide whether and how to communicate with other DBMSs and what information to share with them.
    - Execution autonomy: ability of a component DBMS to execute transaction operations in any manner it wants to
  - Classification along this dimension:
    - Tight integration (one unique logical view of the DB, control is centralized for each user request)
    - Semiautonomous (independent DBMS, selective data sharing, common communication protocols)
    - Total isolation (*multidatabase systems* – totally independent, unaware of each other and of communication systems, no global control, no unified DB view, each DB decides what to share with who)

# DBMS Implementation Alternatives



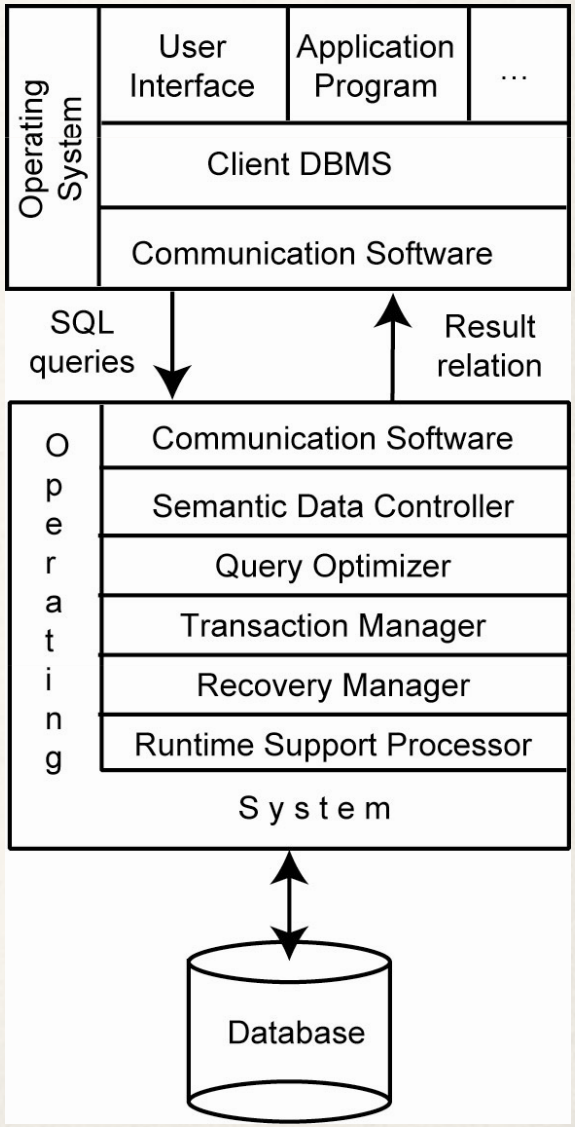
# Terminology disambiguation

- In our discussion, by distributed DBMS and DDBS we mostly refer to fully distributed, **peer-to-peer** data management systems
- In particular, the term "peer-to-peer" is overloaded in the book. It is used to refer to:
  - ➡ "traditional" peer-to-peer DBMS (also referred to as fully distributed DBMS) → our focus is on these systems [see previous two slides]
  - ➡ "modern" peer-to-peer data management systems [see slide slide titled "Recent developments"]
    - ✦ These refer to an evolution of the traditional peer-to-peer architecture, to cope with the need of data sharing, e.g., over the web
    - ✦ Ongoing research area, related issues still being investigated
    - ✦ Out of the scope of this course (see Ch. 16) *

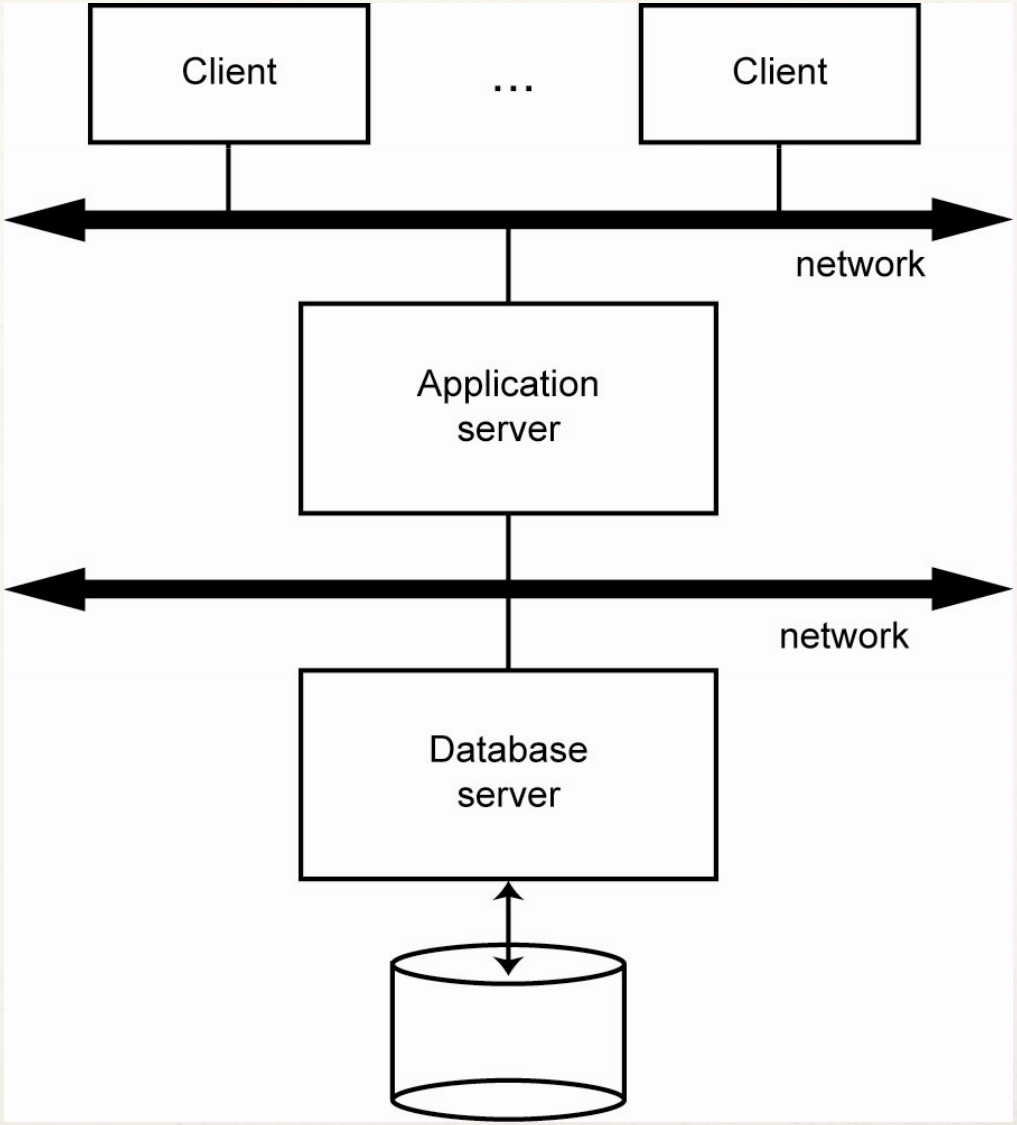
* Özsu and Valduriez, *Principles of Distributed Database Systems* (3rd Ed.), 2011

# Client/Server Architecture

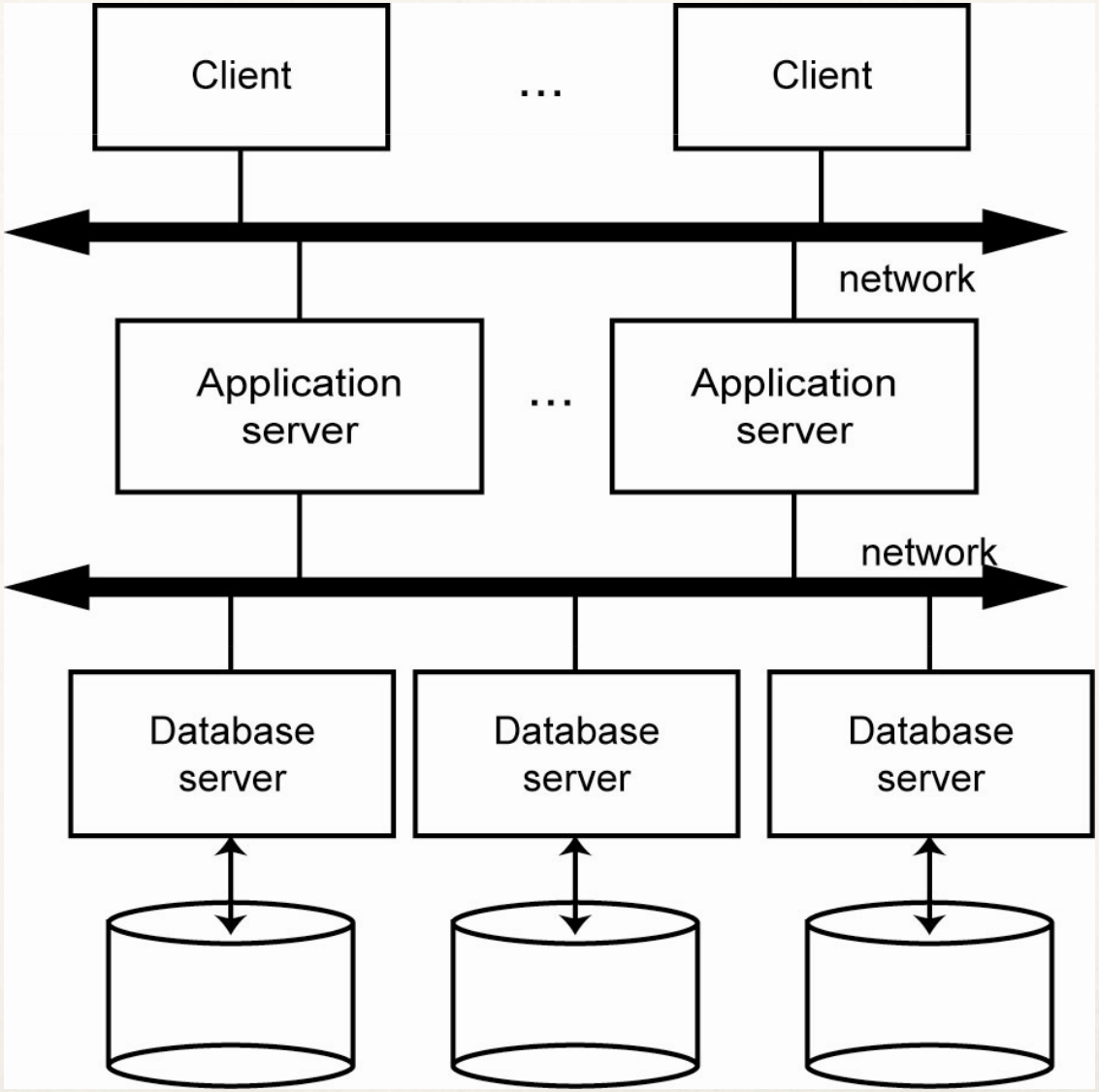
- Not fully distributed: data and control are distributed among few servers (multiple client/multiple servers) or not distributed at all (multiple client/single server)
- Nodes of the network are not identical (divided into two groups: clients and servers)
- DBMS is on server(s) only
- Most of the work is done by server(s)
- On clients: only a DBMS client for sending queries and receiving/displaying results
- Multiple client/single servers: like centralized DBMS (no distribution-related issues)
- Multiple client/multiple servers: mild form of distribution
- Our discussion mainly refers to fully distributed DBMS, but often applies to client/server architectures



# Database Server



# Distributed Database Servers



# Multidatabase system architecture

- Multidatabase system (MDBS) are beyond the scope of this course
- In a nutshell
  - ➡ Characterized by presence of several fully autonomous, independent, and heterogeneous DBMS that are located apart from each other
  - ➡ Unaware of each other existence
  - ➡ Systems do not know how to communicate with other ones
  - ➡ No (explicit) interrelation between DBMS
  - ➡ Each DBMS provides an export schema to make (some of) its data available to (some of) the other systems
  - ➡ In DDBS: unique logical view of the entire DB (transparency) resulting from the "union" of parts of DB stored locally at each node of the network
    In MDBS: not even a clear notion of "entire DB"
  - ➡ Architecture design is built bottom-up (in DDBS it is built top-down)
- If interested, see the discussion at Ch. 1.10, 4, 9 *

* Özsu and Valduriez, *Principles of Distributed Database Systems* (3rd Ed.), 2011

# MDBS Components & Execution