2. Distributed DBMS Architecture

Chapter 4

Distributed DBMS Architecture

Outline

- Introduction
- Top-Down Design of DDBMS Architecture
  - Schema and Distribution Transparency
- Bottom-up Design of DDBMS Architecture
  - Architectural Alternatives for DDBMSs
  - Reference Architectures for a DDBMS
- Global Directory/Dictionary

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Introduction

- Architecture defines the structure of the system
  - components identified
  - functions of each component defined
  - interrelationships and interactions between components defined

Reference Model（参考模型）

A conceptual framework whose purpose is to divide standardization work into manageable pieces and to show at a general level how these pieces are related to one another.

Three Approaches to Define a Reference Model

① Component-based

- Components of the system are defined together with the interrelationships between components.
- Good for design and implementation of the system.

② Function-based

- Classes of users are identified together with the functionality that the system will provide for each class.
- The objectives of the system are clearly identified. But how do you achieve these objectives?

③ Data-based

- Identify different types of data and specify the functional units that will realize and/or use data according to these views.
- The ANSI/SPARC architecture discussed below belongs to this category.

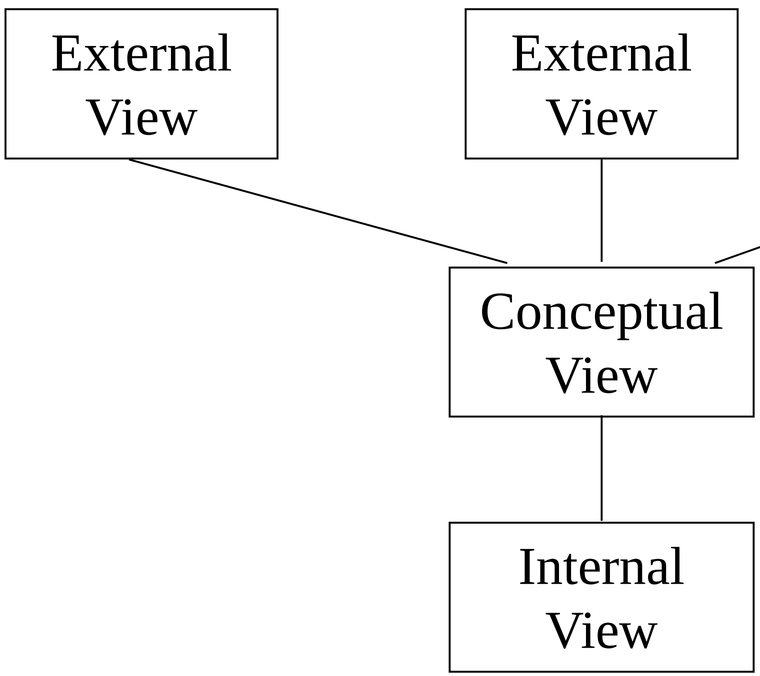
ANSI/SPARC Data-based Architecture

Users

External Schema

Conceptual Schema

Internal Schema



Conceptual Schema （概念模式）

RELATION EMP [
  KEY = {ENO}
  ATTRIBUTES = {
    ENO : CHARACER(9)
    ENAME : CHARACER(15)
    TITLE : CHARACER(10)
  }
]

RELATION PAY [
  KEY = {TITLE}
  ATTRIBUTES = {
    TITLE : CHARACER(10)
    SAL : NUMERIC(6)
  }
]

RELATION PROJECT [
  KEY = {PNO}
  ATTRIBUTES = {
    PNO : CHARACER(7)
    PNAME : CHARACER(20)
    BUDGET : NEMERIC(7)
  }
]

RELATION ASG [
  KEY = {ENO,PNO}
  ATTRIBUTES = {
    ENO : CHARACER(9)
    PNO : CHARACER(7)
    RESP : CHARACER(10)
    DUR : NUMERIC(6)
  }
]

Internal Schema （内部模式）

RELATION EMP [
  KEY = {ENO}
  ATTRIBUTES = {
    ENO : CHARACER(9)
    ENAME : CHARACER(15)
    TITLE : CHARACER(10)
  }
]

INTERNAL_REL EMP [
  INDEX ON ENO **CALL** EMINX
  FIEDLS = {
    HEADER : BYTE(1)
    ENO : BYTE(9)
    ENAME : BYTE(15)
    TITLE : BYTE(10)
  }
]

External View（外部模式 ）– Example 1

Create a BUDGET view from the PROJ relation

```
CREAT  VIEW      BUDGET(PNAME, BUD)
AS     SELECT    PNAME, BUDGET
       FROM      PROJ
```

```
RELATION PROJECT [
    KEY = {PNO}
    ATTRIBUTES = {
        PNO      : CHARACER(7)
        PNAME    : CHARACER(20)
        BUDGET : NEMERIC(7)
    }
]
```

External View（外部模式 ）– Example 2

Create a Payroll view from relations EMP and PAY

```
CREAT  VIEW     PAYROLL(ENO, ENAME, SAL)
AS     SELECT   EMP.ENO, EMP.ENAME, PAY.SAL
       FROM     EMP, PAY
       WHERE    EMP.TITLE = PAY.TITLE
```

```
RELATION EMP [
    KEY = {ENO}
    ATTRIBUTES = {
        ENO      : CHARACER(9)
        ENAME    : CHARACER(15)
        TITLE    : CHARACER(10)
    }
]
```

```
RELATION PAY [
    KEY = {TITLE}
    ATTRIBUTES = {
        TITLE  : CHARACER(10)
        SAL    :  NUMERIC(6)
    }
]
```

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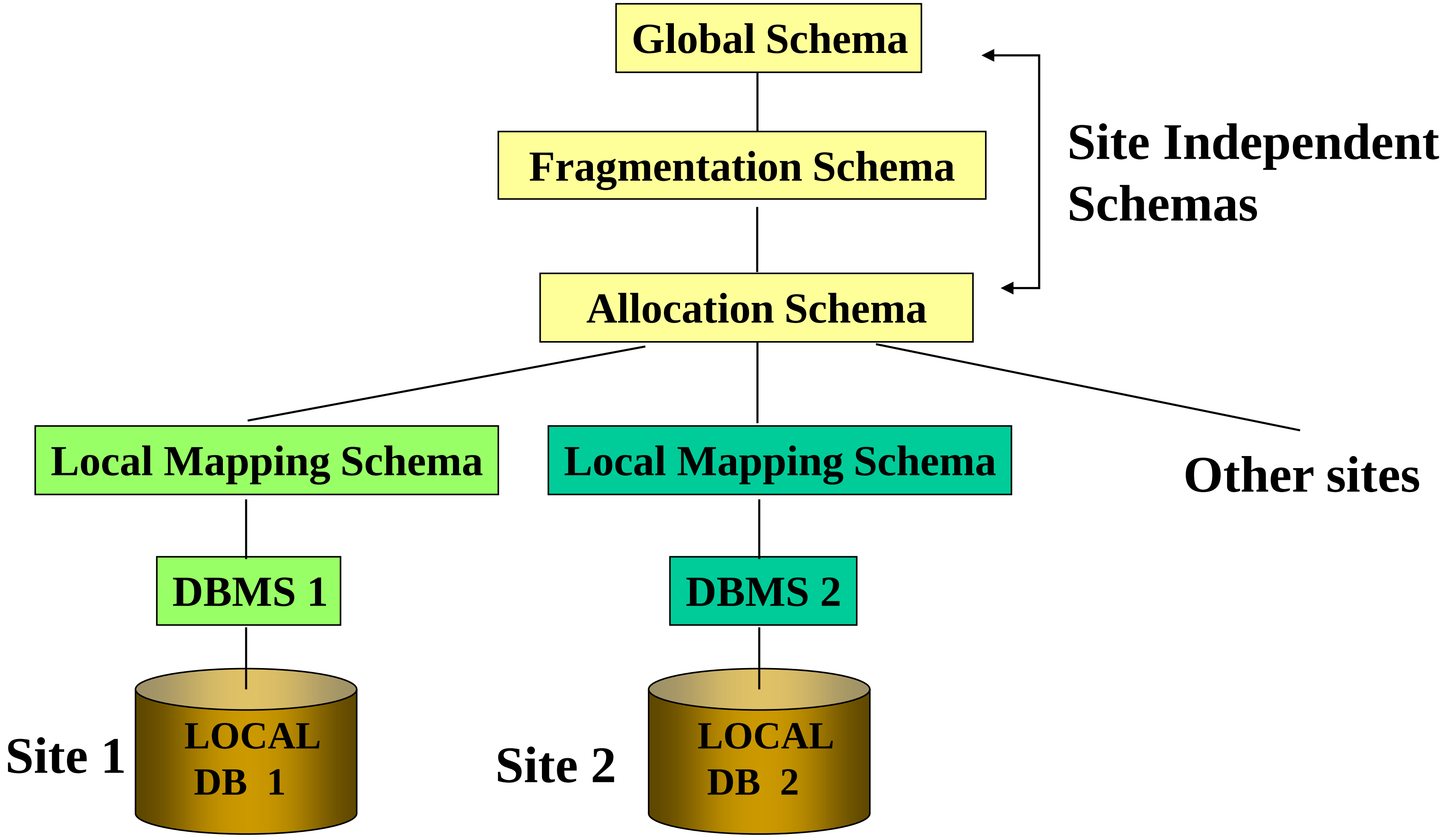
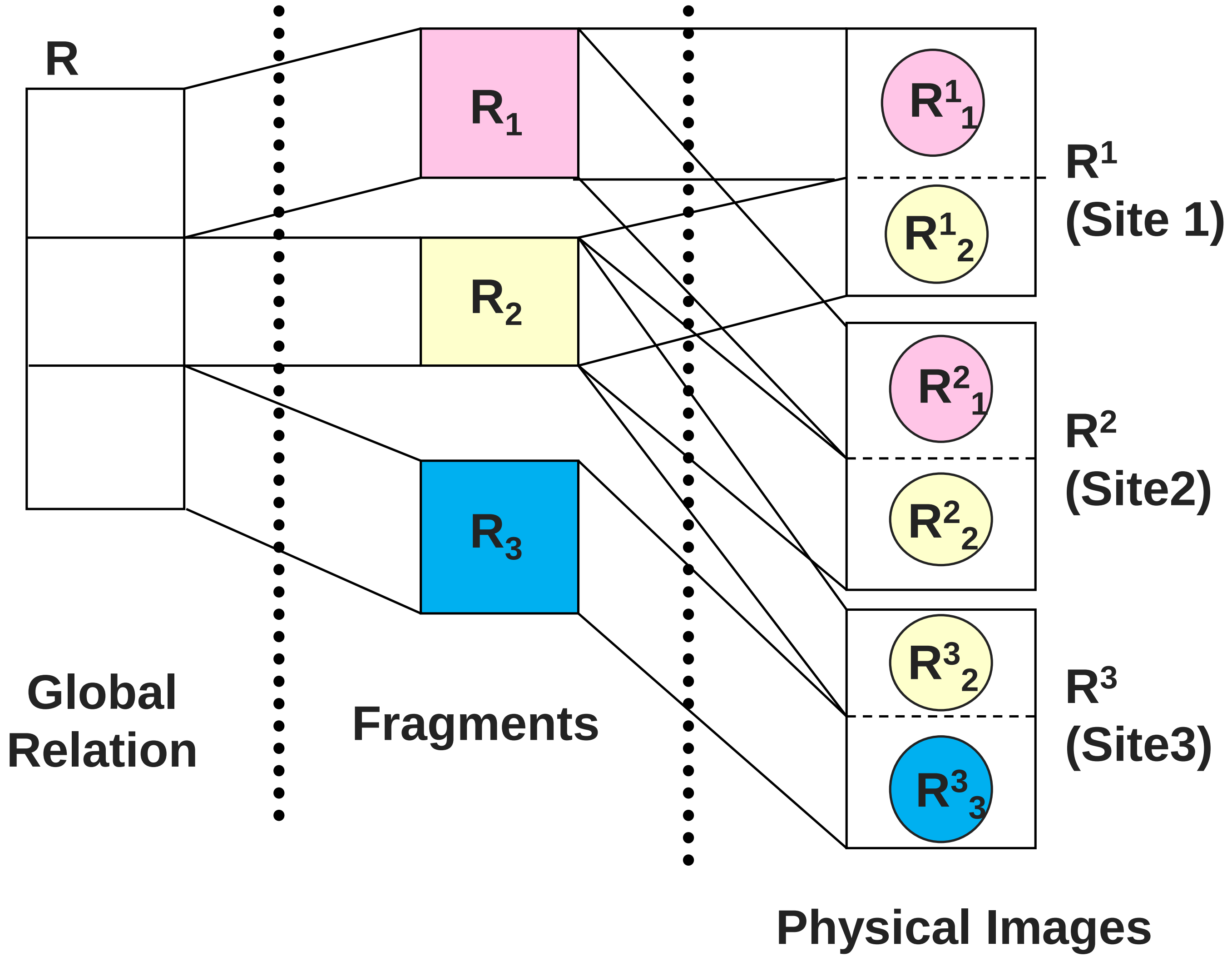
Top-Down Classical DDBMS Architecture



Global Relations, Fragments, and Physical Images



DDBMS Schemas

- **Global Schema: a set of global relations as if database were not distributed at all**
- **Fragmentation Schema: global relation is split into "non-overlapping" (logical) fragments. 1:n mapping from relation R to fragments R_i.**
- **Allocation Schema: 1:1 or 1:n (redundant) mapping from fragments to sites. All fragments corresponding to the same relation R at a site j constitute the physical image R^j. A copy of a fragment is denoted by R^j_i.**
- **Local Mapping Schema: a mapping from physical images to physical objects, which are manipulated by local DBMSs.**

Motivation for this Architecture

- Separating the concept of data fragmentation from the concept of data allocation
- Fragmentation transparency
- Location transparency
- Explicit control of redundancy
- Independence from local databases allows local mapping transparency

Rules for Data Fragmentation

- Completeness

  All the data of the global relation must be mapped into the fragments.

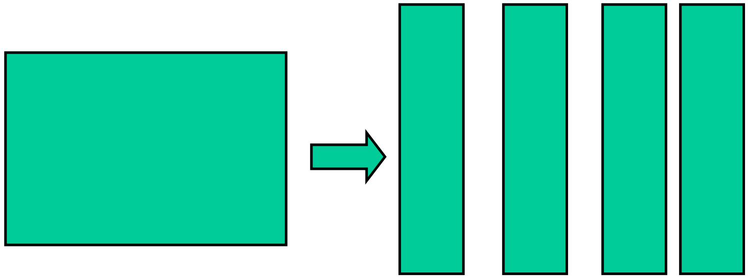
- Reconstruction

  It must always be possible to reconstruct each global relation from its fragments.

- Disjointedness

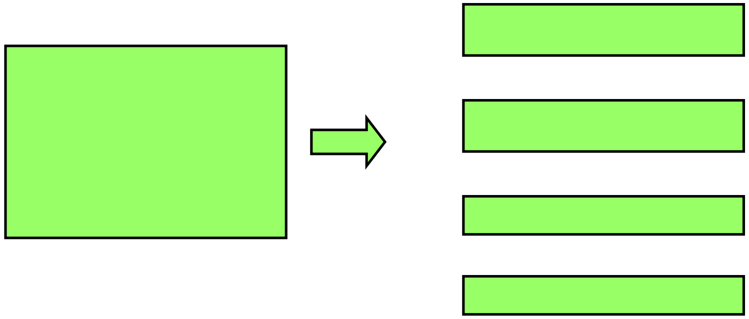
  It is convenient that fragments are disjoint, so that the replication of data can be controlled explicitly at the allocation level.

Types of Data Fragmentation



Vertical Fragmentation

- Projection on relation (subset of attributes)
- Reconstruction by join
- Updates require no tuple migration



Horizontal Fragmentation

- Selection on relation (subset of tuples)
- Reconstruction by union
- Updates may require tuple migration

Mixed Fragmentation

- A fragment is a Select-Project query on relation

Horizontal Fragmentation (水平划分)

- Partitioning the tuples of a global relation into subsets

  Example:

  Supplier (SNum, Name, City)

  Horizontal Fragmentation can be:

  $\mathbf{Supplier_1 = \sigma_{City = ``HK"}\ Supplier}$

  $\mathbf{Supplier_2 = \sigma_{City\ != \text{“HK”}}\ Supplier}$

  Reconstruction is possible:

  $\mathbf{Supplier = Supplier_1 \cup Supplier_2}$

- The set of predicates defining all the fragments must be complete, and mutually exclusive

Derived Horizontal Fragmentation

$Supplier_1 = \sigma_{City = ``HK''} Supplier$

$Supplier_2 = \sigma_{City != “HK”} Supplier$

- The horizontal fragmentation is derived from the horizontal fragmentation of another relation

Example:

Supply (SNum, PNum, DeptNum, Quan)

SNum is a supplier number

$\ltimes$ **semijoin operation**

$$Supply_1 = Supply \ltimes_{SNum=SNum} Supplier_1$$

$$Supply_2 = Supply \ltimes_{SNum=SNum} Supplier_2$$

The predicates defining derived horizontal fragments are:

(Supply.SNum = Supplier.SNum) and (Supplier. City = ``HK")

(Supply.SNum = Supplier.SNum) and (Supplier. City != ``HK")

Vertical Fragmentation (垂直划分)

- The vertical fragmentation of a global relation is the subdivision of its attributes into groups; fragments are obtained by projecting the global relation over each group

Example

EMP (ENum,Name,Sal,Tax,MNum,DNum)

A vertical fragmentation can be

$$EMP_1 = \Pi_{ENum,\ Name,\ MNum,\ DNum}\ EMP$$

$$EMP_2 = \Pi_{ENum,\ Sal,\ Tax}\ EMP$$

Reconstruction:

$$EMP = EMP_1 \bowtie_{ENum = ENum} EMP_2$$

Distribution Transparency (分布透明)

- Different levels of distribution transparency can be provided by DDBMS for applications.

A Simple Application

Supplier(SNum, Name, City)

Horizontally fragmented into:

$Supplier_1 = \sigma_{City = ``HK"}$ Supplier at Site1

$Supplier_2 = \sigma_{City != “HK”}$ Supplier at Site2, Site3

Application:

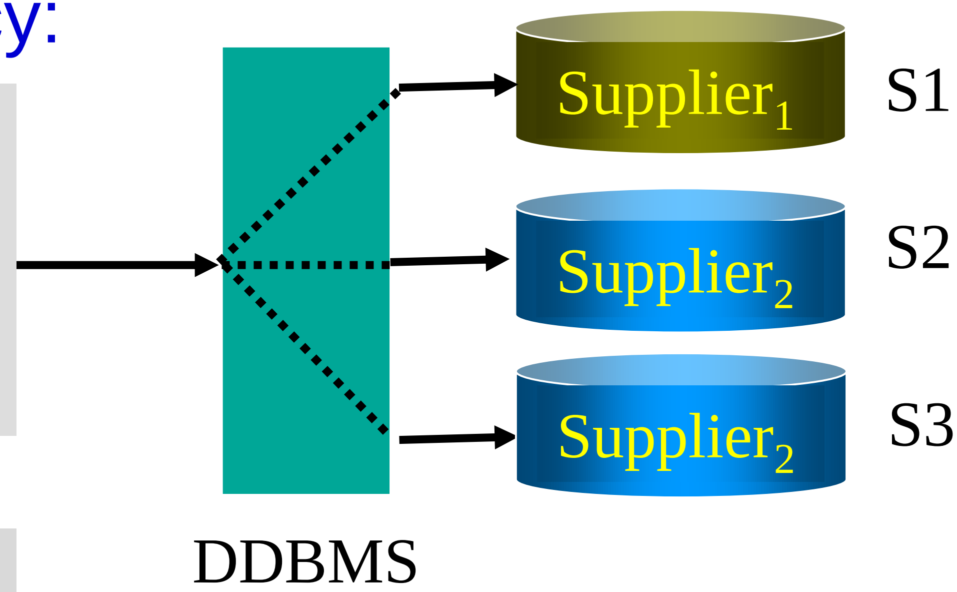
Read the supplier number from the user and return the name of the supplier with that number.

Level 1 of Distribution Transparency

Fragmentation transparency:

```
read (terminal, $SNum);
      Select      Name into $Name
      from        Supplier
      where       SNum = $SNum;
write (terminal, $Name).
```

Read the supplier number from the user and return the name of the supplier with that number.

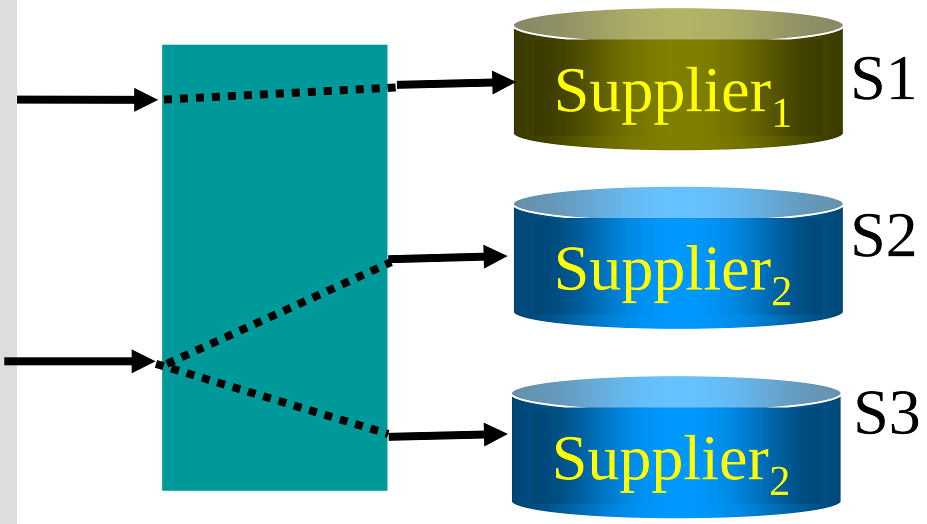


The DDBMS interprets the database operation by accessing the databases at different sites in a way which is completely determined by the system.

Level 2 of Distribution Transparency

Location Transparency (but fragmentation not)

```
read (terminal, $SNum);
      Select      Name into $Name
      from        Supplier1
      where       SNum = $SNum;
 If not FOUND then
      Select      Name into $Name
      from        Supplier2
      where       SNum = $SNum;
write (terminal, $Name).
```

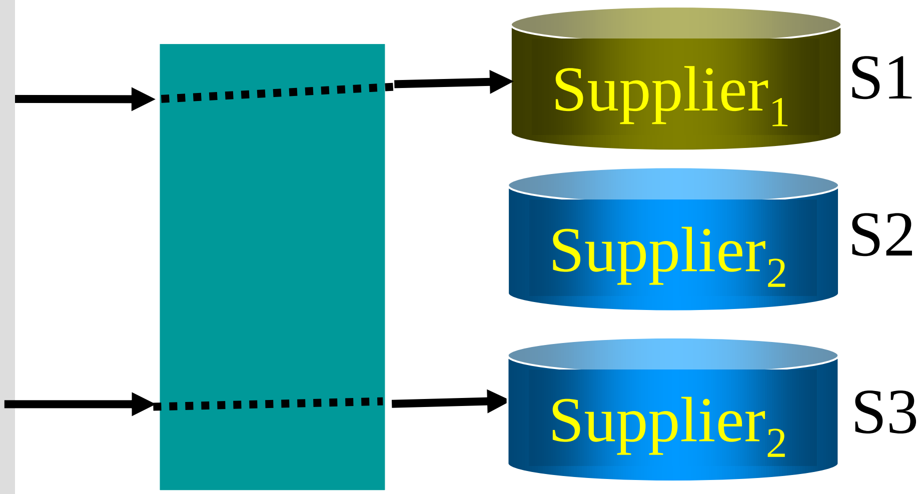


The application is independent from changes in allocation schema, but is not independent from changes to fragmentation schema.

Level 3 of Distribution Transparency

Local Mapping Transparency (but distribution not)

read (terminal, $SNum);
    Select Name into $Name
    from S1.$Supplier_1$
    where SNum = $SNum;
If not FOUND then
    Select Name into $Name
    from S3.$Supplier_2$
    where SNum = $SNum;
write (terminal, $Name).

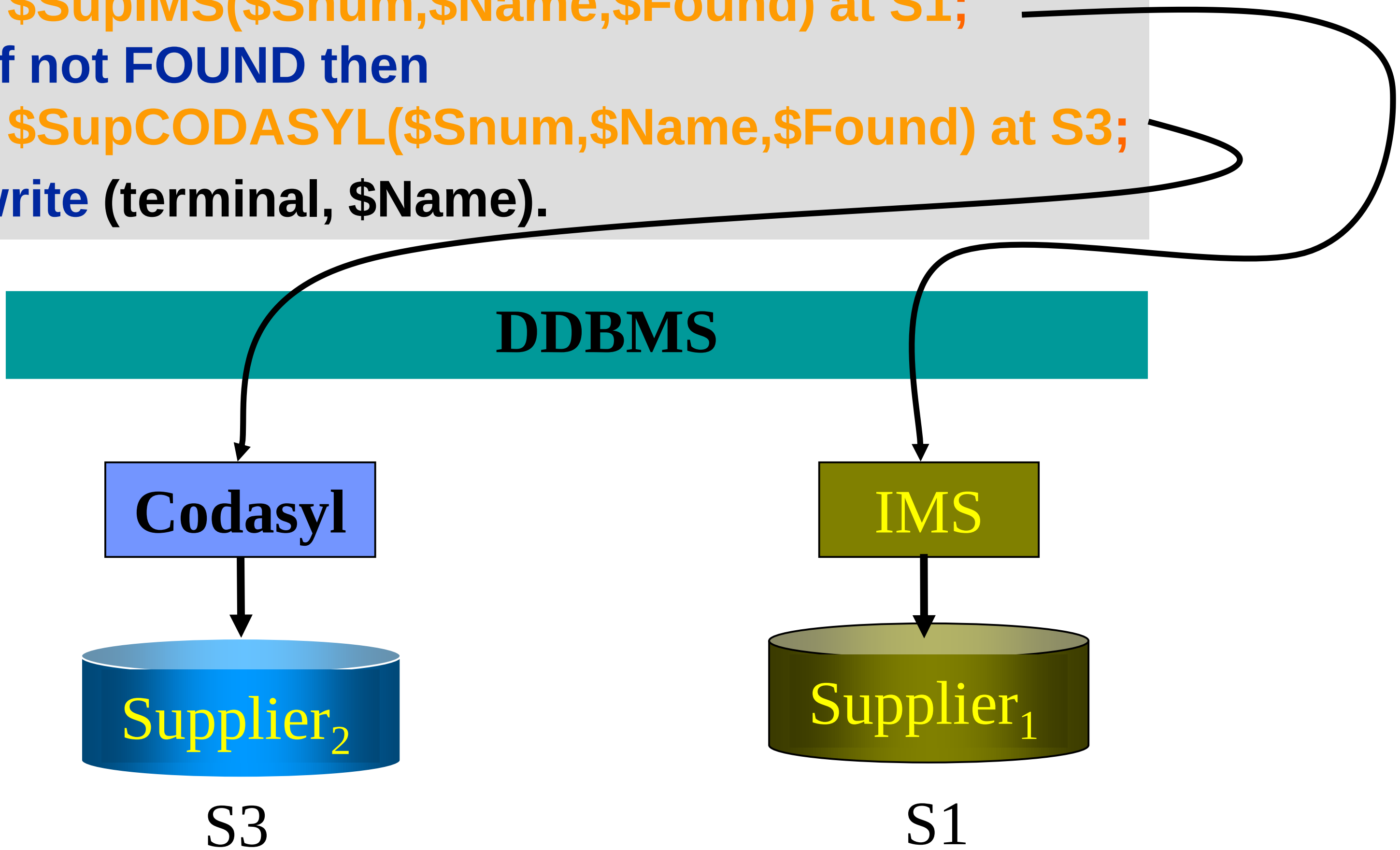


The applications have to specify both the fragment names and the sites where they are located. The mapping of database operations specified in applications to those in DBMSs at sites is transparent.

Level 4 of Distribution Transparency

- No transparency at all !!!

```
read (terminal, $SNum);
  $SupIMS($Snum,$Name,$Found) at S1;
 If not FOUND then
  $SupCODASYL($Snum,$Name,$Found) at S3;
write (terminal, $Name).
```



Distribution Transparency for Updates

Difficulties

- broadcasting updates to all copies
- migration of tuples because of change of fragment defining attributes

$$EMP1 = \Pi_{Enum,Name,Sal,Tax}\,\sigma_{Dnum \leq 10}\ (EMP)$$
$$EMP2 = \Pi_{Enum,Mnum,Dnum}\,\sigma_{Dnum \leq 10}\ (EMP)$$
$$EMP3 = \Pi_{Enum,Name,Dnum}\,\sigma_{Dnum > 10}\ (EMP)$$
$$EMP4 = \Pi_{Enum,Mnum,Sal,Tax}\,\sigma_{Dnum > 10}\ (EMP)$$

EMP1

Enum	Name	Sal	Tax
100	Ann	100	10

EMP2

Enum	Mnum	Dnum
100	20	3

Update Dnum=15 for Employee with Enum=100

EMP3

Enum	Name	Dnum
100	Ann	15

EMP4

Enum	Mnum	Sal	Tax
100	20	100	10

An Update Application

```
UPDATE   EMP
SET      Dnum = 15
WHERE    Enum = 100;
```

With Level 1 Fragmentation Transparency

With Level 2 Location Transparency only

```
Select   Name, Tax, Sal into $Name, $Sal, $Tax
From     EMP 1
Where    Enum = 100;

Select   Mnum into $Mnum
From     EMP 2
Where    Enum = 100;

Insert into EMP 3 (Enum, Name, Dnum)
                  (100, $Name, 15);
Insert into EMP 4 (Enum, Sal, Tax, Mnum)
                  (100, $Sal, $Tax, $Mnum);

Delete EMP 1 where Enum = 100;
Delete EMP 2 where Enum = 100;
```

Levels of Distribution Transparency

- Fragmentation Transparency
  - Just like using global relations
- Location Transparency
  - Need to know fragmentation schema; but no need to know where fragments are located
  - Applications access fragments (no need to specify sites where fragments are located).
- Local Mapping Transparency
  - Need to know both fragmentation and allocation schema; no need to know what the underlying local DBMSs are.
  - Applications access fragments explicitly specifying where the fragments are located.
- No Transparency
  - Need to know local DBMS query languages, and write applications using functionality provided by the Local DBMS

On Distribution Transparency

- More distribution transparency requires appropriate DDBMS support, but makes end-application developers′ work easy.
- The less distribution transparency, the more the end-application developer needs to know about fragmentation and allocation schemes, and how to maintain database consistency.
- There are tough problems in query optimization and transaction management that need to be tackled (in terms of system support and implementation) before fragmentation transparency can be supported.

Some Aspects of the Classical DDBMS Architecture

- Distributed database technology is an “add-on” technology, and most users already have populated centralized DBMSs, whereas top-down design assumes implementation of new DDBMS from scratch.
- In many application environments, such as semi-structured databases, continuous streaming multimedia data, the notion of fragment is difficult to define.

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Bottom-up Distributed Architectural Models

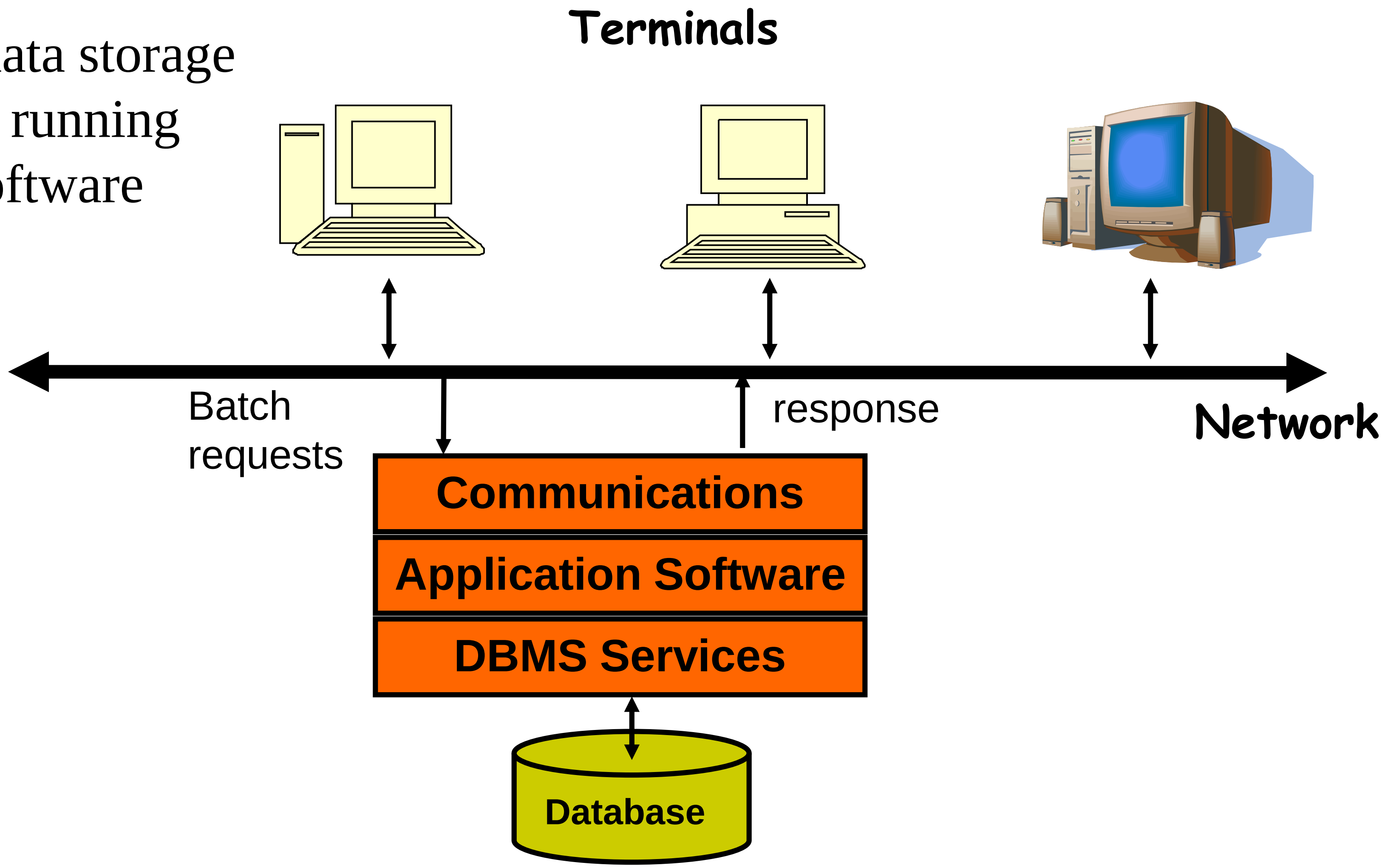
- Possible ways in which multiple data(bases) are put together for sharing, which are characterized according to three dimensions
  - Distribution
  - Heterogeneous
  - Autonomy

Dimension 1: Distribution (分布)

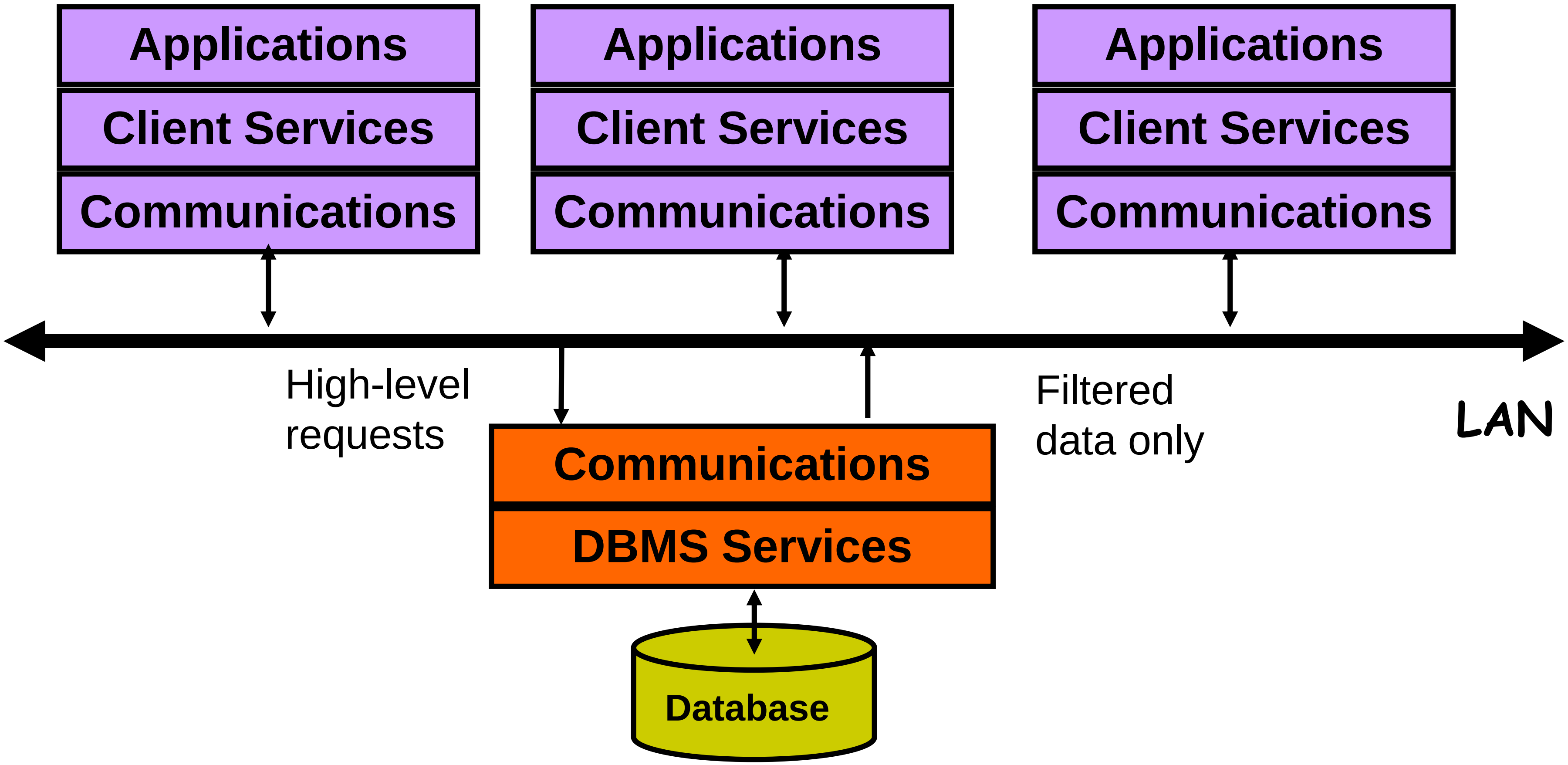
- Whether the components of the system are located on the same machine or not
  - 0 - no distribution - single site (central database)
  - 1 - client-server - distribution of DBMS functionalities
  - 2 - master-slaves - distribution of DBMS functionalities
  - 3 - peer to peer

0 – No Distribution (Time Sharing Access to a Central Database)

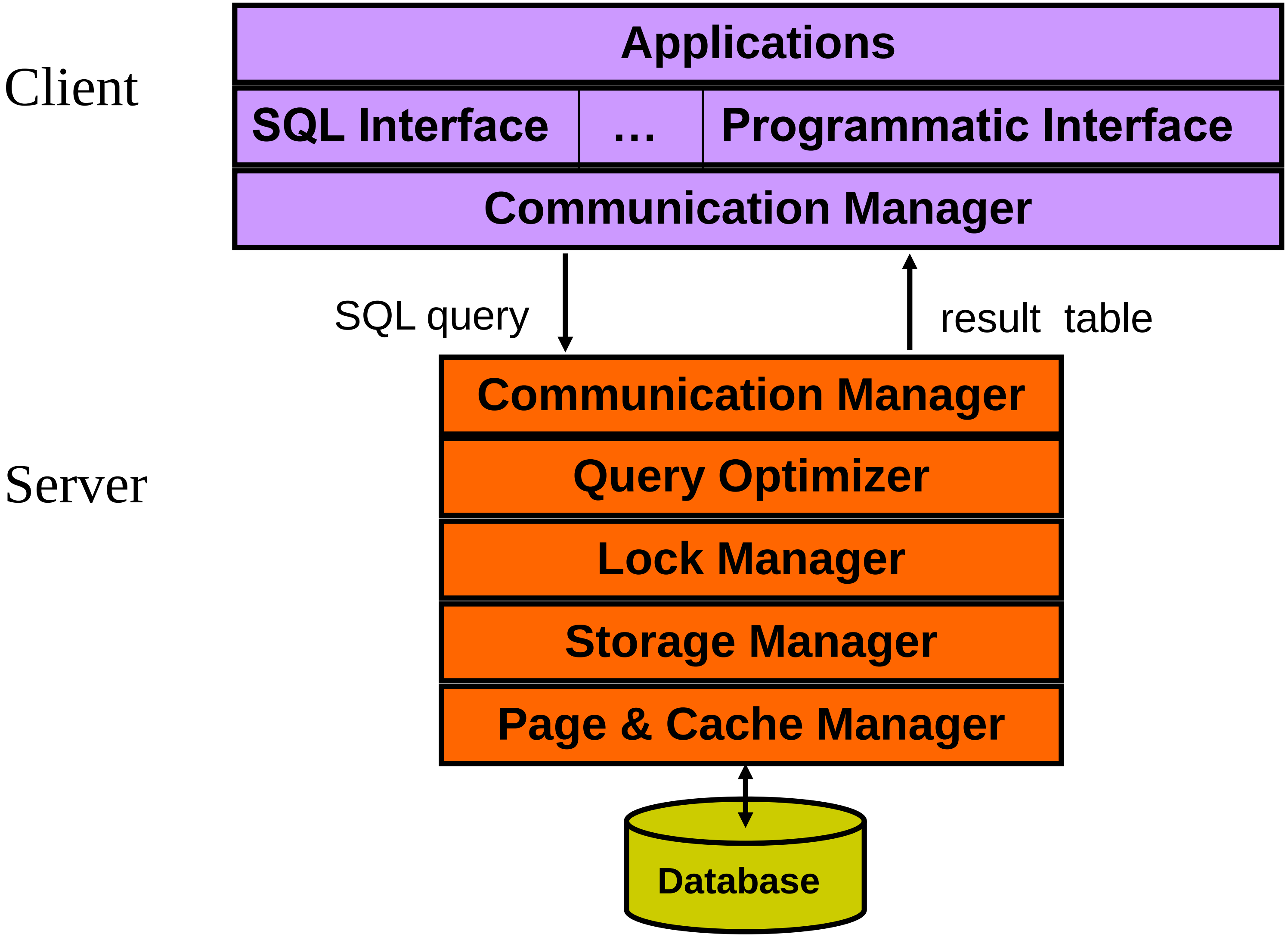
- No data storage
- Host running all software



0 – No Distribution (Multiple Clients / Single Server)



Task Distribution



Advantages of Client-Server Architectures

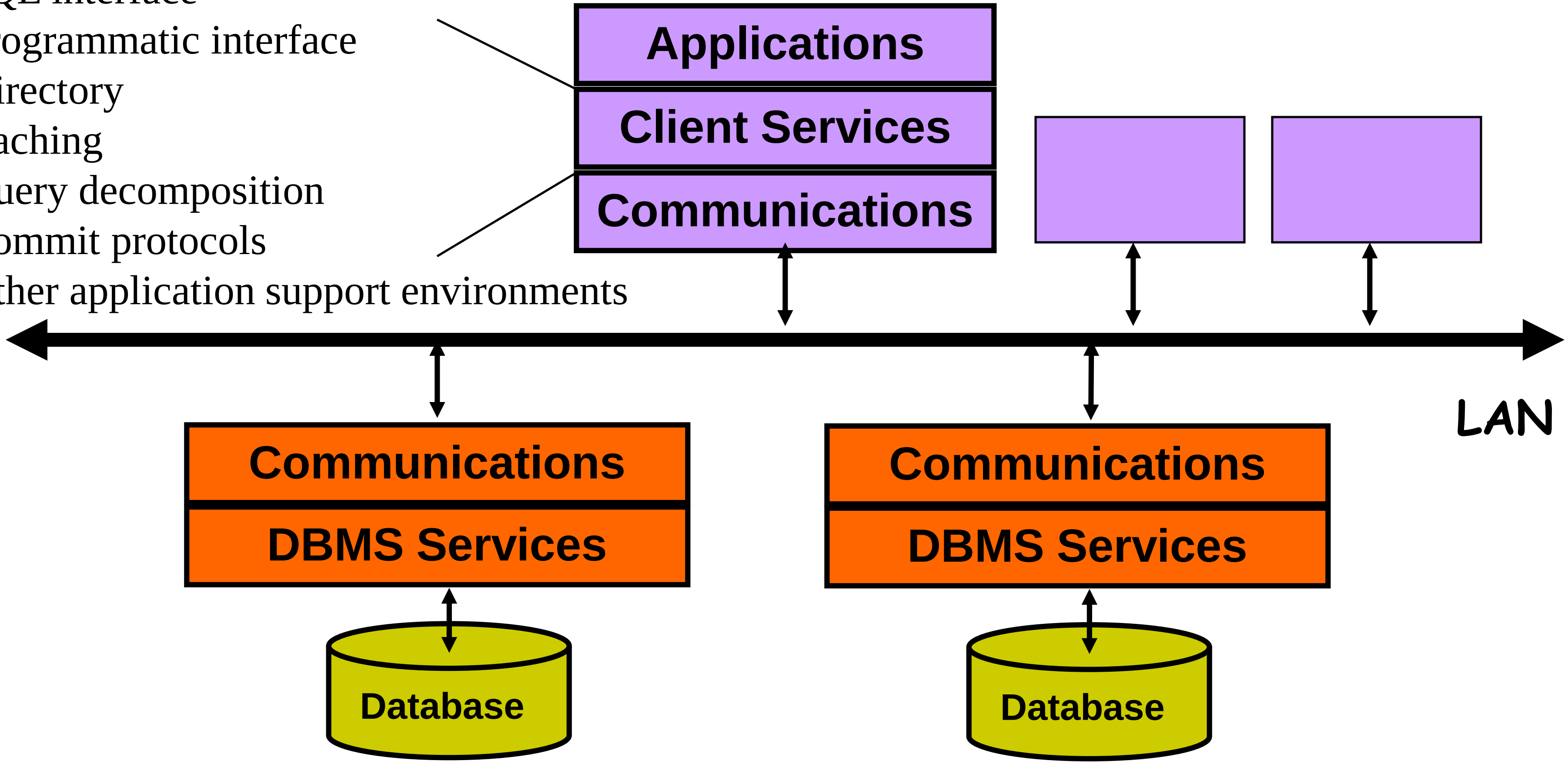
- More efficient division of labor
- Horizontal and vertical scaling of resources
- Better price/performance on client machines
- Ability to use familiar tools on client machines
- Client access to remote data (via standards)
- Full DBMS functionality provided to client workstations
- Overall better system price/performance

Problems with Multiple-Clients / Single Server Architectures

- Server forms bottleneck
- Server forms single point of failure
- Database scaling difficult

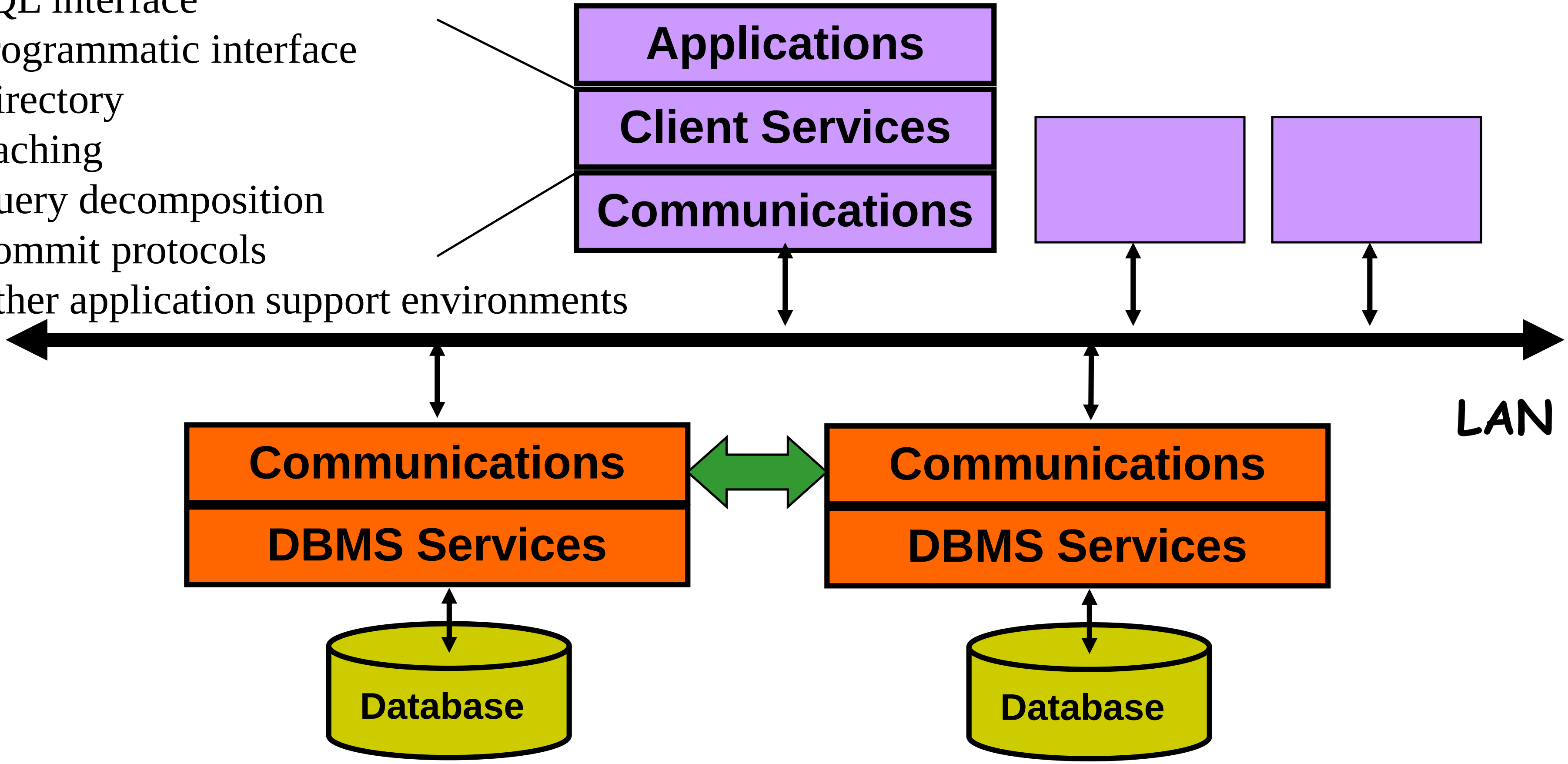
1 - Multiple Clients / Multiple Servers

• SQL interface
• Programmatic interface
• Directory
• Caching
• Query decomposition
• Commit protocols
• Other application support environments



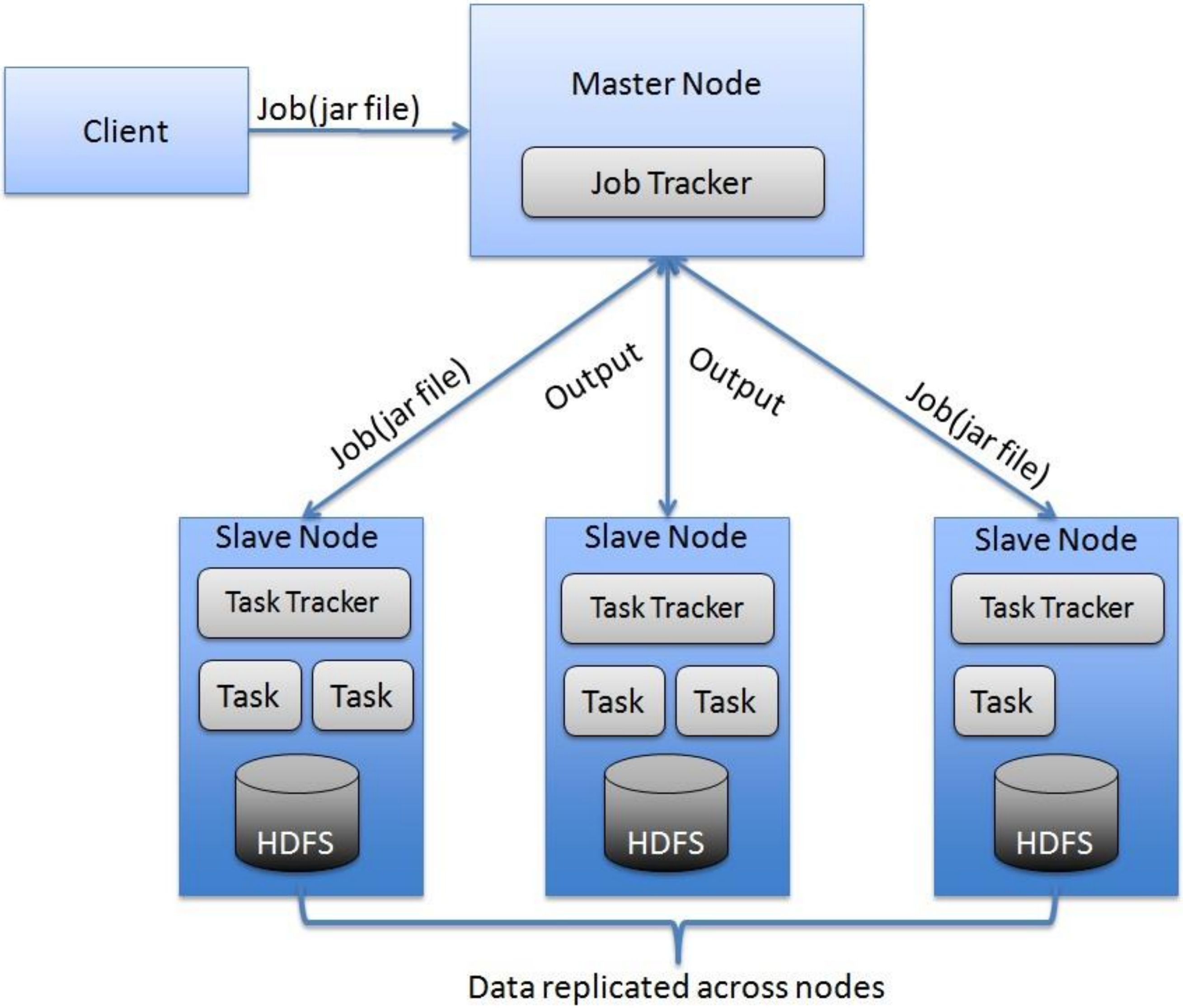
Server to Server

- SQL interface
- Programmatic interface
- Directory
- Caching
- Query decomposition
- Commit protocols
- Other application support environments



2 – Master-Slaves Architecture

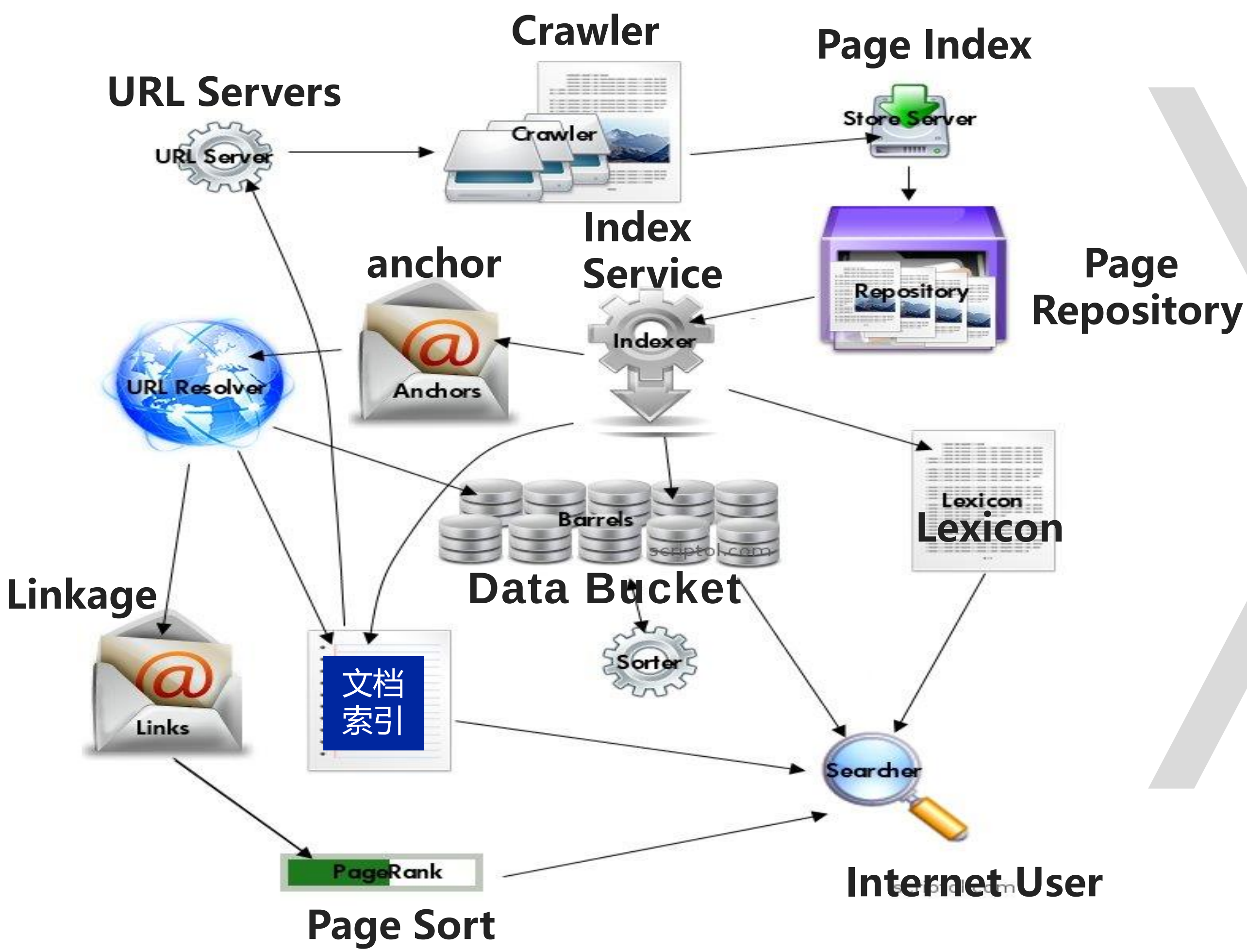
Apache Hadoop



What is Hadoop?

- Hadoop is a software framework for distributed processing of large datasets across large clusters of computers
  - ***Large datasets*** → Terabytes or petabytes of data
  - ***Large clusters*** → hundreds or thousands of nodes
- Hadoop is open-source implementation for **Google *MapReduce*** (a simple programming model)

Google’s Dream and Challenge



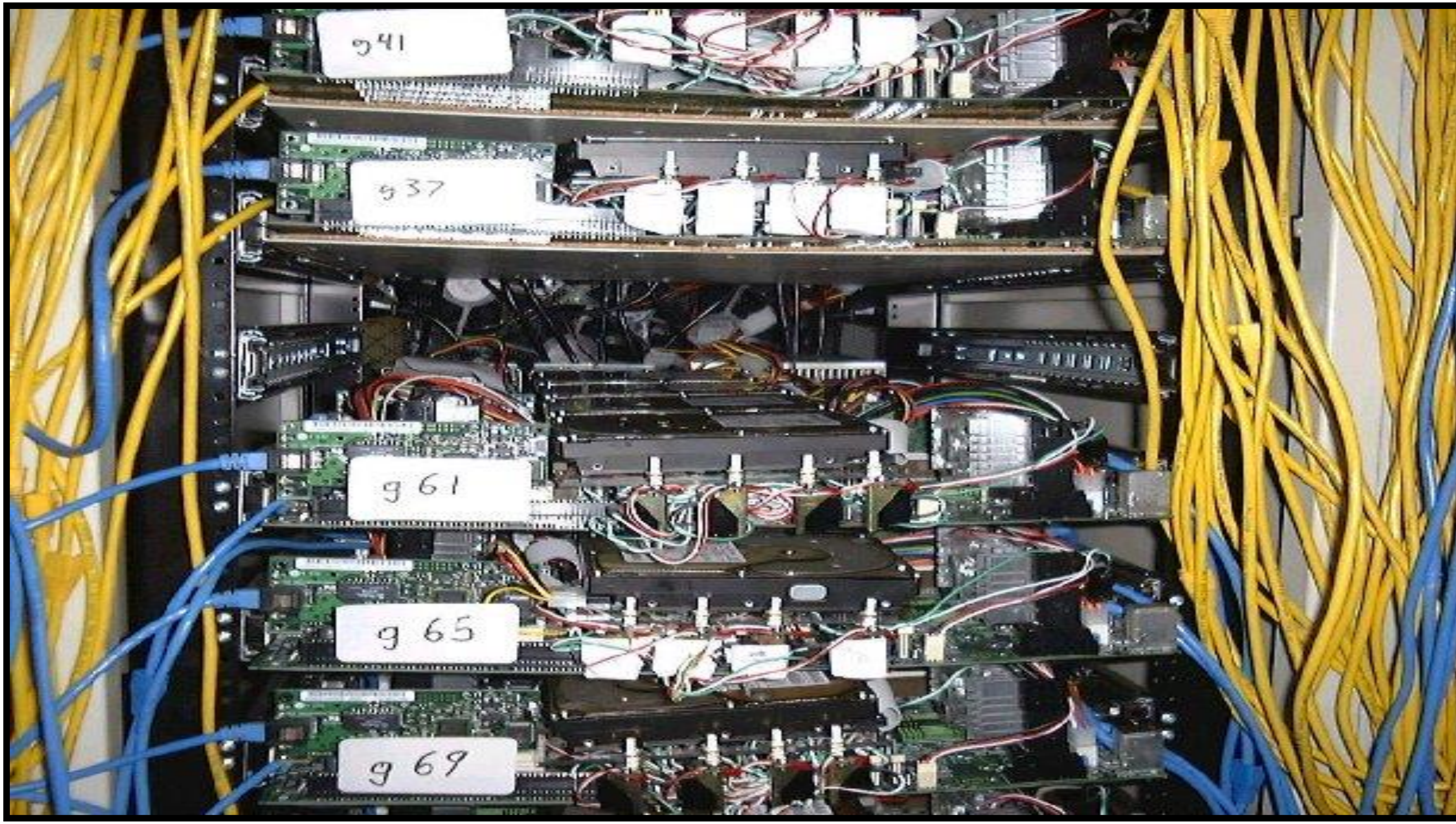
One Write &
Lots of Reads
(millions per second)

Lots of web pages

Low value density

Cost sensitive

Google's DIY Hardware Platform



From: Mass Data Processing Technology on Large Scale Clusters

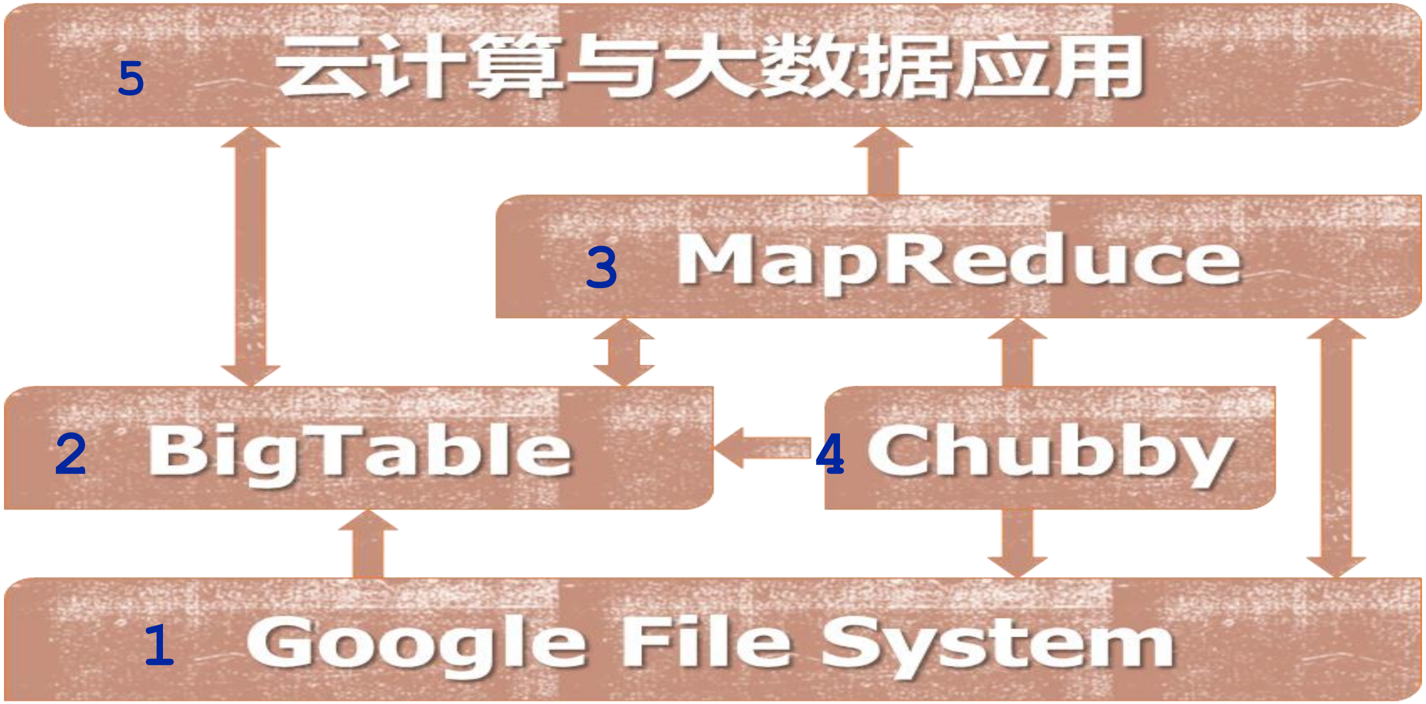
Google's Choice

- **Powerful server or cheap PC?**

	Server	PC
Computational Capability	Strong	Weak
Storage	Big	Small
Fault	Seldom	Frequent
Cost	Expensive	Cheap

- **High volume of web pages with low value density**
- **Cost per query < 5 cents**

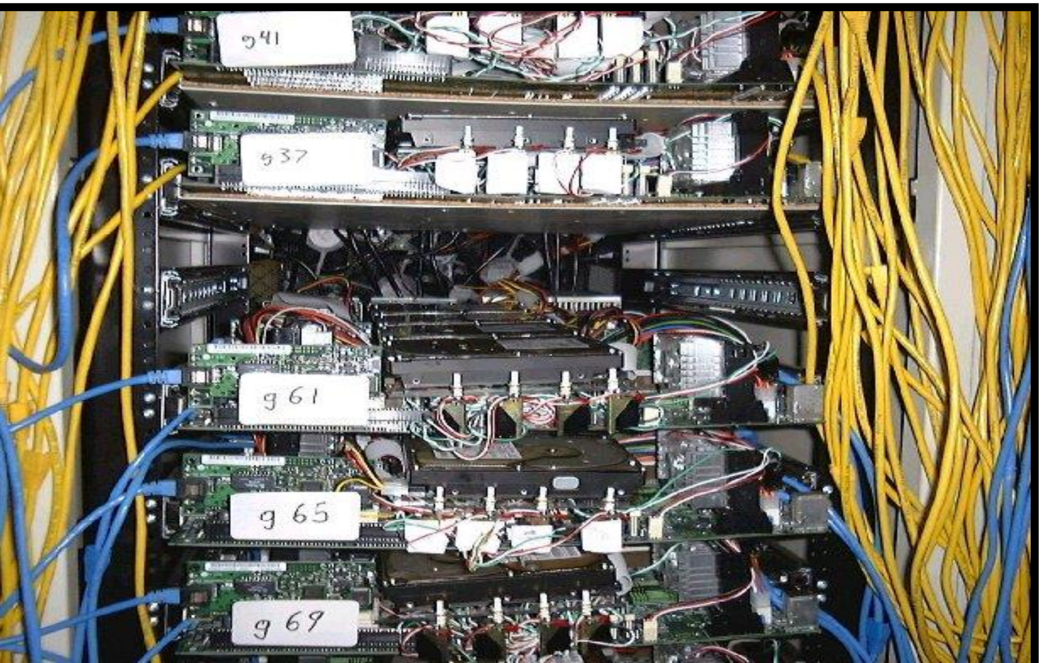
Google's Solution for Big Data



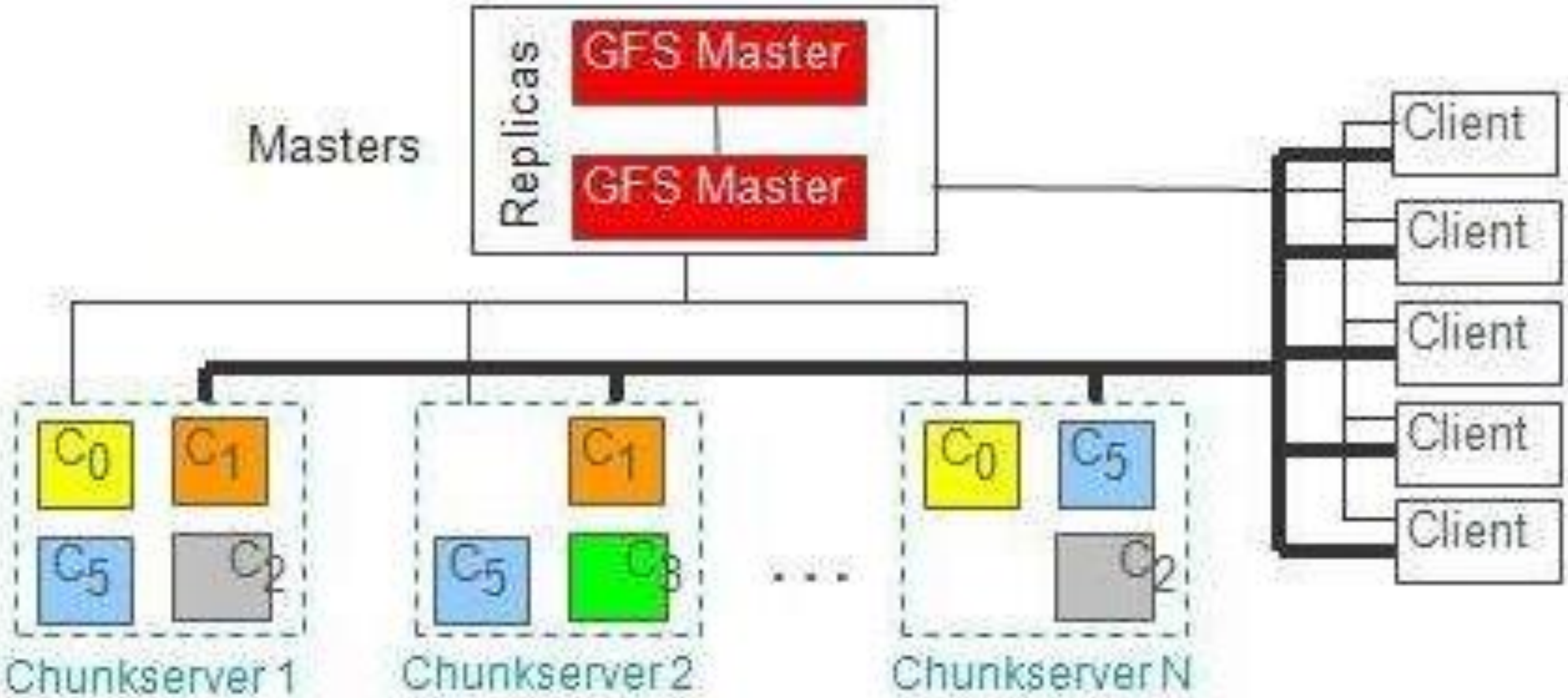
Software stack to make up for hardware defects

Google File System (GFS)

- Turn "small machines" into "big system"
- Turn "bad machines" into "good system"
- Prepare for parallel computation



Google File System (GFS)



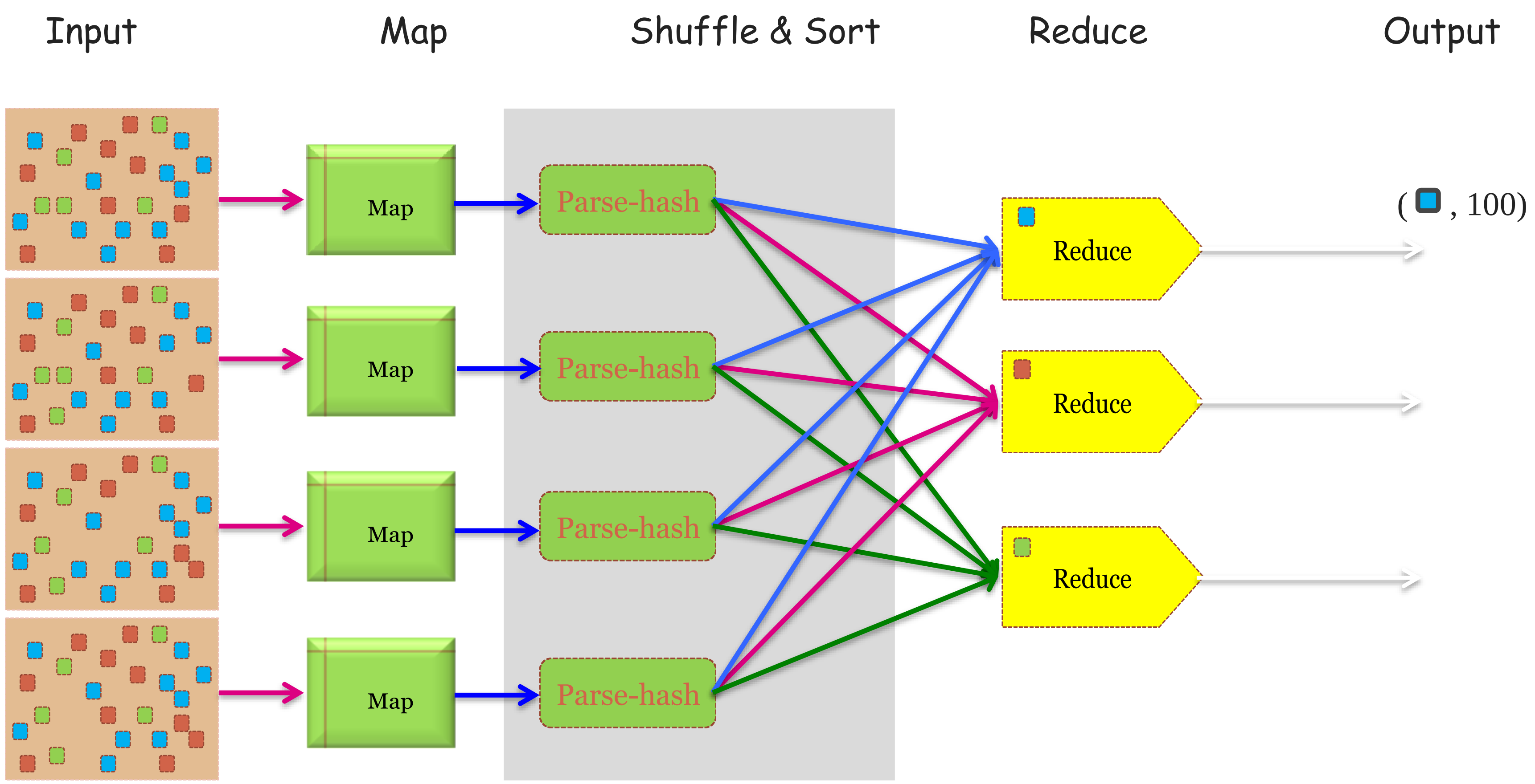
- Files broken into chunks (typically 64 MB)
- Master manages metadata
- Data transfers happen directly between clients/chunkservers

Google MapReduce

- A reliable, fault-tolerant, parallel computing software framework for large-scale data sets for low-cost hardware clusters
  - Large volume of data（>1PB）
  - Large-scale parallel processing（>1 thousand nodes ）
  - Make parallel computation easy

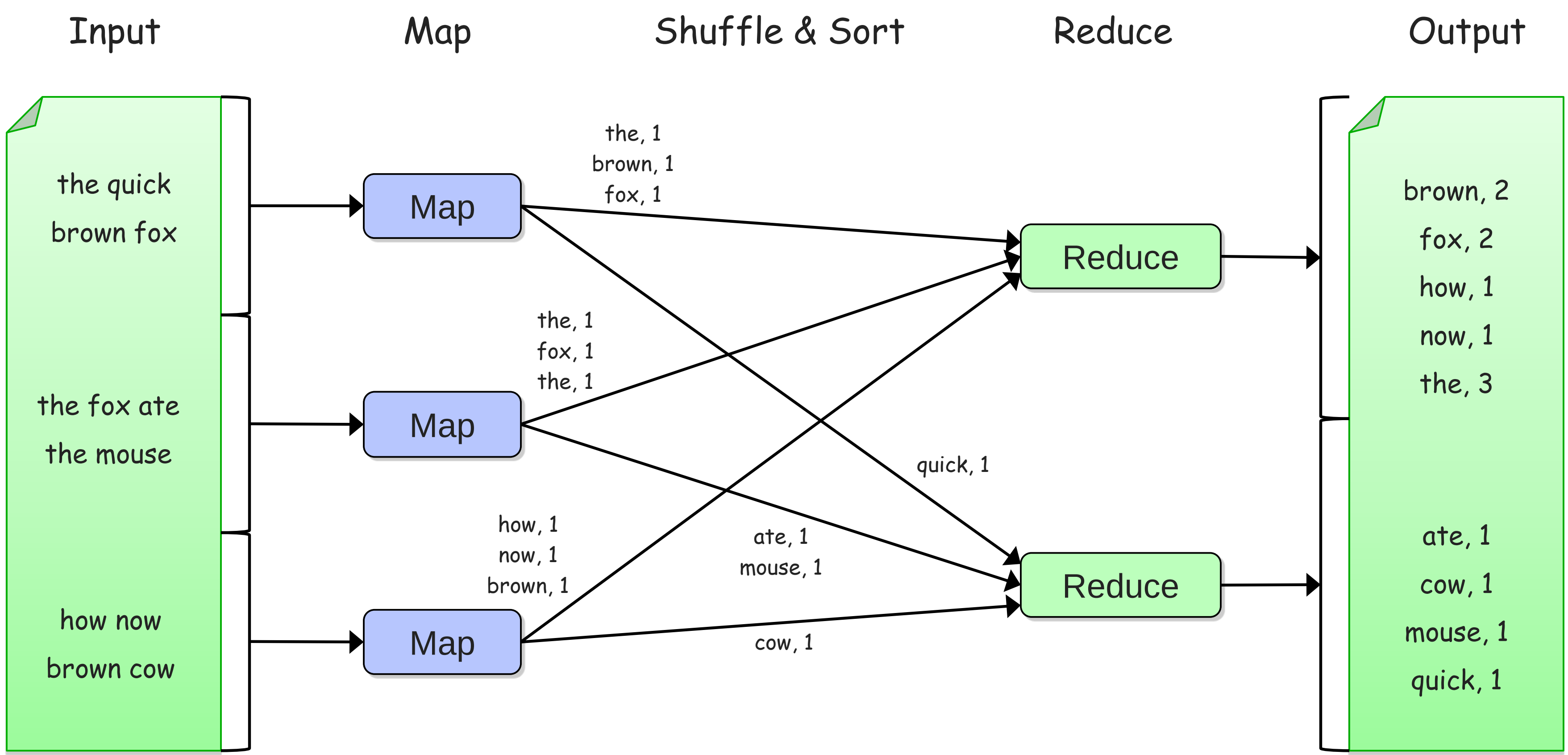
MapReduce = Map（divide）+Reduce（merge and sort）

Example 1: Color Count



Users only provide the "Map" and "Reduce" functions

Example 2: Word Count



Design Principles of Hadoop

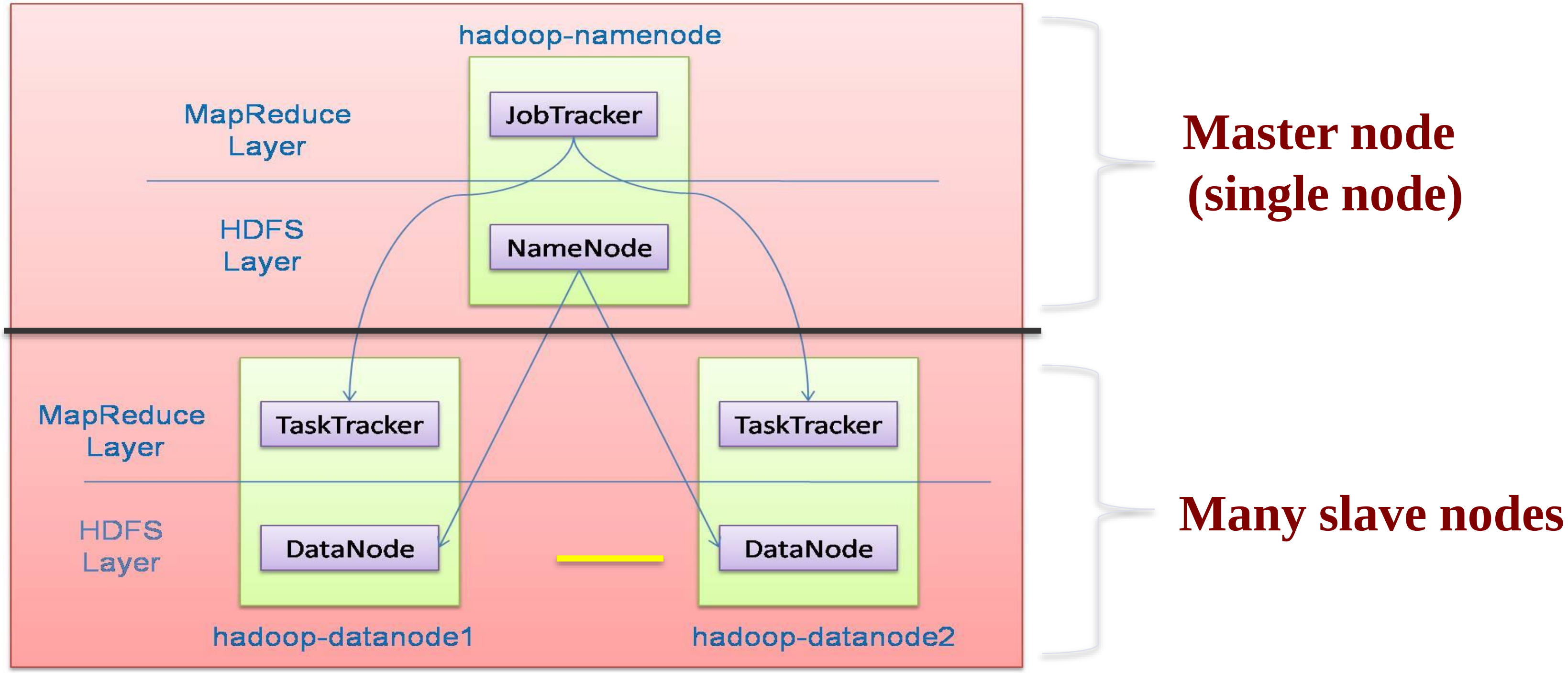
- Need to process big data
- Need to parallelize computation across thousands of nodes
- **Commodity hardware**
  - Large number of low-end cheap machines working in parallel to solve a computing problem
- This is in contrast to traditional parallel DBs
  - Small number of high-end expensive machines

Design Principles of Hadoop (*cont.*)

- **Automatic parallelization & distribution**
  - Hidden from the end-user
- **Fault tolerance and automatic recovery**
  - Nodes/tasks will fail and will recover automatically
- **Clean and simple programming abstraction**
  - Users only provide two functions “map” and “reduce”

Hadoop Architecture

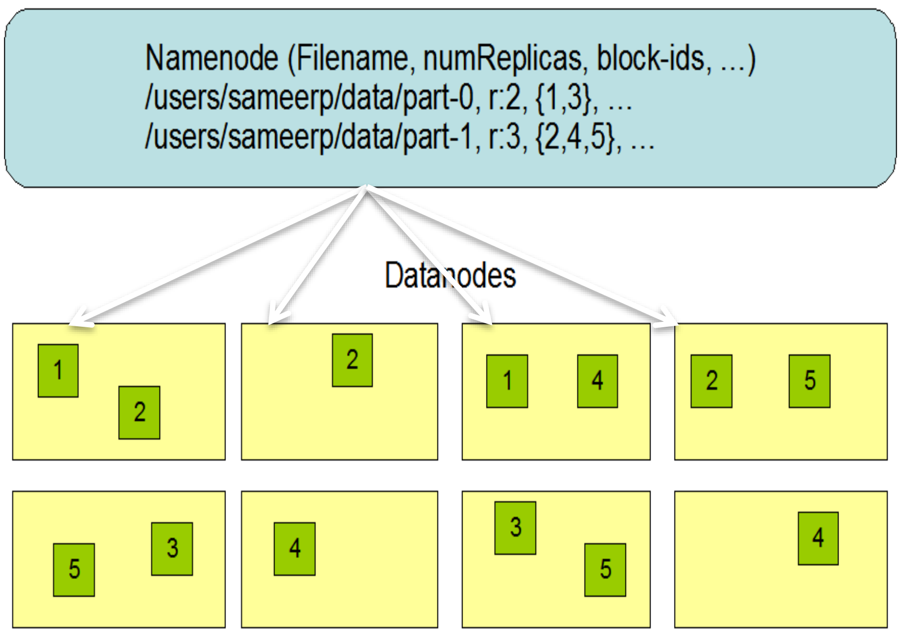
- Master-slave & shared-nothing
- Two layers
  - Distributed file system (HDFS)
  - Execution engine (MapReduce)



Hadoop Distributed File System (HDFS)

Master node

Block Replication



Slave nodes

Centralized namenode

- Maintains metadata info about files

File *F*

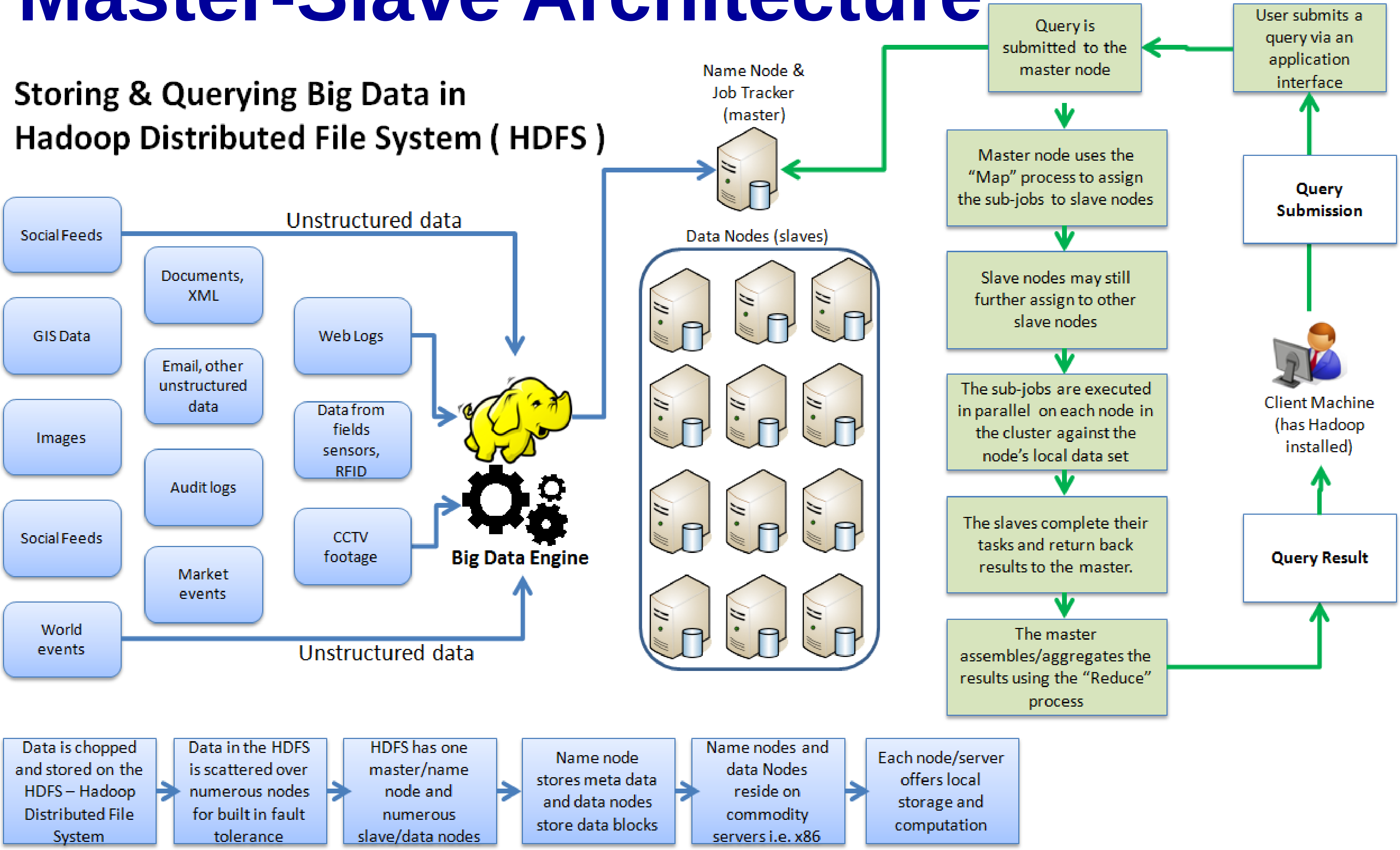
Blocks (64 MB)

Many datanode (1000s)

- Store the actual data
- Files are divided into blocks
- Each block is replicated *N* times (Default = 3)

Master-Slave Architecture

Storing & Querying Big Data in Hadoop Distributed File System (HDFS)



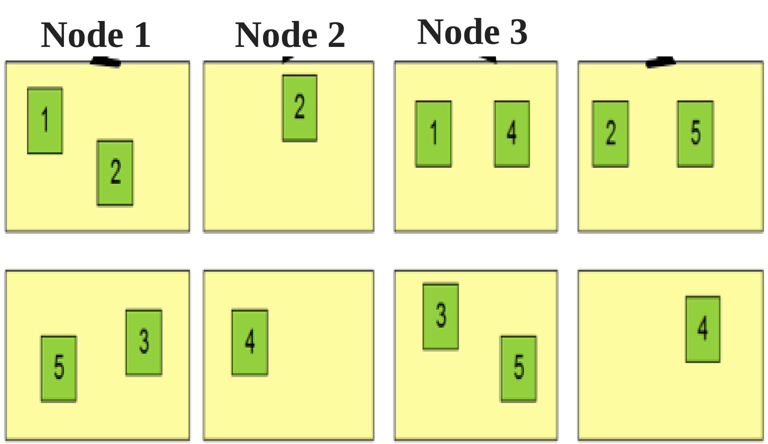
Designed by Sri Prakash, November 2012

Main Properties of HDFS

- ***Large:*** A HDFS instance may consist of thousands of server machines, each storing part of the file system's data
- ***Replication:*** Each data block is replicated many times (default is 3)
- ***Failure:*** Failure is the norm rather than exception
- ***Fault Tolerance:*** Detection of faults and quick, automatic recovery from them is a core architectural goal of HDFS
  - Namenode is consistently checking Datanodes

Properties of MapReduce Engine

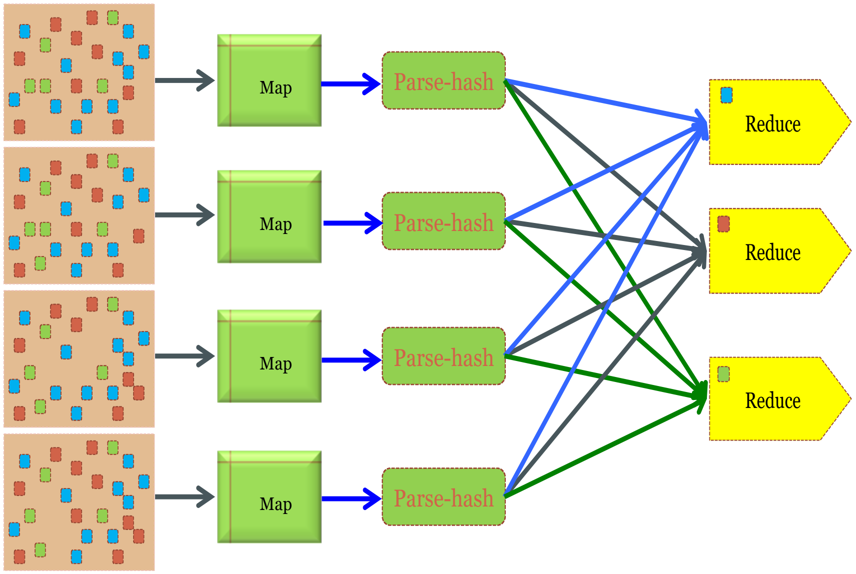
- Job Tracker is the master node (runs with the namenode)
  - Receives the user's job
  - Decides on how many tasks will run (number of mappers)
  - Decides on where to run each mapper (concept of locality)



- This file has 5 blocks → run 5 map tasks
- Where to run the task reading block "1"
  - *Try to run it on Node 1 or Node 3*

Properties of MapReduce Engine (*cont.*)

- Task Tracker is the slave node (runs on each datanode)
  - Receives the task from Job Tracker
  - Runs the task until completion (either map or reduce task)
  - Always in communication with the Job Tracker reporting progress



In this example, 1 map-reduce job consists of 4 map tasks and 3 reduce tasks

(Example: Color Count)

Key-Value Pairs

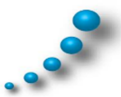
- Mappers and Reducers are users' code (provided functions)
- Just need to obey the Key-Value pairs interface
- **Mappers:**
  - Consume <key, value> pairs
  - Produce <key, value> pairs
- **Reducers:**
  - Consume <key, <list of values>>
  - Produce <key, value>
- **Shuffling and Sorting:**
  - Hidden phase between mappers and reducers
  - Groups all similar keys from all mappers, sorts and passes them to a certain reducer in the form of <key, <list of values>>

Use of MapReduce/Hadoop

- Google: Inventors of MapReduce computing paradigm
- Yahoo: Developing Hadoop open-source of MapReduce
- IBM, Microsoft, Oracle
- Facebook, Amazon, AOL, NetFlex
- Many others + universities and research labs
- Applications
  - Web applications, social networks, scientific applications, applications generating big data

Large-Scale Data Analytics

- MapReduce computing paradigm (e.g., Hadoop) vs. Traditional database systems



Scalability (petabytes of data, thousands of machines)

Flexibility in accepting all data formats (no schema)

Efficient and simple fault-tolerant mechanism

Commodity inexpensive hardware

Performance (tons of indexing, tuning, data organization tech.)

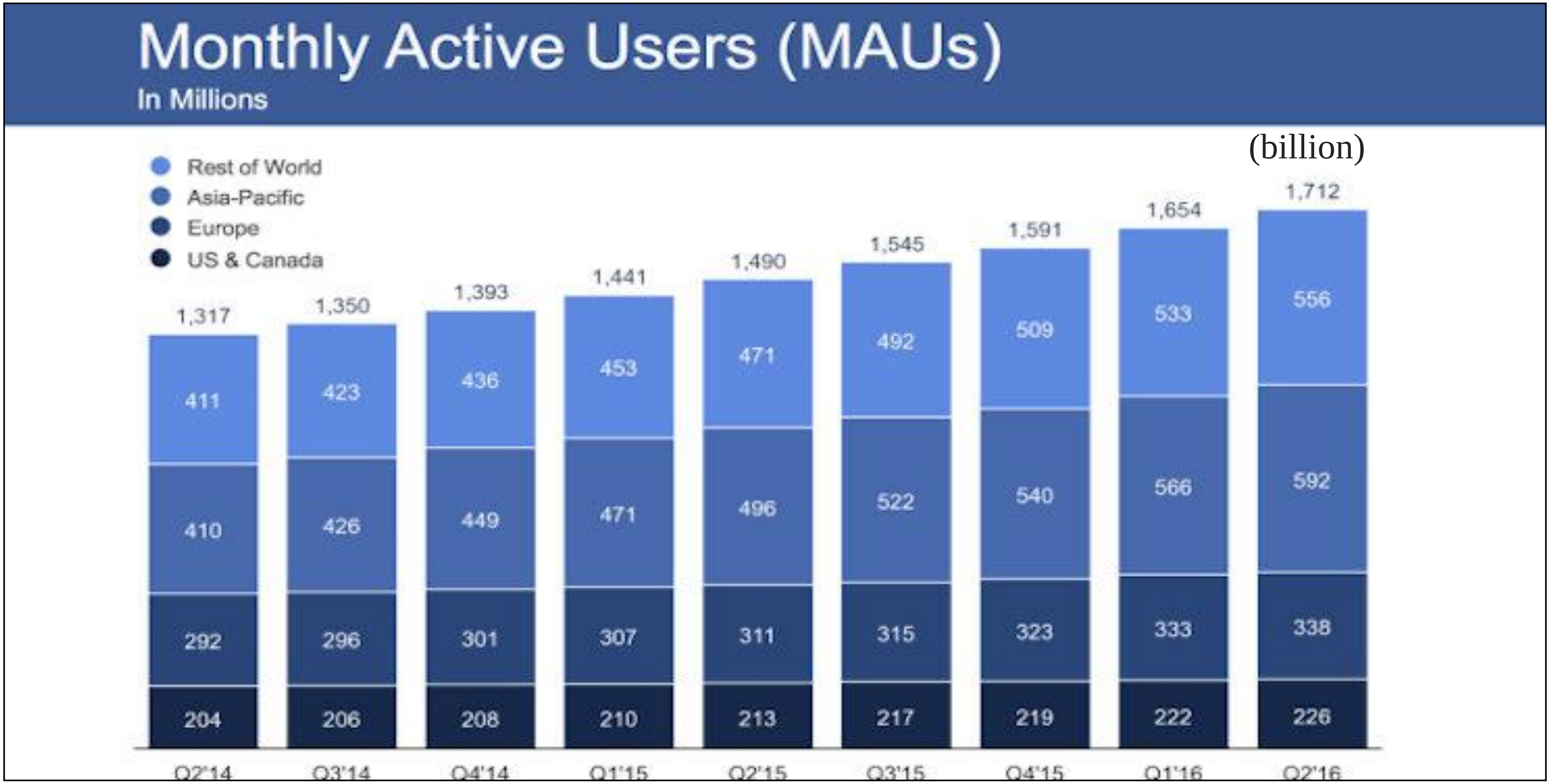
Features:
- Provenance tracking
- Annotation management
- ….

Hadoop vs. DDBS

	Distributed Databases	Hadoop
Computing Model	- Notion of transactions - Transaction is the unit of work - ACID properties, Concurrency control	- Notion of jobs - Job is the unit of work - No concurrency control
Data Model	- Structured data with known schema - Read/Write mode	- Any data will fit in any format - (un)(semi)structured - ReadOnly mode
Cost Model	- Expensive servers	- Cheap commodity machines
Fault Tolerance	- Failures are rare - Recovery mechanisms	- Failures are common over thousands of machines - Simple yet efficient fault tolerance
Key Characteristics	- Efficiency, optimizations, fine-tuning	- Scalability, flexibility, fault tolerance

Another Master-Slave Fashion

TAO - Facebook's Distributed Data Store for the Social Graph



TAO’s Goals/Challenges

Billions of users, billions of data accesses to the social graph

How to handle this huge workload efficiently?

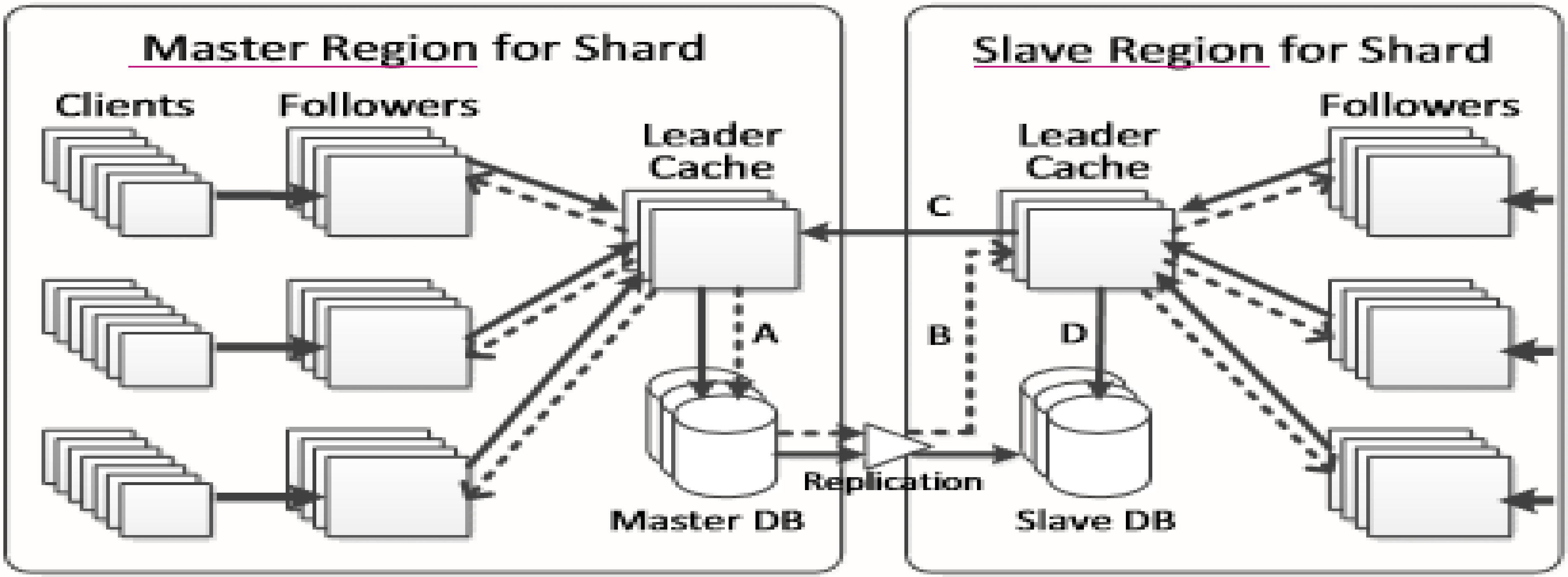
Efficiency at scale

Low read latency

Timeliness of writes

High Read Availability

TAO's Master-Slave Architecture



Why "Regions" ?

Reason: network latency.

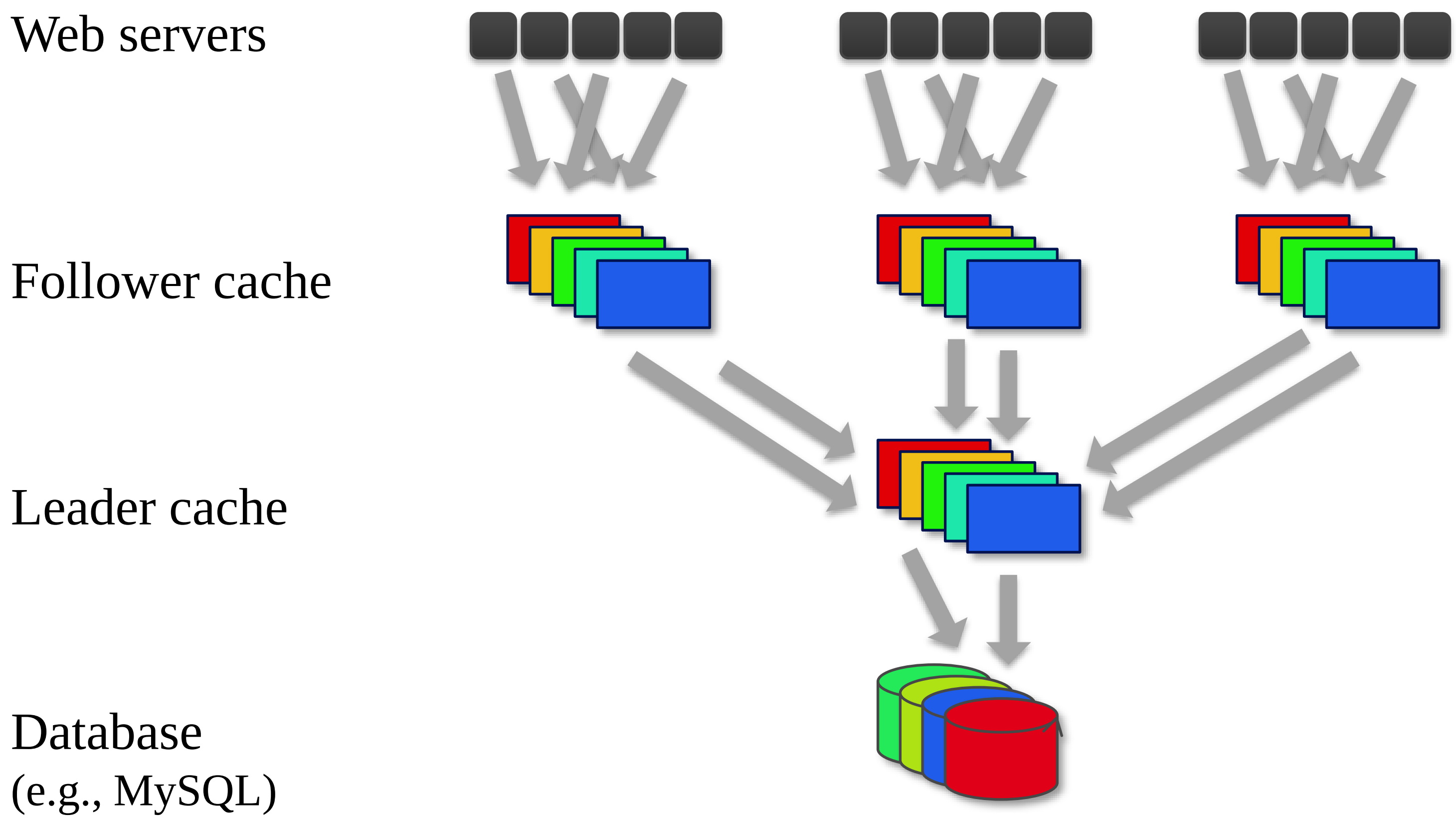
- Each region has one Leader tier and multiple Followers
- Master Region vs. Slave Region
- Master/Slave designation is made separately for each shard

Why Master/Slave ?

Reason: read misses are 25x more frequent than writes. In this way, Slave Regions can entirely self-service read misses without bothering Master Region (via Slave leader).

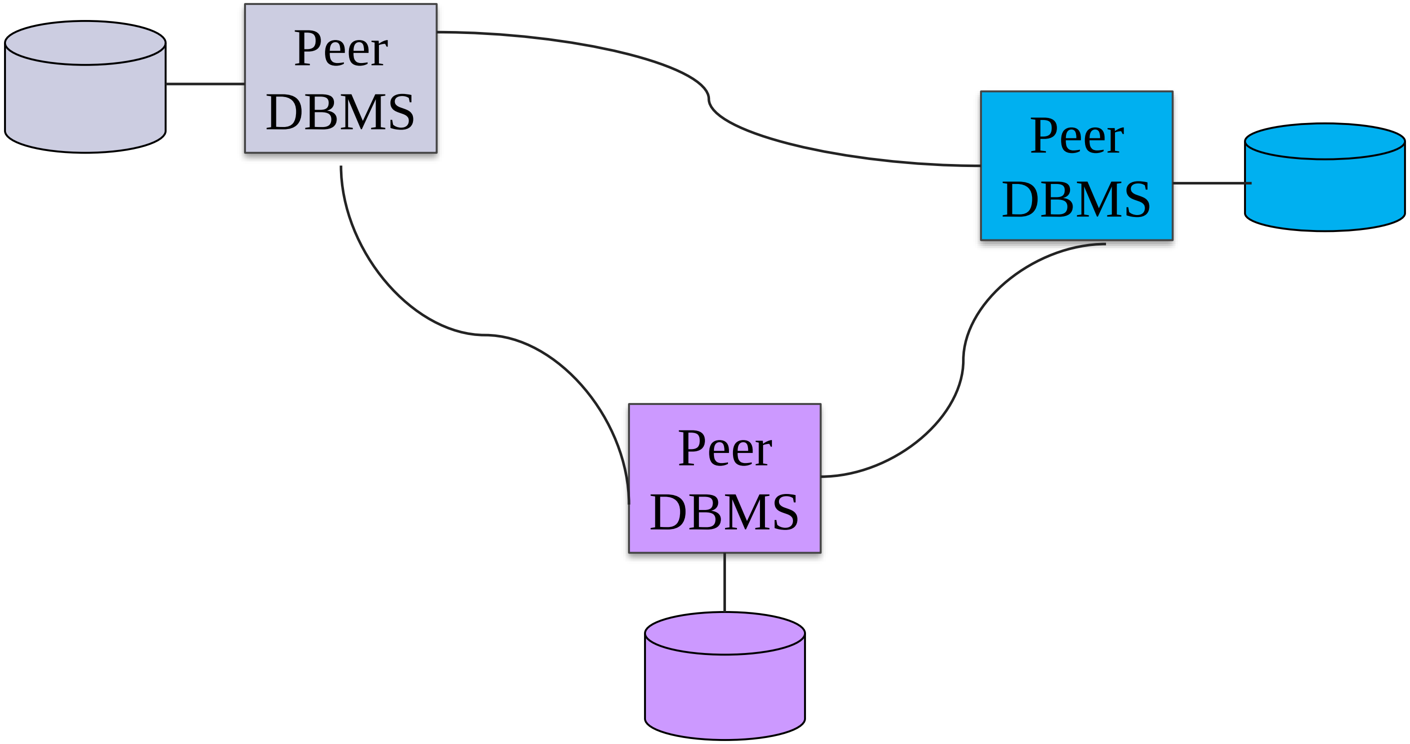
- Writes in a Slave Region go to Master Region
- Consistency is handled asynchronously by sending cache maintenance messages from the Master to Slaves

TAO's Follower and Leader Caches

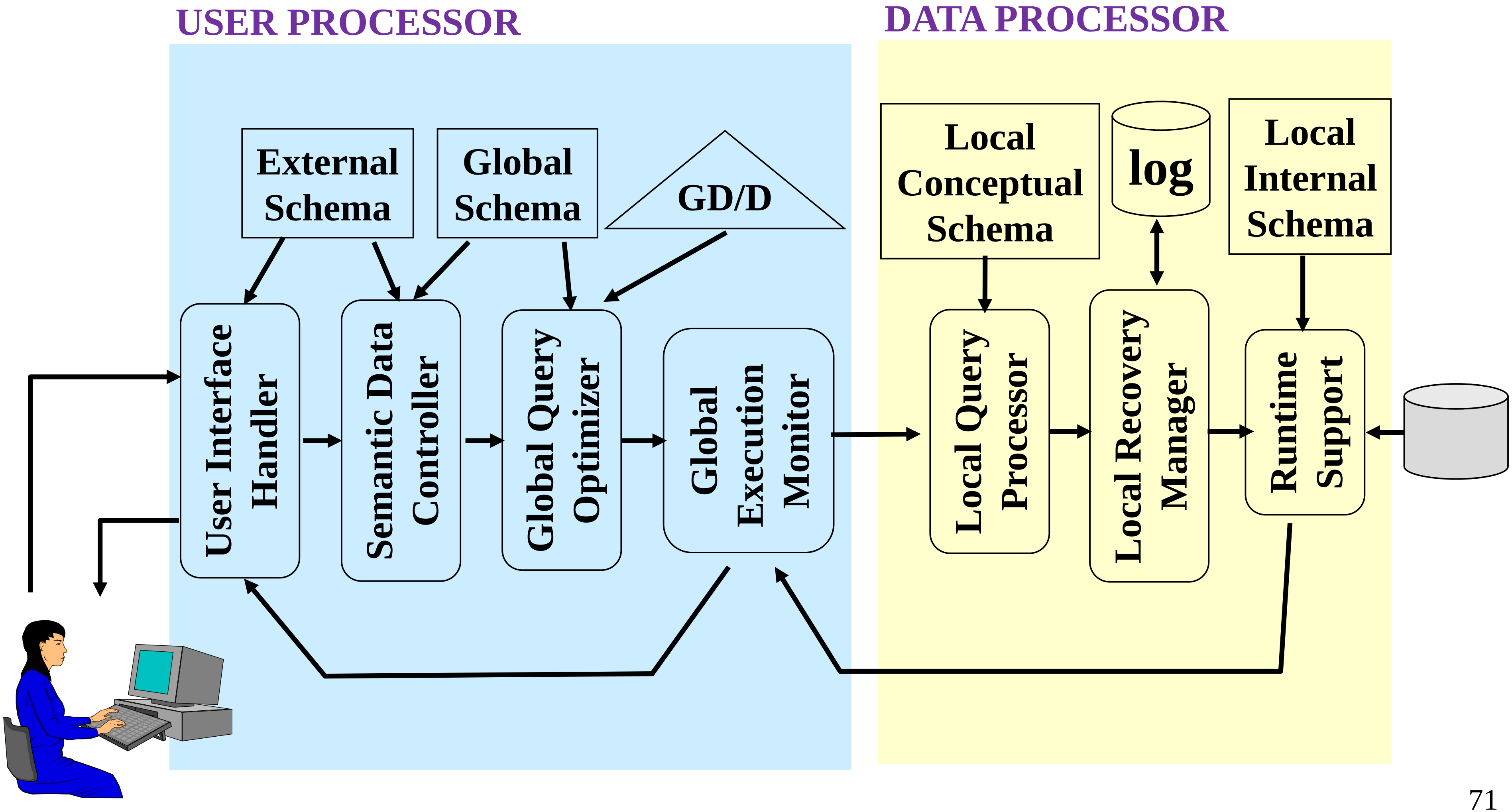


1. Client request goes to a single cache server in a local "follower" tier
2. Follower fulfills request. If read miss or a write, go to a Leader
3. If Leader read miss or a write, Leader will go to the DB

3 - Peer-to-Peer Distributed Architecture

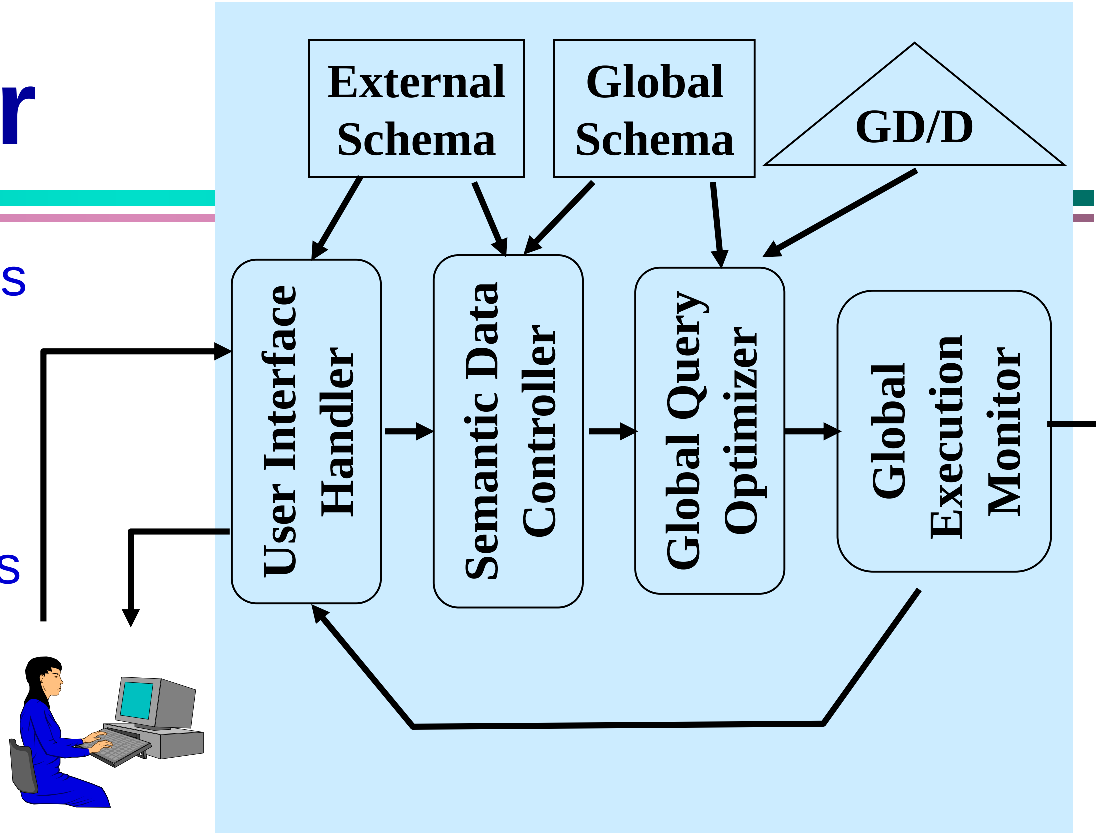


A Peer DBMS



USER PROCESSOR
DATA PROCESSOR
External Schema
Global Schema
GD/D
Local Conceptual Schema
log
Local Internal Schema
User Interface Handler
Semantic Data Controller
Global Query Optimizer
Global Execution Monitor
Local Query Processor
Local Recovery Manager
Runtime Support

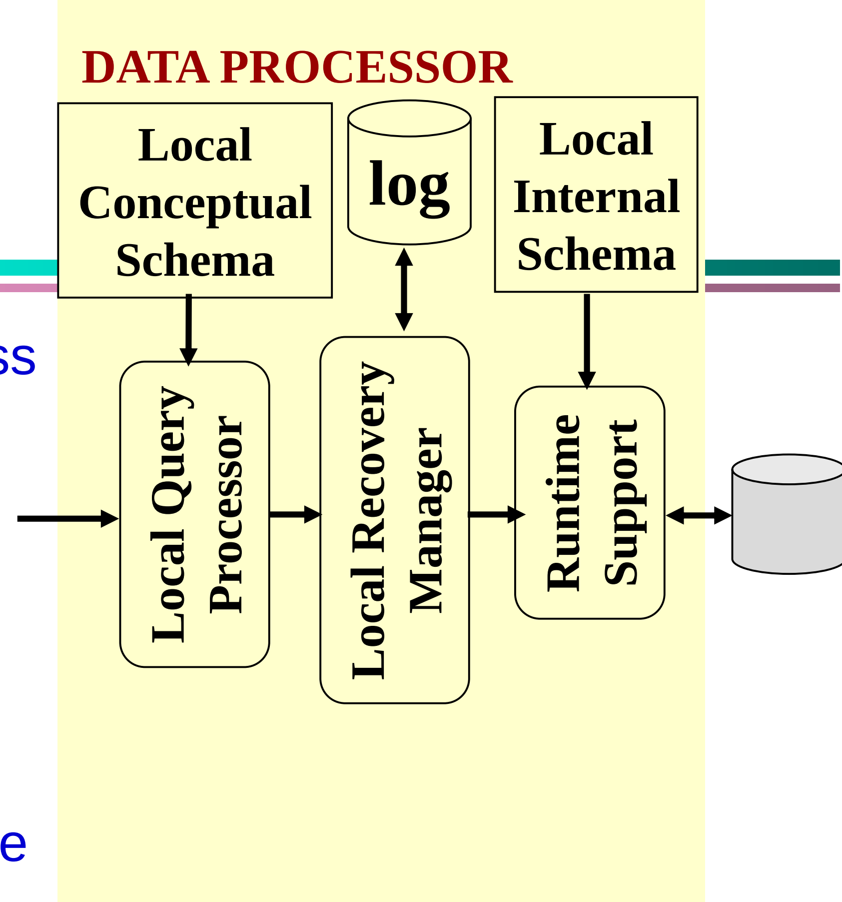
User Processor



- User interface handler interprets user commands and formats the result data as it is sent to the user.
- Semantic data controller checks the integrity constraints and authorization requirements.
- Global query optimizer and decomposer determines execution strategy, translates global queries to local queries, and generates strategy for distributed join operations.
- Global execution monitor (distributed transaction manager) coordinates the distributed execution of the user request.

Data Processor

- Local query processor selects the access path and is involved in local query optimization and join operations.
- Local recovery manager maintains local database consistency.
- Run-time support processor physically accesses the database. It is the interface to the OS and contains database buffer manager.

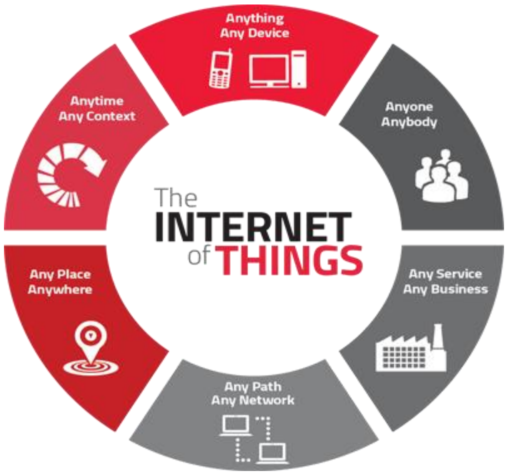


Apache Cassandra: Peer-to-Peer

- A **peer-to-peer distributed storage system** for managing very large amounts of data spread out across many commodity servers, while providing highly available service with no single point of failure.
- Originally developed at Facebook, open sourced in 2008, and became a top-level Apache project in 2010.
- Deployed as the backend storage system for multiple services in Twitter, Reddit, Netflix, Digg, Rackspace, Cisco and more companies that have large, active data sets.

Cassandra

Application Areas of Cassandra



Internet of things applications

Perfect for consuming lots of fast incoming data from devices, sensors and similar mechanisms that exist in many different locations.

Messaging Apps

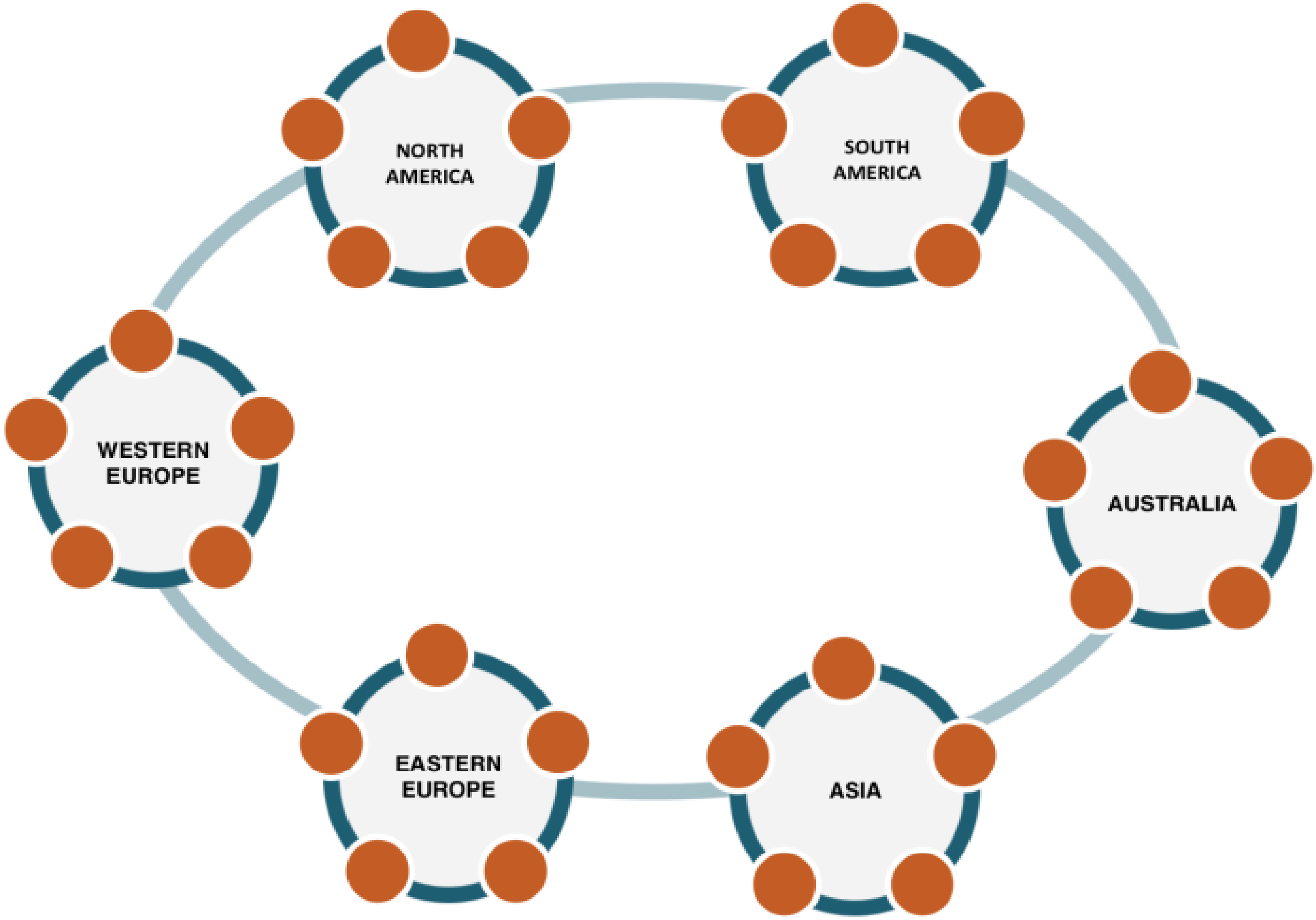
Serves as the database backbone for numerous mobile phone and messaging providers' applications.

Social media analytics and recommendation engines

Many online companies, websites, and social media providers use Cassandra to ingest, analyze, and provide analysis and recommendations to their customers.

Architecture of Cassandra

Masterless "ring" architecture. All nodes play an identical role.



Gossip

- Peer to peer protocol
- Gossip every one second, up to 3 others nodes
- Share state information of the nodes

- Achieve three major functions
  - Failure detection
  - Dynamic load balance
  - Elastic expansion without central control

Dimension 2: Heterogeneity (异质)

- Various levels (hardware, communication, OS)
- DBMS important ones (like data model, query language, transaction management algorithms, etc.)
  - 0 - homogeneous
  - 1 - heterogeneous

Dimension 3: Autonomy (自治)

- Refer to the distribution of control, not of data, indicating the degree to which individual DBMSs can operate independently.
- Requirements of an autonomous system
  - The local operations of the individual DBMSs are not affected by their participation in the DDBS.
  - The individual DBMS query processing and optimization should not be affected by the execution of global queries that access multiple databases.
  - System consistency or operation should not be compromised when individual DBMSs join or leave the distributed database confederation.

Three Versions of Autonomy

- Design autonomy
  - Ability of a component DBMS to decide on issues related to its own design
  - Freedom for individual DBMSs to use data models and transaction management techniques they prefer
- Communication autonomy
  - Ability of a component DBMS to decide whether and how to communication with other DBMSs
  - Freedom for individual DBMSs to decide what information (data & control) is to be exported
- Execution autonomy
  - Ability of a component DBMS to execute local operations in any manner it wants to.
  - Freedom for individual DBMSs to execute transactions submitted in any way that it wants to

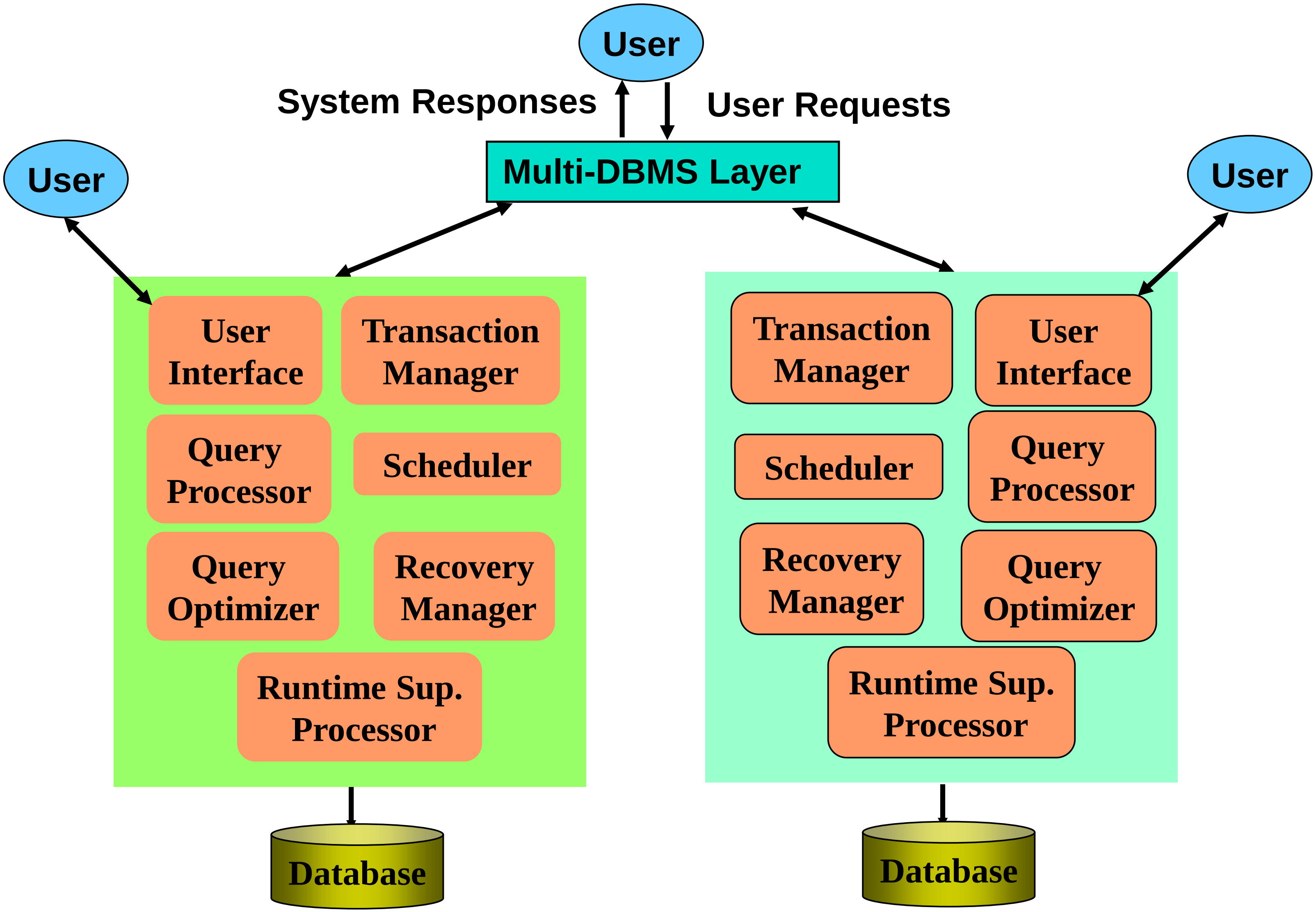
Dimension 3: Autonomy (*cont.*)

- 0 – Tightly coupled - integrated
- 1 – Semi-autonomous - federated
- 2 – Total Isolation – multi-database systems

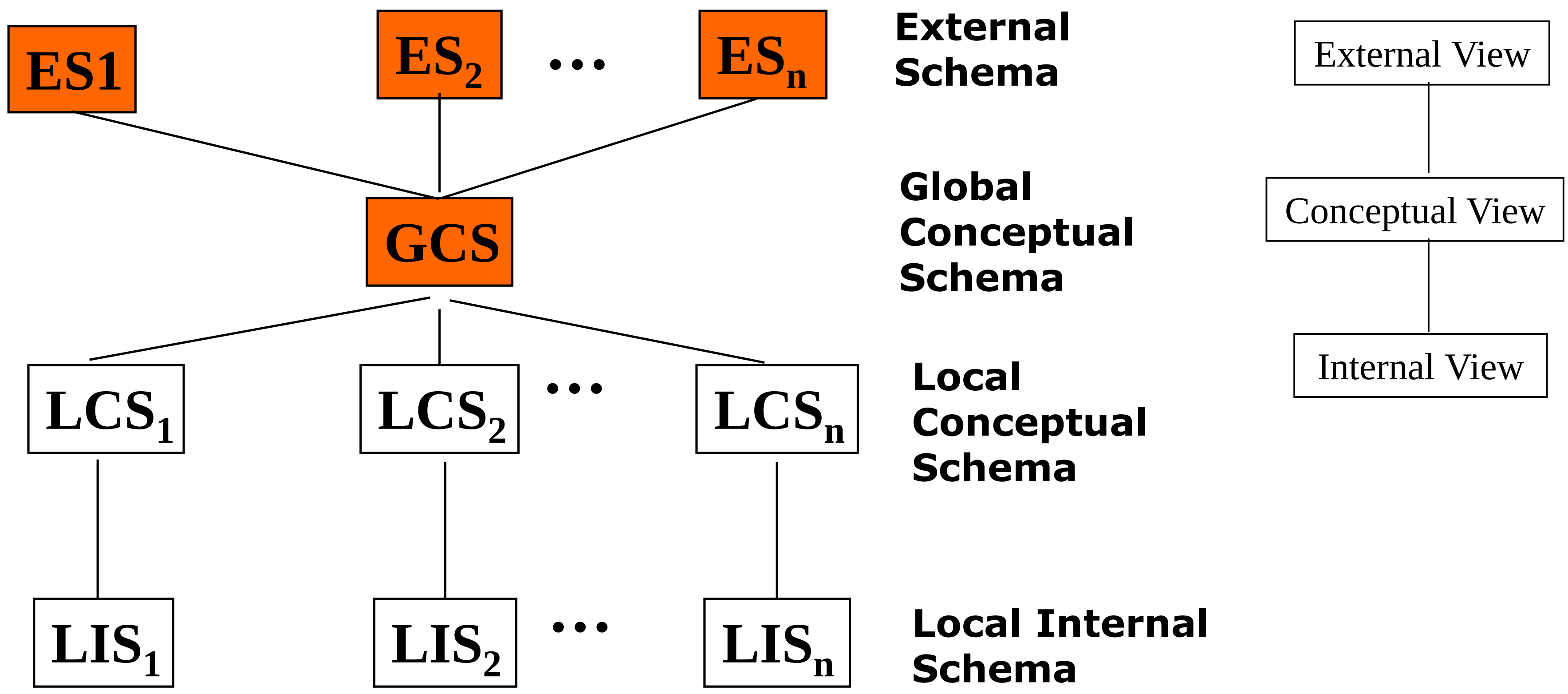
Taxonomy of Distributed Databases

- Composite DBMSs - tight integration
  - single image of entire database is available to any user
  - can be single or multiple sites
  - can be homogeneous or heterogeneous
- Federated DBMSs – semi-autonomous
  - DBMSs that can operate independently, but have decided to make some parts of their local data shareable
  - can be single or multiple sites
  - they need to be modified to enable them to exchange information
- Multi-database Systems - total isolation
  - individual systems are stand alone DBMSs, which know neither the existence of other databases or how to communicate with them
  - no global control over the execution of individual DBMSs.
  - can be single or multiple sites
  - homogeneous or heterogeneous

Components of a Multi-DBMS

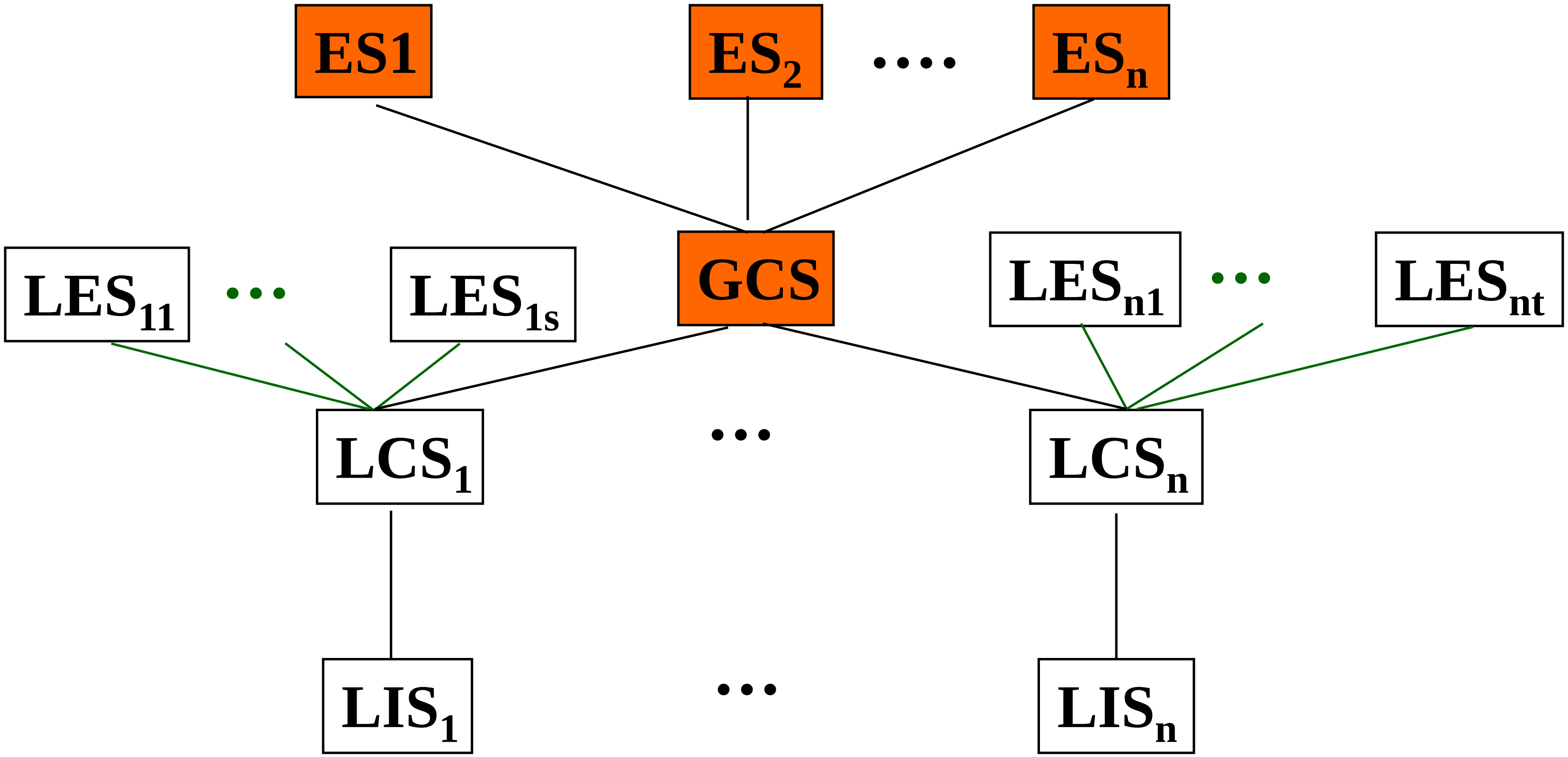


Distributed Database Reference Architecture



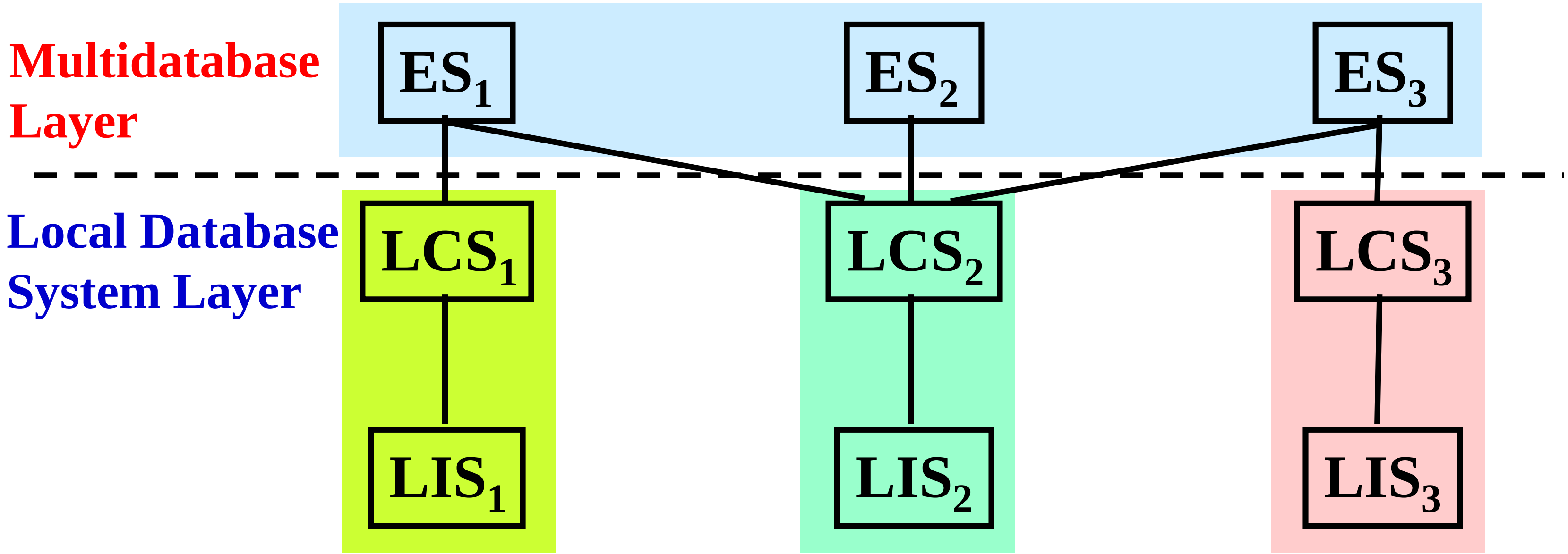
It is logically integrated. Provide for the levels of transparency

Multi-DBMS Architecture with a Global Conceptual Schema



- The GCS is generated by integrating LES's or LCS's
- The users of a local DBMS can maintain their autonomy
- Design of GCS is bottom-up

Multi-DBMS without a Global Conceptual Schema



- Local database system layer consists of several DBMSs which present to multidatabase layer part of their databases
- The shared database has either local conceptual schema or external schema
- External views on one or more LCSs.
- Access to multiple databases through application programs

Multi-DBMS without a Global Conceptual Schema (*cont*.)

- Multi-DBMS components architecture
  - Existence of fully fledged local DBMSs
  - Multi-DBMS is a layer on top of individual DBMSs that support access to different databases
  - The complexity of the layer depends on existence of GCS and heterogeneity
- Federated Database Systems
  - Do not use global conceptual schema
  - Each local DBMS defines export schema
  - Global database is a union of export schemas
  - Each application accesses global database through import schema (external view)

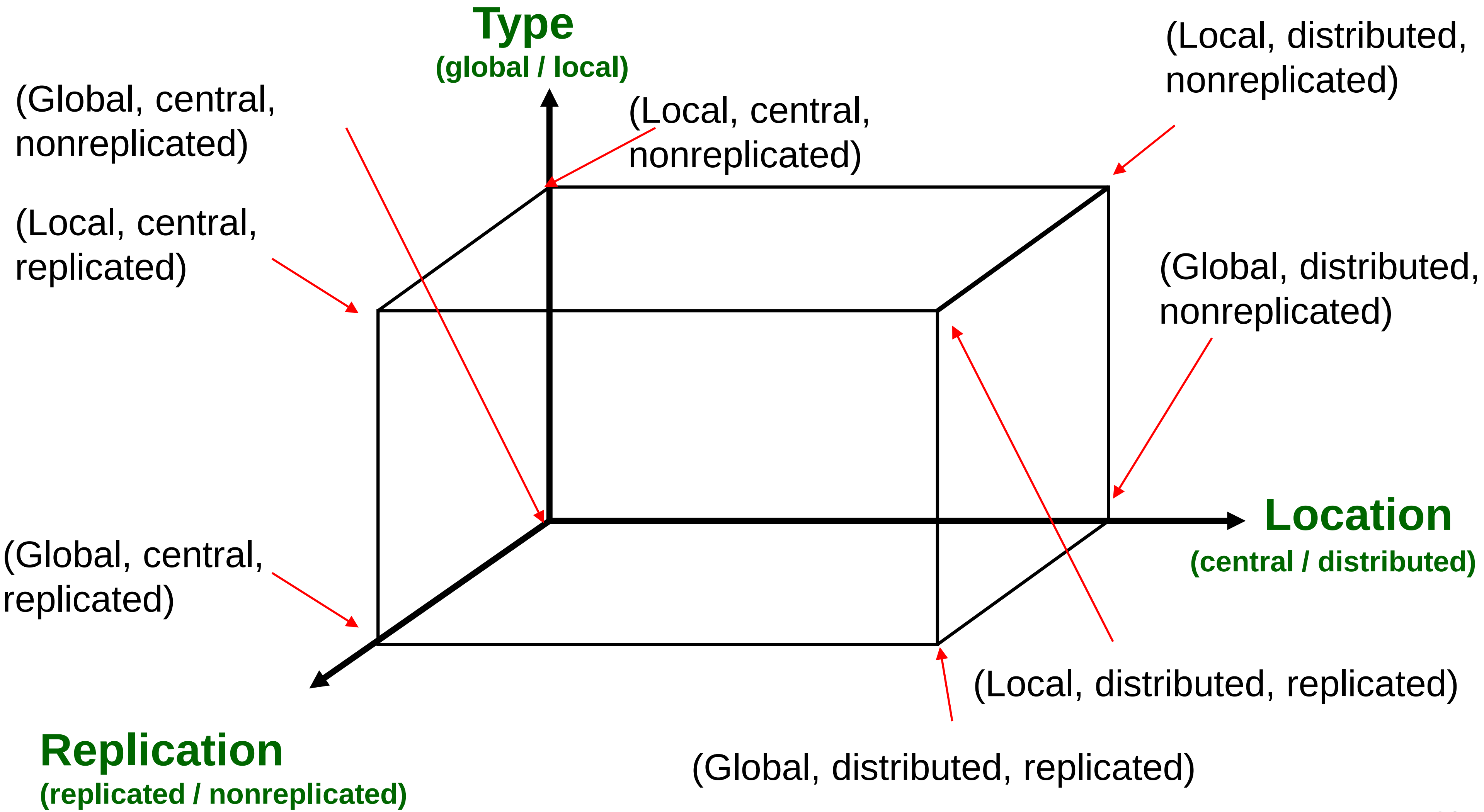
Outline

- Introduction
- Top-Down Design of DDBMS Architecture
  - Schema and Distribution Transparency
- Bottom-up Design of DDBMS Architecture
  - Architectural Alternatives for DDBMSs
  - Reference Architectures for a DDBMS
- ☞ Global Directory/Dictionary

Global Directory/Dictionary

- Directory is itself a database that contains meta-data about the actual data stored in the database. It includes the support for fragmentation transparency in the classical DDBMS architecture.
- Directory can be local or distributed.
- Directory can be replicated and/or partitioned.
- Directory issues are very important for large multi-database applications, such as digital libraries.

Alternative Directory Management Strategies



Question & Answer