Distributed DBMS architecture

- Covered topics
  - Transparencies in DDBMS
  - Architecture of DDBMS
  - Fragmentation, replication, allocation
    - Types and role of fragmentation
    - Types and role of replication
    - Allocation problem

Transparency

- In general: separation of higher-level semantics from lover-level implementation issues
- ‘Hide the implementation from users’
- Forms:
  - data independence
  - network transparency
  - replication transparency
  - fragmentation transparency
- Transparency can be provided at different levels of the system

Transparency

- Data independence
  - logical data independence: user applications are not affected by changes in the logical structure of the DB (schema definition)
  - physical data independence: hiding the details of the storage structure
  - the only form that is important in centralized DBMSs as well
- Network (distribution) transparency
  - location transparency: an operation on data is independent of both the location and the system where it is executed
  - naming transparency: unique name is provided for each object in the DB.

Transparency

- Replication transparency
  - Data is replicated for reliability and performance considerations.
  - The user should not be aware of the existence of copies
- Fragmentation transparency
  - DB relations are divided into smaller fragments for performance and availability reasons
  - The global queries should be translated to fragment queries
  - A question of query processing.

The origin of transparency

- Access layer: transparency features are built into user language which is translated into the requested operations (little transparency is provided from DBMS and OS)
  - typically: language transparency
- DBMS: acts as an integrated OS and DBMS, makes all the necessary translation between OS and user interface.
  - Essential when security and fault tolerance is critical and the OS cannot provide such services.
  - Typically: data, replication and fragmentation transparency
- OS: transparent access to resources provided by OS (e.g. device drivers, etc.) can be extended to distributed environments
  - typically: network transparency

Architecture

- The architecture of a system defines its structure
- In the foregoing parts the ‘architecture’ is a reference model
  - it is an idealized view
  - real world systems may be different
  - yet it shows the essential components and it is a reasonable framework
- Goal:
  - present the issues that need to be addressed at design
  - present a framework within which the design and implementation issues can be discussed
- Analogon: the ISO/OSI 7-layered reference model for computer networks

DBMS architecture

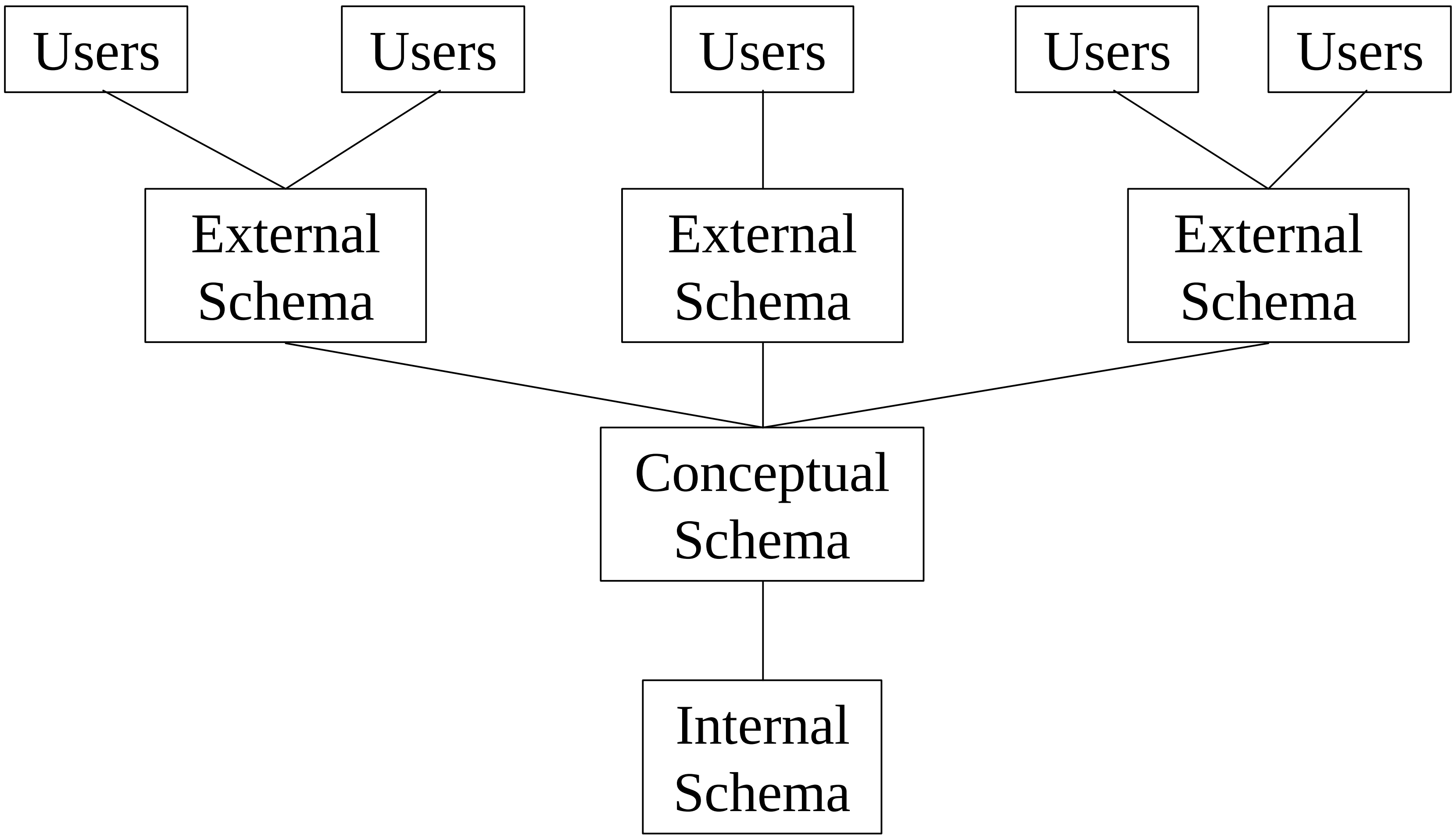
- A reference model can be described:
  - based on *components*. Components and their interrelations are defined.
  - Based on *functions*. Functions that the system will perform are defined.
  - Based on *data*. Different types of data and functional units (within an architectural framework), that will realize or use data, are defined
- Usually there is an interplay among them.

ANSI/SPARC architecture

- A centralized model from the 70s but generated interest and it is the basis of Distributed DBMSs
- Based on data organization
  - external view (user) - highest level, users' view of a portion of the DB and relationships among data
  - conceptual view (enterprise) - abstract definition of the DB, the 'real world' view. Represents data without considering the application or the storage requirements
  - internal view (system) - lowest level, physical definition, storage issues

ANSI/SPARC architecture

- Data organizational view



Example of schemas

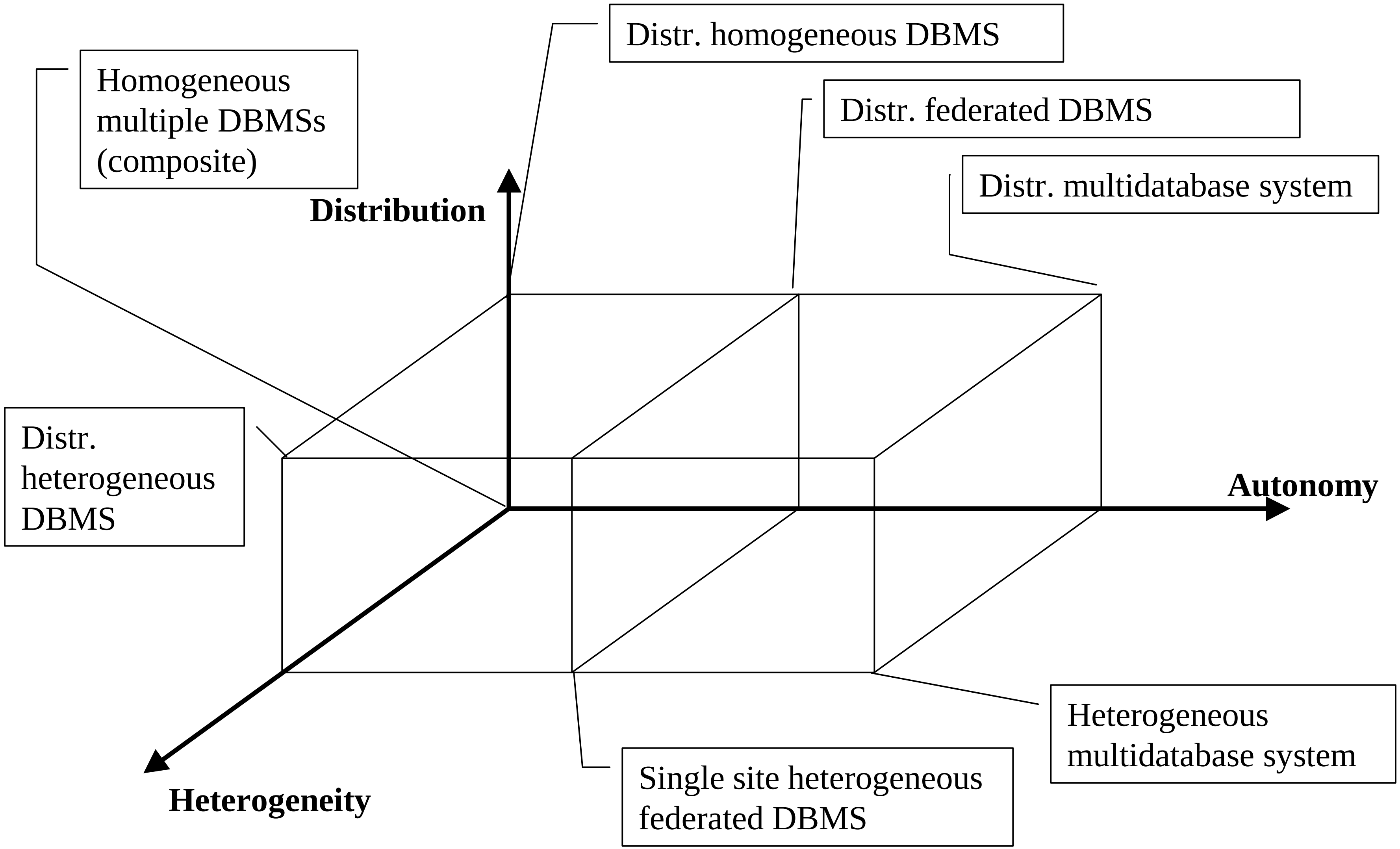
- Conceptual schema: the description of the modeled world (a pseudo code is shown here)
  - ```
    RELATION EMPLOYEE [
       KEY = {EMPLOYEE_NUMBER}
       ATTRIBUTES = {
             EMPLOYEE_NUMBER: CHARACTER(9)
             EMPLOYEE_NAME: CHARACTER(15)
             TITLE: CHARACTER(10) } ]
    ```
  - ```
    RELATION TITLE_SALARY [
       KEY = {TITLE}
       ATTRIBUTES = {
             TITLE: CHARACTER(10)
             SALARY: NUMERIC(6) } ]
    ```

Example of schemas

- Internal view: description of physical realization
  - ```
    INTERNAL_REL EMP [
     INDEX ON E# CALL EMNIX
     FIELD = {
           E#: BYTE(9)
           E_NAME: BYTE(15)
           TIT: BYTE(10) }]
    ```
- External view: a portion of the database in the form that conforms the user's needs (SQL-like notation shown here)
  - ```
    CREATE VIEW PAYROLL (ENO, ENAME, SAL)
    AS SELECT EMPLOYEE.EMPLOYEE_NUMBER,
              EMPLOYEE.EMPLOYEE_NAME
              TITLE_SALARY.SALARY
    FROM      EMPLOYEE, TITLE_SALARY
    WHERE     EMPLOYEE.TITLE=TITLE_SALARY.TITLE
    ```

Architectural models for Distributed DBMSs

- DBMS implementation alternatives



Autonomy

- Distribution of control (and not data) - the degree of independence
  - The local operations of the individual DBMSs are not affected by their participation in the multidatabase system
  - The manner in which individual DBMSs process queries and optimize them should not be affected by the execution of global queries
  - System consistency should not be compromised when individual DBMSs join or leave the multidatabase system

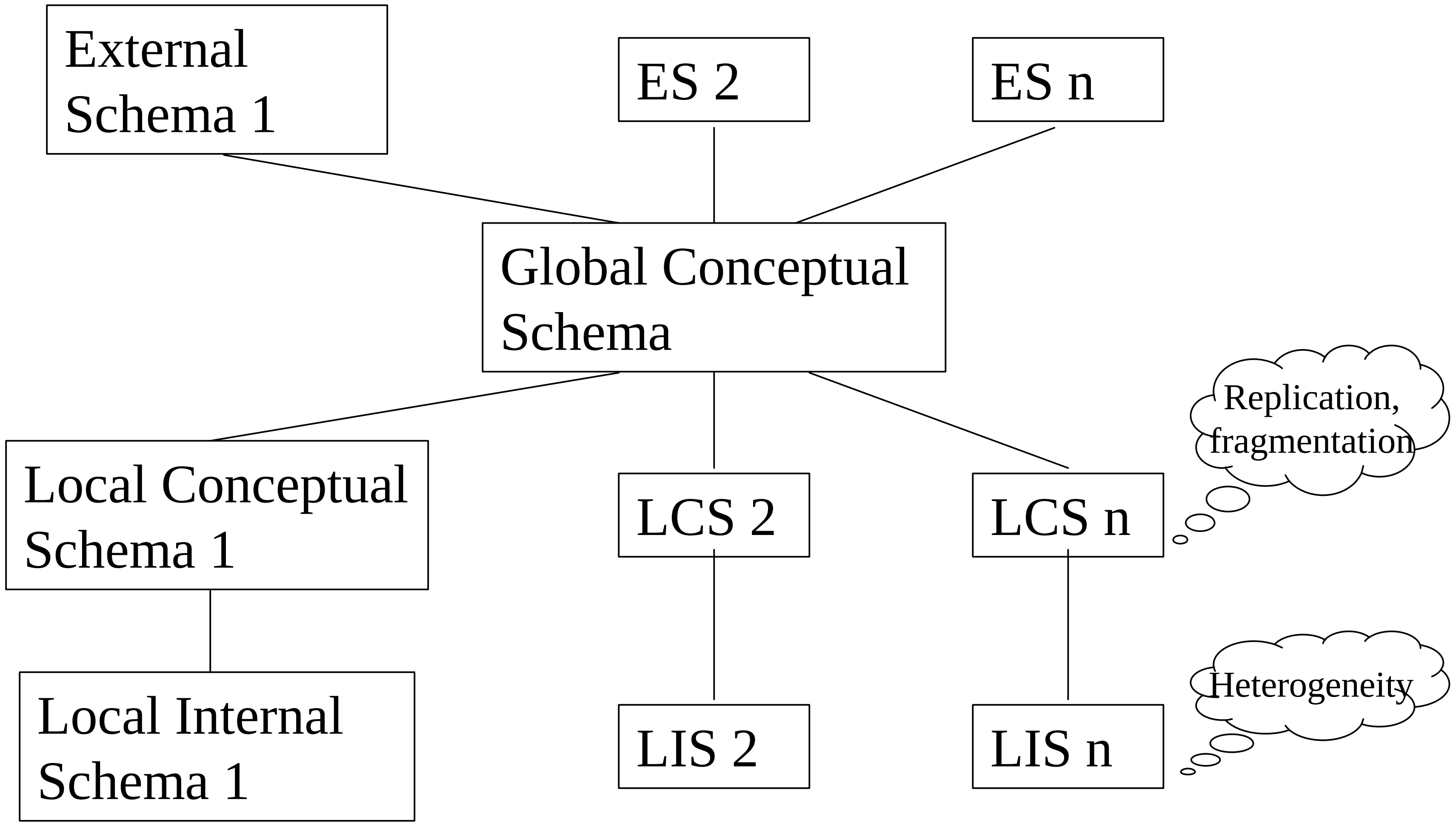
    [Gilgor and Popescu-Zeletin's definition]
- Possibilities:
  - tight integration: a single-image of the entire DB is available
  - semiautonomous (federative) systems: operate independently but participates in a federation, i.e. part of the DB is sharable
  - total isolation

Distributed DBMSs (tight integration)

- From data organizational point of view
  - different physical data organization requires different local internal schemas
  - the DB is fragmented and replicated - each site represents a part of the modeled world - the conceptual schemas at each site are different
  - but: the users access the DB by different external schemas defined above the global conceptual schema
    - it means there is a low level of autonomy - individual DBs are in tight integration

Distributed DBMS architecture

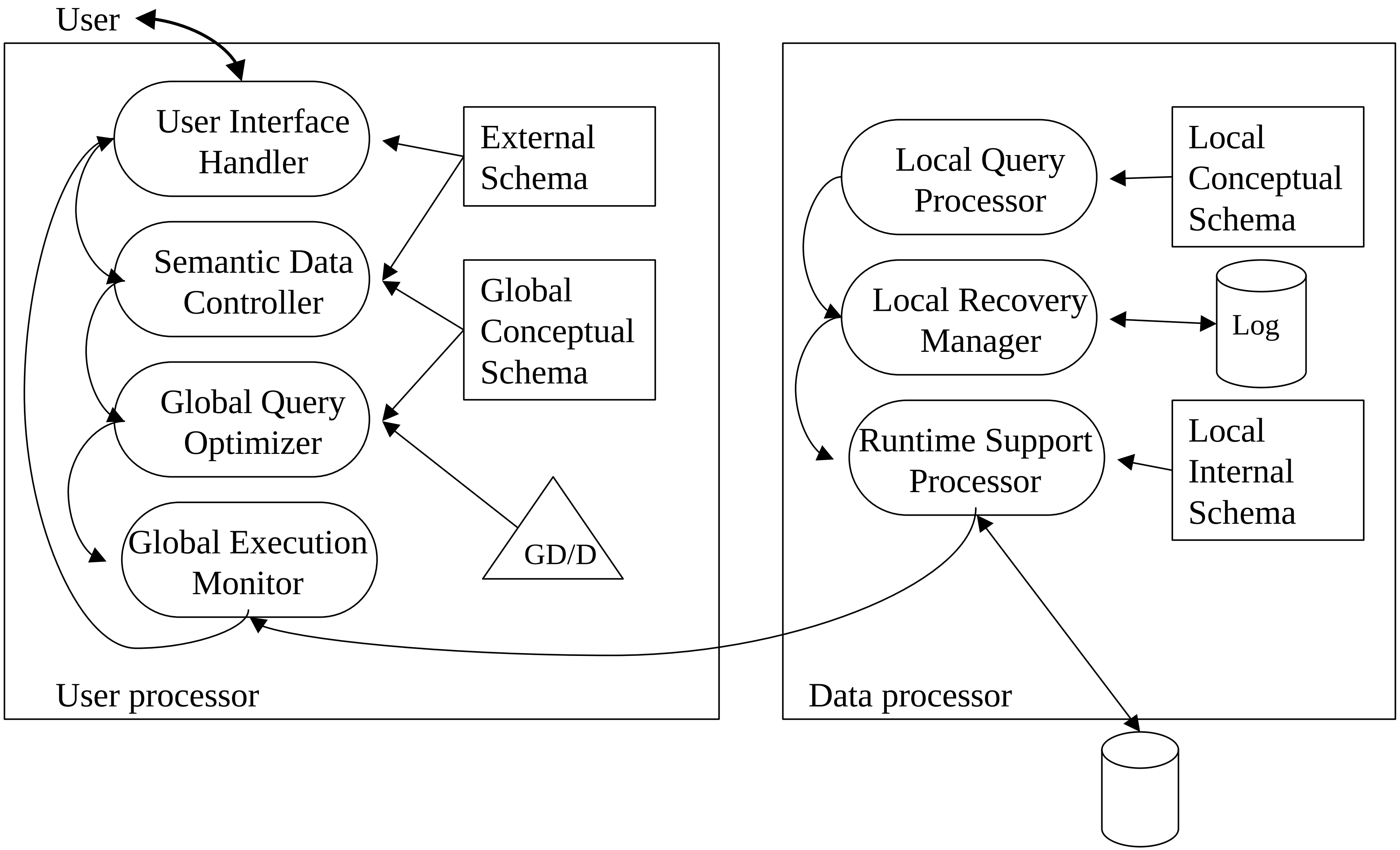
- Data organizational view



Transparency in DDBMS architecture

- Data independence: it is an extension of ANSI/SPARC that supports data independence
- Location and replication transparencies: definition of local and global conceptual schemas and mapping between them
- Network transparency: definition of global conceptual schema

Another view: component based architecture model for distributed DBMS



Components of the DDBMS architecture

- User processor
  - User interface: interprets commands and formats results
  - Semantic data controller: checks integrity constraints and authorizations (def. in GCS) to check if the query can be processed
  - Global query optimizer and decomposer: controls execution strategy, translates global queries into local ones (GCS and LCS)
  - Distributed execution monitor (distributed transaction manager): coordinates the distributed execution of the query (via possible communication with other monitors)

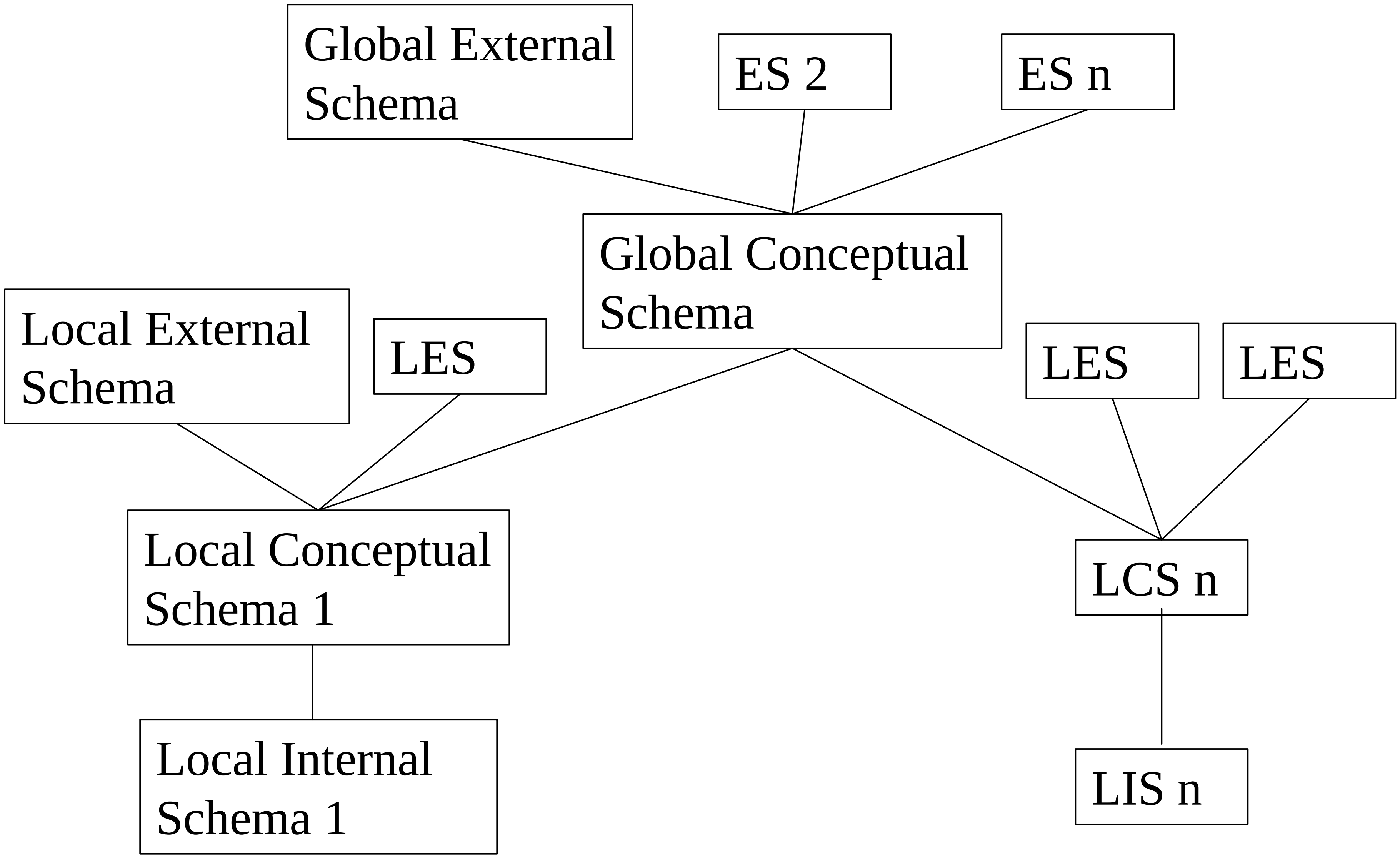
Components of the DDBMS architecture

- Data processor
  - Local query optimizer (access path selector): controls the way how data is accessed (access path means data structures + algorithms to access data, e.g. indexing)
  - Local recovery manager: ensures local consistency
  - Run-time support processor: physically accesses the data storage according to the commands, interfaces the OS

Multi-DBMS architecture

- Difference between distributed multi-DBMSs and distributed tightly integrated DBMSs: autonomy
- Fundamental difference in architecture: the global conceptual schema
  - in DDBMSs it represents the conceptual view of the entire database, while in MDBMSs it represents some of the local databases
- MDBMS
  - using global conceptual schema
  - without global conceptual schema

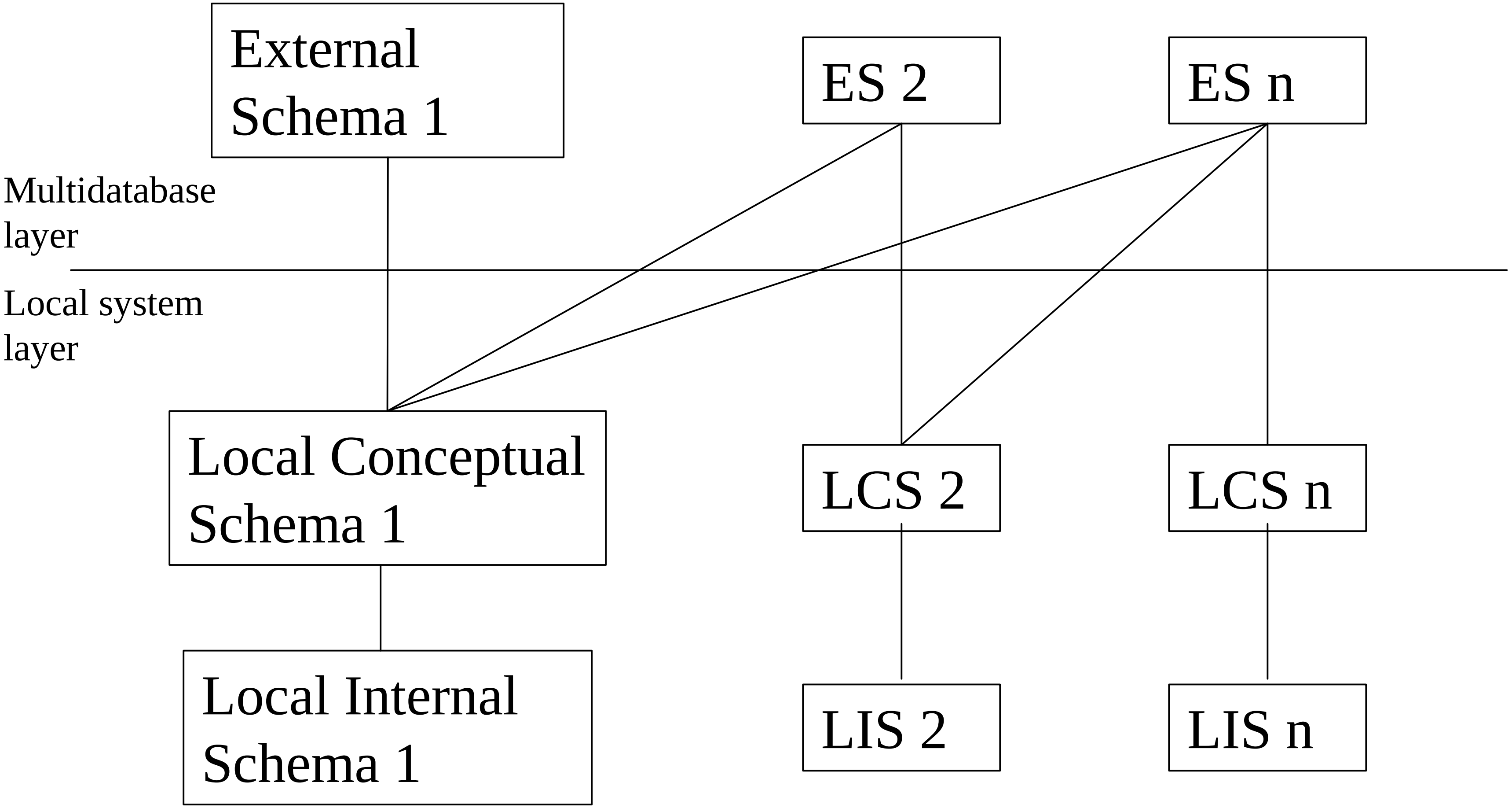
Multi-DBMS using global conceptual schema



Multi-DBMS using global conceptual schema (semiautonomous, federated)

- GCS is defined by either
  - by integrating local external schemas or
  - by integrating parts of the local conceptual schemas
- Main difference between the GCSs
  - integrated DDBMS: mapping from global to local conceptual schemas
  - MDBMS: mapping from local to global conceptual schemas
- In the presence of heterogeneity
  - unilingual and
  - multilingual approaches are possible

Multi-DBMS without a global conceptual schema



Multi-DBMS without a global conceptual schema

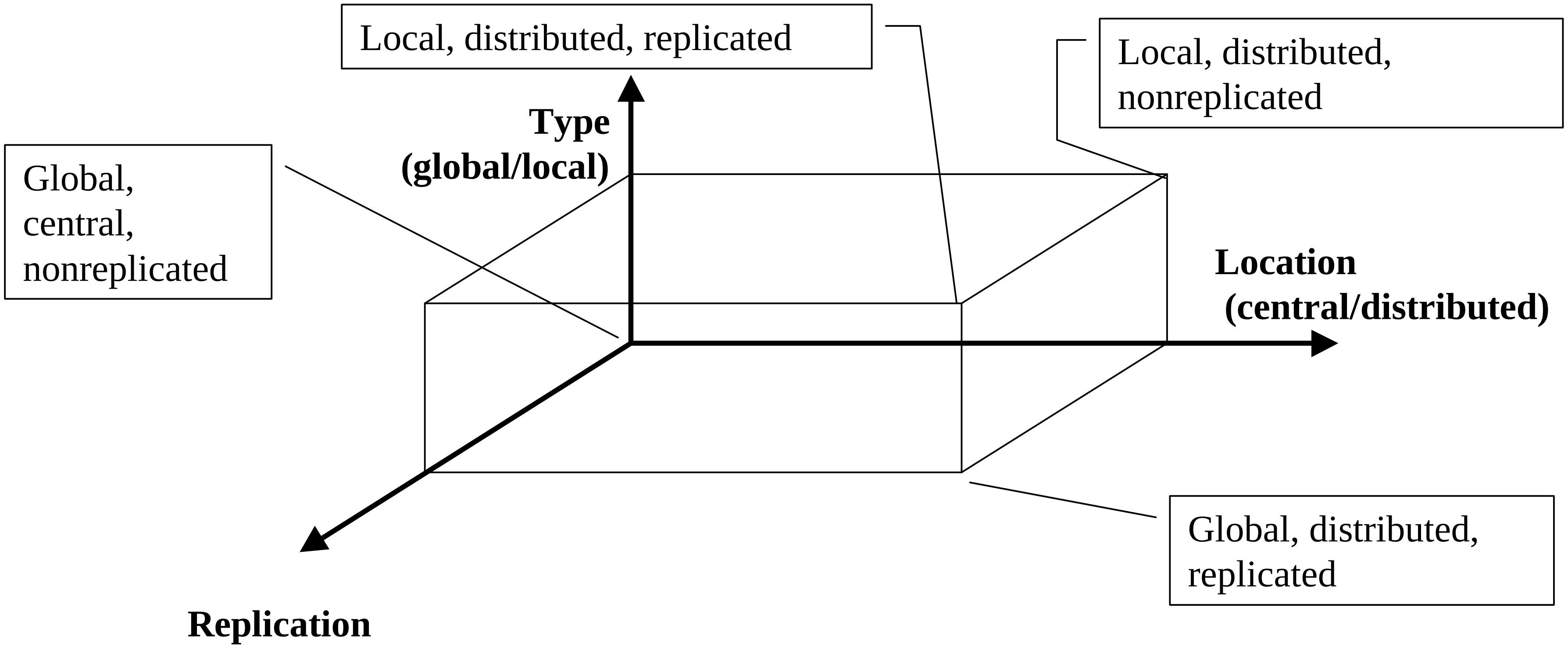
- Some definitions claim the essence of multidatabase management is the lack of global schema
- Federated DB architectures sometimes do not use a global schema, instead
  - export schema for sharing data with others
  - import schema for accessing the global database (global external view)

Multi-DBMS

- Federation: the content (or parts of the content) of different DBs are put together logically
  - they may use different physical implementation (LIS)
  - they may use different data representation (LCS)
- The GCS, the Import and Export Schemas serve as a bridge between the different DBs
  - there is no way to generate these schemas automatically
  - they are created and tailored to each application individually
  - the models presented here are idealized and usually do not appear in this clean form in practice

Global directory

- The global directory is an extension of the ANSI/SPARC dictionary that describes the location and the properties of fragments
- It is a meta-database that contains information about the database, e.g.
  - location of fragments,
  - content of fragments, etc.



Fragmentation, replication, allocation

- Difference between parallel and distributed DBs
  - A distributed DB is fragmented because data is fragmented by nature
    - geographically distributed sites of different architectures, systems, different concepts are put together logically
    - fragmentation is usually given and it is not a fundamental design issue
    - the location of DBs are also given, the allocation is addressed if replication is applied
  - A parallel DB can be fragmented to gain performance
    - fragmentation is a crucial design issue
    - allocation is also up to the designer
    - both have a fundamental impact on performance
    - a parallel DB is essentially a single DB and administrators have a greater freedom to tune the system

The role of fragmentation

- Fragmentation: decomposition of relations
  - it is not aimed at data distribution! Rather:
  - the relation is not a proper unit for distribution, a more appropriate unit can be obtained by partitioning
  - applications view only a subset of relations - locality can be optimized
  - unnecessary replication and high volume of remote memory accesses can be avoided
  - transactions can be executed concurrently: intraquery transaction
- but:
  - conflicting requirements may prevent decomposition into mutually exclusive fragments that can lead to performance degradation
  - semantic data control: checking for dependencies may be difficult

Fragmentation alternatives

JNO	JNAME	BUDGET	LOC
J1	Instrumentation	150000	Montreal
J2	Database	135000	New York
J3	CAD/CAM	250000	New York
J4	Maintenance	310000	Paris

Horizontal
(distr. + parallel)

JNO	JNAME	BUDGET	LOC
J1	Instrumentation	150000	Montreal
J2	Database	135000	New York

JNO	JNAME	BUDGET	LOC
J3	CAD/CAM	250000	New York
J4	Maintenance	310000	Paris

Vertical partitioning
(parallel)

JNO	JNAME
J1	Instrumentation
J2	Database
J3	CAD/CAM
J4	Maintenance

JNO	BUDGET	LOC
J1	150000	Montreal
J2	135000	New York
J3	250000	New York
J4	310000	Paris

Degree of fragmentation

- The extent to which the database is fragmented
  - not fragmented at all
  - fragmented to individual tuples (h) or attributes (v)
- How to decide?
  - The application should be characterized according to a number of parameters
  - Based on the result, the fragmentation can be designed
  - It is essential in parallel DB and less important in distributed DB
  - See chapter ‘Database Design’

Correctness rules of fragmentation

- (Vertical) fragmentation is similar to normalization process
- Rules to avoid semantic changes at fragmentation:
  - Completeness (lossless decomposition): no attributes or tuples may be eliminated at fragmentation
  - Reconstruction: there must be a relational operator (∇) that can reconstruct the original relation, i.e. $R = \nabla R_i, \ \forall R_i \in F_R$ ∇ may be different for different alternatives of fragmentation (horizontal or vertical)
  - Disjointness: horizontal fragments must be disjoint, i.e. if data item d is in R_j, then it is not in any other R_i $(i \neq j)$

Replication

- Fragments of relations are placed across the sites multiple times
  - increases reliability - if some sites fail, the data is still available
  - increases locality - the data can be retrieved from the closest or local site
  - increases performance - a certain fragment may be accessed by less users
- but the question
  - of mutual consistency
  - concurrency control
  - transparency must be addressed
- A DB can be
  - partitioned (no replication)
  - replicated
    - fully replicated - the whole DB is copied to each site
    - partially replicated

The problem of allocation

- After the DB has been partitioned, fragments must be allocated to various sites in the network or processing elements of a parallel machine - possibly multiple times when replicated
- Given a set of fragments $F=\{F_1, F_2, \ldots, F_n\}$ and sites $S=\{S_1, S_2, \ldots, S_m\}$ on which a set of applications $Q=\{Q_1, Q_2, \ldots, Q_q\}$ os running
  - Minimal cost. Minimize the cost of storing each F_i at site S_j, querying F_i at site S_j, updating F_i at all sites where it is stored and the cost of communication
  - Performance. Maintain a performance according to a metric
    - response time
    - throughput
  - Even a very simple formulation of the optimization is proven to be NP-complete - heuristics for suboptimal solutions. For a general model see ‘Database Design’