Distributed Databases

Chapter 16

1

Two Types of Applications that Access Distributed Databases

- The application accesses data at the level of SQL statements.
  - Example: company has nationwide network of warehouses, each with its own database; a transaction can access all databases using their schemas
- The application accesses data at a database using only stored procedures provided by that database.
  - Example: purchase transaction involving a merchant and a credit card company, each providing stored subroutines for its subtransactions

2

Optimizing Distributed Queries

- Only applications of the first type can access data directly and hence employ query optimization strategies.
- These are the applications we consider in this chapter.

3

Some Issues

- How should a distributed database be designed?
- At what site should each item be stored?
- Which items should be replicated and at which sites?
- How should queries that access multiple databases be processed?
- How do issues of query optimization affect query design?

4

Why Might Data Be Distributed

- Data might be distributed to minimize communication costs or response time.
- Data might be kept at the site where it was created so that its creators can maintain control and security.
- Data might be replicated to increase its availability in the event of failure or to decrease response time.

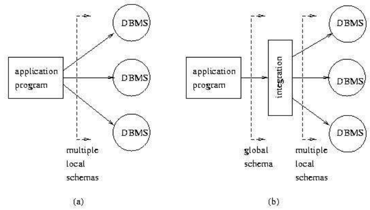
5

Application Designer's View of a Distributed Database

- Designer might see the individual schemas of each local database -- called a **multidatabase** -- in which case distribution is visible**.**
  - Can be **homogeneous** (all databases from one vendor) or **heterogeneous** (databases from different vendors)
- Designer might see a single **global schema** that integrates all local schemas – a view -- in which case distribution is hidden.
- Designer might see a **restricted global schema**, which is the union of all the local schemas.
  - Supported by some vendors of homogeneous systems

6

Views of Distributed Data



- (a) Multidatabase with local schemas
- (b) Integrated distributed db with global schema

Multidatabases

- Application must explicitly connect to each site.
- Application accesses data at a site using SQL statements based on that site's schema.
- Application may have to do reformating in order to integrate data from different sites.
- Application must manage replication.
  - Know where replicas are stored and decide which replica to access

Global and Restricted Global Schemas

- Middleware provides integration of local schemas into a global schema
  - Application need not connect to each site
  - Application accesses data using global schema
    - Need not know where data is stored – **location transparency**
  - Global joins are supported
  - Middleware performs necessary data reformating
  - Middleware manages replication – **replication transparency**

Fragmentation

- Data can be distributed by storing individual tables at different sites
- Data can also be distributed by decomposing a table and storing portions at different sites – called **Fragmentation**
- Fragmentation can be **horizontal** or **vertical**

10

Horizontal Fragmentation

- Each fragment, T_i , of table T contains a subset of the rows and each row is in exactly one fragment:
  - $T_i = \sigma_{C_i}(T)$
  - $T = \cup\, T_i$
  - Horizontal fragmentation is lossless

11

Horizontal Fragmentation

- Example: An Internet grocer has a relation describing inventory at each warehouse
  Inventory(StockNum, Amount, Price, Location)
- It fragments the relation by location and stores each fragment locally: rows with Location = `Chicago` are stored in the Chicago warehouse in a fragment
  Inventory_ch(StockNum, Amount, Price, Location)
- Alternatively, it can use the schema
  Inventory_ch(StockNum, Amount, Price)

12

Vertical Fragmentation

- Each fragment, T_i, of T contains a subset of the columns, each column is in at least one fragment, and each fragment includes the key:
  - $T_i = \Pi_{attr\_list_i}(T)$
  - $T = T_1 \bowtie T_2 \ldots\ldots \bowtie T_n$
  - Vertical fragmentation is lossless
- Example: The Internet grocer has a relation
  Employee(SSnum, Name, Salary, Title, Location)
  - It fragments the relation to put some information at headquarters and some elsewhere:
    Emp1(SSnum, Name, Salary) -- at headquarters
    Emp2(SSnum, Name, Title, Location) -- elsewhere

13

Mixed Fragmentation

- Combinations of horizontal and vertical fragmentation
  - Horizontal then vertical
  - Vertical then horizontal

Exp: After vertical fragmentation to Emp1(Ssnum, Name, Salary, Location) Emp2(Ssnum, Name, Salary, Location)

the company can do a horizontally fragmentation

14

Derived Horizontal Fragmentation

Inventory(StockNum, Amt, Price, WareHN)

Warehouse(WareHN, Cap, Add, Location)

One DB in each city => good for a horizontal fragmentation of **Inventory**

BUT: Location is not an attribute of **Inventory** => Do the natural join then create the horizontal fragmentation; when store data, remove the location attribute

15

Replication

- One of the most useful mechanisms in distributed databases
- Increases
  - Availability
    - If one replica site is down, data can be accessed from another site
  - Performance:
    - Queries can be executed more efficiently because they can access a local or nearby copy
    - Updates might be slower because all replicas must be updated

16

Replication Example

- Internet grocer might have relation

  Customer(CustNum, Address, Location)
  - Queries are executed at
    - Headquarters to produce monthly mailings
    - A warehouse to obtain information about deliveries
  - Updates are executed at
    - Headquarters when new customer registers and when information about a customer changes

17

Example (con't)

- Intuitively it seems appropriate to
  - Store complete relation at headquarters
  - Horizontally fragment a replica of the relation and store a fragment at the corresponding warehouse site
  - Each row is replicated: one copy at headquarters, one copy at a warehouse

18

Example (con't): Performance Analysis

- We consider three alternatives:
  - Store the entire relation at the headquarters site and nothing at the warehouses (no replication)
  - Store the fragments at the warehouses and nothing at the headquarters (no replication)
  - Store entire relation at headquarters and a fragment at each warehouse (replication)

19

Example (con't): Performance Analysis - Assumptions

- To evaluate the alternatives, we estimate the amount of information that must be sent between sites. We make the following assumptions
  - The Customer relation has 100,000 rows
  - The headquarters mailing application sends each customer one mailing a month
  - 500 deliveries are made each day, and a single row must be read for each delivery
  - There are 100 new customers a day (and changes to customer information occur negligibly often)

20

Example: The Evaluation

- Entire relation at headquarters, nothing at warehouses
  - 500 tuples per day from headquarters to warehouses for deliveries
- Fragments at warehouses, nothing at headquarters
  - 100,000 tuples per month from warehouses to headquarters for mailings (3,300 tuples per day, amortized)
  - 100 tuples per day from headquarters to warehouses for new customer registration
- Entire relation at headquarters, fragments at each warehouse
  - 100 tuples per day from headquarters to warehouses for new customer registration

21

Example: Conclusion

- Replication seems best, but there might be other considerations
  - If no data stored at warehouses, the time to handle deliveries might suffer because of the remote access (probably not important)
  - If no data is stored at headquarters, the monthly mailing requires that 100,000 rows be transmitted in a single day, which might clog the network
  - If we replicate, the time to register a new customer might suffer because of the remote update
    - But this update can be done by a separate transaction after the registration transaction commits (**asynchronous update)**

22

Query Planning

- Systems that support a global schema contain a global query optimizer, which analyzes each global query and translates it into an appropriate sequence of steps to be executed at each site
- In a multidatabase system, the query designer must manually decompose each global query into a sequence of SQL statements to be executed at each site
  - Thus a query designer must be her own query optimizer

23

Global Query Optimization

- A familiarity with algorithms for global query optimization helps the application programmer in designing
  - Global queries that will execute efficiently for a particular distribution of data
  - Algorithms for efficiently evaluating global queries in a multidatabase system
  - The distribution of data that will be accessed by global queries

24

Planning Global Joins

- Suppose an application at site A wants to join tables at sites B and C. Two straightforward approaches
  - Transmit both tables to site A and do the join there
    - The application explicitly tests the join condition
    - This approach must be used in multidatabase systems
  - Transmit the smaller of the tables, e.g. the table at site B, to site C; execute the join there; transmit the result to site A
    - This approach might be used in a homogenous distributed database system

25

Global Join Example

- Site B

  Student(Id, Major)
- Site C

  Transcript(StudId, CrsCode)
- Application at Site A wants to compute join with join condition

  Student.Id = Transcript.StudId

26

Assumptions

- Lengths of attributes
  - Id and StudId: 9 bytes
  - Major: 3 bytes
  - CrsCode: 6 bytes
- Student has 15,000 tuples, each of length 12 bytes
- 5000 students are registered for at least 1 course and, on average, each is registered for 4 courses
- Thus Transcript has 20,000 tuples each of length 15 bytes

27

Comparison of Alternatives

- If we send both tables to site A to perform the join, we have to send 480,000 bytes
  - 15,000*12 + 20,000*15
- If we send the smaller table, Student, from site B to site C, compute the join there, and then send the result to Site A, we have to send 540,000 bytes
  - 15,000*12 + 20,000*18
- Thus alternative 1 is better

28

Another Alternative: Semijoin

- At site C, compute a table, P, that is the projection of Transcript on StudId; send P to site B.
  - P contains Ids of students registered for at least 1 course
  - Student tuples having Ids not in P do not contribute to join
- At site B, form the join of Student with P using the join condition; send the result, Q, to site C
  - Q contains tuples of Student corresponding to students registered for at least 1 course
  - Q is the semijoin; it is the set of all Student tuples that will participate in the join
- At site C compute the join of Transcript with Q using the join condition; send the result to A

29

Comparision with Previous Alternatives

- In step 1, we send 45,000 bytes
  - 5,000*9
- In step 2, we send 60,000 bytes
  - 5,000*12
- In step 3, we send 360,000 bytes
  - 20,000*18
- In total, we send 465,000 bytes
  - 45,000 + 60,000 + 360,000
- Semijoin is the best of the three alternatives

30

Definition of Semijoin

- The semijoin of two relations, T_1 and T_2, based on a join condition is the projection over the columns of T_1 of the join of T_1 and T_2
  - In other words, the semijoin consists of the tuples in T_1 that participate in the join with T_2

$\Pi_{attributes(T_1)}(T_1 \bowtie_{join\_condition} T_2)$

31

Using the Semijoin

- To compute the join of T_1 and T_2 based on a join condition, we first compute the semijoin, Q, and then join Q with T_2

$\Pi_{attributes(T_1)}(T_1 \bowtie_{join\_condition} T_2) \bowtie_{join\_condition} T_2$

32

Queries that Involve Joins and Selections

- Suppose the Internet grocer relation Employee is vertically fragmented as

  Emp1(SSnum, Name, Salary) at Site B

  Emp2(SSnum, Title, Location) at Site C
- A query at site A wants the names of all employees with Title = ‘manager’ and Salary > ‘20000’
- **Solution 1:** do join before selection – i.e., evaluate

  $\Pi_{Name} (\sigma_{Title='manager' \text{ AND } Salary>'20000'} (Emp1 \bowtie Emp2))$
  - A semijoin is not helpful because all tuples of each table must be brought together to form join

33

Queries that Involve Joins and Selections

- **Solution 2**: Do selections before the join: evaluate
  $\Pi_{Name}((\sigma_{Salary>'20000'}(Emp1)) \bowtie (\sigma_{Title='manager'}(Emp2)))$
- At site B, select all tuples from Emp1 satisfying Salary > ‘20000’; call the result R1
- At site C, select all tuples from Emp2 satisfying Title = ‘manager’; call the result R2
- At some site to be determined by minimizing communication costs, perform the join of R1 and R2, project on the result using Name; send result to site A
  - In multidatabase join must be performed at Site A, but communication costs are reduced because only “selected” data needs to be sent

34

Choices of the Distributed Database Application Designer

- Place tables at different sites
- Fragment tables in different ways and place fragments at different sites
- Replicate tables or data within tables (i.e. denormalize) and place replicas at different sites
- In multidatabase systems, do manual “query optimization”: choose an optimal sequence of SQL statements to be executed at each site

35