Unit 1: 12 hrs.

1.1 Introduction to Distributed Database: Distributed Data Processing, Concept of Distributed Database. Distributed vs Centralized Database System; advantages and Application. Transparency, performance and reliability. Problem areas of Distributed Database. Integrity Constraints in Distributed Databases.

Introduction to Distributed Database: Distributed Data Processing, Concept of Distributed Database.

Distributed database system (DDBS) technology is the union of what appear to be two diametrically opposed approaches to data processing: database system and computer network technologies.

One of the major motivations behind the use of database systems is the desire to integrate the operational data of an enterprise and to provide centralized, thus controlled access to that data. It is possible to achieve integration without centralization, and that is exactly what the distributed database technology attempts to achieve.

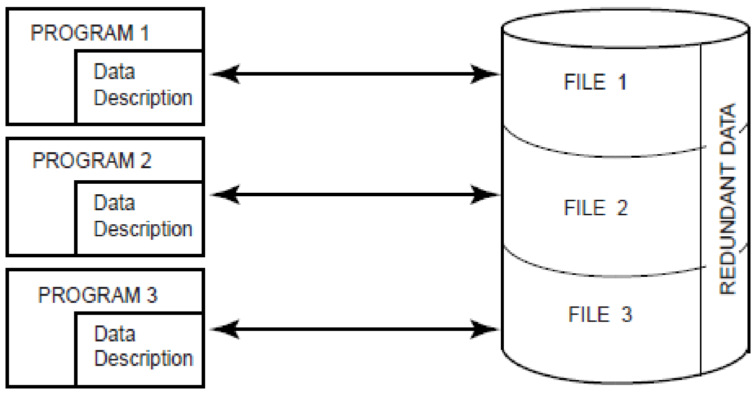


Fig. 1.1 Traditional File Processing

Distributed Data Processing:

-On (Even on single processor) computers where the central processing unit (CPU) and input/ output (I/O) functions are separated and overlapped. This separation and overlap can be considered as one form of distributed processing.
-The working definition " it is a number of autonomous processing elements (not necessarily homogeneous) that are interconnected by a computer network and that cooperate in performing their assigned tasks".
-Arrangement of networked computers in which data processing capabilities are spread across the network. In DDP, specific jobs are performed by specialized computers which may be far removed from the user and/or from other such computers. This arrangement is in contrast to 'centralized' computing in which several client computers share the same server (usually a mini or mainframe computer) or a cluster of servers. DDP provides greater scalability, but also requires more network administration resources.

What is being distributed?
-processing logic.
In fact, the definition of a distributed computing system given above implicitly assumes that the processing logic or processing elements are distributed.
-function.

Various functions of a computer system could be delegated to various pieces of hardware or software.
- data.
Data used by a number of applications may be distributed to a number of processing sites.
- control can be distributed.
The control of the execution of various tasks might be distributed instead of being performed by one computer system.

Why do we distribute at all?
- to make system more reliable and more responsive
- to be better able to cope with the large-scale data management problems by divide-and-conquer rule.
- work efficiently

Distributed Data Processing(DDP)
. Computers are dispersed throughout organisation
. Allows greater flexibility in structure
. More redundancy
. More autonomy

Why is DDP Increasing?
. Dramatically reduced hardware costs
. Increased desktop power
. Improved user interfaces (!)
. Ability to share data across multiple servers

DDP Pros & Cons
. There are no complete solutions
. Key issues
. How does it affect end-users?
. How does it affect management?
. How does it affect productivity?

Benefits of DDP (1)
. Responsiveness
. Availability
. Organisational Patterns
. Resource Sharing
. Incremental Growth
. Increased User Involvement & Control
End-user Productivity
. Distance & location independence
. Privacy and security
. Vendor independence

Drawbacks of DDP
. Difficulties in failure diagnosis
. More components and dependence on communication means more points of failure
. Incompatibility of components
. Incompatibility of data
. More complex management & control
. Difficulty controlling information resources

. Suboptimal procurement
. Duplication of effort

Reasons for DDP

. Need for new applications
. On large centralised systems, development can take years
. On small distributed systems, development can be component-based and very fast
. Need for short response time
. Centralised systems result in contention among users and processes
. Distributed systems provide dedicated resources

Concept of Distributed Database.

A distributed database is a set of interconnected databases that is distributed over the computer network or internet. A Distributed Database Management System (DDBMS) manages the distributed database and provides mechanisms so as to make the databases transparent to the users. In these systems, data is intentionally distributed among multiple nodes so that all computing resources of the organization can be optimally used.

Features

 Databases in the collection are logically interrelated with each other. Often they represent a single logical database.
 Data is physically stored across multiple sites. Data in each site can be managed by a DBMS independent of the other sites.
 The processors in the sites are connected via a network. They do not have any multiprocessor configuration.
 A distributed database is not a loosely connected file system.
 A distributed database incorporates transaction processing, but it is not synonymous with a transaction processing system.

Distributed vs Centralized Database System; advantages and Application.

Distributed databse	Centralized Database
A single logical database that is spread physically across computers in multiple locations that are connected by a data communications link. • Most processing is local • Need for local ownership of data • Data sharing require Note that users think they are working with a single corporate database	• A single database maintained in one location. • Managed by a database administrator. (usually) • Access via a communications network • LAN • WAN • Terminals provide distributed access

Advantages • Minimise communications • Costs • Local control	**Advantages** • Increased reliability and availability • Modular (incremental) growth • Lower communication costs • Faster Response •
Disadvantages • Adds to complexity and cost • Processing overheads • Data Integrity	**Disadvantages** • Software cost and complexity • Processing overheads • Data integrity

Transparency, performance and reliability.

- promises of DDBS technology: transparent management of distributed and replicated data, reliable access to data through distributed transactions, improved performance, and easier system expansion.

Transparent Management of Distributed and Replicated Data
Transparency refers to separation of the higher-level semantics of a system from lower-level implementation issues. In other words, a transparent system "hides" the implementation details from users. The advantage of a fully transparent DBMS is the high level of support that it provides for the development of complex applications.

1. Management of distributed data with different levels of transparency: Ideally, a DBMS should be distribution transparent in the sense of hiding the details of where each file (table, relation) is physically stored within the system. Consider the company database that we have been discussing throughout the book. The EMPLOYEE, PROJECT, and WORKS_ON tables may be fragmented horizontally and stored with possible replication as shown in Figure .

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

The following types of transparencies are possible:

o Distribution or network transparency: This refers to freedom for the user from the operational details of the network. It may be divided into location transparency and naming transparency. Location transparency refers to the fact that the command used to perform a task is independent of the location of data and the location of the system where the command was issued. Naming transparency implies that once a name is specified, the named objects can be accessed unambiguously without additional specification.

o Replication transparency: As we show in Figure 24.02, copies of data may be stored at multiple sites for better availability, performance, and reliability. Replication transparency makes the user unaware of the existence of copies.

o Fragmentation transparency: Two types of fragmentation are possible. Horizontal fragmentation distributes a relation into sets of tuples (rows). Vertical fragmentation distributes a relation into subrelations where each subrelation is defined by a subset of the columns of the original relation. A global query by the user must be transformed into several fragment queries. Fragmentation transparency makes the user unaware of the existence of fragments.

2. Increased reliability and availability: These are two of the most common potential advantages cited for distributed databases. Reliability is broadly defined as the probability that a system is running (not down) at a certain time point, whereas availability is the probability that the system is continuously available during a time interval. When the data and DBMS software are distributed over several sites, one site may fail while other sites continue to operate. Only the data and software that exist at the failed site cannot be accessed. This improves both reliability and availability. Further improvement is achieved by judiciously replicating data and software at more than one site. In a centralized system, failure at a single site makes the whole system unavailable to all users. In a distributed database, some of the data may be unreachable, but users may still be able to access other parts of the database.

3. Improved performance: A distributed DBMS fragments the database by keeping the data closer to where it is needed most. Data localization reduces the contention for CPU and I/O services and simultaneously reduces access delays involved in wide area networks. When a large database is distributed over multiple sites, smaller databases exist at each site. As a result, local queries and transactions accessing data at a single site have better performance because of the smaller local databases. In addition, each site has a smaller number of transactions executing than if all transactions are submitted to a single centralized database. Moreover, interquery and intraquery parallelism can be achieved by executing multiple queries at different sites, or by breaking up a query into a number of subqueries that execute in parallel. This contributes to improved performance.

4. Easier expansion: In a distributed environment, expansion of the system in terms of adding more data, increasing database sizes, or adding more processors is much easier.

Additional Functions of Distributed Databases

Distribution leads to increased complexity in the system design and implementation. To achieve the potential advantages listed previously, the DDBMS software must be able to provide the following functions in addition to those of a centralized DBMS:

• Keeping track of data: The ability to keep track of the data distribution, fragmentation, and replication by expanding the DDBMS catalog.

• Distributed query processing: The ability to access remote sites and transmit queries and data among the various sites via a communication network.

• Distributed transaction management: The ability to devise execution strategies for queries and transactions that access data from more than one site and to synchronize the access to distributed data and maintain integrity of the overall database.

• Replicated data management: The ability to decide which copy of a replicated data item to access and to maintain the consistency of copies of a replicated data item.

• Distributed database recovery: The ability to recover from individual site crashes and from new types of failures such as the failure of a communication links.

• Security: Distributed transactions must be executed with the proper management of the security of the data and the authorization/access privileges of users.

• Distributed directory (catalog) management: A directory contains information (metadata) about data in the database. The directory may be global for the entire DDB, or local for each site. The placement and distribution of the directory are design and policy issues.

Problem areas of Distributed Database. :

Following are the Problems Areas of Distributed database. :-

1) Distributed Concurrency Control: - Distributed Concurrency Control specifies that
synchronization of access to the distributed database such that the integrity of the database is maintained. To maintain Concurrency in distributed database different locking techniques should used which is based on mutual exclusion of access to data. Time stamping algorithm also used where transactions are executed in some order [1].
2) Distributed Deadlock Management :- In distributed database several users are request for
resources from the database if the resources are available at that time , then database grant the resources to that user if not available the user has to wait until the resources are released by other user. Sometimes the users are not released the resources are blocked by some other user. This situation is known as Deadlock. Distributed Deadlock is manage using the different algorithm and techniques such avoidance and detection algorithm.
3) Replication Control: - Replication is a technique that only applies to distributed systems. A database is said to be replicated if the entire database or a portion of it (a table, some tables, one or more fragments, etc.) is copied and the copies are stored at different sites. The issue with having more than one copy of a database is maintaining the mutual consistency of the copies—ensuring that all copies have identical schema and data content.
4) Operating Environment: - To Implement Distributed Database Environment a Specific
Operating System is requirement as per Organizational needs. Operating system plays and
important role for managing the distributed database. Some time Operating system is not supported for Distributed database.
5) Transparent Management: - Transparent management of Data is one of the major problem area in Distributed database. In Distributed database data is situated in multiple locations and number Distributed Database Problem areas and Approaches of users are used that database. To maintain the integrity of database transparent management of
data is important.
6) Security and privacy: - How to apply the security policies to the interdependent system is a great issue in distributed system. Since distributed systems deal with sensitive data and information so the system must have a strong security and privacy measurement. Protection of distributed system assets, including base resources, storage, communications and user-interface I/O as well as higherlevel composites of these resources, like processes, files, messages, display windows and more complex objects, are important issues in distributed system

7) Resource management: - In distributed systems, objects consisting of resources are located on different places. Routing is an issue at the network layer of the distributed system and at the application layer. Resource management in a distributed system will interact with its eterogeneous Nature.

Integrity Constraints in Distributed Databases.

1.2 Distributed Database Architectures: DBMS standardization. Architectural models for Distributed DBMS – autonomy, distribution and heterogeneity. Distributed Database architecture – Client/Server, Peer-to-Peer distributed systems, MDBS Architecture. Distributed Catalog management.

Distributed Database Architectures: DBMS standardization.

The architecture of a system defines its structure. This means that the components of
the system are identified, the function of each component is specified, and the interrelationships
and interactions among these components are defined. The specification
of the architecture of a system requires identification of the various modules, with
their interfaces and interrelationships, in terms of the data and control flow through
the system.

Architecture: The architecture of a system defines its structure:

– the components of the system are identified;

– the function of each component is specified;

– the interrelationships and interactions among the components are defined.

• Applies both for computer systems as well as for software systems, e.g,

– division into modules, description of modules, etc.

– architecture of a computer

• There is a close relationship between the architecture of a system, standardisation efforts, and a reference model.

Motivation for Standardization of DDBMS Architecture

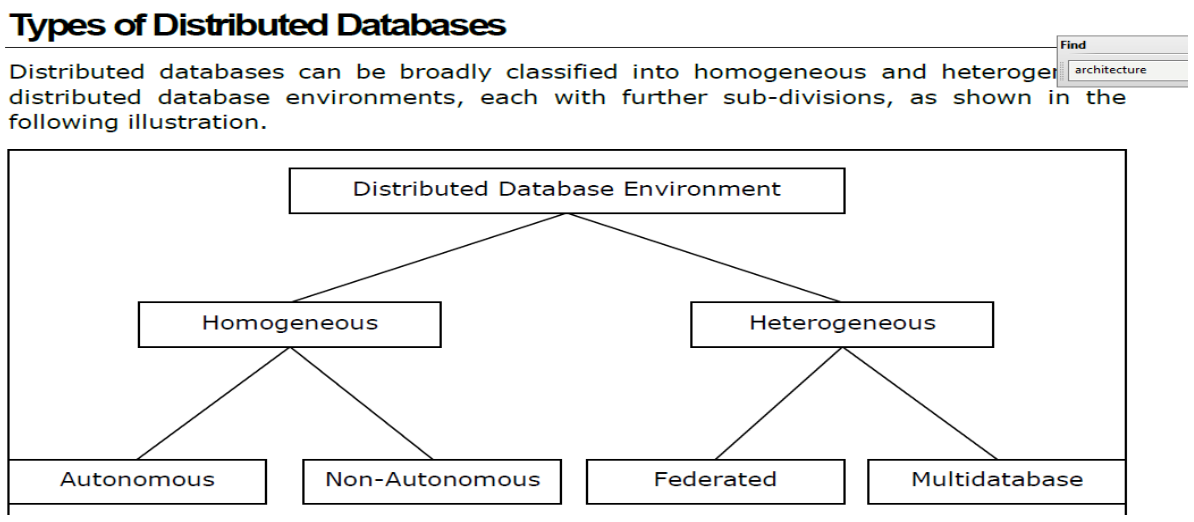
Standardization:

The standardization efforts in databases developed reference models of DBMS.
• Reference Model: 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 each other.
• A reference model can be thought of as an idealized architectural model of the system.
• Commercial systems might deviate from reference model, still they are useful for the standardization process
• A reference model can be described according to 3 different approaches:
– component-based
– function-based
– data-based

Components-based

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

– It might be difficult to determine the functionality of the system from its components
Function-based
– Classes of users are identified together with the functionality that the system will provide for each class
– Typically a hierarchical system with clearly defined interfaces between different layers
– The objectives of the system are clearly identified.
– Not clear how to achieve the objectives
– Example: ISO/OSI architecture of computer networks
Data-based
– Identify the different types of the data and specify the functional units that will realize and/or use data according to these views
– Gives central importance to data (which is also the central resource of any DBMS)
!Claimed to be the preferable choice for standardization of DBMS
– The full architecture of the system is not clear without the description of functional modules.
– Example: ANSI/SPARC architecture of DBMS
The interplay among the 3 approaches is important:
– Need to be used together to define an architectural model
– Each brings a different point of view and serves to focus on different aspects of the model



Types of Distributed Databases

Distributed databases can be broadly classified into homogeneous and heteroger distributed database environments, each with further sub-divisions, as shown in the following illustration.

In a homogeneous distributed database, all the sites use identical DBMS and operating systems. Its properties are:

- The sites use very similar software.
- The sites use identical DBMS or DBMS from the same vendor.
- Each site is aware of all other sites and cooperates with other sites to process user requests.
- The database is accessed through a single interface as if it is a single database.

Types of Homogeneous Distributed Database

There are two types of homogeneous distributed database:

☐ **Autonomous**: Each database is independent that functions on its own. They are integrated by a controlling application and use message passing to share data updates.

☐ **Non-autonomous**: Data is distributed across the homogeneous nodes and a central or master DBMS co-ordinates data updates across the sites.

Heterogeneous Distributed Databases

In a heterogeneous distributed database, different sites have different operating systems, DBMS products and data models. Its properties are:

☐ Different sites use dissimilar schemas and software.
☐ The system may be composed of a variety of DBMSs like relational, network, hierarchical or object oriented.
☐ Query processing is complex due to dissimilar schemas.
☐ Transaction processing is complex due to dissimilar software.
☐ A site may not be aware of other sites and so there is limited co-operation in processing user requests.

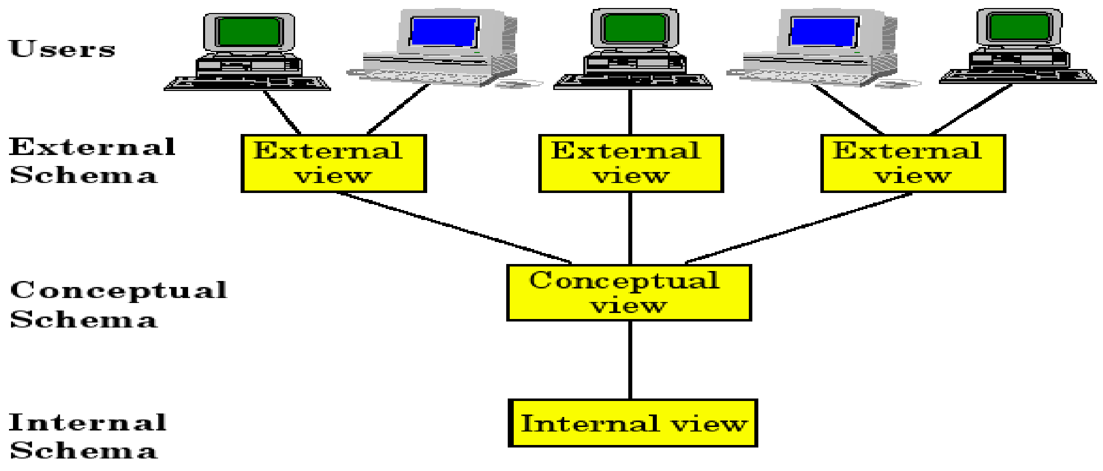
Types of Heterogeneous Distributed Databases:

☐ **Federated**: The heterogeneous database systems are independent in nature and integrated together so that they function as a single database system.

☐ **Un-federated**: The database systems employ a central coordinating module through which the databases are accessed.

ANSI/SPARC architecture is based on data

- 3 views of data: external view, conceptual view, internal view
- Defines a total of 43 interfaces between these views



Conceptual schema: Provides enterprise view of entire database

RELATION EMP [
KEY = {ENO}
ATTRIBUTES = {
ENO : CHARACTER(9)
ENAME: CHARACTER(15)
TITLE: CHARACTER(10)
}
]
RELATION PAY [
KEY = {TITLE}
ATTRIBUTES = {
TITLE: CHARACTER(10)
SAL : NUMERIC(6)

RELATION PROJ [
KEY = {PNO}
ATTRIBUTES = {
PNO : **CHARACTER**(7)
PNAME :
CHARACTER(20)
BUDGET: **NUMERIC**(7)
LOC : **CHARACTER**(15)
}
	RELATION ASG [
	KEY = {ENO,PNO}
	ATTRIBUTES = {
	ENO : **CHARACTER**(9)
	PNO : **CHARACTER**(7)
	RESP: **CHARACTER**(10)
	DUR : **NUMERIC**(3)
	}
	]

}
]

Internal schema: Describes the storage details of the relations.
– Relation EMP is stored on an indexed file
– Index is defined on the key attribute ENO and is called EMINX
– A HEADER field is used that might contain flags (delete, update, etc.)

INTERNAL REL EMPL [
INDEX ON E# **CALL** EMINX
FIELD =
HEADER: **BYTE**(1)
E# : **BYTE**(9)
ENAME : **BYTE**(15)
TIT : **BYTE**(10)
]

Conceptual schema:
RELATION EMP [
KEY = {ENO}
ATTRIBUTES = {
ENO : **CHARACTER**(9)
ENAME: **CHARACTER**(15)
TITLE: **CHARACTER**(10)
}
]

External view: Specifies the view of different users/applications
– Application 1: Calculates the payroll payments for engineers

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

– Application 2: Produces a report on the budget of each project

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

Architectural models for Distributed DBMS – autonomy, distribution and heterogeneity.

Architectural Models for DDBMSs (or more generally for multiple DBMSs) can be classified along three dimensions:
– Autonomy
– Distribution
– Heterogeneity

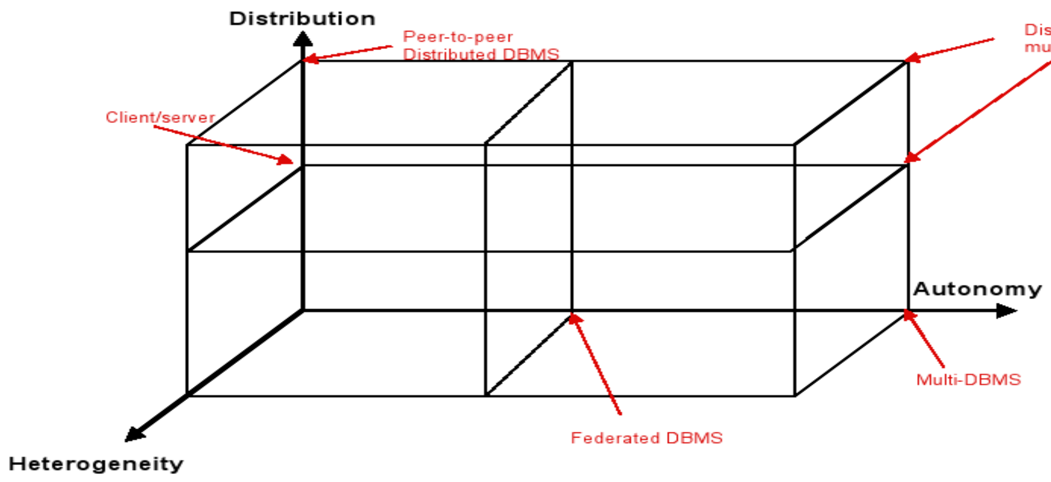
- **Autonomy**: Refers to the distribution of control (not of data) and indicates the degree to which individual DBMSs can operate independently.

– *Tight integration*: a single-image of the entire database is available to any user who wants to share the information (which may reside in multiple DBs); realized such that one data manager is in control of the processing of each user request.
– *Semiautonomous* systems: individual DBMSs can operate independently, but have decided to participate in a federation to make some of their local data sharable.
– *Total isolation*: the individual systems are stand-alone DBMSs, which know neither of the existence of other DBMSs nor how to comunicate with them; there is no global control.
• Autonomy has different dimensions
– *Design autonomy*: each individual DBMS is free to use the data models and transaction management techniques that it prefers.
– *Communication autonomy*: each individual DBMS is free to decide what information to provide to the other DBMSs

– *Execution autonomy*: each individual DBMS can execture the transactions that are submitted to it in any way that it wants to.

 Distribution: Refers to the physical distribution of data over multiple sites.
– *No distribution*: No distribution of data at all
Client/Server distribution:
_ Data are concentrated on the server, while clients provide application environment/user interface
_ First attempt to distribution
–*Peer-to-peer distribution* (also called *full distribution*):
_ No distinction between client and server machine
_ Each machine has full DBMS functionality

Heterogeneity: Refers to heterogeneity of the components at various levels
– hardware
– communications
– operating system
– DB components (e.g., data model, query language, transaction management algorithms)



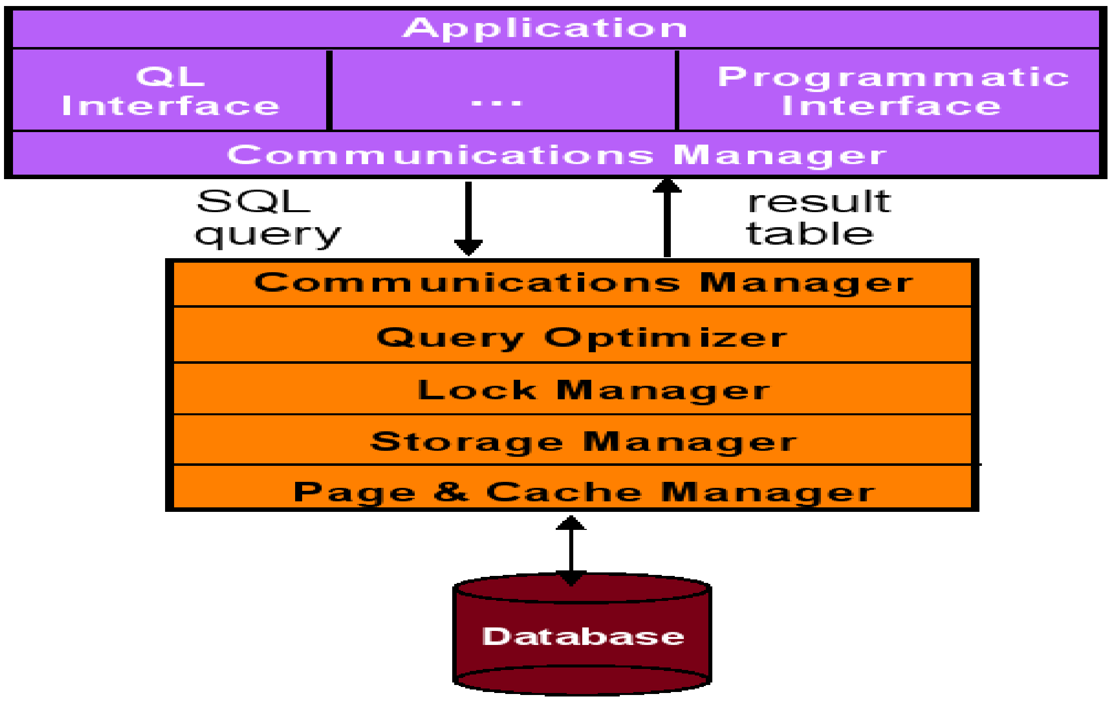
Distributed Database architecture – Client/Server, Peer-to-Peer distributed systems, MDBS Architecture.

Client-Server Architecture for DDBMS (Data-based)

General idea: Divide the functionality into two classes:
*server functions
- mainly data management, including query processing, optimization, transaction management, etc.
*client functions
- might also include some data management functions (consistency checking, transaction management, etc.) not just user interface

• Provides a two-level architecture
• More efficient division of work
• Different types of client/server architecture
– Multiple client/single server

– Multiple client/multiple server



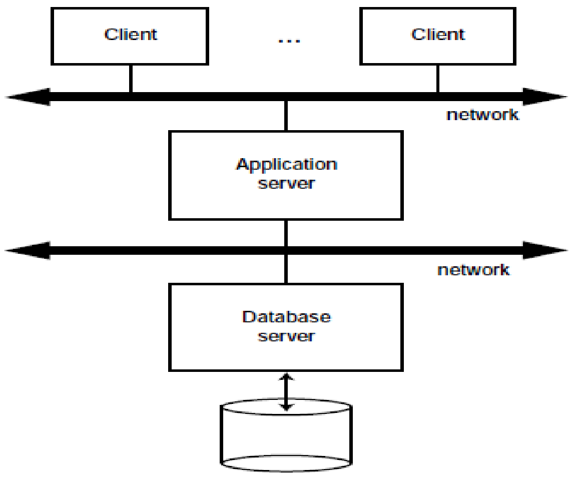


Fig. 1.12 Database Server Approach

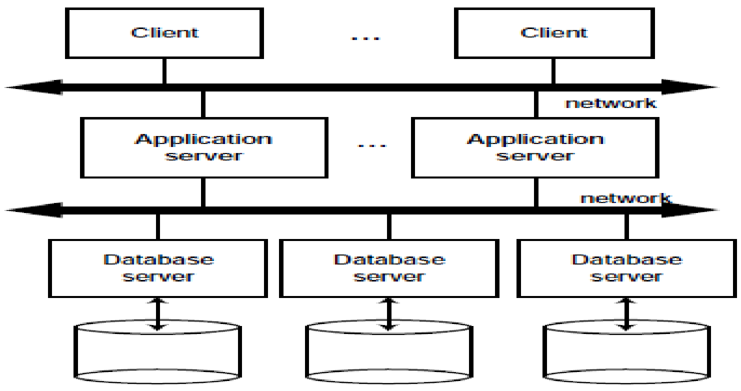


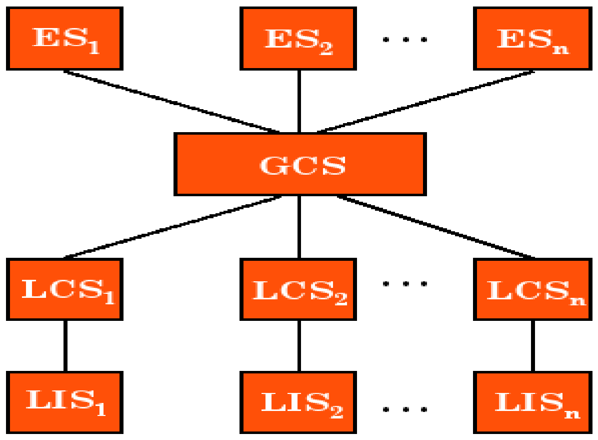
Fig. 1.13 Distributed Database Servers

Peer-to-Peer Architecture for DDBMS (Data-based)

Local internal schema (LIS)

– Describes the local physical data organization (which might be different on each machine)

• *Local conceptual schema* (LCS)
– Describes logical data organization at each site
– Required since the data are fragmented and replicated
• Global conceptual schema (GCS)
– Describes the global logical view of the data
– Union of the LCSs
• *External schema* (ES)
– Describes the user/application view on the data



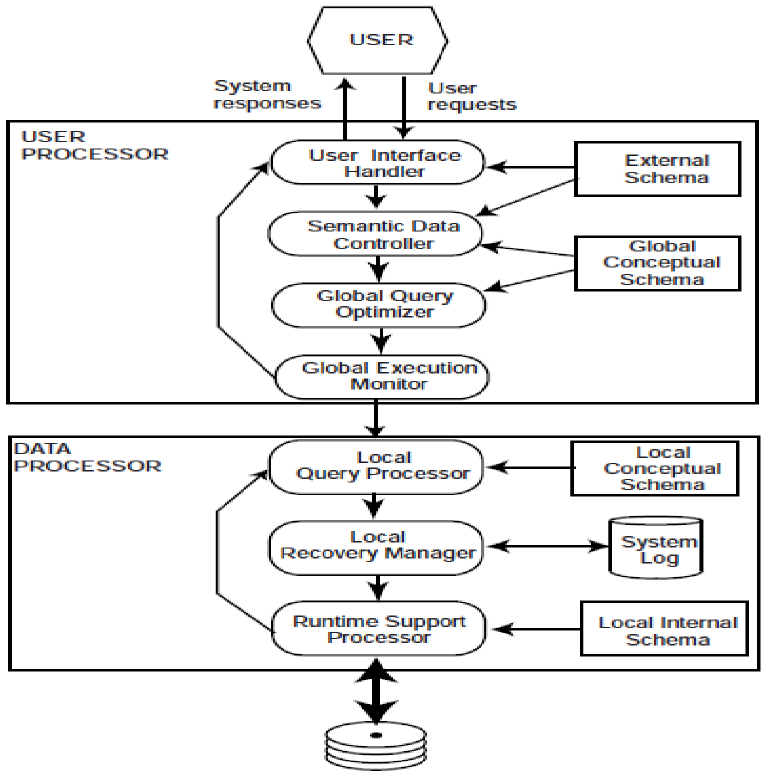


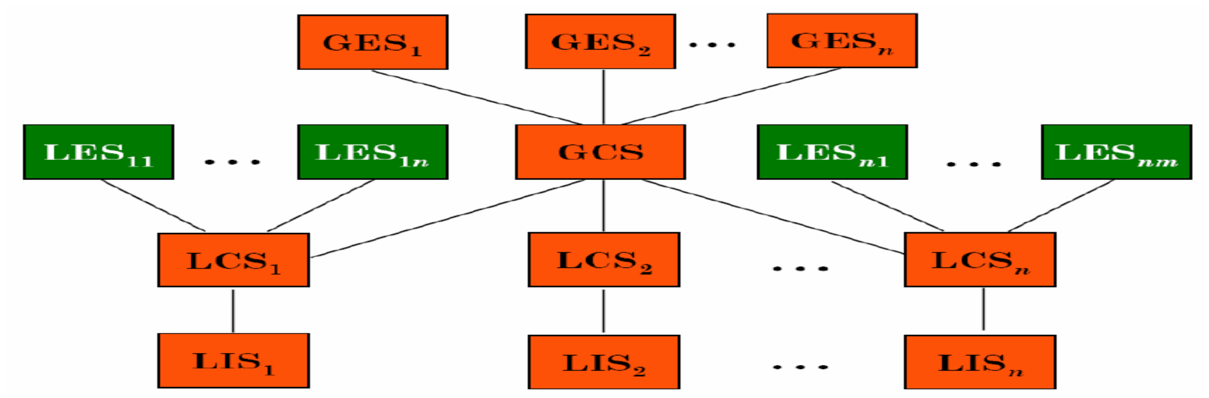
Fig. 1.15 Components of a Distributed DBMS

Multi-DBMS Architecture (Data-based)

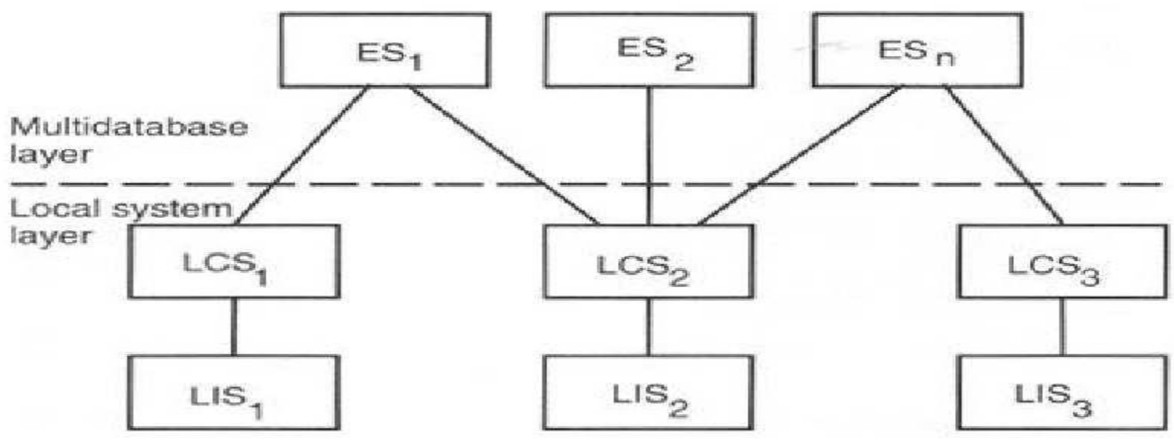
Fundamental difference to peer-to-peer DBMS is in the definition of the global conceptual schema (GCS)
– In a MDBMS the GCS represents only the collection of *some* of the local databases that each local DBMS want to share.
• This leads to the question, whether the GCS should even exist in a MDBMS?
• Two different architecutre models:
– Models with a GCS

– Models without GCS

Model with a GCS
– GCS is the union of parts of the LCSs
– Local DBMS define their own views on the local DB



Model without a GCS
– The local DBMSs present to the multi-database layer the part of their local DB they are willing to share.
– External views are defined on top of LCSs



This is an integrated database system formed by a collection of two or more autonomous database systems.
Multi-DBMS can be expressed through six levels of schemas:
☐ **Multi-database View Level**: Depicts multiple user views comprising of subsets of the integrated distributed database.
☐ **Multi-database Conceptual Level**: Depicts integrated multi-database that comprises of global logical multi-database structure definitions.
☐ **Multi-database Internal Level**: Depicts the data distribution across different sites and multi-database to local data mapping.
Local database View Level: Depicts public view of local data.
☐ **Local database Conceptual Level**: Depicts local data organization at each site.
☐ **Local database Internal Level**: Depicts physical data organization at each site.

Distributed Catalog management.

1.3 Distributed Database Design: Design strategies and issues. Data Replication. Data Fragmentation – Horizontal, Vertical and Mixed. Resource allocation. Semantic Data Control in Distributed DBMS.

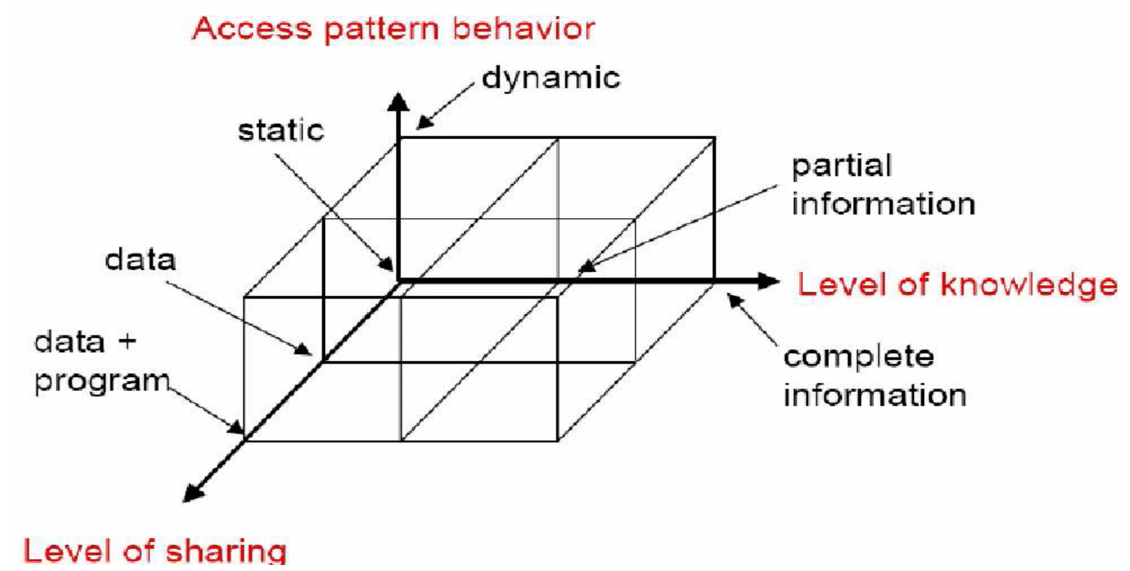
Distributed Database Design: Design strategies and issues.

Design Problem

• **Design problem of distributed systems**: Making decisions about the placement of **data** and **programs** across the sites of a computer network as well as possibly designing the network itself.
• In DDBMS, the distribution of applications involves
– Distribution of the DDBMS software
– Distribution of applications that run on the database
• Distribution of applications will not be considered in the following; instead the distribution of data is studied.

Framework of Distribution

Dimension for the analysis of distributed systems
– Level of sharing: no sharing, data sharing, data + program sharing
– Behavior of access patterns: static, dynamic
– Level of knowledge on access pattern behavior: no information, partial information, complete information.Distributed database design should be considered within this general framework.



Design Strategies

 Top-down approach
– Designing systems from scratch
– Homogeneous systems
• Bottom-up approach
– The databases already exist at a number of sites
– The databases should be connected to solve common tasks

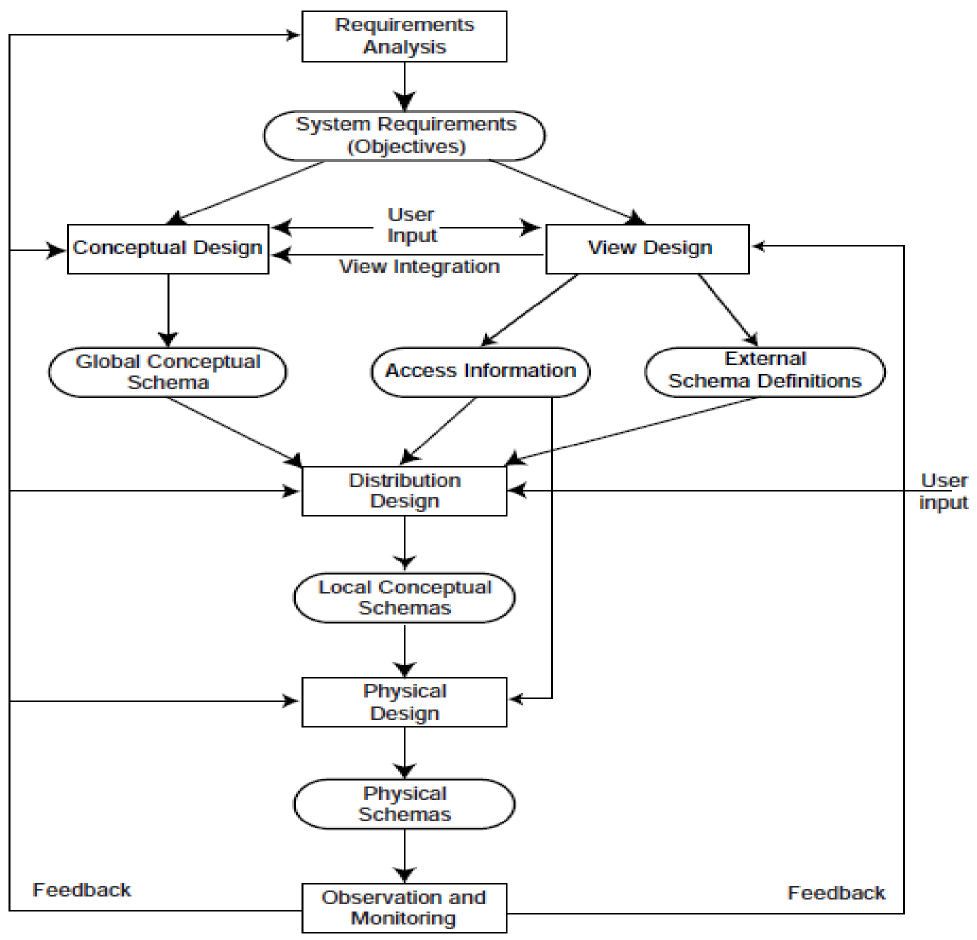


Fig: Top-Down Design Process

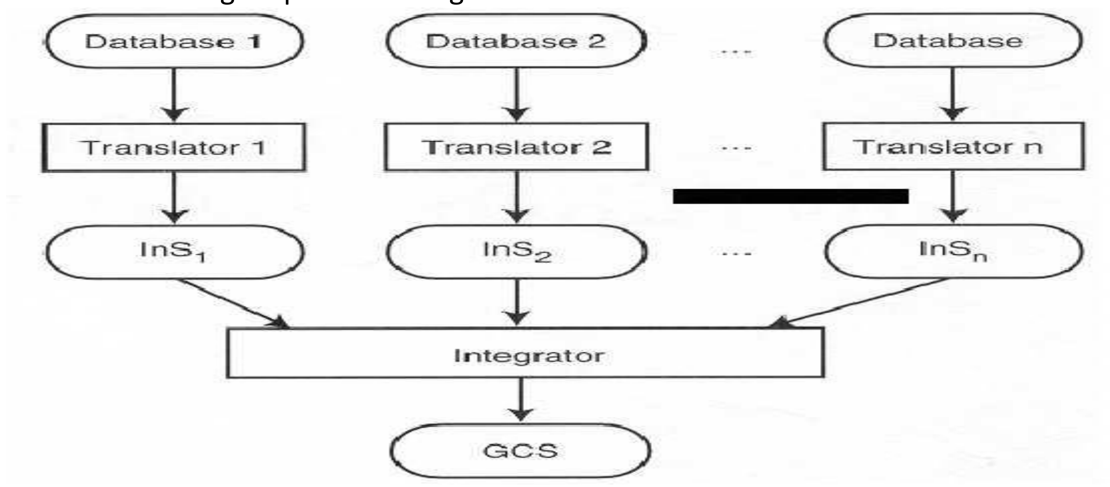


Fig: Bottom-Up Design Process

Distribution design

is the central part of the design in DDBMSs (the other tasks are similar to traditional databases)
– **Objective**: Design the LCSs by distributing the entities (relations) over the sites
– Two main aspects have to be designed carefully
∗ **Fragmentation**
· Relation may be divided into a number of sub-relations, which are distributed
∗ **Allocation** and **replication**
· Each fragment is stored at site with ”optimal” distribution
· Copy of fragment may be maintained at several sites

Distribution Design Issues

The following set of interrelated questions covers the entire issue. We will therefore

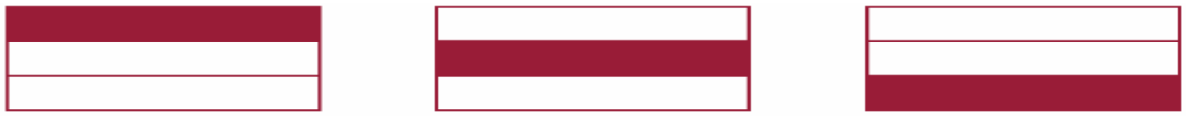
seek to answer them in the remainder of this section.
1. Why fragment at all?
2. How should we fragment?
3. How much should we fragment?
4. Is there any way to test the correctness of decomposition?
5. How should we allocate?
6. What is the necessary information for fragmentation and allocation?

Data Replication. Data Fragmentation – Horizontal, Vertical and Mixed.

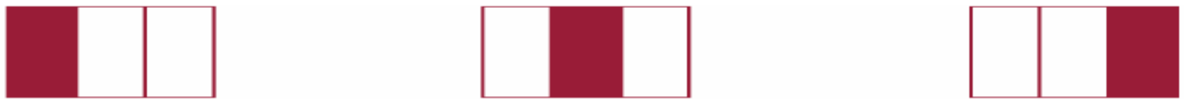
What is a reasonable unit of distribution? Relation or fragment of relation?
• **Relations** as unit of distribution:
– If the relation is not replicated, we get a high volume of remote data accesses.
– If the relation is replicated, we get unnecessary replications, which cause problems in executing updates and waste disk space
– Might be an Ok solution, if queries need all the data in the relation and data stays at the only sites that uses the data
• **Fragments** of relationas as unit of distribution:
– Application views are usually subsets of relations
– Thus, locality of accesses of applications is defined on subsets of relations
– Permits a number of transactions to execute concurrently, since they will access different portions of a relation
– Parallel execution of a single query (intra-query concurrency)
– However, semantic data control (especially integrity enforcement) is more difficult
⇒ Fragments of relations are (usually) the appropriate unit of distribution.

Fragmentation aims to improve:
– Reliability
– Performance
– Balanced storage capacity and costs
– Communication costs
– Security
• The following information is used to decide fragmentation:
– Quantitative information: frequency of queries, site, where query is run, selectivity of the queries, etc.
– Qualitative information: types of access of data, read/write, etc.

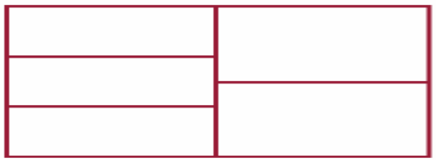
Types of Fragmentation
– Horizontal: partitions a relation along its tuples
– Vertical: partitions a relation along its attributes
– Mixed/hybrid: a combination of horizontal and vertical fragmentation

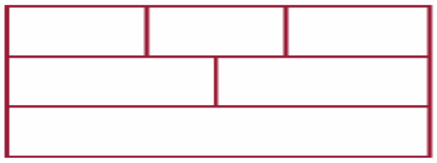


a) Horizontal fragmentation



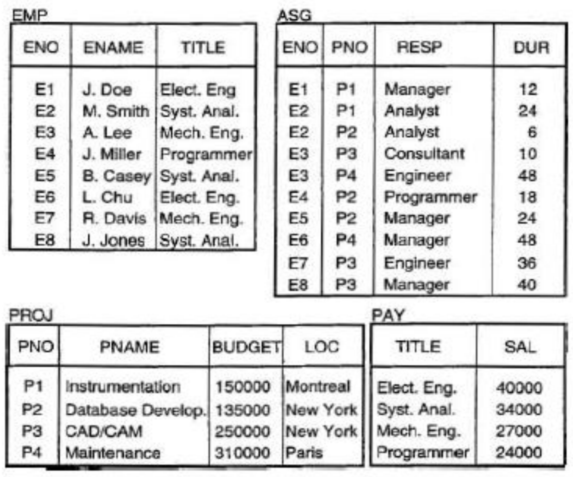
b) Vertical Fragmentation





c) Mixed Fragmentation

- **Exampe**



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

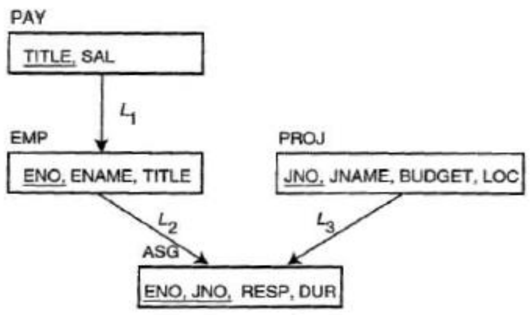
PROJ

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

PAY

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

Data

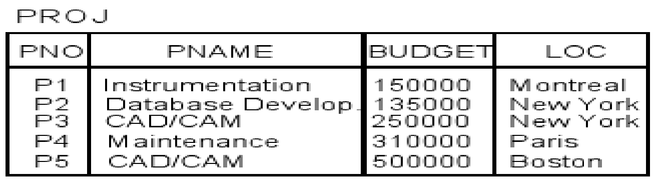


E-R Diagram

Example (contd.): Horizontal fragmentation of PROJ relation

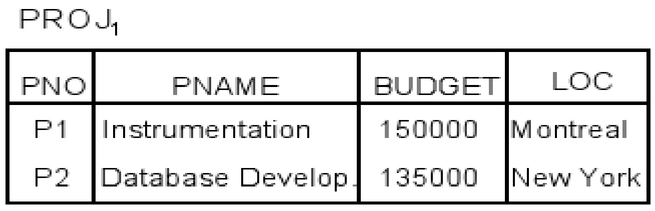
– PROJ1: projects with budgets less than 200, 000

– PROJ2: projects with budgets greater than or equal to 200, 000



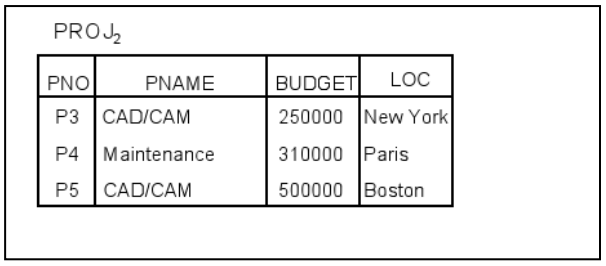
PROJ

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



$PROJ_1$

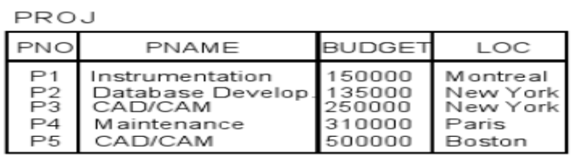
PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
P2	Database Develop.	135000	New York



$PROJ_2$

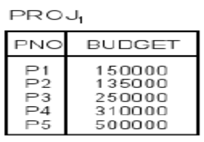
PNO	PNAME	BUDGET	LOC
P3	CAD/CAM	250000	New York
P4	Maintenance	310000	Paris
P5	CAD/CAM	500000	Boston

- **Example (contd.):** Vertical fragmentation of PROJ relation
  - PROJ1: information about project budgets
  - PROJ2: information about project names and locations



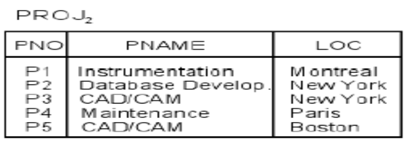
PROJ

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	BUDGET
P1	150000
P2	135000
P3	250000
P4	310000
P5	500000



$PROJ_2$

PNO	PNAME	LOC
P1	Instrumentation	Montreal
P2	Database Develop.	New York
P3	CAD/CAM	New York
P4	Maintenance	Paris
P5	CAD/CAM	Boston

Correctness Rules of Fragmentation

Completeness

– Decomposition of relation R into fragments R1,R2, . . . ,Rn is complete iff each

data item in R can also be found in some Ri.
• **Reconstruction**
– If relation R is decomposed into fragments R1,R2, . . . ,Rn, then there should exist some relational operator ∇ that reconstructs R from its fragments, i.e.,
R = R1∇. . .∇Rn
∗ Union to combine horizontal fragments
∗ Join to combine vertical fragments
• **Disjointness**
– If relation R is decomposed into fragments R1,R2, . . . ,Rn and data item di appears in fragment Rj , then di should not appear in any other fragment Rk, k 6= j (exception: primary key attribute for vertical fragmentation)
∗ For horizontal fragmentation, data item is a tuple
∗ For vertical fragmentation, data item is an attribute

Horizontal Fragmentation

• **Intuition** behind horizontal fragmentation
– Every site should hold all information that is used to query at the site
– The information at the site should be fragmented so the queries of the site run faster
• Horizontal fragmentation is **defined as selection operation**, _p(R)
• **Example**:
_BUDGET<200000(PROJ)
_BUDGET≥200000(PROJ)

Computing horizontal fragmentation (idea)
– Compute the **frequency** of the individual queries of the site q1, . . . , qQ
– Rewrite the queries of the site in the conjunctive normal form (disjunction of conjunctions); the conjunctions are called **minterms**.
– Compute the **selectivity** of the minterms
– Find the **minimal** and **complete** set of minterms (predicates)
∗ The set of predicates is **complete** if and only if any two tuples in the same fragment are referenced with the same probability by any application
∗ The set of predicates is **minimal** if and only if there is at least one query that accesses the fragment
– There is an algorithm how to find these fragments algorithmically (the algorithm CON MIN and PHORIZONTAL (pp 120-122) of the textbook of the course)

Example: Fragmentation of the PROJ relation
– Consider the following query: *Find the name and budget of projects given their PNO.*
– The query is issued at all three sites
– Fragmentation based on LOC, using the set of predicates/minterms
{LOC =′ Montreal′,LOC =′ NewY ork′,LOC =′ Paris′}

$PROJ_1 = \sigma_{LOC='Montreal'}(PROJ)$

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal

$PROJ_2 = \sigma_{LOC='NewYork'}(PROJ)$

PNO	PNAME	BUDGET	LOC
P2	Database Develop.	135000	New York
P3	CAD/CAM	250000	New York

$PROJ_3 = \sigma_{LOC='Paris'}(PROJ)$

PNO	PNAME	BUDGET	LOC
P4	Maintenance	310000	Paris

If access is only according to the location, the above set of predicates is complete
– i.e., each tuple of each fragment PROJi has the same probability of being accessed
• If there is a second query/application to access only those project tuples where the budget is less than \$200000, the set of predicates is not complete.
– P2 in PROJ2 has higher probability to be accessed

Example (contd.):
– Add BUDGET ≤ 200000 and BUDGET > 200000 to the set of predicates to make it complete.
⇒ {LOC =′ Montreal′,LOC =′ NewY ork′,LOC =′ Paris′,
BUDGET ≥ 200000,BUDGET < 200000} is a complete set
– Minterms to fragment the relation are given as follows:
(LOC =′ Montreal′) ∧ (BUDGET ≤ 200000)
(LOC =′ Montreal′) ∧ (BUDGET > 200000)
(LOC =′ NewY ork′) ∧ (BUDGET ≤ 200000)
(LOC =′ NewY ork′) ∧ (BUDGET > 200000)
(LOC =′ Paris′) ∧ (BUDGET ≤ 200000)
(LOC =′ Paris′) ∧ (BUDGET > 200000)

- **Example (contd.):** Now, $PROJ_2$ will be split in two fragments

$PROJ_1 = \sigma_{LOC='Montreal'}(PROJ)$

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal

$PROJ_2 = \sigma_{LOC='NY' \wedge BUDGET<200000}(PROJ)$

PNO	PNAME	BUDGET	LOC
P2	Database Develop.	135000	New York

$PROJ_3 = \sigma_{LOC='Paris'}(PROJ)$

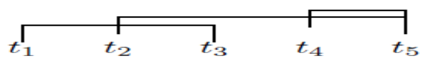
PNO	PNAME	BUDGET	LOC
P4	Maintenance	310000	Paris

$PROJ_2' = \sigma_{LOC='NY' \wedge BUDGET\geq 200000}(PROJ)$

PNO	PNAME	BUDGET	LOC
P3	CAD/CAM	250000	New York

  – $PROJ_1$ and $PROJ_2$ would have been split in a similar way if tuples with budgets smaller and greater than 200.000 would be stored

- In most cases intuition can be used to build horizontal partitions. Let $\{t_1, t_2, t_3\}$, $\{t_4, t_5\}$, and $\{t_2, t_3, t_4, t_5\}$ be query results. Then tuples would be fragmented in the following way:



Vertical Fragmentation

Objective of vertical fragmentation is to partition a relation into a set of smaller relations so that many of the applications will run on only one fragment.
• Vertical fragmentation of a relation R produces fragments R1,R2, . . . , each of which contains a **subset of** R's **attributes**.
• Vertical fragmentation is defined using the **projection operation** of the relational algebra:

$$\Pi_{A_1,A_2,\ldots,A_n}(R)$$

- **Example**:

$$PROJ_1 = \Pi_{PNO,BUDGET}(PROJ)$$
$$PROJ_2 = \Pi_{PNO,PNAME,LOC}(PROJ)$$

• Vertical fragmentation has also been studied for (centralized) DBMS
– Smaller relations, and hence less page accesses
– e.g., MONET system

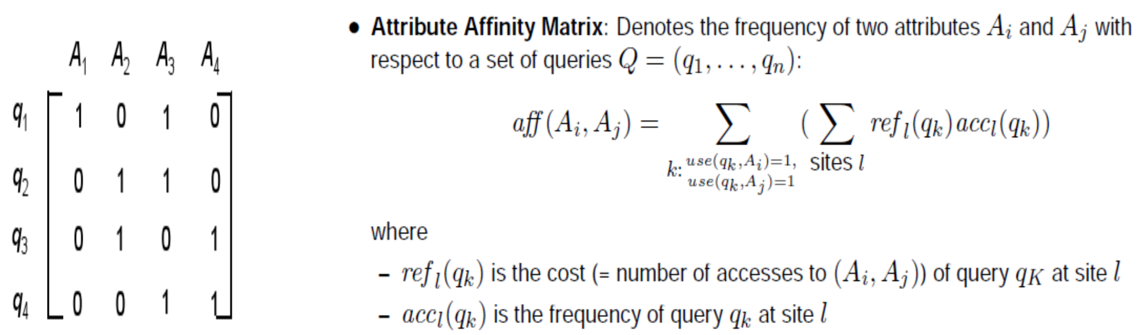
Vertical fragmentation is **inherently more complicated** than horizontal fragmentation
– In horizontal partitioning: for n simple predicates, the number of possible minterms is 2n; some of them can be ruled out by existing implications/constraints.
– In vertical partitioning: for m non-primary key attributes, the number of possible fragments is equal to B(m) (= the mth Bell number), i.e., the number of partitions of a set with m members.
∗ For large numbers, B(m) ≈ mm (e.g., B(15) = 109)
• Optimal solutions are not feasible, and heuristics need to be applied.

Two types of heuristics for vertical fragmentation exist:
– **Grouping**: assign each attribute to one fragment, and at each step, join some of the fragments until some criteria is satisfied.
∗ Bottom-up approach
– **Splitting**: starts with a relation and decides on beneficial partitionings based on the access behaviour of applications to the attributes.
∗ Top-down approach
∗ Results in non-overlapping fragments
∗ "Optimal" solution is probably closer to the full relation than to a set of small relations with only one attribute
∗ Only vertical fragmentation is considered here
DDB

Application information: The major information required as input for vertical fragmentation is related to applications
– Since vertical fragmentation places in one fragment those attributes usually accessed together, there is a need for some measure that would define more precisely the notion of "togetherness", i.e., how closely related the attributes are.
– This information is obtained from queries and collected in the *Attribute Usage Matrix* and *Attribute Affinity Matrix*.

Given are the user queries/applications Q = (q1, . . . , qq) that will run on relation R(A1, . . . ,An)
• **Attribute Usage Matrix**: Denotes which query uses which attribute:
use(qi,Aj) =(1 iff qi uses Aj
0 otherwise
– The use(qi, •) vectors for each application are easy to define if the designer knows the applications that willl run on the DB (consider also the 80-20 rule)

Example: Consider the following relation:
PROJ(PNO, PNAME,BUDGET,LOC)
and the following queries:
q1 = SELECT BUDGET FROM PROJ WHERE PNO=Value
q2 = SELECT PNAME,BUDGET FROM PROJ
q3 = SELECT PNAME FROM PROJ WHERE LOC=Value
q4 = SELECT SUM(BUDGET) FROM PROJ WHERE LOC =Value
• Lets abbreviate A1 = PNO,A2 = PNAME,A3 = BUDGET,A4 = LOC
• Attribute Usage Matrix



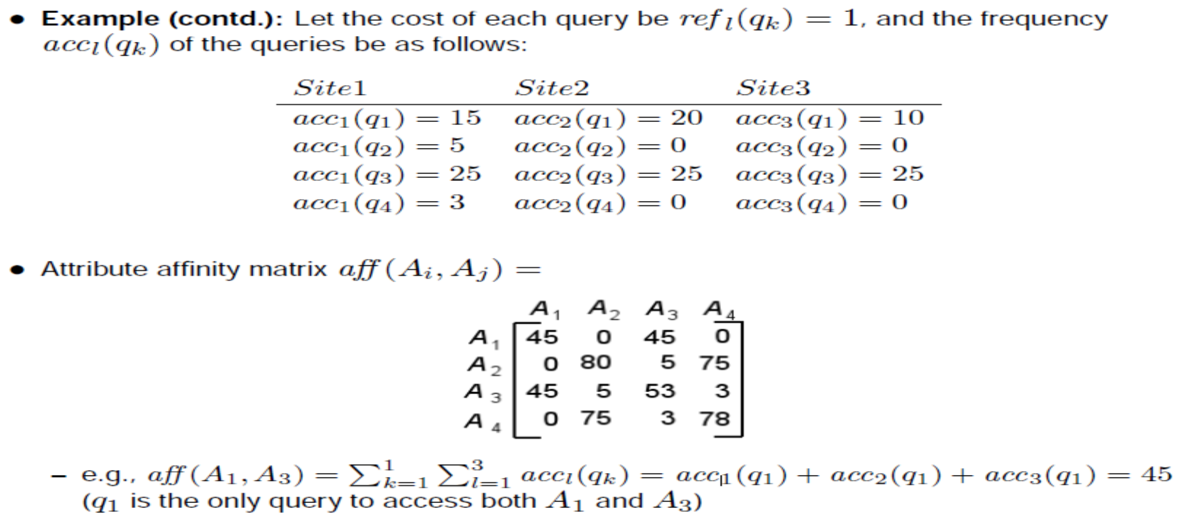
$$\begin{array}{c|cccc} & A_1 & A_2 & A_3 & A_4 \\ \hline q_1 & 1 & 0 & 1 & 0 \\ q_2 & 0 & 1 & 1 & 0 \\ q_3 & 0 & 1 & 0 & 1 \\ q_4 & 0 & 0 & 1 & 1 \end{array}$$

- **Attribute Affinity Matrix**: Denotes the frequency of two attributes A_i and A_j with respect to a set of queries $Q = (q_1, \dots, q_n)$:

$$aff(A_i, A_j) = \sum_{k:\, \substack{use(q_k, A_i)=1,\\ use(q_k, A_j)=1}} \Big(\sum_{\text{sites } l} ref_l(q_k) acc_l(q_k) \Big)$$

where

- $ref_l(q_k)$ is the cost (= number of accesses to (A_i, A_j)) of query q_K at site l
- $acc_l(q_k)$ is the frequency of query q_k at site l



- **Example (contd.):** Let the cost of each query be $ref_l(q_k) = 1$, and the frequency $acc_l(q_k)$ of the queries be as follows:

$Site1$	$Site2$	$Site3$
$acc_1(q_1) = 15$	$acc_2(q_1) = 20$	$acc_3(q_1) = 10$
$acc_1(q_2) = 5$	$acc_2(q_2) = 0$	$acc_3(q_2) = 0$
$acc_1(q_3) = 25$	$acc_2(q_3) = 25$	$acc_3(q_3) = 25$
$acc_1(q_4) = 3$	$acc_2(q_4) = 0$	$acc_3(q_4) = 0$

- Attribute affinity matrix $aff(A_i, A_j) =$

$$\begin{array}{c|cccc} & A_1 & A_2 & A_3 & A_4 \\ \hline A_1 & 45 & 0 & 45 & 0 \\ A_2 & 0 & 80 & 5 & 75 \\ A_3 & 45 & 5 & 53 & 3 \\ A_4 & 0 & 75 & 3 & 78 \end{array}$$

– e.g., $aff(A_1, A_3) = \sum_{k=1}^{1} \sum_{l=1}^{3} acc_l(q_k) = acc_1(q_1) + acc_2(q_1) + acc_3(q_1) = 45$ (q_1 is the only query to access both A_1 and A_3)

Take the attribute affinity matrix (AA) and reorganize the attribute orders to form clusters where the attributes in each cluster demonstrate high affinity to one another.

• **Bond energy algorithm (BEA)** has been suggested to be useful for that purpose for several reasons:

– It is designed specifically to determine groups of similar items as opposed to a linear ordering of the items.

– The final groupings are insensitive to the order in which items are presented.

– The computation time is reasonable (O(n2), where n is the number of attributes)

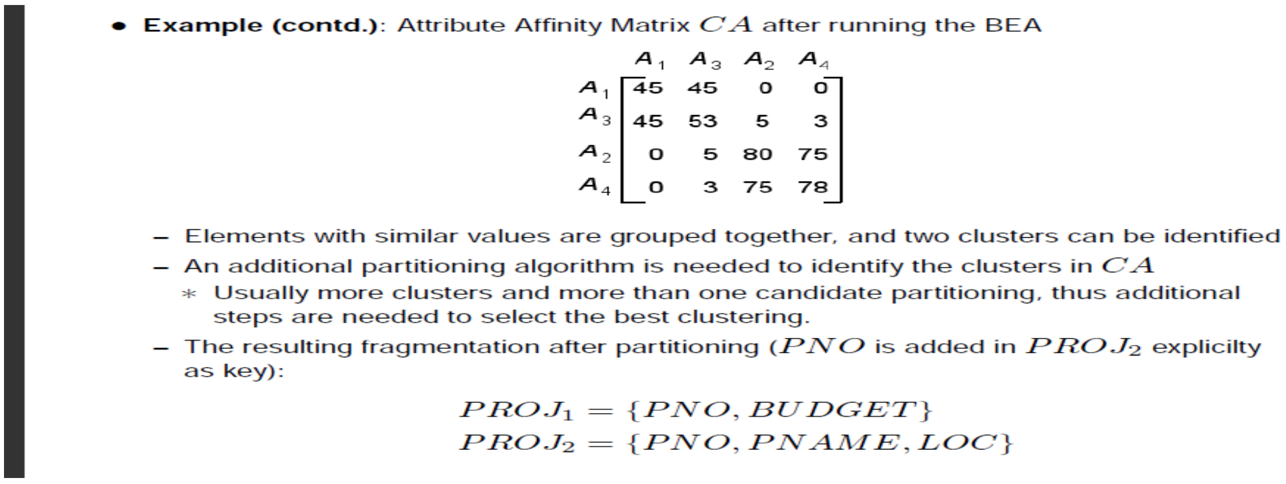
• **BEA**:

– Input: AA matrix

– Output: Clustered AA matrix (CA)

– Permutation is done in such a way to maximize the following **global affinity mesaure** (affinity of Ai and Aj with their neighbors):

$$AM = \sum_{i=1}^{n} \sum_{j=1}^{n} aff(A_i, A_j)[aff(A_i, A_{j-1}) + aff(A_i, A_{j+1}) + aff(A_{i-1}, A_j) + aff(A_{i+1}, A_j)]$$



- **Example (contd.)**: Attribute Affinity Matrix CA after running the BEA

$$\begin{array}{c|cccc} & A_1 & A_3 & A_2 & A_4 \\ \hline A_1 & 45 & 45 & 0 & 0 \\ A_3 & 45 & 53 & 5 & 3 \\ A_2 & 0 & 5 & 80 & 75 \\ A_4 & 0 & 3 & 75 & 78 \end{array}$$

  – Elements with similar values are grouped together, and two clusters can be identified
  – An additional partitioning algorithm is needed to identify the clusters in CA
    ∗ Usually more clusters and more than one candidate partitioning, thus additional steps are needed to select the best clustering.
  – The resulting fragmentation after partitioning (PNO is added in $PROJ_2$ explicilty as key):

$$PROJ_1 = \{PNO, BUDGET\}$$
$$PROJ_2 = \{PNO, PNAME, LOC\}$$

Correctness of Vertical Fragmentation

Relation R is decomposed into fragments R1,R2, . . . ,Rn
– e.g., PROJ = {PNO,BUDGET, PNAME,LOC} into
PROJ1 = {PNO,BUDGET} and PROJ2 = {PNO, PNAME,LOC}
• **Completeness**
– Guaranteed by the partitioning algortihm, which assigns each attribute in A to one partition
• **Reconstruction**
– Join to reconstruct vertical fragments
– R = R1 ⋊⋉ · · · ⋊⋉ Rn = PROJ1 ⋊⋉ PROJ2
• **Disjointness**
– Attributes have to be disjoint in VF. Two cases are distinguished:
∗ If tuple IDs are used, the fragments are really disjoint
∗ Otherwise, key attributes are replicated automatically by the system
∗ e.g., PNO in the above example

Mixed Fragmentation

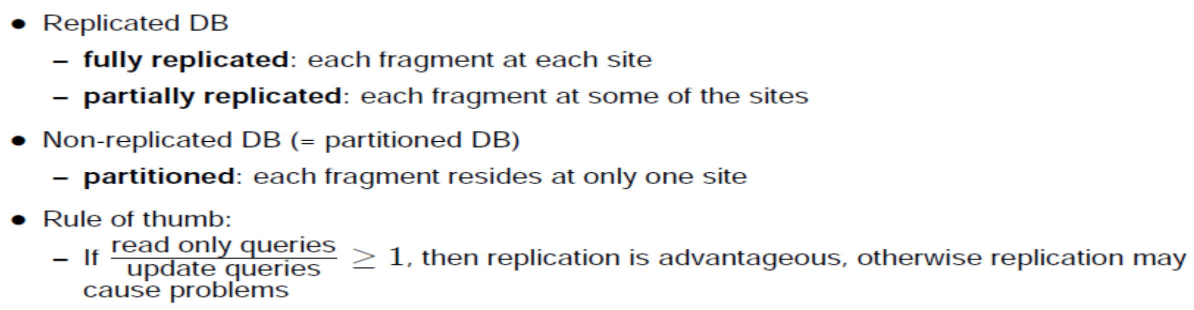
In most cases simple horizontal or vertical fragmentation of a DB schema will not be sufficient to satisfy the requirements of the applications.
• **Mixed fragmentation (hybrid fragmentation)**: Consists of a horizontal fragment followed by a vertical fragmentation, or a vertical fragmentation followed by a horizontal fragmentation
• Fragmentation is defined using the selection and projection operations of relational algebra:

$$\sigma_p(\Pi_{A_1,\ldots,A_n}(R))$$
$$\Pi_{A_1,\ldots,A_n}(\sigma_p(R))$$

Resource allocation.

 Replication: Which fragements shall be stored as multiple copies?
– Complete Replication
∗ Complete copy of the database is maintained in each site
– Selective Replication
∗ Selected fragments are replicated in some sites
• **Allocation**: On which sites to store the various fragments?
– Centralized
∗ Consists of a single DB and DBMS stored at one site with users distributed across

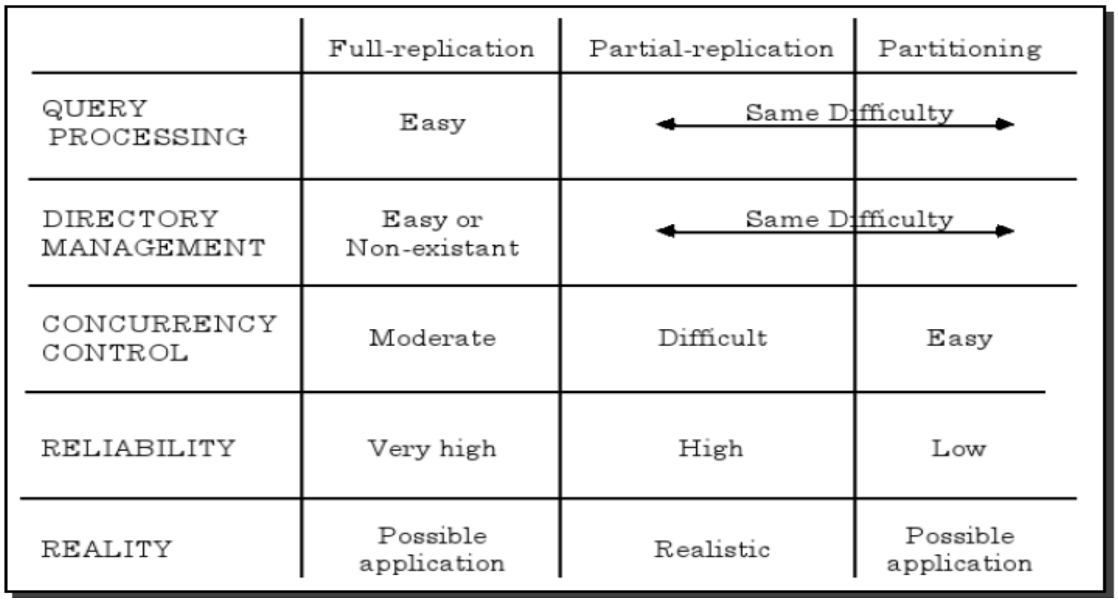
the network
– Partitioned
∗ Database is partitioned into disjoint fragments, each fragment assigned to one site



- Replicated DB
  - **fully replicated**: each fragment at each site
  - **partially replicated**: each fragment at some of the sites
- Non-replicated DB (= partitioned DB)
  - **partitioned**: each fragment resides at only one site
- Rule of thumb:
  - If $\frac{\text{read only queries}}{\text{update queries}} \geq 1$, then replication is advantageous, otherwise replication may cause problems

Replication

- Comparison of replication alternatives



	Full-replication	Partial-replication	Partitioning
QUERY PROCESSING	Easy	← Same Difficulty →	
DIRECTORY MANAGEMENT	Easy or Non-existant	← Same Difficulty →	
CONCURRENCY CONTROL	Moderate	Difficult	Easy
RELIABILITY	Very high	High	Low
REALITY	Possible application	Realistic	Possible application

Fragment Allocation

Fragment allocation problem

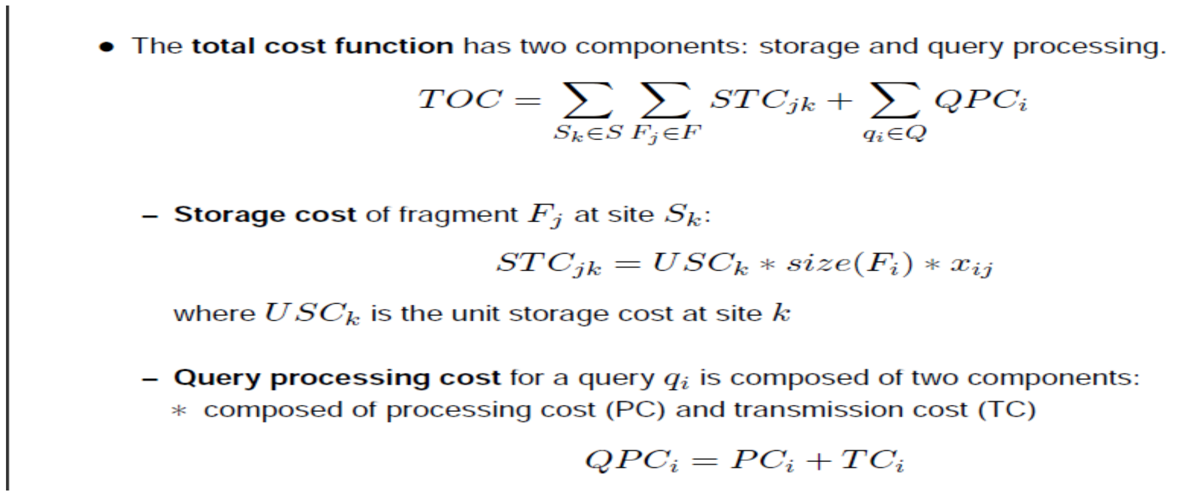
– Given are:
– fragments F = {F1, F2, ..., Fn}
– network sites S = {S1, S2, ..., Sm}
– and applications Q = {q1, q2, ..., ql}
– Find: the ”optimal” distribution of F to S
• **Optimality**
– Minimal cost
∗ Communication + storage + processing (read and update)
∗ Cost in terms of time (usually)
– Performance
∗ Response time and/or throughput
– Constraints
∗ Per site constraints (storage and processing)

Required information

– Database Information
∗ selectivity of fragments
∗ size of a fragment

– Application Information
∗ RRij : number of read accesses of a query qi to a fragment Fj
∗ URij : number of update accesses of query qi to a fragment Fj
∗ uij : a matrix indicating which queries updates which fragments,
∗ rij : a similar matrix for retrievals
∗ originating site of each query
– Site Information
∗ USCk: unit cost of storing data at a site Sk
∗ LPCk: cost of processing one unit of data at a site Sk
– Network Information
∗ communication cost/frame between two sites
∗ frame size

We present an **allocation model** which attempts to
– minimize the total cost of processing and storage
– meet certain response time restrictions
• General Form:
min(Total Cost)
– subject to
∗ response time constraint
∗ storage constraint
∗ processing constraint
• Functions for the total cost and the constraints are presented in the next slides.
• Decision variable xij
xij =(1 if fragment Fi is stored at site Sj
0 otherwise



- The **total cost function** has two components: storage and query processing.

$$TOC = \sum_{S_k \in S} \sum_{F_j \in F} STC_{jk} + \sum_{q_i \in Q} QPC_i$$

– **Storage cost** of fragment F_j at site S_k:

$$STC_{jk} = USC_k * size(F_i) * x_{ij}$$

where USC_k is the unit storage cost at site k

– **Query processing cost** for a query q_i is composed of two components:
∗ composed of processing cost (PC) and transmission cost (TC)

$$QPC_i = PC_i + TC_i$$

- **Processing cost** is a sum of three components:
  - access cost (AC), integrity contraint cost (IE), concurency control cost (CC)

$$PC_i = AC_i + IE_i + CC_i$$

  - **Access cost**:

$$AC_i = \sum_{s_k \in S} \sum_{F_j \in F} (UR_{ij} + RR_{ij}) * x_{ij} * LPC_k$$

    where LPC_k is the unit process cost at site k
  - **Integrity and concurrency costs**:
    * Can be similarly computed, though depends on the specific constraints

- **Note:** AC_i assumes that processing a query involves decomposing it into a set of subqueries, each of which works on a fragment, ...,
  - This is a very simplistic model
  - Does not take into consideration different query costs depending on the operator or different algorithms that are applied

- Modeling the **constraints**
  - **Response time** constraint for a query q_i

$$\text{execution time of } q_i \leq \text{ max. allowable response time for } q_i$$

  - **Storage** constraints for a site S_k

$$\sum_{F_j \in F} \text{storage requirement of } F_j \text{ at } S_k \leq \text{ storage capacity of } S_k$$

  - **Processing** constraints for a site S_k

$$\sum_{q_i \in Q} \text{processing load of } q_i \text{ at site } S_k \leq \text{ processing capacity of} S_k$$

- The **transmission cost** is composed of two components:
  - Cost of processing updates (TCU) and cost of processing retrievals (TCR)

$$TC_i = TCU_i + TCR_i$$

  - **Cost of updates**:
    * Inform all the sites that have replicas + a short confirmation message back

$$TCU_i = \sum_{S_k \in S} \sum_{F_j \in F} u_{ij} * (\text{update message cost} + \text{acknowledgment cost})$$

  - **Retrieval cost**:
    * Send retrieval request to all sites that have a copy of fragments that are needed + sending back the results from these sites to the originating site.

$$TCR_i = \sum_{F_j \in F} \min_{S_k \in S} *(\text{cost of retrieval request} + \text{cost of sending back the result})$$

Solution Methods

– The complexity of this allocation model/problem is NP-complete
– Correspondence between the allocation problem and similar problems in other areas
∗ Plant location problem in operations research
∗ Knapsack problem
∗ Network flow problem
– Hence, solutions from these areas can be re-used
– Use different heuristics to reduce the search space
∗ Assume that all candidate partitionings have been determined together with their

associated costs and benefits in terms of query processing.
· The problem is then reduced to find the optimal partitioning and placement for each relation
∗ Ignore replication at the first step and find an optimal non-replicated solution
· Replication is then handeled in a second step on top of the previous non-replicated solution.

Semantic Data Control in Distributed DBMS.

Semantic Data Control

Semantic data control typically includes view management, security control, and semantic integrity control.
• Informally, these functions must ensure that authorized users perform correct operations on the database, contributing to the maintenance of database integrity.
• In RDBMS semantic data control can be achieved in a uniform way
– views, security constraints, and semantic integrity constraints can be defined as rules that the system automatically enforces

View Management

Views enable full logical data independence
• Views are virtual relations that are defined as the result of a query on base relations
• Views are typically not materialized
– Can be considered a dynamic window that reflects all relevant updates to the database
• Views are very useful for ensuring data security in a simple way
– By selecting a subset of the database, views **hide** some data
– Users cannot see the hidden data

View Management in Distributed Databases

• Definition of views in DDBMS is similar as in centralized DBMS
– However, a view in a DDBMS may be derived from fragmented relations stored at different sites
• Views are conceptually the same as the base relations, therefore we store them in the (possibly) distributed directory/catalogue
– Thus, views might be centralized at one site, partially replicated, fully replicated
– Queries on views are translated into queries on base relations, yielding distributed queries due to possible fragmentation of data
• Views derived from distributed relations may be costly to evaluate
– Optimizations are important, e.g., snapshots
– A snapshot is a static view
∗ does not reflect the updates to the base relations
∗ managed as temporary relations: the only access path is sequential scan
∗ typically used when selectivity is small (no indices can be used efficiently)
∗ is subject to periodic recalculation

Data Security

Data security protects data against unauthorized acces and has two aspects:

– Data protection
– Authorization control

Data Protection

Data protection prevents unauthorized users from understanding the physical content of data.
• Well established standards exist
– Data encryption standard
– Public-key encryption schemes

Authorization Control

Authorization control must guarantee that only authorized users perform operations they are allowed to perform on the database.
• Three actors are involved in authorization
– **users**, who trigger the execution of application programms
– **operations**, which are embedded in applications programs
– **database objects**, on which the operations are performed
• Authorization control can be viewed as a triple *(user, operation type, object)* which specifies that the user has the right to perform an operation of operation type on an object.
• Authentication of (groups of) users is typically done by username and password
• Authorization control in (D)DBMS is more complicated as in operating systems
– In a file system: data objects are files
– In a DBMS: Data objects are views, (fragments of) relations, tuples, attributes

Semantic Integrity Constraints

A database is said to be **consistent** if it satisfies a set of constraints, called **semantic integrity constraints**
• Maintain a database consistent by enforcing a set of constraints is a difficult problem
• Semantic integrity control evolved from procedural methods (in which the controls were embedded in application programs) to declarative methods
– avoid data dependency problem, code redundancy, and poor performance of the procedural methods
• Two main types of constraints can be distinguished:
– **Structural constraints**: basic semantic properties inherent to a data model e.g., unique key constraint in relational model
– **Behavioral constraints**: regulate application behavior e.g., dependencies (functional, inclusion) in the relational model
• A semantic integrity control system has 2 components:
– Integrity constraint specification
– Integrity constraint enforcement

Integrity constraints specification
– In RDBMS, integrity constraints are defined as **assertions**, i.e., expression in tuple relational calculus
– Variables are either universally (∀) or existentially (∃) quantified
– Declarative method
– Easy to define constraints

– Can be seen as a query qualification which is either true or false
– Definition of database consistency clear
– 3 types of integrity constraints/assertions are distinguished:
∗ predefined
∗ precompiled
∗ general constraints
• In the following examples we use the following relations:
EMP(ENO, ENAME, TITLE)
PROJ(PNO, PNAME, BUDGET)
ASG(ENO, PNO, RESP, DUR)

Predefined constraints are based on simple keywords and specify the more common contraints of the relational model
• Not-null attribute:
– e.g., Employee number in EMP cannot be null
ENO **NOT NULL** IN EMP
• Unique key:
– e.g., the pair (ENO,PNO) is the unique key in ASG
(ENO, PNO) **UNIQUE IN** ASG
• Foreign key:
– e.g., PNO in ASG is a foreign key matching the primary key PNO in PROJ
PNO **IN** ASG **REFERENCES** PNO IN PROJ
• Functional dependency:
– e.g., employee number functionally determines the employee name
ENO **IN** EMP **DETERMINES** ENAME

Precompiled constraints express preconditions that must be satisfied by all tuples in a relation for a given update type
• General form:
CHECK ON <relation> [**WHEN** <update type>] <qualification>
• Domain constraint, e.g., constrain the budget:
CHECK ON PROJ(BUDGET>500000 **AND** BUDGET≤1000000)
• Domain constraint on deletion, e.g., only tuples with budget 0 can be deleted:
CHECK ON PROJ **WHEN DELETE** (BUDGET = 0)
• Transition constraint, e.g., a budget can only increase:
CHECK ON PROJ (NEW.BUDGET > OLD.BUDGET **AND**
NEW.PNO = OLD.PNO)
– OLD and NEW are implicitly defined variables to identify the tuples that are subject to Update

General constraints may involve more than one relation
• General form:
CHECK ON <variable>:<relation> (<qualification>)
• Functional dependency:
CHECK ON e1:EMP, e2:EMP
(e1.ENAME = e2.ENAME **IF** e1.ENO = e2.ENO)
• Constraint with aggregate function:
e.g., The total duration for all employees in the CAD project is less than 100

CHECK ON g:ASG, j:PROJ
(**SUM**(g.DUR **WHERE** g.PNO=j.PNO) < 100
IF j.PNAME="CAD/CAM")

Semantic Integrity Constraints Enforcement

Enforcing semantic integrity constraints consists of rejecting update programs that violate some integrity constraints
• Thereby, the major problem is to find **efficient algorithms**
• Two methods to enforce integrity constraints:
– Detection:
1. Execute update u : D → Du
2. If Du is inconsistent then compensate Du → D′
u or undo Du → D
∗ Also called *posttest*
∗ May be costly if undo is very large
– Prevention:
Execute u : D → Du only if Du will be consistent
∗ Also called *pretest*
∗ Generally more efficient
∗ Query modification algorithm by Stonebraker (1975) is a preventive method that is particularly efficient in enforcing domain constraints.
· Add the assertion qualification (constraint) to the update query and check it immediately for each tuple

Example: Consider a query for increasing the budget of CAD/CAM projects by 10%:
UPDATE PROJ
SET BUDGET = BUDGET * 1.1
WHERE PNAME = ‘‘CAD/CAM’’
and the domain constraint
CHECK ON PROJ (BUDGET >= 50K **AND** BUDGET <= 100K)
The query modification algorithm transforms the query into:
UPDATE PROJ
SET BUDGET = BUDGET * 1.1
WHERE PNAME = ‘‘CAD/CAM’’
AND NEW.BUDGET >= 50K
AND NEW.BUDGET <= 100K

Distributed Constraints

Three classes of **distributed integrity constraints/assertions** are distinguished:
– Individual assertions
∗ Single relation, single variable
∗ Refer only to tuples to be updated independenlty of the rest of the DB
∗ e.g., domain constraints
– Set-oriented assertions
∗ Single relation, multi variable (e.g., functional dependencies)
∗ Multi-relation, multi-variable (e.g., foreign key constraints)

∗ Multiple tuples form possibly different relations are involved
– Assertions involving **aggregates**
∗ Special, costly processing of aggregates is required

Particular difficulties with distributed constraints arise from the fact that relations are fragmented and replicated:
– Definition of assertions
– Where to store the assertions?
– How to enforce the assertions?

Definition and storage of assertions
– The definition of a new integrity assertion can be started at one of the sites that store the relations involved in the assertion, but needs to be propagated to sites that might store fragments of that relation.
– Individual assertions
∗ The assertion definition is sent to all other sites that contain fragments of the relation involved in the assertion.
∗ At each fragment site, check for compatibility of assertion with data
∗ If compatible, store; otherwise reject
∗ If any of the sites rejects, globally reject
– Set-oriented assertions
∗ Involves joins (between fragments or relations)
∗ Maybe necessary to perform joins to check for compatibility
∗ Store if compatible

Enforcement of assertions in DDBMS is more complex than in centralized DBMS
• The main problem is to decide where (at which site) to enforce each assertion?
– Depends on type of assertion, type of update, and where update is issued
• Individual assertions
– Update = insert
∗ enforce at the site where the update is issued (i.e., where the user inserts the tuples)
– Update = delete or modify
∗ Send the assertions to all the sites involved (i.e., where qualified tuples are updated)
∗ Each site enforce its own assertion
• Set-oriented assertions
– Single relation
∗ Similar to individual assertions with qualified updates
– Multi-relation
∗ Move data between sites to perform joins
∗ Then send the result to the query master site (the site the update is issued)

Unit 2: 17 hrs.

2.1 Distributed Query Processing: Query Decomposition and Data localization for distributed data, join ordering, semi-join strategy, Distributed Query optimization methods.

Distributed Query Processing: Query Decomposition and Data localization for distributed data,

Query Processing Overview:

Query processing: A 3-step process that transforms a high-level query (of relational calculus/SQL) into an equivalent and more efficient lower-level query (of relational algebra).

1. Parsing and translation

– Check syntax and verify relations.

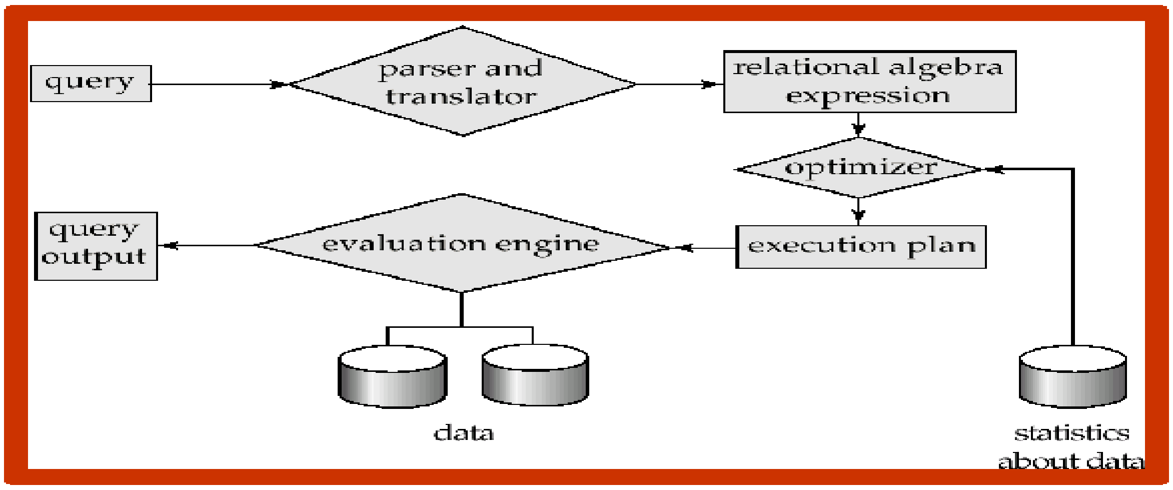
– Translate the query into an equivalent relational algebra expression.

2. Optimization

– Generate an optimal evaluation plan (with lowest cost) for the query plan.

3. Evaluation

– The query-execution engine takes an (optimal) evaluation plan, executes that plan, and returns the answers to the query.



The success of RDBMSs is due, in part, to the availability
– of declarative query languages that allow to easily express complex queries without knowing about the details of the physical data organization and
– of advanced query processing technology that transforms the high-level user/application queries into efficient lower-level query execution strategies.
• The query transformation should achieve both **correctness** and **efficiency**
– The main difficulty is to achieve the efficiency
– This is also one of the most important tasks of any DBMS
• **Distributed query processing**: Transform a high-level query (of relational calculus/SQL) on a distributed database (i.e., a set of global relations) into an **equivalent** and **efficient** lower-level query (of relational algebra) on relation fragments.
• Distributed query processing is more complex
– Fragmentation/replication of relations
– Additional communication costs
– Parallel execution

Query Optimization

Query optimization is a crucial and difficult part of the overall query processing

• Objective of query optimization is to minimize the following cost function:

I/O cost + CPU cost + communication cost

• Two different scenarios are considered:

– Wide area networks

———————————— Communication cost dominates

· low bandwidth

· low speed

· high protocol overhead

———————————— Most algorithms ignore all other cost components

– Local area networks

———————————— Communication cost not that dominant

———————————— Total cost function should be considered

Ordering of the operators of relational algebra is crucial for efficient query processing

• Rule of thumb: move expensive operators at the end of query processing

• Cost of RA operations:

Operation	Complexity
Select, Project (without duplicate elimination)	$O(n)$
Project (with duplicate elimination)	$O(n \log n)$
Group Join Semi-join Division Set Operators	$O(n \log n)$
Cartesian Product	$O(n^2)$

Query Optimization Issues

Several issues have to be considered in query optimization

• Types of query optimizers

– wrt the search techniques (exhaustive search, heuristics)

– wrt the time when the query is optimized (static, dynamic)

• Statistics

• Decision sites

• Network topology

• Use of semijoins

Types of Query Optimizers wrt Search Techniques

Exhaustive search

_ Cost-based

_ Optimal

_ Combinatorial complexity in the number of relation

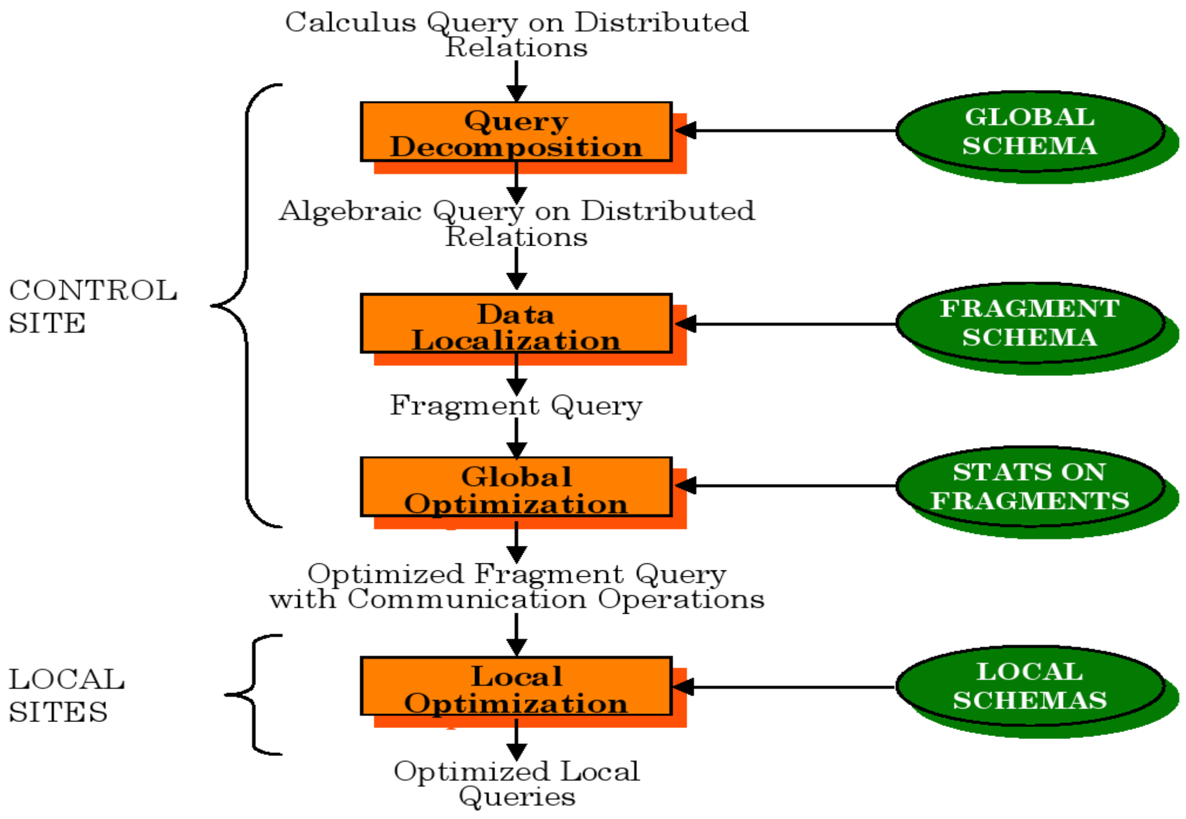
Heuristics search

_ Not optimal

_ Regroups common sub-expressions
_ Performs selection, projection first
_ Replaces a join by a series of semijoins
_ Reorders operations to reduce intermediate relation size
_ Optimizes individual operations
Types of Query Optimizers wrt Optimization Timing
– Static
———————————— Query is optimized prior to the execution
———————————— As a consequence it is difficult to estimate the size of the intermediate results
———————————— Typically amortizes over many executions
– Dynamic
———————————— Optimization is done at run time
———————————— Provides exact information on the intermediate relation sizes
———————————— Have to re-optimize for multiple executions
– Hybrid
———————————— First, the query is compiled using a static algorithm
———————————— Then, if the error in estimate sizes greater than threshold, the query is re-optimized
at run time
** Statistics
– Relation/fragments
———————————— Cardinality
———————————— Size of a tuple
———————————— Fraction of tuples participating in a join with another relation/fragment
– Attribute
———————————— Cardinality of domain
———————————— Actual number of distinct values
———————————— Distribution of attribute values (e.g., histograms)
– Common assumptions
———————————— Independence between different attribute values
———————————— Uniform distribution of attribute values within their domain
**Decision sites
– Centralized
———————————— Single site determines the ”best” schedule
———————————— Simple
———————————— Knowledge about the entire distributed database is needed
– Distributed
———————————— Cooperation among sites to determine the schedule
———————————— Only local information is needed
———————————— Cooperation comes with an overhead cost
– Hybrid

———————————— One site determines the global schedule
———————————— Each site optimizes the local sub-queries
**Network topology
– Wide area networks (WAN) point-to-point
———————————— Characteristics
· Low bandwidth
· Low speed
· High protocol overhead
———————————— Communication cost dominate; all other cost factors are ignored
———————————— Global schedule to minimize communication cost
———————————— Local schedules according to centralized query optimization
– Local area networks (LAN)
———————————— Communication cost not that dominant
———————————— Total cost function should be considered
———————————— Broadcasting can be exploited (joins)
———————————— Special algorithms exist for star networks
**
Use of Semijoins
– Reduce the size of the join operands by first computing semijoins
– Particularly relevant when the main cost is the communication cost
– Improves the processing of distributed join operations by reducing the size of data exchange between sites
– However, the number of messages as well as local processing time is increased

Query Decomposition



Query decomposition: Mapping of calculus query (SQL) to algebra operations (select, project, join, rename)

• Both input and output queries refer to global relations, without knowledge of the distribution of data.

• The output query is semantically correct and good in the sense that redundant work is avoided.

• Query decomposistion consists of 4 steps:

1. Normalization: Transform query to a normalized form
2. Analysis: Detect and reject ”incorrect” queries; possible only for a subset of relational calculus
3. Elimination of redundancy: Eliminate redundant predicates
4. Rewriting: Transform query to RA and optimize query

Normalization: Transform the query to a normalized form to facilitate further processing. Consists mainly of two steps.

1. **Lexical** and **syntactic** analysis

– Check validity (similar to compilers)

– Check for attributes and relations

– Type checking on the qualification

2. Put into **normal form**

– With SQL, the query qualification (WHERE clause) is the most difficult part as it might be an arbitrary complex predicate preceeded by quantifiers (9, 8)

– Conjunctive normal form

(p11 _ p12 _ · · · _ p1n) ^ · · · ^ (pm1 _ pm2 _ · · · _ pmn)

– Disjunctive normal form

(p11 ^ p12 ^ · · · ^ p1n) _ · · · _ (pm1 ^ pm2 ^ · · · ^ pmn)

– In the disjunctive normal form, the query can be processed as independent conjunctive subqueries linked by unions (corresponding to the disjunction)

Example: Consider the following query: *Find the names of employees who have been working on project P1 for 12 or 24 months?*

• The query in SQL:

SELECT ENAME
FROM EMP, ASG
WHERE EMP.ENO = ASG.ENO **AND**
ASG.PNO = ‘‘P1’’ **AND**
DUR = 12 **OR** DUR = 24

• The qualification in conjunctive normal form:

EMP.ENO = ASG.ENO ^ ASG.PNO = ”P1” ^ (DUR = 12 _ DUR = 24)

• The qualification in disjunctive normal form:

(EMP.ENO = ASG.ENO ^ ASG.PNO = ”P1” ^ DUR = 12) _
(EMP.ENO = ASG.ENO ^ ASG.PNO = ”P1” ^ DUR = 24)

Query Decomposition – Analysis

Analysis: Identify and reject type incorrect or semantically incorrect queries

• Type incorrect

– Checks whether the attributes and relation names of a query are defined in the global schema

– Checks whether the operations on attributes do not conflict with the types of the attributes, e.g., a comparison > operation with an attribute of type string

• Semantically incorrect

– Checks whether the components contribute in any way to the generation of the result

– Only a subset of relational calculus queries can be tested for correctness, i.e., those that do not contain disjunction and negation

– Typical data structures used to detect the semantically incorrect queries are:

—————————————— Connection graph (query graph)

—————————————— Join graph

Example: Consider a query:

SELECT ENAME,RESP

FROM EMP, ASG, PROJ

WHERE EMP.ENO = ASG.ENO

AND ASG.PNO = PROJ.PNO

AND PNAME = "CAD/CAM"

AND DUR 36

AND TITLE = "Programmer"

• Query/connection graph

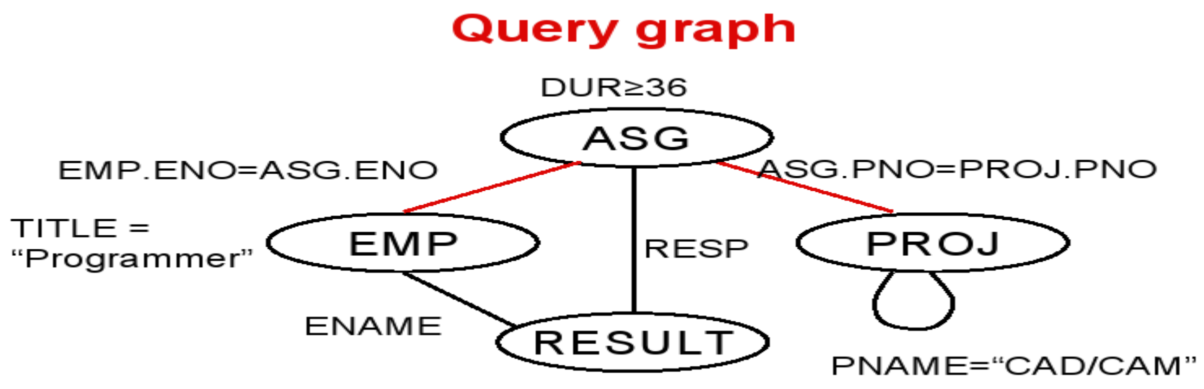
– Nodes represent operand or result relation

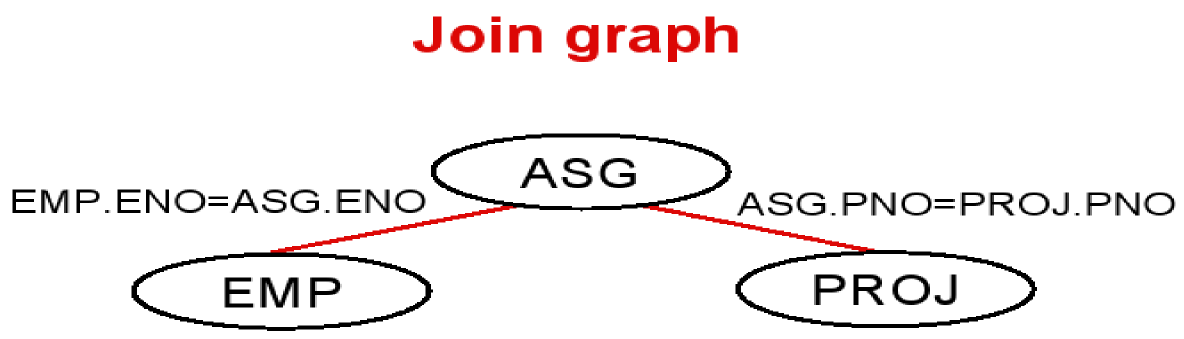
– Edge represents a join if both connected nodes represent an operand relation, otherwise it is a projection

• Join graph

– a subgraph of the query graph that considers only the joins

• Since the query graph is connected, the query is semantically correct





Example: Consider the following query and its query graph:

SELECT ENAME,RESP

FROM EMP, ASG, PROJ

WHERE EMP.ENO = ASG.ENO

AND PNAME = "CAD/CAM"

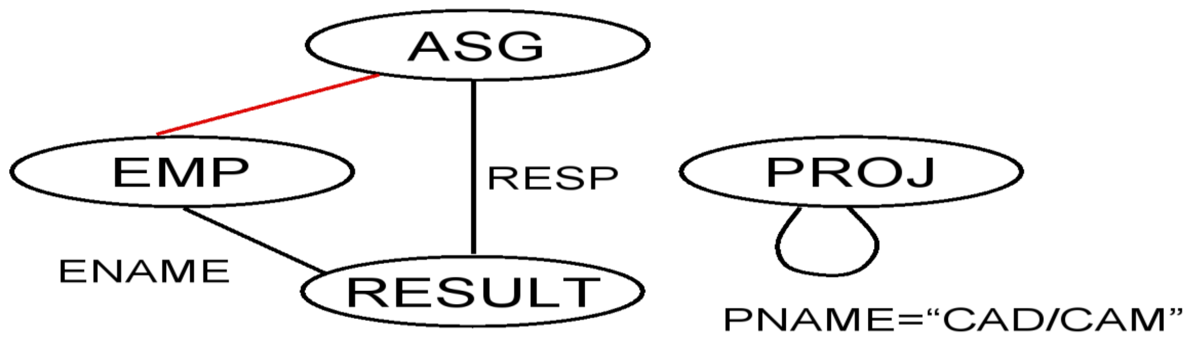
AND DUR _ 36

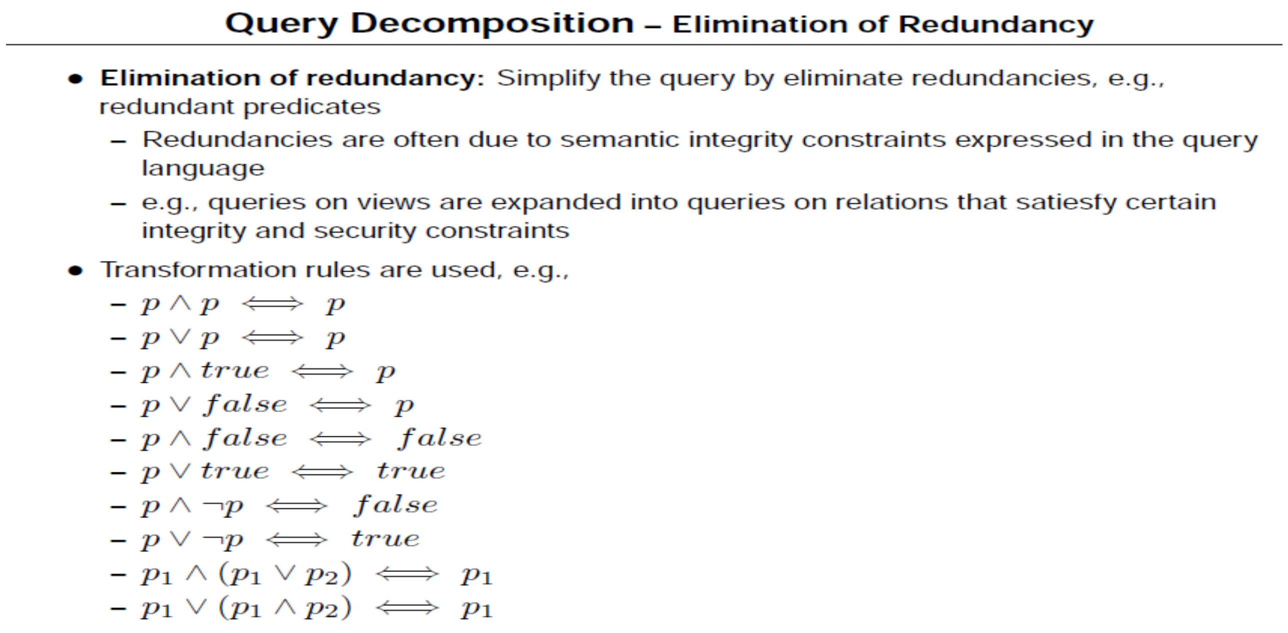
AND TITLE = "Programmer"

• Since the graph **is not connected**, the query is semantically incorrect.

• 3 possible solutions:

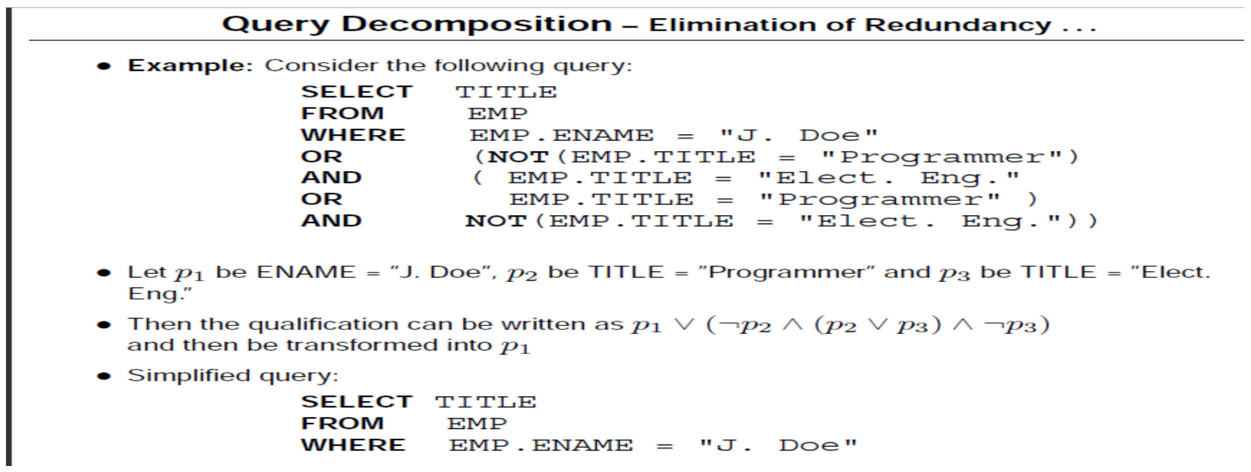
– Reject the query
– Assume an implicit Cartesian Product between ASG and PROJ
– Infer from the schema the missing join predicate ASG.PNO = PROJ.PNO





Query Decomposition – Elimination of Redundancy

- **Elimination of redundancy:** Simplify the query by eliminate redundancies, e.g., redundant predicates
  - Redundancies are often due to semantic integrity constraints expressed in the query language
  - e.g., queries on views are expanded into queries on relations that satiesfy certain integrity and security constraints
- Transformation rules are used, e.g.,
  - $p \wedge p \iff p$
  - $p \vee p \iff p$
  - $p \wedge true \iff p$
  - $p \vee false \iff p$
  - $p \wedge false \iff false$
  - $p \vee true \iff true$
  - $p \wedge \neg p \iff false$
  - $p \vee \neg p \iff true$
  - $p_1 \wedge (p_1 \vee p_2) \iff p_1$
  - $p_1 \vee (p_1 \wedge p_2) \iff p_1$



Query Decomposition – Elimination of Redundancy . . .

- **Example:** Consider the following query:

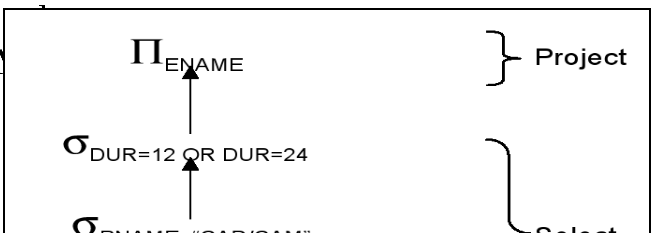
```
SELECT   TITLE
FROM      EMP
WHERE     EMP.ENAME = "J. Doe"
OR        (NOT(EMP.TITLE = "Programmer")
AND       ( EMP.TITLE = "Elect. Eng."
OR          EMP.TITLE = "Programmer" )
AND       NOT(EMP.TITLE = "Elect. Eng."))
```

- Let p_1 be ENAME = "J. Doe", p_2 be TITLE = "Programmer" and p_3 be TITLE = "Elect. Eng."
- Then the qualification can be written as $p_1 \vee (\neg p_2 \wedge (p_2 \vee p_3) \wedge \neg p_3)$ and then be transformed into p_1
- Simplified query:

```
SELECT  TITLE
FROM     EMP
WHERE    EMP.ENAME = "J. Doe"
```

Query Decomposition – Rewriting

Rewriting: Convert relational calculus query to relational algebra query and find an **efficient** expression.
• **Example:** Find the names of employees
than J. Doe who worked on the CAD/CA
project for either 1 or 2 years.
• **SELECT** ENAME
FROM EMP, ASG, PROJ

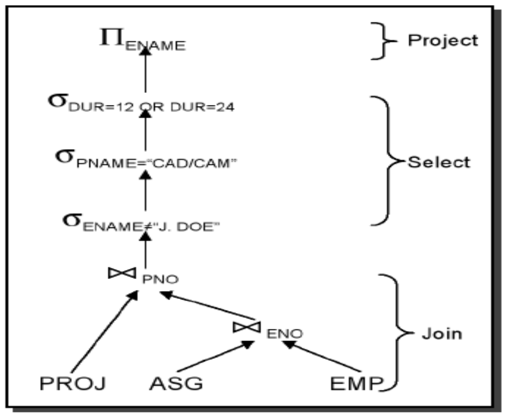


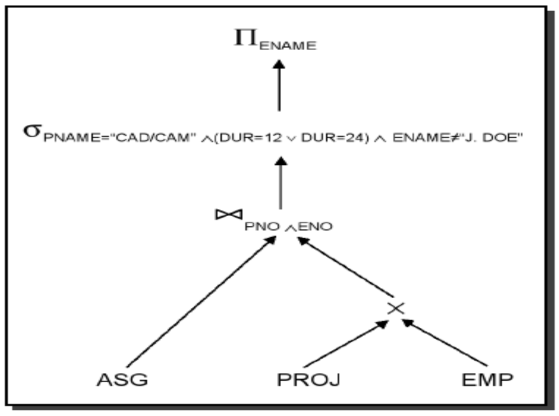
WHERE EMP.ENO = ASG.ENO
AND ASG.PNO = PROJ.PNO
AND ENAME 6= "J. Doe"
AND PNAME = "CAD/CAM"
AND (DUR = 12 **OR** DUR = 24)
• A **query tree** represents the RA-expression
– Relations are leaves (FROM clause)
– Result attributes are root (SELECT clause)
– Intermediate leaves should give a result
from the leaves to the root

- By applying **transformation rules**, many different trees/expressions may be found that are **equivalent** to the original tree/expression, but might be more efficient.
- In the following we assume relations $R(A_1, \ldots, A_n)$, $S(B_1, \ldots, B_n)$, and T which is union-compatible to R.
- **Commutativity** of binary operations
  - $R \times S = S \times R$
  - $R \bowtie S = S \bowtie R$
  - $R \cup S = S \cup R$
- **Associativity** of binary operations
  - $(R \times S) \times T = R \times (S \times T)$
  - $(R \bowtie S) \bowtie T = R \bowtie (S \bowtie T)$
- **Idempotence** of unary operations
  - $\Pi_A(\Pi_A(R)) = \Pi_A(R)$
  - $\sigma_{p1(A1)}(\sigma_{p2(A2)}(R)) = \sigma_{p1(A1) \wedge p2(A2)}(R)$

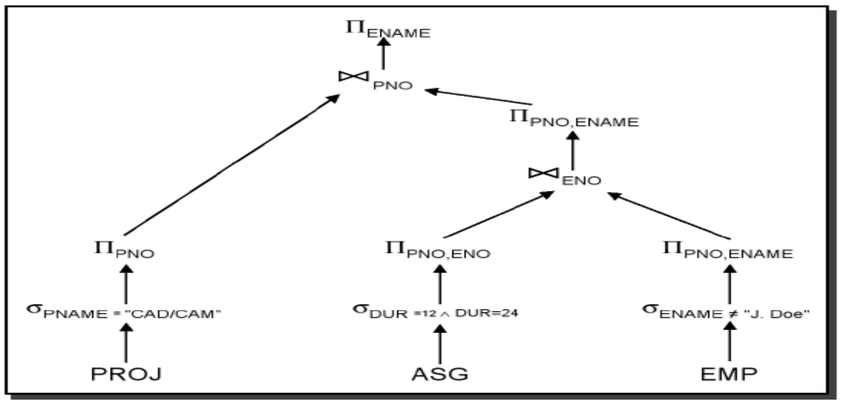
- **Commuting selection** with binary operations
  - $\sigma_{p(A)}(R \times S) \iff \sigma_{p(A)}(R) \times S$
  - $\sigma_{p(A_1)}(R \bowtie_{p(A_2,B_2)} S) \iff \sigma_{p(A_1)}(R) \bowtie_{p(A_2,B_2)} S$
  - $\sigma_{p(A)}(R \cup T) \iff \sigma_{p(A)}(R) \cup \sigma_{p(A)}(T)$
    - $*$ (A belongs to R and T)
- **Commuting projection** with binary operations (assume $C = A' \cup B'$, $A' \subseteq A$, $B' \subseteq B$)
  - $\Pi_C(R \times S) \iff \Pi_{A'}(R) \times \Pi_{B'}(S)$
  - $\Pi_C(R \bowtie_{p(A',B')} S) \iff \Pi_{A'}(R) \bowtie_{p(A',B')} \Pi_{B'}(S)$
  - $\Pi_C(R \cup S) \iff \Pi_C(R) \cup \Pi_C(S)$

- **Example:** Two equivalent query trees for the previous example
  - Recall the schemas: EMP(ENO, ENAME, TITLE)
    PROJ(PNO, PNAME, BUDGET)
    ASG(ENO, PNO, RESP, DUR)


Π_{ENAME}
Project
$\sigma_{DUR=12 \text{ OR } DUR=24}$
$\sigma_{PNAME=\text{"CAD/CAM"}}$
$\sigma_{ENAME \neq \text{"J. DOE"}}$
Select
$\bowtie_{PNO}$
$\bowtie_{ENO}$
Join
PROJ
ASG
EMP


Π_{ENAME}
$\sigma_{PNAME=\text{"CAD/CAM"} \wedge (DUR=12 \vee DUR=24) \wedge ENAME \neq \text{"J. DOE"}}$
$\bowtie_{PNO \wedge ENO}$
$\times$
ASG
PROJ
EMP

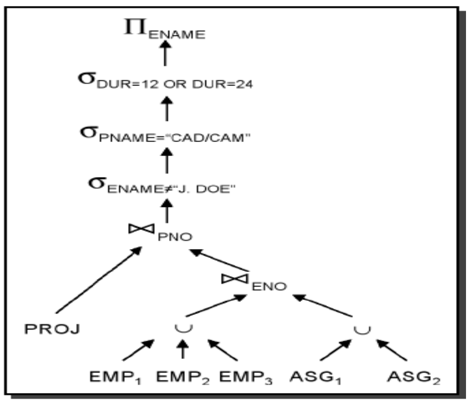
- **Example (contd.):** Another equivalent query tree, which allows a more efficient query evaluation, since the most selective operations are applied first.



Data Localization

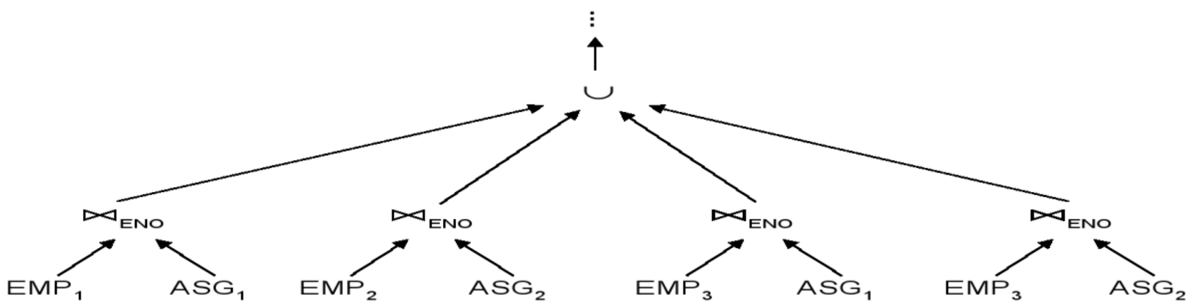
– Input: Algebraic query on global conceptual schema
– Purpose: Apply data distribution information to the algebra operations and determine which fragments are involved
_ Substitute global query with queries on fragments
_ Optimize the global query

- **Example:**
  - Assume EMP is horizontally fragmented into EMP1, EMP2, EMP3 as follows:
    - $EMP1 = \sigma_{ENO \leq "E3"}(EMP)$
    - $EMP2 = \sigma_{"E3" < ENO \leq "E6"}(EMP)$
    - $EMP3 = \sigma_{ENO > "E6"}(EMP)$
  - ASG fragmented into ASG1 and ASG2 as follows:
    - $ASG1 = \sigma_{ENO \leq "E3"}(ASG)$
    - $ASG2 = \sigma_{ENO > "E3"}(ASG)$
- Simple approach: Replace in all queries
  - EMP by (EMP1∪EMP2∪ EMP3)
  - ASG by (ASG1∪ASG2)
  - Result is also called **generic query**

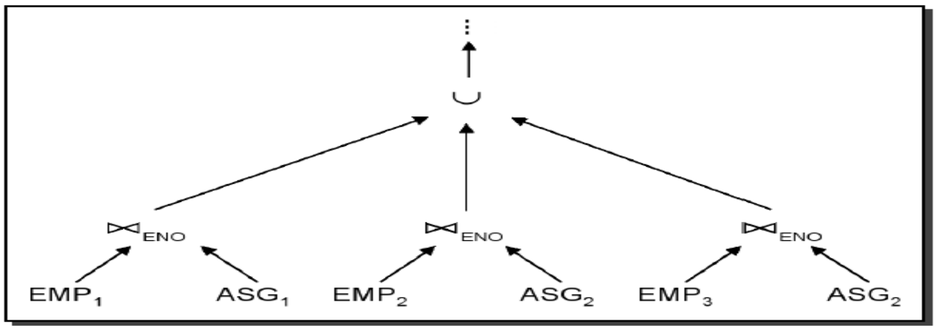

Π_{ENAME}
$\sigma_{DUR=12 \text{ OR } DUR=24}$
$\sigma_{PNAME="CAD/CAM"}$
$\sigma_{ENAME \neq "J. DOE"}$
$\bowtie_{PNO}$
$\bowtie_{ENO}$
PROJ
∪
∪
EMP_1 EMP_2 EMP_3 ASG_1 ASG_2

- In general, the **generic query is inefficient** since important restructurings and simplifications can be done.

Example (contd.): Parallelsim in the evaluation is often possible
– Depending on the horizontal fragmentation, the fragments can be joined in parallel followed by the union of the intermediate results.



- **Example (contd.)**: Unnecessary work can be eliminated
  - e.g., $EMP_3 \bowtie ASG_1$ gives an empty result
    - $EMP3 = \sigma_{ENO>"E6"}(EMP)$
    - $ASG1 = \sigma_{ENO\leq"E3"}(ASG)$



Data Localizations Issues

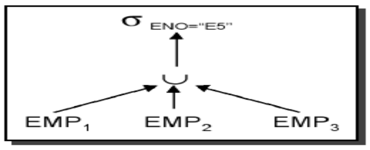
Various more advanced reduction techniques are possible to generate simpler and optimized queries.
• Reduction of horizontal fragmentation (HF)
– Reduction with selection
– Reduction with join
• Reduction of vertical fragmentation (VF)
– Find empty relations

Data Localizations Issues – Reduction of HF

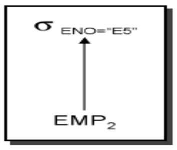
- **Reduction with selection for HF**
  - Consider relation R with horizontal fragmentation $F = \{R_1, R_2, \ldots, R_k\}$, where $R_i = \sigma_{p_i}(R)$
  - **Rule1**: Selections on fragments, $\sigma_{p_j}(R_i)$, that have a qualification contradicting the qualification of the fragmentation generate empty relations, i.e.,

$$\sigma_{p_j}(R_i) = \emptyset \iff \forall x \in R(p_i(x) \wedge p_j(x) = false)$$

  - Can be applied if fragmentation predicate is inconsistent with the query selection predicate.
- **Example**: Consider the query: **SELECT** * **FROM** EMP **WHERE** ENO="E5"



After commuting the selection with the union operation, it is easy to detect that the selection predicate contradicts the predicates of EMP$_1$ and EMP$_3$.

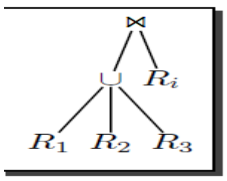


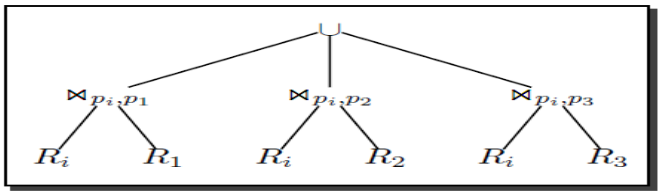
- **Reduction with join for HF**
  - Joins on horizontally fragmented relations can be simplified when the joined relations are fragmented according to the join attributes.
  - Distribute join over union

$$(R_1 \cup R_2) \bowtie S \iff (R_1 \bowtie S) \cup (R_2 \bowtie S)$$

  - **Rule 2**: Useless joins of fragments, $R_i = \sigma_{p_i}(R)$ and $R_j = \sigma_{p_j}(R)$, can be determined when the qualifications of the joined fragments are contradicting, i.e.,

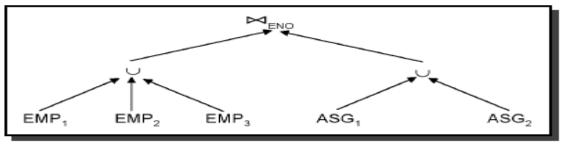
$$R_i \bowtie R_j = \emptyset \iff \forall x \in R_i, \forall y \in R_j(p_i(x) \wedge p_j(y) = false)$$



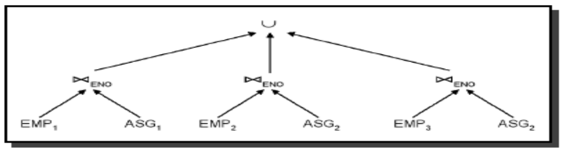


Data Localizations Issues – Reduction for HF ...

- **Example:** Consider the following query and fragmentation:
  - Query: **SELECT** * **FROM** EMP, ASG **WHERE** EMP.ENO=ASG.ENO
  - Horizontal fragmentation:
    - $EMP1 = \sigma_{ENO \leq "E3"}(EMP)$
    - $EMP2 = \sigma_{"E3" < ENO \leq "E6"}(EMP)$
    - $EMP3 = \sigma_{ENO > "E6"}(EMP)$
    - $ASG1 = \sigma_{ENO \leq "E3"}(ASG)$
    - $ASG2 = \sigma_{ENO > "E3"}(ASG)$
  - Generic query



  - The query reduced by distributing joins over unions and applying rule 2 can be implemented as a union of three partial joins that can be done in parallel.



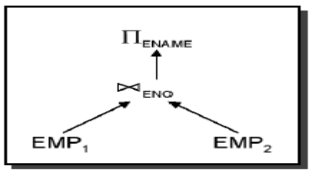
- **Reduction with join for derived HF**
  - The horizontal fragmentation of one relation is **derived** from the horizontal fragmentation of another relation by using semijoins.
- If the fragmentation is not on the same predicate as the join (as in the previous example), derived horizontal fragmentation can be applied in order to make efficient join processing possible.
- **Example:** Assume the following query and fragmentation of the EMP relation:
  - Query: **SELECT** * **FROM** EMP, ASG **WHERE** EMP.ENO=ASG.ENO
  - Fragmentation (**not** on the join attribute):
    - EMP1 = $\sigma_{\text{TITLE="Prgrammer"}}$(EMP)
    - EMP2 = $\sigma_{\text{TITLE}\neq\text{"Prgrammer"}}$(EMP)
  - To achieve efficient joins ASG can be fragmented as follows:
    - ASG1= ASG$\rhd\!\!<_{ENO}$EMP1
    - ASG2= ASG$\rhd\!\!<_{ENO}$EMP2
  - The fragmentation of ASG is derived from the fragmentation of EMP
  - Queries on derived fragments can be reduced, e.g., $ASG_1 \bowtie EMP_2 = \emptyset$

Data Localizations Issues – Reduction for VF

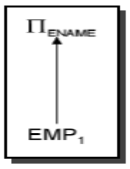
- **Reduction for Vertical Fragmentation**
  - Recall, VF distributes a relation based on projection, and the reconstruction operator is the join.
  - Similar to HF, it is possible to identify useless intermediate relations, i.e., fragments that do not contribute to the result.
  - Assume a relation $R(A)$ with $A = \{A_1, \dots, A_n\}$, which is vertically fragmented as $R_i = \pi_{A'_i}(R)$, where $A'_i \subseteq A$.
  - **Rule 3**: $\pi_{D,K}(R_i)$ is useless if the set of projection attributes D is not in A'_i and K is the key attribute.
  - Note that the result is not empty, but it is useless, as it contains only the key attribute.

Data Localizations Issues – Reduction for VF . . .

- **Example:** Consider the following query and vertical fragmentation:
  - Query: **SELECT** ENAME **FROM** EMP
  - Fragmentation:
    - $EMP1 = \Pi_{ENO,ENAME}(EMP)$
    - $EMP2 = \Pi_{ENO,TITLE}(EMP)$
- Generic query

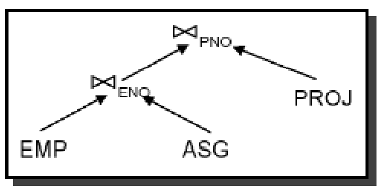


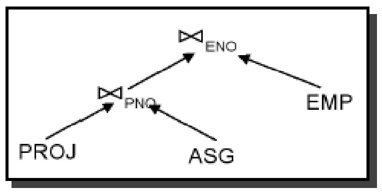
- Reduced query
  - By commuting the projection with the join (i.e., projecting on ENO, ENAME), we can see that the projection on EMP$_2$ is useless because ENAME is not in EMP$_2$.

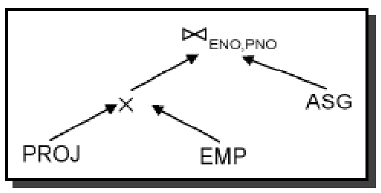


Distributed Query optimization methods.

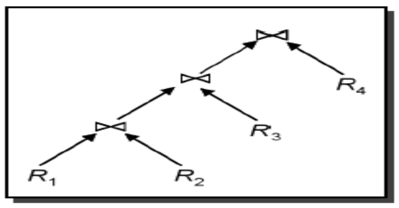
Query optimization: Process of producing an optimal (close to optimal) query execution plan which represents an execution strategy for the query
– The main task in query optimization is to consider different orderings of the operations
• Centralized query optimization:
– Find (the best) query execution plan in the space of equivalent query trees
– Minimize an objective cost function
– Gather statistics about relations
• Distributed query optimization brings additional issues
– Linear query trees are not necessarily a good choice
– Bushy query trees are not necessarily a bad choice
– What and where to ship the relations
– How to ship relations (ship as a whole, ship as needed)
– When to use semi-joins instead of joins
**Search space: The set of alternative query execution plans (query trees)
– Typically very large
– The main issue is to optimize the joins
– For N relations, there are O(N!) equivalent join trees that can be obtained by applying commutativity and associativity rules
• Example: 3 equivalent query trees (join trees) of the joins in the following query
SELECT ENAME,RESP
FROM EMP, ASG, PROJ
WHERE EMP.ENO=ASG.ENO AND ASG.PNO=PROJ.PNO



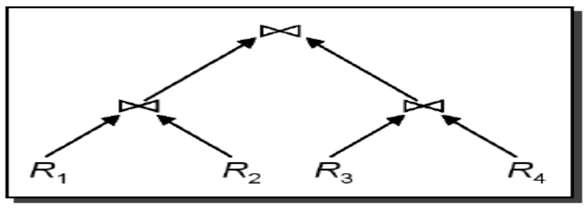




- **Reduction** of the search space
  - Restrict by means of heuristics
    - ∗ Perform unary operations before binary operations, etc
  - Restrict the shape of the join tree
    - ∗ Consider the type of trees (linear trees, vs. bushy ones)



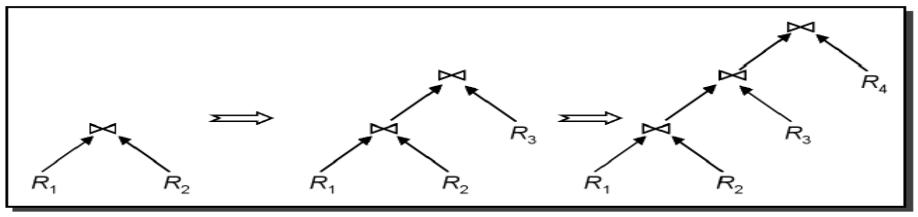
Linear Join Tree



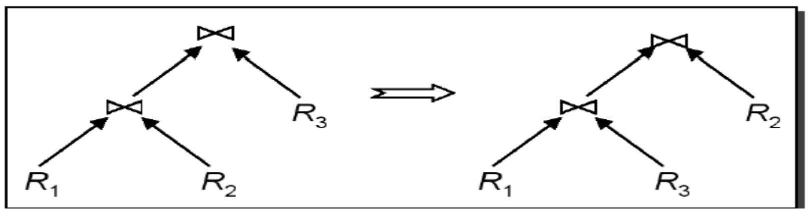
Bushy Join Tree

- There are two main strategies to **scan the search space**
  - Deterministic
  - Randomized

- **Deterministic scan** of the search space
  - Start from base relations and build plans by adding one relation at each step
  - Breadth-first strategy: build all possible plans before choosing the "best" plan (dynamic programming approach)
  - Depth-first strategy: build only one plan (greedy approach)



- **Randomized scan** of the search space
  - Search for optimal solutions around a particular starting point
  - e.g., iterative improvement or simulated annealing techniques
  - Trades optimization time for execution time
    - ∗ Does not guarantee that the best solution is obtained, but avoid the high cost of optimization
  - The strategy is better when more than 5-6 relations are involved

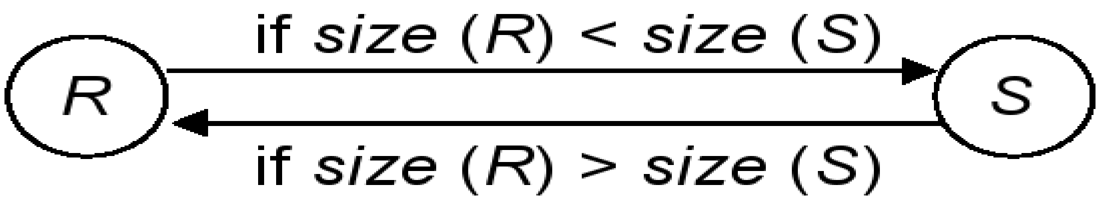


join ordering,

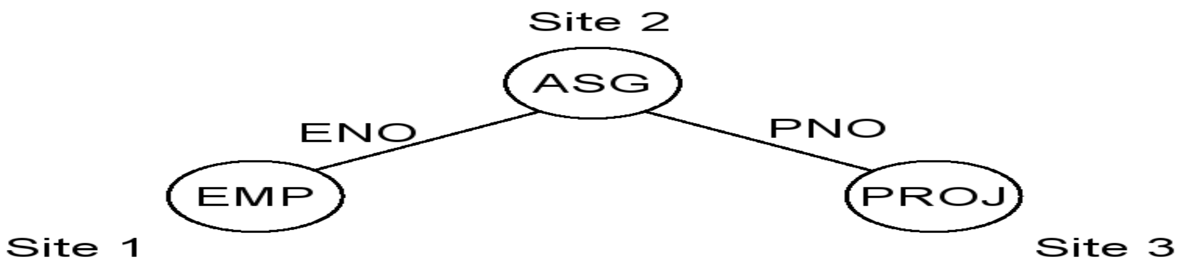
Join ordering is an important aspect in centralized DBMS, and it **is even more important in a DDBMS** since joins between fragments that are stored at different sites may increase the communication time.
• Two approaches exist:
***Optimize the ordering of joins directly
_ INGRES and distributed INGRES
_ System R and System R∗
* Replace joins by combinations of semijoins in order to minimize the communication

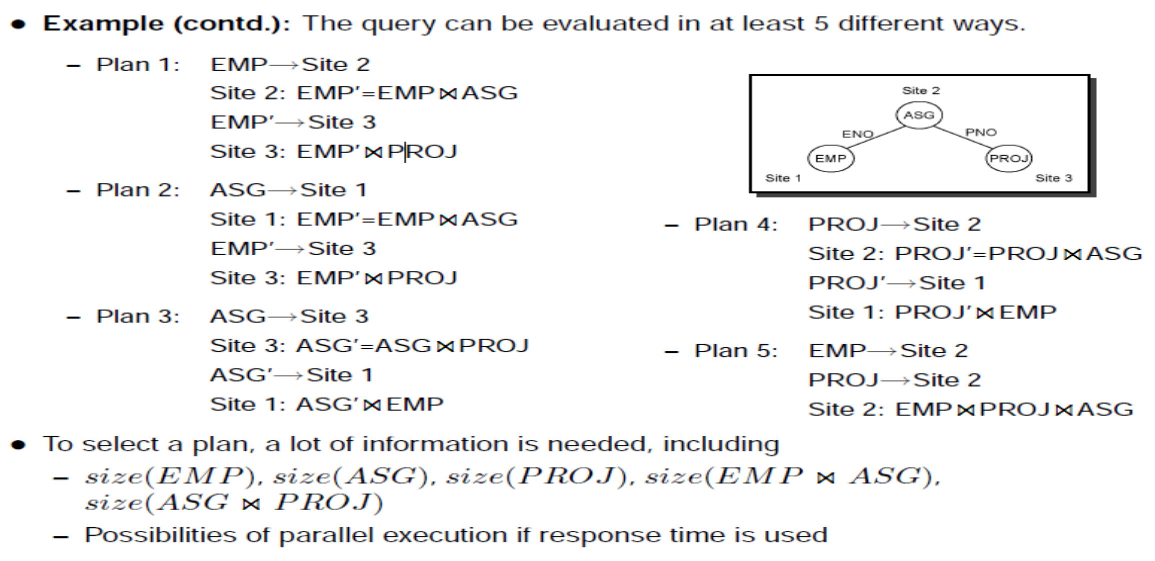
costs
_ Hill Climbing and SDD-1

Direct join odering of two relation/fragments located at different sites
– Move the smaller relation to the other site
– We have to estimate the size of R and S


if *size* (*R*) < *size* (*S*)
R
S
if *size* (*R*) > *size* (*S*)

Direct join ordering of queries involving more than two relations is substantially more complex
• **Example:** Consider the following query and the respective join graph, where we make also assumptions about the locations of the three relations/fragments
PROJ ⋊⋉PNO ASG ⋊⋉ENO EMP



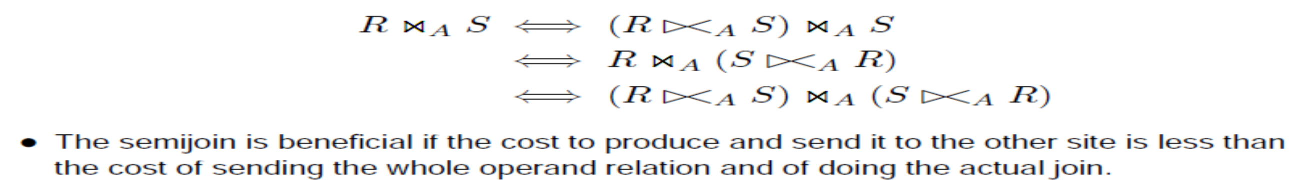


- **Example (contd.):** The query can be evaluated in at least 5 different ways.
  - Plan 1: EMP⟶Site 2
    Site 2: EMP'=EMP⋈ASG
    EMP'⟶Site 3
    Site 3: EMP'⋈PROJ
  - Plan 2: ASG⟶Site 1
    Site 1: EMP'=EMP⋈ASG
    EMP'⟶Site 3
    Site 3: EMP'⋈PROJ
  - Plan 3: ASG⟶Site 3
    Site 3: ASG'=ASG⋈PROJ
    ASG'⟶Site 1
    Site 1: ASG'⋈EMP
  - Plan 4: PROJ⟶Site 2
    Site 2: PROJ'=PROJ⋈ASG
    PROJ'⟶Site 1
    Site 1: PROJ'⋈EMP
  - Plan 5: EMP⟶Site 2
    PROJ⟶Site 2
    Site 2: EMP⋈PROJ⋈ASG
- To select a plan, a lot of information is needed, including
  - $size(EMP)$, $size(ASG)$, $size(PROJ)$, $size(EMP \bowtie ASG)$, $size(ASG \bowtie PROJ)$
  - Possibilities of parallel execution if response time is used

semi-join strategy,

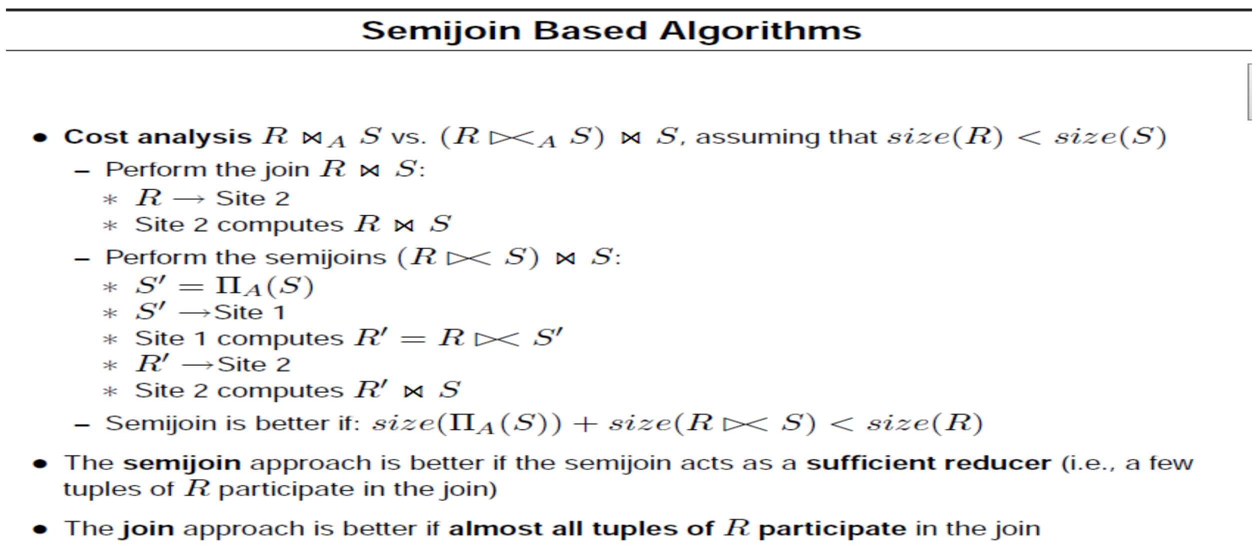
 Semijoins can be used to efficiently implement joins
– The semijoin acts as a size reducer (similar as to a selection) such that smaller relations need to be transferred
• Consider two relations: R located at site 1 and S located and site 2
– Solution with semijoins: Replace one or both operand relations/fragments by a

semijoin, using the following rules:



$$R \bowtie_A S \iff (R \rhd\!\!< _A S) \bowtie_A S$$
$$\iff R \bowtie_A (S \rhd\!\!<_A R)$$
$$\iff (R \rhd\!\!<_A S) \bowtie_A (S \rhd\!\!<_A R)$$

- The semijoin is beneficial if the cost to produce and send it to the other site is less than the cost of sending the whole operand relation and of doing the actual join.

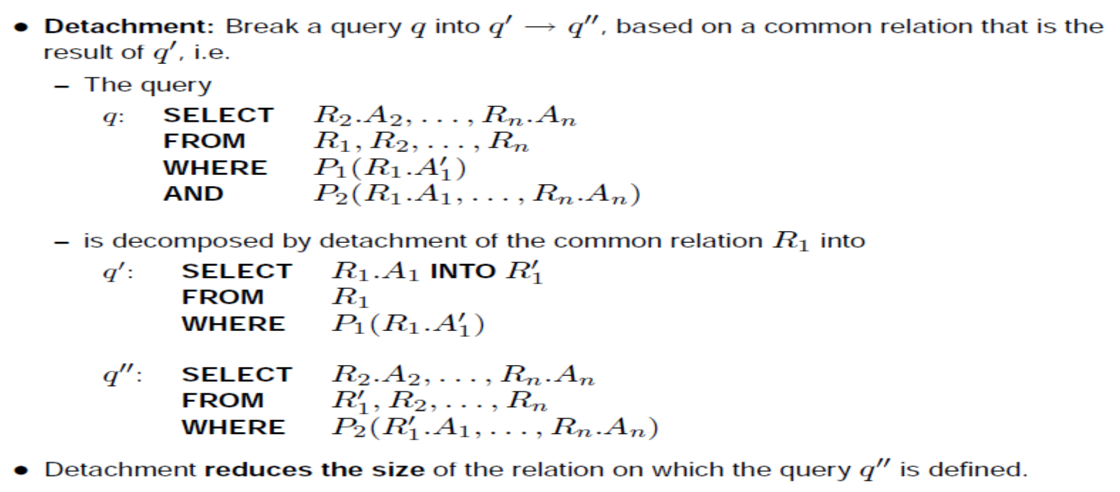


Semijoin Based Algorithms

- **Cost analysis** $R \bowtie_A S$ vs. $(R \rhd\!\!<_A S) \bowtie S$, assuming that $size(R) < size(S)$
  - Perform the join $R \bowtie S$:
    - * $R \longrightarrow$ Site 2
    - * Site 2 computes $R \bowtie S$
  - Perform the semijoins $(R \rhd\!\!< S) \bowtie S$:
    - * $S' = \Pi_A(S)$
    - * $S' \longrightarrow$Site 1
    - * Site 1 computes $R' = R \rhd\!\!< S'$
    - * $R' \longrightarrow$Site 2
    - * Site 2 computes $R' \bowtie S$
  - Semijoin is better if: $size(\Pi_A(S)) + size(R \rhd\!\!< S) < size(R)$
- The **semijoin** approach is better if the semijoin acts as a **sufficient reducer** (i.e., a few tuples of R participate in the join)
- The **join** approach is better if **almost all tuples of R participate** in the join

INGRES Algorithm

INGRES uses a dynamic query optimization algorithm that recursively breaks a query into smaller pieces. It is based on the following ideas:
– An n-relation query q is **decomposed** into n subqueries q1 →q2 → · · · → qn
_ Each qi is a mono-relation (mono-variable) query
_ The output of qi is consumed by qi+1
– For the decomposition two basic techniques are used: **detachment** and **substitution**
– There's a processor that can **efficiently** process mono-relation queries
_ Optimizes each query independently for the access to a single relation



- **Detachment:** Break a query q into $q' \longrightarrow q''$, based on a common relation that is the result of q', i.e.
  - The query

```
q:  SELECT  R2.A2, ..., Rn.An
    FROM    R1, R2, ..., Rn
    WHERE   P1(R1.A'1)
    AND     P2(R1.A1, ..., Rn.An)
```

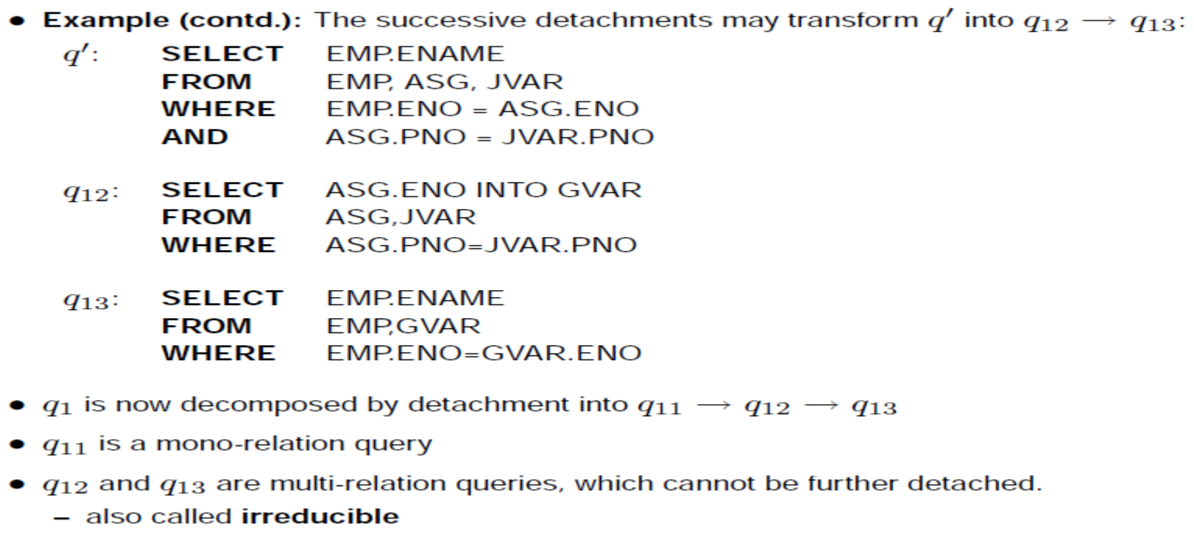
  - is decomposed by detachment of the common relation R_1 into

```
q':  SELECT  R1.A1 INTO R'1
     FROM    R1
     WHERE   P1(R1.A'1)

q'': SELECT  R2.A2, ..., Rn.An
     FROM    R'1, R2, ..., Rn
     WHERE   P2(R'1.A1, ..., Rn.An)
```

- Detachment **reduces the size** of the relation on which the query q'' is defined.

Example: Consider query q1: "Names of employees working on the CAD/CAM project"
q1: **SELECT** EMP.ENAME
FROM EMP, ASG, PROJ
WHERE EMP.ENO = ASG.ENO
AND ASG.PNO = PROJ.PNO

AND PROJ.PNAME = ”CAD/CAM”
• Decompose q1 into q11 → q′:
q11: **SELECT** PROJ.PNO INTO JVAR
FROM PROJ
WHERE PROJ.PNAME = ”CAD/CAM”
q′: **SELECT** EMP.ENAME
FROM EMP, ASG, JVAR
WHERE EMP.ENO = ASG.ENO
AND ASG.PNO = JVAR.PNO



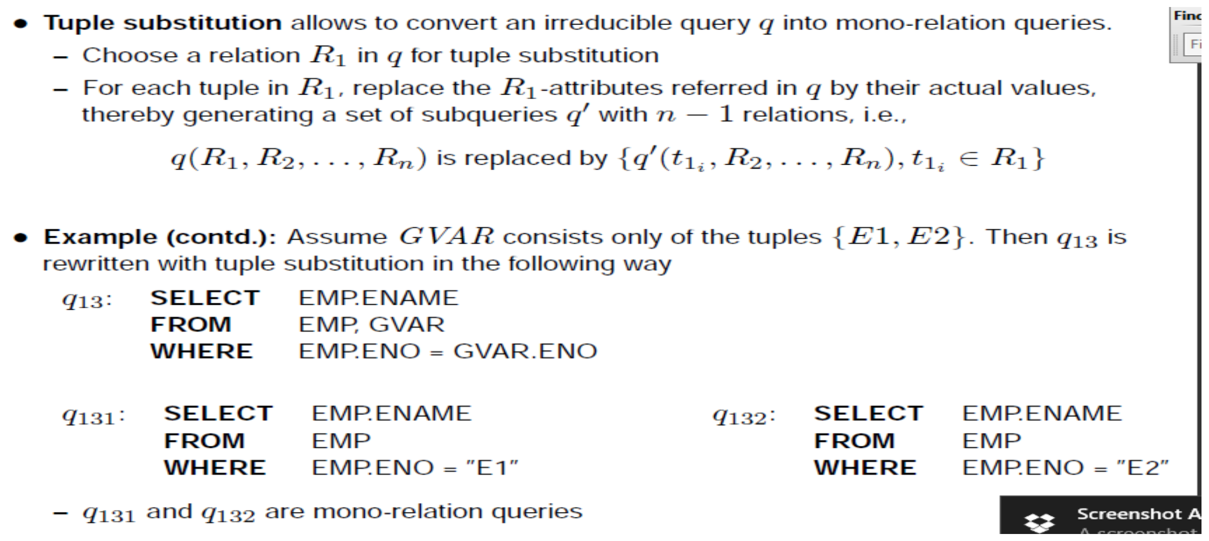
- **Example (contd.):** The successive detachments may transform q' into $q_{12} \longrightarrow q_{13}$:

q':
```
SELECT   EMP.ENAME
FROM     EMP, ASG, JVAR
WHERE    EMP.ENO = ASG.ENO
AND      ASG.PNO = JVAR.PNO
```

q_{12}:
```
SELECT   ASG.ENO INTO GVAR
FROM     ASG,JVAR
WHERE    ASG.PNO=JVAR.PNO
```

q_{13}:
```
SELECT   EMP.ENAME
FROM     EMP,GVAR
WHERE    EMP.ENO=GVAR.ENO
```

- q_1 is now decomposed by detachment into $q_{11} \longrightarrow q_{12} \longrightarrow q_{13}$
- q_{11} is a mono-relation query
- q_{12} and q_{13} are multi-relation queries, which cannot be further detached.
  - also called **irreducible**



- **Tuple substitution** allows to convert an irreducible query q into mono-relation queries.
  - Choose a relation R_1 in q for tuple substitution
  - For each tuple in R_1, replace the R_1-attributes referred in q by their actual values, thereby generating a set of subqueries q' with $n - 1$ relations, i.e.,

$$q(R_1, R_2, \dots, R_n) \text{ is replaced by } \{q'(t_{1_i}, R_2, \dots, R_n), t_{1_i} \in R_1\}$$

- **Example (contd.):** Assume $GVAR$ consists only of the tuples $\{E1, E2\}$. Then q_{13} is rewritten with tuple substitution in the following way

q_{13}:
```
SELECT   EMP.ENAME
FROM     EMP, GVAR
WHERE    EMP.ENO = GVAR.ENO
```

q_{131}:
```
SELECT   EMP.ENAME
FROM     EMP
WHERE    EMP.ENO = "E1"
```

q_{132}:
```
SELECT   EMP.ENAME
FROM     EMP
WHERE    EMP.ENO = "E2"
```

  - q_{131} and q_{132} are mono-relation queries

Distributed INGRES Algorithm

The **distributed INGRES query optimization algorithm** is very similar to the centralized INGRES algorithm.
– In addition to the centralized INGRES, the distributed one should break up each query qi into sub-queries that operate on fragments; only horizontal fragmentation is handled.
– Optimization with respect to a combination of communication cost and response time

System R Algorithm

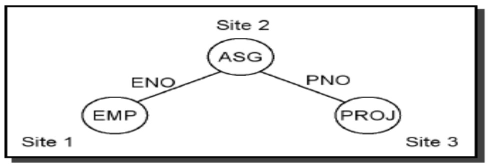
The System R (centralized) query optimization algorithm
– Performs static query optimization based on “exhaustive search” of the solution space

and a cost function (IO cost + CPU cost)
———————————— Input: relational algebra tree
———————————— Output: optimal relational algebra tree
———————————— Dynamic programming technique is applied to reduce the number of alternative
plans
– The optimization algorithm consists of two steps
1. Predict the best access method to each individual relation (mono-relation query)
———————————— Consider using index, file scan, etc.
2. For each relation R, estimate the best join ordering
———————————— R is first accessed using its best single-relation access method
———————————— Efficient access to inner relation is crucial
– Considers two different join strategies
———————————— (Indexed-) nested loop join
———————————— Sort-merge join

- **Example:** Consider query $q1$: "*Names of employees working on the CAD/CAM project*"

$$PROJ \ltimes_{PNO} ASG \ltimes_{ENO} EMP$$

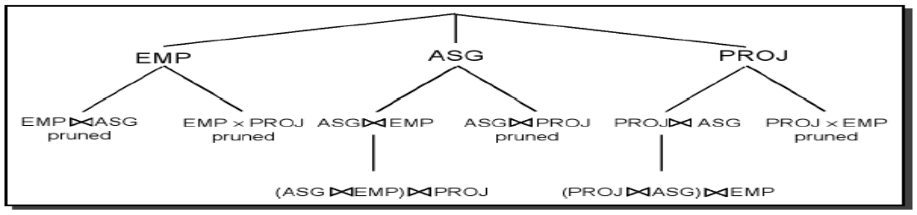
  – Join graph



  – Indexes
    * EMP has an index on ENO
    * ASG has an index on PNO
    * PROJ has an index on PNO and an index on PNAME

Example (contd.): Step 1 – Select the best single-relation access paths
– EMP: sequential scan (because there is no selection on EMP)
– ASG: sequential scan (because there is no selection on ASG)
– PROJ: index on PNAME (because there is a selection on PROJ based on PNAME)

- **Example (contd.):** Step 2 – Select the best join ordering for each relation



  – (EMP $\times$ PROJ) and (PROJ $\times$ EMP) are pruned because they are CPs
  – (ASG $\times$ PROJ) pruned because we assume it has higher cost than (PROJ $\times$ ASG); similar for (PROJ $\times$ EMP)
  – Best total join order ((PROJ$\ltimes$ ASG)$\ltimes$ EMP), since it uses the indexes best
    * Select PROJ using index on PNAME
    * Join with ASG using index on PNO
    * Join with EMP using index on ENO

Distributed System R* Algorithm

• The **System** R∗ **query optimization** algorithm is an extension of the System R query optimization algorithm with the following main characteristics:
– Only the whole relations can be distributed, i.e., fragmentation and replication is not considered

– Query compilation is a distributed task, coordinated by a **master site**, where the query is initiated
– Master site makes all inter-site decisions, e.g., selection of the execution sites, join ordering, method of data transfer, ...
– The **local sites** do the intra-site (local) optimizations, e.g., local joins, access paths
• Join ordering and data transfer between different sites are the most critical issues to be considered by the master site

Two methods for inter-site data transfer

– Ship whole: The entire relation is shipped to the join site and stored in a temporary relation

———————————— Larger data transfer
———————————— Smaller number of messages
———————————— Better if relations are small

– Fetch as needed: The external relation is sequentially scanned, and for each tuple the join value is sent to the site of the inner relation and the matching inner tuples are sent back (i.e., semijoin)

———————————— Number of messages = O(cardinality of outer relation)
———————————— Data transfer per message is minimal
———————————— Better if relations are large and the selectivity is good

Hill-Climbing Algorithm

Hill-Climbing query optimization algorithm
– Refinements of an initial feasible solution are recursively computed until no more cost improvements can be made
– Semijoins, data replication, and fragmentation are not used
– Devised for wide area point-to-point networks
– The first distributed query processing algorithm

The hill-climbing algorithm proceeds as follows
1. Select initial feasible execution strategy ES0
– i.e., a global execution schedule that includes all intersite communication
– Determine the candidate result sites, where a relation referenced in the query exist
– Compute the cost of transferring all the other referenced relations to each candidate site
– ES0 = candidate site with minimum cost
2. Split ES0 into two strategies: ES1 followed by ES2
– ES1: send one of the relations involved in the join to the other relation’s site
– ES2: send the join result to the final result site
3. Replace ES0 with the split schedule which gives
cost(ES1) + cost(local join) + cost(ES2) < cost(ES0)
4. Recursively apply steps 2 and 3 on ES1 and ES2 until no more benefit can be gained
5. Check for redundant transmissions in the final plan and eliminate them

- **Example:** *What are the salaries of engineers who work on the CAD/CAM project?*

  $\Pi_{SAL}(PAY \bowtie_{TITLE} EMP \bowtie_{ENO} (ASG \bowtie_{PNO} (\sigma_{PNAME=\text{"}CAD/CAM\text{"}}(PROJ))))$

  – Schemas: EMP(ENO, ENBAME, TITLE), ASG(ENO, PNO, RESP, DUR), PROJ(PNO, PNAME, BUDGET, LOC), PAY(TITLE, SAL)

  – Statistics

Relation	Size	Site
EMP	8	1
PAY	4	2
PROJ	1	3
ASG	10	4

  – Assumptions:
    - ∗ Size of relations is defined as their cardinality
    - ∗ Minimize total cost
    - ∗ Transmission cost between two sites is 1
    - ∗ Ignore local processing cost
    - ∗ size(EMP ⋈ PAY) = 8, size(PROJ ⋈ ASG) = 2, size(ASG ⋈ EMP) = 10

- **Example (contd.):** Determine initial feasible execution strategy
  – Alternative 1: Resulting site is site 1

$$\begin{aligned} Total\_cost &= cost(\text{PAY} \longrightarrow \text{Site1}) + cost(\text{ASG} \longrightarrow \text{Site1}) + cost(\text{PROJ} \longrightarrow \text{Site1}) \\ &= 4 + 10 + 1 = 15 \end{aligned}$$

  – Alternative 2: Resulting site is site 2

$$\text{Total cost} = 8 + 10 + 1 = 19$$

  – Alternative 3: Resulting site is site 3

$$\text{Total cost} = 8 + 4 + 10 = 22$$

  – Alternative 4: Resulting site is site 4

$$\text{Total cost} = 8 + 4 + 1 = 13$$

  – Therefore ES0 = EMP⟶Site4; PAY ⟶ Site4; PROJ ⟶ Site4

- **Example (contd.):** Candidate split

  – Alternative 1: ES1, ES2, ES3
    - ∗ ES1: EMP⟶Site 2
    - ∗ ES2: (EMP⋈PAY) ⟶ Site4
    - ∗ ES3: PROJ⟶Site 4

$$\begin{aligned} Total\_cost &= cost(\text{EMP} \longrightarrow \text{Site2}) + \\ &\quad cost((\text{EMP} \bowtie \text{PAY}) \longrightarrow \text{Site4}) + \\ &\quad cost(\text{PROJ} \longrightarrow \text{Site4}) \\ &= 8 + 8 + 1 = 17 \end{aligned}$$

  – Alternative 2: ES1, ES2, ES3
    - ∗ ES1: PAY ⟶ Site1
    - ∗ ES2: (PAY ⋈ EMP) ⟶ Site4
    - ∗ ES3: PROJ ⟶ Site 4

$$\begin{aligned} Total\_cost &= cost(\text{PAYSite} \longrightarrow 1) + \\ &\quad cost((\text{PAY} \bowtie \text{EMP}) \longrightarrow \text{Site4}) + \\ &\quad cost(\text{PROJ} \longrightarrow \text{Site4}) \\ &= 4 + 8 + 1 = 13 \end{aligned}$$

- Both alternatives are not better than ES0, so keep it (or take alternative 2 which has the same cost)

- **Problems**
  – Greedy algorithm determines an initial feasible solution and iteratively improves it
  – If there are local minima, it may not find the global minimum
  – An optimal schedule with a high initial cost would not be found, since it won't be chosen as the initial feasible solution

- **Example:** A better schedule is
  – PROJ⟶Site 4
  – ASG′ = (PROJ⋈ASG)⟶Site 1
  – (ASG′⋈EMP)⟶Site 2
  – Total cost= $1 + 2 + 2 = 5$

SDD-1

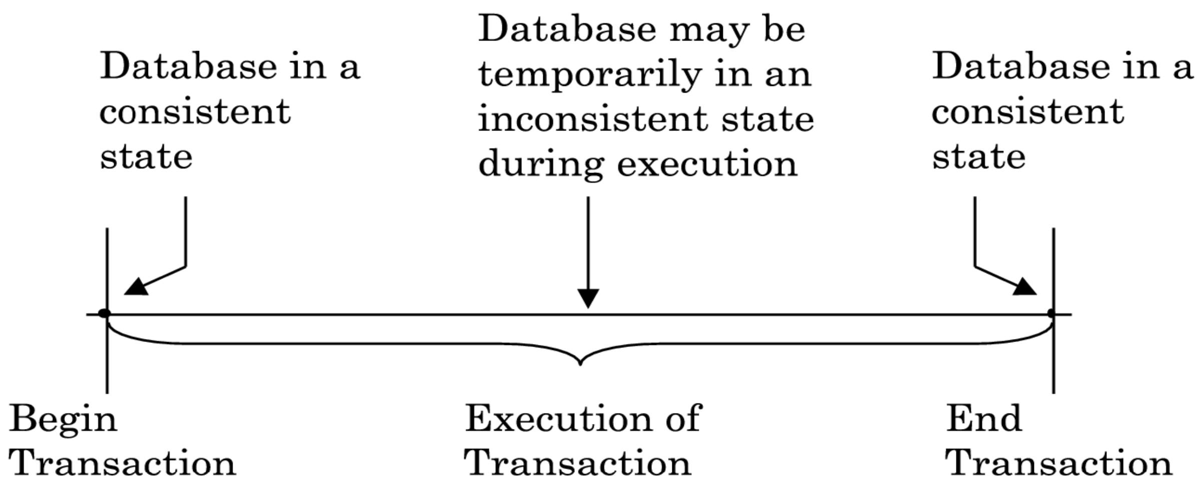
The **SDD-1 query optimization** algorithm improves the Hill-Climbing algorithm in a number of directions:
– Semijoins are considered
– More elaborate statistics

– Initial plan is selected better
– Post-optimization step is introduced

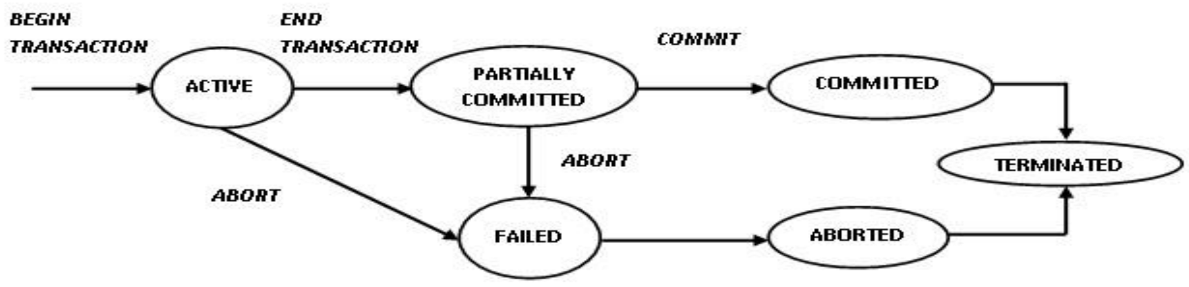
2.2 Distributed Transaction Management: The concept and role of transaction. Properties of transactions-Atomicity, Consistency, Isolation and Durability. Architectural aspects of Distributed Transaction, Transaction Serialization.

Distributed Transaction Management: The concept and role of transaction.

Transaction: A collection of actions that transforms the DB from one consistent state into another consistent state; during the exectuion the DB might be inconsistent.


Database in a consistent state
Database may be temporarily in an inconsistent state during execution
Database in a consistent state
Begin Transaction
Execution of Transaction
End Transaction

States of a transaction
– **Active**: Initial state and during the execution
– **Paritally committed**: After the final statement has been executed
– **Committed:** After successful completion
– **Failed:** After the discovery that normal execution can no longer proceed
– **Aborted:** After the transaction has been rolled back and the DB restored to its state prior to the start of the transaction. Restart it again or kill it.



Example: Consider an SQL query for increasing by 10% the budget of the CAD/CAM project. This query can be specified as a transaction by providing a name for the transaction and inserting a begin and end tag.
Transaction BUDGET_UPDATE
begin
EXEC SQL
UPDATE PROJ
SET BUDGET = BUDGET * 1.1

WHERE PNAME = "CAD/CAM"
end.

Example: Consider an airline DB with the following relations:
FLIGHT(FNO, DATE, SRC, DEST, STSOLD, CAP)
CUST(CNAME, ADDR, BAL)
FC(FNO, DATE, CNAME, SPECIAL)
• Consider the reservation of a ticket, where a travel agent enters the flight number, the date, and a customer name, and then asks for a reservation.

```
Begin transaction Reservation
begin
input(flight_no, date, customer_name);
EXEC SQL UPDATE FLIGHT
SET STSOLD = STSOLD + 1
WHERE FNO = flight_no AND DATE = date;
EXEC SQL INSERT
INTO FC(FNO, DATE, CNAME, SPECIAL);
VALUES (flight_no, date, customer_name, null);
output("reservation completed")
end.
```

Transactions are mainly characterized by its Read and Write operations
– Read set (RS): The data items that a transaction reads
– Write set (WS): The data items that a transaction writes
– Base set (BS): the union of the read set and write set

Formalization of a Transaction

We use the following notation:
– Ti be a transaction and x be a relation or a data item of a relation
– Oij ∈ {R(x),W(x)} be an atomic read/write operation of Ti on data item x
– OSi = Sj Oij be the set of all operations of Ti
– Ni ∈ {A,C} be the termination operation, i.e., abort/commit
• Two operations Oij(x) and Oik(x) on the same data item are in **conflict** if at least one of them is a write operation
• A **transaction** Ti is a **partial order** over its operations, i.e., Ti = {_i,≺i}, where
– _i = OSi ∪ Ni
– For any Oij = {R(x) ∨W(x)} and Oik = W(x), either Oij ≺i Oik or
Oik ≺i Oij
– ∀Oij ∈ OSi(Oij ≺i Ni)
• Remarks
– The partial order ≺ is given and is actually application dependent
– It has to specify the **execution order** between the conflicting operations and between all operations and the termination operation

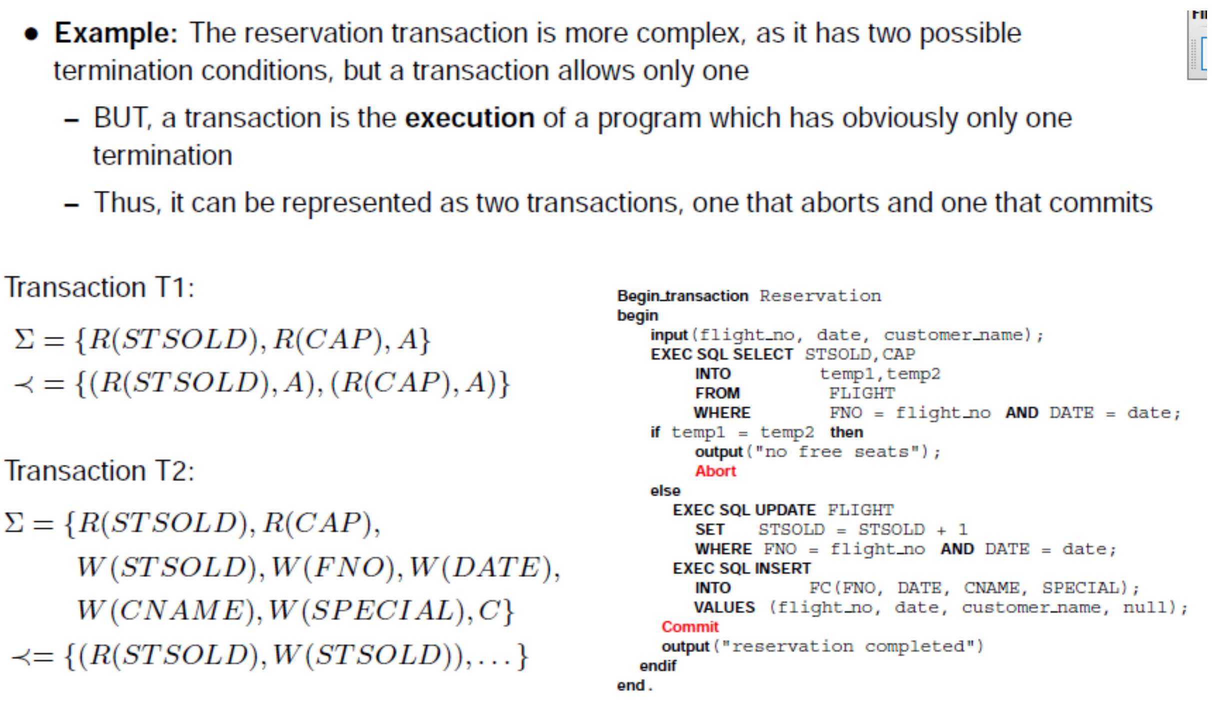
Example: Consider the following transaction T
Read(x)
Read(y)
x ← x + y

Write(x)
Commit
• The transaction is formally represented as
_ = {R(x),R(y),W(x),C}
≺ = {(R(x),W(x)), (R(y),W(x)), (W(x),C), (R(x),C), (R(y),C)}

Example (contd.): A transaction can also be specified/represented as a directed acyclic graph (DAG), where the vertices are the operations and the edges indicate the ordering.
– Assume
≺= {(R(x),W(x)), (R(y),W(x)), (W(x),C), (R(x),C), (R(y),C)}

– The DAG is

$$\begin{tikzcd}
R(x) \arrow[dr] & & \\
 & W(x) \arrow[r] & C \\
R(y) \arrow[ur] & &
\end{tikzcd}$$



- **Example:** The reservation transaction is more complex, as it has two possible termination conditions, but a transaction allows only one
  - BUT, a transaction is the **execution** of a program which has obviously only one termination
  - Thus, it can be represented as two transactions, one that aborts and one that commits

Transaction T1:

$$\Sigma = \{R(STSOLD), R(CAP), A\}$$
$$\prec = \{(R(STSOLD), A), (R(CAP), A)\}$$

Transaction T2:

$$\Sigma = \{R(STSOLD), R(CAP), W(STSOLD), W(FNO), W(DATE), W(CNAME), W(SPECIAL), C\}$$
$$\prec = \{(R(STSOLD), W(STSOLD)), \dots\}$$

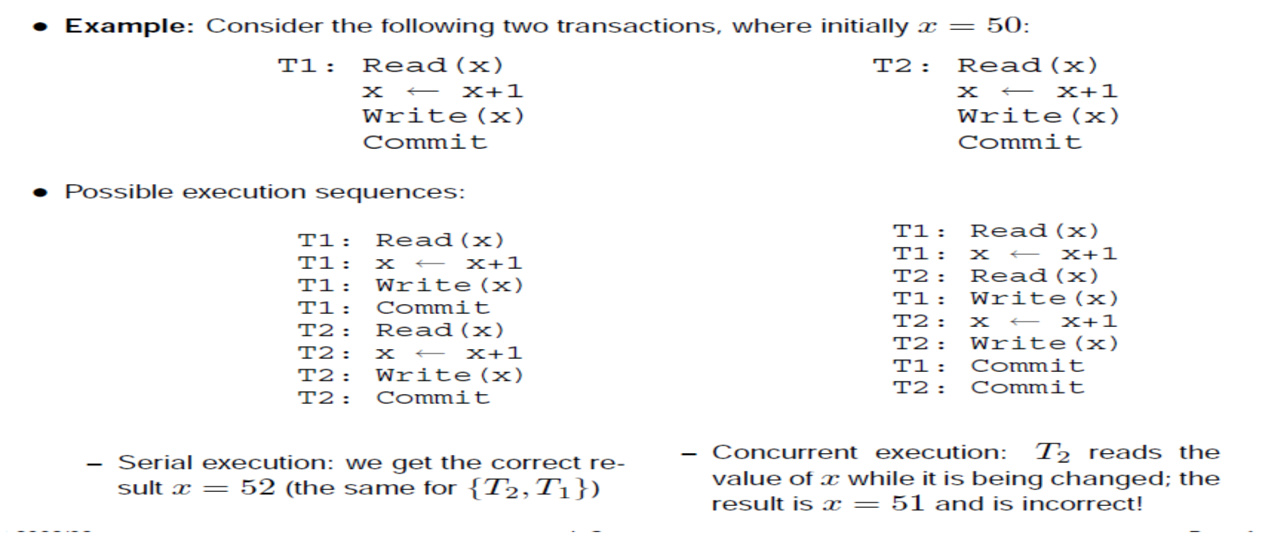
```
Begin_transaction Reservation
begin
    input(flight_no, date, customer_name);
    EXEC SQL SELECT STSOLD,CAP
         INTO        temp1,temp2
         FROM         FLIGHT
         WHERE        FNO = flight_no AND DATE = date;
    if temp1 = temp2 then
         output("no free seats");
         Abort
    else
       EXEC SQL UPDATE FLIGHT
         SET    STSOLD = STSOLD + 1
         WHERE FNO = flight_no AND DATE = date;
       EXEC SQL INSERT
         INTO        FC(FNO, DATE, CNAME, SPECIAL);
         VALUES (flight_no, date, customer_name, null);
      Commit
      output("reservation completed")
   endif
end.
```

Properties of transactions-Atomicity, Consistency, Isolation and Durability.

The **ACID properties**
– **Atomicity**
∗ A transaction is treated as a single/atomic unit of operation and is either executed completely or not at all
– **Consistency**
∗ A transaction preserves DB consistency, i.e., does not violate any integrity constraints
– **Isolation**
∗ A transaction is executed as if it would be the only one.

– **Durability**
∗ The updates of a committed transaction are permanent in the DB

 Atomicity
– Either **all or none** of the transaction's operations are performed
– Partial results of an interrupted transactions must be undone
– **Transaction recovery** is the activity of the restoration of atomicity due to input errors, system overloads, and deadlocks
– **Crash recovery** is the activity of ensuring atomicity in the presence of system Crashes
 Consistency
– The consistency of a transaction is simply its correctness and ensures that a transaction transforms a consistent DB into a consistent DB
– Transactions are **correct** programs and do not violate database integrity constraints
– **Dirty data** is data that is updated by a transaction that has not yet committed
– Different **levels of DB consistency** (by Gray et al., 1976)
∗ Degree 0
· Transaction T does not overwrite dirty data of other transactions
∗ Degree 1
· Degree 0 + T does not commit any writes before EOT
∗ Degree 2
· Degree 1 + T does not read dirty data from other transactions
∗ Degree 3
· Degree 2 + Other transactions do not dirty any data read by T before T Completes
 Isolation
– Isolation is the property of transactions which requires each transaction to see a consistent DB at all times.
– If two concurrent transactions access a data item that is being updated by one of them (i.e., performs a **write** operation), it is not possible to guarantee that the second will read the correct value
– Interconsistency of transactions is obviously achieved if transactions are executed serially
– Therefore, if several transactions are executed concurrently, the result must be the same as if they were executed serially in some order (→serializability)



- **Example:** Consider the following two transactions, where initially $x = 50$:

```
T1:  Read(x)                T2:  Read(x)
     x ← x+1                     x ← x+1
     Write(x)                    Write(x)
     Commit                      Commit
```

- Possible execution sequences:

```
T1:  Read(x)                T1:  Read(x)
T1:  x ← x+1                T1:  x ← x+1
T1:  Write(x)               T2:  Read(x)
T1:  Commit                 T1:  Write(x)
T2:  Read(x)                T2:  x ← x+1
T2:  x ← x+1                T2:  Write(x)
T2:  Write(x)               T1:  Commit
T2:  Commit                 T2:  Commit
```

– Serial execution: we get the correct result $x = 52$ (the same for $\{T_2, T_1\}$)

– Concurrent execution: T_2 reads the value of x while it is being changed; the result is $x = 51$ and is incorrect!

SQL-92 specifies 3 phenomena/situations that occur if proper isolation is not maintained
– Dirty read
∗ T1 modifies x which is then read by T2 before T1 terminates; if T1 aborts, T2 has read value which never exists in the DB:
– Non-repeatable (fuzzy) read
∗ T1 reads x; T2 then modifies or deletes x and commits; T1 tries to read x again but reads a different value or can't find it
– Phantom
∗ T1 searches the database according to a predicate P while T2 inserts new tuples that satisfy P

****Based on the 3 phenomena, SQL-92 specifies different isolation levels:
– Read uncommitted
∗ For transactions operating at this level, all three phenomena are possible
– Read committed
∗ Fuzzy reads and phantoms are possible, but dirty reads are not
– Repeatable read
∗ Only phantoms possible
– Anomaly serializable
∗ None of the phenomena are possible

• **Durability**
– Once a transaction commits, the system must guarantee that the results of its operations will never be lost, in spite of subsequent failures
– Database recovery is used to achieve the task

Classification of Transactions

Classification of transactions according to various criteria
– **Duration** of transaction
∗ On-line (short-life)
∗ Batch (long-life)
– **Organization** of **read** and **write** instructions in transaction
∗ General model
T1 : {R(x),R(y),W(y),R(z),W(x),W(z),W(w),C}

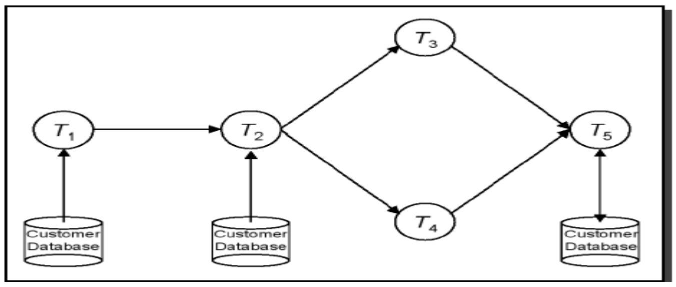
∗ Two-step (all reads before writes)
T2 : {R(x),R(y),R(z),W(x),W(z),W(y),W(w),C}
∗ Restricted (a data item has to be read before an update)
T3 : {R(x),R(y),W(y),R(z),W(x),W(z),R(w),W(w),C}
∗ Action model: each (read,write) pair is executed atomically
T2 : {[R(x),W(x)], [R(y),W(y)], [R(z),W(z)], [R(w),W(w)],C}

Classification of transactions according to various criteria . . .
– **Structure** of transaction
∗ **Flat** transaction
· Consists of a sequence of primitive operations between a begin and end marker
Begin transaction Reservation
...
end.
∗ **Nested** transaction
· The operations of a transaction may themselves be transactions.
Begin transaction Reservation
...
Begin transaction Airline
...
end.
Begin transaction Hotel
...
end.
end.
∗ **Workflows** ()

• **Workflows:** A collection of tasks organized to accomplish a given business process
– Workflows generalize transactions and are more expressive to model complex business processes
– Types of workflows:
∗ Human-oriented workflows
· Involve humans in performing the tasks.
· System support for collaboration and coordination; but no system-wide consistency definition
∗ System-oriented workflows
· Computation-intensive and specialized tasks that can be executed by a computer
· System support for concurrency control and recovery, automatic task execution, notification, etc.
∗ Transactional workflows
· In between the previous two; may involve humans, require access to heterogeneous, autonomous and/or distributed systems, and support selective use of ACID properties

- **Example:** We extend the reservation example and show a typical workflow

- $T1$: Customer request
- $T2$: Airline reservation
- $T3$: Hotel reservation
- $T4$: Auto reservation
- $T5$: Bill



Transaction Processing Issues

• Transaction structure (usually called transaction model)
– Flat (simple), nested
• Internal database consistency
– Semantic data control (integrity enforcement) algorithms
• Reliability protocols
– Atomicity and Durability
– Local recovery protocols
– Global commit protocols
• Concurrency control algorithms
– How to synchronize concurrent transaction executions (correctness criterion)
– Intra-transaction consistency, isolation
• Replica control protocols
– How to control the mutual consistency of replicated data

Architectural aspects of Distributed Transaction,

1. Begin transaction. This is an indicator to the TM that a new transaction is starting. The TM does some bookkeeping, such as recording the transaction's name, the originating application, and so on, in coordination with the data processor.
2. Read. If the data item to be read is stored locally, its value is read and returned to the transaction. Otherwise, the TM finds where the data item is stored and requests its value to be returned (after appropriate concurrency control measures are taken).
3. Write. If the data item is stored locally, its value is updated (in coordination with the data processor). Otherwise, the TM finds where the data item is located and requests the update to be carried out at that site after appropriate concurrency control measures are taken).
4. Commit. The TM coordinates the sites involved in updating data items on behalf of this transaction so that the updates are made permanent at every site.
5. Abort. The TM makes sure that no effects of the transaction are reflected in any of the databases at the sites where it updated data items.

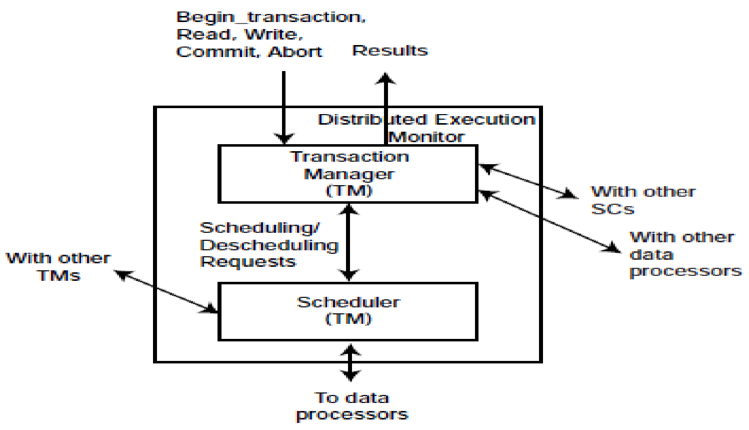


Fig. 10.5 Detailed Model of the Distributed Execution Monitor

Transaction Serialization.

2.3 Distributed Concurrency Control: Lock-based and Timestamp-based Concurrency Control methods. Optimistic method for Concurrency Control. Deadlock management- prevention, avoidance detection, and resolution. Non-serializable schedule and nested distributed transaction.

Concurrency control is the problem of synchronizing concurrent transactions (i.e., order the operations of concurrent transactions) such that the following two properties are achieved:
– the consistency of the DB is maintained
– the maximum degree of concurrency of operations is achieved
• Obviously, the serial execution of a set of transaction achieves consistency, if each single transaction is consistent

Conflicting operations: Two operations Oij(x) and Okl(x) of transactions Ti and Tk are in **conflict** iff at least one of the operations is a write, i.e.,
– Oij = read(x) and Okl = write(x)
– Oij = write(x) and Okl = read(x)
– Oij = write(x) and Okl = write(x)
• Intuitively, a conflict between two operations indicates that their order of execution is important.
• Read operations do not conflict with each other, hence the ordering of read operations does not matter.
• **Example:** Consider the following two transactions

T1: Read(x)	T2: Read(x)
$x \leftarrow x + 1$	$x \leftarrow x + 1$
Write(x)	Write(x)
Commit	Commit

– To preserve DB consistency, it is important that the read(x) of one transaction is not between read(x) and write(x) of the other transaction.

Schedules:

- A **schedule** (history) specifies a possibly interleaved order of execution of the operations O of a set of transactions $T = \{T_1, T_2, \ldots, T_n\}$, where T_i is specified by a partial order $(\Sigma_i, \prec_i)$. A schedule can be specified as a partial order over O, where
  - $\Sigma_T = \bigcup_{i=1}^{n} \Sigma_i$
  - $\prec_T \supseteq \bigcup_{i=1}^{n} \prec_i$
  - For any two conflicting operations $O_{ij}, O_{kl} \in \Sigma_T$, either $O_{ij} \prec_T O_{kl}$ or $O_{kl} \prec_T O_{ij}$

- A schedule is **serial** if all transactions in T are executed serially.
- **Example:** Consider the following two transactions

T_1:	$Read(x)$	T_2:	$Read(x)$
	$x \leftarrow x + 1$		$x \leftarrow x + 1$
	$Write(x)$		$Write(x)$
	$Commit$		$Commit$

  - The two serial schedules are $S_1 = \{\Sigma_1, \prec_1\}$ and $S_2 = \{\Sigma_2, \prec_2\}$, where

$$\begin{aligned}
\Sigma_1 = \Sigma_2 &= \{R_1(x), W_1(x), C_1, R_2(x), W_2(x), C_2\} \\
\prec_1 &= \{(R_1, W_1), (R_1, C_1), (W_1, C_1), (R_2, W_2), (R_2, C_2), (W_2, C_2), \\
&\quad (C_1, R_2), \ldots\} \\
\prec_2 &= \{(R_1, W_1), (R_1, C_1), (W_1, C_1), (R_2, W_2), (R_2, C_2), (W_2, C_2), \\
&\quad (C_2, R_1), \ldots\}
\end{aligned}$$

- We will also use the following notation:
  - $\{T_1, T_2\} = \{R_1(x), W_1(x), C_1, R_2(x), W_2(x), C_2\}$
  - $\{T_2, T_1\} = \{R_2(x), W_2(x), C_2, R_1(x), W_1(x), C_1\}$

Serializability:

• Two schedules are said to be **equivalent** if they have the same effect on the DB.
• **Conflict equivalence:** Two schedules S1 and S2 defined over the same set of transactions T = {T1, T2, . . . , Tn} are said to be **conflict equivalent** if for each pair of conflicting operations Oij and Okl, whenever Oij <1 Okl then Oij <2 Okl.
– i.e., conflicting operations must be executed in the same order in both transactions.
• A concurrent schedule is said to be **(conflict-)serializable** iff it is conflict equivalent to a serial schedule
• A conflict-serializable schedule can be transformed into a serial schedule by swapping non-conflicting operations
• **Example:** Consider the following two schedules

T1: Read(x)
x ← x + 1
Write(x)
Write(z)
Commit

T2: Read(x)
x ← x + 1
Write(x)
Commit

– The schedule {R1(x),W1(x),R2(x),W2(x),W1(z),C2,C1} is conflict-equivalent to {T1, T2} but not to {T2, T1}

• The **primary function** of a concurrency controller is to generate a serializable schedule for the execution of pending transactions.
• In a DDBMS two schedules must be considered
– Local schedule
– Global schedule (i.e., the union of the local schedules)
• **Serializability** in DDBMS
– Extends in a straightforward manner to a DDBMS if data is *not replicated*
– Requires more care if data is *replicated*: It is possible that the local schedules are serializable, but the mutual consistency of the DB is not guaranteed.

∗ Mutual consistency: All the values of all replicated data items are identical
• Therefore, a **serializable global schedule** must meet the following conditions:
– Local schedules are serializable
– Two conflicting operations should be in the same relative order in all of the local schedules they appear
∗ Transaction needs to be run on each site with the replicated data item

• **Example:** Consider two sites and a data item x which is replicated at both sites.

T1: Read(x)
$x \leftarrow x + 5$
Write(x)

T2: Read(x)
$x \leftarrow x * 10$
Write(x)

– Both transactions need to run on both sites
– The following two schedules might have been produced at both sites (the order is implicitly given):
∗ Site1: S1 = {R1(x),W1(x),R2(x),W2(x)}
∗ Site2: S2 = {R2(x),W2(x),R1(x),W1(x)}
– Both schedules are (trivially) serializable, thus are correct in the local context
– But they produce different results, thus violate the mutual consistency

Distributed Concurrency Control: Lock-based and Timestamp-based Concurrency Control methods.

Concurrency Control Algorithms:

• **Taxonomy** of concurrency control algorithms
– **Pessimistic** methods assume that many transactions will conflict, thus the concurrent execution of transactions is synchronized early in their execution life cycle
∗ Two-Phase Locking (2PL)
· Centralized (primary site) 2PL
· Primary copy 2PL
· Distributed 2PL
∗ Timestamp Ordering (TO)
· Basic TO
· Multiversion TO
· Conservative TO
∗ Hybrid algorithms
– **Optimistic** methods assume that not too many transactions will conflict, thus delay the synchronization of transactions until their termination
∗ Locking-based
∗ Timestamp ordering-based

Locking Based Algorithms:

• **Locking-based concurrency algorithms** ensure that data items shared by conflicting operations are accessed in a mutually exclusive way. This is accomplished by associating a “lock” with each such data item.
• Two types of **locks** (lock modes)
– **read lock** (rl) – also called **shared** lock
– **write lock** (wl) – also called **exclusive** lock

• **Compatibility matrix** of locks

	$rl_i(x)$	$wl_i(x)$
$rl_j(x)$	compatible	not compatible
$wl_j(x)$	not compatible	not compatible

• General locking algorithm
1. Before using a data item x, transaction requests lock for x from the lock manager
2. If x is already locked and the existing lock is incompatible with the requested lock, the transaction is delayed
3. Otherwise, the lock is granted

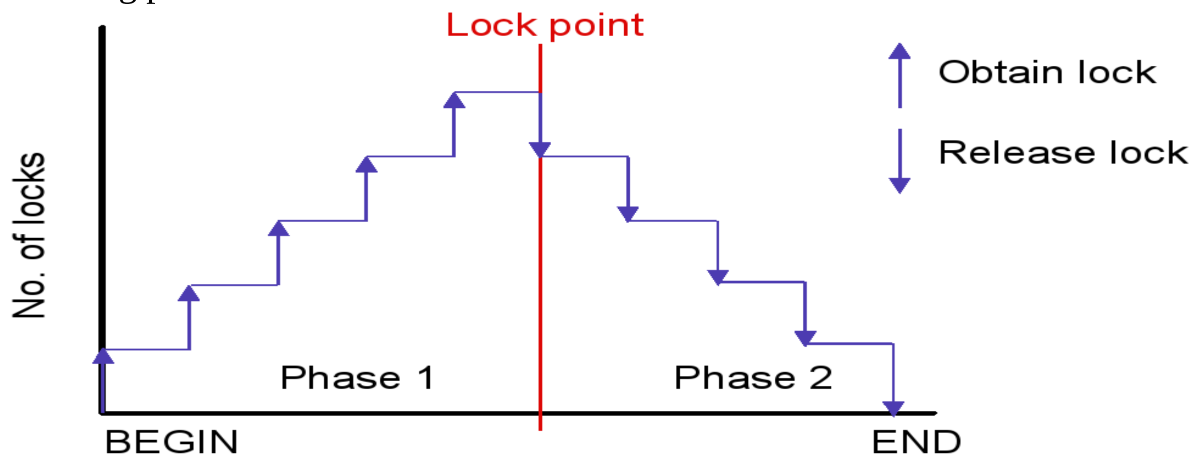
• **Example:** Consider the following two transactions

T1: Read(x)	T2: Read(x)
x ← x + 1	x ← x ∗ 2
Write(x)	Write(x)
Read(y)	Read(y)
y ← y – 1	y ← y ∗ 2
Write(y)	Write(y)

– The following schedule is a valid locking-based schedule (lri(x) indicates the release of a lock on x):
S = {wl1(x),R1(x),W1(x), lr1(x)
wl2(x),R2(x),W2(x), lr2(x)
wl2(y),R2(y),W2(y), lr2(y)
wl1(y),R1(y),W1(y), lr1(y)}
– However, S is not serializable
∗ S cannot be transformed into a serial schedule by using only non-conflicting swaps
∗ The result is different from the result of any serial execution

Two-Phase Locking (2PL):

• **Two-phase locking** protocol
– Each transaction is executed in two phases
∗ **Growing phase:** the transaction obtains locks
∗ **Shrinking phase:** the transaction releases locks
– The **lock point** is the moment when transitioning from the growing phase to the shrinking phase



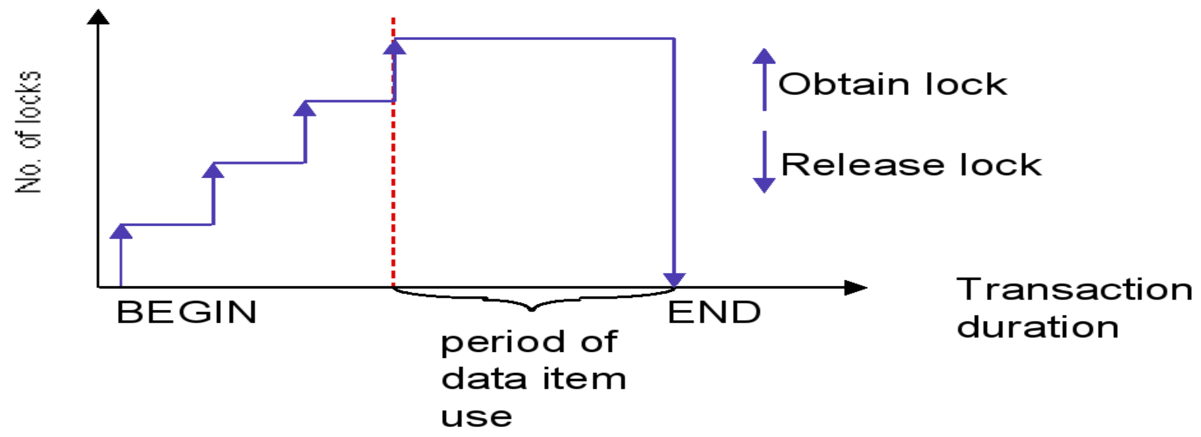
• **Properties** of the 2PL protocol
– Generates **conflict-serializable** schedules

– But schedules may cause **cascading aborts**

* If a transaction aborts after it releases a lock, it may cause other transactions that
have accessed the unlocked data item to abort as well

• **Strict 2PL locking** protocol

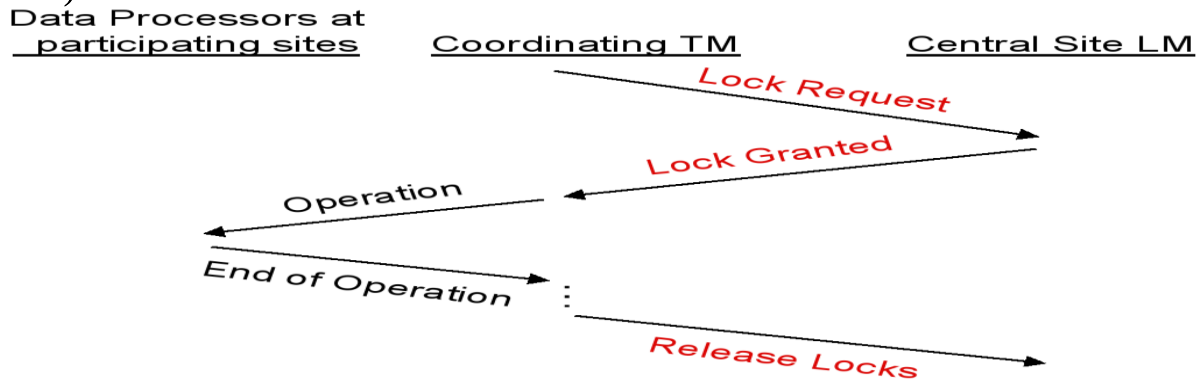
– Holds the locks till the end of the transaction
– Cascading aborts are avoided



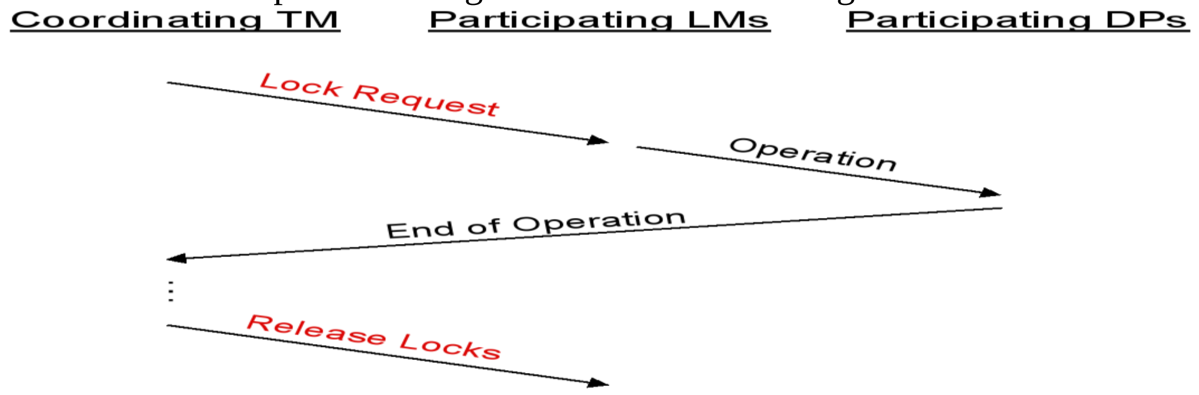
• **Example:** The schedule S of the previous example is not valid in the 2PL protocol:
S = {wl1(x),R1(x),W1(x), lr1(x)
wl2(x),R2(x),W2(x), lr2(x)
wl2(y),R2(y),W2(y), lr2(y)
wl1(y),R1(y),W1(y), lr1(y)}
– e.g., after lr1(x) (in line 1) transaction T1 cannot request the lock wl1(y) (in line 4).
– Valid schedule in the 2PL protocol
S = {wl1(x),R1(x),W1(x),
wl1(y),R1(y),W1(y), lr1(x), lr1(y)
wl2(x),R2(x),W2(x),
wl2(y),R2(y),W2(y), lr2(x), lr2(y)}

2PL for DDBMS:
• Various extensions of the 2PL to DDBMS
• **Centralized 2PL**
– A single site is responsible for the lock management, i.e., one lock manager for the whole DDBMS
– Lock requests are issued to the lock manager
– Coordinating transaction manager (TM at site where the transaction is initiated) can make all locking requests on behalf of local transaction managers
• Advantage: Easy to implement
• Disadvantages: Bottlenecks
and lower reliability
• Replica control protocol is additionally
needed if data are replicated

(see also primary copy
2PL)



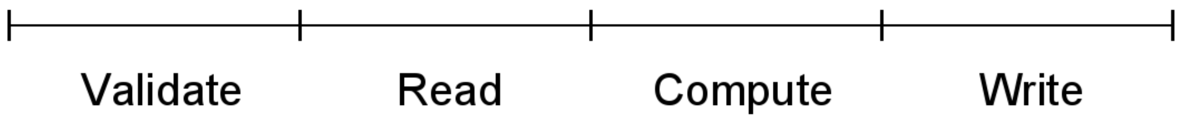
• **Primary copy 2PL**
– Several lock managers are distributed to a number of sites
– Each lock manager is responsible for managing the locks for a set of data items
– For replicated data items, one copy is chosen as primary copy, others are slave copies
– Only the primary copy of a data item that is updated needs to be write-locked
– Once primary copy has been updated, the change is propagated to the slaves
• Advantages
– Lower communication costs and better performance than the centralized 2PL
• Disadvantages
– Deadlock handling is more complex
• **Distributed 2PL**
– Lock managers are distributed to all sites
– Each lock manager responsible for locks for data at that site
– If data is not replicated, it is equivalent to primary copy 2PL
– If data is replicated, the Read-One-Write-All (ROWA) replica control protocol is implemented
∗ Read(x): Any copy of a replicated item x can be read by obtaining a read lock on the copy
∗ Write(x): All copies of x must be write-locked before x can be updated
• Disadvantages
– Deadlock handling more complex
– Communication costs higher than primary copy 2PL
• Communication structure of the distributed 2PL
– The coordinating TM sends the lock request to the lock managers of all participating sites
– The LMs pass the operations to the data processors
– The end of the operation is signaled to the coordinating TM



Timestamp Ordering:

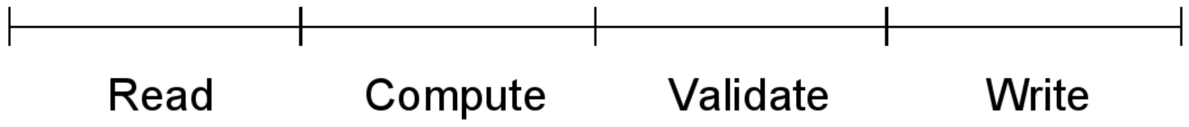
• **Timestamp-ordering** based algorithms do not maintain serializability by mutual exclusion, but select (a priori) a serialization order and execute transactions accordingly.
– Transaction Ti is assigned a globally unique timestamp ts(Ti)
– Conflicting operations Oij and Okl are resolved by timestamp order, i.e., Oij is executed before Okl iff ts(Ti) < ts(Tk).
• To allow for the scheduler to check whether operations arrive in correct order, each data item is assigned a write timestamp (wts) and a read timestamp (rts):
– rts(x): largest timestamp of any read on x
– wts(x): largest timestamp of any write on x
• Then the scheduler has to perform the following checks:
– Read operation, Ri(x):
∗ If ts(Ti) < wts(x): Ti attempts to read overwritten data; abort Ti
∗ If ts(Ti) ≥ wts(x): the operation is allowed and rts(x) is updated
– Write operations,Wi(x):
∗ If ts(Ti) < rts(x): x was needed before by other transaction; abort Ti
∗ If ts(Ti) < wts(x): Ti writes an obsolete value; abort Ti
∗ Otherwise, executeWi(x)
• Generation of **timestamps** (TS) in a distributed environment
– TS needs to be locally and globally **unique** and **monotonically increasing**
– System clock, incremental event counter at each site, or global counter are unsuitable (difficult to maintain)
– Concatenate local timestamp/counter with a unique site identifier:
<*local timestamp, site identifier*>
∗ site identifier is in the least significant position in order to distinguish only if the local timestamps are identical
• Schedules generated by the basic TO protocol have the following **properties**:
– Serializable
– Since transactions never wait (but are rejected), the schedules are deadlock-free
– The price to pay for deadlock-free schedules is the potential restart of a transaction several times
• Basic timestamp ordering is "**aggressive**": It tries to execute an operation as soon as it receives it
• **Conservative** timestamp ordering delays each operation until there is an assurance that it will not be restarted, i.e., that no other transaction with a smaller timestamp can arrive
– For this, the operations of each transaction are buffered until an ordering can be established so that rejections are not possible
• If this condition can be guaranteed, the scheduler will never reject an operation
• However, this delay introduces the possibility for deadlocks
• **Multiversion timestamp ordering**
– Write operations do not modify the DB; instead, a new version of the data item is created: x1, x2, . . . , xn
– Ri(x) is always successful and is performed on the appropriate version of x, i.e., the version of x (say xv) such that wts(xv) is the largest timestamp less than ts(Ti)
– Wi(x) produces a new version xw with ts(xw) = ts(Ti) if the scheduler has not yet processed any Rj(xr) on a version xr such that
ts(Ti) < rts(xr)
i.e., the write is too late.

– Otherwise, the write is rejected.
• The previous concurrency control algorithms are pessimistic



Optimistic method for Concurrency Control.

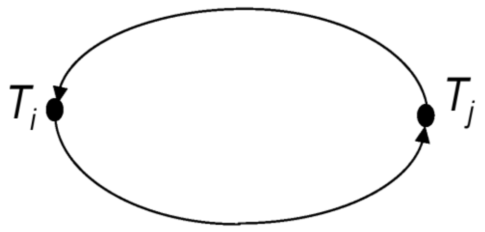
• **Optimistic concurrency control algorithms**
– Delay the validation phase until just before the write phase
– Ti run independently at each site on local copies of the DB (without updating the DB)
– Validation test then checks whether the updates would maintain the DB consistent:
∗ If yes, all updates are performed
∗ If one fails, all Ti's are rejected



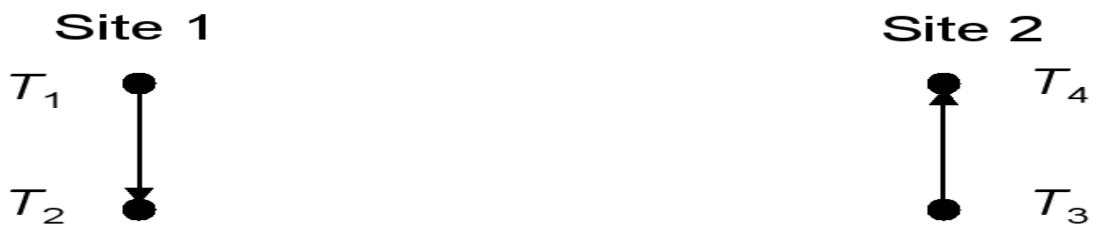
- Potentially allow for a higher level of concurrency

Deadlock management- prevention, avoidance detection, and resolution.

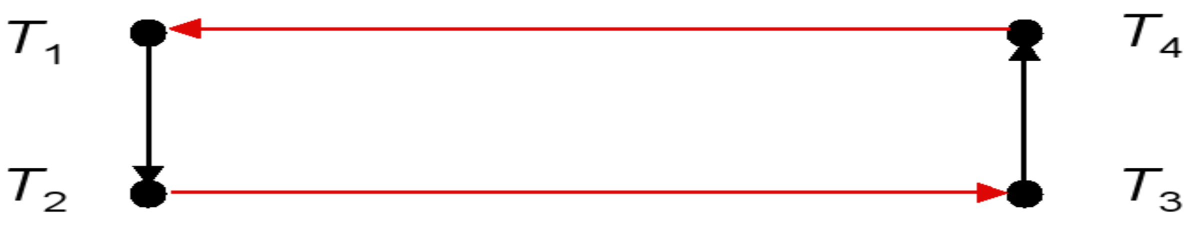
• **Deadlock:** A set of transactions is in a deadlock situation if several transactions wait for each other. A deadlock requires an outside intervention to take place.
• Any locking-based concurrency control algorithm may result in a deadlock, since there is mutual exclusive access to data items and transactions may wait for a lock
• Some TO-based algorihtms that require the waiting of transactions may also cause deadlocks
• A **Wait-for Graph** (WFG) is a useful tool to identify deadlocks
– The nodes represent transactions
– An edge from Ti to Tj indicates that Ti is waiting for Tj
– If the WFG has a cycle, we have a deadlock situation



• Deadlock management in a DDBMS is more complicate, since lock management is not centralized
• We might have **global deadlock**, which involves transactions running at different sites
• A Local Wait-for-Graph (LWFG) may not show the existence of global deadlocks
• A Global Wait-for Graph (GWFG), which is the union of all LWFGs, is needed
• **Example:** Assume T1 and T2 run at site 1, T3 and T4 run at site 2, and the following wait-for relationships between them: T1 → T2 → T3 → T4 → T1. This deadlock cannot be detected by the LWFGs, but by the GWFG which shows intersite waiting.
– Local WFG:



– Global WFG:



Deadlock Prevention:

• **Deadlock prevention**: Guarantee that deadlocks never occur
– Check transaction when it is initiated, and start it only if all required resources are available.
– All resources which may be needed by a transaction must be predeclared
• Advantages
– No transaction rollback or restart is involved
– Requires no run-time support
• Disadvantages
– Reduced concurrency due to pre-allocation
– Evaluating whether an allocation is safe leads to added overhead
– Difficult to determine in advance the required resources

Deadlock Avoidance:

• **Deadlock avoidance:** Detect potential deadlocks in advance and take actions to ensure that a deadlock will not occur. Transactions are allowed to proceed unless a requested resource is unavailable
• Two different approaches:
– **Ordering of data items**: Order data items and sites; locks can only be requested in that order (e.g., graph-based protocols)
– **Prioritize transactions:** Resolve deadlocks by aborting transactions with higher or lower priority. The following schemes assume that Ti requests a lock hold by Tj :
∗ **Wait-Die Scheme: if** ts(Ti) < ts(Tj) **then** Ti waits **else** Ti dies
∗ **Wound-Wait Scheme: if** ts(Ti) < ts(Tj) **then** Tj wounds (aborts) **else** Ti waits
• Advantages
– More attractive than prevention in a database environment
– Transactions are not required to request resources a priori
• Disadvantages
– Requires run time support

Deadlock Detection

• **Deadlock detection and resolution:** Transactions are allowed to wait freely, and hence to form deadlocks. Check global wait-for graph for cycles. If a deadlock is found, it is resolved by aborting one of the involved transactions (also called the victim).
• Advantages
– Allows maximal concurrency
– The most popular and best-studied method
• Disadvantages

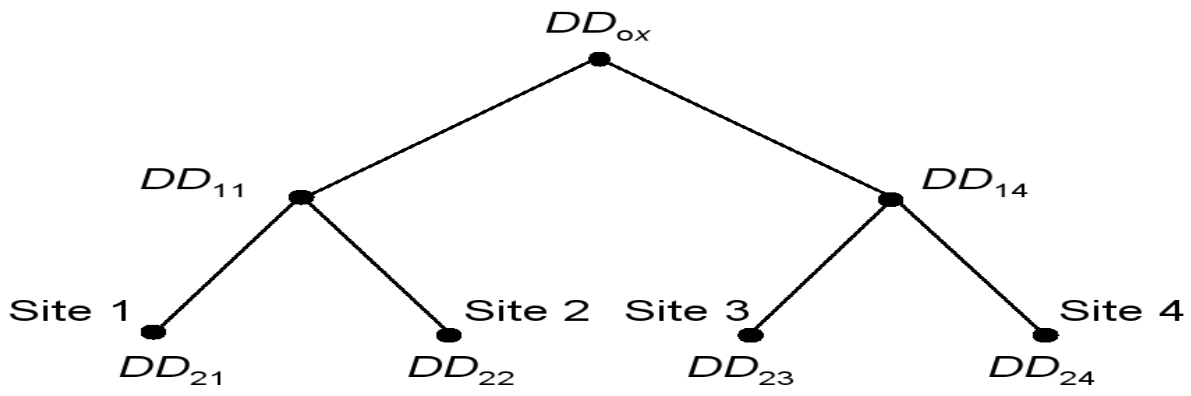
– Considerable amount of work might be undone
• Topologies for deadlock detection algorithms
– Centralized
– Distributed
– Hierarchical

• Centralized deadlock detection

– One site is designated as the deadlock detector (DDC) for the system
– Each scheduler periodically sends its LWFG to the central site
– The site merges the LWFG to a GWFG and determines cycles
– If one or more cycles exist, DDC breaks each cycle by selecting transactions to be rolled back and restarted
• This is a reasonable choice if the concurrency control algorithm is also centralized

• Hierarchical deadlock detection

– Sites are organized into a hierarchy
– Each site sends its LWFG to the site above it in the hierarchy for the detection of deadlocks
– Reduces dependence on centralized detection site



• Distributed deadlock detection

– Sites cooperate in deadlock detection
– The local WFGs are formed at each site and passed on to the other sites.
– Each local WFG is modified as follows:
∗ Since each site receives the potential deadlock cycles from other sites, these edges are added to the local WFGs
∗ i.e., the waiting edges of the local WFG are joined with waiting edges of the external WFGs
– Each local deadlock detector looks for two things:
∗ If there is a cycle that does not involve the external edge, there is a local deadlock which can be handled locally
∗ If there is a cycle involving external edges, it indicates a (potential) global deadlock.

Non-serializable schedule and nested distributed transaction.

Non-serializable Histories:

Serializability is a fairly simple and elegant concept which can be enforced with acceptable overhead. However, it is considered to be too “strict” for certain applications since it does not consider as correct certain histories that might be argued as reasonable. We have shown one case when we discussed the ordered shared lock concept. In addition, consider the Reservation transaction of Example 10.10. One can argue that the history generated by two concurrent executions of this transaction can be non-serializable, but correct – one may do the Airline reservation first and then do the Hotel reservation while the other one reverses the order – as long as both executions successfully terminate. The question, however, is how one can generalize these intuitive observations. The solution is to observe and exploit the "semantics" of these transactions.

There have been a number of proposals for exploiting transaction semantics. Of particular interest for distributed DBMS is one class that depends on identifying transaction steps, which may consist of a single operation or a set of operations, and establishing how transactions can interleave with each other between steps. Garcia-Molina [1983] classifies transactions into classes such that transactions in the same class are compatible and can interleave arbitrarily while transactions in different classes are incompatible and have to be synchronized. The synchronization is based on semantic notions, allowing more concurrency than serializability. The use of the concept of transaction classes can be traced back to SDD-1 [Bernstein et al., 1980b].

The concept of compatibility is refined by Lynch [1983b] and several levels of compatibility among transactions are defined. These levels are structured hierarchically so that interleavings at higher levels include those at lower levels. Furthermore, Lynch [1983b] introduces the concept of breakpoints within transactions, which represent points at which other transactions can interleave. This is an alternative to the use of compatibility sets.

Another work along these lines uses breakpoints to indicate the interleaving points, but does not require that the interleavings be hierarchical [Farrag and O¨ zsu, 1989]. A transaction is modeled as consisting of a number of steps. Each step consists of a sequence of atomic operations and a breakpoint at the end of these operations. For each breakpoint in a transaction the set of transaction types that are allowed to interleave at that breakpoint is specified. A correctness criterion called relative consistency is defined based on the correct interleavings among transactions. Intuitively, a relatively consistent history is equivalent to a history that is stepwise serial (i.e., the operations and breakpoint of each step appear without interleaving), and in which a step (T_{ik}) of transaction T_i interleaves two consecutive steps (T_{jm} and T_{jm+1}) of transaction T_j only if transactions of T_i's type are allowed to interleave T_{jm} at its breakpoint. It can be shown that some of the relatively consistent histories are not serializable, but are still "correct" [Farrag and O¨ zsu, 1989].

A unifying framework that combines the approaches of Lynch [1983b] and Farrag and O¨ zsu [1989] has been proposed by Agrawal et al. [1994]. A correctness criterion called semantic relative atomicity is introduced which provides finer interleavings and more concurrency.

Nested Distributed Transactions:

We introduced the nested transaction model in the previous chapter. The concurrent execution of nested transactions is interesting, especially since they are good candidates for distributed execution.

Let us first consider closed nested transactions [Moss, 1985]. The concurrency control of nested transactions have generally followed a locking-based approach. The following rules govern the management of the locks and the completion of transaction execution in the case of closed nested transactions:

1. Each subtransaction executes as a transaction and upon completion transfers its lock to its parent transaction.
2. A parent inherits both the locks and the updates of its committed subtransactions.
3. The inherited state will be visible only to descendants of the inheriting parent transaction. However, to access the sate, a descendant must acquire appropriate locks. Lock conflicts are determined as for flat transactions, except that one ignores inherited locks retained by ancestor's of the requesting subtransaction.
4. If a subtransaction aborts, then all locks and updates that the subtransaction and its descendants are discarded. The parent of an aborted subtransaction need not, but may, choose to abort.

From the perspective of ACID properties, closed nested transactions relax durability since the effects of successfully completed subtransactions can be erased if an ancestor transaction aborts. They also relax the isolation property in a limited way since they share their state with other subtransactions within the same nested transaction.

The distributed execution potential of nested transactions is obvious. After all, nested transactions are meant to improve intra-transaction concurrency and one can view each subtransaction as a potential unit of distribution if data are also appropriately distributed.

However, from the perspective of lock management, some care has to be observed. When subtransactions release their locks to their parents, these lock releases cannot be reflected in the lock tables automatically. The subtransaction commit commands do not have the same semantics as flat transactions.

Open nested transactions are even more relaxed than their closed nested counterparts. They have been called "anarchic" forms of nested transactions [Gray and Reuter, 1993]. The open nested transaction model is best exemplified in the saga model [Garcia-Molina and Salem, 1987; Garcia-Molina et al., 1990] which was discussed in Section 10.3.2.

From the perspective of lock management, open nested transactions are easy to deal with. The locks held by a subtransaction are released as soon as it commits or aborts and this is reflected in the lock tables.

A variant of open nested transactions with precise and formal semantics is the multilevel transaction model [Weikum, 1986; Weikum and Schek, 1984; Beeri et al., 1988; Weikum, 1991]. Multilevel transactions "are a variant of open nested transactions in which the subtransactions correspond to operations at different levels of a layered system architecture" [Weikum and Hasse, 1993]. We introduce the concept with an example taken from [Weikum, 1991]. We consider a transaction specification language which allows users to write transactions involving abstract operations so as to be able to exploit application semantics.

Consider two transactions that transfer funds from one bank account to another:

T_1: Withdraw(o; x) T_2: Withdraw(o; y)

Deposit(p; x) Deposit(p;y)

The notation here is that each T_i withdraws x (y) amount from account o and deposits that amount to account p. The semantics of Withdraw is test-and-withdraw to ensure that the account balance is sufficient to meet the withdrawal request. In relational systems, each of these abstract operations will be translated to tuple operations Select (Sel), and Update (Upd) which will, in turn, be translated into page-level Read and Write operations (assuming o is on page r and p is on page w). This results in a layered abstraction of transaction execution as depicted in Figure 11.19.

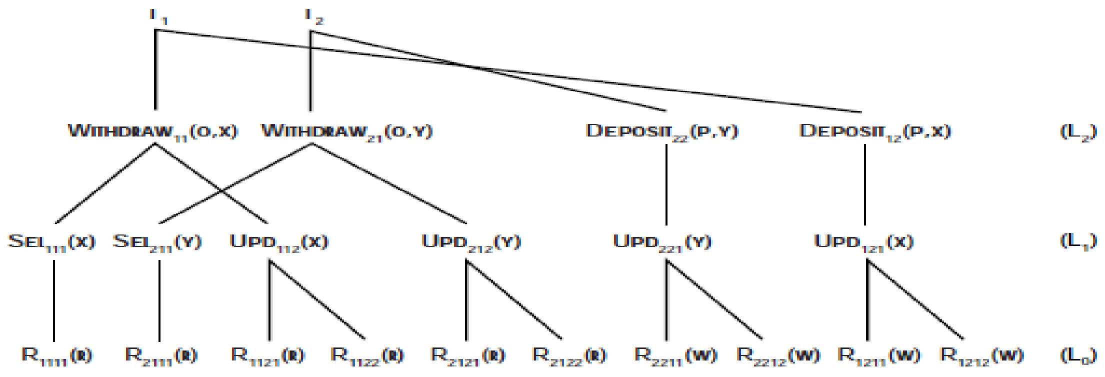


Fig. 11.19 Multilevel Transaction Example (Based on [Weikum, 1991])

Fig. 11.19 Multilevel Transaction Example (Based on [Weikum, 1991])

The traditional method of dealing with these types of histories is to develop a scheduler that enforces serializability at the lowest level (L_0). This, however, reduces the level of concurrency since it does not take into account application semantics and the granularity of synchronization is too coarse. Abstracting from the lower-level details can provide higher concurrency. For example, the page-level history (L_0) in Figure 11.19 is not serializable with respect to transactions T_1 and T_2, but the tuplelevel history L_1 is serializable (T_2 !T_1). When one goes up to level L_2, it is possible to make use of the semantics of the abstract operations (i.e., their commutativity) to provide even more concurrency. Therefore, multilevel serializability is defined to reason about the serializability of multilevel histories and multilevel histories are proposed to enforce it [Weikum, 1991].

2.4 Reliability of Distributed DBMS and Recovery: Concept and measures of reliability, Failure analysis, types of failures. Distributed Reliability Protocols. Recovery techniques. Two Phase Commit , Presumed abort, Presumed commit. Three phase commit, Partitions, Scalability of Replication.

Reliability of Distributed DBMS and Recovery: Concept and measures of reliability, Failure analysis, types of failures.

• A **reliable DDBMS** is one that can continue to process user requests even when the underlying system is unreliable, i.e., failures occur

• **Failures**

– Transaction failures

– System (site) failures, e.g., system crash, power supply failure

– Media failures, e.g., hard disk failures

– Communication failures, e.g., lost/undeliverable messages

• Reliability is closely related to the problem of how to maintain the **atomicity** and **durability** properties of transactions

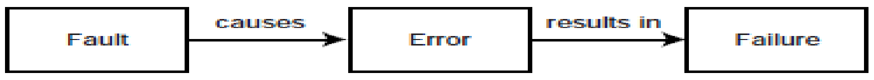


Fig. 12.1 Chain of Events Leading to System Failure

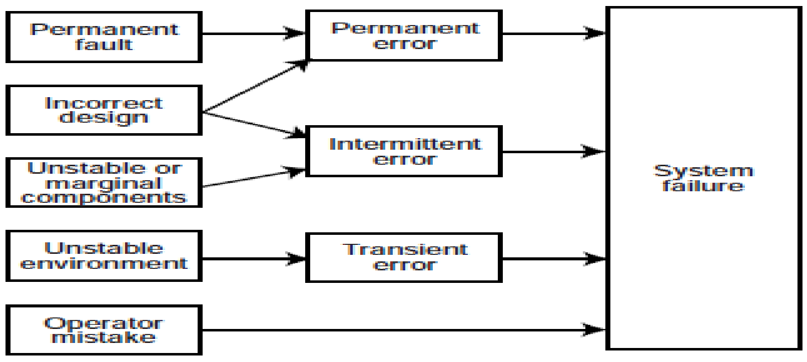


Fig. 12.2 Sources of System Failure (Based on [Siewiorek and Swarz, 1982])

Failures in Distributed DBMS:

Designing a reliable system that can recover from failures requires identifying the types of failures with which the system has to deal. In a distributed database system, we need to deal with four types of failures: transaction failures (aborts), site (system) failures, media (disk) failures, and communication line failures. Some of these are due to hardware and others are due to software. The ratio of hardware failures vary from study to study and range from 18% to over 50%. Soft failures make up more than 90% of all hardware system failures.

Transaction Failures

Transactions can fail for a number of reasons. Failure can be due to an error in the transaction caused by incorrect input data (e.g., Example 10.3) as well as the detection of a present or potential deadlock. Furthermore, some concurrency control algorithms do not permit a transaction to proceed or even to wait if the data that they attempt to access are currently being accessed by another transaction. This might also be considered a failure. The usual approach to take in cases of transaction failure is to abort the transaction, thus resetting the database to its state prior to the start of this transaction.[2]

The frequency of transaction failures is not easy to measure. An early study reported that in System R, 3% of the transactions aborted abnormally [Gray et al., 1981]. In general, it can be stated that (1) within a single application, the ratio of transactions that abort themselves is rather constant, being a function of the incorrect data, the available semantic data control features, and so on; and (2) the number of transaction aborts by the DBMS due to concurrency control considerations (mainly deadlocks) is dependent on the level of concurrency (i.e., number of concurrent transactions), the interference of the concurrent applications, the granularity of locks, and so on [H¨arder and Reuter, 1983].

Site (System) Failures

The reasons for system failure can be traced back to a hardware or to a software failure. The important point from the perspective of this discussion is that a system failure is always assumed to result in the loss of main memory contents. Therefore, any part of the database that was in main memory buffers is lost as a result of a system failure. However, the database that is stored in secondary storage is assumed to be safe and correct. In distributed database terminology, system failures are typically referred to as site failures, since they result in the failed site being unreachable from other sites in the distributed system.

We typically differentiate between partial and total failures in a distributed system. Total failure refers to the simultaneous failure of all sites in the distributed system; partial failure indicates the failure of only some sites while the others remain operational. As indicated in Chapter 1, it is this aspect of distributed systems that makes them more available.

Media Failures

Media failure refers to the failures of the secondary storage devices that store the database. Such failures may be due to operating system errors, as well as to hardware faults such as head crashes or controller failures. The important point from the perspective of DBMS reliability is that all or part of the database that is on the secondary storage is considered to be destroyed and inaccessible. Duplexing of disk storage and maintaining archival copies of the database are common techniques that deal with this sort of catastrophic problem.

Media failures are frequently treated as problems local to one site and therefore not specifically addressed in the reliability mechanisms of distributed DBMSs. We consider techniques for dealing with them in Section 12.3.5 under local recovery management. We then turn our attention to site failures when we consider distributed recovery functions.

Communication Failures

The three types of failures described above are common to both centralized and distributed DBMSs. Communication failures, however, are unique to the distributed case. There are a number of types of communication failures. The most common ones are the errors in the messages, improperly ordered messages, lost (or undeliverable) messages, and communication line failures. As discussed in Chapter 2, the first two errors are the responsibility of the computer network; we will not consider them further. Therefore, in our discussions of distributed DBMS reliability, we expect the underlying computer network hardware and software to ensure that two messages sent from a process at some originating site to another process at some destination site are delivered without error and in the order in which they were sent.

Lost or undeliverable messages are typically the consequence of communication line failures or (destination) site failures. If a communication line fails, in addition to losing the message(s) in transit, it may also divide the network into two or more disjoint groups. This is called network partitioning. If the network is partitioned, the sites in each partition may continue to operate. In this case, executing transactions that access data stored in multiple partitions becomes a major issue.

Network partitions point to a unique aspect of failures in distributed computer systems. In centralized systems the system state can be characterized as all-ornothing:

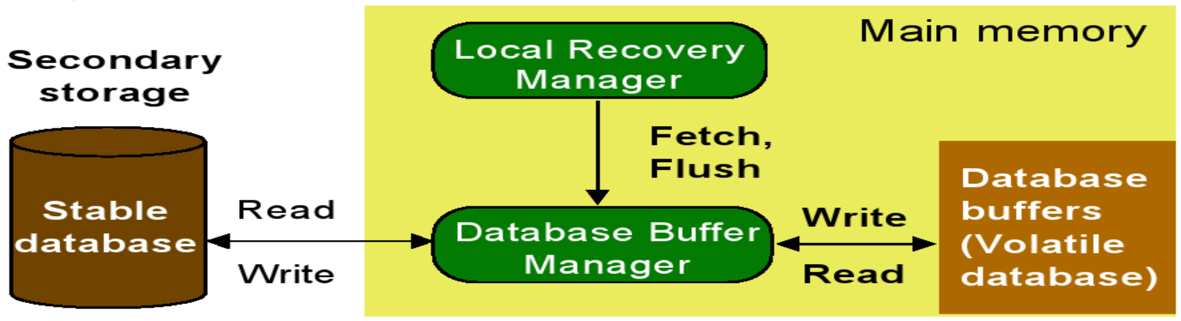
either the system is operational or it is not. Thus the failures are complete:
when one occurs, the entire system becomes non-operational. Obviously, this is not
true in distributed systems. As we indicated a number of times before, this is their
potential strength. However, it also makes the transaction management algorithms
more difficult to design.
If messages cannot be delivered, we will assume that the network does nothing
about it. It will not buffer it for delivery to the destination when the service is
reestablished and will not inform the sender process that the message cannot be delivered. In short, the message will simply be lost.We make this assumption because
it represents the least expectation from the network and places the responsibility of
dealing with these failures to the distributed DBMS.
As a consequence, the distributed DBMS is responsible for detecting that a message
is undeliverable is left to the application program (in this case the distributed
DBMS). The detection will be facilitated by the use of timers and a timeout mechanism
that keeps track of how long it has been since the sender site has not received
a confirmation from the destination site about the receipt of a message. This timeout
interval needs to be set to a value greater than that of the maximum round-trip
propagation delay of a message in the network. The term for the failure of the communication
network to deliver messages and the confirmations within this period
is performance failure. It needs to be handled within the reliability protocols for
distributed DBMSs.

Distributed Reliability Protocols.

• **Recovery system:** Ensures atomicity and durability of transactions in the presence of failures (and concurrent transactions)
• Recovery algorithms have two parts
1. Actions taken during normal transaction processing to ensure enough information exists to recover from failures
2. Actions taken after a failure to recover the DB contents to a state that ensures atomicity, consistency and durability

Local Recovery Management:

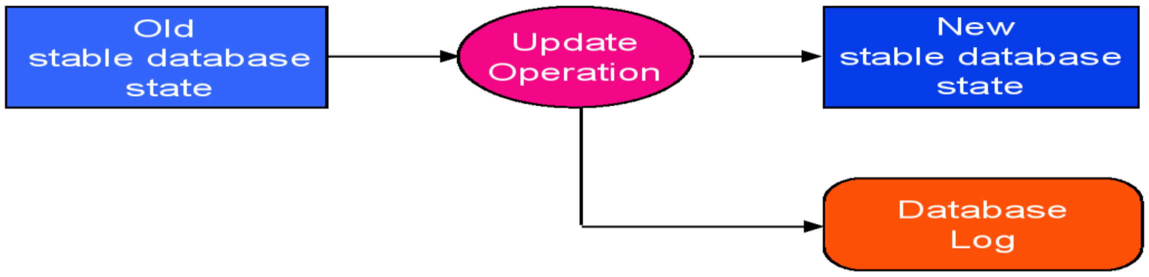
• The **local recovery manager (LRM)** maintains the atomicity and durability properties of local transactions at each site.
• **Architecture**
– **Volatile** storage: The main memory of the computer system (RAM)
– **Stable** storage
_ A storage that “never” looses its contents
_ In reality this can only be approximated by a combination of hardware (non-volatile storage) and software (stable-write, stable-read, clean-up) components



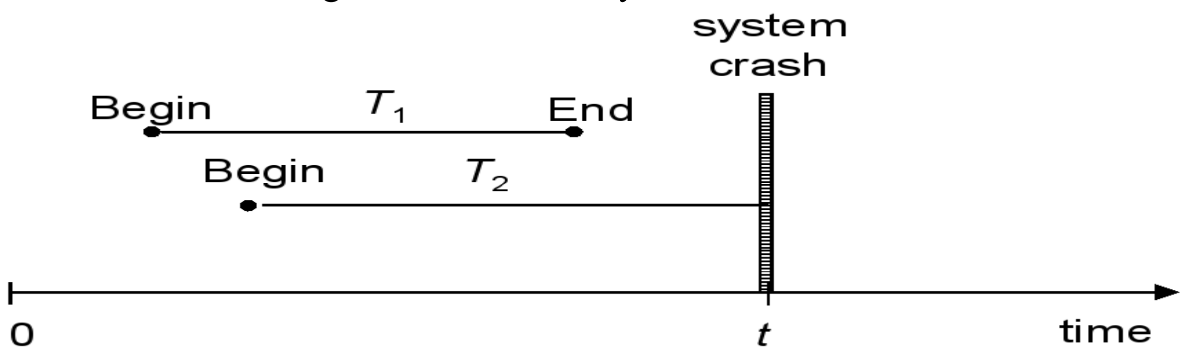
• Two ways for the LRM to deal with update/write operations
*** In-place update**
_ Physically changes the value of the data item in the stable database
_ As a result, previous values are lost

_ Mostly used in databases
*** Out-of-place update**
_ The new value(s) of updated data item(s) are stored separately from the old value(s)
_ Periodically, the updated values have to be integrated into the stable DB

In-Place Update:
• Since in-place updates cause previous values of the affected data items to be lost, it is necessary to keep enough information about the DB updates in order to allow recovery in the case of failures
• Thus, every action of a transaction must not only perform the action, but must also write a log record to an append-only **log file**

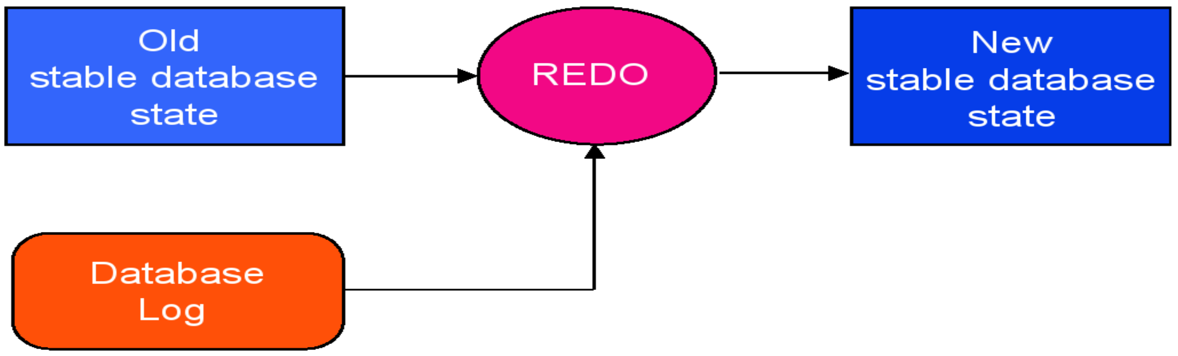


• A **log** is the most popular structure for recording DB modifications on stable storage
• Consists of a sequence of **log records** that record all the update activities in the DB
• Each log record describes a significant event during transaction processing
• Types of log records
– < Ti, start >: if transaction Ti has started
– < Ti,Xj , V1, V2 >: before Ti executes a write(Xj), where V1 is the old value before the write and V2 is the new value after the write
– < Ti, commit >: if Ti has committed
– < Ti, abort >: if Ti has aborted
– < checkpoint >
• With the information in the log file the recovery manager can restore the consistency of the DB in case of a failure.
• Assume the following situation when a system crash occurs

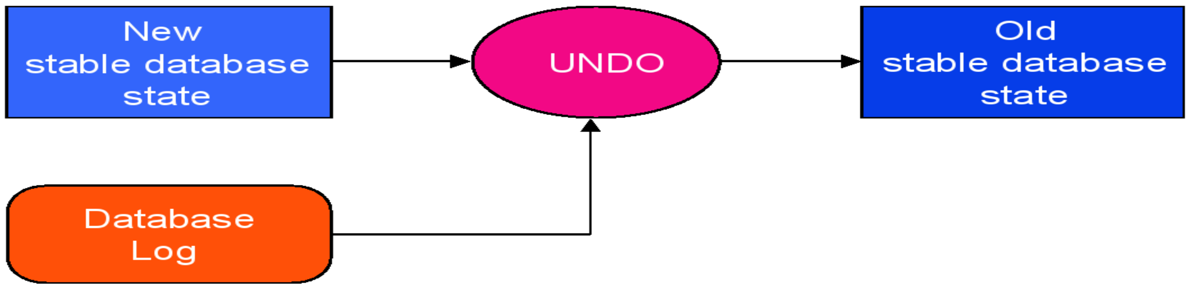


• Upon recovery:
– All effects of transaction T1 should be reflected in the database (➔REDO)
– None of the effects of transaction T2 should be reflected in the database (➔UNDO)
• **REDO Protocol**
– REDO'ing an action means performing it again
– The REDO operation uses the log information and performs the action that might

have been done before, or not done due to failures
– The REDO operation generates the new image



• **UNDO Protocol**
– UNDO’ing an action means to restore the object to its image before the transaction has started
– The UNDO operation uses the log information and restores the old value of the object



- **Example:** Consider the transactions T_0 and T_1 (T_0 executes before T_1) and the following initial values: $A = 1000$, $B = 2000$, and $C = 700$

```
T0:  read(A)                      T1:  read(C)
     A = A − 50                        C = C − 100
     write(A)                          write(C)
     read(B)
     B = B + 50
     write(B)
```

  – Possible order of actual outputs to the log file and the DB:

Log	DB
$< T_0, start >$	
$< T_0, A, 1000, 950 >$	
$< T_0, B, 2000, 2050 >$	
$< T_0, commit >$	
	$A = 950$
	$B = 2050$
$< T_1, start >$	
$< T_1, C, 700, 600 >$	
$< T_1, commit >$	
	$C = 600$

- **Example (contd.):** Consider the log after some system crashes and the corresponding recovery actions

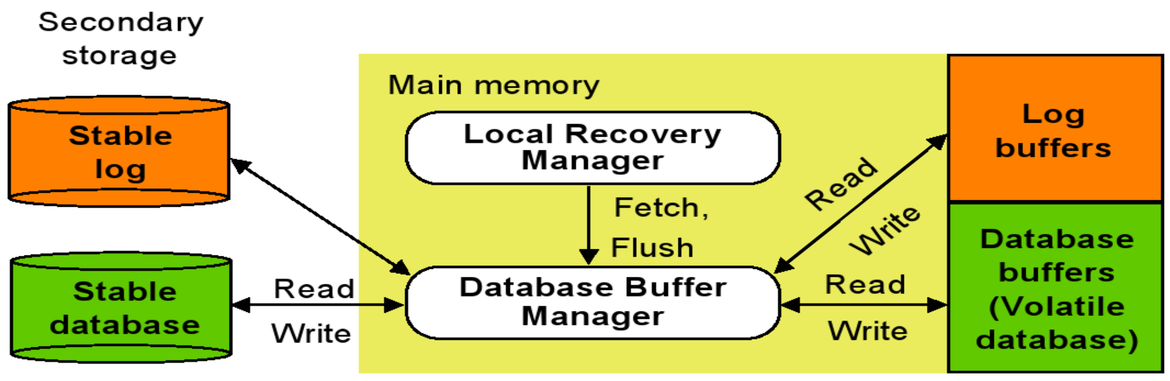
(a)	(b)	(c)
$< T_0, start >$	$< T_0, start >$	$< T_0, start >$
$< T_0, A, 1000, 950 >$	$< T_0, A, 1000, 950 >$	$< T_0, A, 1000, 950 >$
$< T_0, B, 2000, 2050 >$	$< T_0, B, 2000, 2050 >$	$< T_0, B, 2000, 2050 >$
	$< T_0, commit >$	$< T_0, commit >$
	$< T_1, start >$	$< T_1, start >$
	$< T_1, C, 700, 600 >$	$< T_1, C, 700, 600 >$
		$< T_1, commit >$

(a) undo(T0): B is restored to 2000 and A to 1000

(b) undo(T1) and redo(T0): C is restored to 700, and then A and B are set to 950 and 2050, respectively

(c) redo(T0) and redo(T1): A and B are set to 950 and 2050, respectively; then C is set to 600

• Logging Interface:



• Log pages/buffers can be written to stable storage in two ways:
*** synchronously**
_ The addition of each log record requires that the log is written to stable storage
_ When the log is written synchronoously, the executtion of the transaction is supended until the write is complete!delay in response time
*** asynchronously**
_ Log is moved to stable storage either at periodic intervals or when the buffer fills up.

• **When to write** log records into stable storage?
• Assume a transaction T updates a page P
• Fortunate case
– System writes P in stable database
– System updates stable log for this update

– SYSTEM FAILURE OCCURS!... (before T commits)
– We can recover (undo) by restoring P to its old state by using the log
• Unfortunate case
– System writes P in stable database
– SYSTEM FAILURE OCCURS!... (before stable log is updated)
– We cannot recover from this failure because there is no log record to restore the old value
• Solution: Write-Ahead Log (WAL) protocol

• Notice:
– If a system crashes before a transaction is committed, then all the operations must be undone. We need only the before images (undo portion of the log)
– Once a transaction is committed, some of its actions might have to be redone. We need the after images (redo portion of the log)
• **Write-Ahead-Log (WAL) Protocol**
– Before a stable database is updated, the undo portion of the log should be written to the stable log
– When a transaction commits, the redo portion of the log must be written to stable log prior to the updating of the stable database

Out-of-Place Update:

• *Two out-of-place strategies* are shadowing and differential files
• **Shadowing**
– When an update occurs, don't change the old page, but create a shadow page with the new values and write it into the stable database
– Update the access paths so that subsequent accesses are to the new shadow page
– The old page is retained for recovery
• **Differential files**
– For each DB file F maintain
_ a read-only part FR
_ a differential file consisting of insertions part (DF+) and deletions part (DF−)
– Thus, F = (FR [DF+) − DF−

Distributed Reliability Protocols:

• As with local reliability protocols, the distributed versions aim to maintain the atomicity and durability of distributed transactions
• Most problematic issues in a distributed transaction are commit, termination, and recovery
*** Commit protocols**
_ How to execute a commit command for distributed transactions
_ How to ensure atomicity (and durability)?
***Termination protocols**
_ If a failure occurs at a site, how can the other operational sites deal with it
_ **Non-blocking:** the occurrence of failures should not force the sites to wait until the failure is repaired to terminate the transaction
***Recovery protocols**
_ When a failure occurs, how do the sites where the failure occurred deal with it

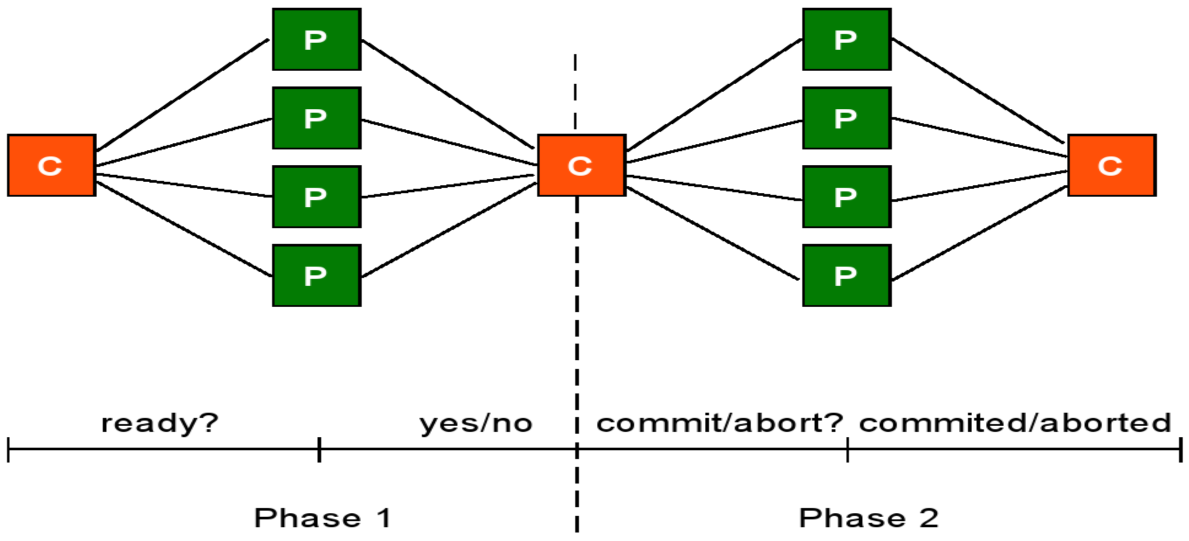
_ **Independent:** a failed site can determine the outcome of a transaction without having to obtain remote information

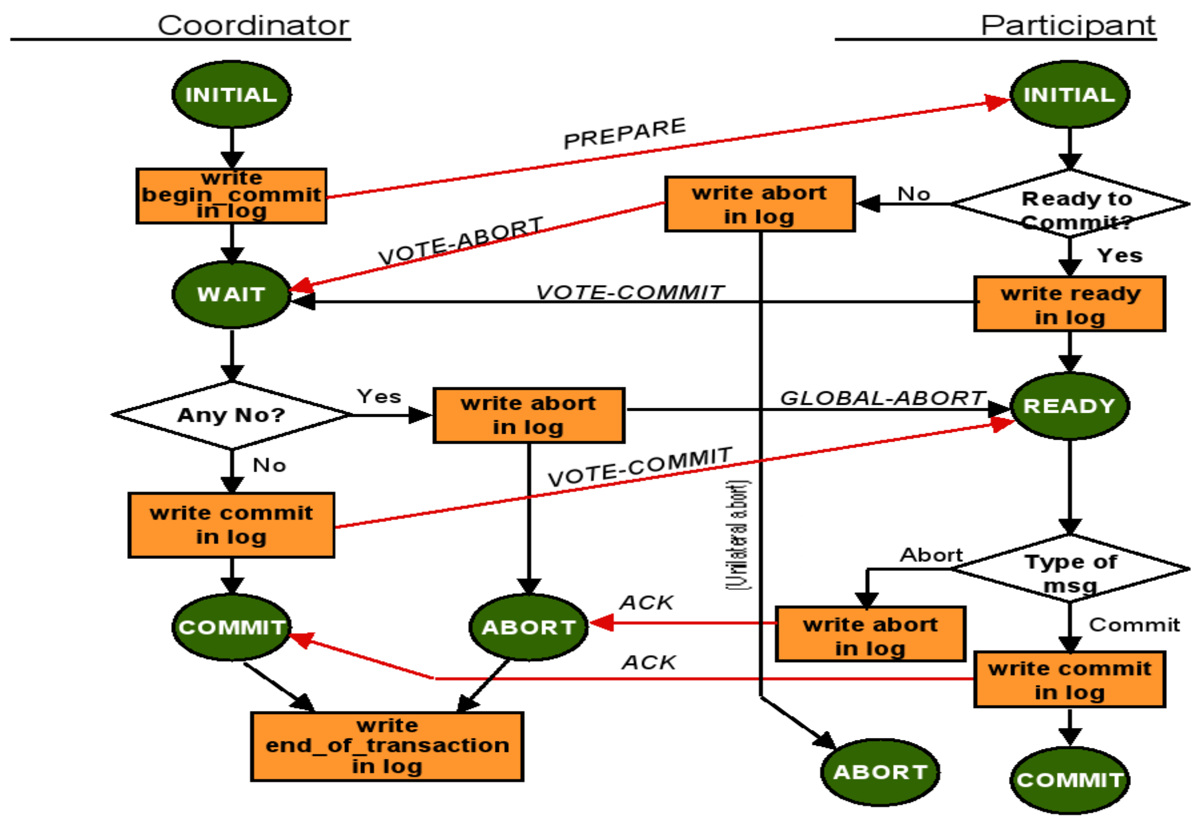
Commit Protocols:

• Primary requirement of commit protocols is that they maintain the atomicity of distributed transactions (**atomic commitment**)
– i.e., even though the exectution of the distributed transaction involves multiple sites, some of which might fail while executing, the effects of the transaction on the distributed DB is all-or-nothing.
• In the following we distinguish two roles
– Coordinator: The process at the site where the transaction originates and which controls the execution
– Participant: The process at the other sites that participate in executing the transaction

Centralized Two Phase Commit Protocol (2PC):

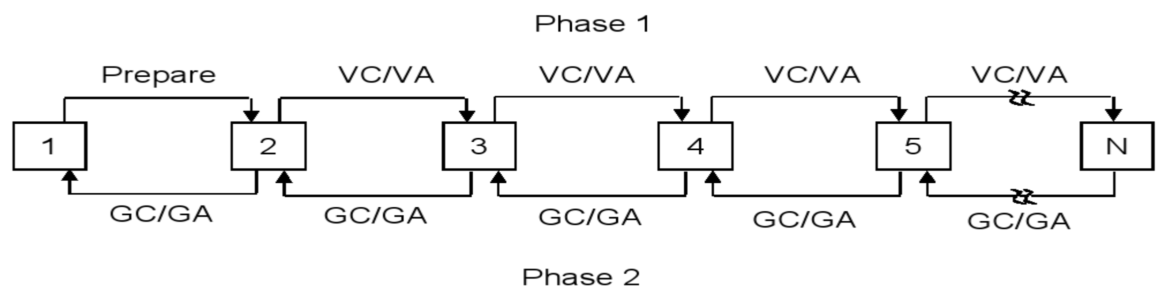
• Very simple protocol that ensures the atomic commitment of distributed transactions.
• **Phase 1:** The coordinator gets the participants ready to write the results into the database
• **Phase 2:** Everybody writes the results into the database
• **Global Commit Rule**
– The coordinator aborts a transaction if and only if at least one participant votes to abort it
– The coordinator commits a transaction if and only if all of the participants vote to commit it
• **Centralized** since communication is only between coordinator and the participants





Linear 2PC Protocol

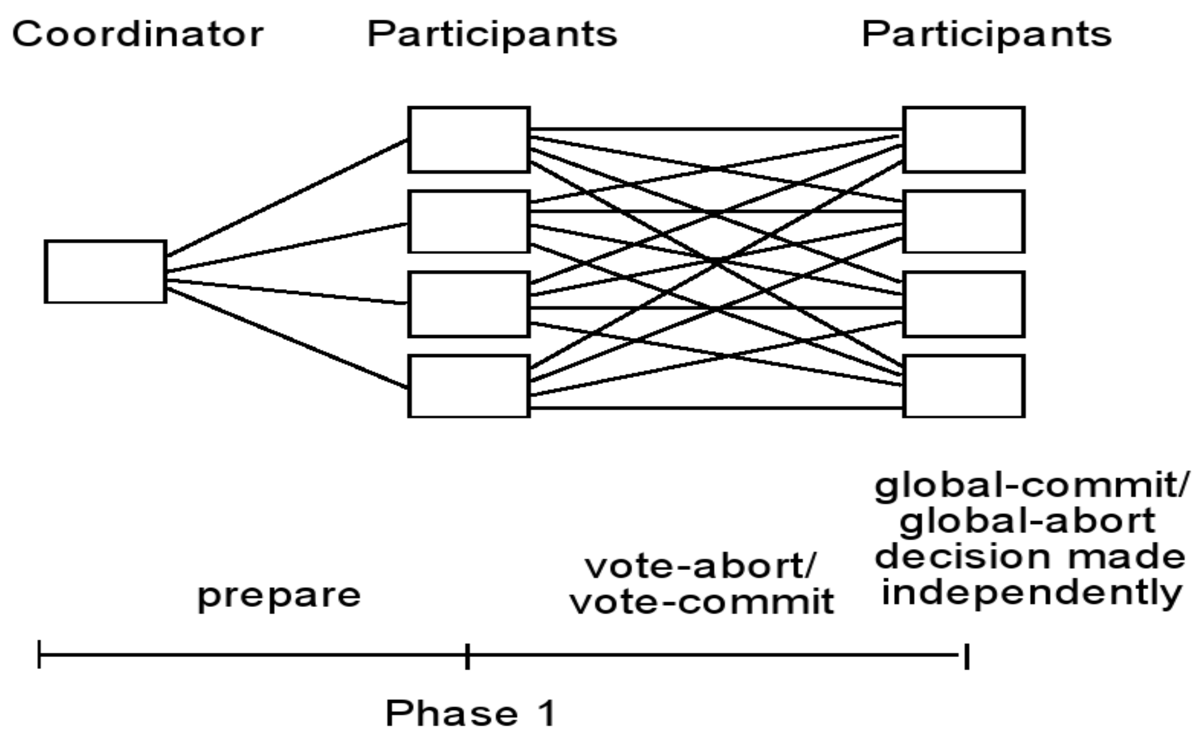
• There is linear ordering between the sites for the purpose of communication
• Minimizes the communication, but low response time as it does not allow any parallelism



VC: Vote-Commit, VA: Vote-Abort, GC: Global-commit, GA: Global-abort

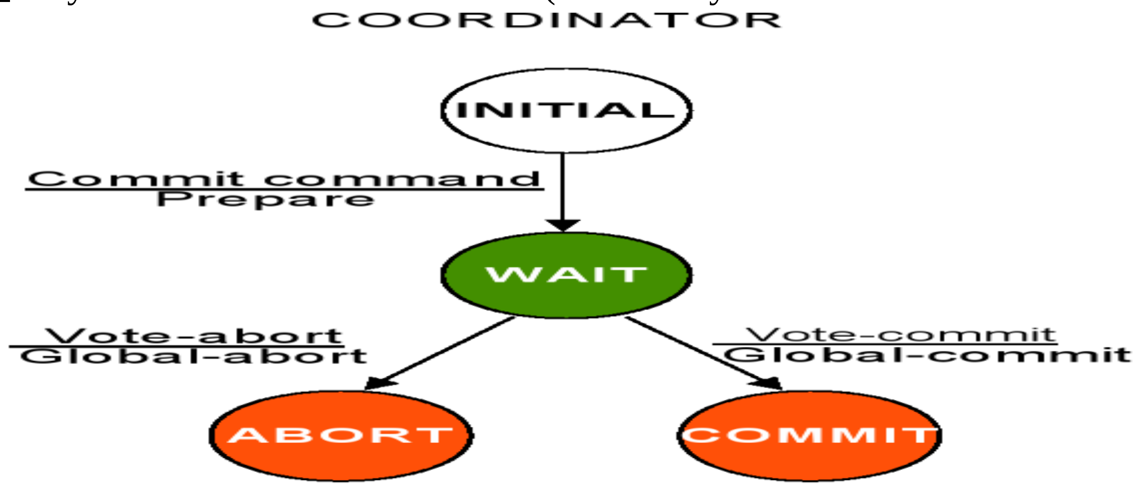
Distributed 2PC Protocol

• Distributed 2PC protocol increases the communication between the nodes
• Phase 2 is not needed, since each participant sends its vote to all other participants (+ the coordinator), thus each participants can derive the global decision



2PC Protocol and Site Failures

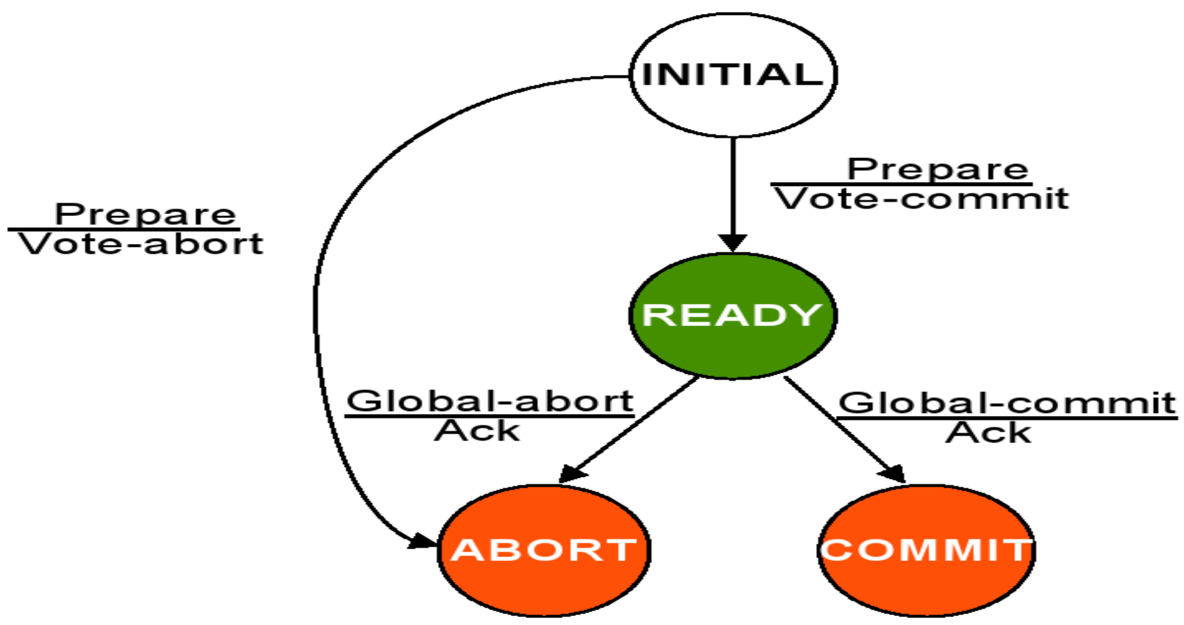
• **Site failures** in the 2PC protocol might lead to **timeouts**
• Timeouts are served by **termination protocols**
• We use the state transition diagrams of the 2PC for the analysis
• **Coordinator timeouts:** One of the participants is down. Depending on the state, the coordinator can take the following actions:
*****Timeout in INITIAL
_ Do nothing
*****Timeout in WAIT
_ Coordinator is waiting for local decisions
_ Cannot unilaterally commit
_ Can unilaterally abort and send an appropriate message to all participants
*****Timeout in ABORT or COMMIT
_ Stay blocked and wait for the acks (indefinitely if the site is down indefinitely)



• **Participant timeouts:** The coordinator site is down. A participant site is in
– Timeout in INITIAL
_ Participant waits for “prepare”, thus coordinator must have failed in INITIAL state

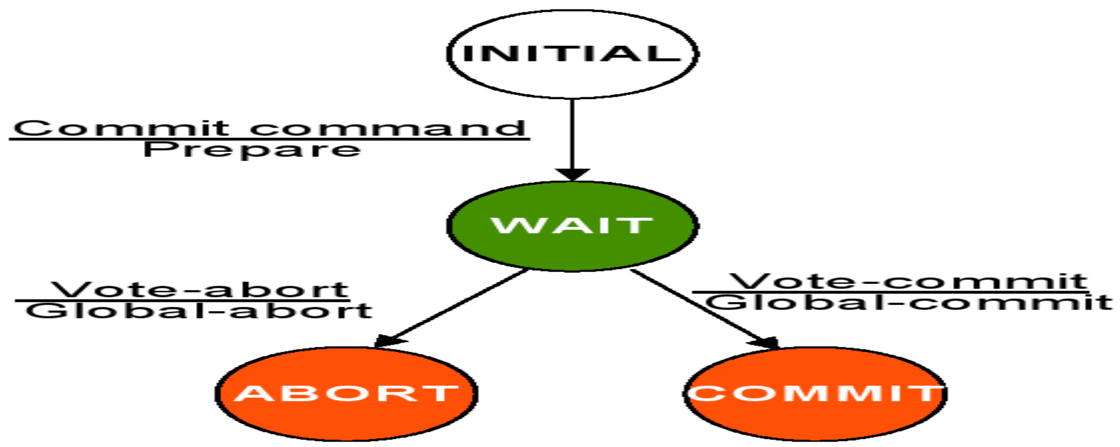
_ Participant can unilaterally abort
– Timeout in READY
_ Participant has voted to commit, but does not know the global decision
_ Participant stays blocked (indefinitely, if the coordinator is permanently down), since participant cannot change its vote or unilaterally decide to commit

PARTICIPANTS

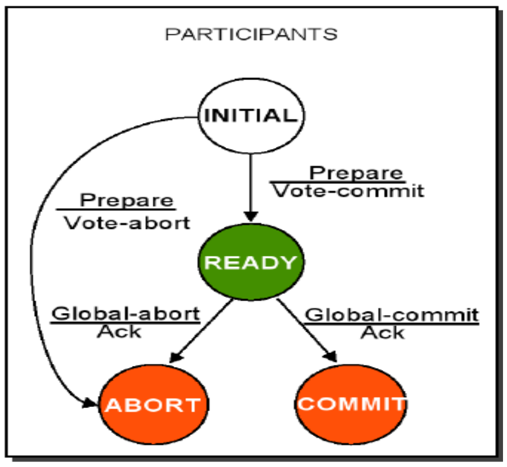


• The actions to be taken after a recovery from a failure are specified in the **recovery protocol**
• **Coordinator site failure:** Upon recovery, it takes the following actions:
*Failure in INITIAL
_ Start the commit process upon recovery (since coordinator did not send anything to the sites)
*Failure in WAIT
_ Restart the commit process upon recovery (by sending “prepare” again to the participants)
*Failure in ABORT or COMMIT
_ Nothing special if all the acks have been received from participants
_ Otherwise the termination protocol is involved (re-ask the acks)

COORDINATOR



- **Participant site failure:** The coordinator sites recovers
  - Failure in INITIAL
    - ∗ Unilaterally abort upon recovery as the coordinator will eventually timeout since it will not receive the participant's decision due to the failure
  - Failure in READY
    - ∗ The coordinator has been informed about the local decision
    - ∗ Treat as timeout in READY state and invoke the termination protocol (re-ask the status)
  - Failure in ABORT or COMMIT
    - ∗ Nothing special needs to be done



• Additional cases
– Coordinator site fails after writing ”begin commit” log and before sending ”prepare” command
_ treat it as a failure in WAIT state; send ”prepare” command
– Participant site fails after writing ”ready” record in log but before ”vote-commit” is sent
_ treat it as failure in READY state
_ alternatively, can send ”vote-commit” upon recovery
– Participant site fails after writing ”abort” record in log but before ”vote-abort” is sent
_ no need to do anything upon recovery
– Coordinator site fails after logging its final decision record but before sending its decision to the participants
_ coordinator treats it as a failure in COMMIT or ABORT state
_ participants treat it as timeout in the READY state
– Participant site fails after writing ”abort” or ”commit” record in log but before acknowledgement is sent
_ participant treats it as failure in COMMIT or ABORT state
_ coordinator will handle it by timeout in COMMIT or ABORT state

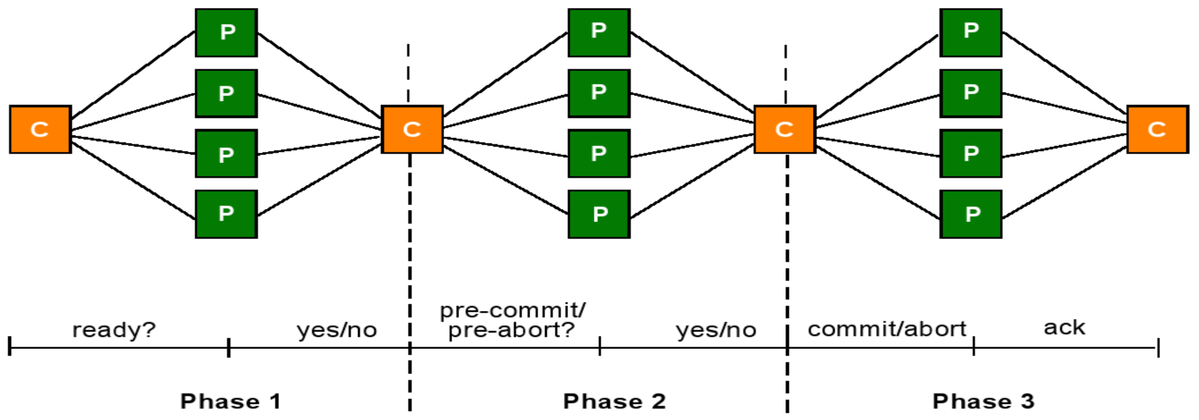
Problems with 2PC Protocol:

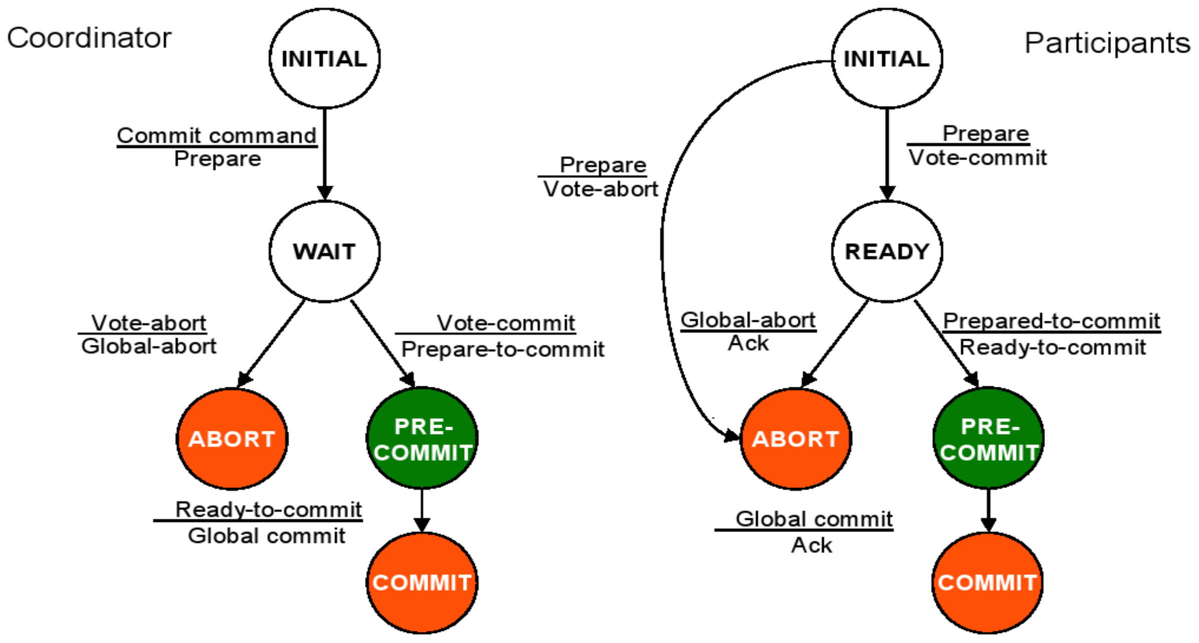
• A protocol is **non-blocking** if it permits a transaction to terminate at the operational sites without waiting for recovery of the failed site.
– Significantly improves the response-time of transactions
• 2PC protocol is **blocking**
– Ready implies that the participant waits for the coordinator
– If coordinator fails, site is blocked until recovery; independent recovery is not possible
– The problem is that sites might be in both: commit and abort phases.

Three Phase Commit Protocol (3PC):

• 3PC is a **non-blocking protocol** when failures are restricted to **single site** failures
• The state transition diagram contains
– no state which is ”adjacent” to both a commit and an abort state
– no non-committable state which is ”adjacent” to a commit state
• Adjacent: possible to go from one status to another with a single state transition
• Committable: all sites have voted to commit a transaction (e.g.: COMMIT state)

• Solution: Insert another state between the WAIT (READY) and COMMIT states





Recovery techniques.

Two Phase Commit , Presumed abort, Presumed commit.

Three phase commit, Partitions, Scalability of Replication.

Unit 3: 16 hrs.

3.1 Object Oriented Database Concept: Data types and Object, Evolution of Object Oriented Concepts, Characteristics of Object Oriented Data Model. Object Hierarchies - Generalization, Specialization, Aggregation. Object Schema. Inter-object Relationships, Similarities and difference between Object Oriented Database model and Other Data models.

Object Oriented Database Concept: Data types and Object, Evolution of Object Oriented Concepts,

The term object-oriented—abbreviated by OO or O-O—has its origins in OO programming languages, or OOPLs. Today OO concepts are applied in the areas of databases, software engineering, knowledge bases, artificial intelligence, and computer systems in general. OOPLs have their roots in the SIMULA language, which was proposed in the late 1960s. In SIMULA, the concept of a class groups together the internal data structure of an object in a class declaration. Subsequently, researchers proposed the concept of abstract data type, which hides the internal data structures and specifies all possible external operations that can be applied to an object, leading to the concept of encapsulation. The programming language SMALLTALK, developed at Xerox PARC (Note 9) in the 1970s, was one of the first languages to explicitly incorporate additional OO concepts, such as message passing and inheritance. It is known as a pure OO programming language, meaning that it was explicitly designed to be object-oriented. This contrasts with hybrid OO programming languages, which incorporate OO concepts into an already existing language. An example of the latter is C++, which incorporates OO concepts into the popular C programming language.

An object typically has two components: state (value) and behavior (operations). Hence, it is somewhat similar to a program variable in a programming language, except that it will typically have a complex data structure as well as specific operations defined by the programmer (Note 10). Objects in an OOPL exist only during program execution and are hence called transient objects. An OO database can extend the existence of objects so that they are stored permanently, and hence the objects persist beyond program termination and can be retrieved later and shared by other programs. In other words, OO databases store persistent objects permanently on secondary storage, and allow the sharing of these objects among multiple programs and applications. This requires the incorporation of other well-known features of database management systems, such as indexing mechanisms, concurrency control, and recovery. An OO database system interfaces with one or more OO programming languages to provide persistent and shared object capabilities.

Another key concept in OO systems is that of type and class hierarchies and inheritance. This permits specification of new types or classes that inherit much of their structure and operations from previously defined types or classes. Hence, specification of object types can proceed systematically. This makes it easier to develop the data types of a system incrementally, and to reuse existing type definitions when creating new types of objects.

Evolution:

Traditional data models and systems, such as relational, network, and hierarchical, have been quite successful in developing the database technology required for many traditional business database applications. However, they have certain shortcomings when more complex database applications must be designed and implemented—for example, databases for engineering design and manufacturing (CAD/CAM and CIM (Note 2)), scientific experiments, telecommunications, geographic information systems, and multimedia (Note 3). These newer applications have requirements and characteristics that differ from those of traditional business applications, such as more complex structures for objects, longer-duration transactions, new data types for storing images or large textual items, and the need to define nonstandard application-specific operations. Object-oriented databases were proposed to meet the needs of these more complex applications. The object-oriented approach offers the flexibility to handle some of these requirements without being limited by the data types and query languages available in traditional database systems. A key feature of object-oriented databases is the power they give the designer to specify both the structure of complex objects and the operations that can be applied to these objects.

Another reason for the creation of object-oriented databases is the increasing use of object-oriented programming languages in developing software applications. Databases are now becoming fundamental components in many software systems, and traditional databases are difficult to use when embedded in object-oriented software applications that are developed in an object-oriented

programming language such as C++, SMALLTALK, or JAVA. Object-oriented databases are designed so they can be directly—or seamlessly—integrated with software that is developed using object-oriented programming languages.

The need for additional data modeling features has also been recognized by relational DBMS vendors, and the newer versions of relational systems are incorporating many of the features that were proposed for object-oriented databases. This has led to systems that are characterized as object-relational or extended relational DBMSs (see Chapter 13). The next version of the SQL standard for relational DBMSs, SQL3, will include some of these features.

In the past few years, many experimental prototypes and commercial object-oriented database systems have been created. The experimental prototypes include the ORION system developed at MCC (Note 4), OPENOODB at Texas Instruments, the IRIS system at Hewlett-Packard laboratories, the ODE system at AT&T Bell Labs (Note 5), and the ENCORE/ObServer project at Brown University. Commercially available systems include GEMSTONE/OPAL of GemStone Systems, ONTOS of Ontos, Objectivity of Objectivity Inc., Versant of Versant Object Technology, ObjectStore of Object Design, ARDENT of ARDENT Software (Note 6), and POET of POET Software. These represent only a partial list of the experimental prototypes and the commercially available object-oriented database systems.

As commercial object-oriented DBMSs became available, the need for a standard model and language was recognized. Because the formal procedure for approval of standards normally takes a number of years, a consortium of object-oriented DBMS vendors and users, called ODMG (Note 7), proposed a standard that is known as the ODMG-93 standard, which has since been revised with the latest version being ODMG version 2.0.

Object-oriented databases have adopted many of the concepts that were developed originally for object-oriented programming languages. It contains origins of the object-oriented approach and how it applies to database systems, key concepts utilized in many object-oriented database systems. discusses object identity, object structure, and type constructors, encapsulation of operations and definition of methods as part of class declarations, and also discusses the mechanisms for storing objects in a database by making them persistent, type and class hierarchies and inheritance in object-oriented databases ,issues that arise when complex objects need to be represented and stored, polymorphism, operator overloading, dynamic binding, multiple and selective inheritance, and versioning and configuration of objects.

Characteristics of Object Oriented Data Model.

- Creating Abstract Data types
- Embedding the object types to tables
- Using Constructor methods
- Use of Varrays

- Use of Nested Tables
- Using REF and DEREF constructs
- Using Member Functions
- Using object views

b) <u>Embedding the object types to tables:</u>

- Objects that appear in object tables are called **row objects.**
- Objects that appear only in table columns or as attributes of other objects are called **column objects.**
- An embedded object is one that is completely contained within another.
- A column object is one that is represented as a column in a table.
- To take advantage of OO capabilities, a database must also support ROW OBJECTS – Objects that are represented as rows instead of columns.
- Object tables are used to establish a master-child relationship between objects.

Object Tables And OID (ROW OBJECTS)

- An object table is a special kind of table that holds objects and provides a relational view of the attributes of those objects. In an object table, each row is a row object.
- **Example**

```
CREATE OR REPLACE TYPE deptype AS OBJECT

(

deptno NUMBER,

dname VARCHAR2(20),

loc VARCHAR2(20)

);
```

<u>Embedding the object types to tables:</u>

Object Tables

Example

```
CREATE OR REPLACE TYPE deptype AS OBJECT

(

deptno NUMBER,

dname VARCHAR2(20),

loc VARCHAR2(20)

);
```

- This is a simple object type. To create a table out of this object type, the following syntax must be used.

CREATE TABLE deptab OF deptype;

<u>REFs</u>

- In the relational model, foreign keys express many—to—one relationship.
- Object option provides a more efficient means of expressing many-to-one relationships when the “one” side of the relationship is a row object.
- REFs only describe a relationship in one direction.
- Consider the deptab object table created using the deptype abstract data type :

CREATE TABLE EMPLOYEES

(

EMPNO NUMBER,

ename VARCHAR2(20),

deptno REF deptype);

- In the above example, DEPTNO column references data that is stored elsewhere. The REF operator points the DEPTNO column to the DEPTYPE data type.

<u>Using Object Views</u>

With object views, you can achieve the following benefits:

- **Efficiency of object access:** In PL/SQL, and particularly in Oracle Call Interface (OCI) applications, object programming constructs provide for convenient retrieval, caching, and updating of object data.
- **Ability to navigate using REFs.: C**an retrieve attributes from related "virtual objects" using dot notation rather than explicit joins.
- **Easier schema evolution:** object views offer more ways that you can change both table structure and object type definitions of an existing system.
- **Consistency with new object-based applications: T**he new components can be implemented in object tables; new object-oriented applications requiring access to existing data can employ a consistent programming model.

<u>Member Functions</u>

- When dealing with numbers, common convention dictates that the number with the larger value is greater than the other.
- But when objects are compared, the attributes based on the comparison may not be determined.
- In order to compare objects, Oracle allows declaring two

  types of **member functions** called **MAP** and **ORDER**.

  <u>MAP</u>

- Map Function is used to specify a single numeric value that is used to compare two objects of the same type.

- The greater than or less than or equality is based on this value.

  ORDER

- Order Function is used to write the specific code in order to compare two objects and the return value indicates the equality or greater or lesser comparisons.

Object Hierarchies - Generalization, Specialization, Aggregation. Object Schema.

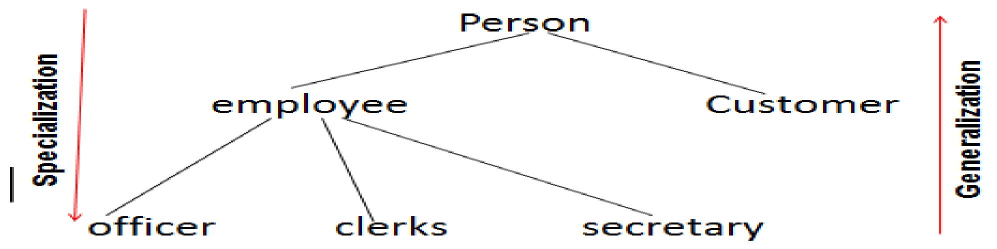
Class Definition Example

```
class employee {

/* Variables */

String  name;

string   address;

Date     start-date;

int        salary ;

/* Messages */

int        annual-salary ();

string    get-name();

string     get-address();

int         set-address(string new-address);

int         employment-length();

};
```

Object Hierarchies(generalisation-specialization)

- E.g., class of **bank customers** similar to class of **bank employees**: both share some variables and messages, e.g., name and address.
- But there are variables and messages specific to each class e.g., **salary** for employees and **credit-rating** for customers.
- Every employee is a person; thus employee is a specialization of person
- *Similarly, customer is a specialization of person.*
- Create classes person, employee and customer
- – variables/messages applicable to all persons associated with class person.
- – variables/messages specific to employees associated with class employee; similarly for customer

- Place classes into a specialization/IS-A hierarchy
- variables/messages belonging to class person are inherited by class employee as well as customer
- Result is a class hierarchy as shown below



(Note: It is analogous with ISA hierarchy in the E-R model)

- **class person *{***

  string name;

  string address; *}* ;

- **class customer isa person *{***

  int credit-rating; *}*;

- **class employee isa person {**

  date start-date;

  int salary ; };

- **class officer isa employee *{***

  int office-number ;

  int expense-account-number ;*}*;

- Full variable list for objects in the class officer:
- **office-number, expense-account-number: defined locally**
- **start-date, salary: inherited from employee**
- **name, address: inherited from person**
- *Methods are inherited similar to variables.*
- **Generalization/Specialization is the IS A relationship, which is supported in OODB through** class hierarchy.
- E.g. An ArtBook is a Book, therefore the ArtBook class is a subclass of Book class. A subclass inherits all the attribute and method of its super class.
- Three subclasses—Officer, Clerks and Secretary are **generalized** into a **super class** called Employee.

Object Hierarchies(Aggregation)

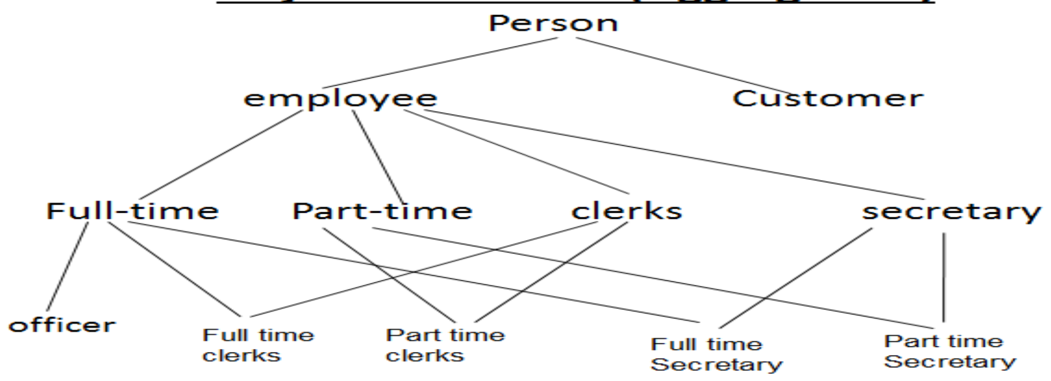


fig.(Class DAG for banking class)

- Aggregation means class composition.

- The class/subclass relationship is represented by a directed acyclic graph (DAG) — a class may have more than one super class.
- *A class inherits variables and methods from all its*

  Super classes.
- There is potential for ambiguity. E.g., variable with the same name inherited from two super classes.
- Can use multiple inheritance to model "roles" of an object.

  e.g. a person can play the role of employee, customer and at the same time of a secretary(either one or all the three roles).

  Object Schema(Object Class)
- Similar objects are grouped into a class; each such object is called an instance of its class.
- *All objects in a class have the same*

  – variable types

  – message interface

  – methods
- They may differ in the values assigned to variables
- *Example: Group objects for people into a person class*
- *Classes are analogous to entity sets in the E-R model*

  Inter Object Relationship
- Object references are inherently unidirectional.
- In using direct references between entities, the basic object-oriented data model inhibits the maintenance of data independence and the expression of multi-directional relationships, which improves semantic modeling.
- New integrity constraints can guarantee the uniqueness of either or both participants in one-to-many, many-to-one, and one-to-one relationships.
- Object relationships become explicit instead of being hidden throughout object implementations .

- The use of relationships enhances the *data independence of a database.*
- An inter-object relationship indicates that the referenced object should be the most current, and transient version.
- An inter-object relationship indicates that the referenced object should be a *specific* working version.

<u>Differences in Data Models</u>

- The type of a database is decided by the data model used in the design of the database.
- Data models are data structures which describe how data are represented and accessed.

➢ **Hierarchical model** contains data organized into a tree-like structure.

➢ This supports parent-child relationships between data similar to a tree data structure where object types are represented by nodes and their relationships are represented by arcs.

- This model is restrictive in that it only allows **one to many relationship** (a parent can have many children but a child can only have one parent)
- **Network Model** is similar to the hierarchical model in representation of data but allows for greater flexibility in data access as it supports **many to many** relationships.
- **Relational Model** organizes data into two dimensional arrays known as relations(tables) and each relation consists of rows and columns.
- Another major characteristic of relational model is that of keys – designated columns in a relation used to order data or establish relations.
- **Object Data Model** aims to reduce the overhead of converting information representation in the database to an application specific representation.
- object model allows for data persistence and storage by storing objects in the databases .
- The relationships between various objects are inherent in the structure of the objects.
- This is mainly used for complex data structures.
- **Object oriented databases or object databases** incorporate the object data model to define data structures on which database operations such as CRUD can be performed.
- They store objects rather than data such as integers and strings. The relationship between various data is implicit to the object and manifests as object attributes and methods
- Object database management systems extend the object programming language with transparently persistent data, concurrency control, data recovery, associative queries, and other database capabilities.

<u>Similarities</u>

- An object corresponds to an entity in the E-R model.
- The object-oriented paradigm is based on encapsulating code and data related to an object into a single unit.
- The object-oriented data model is a logical model like the E-R model.
    - Comparison between OODBMS and RDBMS

OODBMS	**RDBMS**
object class	tuple
Instance variable	column, attribute
class hierarchy	database scheme (is-a relation)
collection class	Relation
OID(Object Identifier)	Key
Message	Procedure Call
Methods	Procedure Body

- The following table shows the advantages and disadvantages using OODBS over RDBS.

Advantages	**Disadvantages**
• Complex objects & relations • Class hierarchy • No impedance mismatch • No primary keys • One data model • High performance on certain tasks • Less programming effort because of inheritance, re-use and extensibility of code	• Schema change (creating, updating.) is non trivial, it involves a system wide recompile. • Lack of agreed upon standard • Lack of universal query language • Lack of Ad-Hoc query • Language dependence: tied to a specific language • Don't support a lot of concurrent users

Achievements Of OODBMS

1. ***Support for User Defined data types:*** *OODBs* provides the facilities of defining new user defined data types and to maintain them.

2. ***OODB's allow creating new type of relationships :*** OODBs allow creating a new type of relationship between objects is called inverse relationship (a binary relationship).

3. ***No need of keys for identification:*** *Unlike, relational* model, object data model uses object identity (OID) to identify object in the system

4. ***Development of Equality predicates:*** *In OODBs, four* types equality predicates are:

• Identity equality

• Value equality of objects

• Value equality of properties

• Identity equality of properties

5. ***No need of joins for OODBMS's****: OODBs has ability* to reduce the need of joins .

6. ***Performance gains over RDBMS:*** *Performance gains* changes application to application. Applications that make the use of object identity concept having performance gains over RDBMS's.

7. ***Provide Facility for versioning management:*** *The* control mechanisms are missing in most of the RDBMS's, but it is supported by the OODBMS's .

8. ***Support for nested and long Duration transactions:*** Most of the RDBMS's do not support for long and nested transactions, but OODBMS's support for nested and long duration transactions.

9. ***Development of object algebra:*** *Relational algebra is* based on relational mathematics and fully implemented, but object algebra has not been defined in proper way. Five fundamental object preserving operators are: union, difference, select, generate and map.

Drawbacks Of OODBMS

1. *Coherency between Relational and Object Model:* Relational databases are founded in every organization. To overcome relational databases, object databases have to be providing coherent services to users to migrate from relational database to object database. Architecture of Relational model and Object model must be provide some coherency between them [9].

2. *Optimization of Query Expression:* *Query expression* optimization is done to increase the performance of the system Optimization of queries is very important for performance gains. But due to following reasons it is difficult to optimize queries in object databases:

• User defined data types

• Changing variety of types

• Complex objects, methods and encapsulation

• Object Query language has nested structure

• Object Identity

3. *No fixed query algebra for OODBMS's:* *Due to lack* of the standards in OODBMS, there is no standard query algebra for OODB. Lack of standard query algebra becomes one of the reasons for problem of query optimization. There are different query languages for different object databases.

4. No full-fledged query system: *Query system also not* fully implemented. Some query facilities lacks in Object databases like nested sub-queries, set queries and aggregation function.

5. *No facility for Views:* *In relational databases, views* are temporary tables. Object databases having no facility for views. An object oriented view capability is difficult to implement due to the features of Object Model such as object identity. Object oriented programming concepts like inheritance and encapsulation makes the difficult to implement views in object databases.

6. _*Security problems in Object databases:*_ *Security is* related to authentication, authorization and accounting. Discretionary Access Control (DAC), Mandatory Access Control (MAC) security policies are implemented in object databases to secure data. In some systems provide security on the basis of object oriented concepts like encapsulation. Object database having to facilities for authorization.

A **schema** is a collection of logical structures of data, or schema objects. A schema is owned by a database user and has the same name as that user. Each user owns a single schema. Schema objects can be created and manipulated with SQL and include the following types of objects:

- Clusters
- Database links
- Database triggers
- Dimensions
- External procedure libraries
- Indexes and index types
- Java classes, Java resources, and Java sources
- Materialized views and materialized view logs
- Object tables, object types, and object views
- Operators
- Sequences
- Stored functions, procedures, and packages
- Synonyms
- Tables and index-organized tables
- Views

Other types of objects are also stored in the database and can be created and manipulated with SQL but are not contained in a schema:

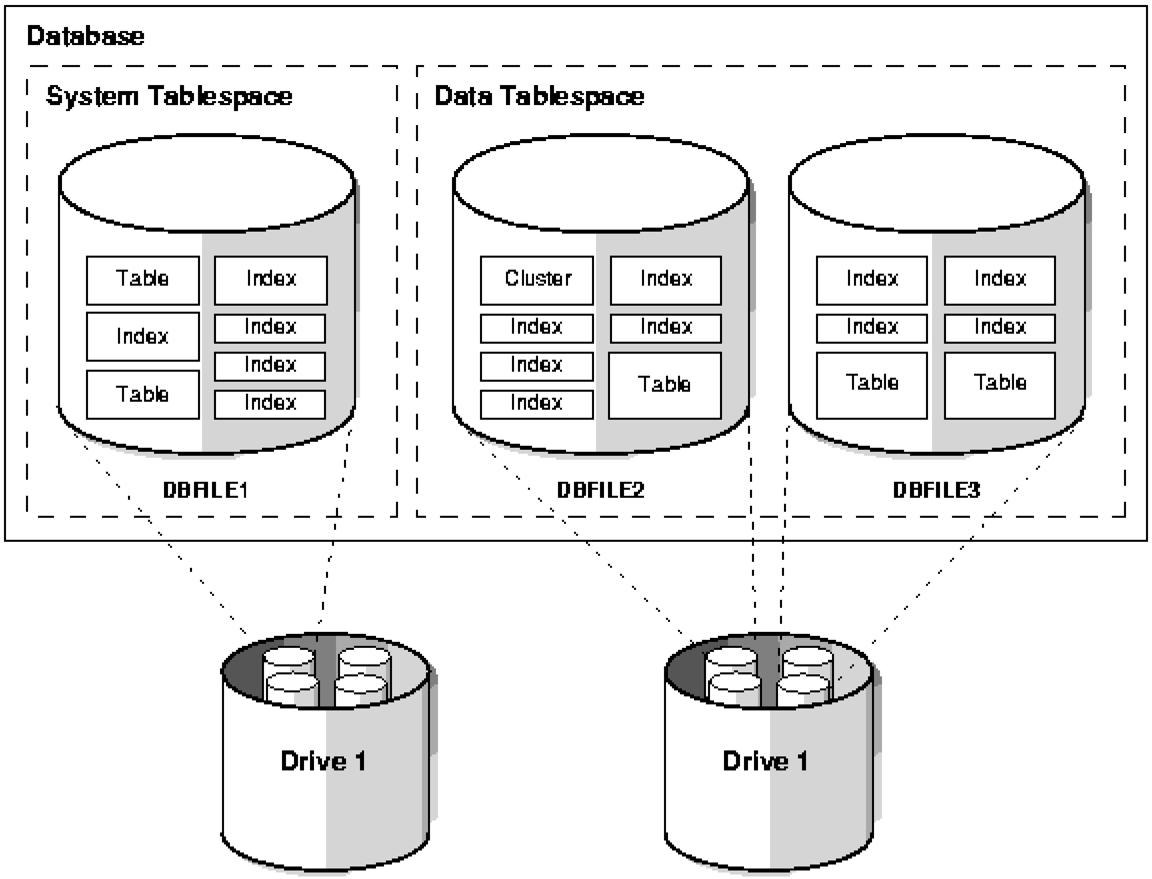
- Contexts
- Directories
- Profiles
- Roles
- Tablespaces
- Users
- Rollback segments

Schema objects are logical data storage structures. Schema objects do not have a one-to-one correspondence to physical files on disk that store their information. However, Oracle stores a schema object logically within a tablespace of the database. The data of each object is physically contained in one or more of the tablespace's datafiles. For some objects, such as tables, indexes, and clusters, you can specify how much disk space Oracle allocates for the object within the tablespace's datafiles.

There is no relationship between schemas and tablespaces: a tablespace can contain objects from different schemas, and the objects for a schema can be contained in different tablespaces.

Figure 10-1 illustrates the relationship among objects, tablespaces, and datafiles.

Figure 10-1 Schema Objects, Tablespaces, and Datafiles



Inter-object Relationships, Similarities and difference between Object Oriented Database model and Other Data models.

3.2 OODBMS Architecture Approach: The Extended Relational Model Approach. Semantic Database Approach, Object Oriented Programming Language Extension Approach, DBMS Generator Approach, the Object Definition Language and the Object Query Language.

OODBMS Architecture Approach: The Extended Relational Model Approach.

Semantic Database Approach,

Object Oriented Programming Language Extension Approach,

DBMS Generator Approach,

the Object Definition Language and the Object Query Language.

3.3 The Object Oriented DBMS Architecture, Performance Issue in Object Oriented DBMS, Application Selection for Object Oriented DBMS, the Database Design for an Object Relational DBMS. The Structured Typed and ADTs, Object identity, Extending the ER Model ,Storage and Access Methods, Query Processing Query Optimization, Data Access API(ODBC,DB Library, DAO,ADO,JDBC,OLEDB), Distributed Computing Concept in COM, COBRA.

The Object Oriented DBMS Architecture,

The very popular ANSI/SPARC architecture [1] gives three levels that drive the data access and management of a database. These three levels are external, conceptual, and the internal. The external level consists of particular views of data dedicated to particular client applications or particular users. In relational databases the external level implements two kinds of facilities: access privileges to particular resources grated by database administrator to particular users. The SQL views that customize encapsulated and restrict resources to be accessed. This approach has proven to be enough simple and satisfactory for majority of applications of relational databases. The conceptual level is common for the entire database environment. In this level the storage structure of data is defined. The Internal of Physical level describes the physical storage of data on secondary device.

But the situation is different in object oriented database, the complex structure data is managed by object oriented database. Piotr Habela1 et. al. [2] provides foundation for three-level database architecture and correspondingly three database development roles: (1) a database programmer defines stored objects, i.e. their state and behavior; (2) a database administrator (DBA) creates views and interfaces which encapsulate stored objects and possibly limit access rights on them; (3) an application programmer or a user
receives access and updating grants from DBA in the form of interfaces to views. They present a concrete solution that they developed as a platform for grid and Web applications.
The problem how to efficiently store, retrieve, analyze and modify the biological data and multimedia data are
becoming an important issue for most biological scientists and computer scientists who is working in the field of multimedia data manipulation. In order to solve this problem, a Domain Specific Object Oriented Data Base Management System (DSOODBMS) is designed to manipulate Protein Data that is biological data, Yanchao Wang et. al.[3]. They have designed special architecture for the protein data in object oriented databases.
Muhammad Ubaid et al.[4] have describe in their paper that the object oriented techniques may include features such as encapsulation, modularity, polymorphism, and inheritance, for implementing this paradigm. They suggested that there should be a good architecture design of classes' schema for the OODBM system that could help to maintain the relationship between the objects and fulfill the core concept of the object oriented. When we are storing the data as object in OODBMS than OODBMS maintain the Object Identity (OID) and the identity of an object has an existence independent of the values of the object attributes, Elisa Bertino et. al. [5].

2. 2. Architecture design issues for OODBMS

The architecture play important role in database system to manage the data. The architecture design decisions concern the rules for data transfer from database server to client and client to database server, vice versa. The error handling is also important issue while transferring data
between user and machine. The machine is consisting with physical devices. The error may

occur due to power fluctuation while storing the data in physical memory. The different kinds of users and is independent of databases, therefore users can request data in Object Oriented format, but data can be stored in multiple formats in Object oriented databases system, Yanchao Wang1 et. al. [6]. They used Object oriented database as their middleware part that reduced interpretation work and interpretation time among different language translation. If one chooses some object-oriented database system (OODBMS) to manage the data, then the data needs to be loaded and stored by that system in its internal data formats (i.e. persistent C++ structures). These data formats will not work with legacy software, Arie Shoshani [7]. Similarly, if the data is stored in traditional table formats, that cannot be readily used by C++ programs. Rick Cattell [8], has described in his paper, if someone want the object-oriented programming language integration of object-oriented DBMSs, they can use object/relational mapping solutions, albeit with some performance and convenience drawbacks.

3. Object oriented database layers architecture model

This section describes the layers architecture in object oriented databases. Data are transfer from database server to client, which passes through six layers. These six layers have different responsibility do as per requirement. The fig 1.1 shows the six layer architecture model for object oriented data model.

3.1 Interaction layer

The interaction layer is first layer of Six Layers Architecture Model for Object Oriented Databases. In this layer, user can interact with the databases. The user can send the data to databases as well as data can be retrieved from database to user. Robert Greene [9] has talking about individual operations within a transaction, and then there are lots of possibilities. To that end, I'm not sure what was Mariott's point about millions of objects needing to be locked and the impact of that in the object based architecture.

3.2 Application layer

The application is the second layer in this model. Robert Greene[10] making that assumption, if by chance an early adopter choose an ODB who's architecture was ill suited for their applications needs, the reasoning lead immediately to the conclusion that no ODB was suited to solve their needs. From this illogical thinking came the permeation of misconceptions regarding the OODB: they are too slow, they don't handle high concurrency, and they don't scale with large data.

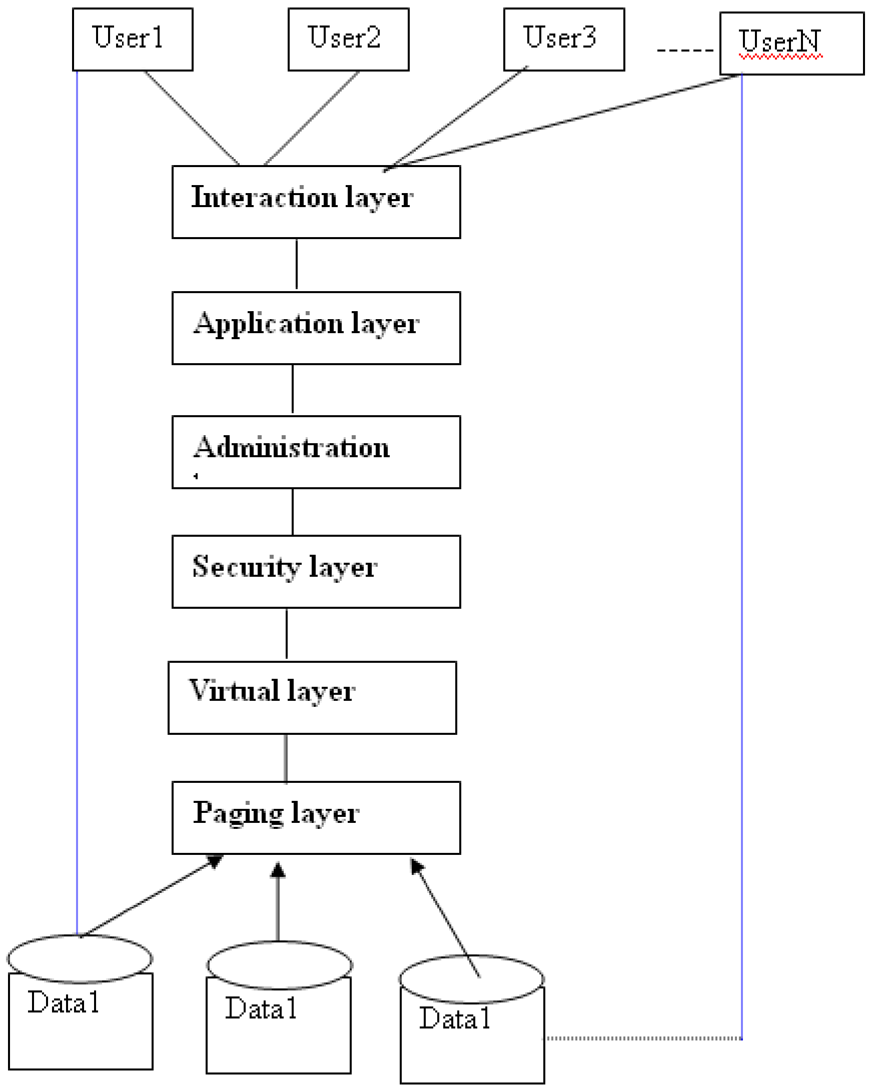


Fig: 1.1 Six layers Architecture Model for Object oriented database

3.3 Administration Layer

This layer is responsible for management of administrative information. This layer can change responsibility as per requirement. Cristina Ribeiroet al.[11] disused the traditional administrative information, pharmaceutical companies, as knowledge intensive organizations, retain a large number of scientific records pertaining to their research and development activities. They also strict requirements of the quality system impose complex data as well as document workflows. The success in preserving complex structures like
databases depends crucially on the amount of information that is lost in the process and this is inversely related to the amount of metadata included in the preservation package. In this model Administration layer control the flow of data as well as provide the permission to access the data.

3.4 Security Layer

The security layer play important role in this model. The security layer is responsible to provide the full security to data and also provide to the security of application used to manage the data also. David Litchfield[14] examined the differences between the security posture of Microsoft's SQL server and Oracle's RDBMS based upon flaws reported by external security researchers and since fixed by the vendor. This layer can provide the authentication to the uses as well as the authentication to databases administrators. All the security concerned is considered in this layer. Who can use what type of data.

3.5 Virtual Layer

M. Abdelguerfi et. al[12] have shown that the main advantage in their approach is that the memory requirement of each slice processor is very small and is independent of input size. In this model the virtual layer manage the data virtually. This time the large volume of data are managed. The concept of virtual is to put the data outside the memory. As per the requirement the data are converted in real memory. In this ways, the problem to manage large data is solved.

3.6 Paging Layer

M. K. Mohania and N. L. Sarda [13] described three level architecture for a DDedDBS which addresses the problems of partitioning and distributing a large rule base and efficient query handling. The paging layer is responsible to divide the data in the form of pages. The pages are managed easily. The data are divided into pages as the same size of page frame; the page frame is that dividing memory in equal number of partitions. In this way large volume of data can be managed efficiently.

4. Conclusions

This model will be beneficial to manage the large and complex data. The large and complex data are managed efficiently in object oriented database management system. This model is developed by considering the all aspect of data. In this model data can passed through different layer and each layer con perform their duties separately.

Performance Issue in Object Oriented DBMS,

1) Better Support for Complex Applications

- ODBMSs have provided better support for certain applications requiring high performance and modeling of complex relationships and heavily inter-related data that have traditionally not been well served by other DBMSs.

2)Enhance Programmability

- The seamless integration of an application programming language and database DDL/DML

enables further savings in code.

3)Improve Performance

- An ODBMS has more "knowledge" of the operations being performed, and can therefore provide better control of concurrently executing transactions. This leads to better performance.

4) Improve Navigational Access

- Using declarative query languages has proved to be very useful in relational systems.
- However, users should not be constrained in the way they interact with a database. It should be possible to support a variety of interaction styles (e.g. natural language, menus, prompts, graphical browsers, etc.) that can all be used to augment the formal command language of the database. In any case, there are many structures for which a navigational mode of access is more natural and intuitive than using a declarative query language.

5)Simplify Concurrency Control

- Detailed locking strategies for some ODBMSs provide highly sophisticated control of objects (e.g. ORION).

- At a coarse level of granularity, it is possible to place a single lock on an entire object hierarchy.
- In contrast, an RDBMS would require multiple locks to get information from related but scattered data in the database.
- At a fine level of granularity, individual objects or attributes of objects could be locked.

6) Reduce Problems of Referential Integrity

- One of the major problems with relational databases has been that of dangling references.
- This problem has been solved in object databases by giving the responsibility of pointer maintenance to the database itself, rather than to each application.

7) Abstraction Gain

- The object paradigm provides a better modeling framework that captures not only data and behavior, but raises the level of abstraction (an object is more

than the sum of its attributes and methods).

Application Selection for Object Oriented DBMS,

- Basically, an OODBMS is an object database that provides DBMS capabilities to objects that have been created using an object-oriented programming language (OOPL).
- The basic principle is to add persistence to objects and to make objects persistent.
- Consequently application programmers who use OODBMSs typically write programs in a native OOPL such as Java, C++ or Smalltalk, and the language has some kind of Persistent class, Database class, Database Interface, or Database API that provides DBMS functionality as, effectively, an extension of the OOPL.
- Object-oriented DBMSs, therefore, support advanced object-oriented database applications with features like support for persistent objects from more than one programming language, distribution of data, advanced transaction models, versions, schema evolution, and dynamic generation of new types.
- In today's world, Client-Server applications that rely on a database on the server as a data store while servicing requests from multiple clients are quite commonplace.
- Most of these applications use a Relational Database Management System (RDBMS) as their data store while using an object oriented programming language for development.
- This causes a certain inefficency as objects must be mapped to tuples in the database and vice versa instead of the data being stored in a way that is consistent with the programming model.

- An OODBMS is thus a full scale object oriented development environment as well as a database management system. Features that are common in the RDBMS world such as transactions, the ability to handle large amounts of data, indexes, deadlock detection, backup and restoration features and data recovery mechanisms also exist in the OODBMS world.
- A primary feature of an OODBMS is that accessing objects in the database is done in a transparent manner such that interaction with persistent objects is no different from interacting with in-memory objects.
- An object-oriented database management system (OODBMS), sometimes shortened to *ODBMS* for *object database management system*), is a database management system (DBMS) that supports the modelling and creation of data as objects.

the Database Design for an Object Relational DBMS.

- Idea is to not use a DBMS (Relational or Object-Oriented.)
- Instead, design data management classes which handle persistence, caching, etc.
- These classes decouple applications from their persistent storage.
- Use data management classes whenever you need to:

✓ Store an application object;

✓ Search for or retrieve stored objects;

✓ Interface with an external database.

✓ This solution won't work for large data sets!

Data Storage layer:

- Options for locating the operations that handle the tasks of storing and retrieving objects:
- All persistent objects in the system could inherit methods for storage from an abstract superclass i.e.PersistentObject
- Introduce separate classes into the system whose role is to deal with the storage and retrieval of other classes i.e. (Database broker approach)

1. ***PersistentObject Superclass Approach***

- A superclass PersistentObject encapsulates the

  mechanisms for an object of any class to store itself in, or retrieve itself from a database.
- This superclass implements operations to get an object by object identifier, store, delete and update objects and to iterate through a set of objects (write and read operations).

2. *Database Broker Approach*

- Each persistent class could be responsible for its own storage...but
- ✓ highly coupled (to storage mechanism);
- ✓ lessens class cohesion;
- ✓ class must now have expert knowledge of storage tasks;
- ✓ these are unrelated to application tasks.
- Separates the business objects from their data storage implementation.
- The classes that provide the data storage services will be held in a separate package.
- For each business class that needs to be persistent, there will be an associated database broker class.

<u>The Broker Class:</u>

- The broker class provides the mechanisms to materialize objects from the database and dematerialize them back to the database.

<u>The Database Broker:</u>

- The database broker object is responsible for:
- ✓ "materialising" objects,
- ✓ "dematerialising" objects,
- ✓ caching objects.
- Application classes are insulated from storage.
- Allows migration of storage sub-systems, e.g., implement on existing relational system.
- Replace this with OODBMS.
- Application programs unaffected by change.

<u>Caching Objects</u>

- Objects can be cached for efficiency.
- The cache is a collection maintained by the database broker.
- When an object is requested, the cache is searched first.
- If the object sought is not in the cache it is materialised by the database broker from the database.

Collections

- In systems where collection classes are used in design, these

  may be replaced by database broker objects.

- Database objects provide collection-like services for large volumes of data (more than you would maintain in a collection

class in memory).

The Structured Typed and ADTs, Object identity,

Object identifier

- An object is defined by a triple (OID, type constructor, state) where OID is the unique object identifier, type constructor is its type (such as atom, tuple, set, list, array, bag, etc.) and state is its actual value.
- Example:
  (i1, atom, 'John')
  (i2, atom, 30)
- An object has structure or state (variables) and methods (behavior/operations)
- An object is described by four characteristics

✓ Identifier: a system-wide unique id for an object

✓ Name: an object may also have a unique name in DB (optional)

✓ Lifetime: determines if the object is persistent or transient

✓ Structure: Construction of objects using type constructors

Using an oid to refer to an object is similar to using a foreign key to refer to a record in another relation, but not quiet the same:

- An **oid** can point to an object of theater_t that is stored anywhere in the database, even in a field
- Whereas a **foreign key** reference is constrained to point to an object in a particular reference relation.

Extending the ER Model ,

Storage and Access Methods,

- The main purpose of a DBMS was to centralize and organize data storage. A DBMS program ran on a single, large machine.

- Data is often distributed among many systems, which is the consequence of an external program without changing the code in any way, or even recompiling it.
- But making such system scalable requires using other features of the ORDBMS: the distributed database functionality, commercially available gateways, and the open storage manager . Combining these facilities provides the kind of *location transparency necessary for the development of distributed information* systems.
- ORDBMSs possess storage manager facilities similar to RDBMSs.
- Disk space is taken under the control of the ORDBMS, and data is written into it according to whatever administrative rules are specified.
- All the indexing, query processing, and cache management techniques that are part of an RDBMS are also used in an ORDBMS.
- Further, distributed database techniques can be adapted to incorporate user-defined types and functions. However, all of these mechanisms must be re-implemented to generalize them so that they can work for user-defined types.

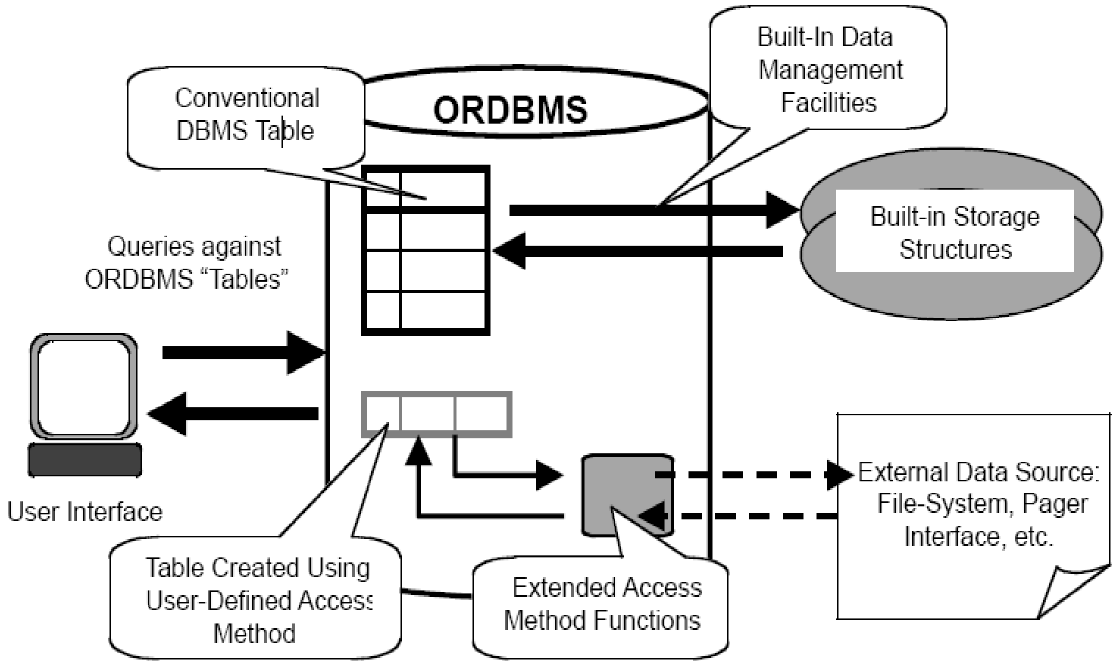

Built-In Data Management Facilities
Conventional DBMS Table
ORDBMS
Built-in Storage Structures
Queries against ORDBMS "Tables"
User Interface
External Data Source: File-System, Pager Interface, etc.
Table Created Using User-Defined Access Method
Extended Access Method Functions

Figure 1–6. *Extensible Storage Manager*

<u>New Data Types</u>

- User-define abstract data type (ADT)
    - ✓ ADT include image, voice, and video footage, and these must be stored in the database - Must write compress functions to support (lower resolution).
- ✓ ORDBMS key feature is allowing users to define arbitrary new data type. Such as:

        - compress, rotate, shrink and crop

- ✓ Combination of an atomic data type and its associated methods is called: Abstract data type (ADT). Such object-relational systems, user allows to include ADT.
    - Structured types
    - In this application, as needed in many traditional business data processing applications, we need new types built up from atomic types using constructors for creating sets, records, arrays, sequences, and so on..

- Structured types

- ✓ ROW

A type representing a row, or record, of n field with fields n of type n….etc

- ✓ Listof(base)

Type representing a sequence of base-type items

- ✓ Array(base)

A type representing an array of base-type items

- ✓ Setof(base)

A type representing a set of base-type items. Sets cannot contain duplicate elements.

- ✓ bagof(base)

A type resenting a bag or multiset of based-type items

Query Processing

- **It was commonly believed that the application domains that OODBMS technology targets do not need querying capabilities.**
- **The issues related to the *optimization and execution of OODBMS query languages* which we collectively call *query processing*.**

Query Optimization,

Query Processing Architecture

two architectural issues:

- the query processing methodology and
- the query optimizer architecture.

Query Processing Methodology

- A query processing methodology similar to relational DBMSs, but modified to deal with the difficulties can be followed in OODBMSs.

Steps of methodology are

- Queries are expressed in a declarative language which requires no user knowledge of object implementations, access paths or processing strategies.
- The calculus expression is first reduced to a normalized form by eliminating duplicate predicates, applying identities and rewriting.
- The normalized expression is then converted to an equivalent object algebra expression.
- This form of the query is a nested expression which can be viewed as a tree whose nodes are algebra operators and whose leaves represent extents of classes in the database.
- The algebra expression is next checked for type consistency to insure that predicates and methods are not applied to objects which do not support the requested functions.
- This is not as simple as type checking in general programming languages since intermediate results, which are sets of objects, may be composed of heterogeneous types.
- The next step in query processing is the application of equivalence-preserving rewrite rules to the type consistent algebra expression. Lastly, an execution plan which takes into account object implementations is generated from the optimized algebra expression.

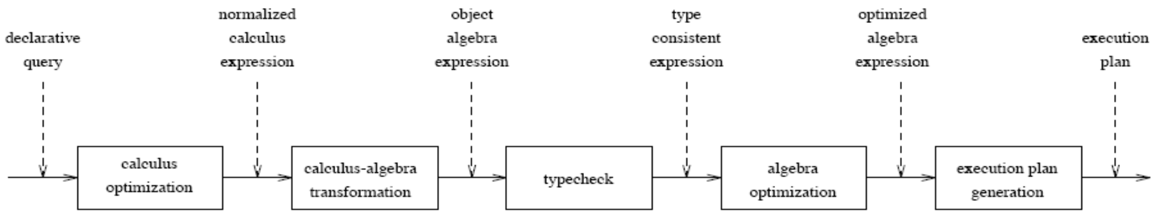

declarative query
normalized calculus expression
object algebra expression
type consistent expression
optimized algebra expression
execution plan
calculus optimization
calculus-algebra transformation
typecheck
algebra optimization
execution plan generation

Figure 1: Object query processing methodology

Optimizer Architecture

- Query optimization can be modeled as an optimization problem whose solution is the choice of the "optimum" *state in* a *state space (also called search space). In query optimization, each state corresponds to an algebraic query indicating* an execution schedule and represented as a processing tree.

- The state space is a family of equivalent (in the sense of generating the same result) algebraic queries.
- Query optimizers generate and search a state space using a *search strategy applying a cost function to each state and finding one with minimal cost1.*

Thus, to characterize a query optimizer three things need to be specified:

1. the search space and the the transformation rules that generate the alternative query expressions which constitute the search space;
2. a search algorithm that allows one to move from one state to another in the search space; and
3. the cost function that is applied to each state.

Optimization Techniques

The optimization techniques for object queries follows two fundamental directions.

1. The first is the **cost-based optimization of queries based on algebraic manipulations.** Algebraic optimization techniques have been studied quite extensively within the context of the relational model.
2. The second is the optimization of ***path expressions.***

Path expressions represent traversal paths between objects and are unique to OODBMSs. The optimization of path expressions is an important issue in OODBMSs and has been a subject of considerable investigation.

1. **Algebraic Optimization**

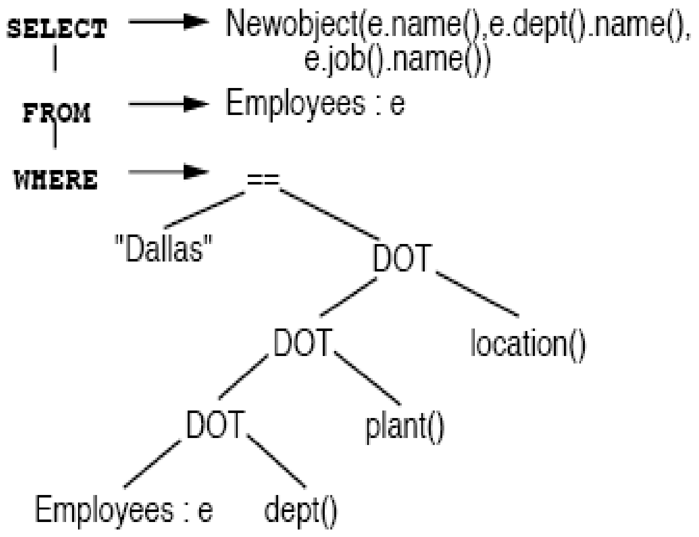
- ✓ Search Space and Transformation Rules
- ✓ Search Algorithm
- ✓ Cost Function
- ✓ Parameterization

2. **Path Expressions**

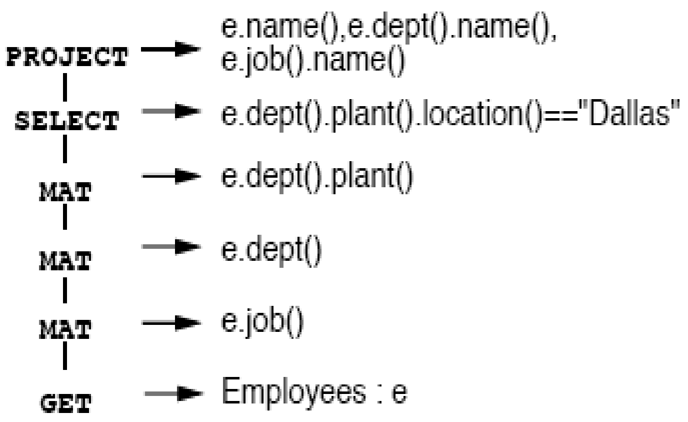
- ✓ **Rewriting**
- ✓ **Algebraic optimization**
- ✓ **Path indexes**

```
SELECT Newobject(e.name(),e.dept().name(),
                 e.job().name())
FROM Employee e IN Employees
WHERE e.dept().plant().location()=="Dallas";
```

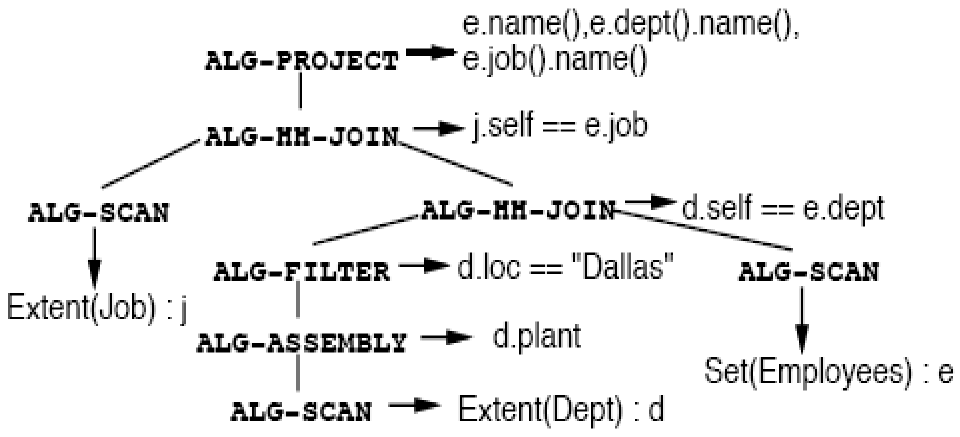
(a) User Query.



(b) After Parsing.



(c) After Rewriting.



(d) After Optimization.

Query Execution

- The relational DBMSs benefit from the close correspondence between the relational algebra operations and the access primitives of the storage system.
- Therefore, the generation of the execution plan for a query expression basically concerns the choice and implementation of the most efficient algorithms for executing individual algebra operators and their combinations.
- In OODBMSs the issue is more complicated due to the difference in the abstraction levels of behaviorally defined objects and their storage.
- Encapsulation of objects, which hides their implementation details, and the storage of methods with objects.

- A query-execution engine requires three basic classes of algorithms on collections of objects: (collection) *scan, indexed scan, and collection matching. Collection scan is a straightforward algorithm that sequentially accesses all* objects in a collection.

Data Access API(ODBC,DB Library, DAO,ADO,JDBC,OLEDB),

ODBC

- **Open Database Connectivity** (**ODBC**) is a standard application programming interface (API) for accessing database management systems (DBMS). The designers of ODBC aimed to make it independent of database systems and operating systems.
- An application written using ODBC can be ported to other platforms, both on the client and server side, with few changes to the data access code.
- ODBC accomplishes DBMS independence by using an *ODBC driver* as a translation layer between the application and the DBMS.
- The application uses ODBC functions through an *ODBC driver manager* with which it is linked, and the driver passes the query to the DBMS.
- ODBC provides a vendor-independent database-access API. The ODBC API has been wildly successful as a database-access standard. Virtually all products that require database access support it, and the most recent ODBC driver supports the SQL Server 7.0 enhancements. You use a call-level interface (CLI) to implement the ODBC API.

ODBC(Components of odbc)

- **ODBC API**

A library of function calls, a set of error codes, and a standard SQL syntax for accessing data on DBMSs.

- **ODBC Driver Manager**

A dynamic-link library (Odbc32.dll) that loads ODBC database drivers on behalf of an application. This DLL is transparent to your application.

- **ODBC database drivers**

One or more DLLs that process ODBC function calls for specific DBMSs. For a list of supplied drivers, see ODBC Driver List.

- **ODBC Cursor Library**

A dynamic-link library (Odbccr32.dll) that resides between the ODBC Driver Manager and the drivers and handles scrolling through the data.

- **ODBC Administrator**

A tool used for configuring a DBMS to make it available as a data source for an application.

Db library

- DB-Library provides source code compatibility for older Sybase applications. Sybase encourages programmers to implement new applications with Client-Library or Embedded SQL.
- DB-Library/C includes C routines and macros that allow an application to interact with Adaptive Server and Open Server applications.
- It includes routines that send commands to Adaptive Server and Open Server applications and others that process the results of those commands. Other routines handle error conditions, perform data conversion, and provide a variety of information about the application's interaction with a server.
- DB-Library/C also contains several header files that define structures and values used by the routines. Versions of DB-Library have been developed for a number of languages besides C, including COBOL, FORTRAN, Ada, and Pascal.

DAO(Data Access Objects)

- In computer software, a **data access object** (**DAO**) is an object that provides an abstract interface to some type of database or other persistence mechanism.
- By mapping application calls to the persistence layer, the DAO provides some specific data operations without exposing details of the database.
- This isolation supports the Single responsibility principle. It separates what data access the application needs, in terms of domain-specific objects and data types (the public interface of the DAO), from how these needs can be satisfied with a specific DBMS, database schema, etc. (the implementation of the DAO).
- it is traditionally associated with Java EE applications and with relational databases (accessed via the JDBC API)
- The advantage of using data access objects is the relatively simple and rigorous separation between two important parts of an application that can but should not know anything of each other, and which can be expected to evolve frequently and independently.
- Changing business logic can rely on the same DAO interface, while changes to persistence logic do not affect DAO clients as long as the interface remains correctly implemented. All details of storage are hidden from the rest of the application (information hiding).
- DAOs act as an intermediary between the application and the database. They move data back and forth between objects and database records.

JDBC(Java database connectivity)

- The Java Database Connectivity (JDBC) API is the industry standard for database-independent connectivity between the Java programming language and a wide range of databases – SQL databases and other tabular data sources, such as spreadsheets or flat files. The JDBC API provides a call-level API for SQL-based database access.
- JDBC technology allows you to use the Java programming language to exploit "Write Once, Run Anywhere" capabilities for applications that require access to enterprise data. With a JDBC technology-enabled driver, you can connect all corporate data even in a heterogeneous environment.

Oledb

- **OLE DB** (*Object Linking and Embedding, Database*, sometimes written as **OLEDB** or **OLE-DB**), an API designed by Microsoft, allows accessing data from a variety of sources in a uniform manner. The API provides a set of interfaces implemented using the Component Object Model (COM); it is otherwise unrelated to OLE. Microsoft originally intended OLE DB as a higher-level replacement for, and successor to, ODBC, extending its feature set to support a wider variety of non-relational databases, such as object databases and spreadsheets that do not necessarily implement SQL.
- OLE DB is Microsoft's strategic low-level application program interface for access to different data sources. OLE DB includes not only the Structured Query Language capabilities of the Microsoft-sponsored standard data interface Open Database Connectivity but also includes access to data other than SQL data.

Distributed Computing Concept in COM, COBRA.

What is COM?

- Microsoft COM (Component Object Model) technology in the Microsoft Windows-family of Operating Systems enables software components to communicate. COM is used by developers to create re-usable software components, link components together to build applications, and take advantage of Windows services. COM objects can be created with a variety of programming languages. Object-oriented languages, such as C++, provide programming mechanisms that simplify the implementation of COM objects. The family of COM technologies includes COM+, Distributed COM (DCOM) and ActiveX® Controls.
- Microsoft provides COM interfaces for many Windows application programming interfaces such as Direct Show, Media Foundation, Packaging API, Windows Animation Manager, Windows Portable Devices, and Microsoft Active Directory (AD).
- COM is used in applications such as the Microsoft Office Family of products.

What is CORBA?

- The Common Object Request Broker Architecture (CORBA) is a standard developed by the Object Management Group (OMG) to provide interoperability among distributed objects.

- CORBA is the world's leading middleware solution enabling the exchange of information, independent of hardware platforms, programming languages, and operating systems.
- CORBA is essentially a design specification for an Object Request Broker (ORB), where an ORB provides the mechanism required for distributed objects to communicate with one another, whether locally or on remote devices, written in different languages, or at different locations on a network.
- CORBA is often described as a "software bus" because it is a software-based communications interface through which objects are located and accessed.

- Using CORBA, application components can communicate with one another no matter where they are located, or who has designed them. CORBA provides the location transparency to be able to execute these applications.
- In order to build a system that uses or implements a CORBA-based distributed object interface, a developer must either obtain or write the IDL code that defines the object-oriented interface to the logic the system will use or implement.
- Typically, an ORB implementation includes a tool called an IDL compiler that translates the IDL interface into the target language for use in that part of the system.
- A traditional compiler then compiles the generated code to create the linkable-object files for use in the application.

- One of the benefits of using CORBA to implement a system such as our shopping cart application is that the objects can be accessed by services written in different languages.
- To accomplish this task, CORBA defines an interface to which all languages must conform.
- The CORBA interface is called the *Interface Definition Language (IDL).*
- *For* CORBA to work, both sides of the wire, the client and server, must adhere to the contract as stated in the IDL.
- The main premise of CORBA (Common Object Request Broker Architecture) is this: Using a standard protocol,CORBA allows programs from different vendors to communicate with each other.This interoperability covers hardware and software.Thus, vendors can write applications on various hardware platforms and operating systems using a wide variety of programming languages, operating over different vendor networks.