Advanced Management of Data

Concepts of Distributed Databases (1)

Distributed Databases

Distributed Computing System

- number of processing sites or nodes (computers)
- nodes are interconnected by a computer network
- nodes cooperate in performing certain tasks

Goal

- decompose big, unmanageable problems into smaller tasks
- solve the parts in a coordinated way

Distributed Databases

Big Data Technologies

Distributed databases combine concepts of distributed systems and database technologies to deal with the vast amounts of data that are being produced and collected, which includes

- storage
- retrieval
- analysis & mining
  - data mining and machine learning algorithms are often used to extract the needed knowledge

Distributed Database Concepts

Distributed Database (DDB)

- collection of database nodes that must be
  - logically related
  - connected over a computer network to transmit data and commands among sites

Distributed database management system (DDBMS)

- software system that manages a distributed database
- in most cases the distribution is made transparent to the user

Distributed Database Concepts

Heterogeneous DDBMS

Different sites may run different hardware, different DBMS products, and may even be based on different underlying data models. Translations are required to allow communication between different DBMSs.

Heterogeneous systems usually result when individual sites have implemented their own databases and integration is considered at a later stage.

Homogeneous DDBMS

All sites use the same DBMS product.

Homogeneous systems are much easier to design and manage. They provide incremental growth, making the addition of a new site to the DDBMS easy, and allow increased performance by exploiting the parallel processing capability of multiple sites.

Distributed Database Concepts

Transparency

- data organization / distribution / network transparency
  - location transparency
  - naming transparency
- replication transparency
- fragmentation transparency
  - horizontal fragmentation
  - vertical fragmentation
- design transparency
- execution transparency

Example

PROJECT

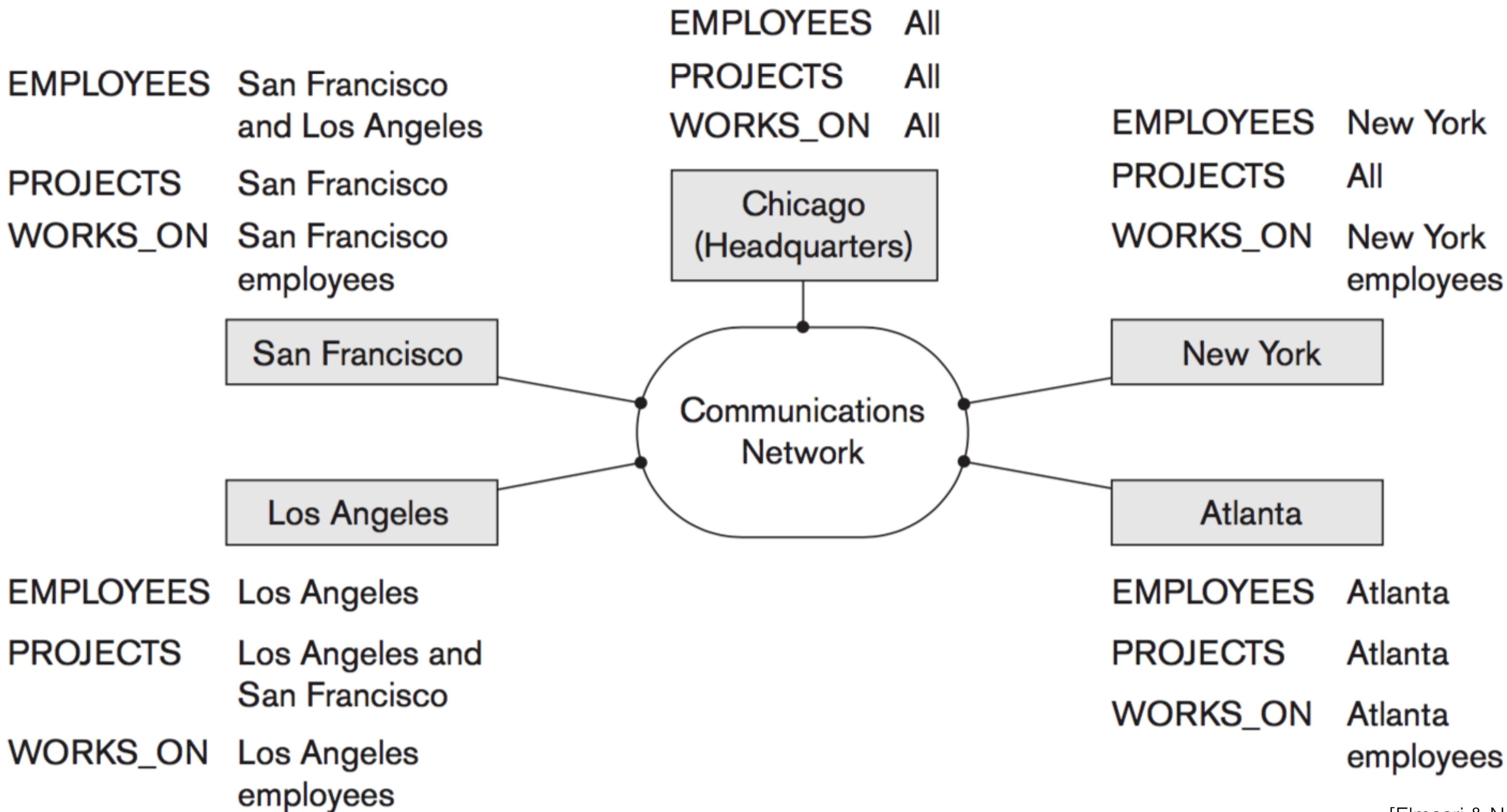
Pname	<u>Pnumber</u>	Plocation	Dnum

WORKS_ON

<u>Essn</u>	<u>Pno</u>	Hours

EMPLOYEE

Fname	Minit	Lname	<u>Ssn</u>	Bdate	Address	Sex	Salary	Super_ssn	Dno



[Elmasri & Navathe]

Distributed Database Concepts

Reliability

- probability that a system is running at a certain time point.

Availability

- probability that the system is continuously available during a time interval

Failure

- deviation of a system’s behaviour from that which is specified in order to ensure correct execution of operations

Errors

- subset of system states that causes the failure

Fault

- cause of an error

Distributed Database Concepts

Cause of DDBMS failures

- transactions
- hardware
- communication networks
    - occur due to errors associated with messages and line failures
    - message errors can include loss, corruption, or out-of-order arrival at destination

Reliable DDBMS

- tolerates failures of underlying components
- processes user requests as long as database consistency is not violated

Distributed Database Concepts

Scalability

Scalability determines the extent to expand the capacity of a distributed system while continuing to operate without interruption:

- Horizontal scalability

  The number of nodes in the distributed system can be expanded to distribute some of the data and processing loads from existing nodes to the new nodes.

- Vertical scalability

  The capacity of individual nodes in the system can be expanded.

Distributed Database Concepts

Network Partitioning

As the number of nodes of a distributed system expands, it is possible that the connecting network may have faults.

This can cause the nodes to be partitioned into groups of nodes.

The nodes within each partition are still connected by a subnetwork, but communication among the partitions is lost.

Partition tolerance

A distributed system should have the capacity to continue operating while the network is partitioned.

Distributed Database Concepts

Autonomy

determines the extent to which individual nodes in a DDBMS can operate independently.

• design autonomy	Data model usage and transaction management techniques among nodes are independent.
• communication autonomy	To which extent each node can decide on sharing of information with other nodes?
• execution autonomy	Users are independent to act as they wish.

Data Fragmentation

Horizontal Fragmentation (Sharding)

Horizontal fragmentation divides a relation R horizontally by grouping rows to create subsets of tuples (shards). Each subset has a certain logical meaning and can be specified in the relational algebra by a $\sigma_{C_i}(R)$ operation.

Complete horizontal fragmentation

Is a set of horizontal fragments whose conditions C_1, C_2, ... , C_n include all the tuples in R, that is, every tuple in R satisfies (C_1 OR C_2 OR ... OR C_n)

By applying a UNION operation, the relation R can be reconstructed from a complete horizontal fragmentation.

Derived horizontal fragmentation

The partitioning of a primary relation can be applied to other (secondary) relations, which are related to the primary relation via a foreign key.

Example

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4
James	E	Borg	888665555	1937-11-10	450 Stone, Houston, TX	M	55000	NULL	1

[Elmasri & Navathe]

Sharding based on Department (Dno): The following set C_n is a complete horizontal fragmentation:

```
C1: select * from EMPLOYEE where Dno = 1
C2: select * from EMPLOYEE where Dno = 4
C3: select * from EMPLOYEE where Dno = 5
```

Data Fragmentation

Vertical Fragmentation

A vertical fragment of a relation keeps only certain attributes of a relation R and can be specified by a $\pi_{L_i}(R)$ operation in the relational algebra.

Complete Vertical Fragmentation

A set of vertical fragments whose projection lists $L_1, L_2, \ldots, L_n$ include all the attributes in R but share only the primary key attribute of R. The projection lists satisfy the following conditions:

- $L_1 \cup L_2 \cup \ldots \cup L_n = ATTRS(R)$, where ATTRS(R) is the set of attributes of R
- $L_i \cap L_j = PK(R)$ for any $i \neq j$, where PK(R) is the primary key of R

R can be reconstructed from a complete vertical fragmentation by applying a Full-Outer-Join operation.

Example

PROJECT

Pname	Pnumber	Plocation	Dnum
ProductX	1	Bellaire	5
ProductY	2	Sugarland	5
ProductZ	3	Houston	5
Computerization	10	Stafford	4
Reorganization	20	Houston	1
Newbenefits	30	Stafford	4

Complete vertical fragmentation of PROJECT into

- PROJ_DATA:

```
SELECT Pname, Pnumber, Plocation
FROM   PROJECT
```

- PROJ_DEPT:

```
SELECT Pnumber, Dnum
FROM   PROJECT
```

PROJ_DATA

Pname	Pnumber	Plocation
ProductX	1	Bellaire
ProductY	2	Sugarland
ProductZ	3	Houston
Computerization	10	Stafford
Reorganization	20	Houston
Newbenefits	30	Stafford

PROJ_DEPT

Pnumber	Dnum
1	5
2	5
3	5
10	4
20	1
30	4

Data Fragmentation

Mixed Fragmentation

Horizontal and vertical fragmentation can be intermixed.

A fragment of a relation R can be specified by a selection / projection combination of operations $\pi_L(\sigma_C(R))$:

- vertical fragment: C = TRUE and L ≠ ATTRS(R)
- horizontal fragment: C ≠ TRUE and L = ATTRS(R)
- mixed fragment: C ≠ TRUE and L ≠ ATTRS(R)
- relation itself: C = TRUE and L = ATTRS(R)

Data Fragmentation

Fragmentation schema

- defines a set of fragments that includes all attributes and tuples in the database

  By applying some sequence of OUTER JOIN and UNION operations the whole database must be reconstructable from these fragments.

Allocation schema

- describes the allocation of fragments to nodes

Replication

A fragment is said to be replicated, if it is stored at more than one site.

Data Replication

Full Replication

The whole database is replicated at every node in the distributed system.

Advantages: As long as at least one site is up, the system can continue to operate, which maximizes availability.

It also improves performance of retrieval for global queries because the results of such queries can be obtained locally from any one site.

Disadvantages: Update operations can be slowed down drastically, since every copy must be updated similarly to keep consistency.

Concurrency control and recovery techniques are becoming more expensive.

Data Replication

No Replication

Each fragment is stored at only one site.

In this case, all fragments must be disjoint, except for the repetition of primary keys among vertical or mixed fragments.

Partial Replication

Some fragments of the database may be replicated whereas others may not.

The number of copies of each fragment can range from one up to the total number of sites in the distributed system.

Replication Schema

A description of the replication of fragments.

Data Allocation

Criteria for data distribution

Each (copy of a) fragment must be assigned to a particular site in the distributed system.

The choice of sites and the degree of replication depend on

- performance and availability goals of the system
- types and frequencies of transactions submitted at each site

Data that is frequently accessed at multiple sites should be replicated at those sites.

If many updates are performed, it may be useful to limit replication.

Finding an optimal or even a good solution to distributed data allocation is a complex optimization problem.

Example (1)

We want to fragment and distribute the following company database:

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno

DEPARTMENT

Dname	Dnumber	Mgr_ssn	Mgr_start_date

DEPT_LOCATIONS

Dnumber	Dlocation

PROJECT

Pname	Pnumber	Plocation	Dnum

WORKS_ON

Essn	Pno	Hours

[Elmasri & Navathe]

Example (2)

Description / Requirements

The company has three computer sites - one for each department:

- Site 1 is used by company headquarters and accesses all employee and project information regularly.
- Site 2 is used for department 5 only
- Site 3 is used for department 4 only

At all sites, we expect frequent access to the EMPLOYEE and PROJECT information for the employees who work in that department and the projects controlled by that department.

These sites mainly access the Name, Ssn, Salary, and Super_ssn attributes of EMPLOYEE.

Example (3)

According to these requirements, the whole database can be stored at site 1.

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4
James	E	Borg	888665555	1937-11-10	450 Stone, Houston, TX	M	55000	NULL	1

DEPARTMENT

Dname	Dnumber	Mgr_ssn	Mgr_start_date
Research	5	333445555	1988-05-22
Administration	4	987654321	1995-01-01
Headquarters	1	888665555	1981-06-19

DEPT_LOCATIONS

Dnumber	Dlocation
1	Houston
4	Stafford
5	Bellaire
5	Sugarland
5	Houston

Example (4)

According to these requirements, the whole database can be stored at site 1.

WORKS_ON

Essn	Pno	Hours
123456789	1	32.5
123456789	2	7.5
666884444	3	40.0
453453453	1	20.0
453453453	2	20.0
333445555	2	10.0
333445555	3	10.0
333445555	10	10.0
333445555	20	10.0
999887777	30	30.0
999887777	10	10.0
987987987	10	35.0
987987987	30	5.0
987654321	30	20.0
987654321	20	15.0
888665555	20	NULL

PROJECT

Pname	Pnumber	Plocation	Dnum
ProductX	1	Bellaire	5
ProductY	2	Sugarland	5
ProductZ	3	Houston	5
Computerization	10	Stafford	4
Reorganization	20	Houston	1
Newbenefits	30	Stafford	4

Example (5)

To determine the fragments to be replicated at sites 2 and 3, first we horizontally fragment DEPARTMENT by its key (Dnumber).

DEPARTMENT

Dname	Dnumber	Mgr_ssn	Mgr_start_date
Research	5	333445555	1988-05-22
Administration	4	987654321	1995-01-01
Headquarters	1	888665555	1981-06-19

DEP_5

Dname	Dnumber	Mgr_ssn	Mgr_start_date
Research	5	333445555	1988-05-22

DEP_4

Dname	Dnumber	Mgr_ssn	Mgr_start_date
Administration	4	987654321	1995-01-01

Example (6)

We apply derived fragmentation to the PROJECT and DEPT_LOCATIONS relations based on their foreign keys for department number (Dnum, Dnumber).

PROJECT

Pname	Pnumber	Plocation	Dnum
ProductX	1	Bellaire	5
ProductY	2	Sugarland	5
ProductZ	3	Houston	5
Computerization	10	Stafford	4
Reorganization	20	Houston	1
Newbenefits	30	Stafford	4

DEPT_LOCATIONS

Dnumber	Dlocation
1	Houston
4	Stafford
5	Bellaire
5	Sugarland
5	Houston

PROJS_5

Pname	Pnumber	Plocation	Dnum
ProductX	1	Bellaire	5
ProductY	2	Sugarland	5
ProductZ	3	Houston	5

DEP_5_LOCS

Dnumber	Dlocation
5	Bellaire
5	Sugarland
5	Houston

PROJS_4

Pname	Pnumber	Plocation	Dnum
Computerization	10	Stafford	4
Newbenefits	30	Stafford	4

DEP_4_LOCS

Dnumber	Dlocation
4	Stafford

Example (7)

We apply derived fragmentation to EMPLOYEE based on its foreign keys for department number (Dno).

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4
James	E	Borg	888665555	1937-11-10	450 Stone, Houston, TX	M	55000	NULL	1

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4

Example (8)

We vertically fragment the resulting EMPLOYEE fragments to include only the most frequently accessed attributes.

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5

EMPD_5

Fname	Minit	Lname	Ssn	Salary	Super_ssn	Dno
John	B	Smith	123456789	30000	333445555	5
Franklin	T	Wong	333445555	40000	888665555	5
Ramesh	K	Narayan	666884444	38000	333445555	5
Joyce	A	English	453453453	25000	333445555	5

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4

EMPD_4

Fname	Minit	Lname	Ssn	Salary	Super_ssn	Dno
Alicia	J	Zelaya	999887777	25000	987654321	4
Jennifer	S	Wallace	987654321	43000	888665555	4
Ahmad	V	Jabbar	987987987	25000	987654321	4

Example (9)

EMPD_5

Fname	Minit	Lname	Ssn	Salary	Super_ssn	Dno
John	B	Smith	123456789	30000	333445555	5
Franklin	T	Wong	333445555	40000	888665555	5
Ramesh	K	Narayan	666884444	38000	333445555	5
Joyce	A	English	453453453	25000	333445555	5

DEP_5

Dname	Dnumber	Mgr_ssn	Mgr_start_date
Research	5	333445555	1988-05-22

DEP_5_LOCS

Dnumber	Location
5	Bellaire
5	Sugarland
5	Houston

PROJS_5

Pname	Pnumber	Plocation	Dnum
Product X	1	Bellaire	5
Product Y	2	Sugarland	5
Product Z	3	Houston	5

Allocation of fragments to sites

- relation fragments at site 2 correspond to department 5
- EMPD_5 shows a mixed fragment which includes the EMPLOYEE tuples satisfying the condition Dno = 5
- the horizontal fragments of PROJECT, DEPARTMENT, and DEPT_LOCATIONS are similarly fragmented by department number 5

Example (10)

EMPD_4

Fname	Minit	Lname	Ssn	Salary	Super_ssn	Dno
Alicia	J	Zelaya	999887777	25000	987654321	4
Jennifer	S	Wallace	987654321	43000	888665555	4
Ahmad	V	Jabbar	987987987	25000	987654321	4

DEP_4

Dname	Dnumber	Mgr_ssn	Mgr_start_date
Administration	4	987654321	1995-01-01

DEP_4_LOCS

Dnumber	Location
4	Stafford

PROJS_4

Pname	Pnumber	Plocation	Dnum
Computerization	10	Stafford	4
New_benefits	30	Stafford	4

Allocation of fragments to sites

- relation fragments at site 3 correspond to department 4
- EMPD_4 shows a mixed fragment which includes the EMPLOYEE tuples satisfying the condition Dno = 4
- the horizontal fragments of PROJECT, DEPARTMENT, and DEPT_LOCATIONS are similarly fragmented by department number 4

Example (11)

WORKS_ON

Essn	Pno	Hours
123456789	1	32.5
123456789	2	7.5
666884444	3	40.0
453453453	1	20.0
453453453	2	20.0
333445555	2	10.0
333445555	3	10.0
333445555	10	10.0
333445555	20	10.0
999887777	30	30.0
999887777	10	10.0
987987987	10	35.0
987987987	30	5.0
987654321	30	20.0
987654321	20	15.0
888665555	20	NULL

We must now fragment the WORKS_ON relation and decide which fragments of WORKS_ON to store at sites 2 and 3.

Since each tuple in WORKS_ON relates an employee to a project, the problem arises that no attribute of WORKS_ON directly indicates the department to which each tuple belongs.

There may be projects, which are controlled by a different department than the related employee.

Hence, we should fragment WORKS_ON based on the department in which the employee works and then fragment further based on the department that controls the projects that employee is working on

Example (12)

Employees in Department 5

G1

Essn	Pno	Hours
123456789	1	32.5
123456789	2	7.5
666884444	3	40.0
453453453	1	20.0
453453453	2	20.0
333445555	2	10.0
333445555	3	10.0

C1 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 5))

G2

Essn	Pno	Hours
333445555	10	10.0

C2 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 4))

G3

Essn	Pno	Hours
333445555	20	10.0

C3 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 1))

PROJECT

Pname	Pnumber	Plocation	Dnum
ProductX	1	Bellaire	5
ProductY	2	Sugarland	5
ProductZ	3	Houston	5
Computerization	10	Stafford	4
Reorganization	20	Houston	1
Newbenefits	30	Stafford	4

Fragments of WORKS_ON for employees working in department 5

C = Essn in (SELECT Ssn
FROM EMPLOYEE
WHERE Dno = 5)

The union of fragments G_1, G_2, and G_3 gives all WORKS_ON tuples for employees who work for department 5.

WORKS_ON

Essn	Pno	Hours
123456789	1	32.5
123456789	2	7.5
666884444	3	40.0
453453453	1	20.0
453453453	2	20.0
333445555	2	10.0
333445555	3	10.0
333445555	10	10.0
333445555	20	10.0
999887777	30	30.0
999887777	10	10.0
987987987	10	35.0
987987987	30	5.0
987654321	30	20.0
987654321	20	15.0
888665555	20	NULL

Example (13)

Employees in Department 4

G4

Essn	Pno	Hours

C4 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 5))

G5

Essn	Pno	Hours
999887777	30	30.0
999887777	10	10.0
987987987	10	35.0
987987987	30	5.0
987654321	30	20.0

C5 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 4))

G6

Essn	Pno	Hours
987654321	20	15.0

C6 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 1))

PROJECT

Pname	Pnumber	Plocation	Dnum
ProductX	1	Bellaire	5
ProductY	2	Sugarland	5
ProductZ	3	Houston	5
Computerization	10	Stafford	4
Reorganization	20	Houston	1
Newbenefits	30	Stafford	4

Fragments of WORKS_ON for employees working in department 4

C = Essn in (SELECT Ssn
FROM EMPLOYEE
WHERE Dno = 4)

The union of fragments G4, G5, and G6 gives all WORKS_ON tuples for employees who work for department 4.

WORKS_ON

Essn	Pno	Hours
123456789	1	32.5
123456789	2	7.5
666884444	3	40.0
453453453	1	20.0
453453453	2	20.0
333445555	2	10.0
333445555	3	10.0
333445555	10	10.0
333445555	20	10.0
999887777	30	30.0
999887777	10	10.0
987987987	10	35.0
987987987	30	5.0
987654321	30	20.0
987654321	20	15.0
888665555	20	NULL

Example (14)

Employees in Department 1

G7

Essn	Pno	Hours

C7 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 5))

G8

Essn	Pno	Hours

C8 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 4))

G9

Essn	Pno	Hours
888665555	20	Null

C9 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 1))

PROJECT

Pname	Pnumber	Plocation	Dnum
ProductX	1	Bellaire	5
ProductY	2	Sugarland	5
ProductZ	3	Houston	5
Computerization	10	Stafford	4
Reorganization	20	Houston	1
Newbenefits	30	Stafford	4

Fragments of WORKS_ON for employees working in department 1

C = Essn in (SELECT Ssn
FROM EMPLOYEE
WHERE Dno = 1)

The union of fragments G7, G8, and G9 gives all WORKS_ON tuples for employees who work for department 1.

WORKS_ON

Essn	Pno	Hours
123456789	1	32.5
123456789	2	7.5
666884444	3	40.0
453453453	1	20.0
453453453	2	20.0
333445555	2	10.0
333445555	3	10.0
333445555	10	10.0
333445555	20	10.0
999887777	30	30.0
999887777	10	10.0
987987987	10	35.0
987987987	30	5.0
987654321	30	20.0
987654321	20	15.0
888665555	20	NULL

Example (15)

G1

Essn	Pno	Hours
123456789	1	32.5
123456789	2	7.5
666884444	3	40.0
453453453	1	20.0
453453453	2	20.0
333445555	2	10.0
333445555	3	10.0

C1 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 5))

G2

Essn	Pno	Hours
333445555	10	10.0

C2 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 4))

G3

Essn	Pno	Hours
333445555	20	10.0

C3 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 1))

The union of fragments G1, G4, and G7 gives all WORKS_ON tuples for projects controlled by department 5.

Additionally, we union fragments G2 and G3 at site 2 (WORKS_ON_5)

This allocation strategy permits the join between the local EMPLOYEE or PROJECT fragments at site 2 and the local WORKS_ON fragment to be performed completely locally.

G4

Essn	Pno	Hours

C4 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 5))

G7

Essn	Pno	Hours

C7 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 5))

WORKS_ON_5

Essn	Pno	Hours
123456789	1	32.5
123456789	2	7.5
666884444	3	40.0
453453453	1	20.0
453453453	2	20.0
333445555	2	10.0
333445555	3	10.0
333445555	10	10.0
333445555	20	10.0

Example (16)

G4

Essn	Pno	Hours

C4 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 5))

G5

Essn	Pno	Hours
999887777	30	30.0
999887777	10	10.0
987987987	10	35.0
987987987	30	5.0
987654321	30	20.0

C5 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 4))

G6

Essn	Pno	Hours
987654321	20	15.0

C6 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 1))

The union of fragments G2, G5, and G8 gives all WORKS_ON tuples for projects controlled by department 4.

Additionally, we union fragments G4, and G6 at site 3 (WORKS_ON_4)

This allocation strategy permits the join between the local EMPLOYEE or PROJECT fragments at site 3 and the local WORKS_ON fragment to be performed completely locally.

G2

Essn	Pno	Hours
333445555	10	10.0

C2 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 4))

G8

Essn	Pno	Hours

C8 = C and (Pno in (SELECT Pnumber FROM PROJECT WHERE Dnum = 4))

WORKS_ON_4

Essn	Pno	Hours
333445555	10	10.0
999887777	30	30.0
999887777	10	10.0
987987987	10	35.0
987987987	30	5.0
987654321	30	20.0
987654321	20	15.0