DISTRIBUTED DATABASE DESIGN

Topics

- Data Fragmentation
- Data Replication
- Allocation Techniques

Data Fragmentation

Data Fragmentation

- Techniques that are used to break up the database into logical units, called fragments, which may be assigned for storage at the various sites.
- In a DDB, decisions must be made regarding which site should be used to store which portions of the database.
- Before we are deciding on how to distribute the data, the logical units of the database must be determined that are to be distributed.
- The simplest logical units are the relations themselves; that is, each whole relation is to be stored at a particular site.
- The data fragmentation process should be carried out in such a way that the reconstruction of original database from the fragment is possible.

Data Fragmentation

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

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

DEPENDENT

Essn	Dependent_name	Sex	Bdate	Relationship
333445555	Alice	F	1986-04-05	Daughter
333445555	Theodore	M	1983-10-25	Son
333445555	Joy	F	1958-05-03	Spouse
987654321	Abner	M	1942-02-28	Spouse
123456789	Michael	M	1988-01-04	Son
123456789	Alice	F	1988-12-30	Daughter
123456789	Elizabeth	F	1967-05-05	Spouse

Here relations are:

- Employee
- Department
- Dept_Locations
- Works_on
- Project
- Dependent

Data Fragmentation

- A relation can be divided into smaller logical units for distribution.
- For eg. Assume there are three computer sites—one for each department in the company.
- There are 2 types of Fragmentaion:

1. **Horizontal Fragmentation:**

- A horizontal fragment of a relation is a subset of the tuples in that relation.
- The tuples that belong to the horizontal fragment are specified by a condition on one or more attributes of the relation.
- Often, only a single attribute is involved.

Data Fragmentation

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
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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

Example 1:

- we may define three horizontal fragments on the EMPLOYEE relation with the following conditions:
- Dno = 5, Dno = 4, Dno = 1.
- Each fragment contains the EMPLOYEE tuples working for a particular department.

Example 2:

- we may define three horizontal fragments for the PROJECT relation with the following condition:
- Dnum = 5, Dnum = 4, Dnum = 1.
- Each fragment contains the PROJECT tuples controlled by a particular department.

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

Data Fragmentation

- Horizontal fragmentation divides a relation horizontally by grouping rows to create subsets of tuples, where each subset has a certain logical meaning.
- These fragments can then be assigned to different sites in the distributed system.

Different types of Horizontal Fragmentation:

1. Primary Horizontal Fragmentation:

- It is the process of fragmenting a single table row wise using a set of conditions.

2. Derived Horizontal Fragmentation:

- Derived horizontal fragmentation applies the partitioning of a primary relation to other secondary relations which are related to the primary via a foreign key.
- This way, related data between the primary and the secondary relations gets fragmented in the same way.

Data Fragmentation

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
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2. Vertical Fragmentation:

- Each site may not need all the attributes of a relation, which would indicate the need for a different type of fragmentation.
- Vertical Fragmentation divides a relation "vertically" by columns.
- A vertical fragment of a relation keeps only certain attributes of a relation.
- Example:
- We may want to fragment the EMPLOYEE relation into two vertical fragments.
- The first fragment includes personal information: Fname, Bdate, Address, and Sex.
- The second includes work-related information: Ssn, Salary, Super_ssn, and Dno.

Data Fragmentation

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
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Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
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- This vertical fragmentation is not quite proper, because if the two fragments are stored separately, we cannot put the original employee tuples back together, since there is no common attribute between the two fragments.
- It is necessary to include the primary key or some candidate key attribute in every vertical fragment so that the full relation can be reconstructed from the fragments.
- Hence, we must add the Ssn attribute to the personal information fragment

Data Fragmentation

- Each horizontal fragment on a relation R can (be specified in the relational algebra by a σ_{Ci} (R) operation.
- A set of horizontal fragments whose conditions C1, C2, ..., Cn include all the tuples in R - that is, every tuple in R satisfies (C1 OR C2 OR ... OR Cn) is called a **complete horizontal fragmentation** of R.
- **Example:**
- For the PROJECT relation with the following condition:
- Dnum = 5

PROJECT

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

PROJECT

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

PROJECT

Pname	Pnumber	Plocation	Dnum
Reorganization	20	Houston	1

PROJECT

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

- To reconstruct the relation R from a complete horizontal fragmentation, we need to apply the UNION operation to the fragments.

Data Fragmentation

- Each horizontal fragment on a relation R can (be specified in the relational algebra by a σ_{Ci} (R) operation.
- A vertical fragment on a relation R can be specified by a π_{Li} (R) operation in the relational Algebra.
- A set of vertical fragments whose projection lists L1, L2, ..., Ln include all the attributes in R but share only the primary key attribute of R is called a **complete vertical fragmentation** of R.
- In this case the projection lists satisfy the following two conditions:
- $L_1 \cup L_2 \cup \ldots \cup L_n = ATTRS(R)$
- $Li \cap Lj = PK(R)$ for any $i \neq j$, where ATTRS(R) is the set of attributes of R and PK(R) is the primary key of R.
- To reconstruct the relation R from a complete vertical fragmentation, we apply the OUTER UNION operation to the vertical fragments
- The two vertical fragments of the EMPLOYEE relation with projection lists:
  - L1 = {**Ssn**, Name, Bdate, Address, Sex} and
  - L2 = {**Ssn**, Salary, Super_ssn, Dno}
  - constitute a complete vertical fragmentation of EMPLOYEE.

Data Fragmentation

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
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Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
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3. Mixed (Hybrid) Fragmentation:

- We can intermix the two types of fragmentation, yielding a mixed fragmentation.
- A fragment of a relation R can be specified by a SELECT-PROJECT combination of operations $\pi_L(\sigma_C(R))$.
- In some situations, the horizontal and the vertical fragmentation isn't enough to distribute data for some applications and in that conditions, we need a fragmentation called a mixed fragmentation.

Mixed fragmentation can be done in two different ways:

- The first method is to first create a set or group of horizontal fragments and then create vertical fragments from one or more of the horizontal fragments.
- The second method is to first create a set or group of vertical fragments and then create horizontal fragments from one or more of the vertical fragments.
- **Example:**
- $\pi_{\text{Fname, Minit, Dno}}(\sigma_{\text{Salary}} <= 30000\ (\text{Employee}))$

EMPLOYEE

Fname	Minit	Dno
John	B	5
Alicia	J	4
Joyce	A	5
Ahmad	V	4

Data Replication and Allocation

Data Replication

- Replication is useful in improving the availability of data.
- The most extreme case is replication of the whole database at every site in the distributed system, thus creating a fully replicated distributed database.
- This can improve availability remarkably because the system can continue to operate as long as at least one site is up.
- It also improves performance of retrieval for global queries because the results of such queries can be obtained locally from any one site; hence, a retrieval query can be processed at the local site where it is submitted, if that site includes a server module.
- The disadvantage of full replication is that it can slow down update operations drastically, since a single logical update must be performed on every copy of the database to keep the copies consistent.
- This is especially true if many copies of the database exist.
- Full replication makes the concurrency control and recovery techniques more expensive than they would be if there was no replication.

Data Replication

- The other extreme from full replication involves having no replication - that is, each fragment is stored at exactly one site.
- All fragments must be disjoint except for the repetition of primary keys among vertical (or mixed) fragments.
- This is also called **nonredundant allocation**.
- Between these two extremes, we have a wide spectrum of partial replication of the data—that is, 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.
- A description of the replication of fragments is sometimes called a **replication schema.**

Data Allocation

- Each copy of a fragment must be assigned to a particular site in the distributed system.
- This process is called **data distribution** or **data allocation**.
- The choice of sites and the degree of replication depend on the performance and availability goals of the system and on the types and frequencies of transactions submitted at each site.
- If high availability is required, transactions can be submitted at any site, and most transactions are retrieval only, a fully replicated database is a good choice.
- If certain transactions that access particular parts of the database are mostly submitted at a particular site, the corresponding set of fragments can be allocated at that site only.
- Data that is accessed at multiple sites can be replicated at those sites.

To summarize the Allocation:

- **Centralises**: Entire database is stored at a single site. No data distribution occurs
- **Partitioned**: The database gets divided into different fragments which are stored at several sites.
- **Replicated**: Copies of the database are stored at different locations to access the data.