Chapter 5: Overview of Query Processing

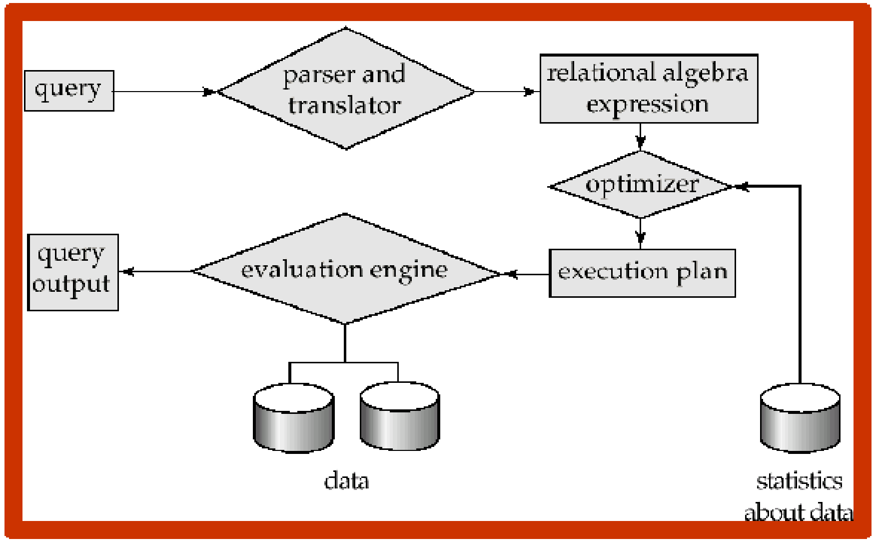
- Query Processing Overview
- Query Optimization
- Distributed Query Processing Steps

Acknowledgements: I am indebted to Arturas Mazeika for providing me his slides of this course.

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.



Query Processing . . .

- 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 Processing Example

- **Example:** Transformation of an SQL-query into an RA-query.
  Relations: EMP(ENO, ENAME, TITLE), ASG(ENO,PNO,RESP,DUR)
  Query: *Find the names of employees who are managing a project*?

  – High level query

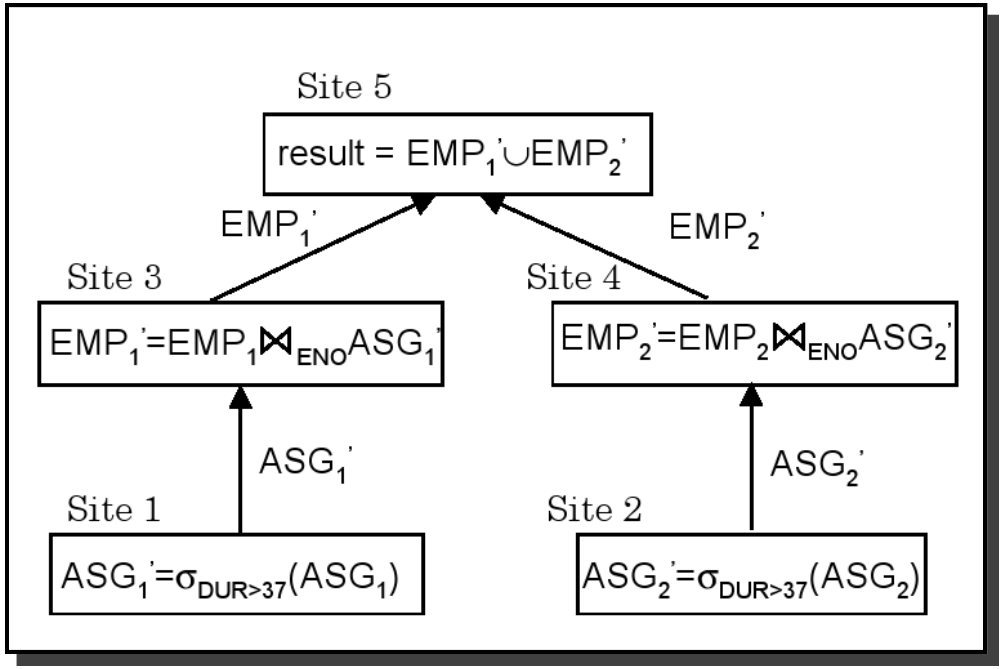
```
SELECT ENAME
FROM   EMP,ASG
WHERE  EMP.ENO = ASG.ENO AND DUR > 37
```

  – Two possible transformations of the query are:
    * Expression 1: $\Pi_{ENAME}(\sigma_{DUR>37 \wedge EMP.ENO=ASG.ENO}(EMP \times ASG))$
    * Expression 2: $\Pi_{ENAME}(EMP \bowtie_{ENO} (\sigma_{DUR>37}(ASG)))$

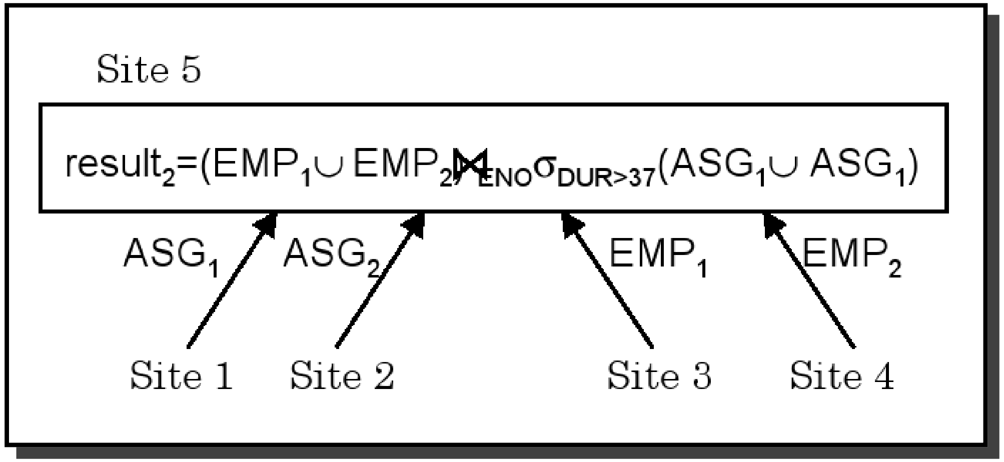
  – Expression 2 avoids the expensive and large intermediate Cartesian product, and therefore typically is better.

- We make the following assumptions about the data fragmentation
  - Data is (horizontally) fragmented:
    * Site1: $ASG1 = \sigma_{ENO \leq "E3"}(ASG)$
    * Site2: $ASG2 = \sigma_{ENO > "E3"}(ASG)$
    * Site3: $EMP1 = \sigma_{ENO \leq "E3"}(EMP)$
    * Site4: $EMP2 = \sigma_{ENO > "E3"}(EMP)$
    * Site5: Result
  - Relations ASG and EMP are fragmented in the same way
  - Relations ASG and EMP are locally clustered on attributes RESP and ENO, respectively

- Now consider the expression $\Pi_{ENAME}(EMP \bowtie_{ENO} (\sigma_{DUR>37}(ASG)))$
- Strategy 1 (partially parallel execution):
  - Produce ASG'_1 and move to Site 3
  - Produce ASG'_2 and move to Site 4
  - Join ASG'_1 with EMP_1 at Site 3 and move the result to Site 5
  - Join ASG'_2 with EMP_2 at Site 4 and move the result to Site 5
  - Union the result in Site 5



- Strategy 2:
  - Move ASG_1 and ASG_2 to Site 5
  - Move EMP_1 and EMP_2 to Site 5
  - Select and join at Site 5



- For simplicity, the final projection is omitted.

Query Processing Example ...

- Calculate the cost of the two strategies under the following assumptions:
  - Tuples are uniformly distributed to the fragments; 20 tuples satisfy DUR$>$37
  - size(EMP) = 400, size(ASG) = 1000
  - tuple access cost = 1 unit; tuple transfer cost = 10 units
  - ASG and EMP have a local index on DUR and ENO
- Strategy 1
  - Produce ASG's: (10+10) * tuple access cost — 20
  - Transfer ASG's to the sites of EMPs: (10+10) * tuple transfer cost — 200
  - Produce EMP's: (10+10) * tuple access cost * 2 — 40
  - Transfer EMP's to result site: (10+10) * tuple transfer cost — 200
  - Total cost — 460
- Strategy 2
  - Transfer EMP_1, EMP_2 to site 5: 400 * tuple transfer cost — 4,000
  - Transfer ASG_1, ASG_2 to site 5: 1000 * tuple transfer cost — 10,000
  - Select tuples from $ASG_1 \cup ASG_2$: 1000 * tuple access cost — 1,000
  - Join EMP and ASG': 400 * 20 * tuple access cost — 8,000
  - Total cost — 23,000

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:

$$\text{I/O cost} + \text{CPU cost} + \text{communication cost}$$

- 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

Query Optimization . . .

- **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

Query Optimization Issues . . .

- **Types of Query Optimizers wrt Search Techniques**
  - Exhaustive search
    - Cost-based
    - Optimal
    - Combinatorial complexity in the number of relations
  - Heuristics
    - 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

Query Optimization Issues . . .

- **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

Query Optimization Issues . . .

- **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

Query Optimization Issues . . .

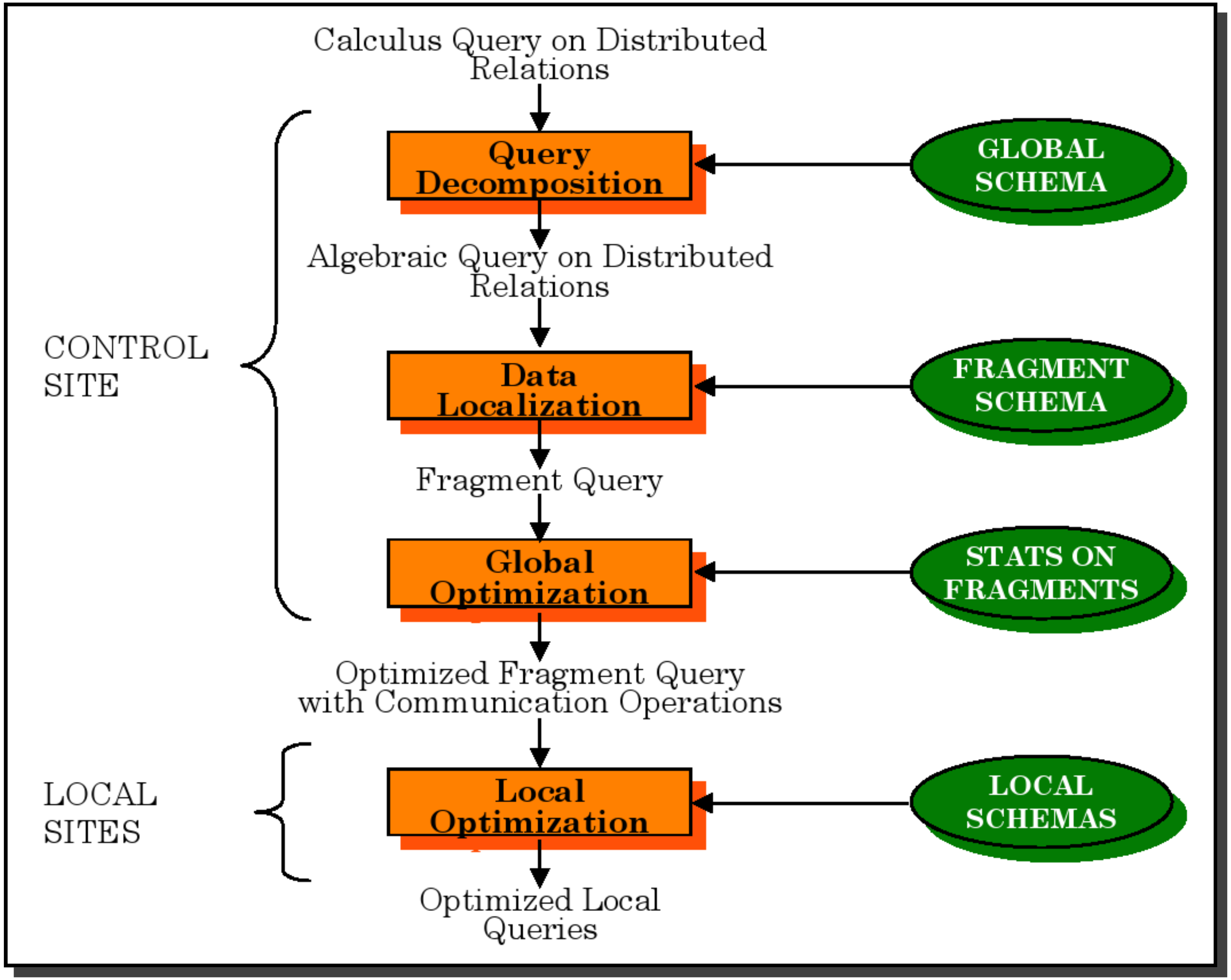
- **Decision sites**
  - Centralized
    - ∗ Single site determines the ”best” schedule
    - ∗ Simple
    - ∗ Knowledge about the entire distributed database is needed
  - Distributed
    - ∗ Cooperation among sites to determine the schedule
    - ∗ Only local information is needed
    - ∗ Cooperation 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

Query Optimization Issues . . .

- **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

Distributed Query Processing Steps



Conclusion

- Query processing transforms a high level query (relational calculus) into an equivalent lower level query (relational algebra). The main difficulty is to achieve the efficiency in the transformation
- Query optimization aims to mimize the cost function:

$$\text{I/O cost} + \text{CPU cost} + \text{communication cost}$$

- Query optimizers vary by search type (exhaustive search, heuristics) and by type of the algorithm (dynamic, static, hybrid). Different statistics are collected to support the query optimization process
- Query optimizers vary by decision sites (centralized, distributed, hybrid)
- Query processing is done in the following sequence: query decomposition→data localization→global optimization→ local optimization