Systems Infrastructure for Data Science

Web Science Group
Uni Freiburg
WS 2013/14

Lecture VI: Introduction to Distributed Databases

Why do we distribute?

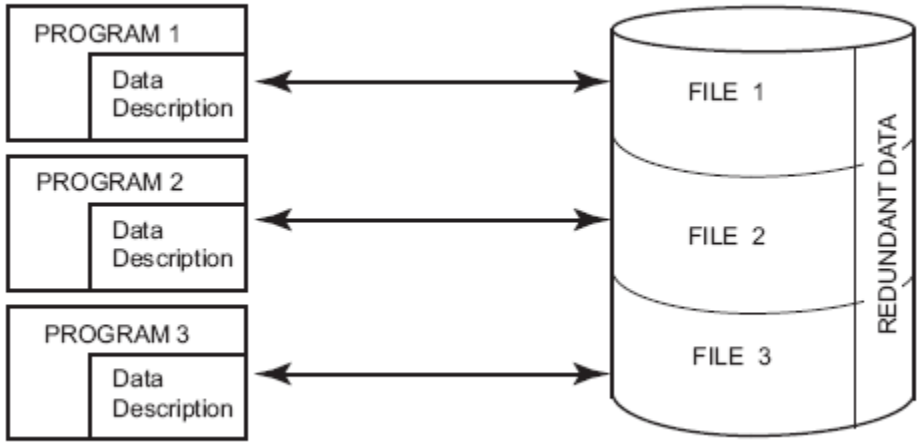
- Applications are inherently distributed.
- A distributed system is more reliable.
- A distributed system performs better.
- A distributed system scales better.

Distributed Database Systems

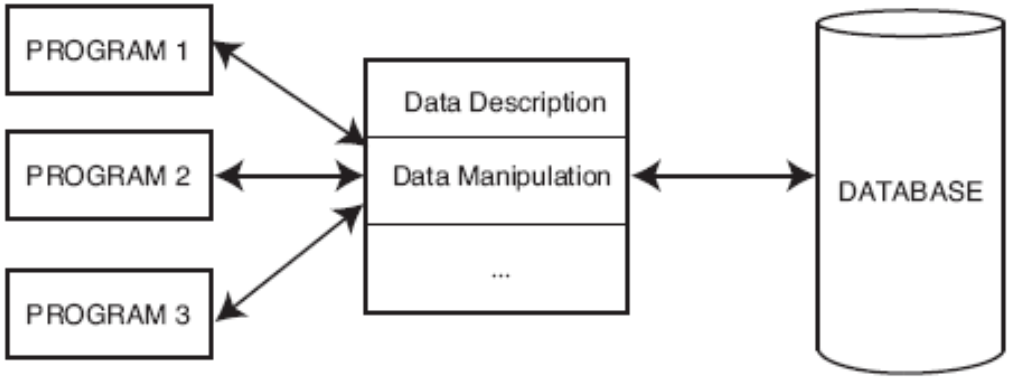
- Union of two technologies:
  - Database Systems + Computer Networks
- Database systems provide
  - data independence (physical & logical)
  - centralized and controlled data access
  - integration
- Computer networks provide distribution.
- integration ≠ centralization
- integration + distribution

DBMS Provides Data Independence

File Systems



Database Management Systems



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Distributed Systems

- Tanenbaum et al:

  "*a collection of independent computers that appears to its users as a single coherent system*"

- Coulouris et al:

  "*a system in which hardware and software components located at networked computers communicate and coordinate their actions only by passing messages*"

Distributed Systems

- Ozsu et al:

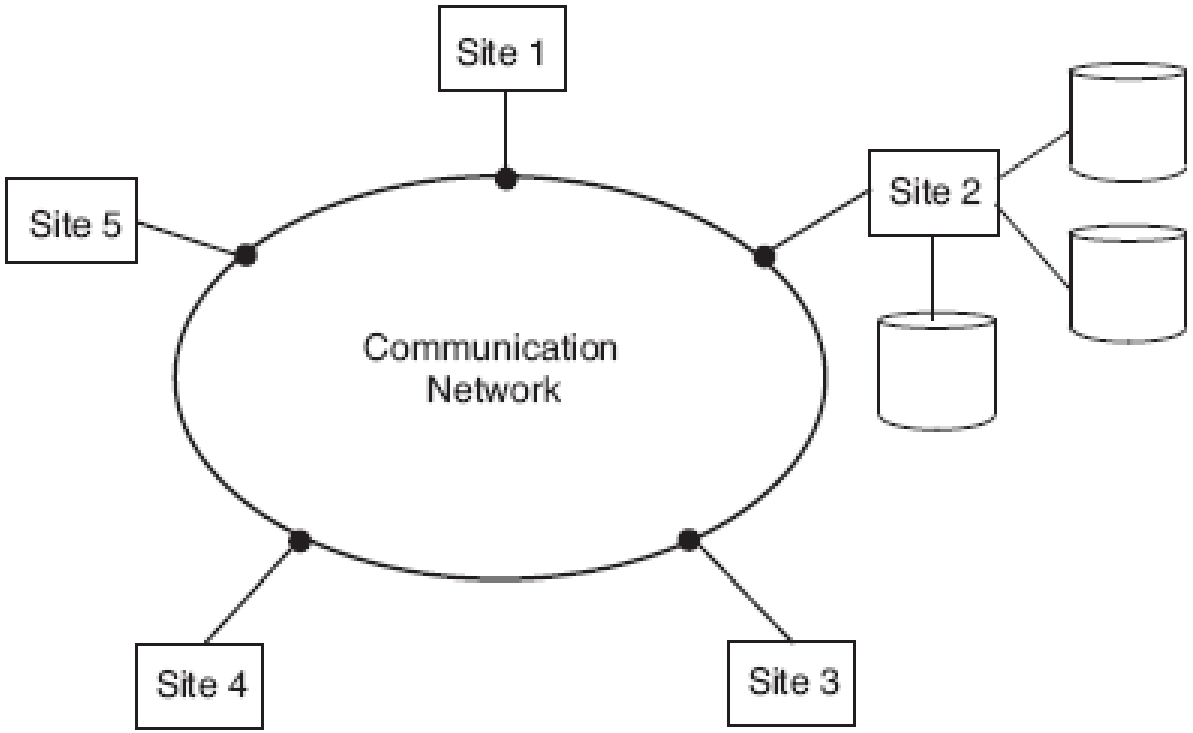
  "a number of autonomous processing elements (not necessarily homogeneous) that are interconnected by a computer network and that cooperate in performing their assigned tasks"

What is being distributed?

- Processing logic
- Function
- Data
- Control

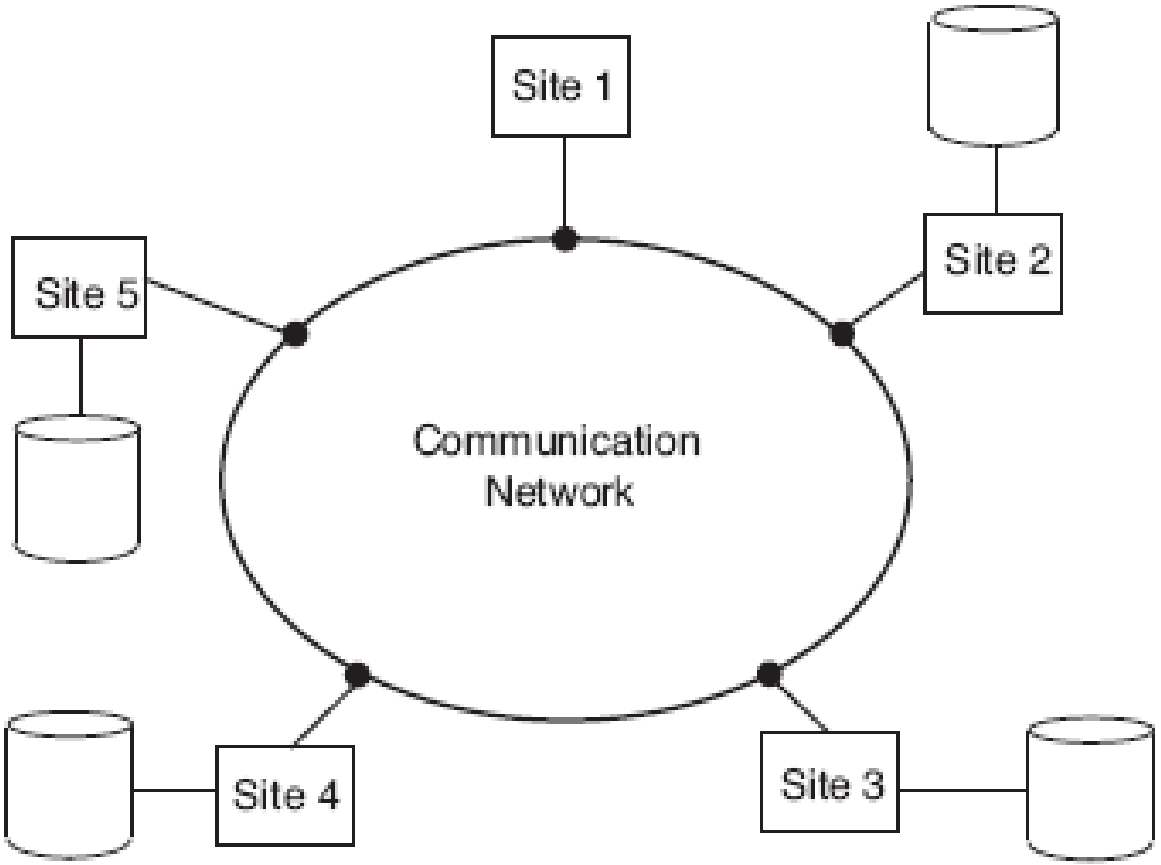
- For distributed DBMSs, all are required.

Centralized DBMS on a Network



What is being distributed here?

Distributed DBMS



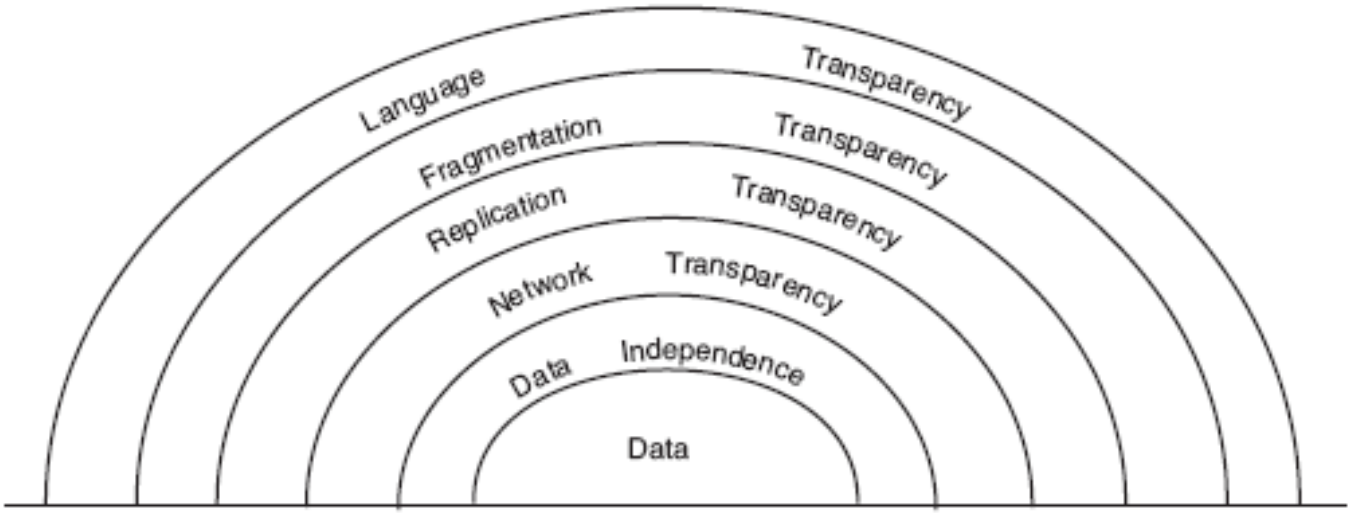
And here?

Distributed DBMS Promises

1. Transparent management of distributed and replicated data
2. Reliability/availability through distributed transactions
3. Improved performance
4. Easier and more economical system expansion

Promise #1: Transparency

- Hiding implementation details from users
- Providing **data independence** in the distributed environment
- Different transparency types, related:



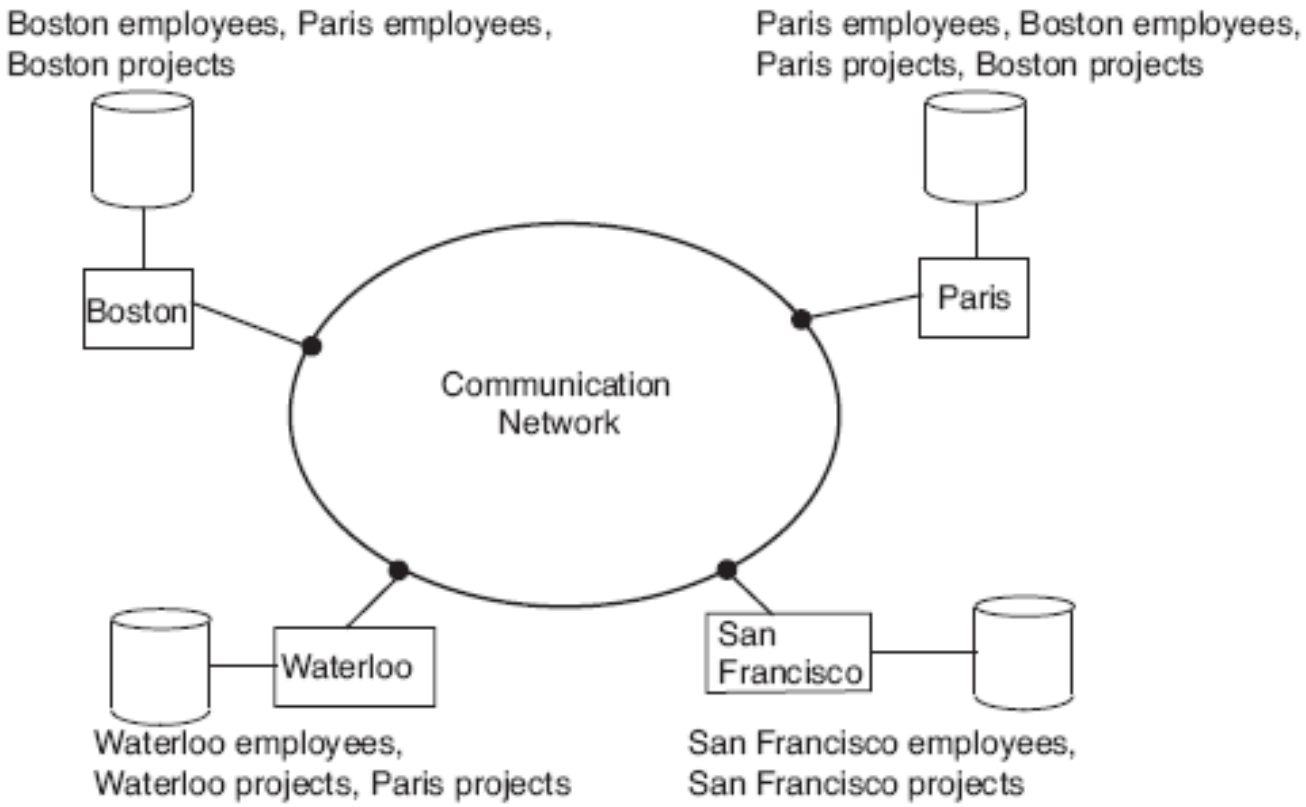
- Full transparency is neither always possible nor desirable!

Transparency Example

- Employee (eno, ename, title)
- Project (pno, pname, budget)
- Salary (title, amount)
- Assignment (eno, pno, responsibility, duration)

```
SELECT   ename, amount
FROM     Employee, Assignment, Salary
WHERE    Assigment.duration > 12
AND      Employee.eno = Assignment.eno
AND      Salary.title = Employee.title
```

Transparency Example



What types of transparencies are provided here?

Promise #2: Reliability & Availability

- Distribution of replicated components
- When sites or links between sites fail
  - No single point of failure
- Distributed transaction protocols keep database consistent via
  - Concurrency transparency
  - Failure atomicity
- Caveat: CAP theorem!

Promise #3: Improved Performance

- Place data fragments closer to their users
  - less contention for CPU and I/O at a given site
  - reduced remote access delay
- Exploit parallelism in execution
  - inter-query parallelism
  - intra-query parallelism

Promise #4: Easy Expansion

- It is easier to scale a distributed collection of smaller systems than one big centralized system.

Distributed DBMS Major Design Issues

- Distributed DB design (Data storage)
  - partition vs. replicate
  - full vs. partial replicas
  - optimal fragmentation and distribution is NP-hard
- Distributed metadata management
  - where to place directory data
- Distributed query processing
  - cost-efficient query execution over the network
  - query optimization is NP-hard

Distributed DBMS Techniques: Partitioning

- Each relation is divided into n partitions that are mapped onto different systems/locations.
- Provides storing large amounts of data and improved performance
- Fragmentation of tables:
  - Among rows/values
  - Among columns

Distributed DBMS Techniques : Replication

- Storing copies of data on different nodes
- Provides high availability and reliability
- Requires distributed transactions to keep replicas consistent:
  - Two phase commit - data always consistent but the system is fragile
  - Eventually consistency - eventually becomes consistent but always writable

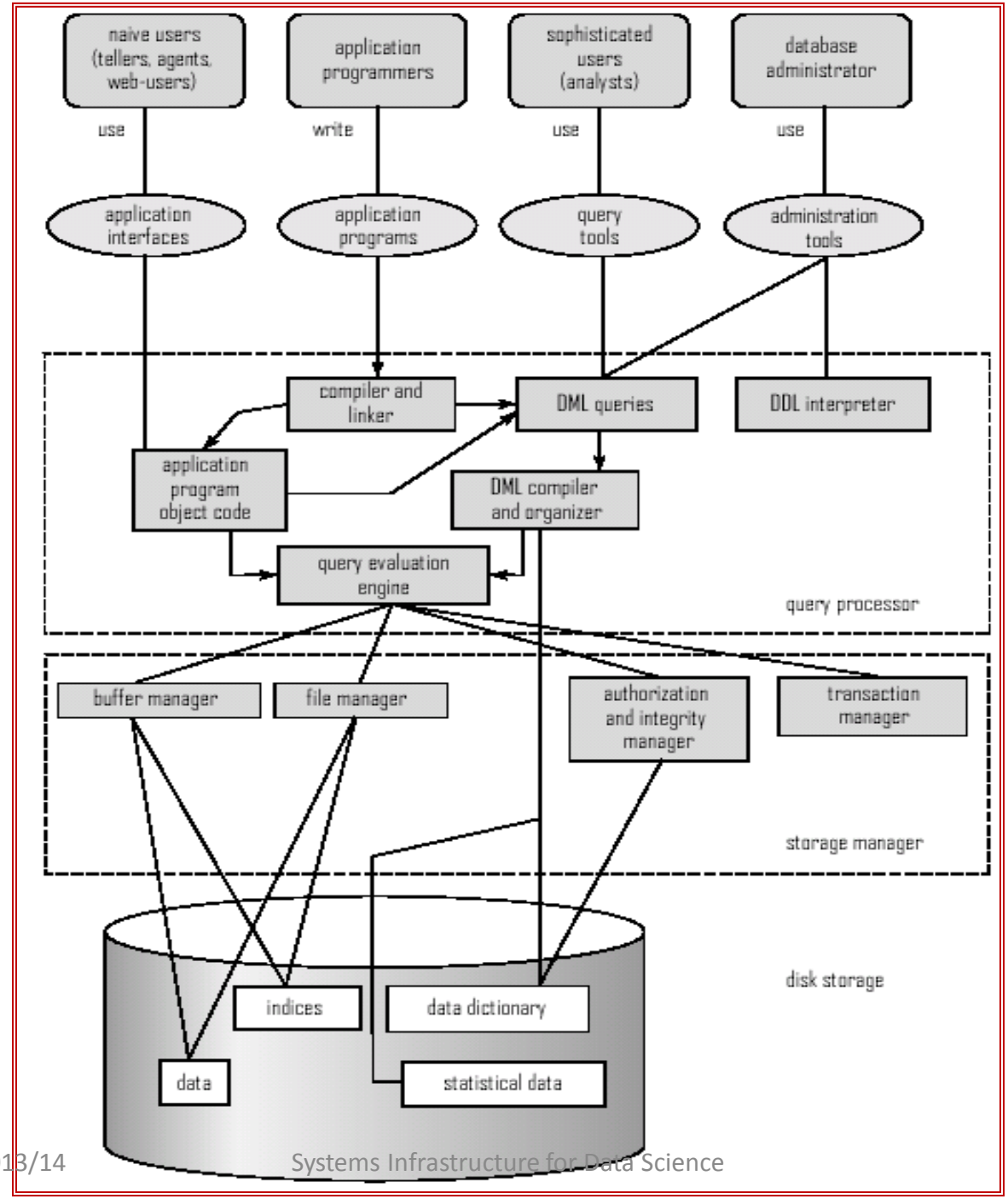
Distributed transaction management

- Synchronizing concurrent access
- Consistency of multiple copies of data
- Detecting and recovering from failures
- Deadlock management
- Providing ACID properties in general

=> Distributed Systems Lecture (w/ Prof. Schindelhauer in SS 2014)

Shared-Nothing Techniques: Query Decomposition and Shipping

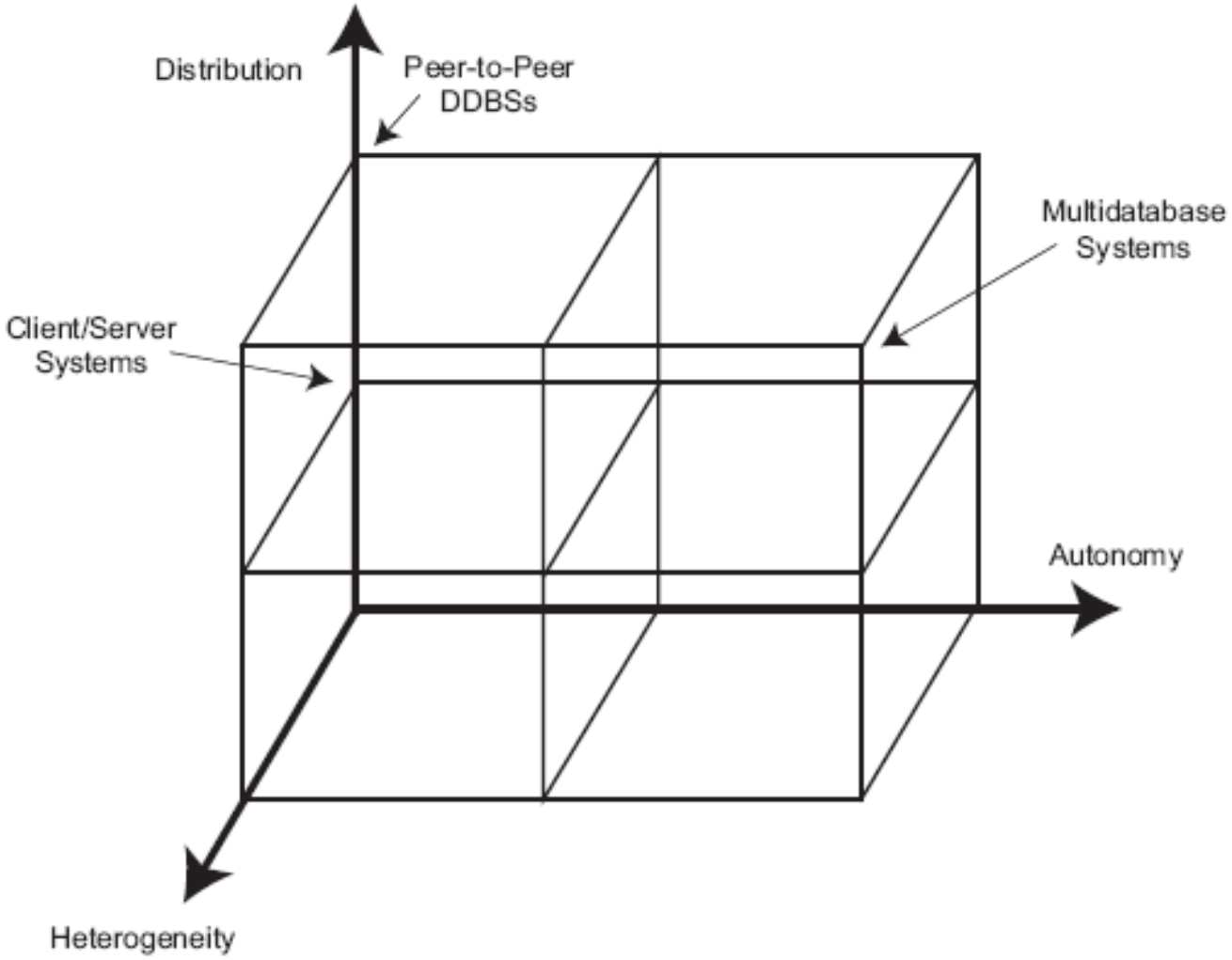
- Query operations are performed where the data resides.
  - Query is decomposed into subtasks according to the data placement (partitioning and replication).
  - Subtasks are executed at the corresponding nodes.
- Data placement is always good only for some queries =>
  - hard to design database
  - need to redesign when queries change



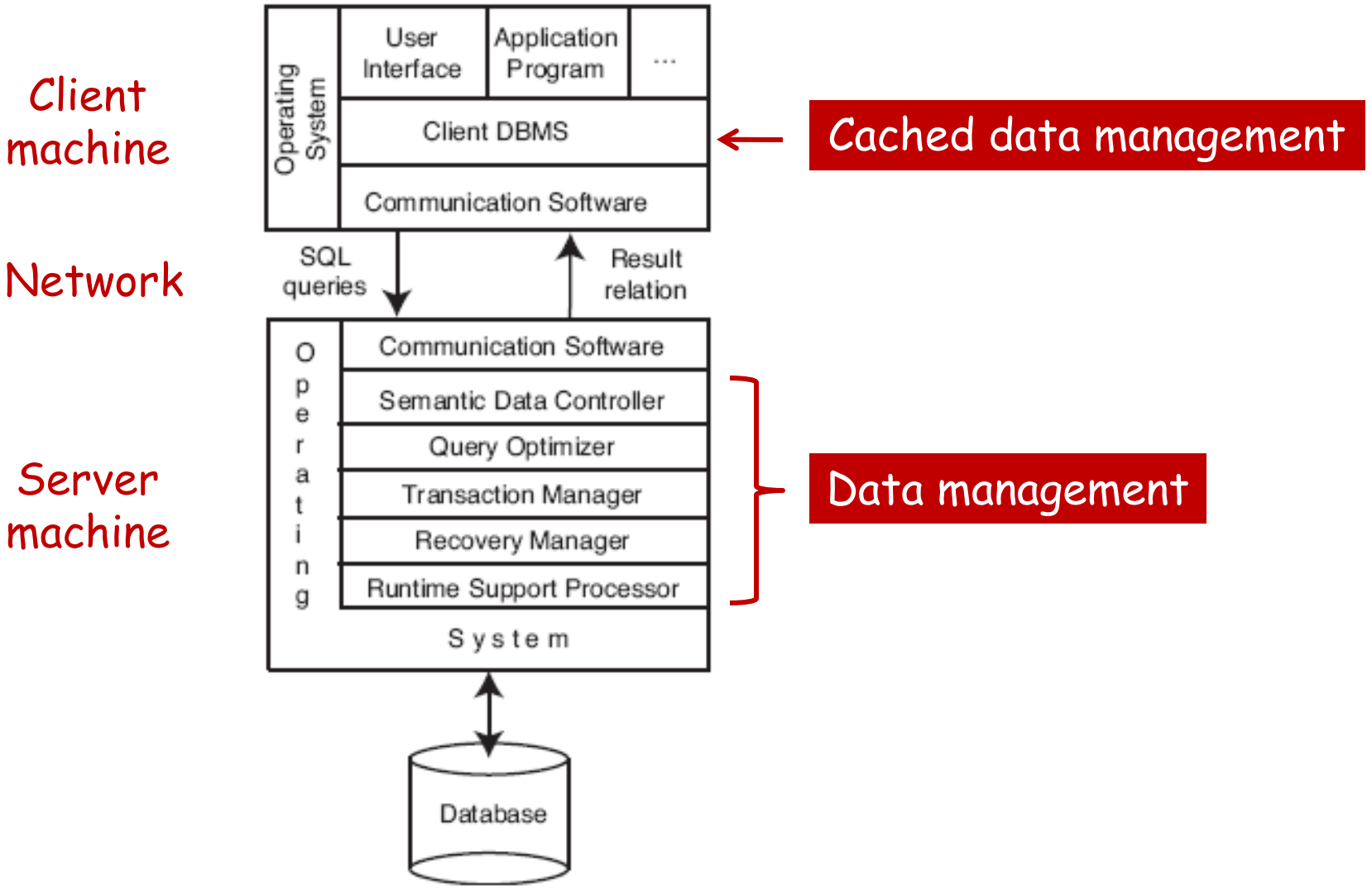
Typical Centralized DBMS Architecture

[Silberschatz et al]

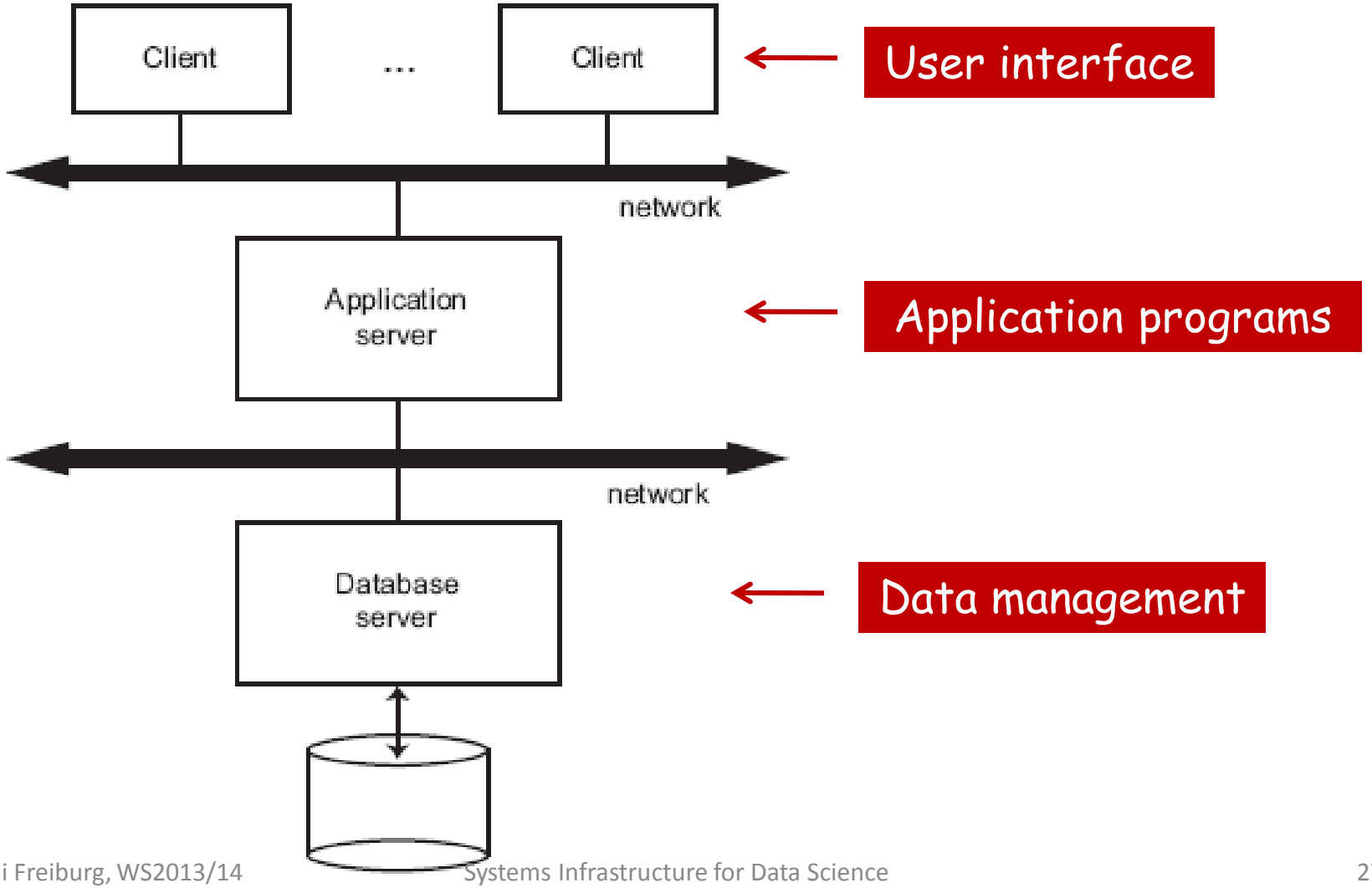
Important Architectural Dimensions for Distributed DBMSs



Client/Server DBMS Architecture



Three-tier Client/Server Architecture



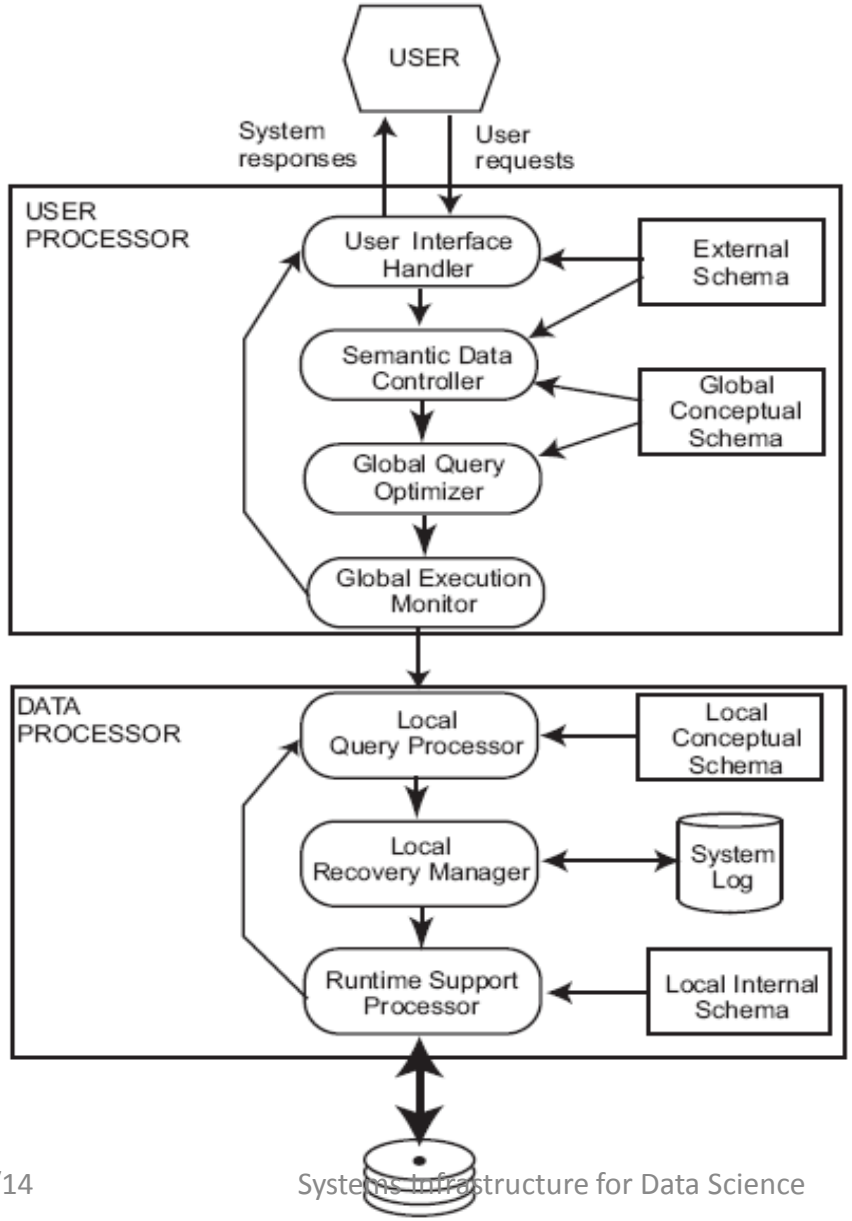
Extensions to Client/Server Architectures

- Multiple clients
- Multiple application servers
- Multiple database servers

Peer-to-Peer DBMS Systems

- Classical (same functionality at each site)
- Modern (as in P2P data sharing systems)
  - Large scale
  - Massive distribution
  - High heterogeneity
  - High autonomy

Classical Peer-to-Peer DBMS Architecture



Peer machine

User view

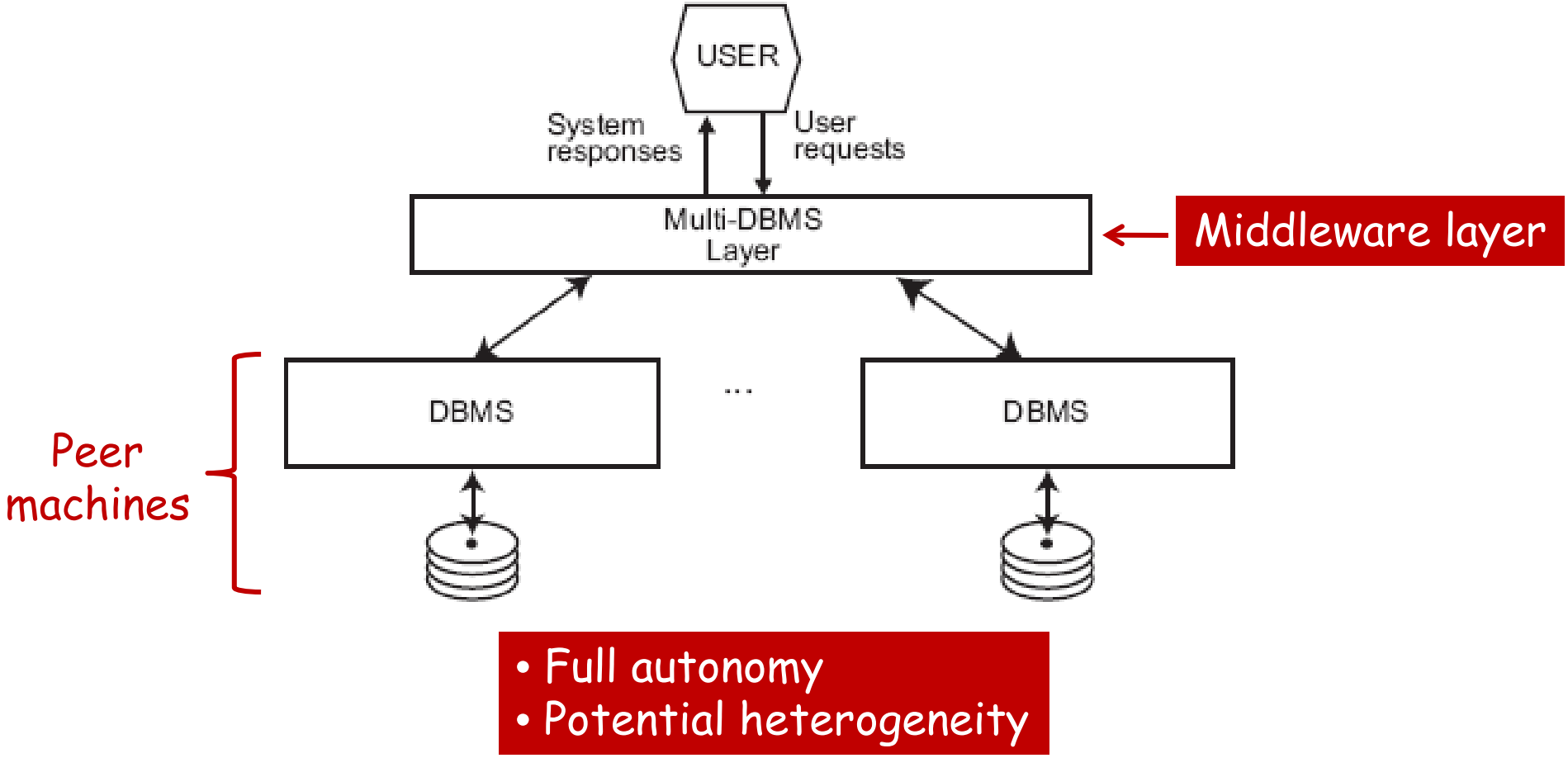
Logical organization of data at all sites

Logical organization of data at local site

Physical organization of data at local site

Transparency support

Multi-database System Architecture



What is a Distributed DBMS?

- Distributed database:
  - *"a collection of multiple, logically interrelated databases distributed over a computer network"*
- Distributed DBMS:
  - *"the software system that permits the management of the distributed database and makes the distribution transparent to the users"*
- This definition is relaxed for modern networked information systems (e.g., web).