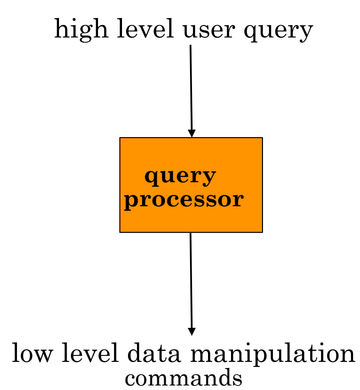
Outline

- Introduction & architectural issues
- Data distribution
- Distributed query processing
  - Query Processing Methodology
  - Localization
- Distributed query optimization
- Distributed transactions & concurrency control
- Distributed reliability
- Data replication
- Parallel database systems
- Database integration & querying
- Advanced topics

Query Processing



Query Processing Components

- Query language that is used
  - SQL: "intergalactic dataspeak"
- Query execution methodology
  - The steps that one goes through in executing high-level (declarative) user queries.
- Query optimization
  - How do we determine the "best" execution plan?

Selecting Alternatives

```
SELECT   ENAME
FROM     EMP,ASG
WHERE    EMP.ENO = ASG.ENO
AND      RESP = "Manager"
```

Strategy 1

$$\Pi_{ENAME}(\sigma_{RESP=\text{“Manager”} \wedge EMP.ENO=ASG.ENO}\,(EMP \cdot ASG))$$

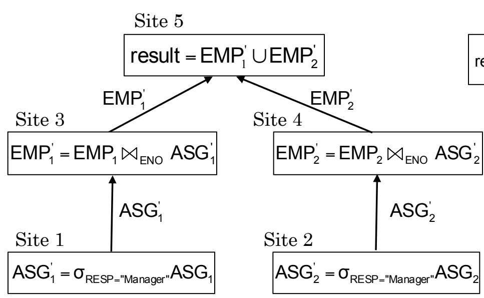
Strategy 2

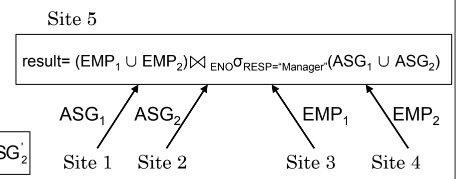
$$\Pi_{ENAME}(EMP \bowtie_{ENO} (\sigma_{RESP=\text{“Manager”}}\,(ASG)))$$

Strategy 2 avoids Cartesian product, so is "better"

What is the Problem?

Site 1	Site 2	Site 3	Site 4	Site 5
$ASG_1=\sigma_{ENO\leq\text{"E3"}}(ASG)$	$ASG_2=\sigma_{ENO>\text{"E3"}}(ASG)$	$EMP_1=\sigma_{ENO\leq\text{"E3"}}(EMP)$	$EMP_2=\sigma_{ENO>\text{"E3"}}(EMP)$	Result





Cost of Alternatives

- Assume:
  - *size*(EMP) = 400, *size*(ASG) = 1000
  - tuple access cost = 1 unit; tuple transfer cost = 10 units
- Strategy 1

❶	produce ASG': (10+10)∗tuple access cost	20
❷	transfer ASG' to the sites of EMP: (10+10)∗tuple transfer cost	200
❸	produce EMP': (10+10) ∗tuple access cost∗2	40
❹	transfer EMP' to result site: (10+10) ∗tuple transfer cost	200
	Total cost	460

- Strategy 2

❶	transfer EMP to site 5: 400∗tuple transfer cost	4,000
❷	transfer ASG to site 5 :1000∗tuple transfer cost	10,000
❸	produce ASG':1000∗tuple access cost	1,000
❹	join EMP and ASG':400∗20∗tuple access cost	8,000
	Total cost	23,000

Query Optimization Objectives

Minimize a cost function

I/O cost + CPU cost + communication cost

These might have different weights in different distributed environments

Wide area networks

- communication cost will dominate
  - 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

Can also maximize throughput

Query Optimization Issues – Types Of Optimizers

- Exhaustive search
  - Cost-based
  - Optimal
  - Combinatorial complexity in the number of relations
- Heuristics
  - Not optimal
  - Regroup common sub-expressions
  - Perform selection, projection first
  - Replace a join by a series of semijoins
  - Reorder operations to reduce intermediate relation size
  - Optimize individual operations

Query Optimization Issues – Optimization Granularity

- Single query at a time
  - Cannot use common intermediate results
- Multiple queries at a time
  - Efficient if many similar queries
  - Decision space is much larger

Query Optimization Issues – Optimization Timing

- Static
  - Compilation ⇒ optimize prior to the execution
  - Difficult to estimate the size of the intermediate results ⇒ error propagation
  - Can amortize over many executions
  - R*
- Dynamic
  - Run time optimization
  - Exact information on the intermediate relation sizes
  - Have to reoptimize for multiple executions
  - Distributed INGRES
- Hybrid
  - Compile using a static algorithm
  - If the error in estimate sizes > threshold, reoptimize at run time
  - Mermaid

Query Optimization Issues – Statistics

- Relation
  - Cardinality
  - Size of a tuple
  - Fraction of tuples participating in a join with another relation
- Attribute
  - Cardinality of domain
  - Actual number of distinct values
- Common assumptions
  - Independence between different attribute values
  - Uniform distribution of attribute values within their domain

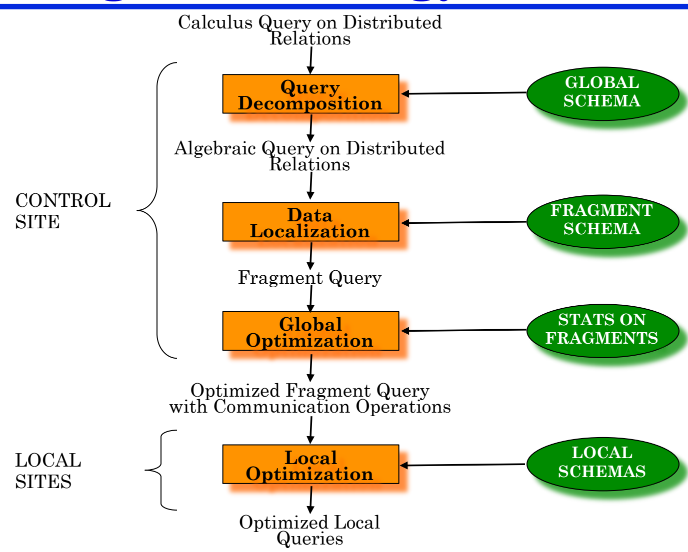
Query Optimization Issues – Decision Sites

- Centralized
  - Single site determines the "best" schedule
  - Simple
  - Need knowledge about the entire distributed database
- Distributed
  - Cooperation among sites to determine the schedule
  - Need only local information
  - Cost of cooperation
- Hybrid
  - One site determines the global schedule
  - Each site optimizes the local subqueries

Query Optimization Issues – Network Topology

- Wide area networks (WAN) – point-to-point
  - Characteristics
    - Low bandwidth
    - Low speed
    - High protocol overhead
  - Communication cost will dominate; ignore all other cost factors
  - 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

Distributed Query Processing Methodology



Step 1 – Query Decomposition

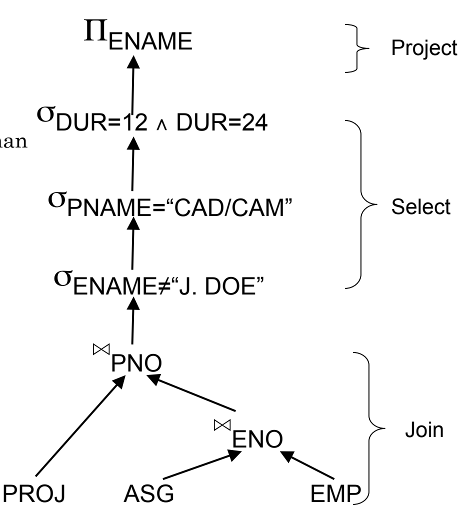
- Input : calculus query on global relations
- Normalization
  - Manipulate query quantifiers and qualification
- Analysis
  - Detect and reject “incorrect” queries
  - Possible for only a subset of relational calculus
- Simplification
  - Eliminate redundant predicates
- Restructuring
  - Calculus query ⇒ algebraic query
  - More than one translation is possible
  - Use transformation rules

Restructuring

- Convert relational calculus to relational algebra
- Make use of query trees
- Example

Find the names of employees other than J. Doe who worked on the CAD/CAM 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 ≠ “J. Doe”
AND     PNAME = “CAD/CAM”
AND     DUR = 12 or DUR = 24)
```

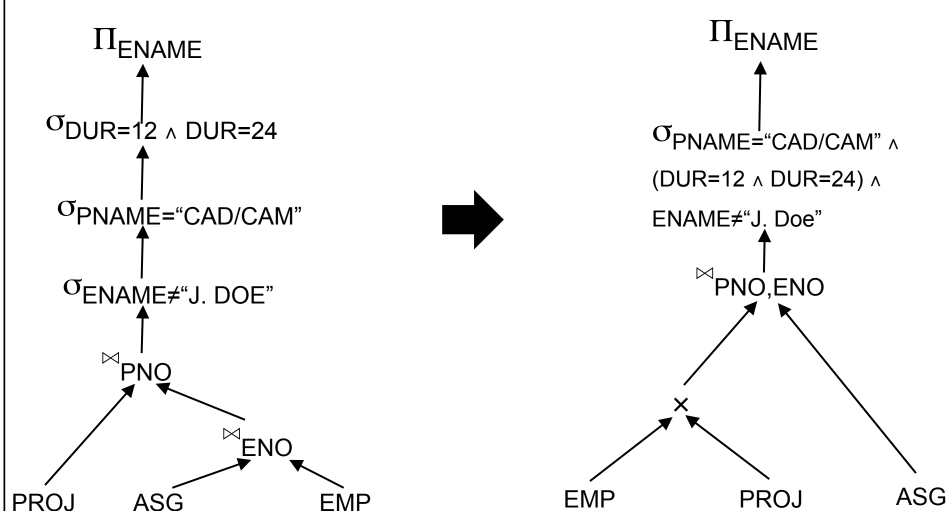


Restructuring – Transformation Rules

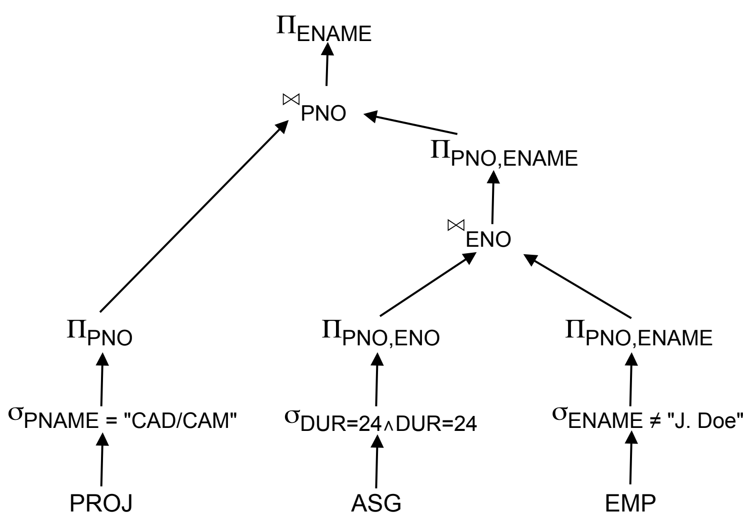
- Commutativity of binary operations
  - $R \times S \Leftrightarrow S \times R$
  - $R \bowtie S \Leftrightarrow S \bowtie R$
  - $R \cup S \Leftrightarrow S \cup R$
- Associativity of binary operations
  - $(R \times S) \times T \Leftrightarrow R \times (S \times T)$
  - $(R \bowtie S) \bowtie T \Leftrightarrow R \bowtie (S \bowtie T)$
- Idempotence of unary operations
  - $\Pi_{A'}(\Pi_{A''}(R)) \Leftrightarrow \Pi_{A'}(R)$
  - $\sigma_{p_1(A_1)}(\sigma_{p_2(A_2)}(R)) \Leftrightarrow \sigma_{p_1(A_1) \wedge p_2(A_2)}(R)$

  where $R[A]$ and $A' \subseteq A$, $A'' \subseteq A$ and $A' \subseteq A''$
- Commuting selection with projection

Previous Example – Equivalent Query



Restructuring



Step 2 – Data Localization

Input: Algebraic query on distributed relations

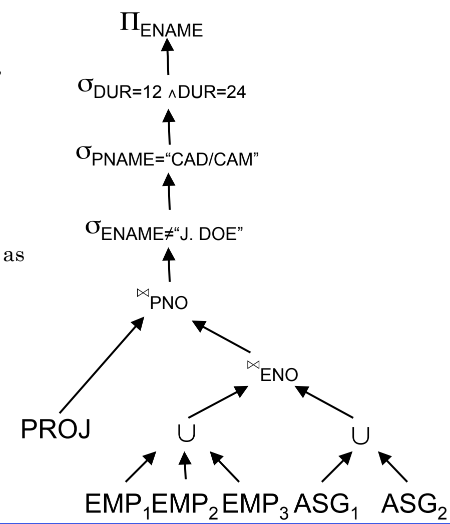
- Determine which fragments are involved
- Localization program
  - substitute for each global query its materialization program
  - optimize

Example

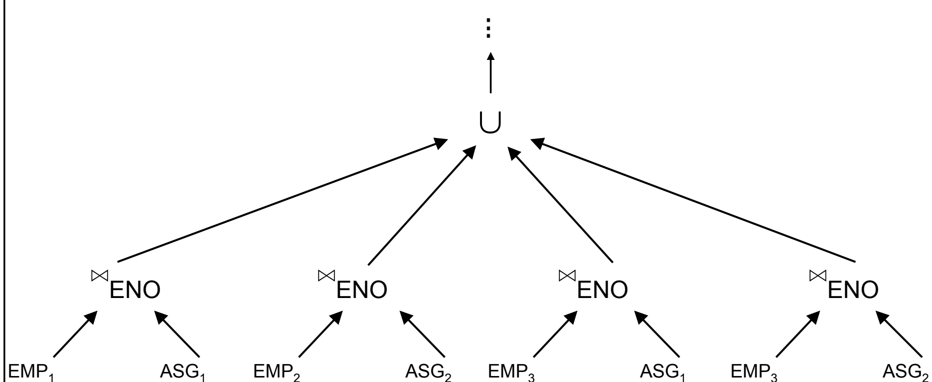
Assume

- EMP is fragmented into EMP_1, EMP_2, EMP_3 as follows:
  - $EMP_1 = \sigma_{ENO \leq \text{“E3”}}(EMP)$
  - $EMP_2 = \sigma_{\text{“E3”} < ENO \leq \text{“E6”}}(EMP)$
  - $EMP_3 = \sigma_{ENO \geq \text{“E6”}}(EMP)$
- ASG fragmented into ASG_1 and ASG_2 as follows:
  - $ASG_1 = \sigma_{ENO \leq \text{“E3”}}(ASG)$
  - $ASG_2 = \sigma_{ENO > \text{“E3”}}(ASG)$

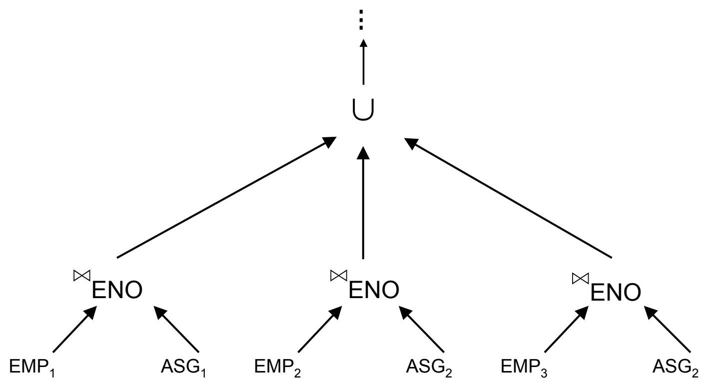
Replace EMP by ($EMP_1 \cup EMP_2 \cup EMP_3$)
and ASG by ($ASG_1 \cup ASG_2$) in any query



Provides Parallellism



Eliminates Unnecessary Work

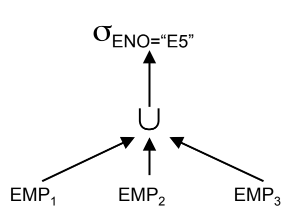


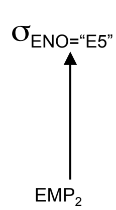
Reduction for PHF

- Reduction with selection
  - Relation R and $F_R=\{R_1, R_2, \ldots, R_w\}$ where $R_j=\sigma_{p_j}(R)$

    $\sigma_{p_i}(R_j)=\varnothing$ if $\forall x$ in R: $\neg(p_i(x) \wedge p_j(x))$
  - Example

```
SELECT *
FROM         EMP
WHERE  ENO="E5"
```





Reduction for PHF

- Reduction with join
  - Possible if fragmentation is done on join attribute
  - Distribute join over union

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

  - Given $R_i = \sigma_{p_i}(R)$ and $R_j = \sigma_{p_j}(R)$

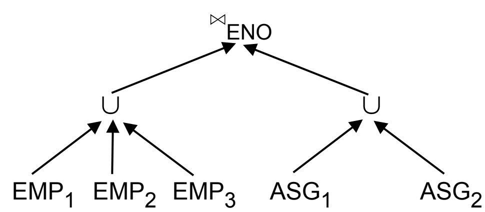
$$R_i \bowtie R_j = \emptyset \text{ if } \forall x \text{ in } R_i, \forall y \text{ in } R_j\text{: } \neg(p_i(x) \wedge p_j(y))$$

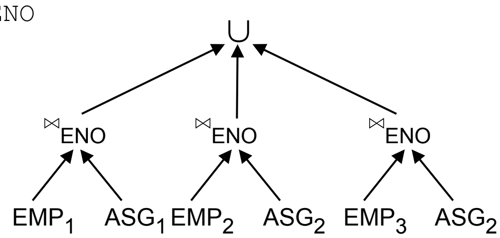
Reduction for PHF

- Assume EMP is fragmented as before and
  - ASG_1: $\sigma_{ENO \le "E3"}(ASG)$
  - ASG_2: $\sigma_{ENO > "E3"}(ASG)$
- Consider the query

```
SELECT *
FROM   EMP,ASG
WHERE  EMP.ENO=ASG.ENO
```

- Distribute join over unions
- Apply the reduction rule





Reduction for VF

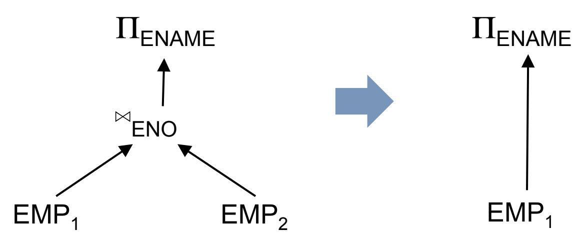
- Find useless (not empty) intermediate relations

  Relation R defined over attributes $A = \{A_1, ..., A_n\}$ vertically fragmented as $R_i = \Pi_{A'}(R)$ where $A' \subseteq A$:

  $\Pi_{D,K}(R_i)$ is useless if the set of projection attributes D is not in A'

  Example: $EMP_1 = \Pi_{ENO,ENAME}(EMP)$; $EMP_2 = \Pi_{ENO,TITLE}(EMP)$

```
SELECT  ENAME
FROM    EMP
```



Reduction for DHF

- Rule :
  - Distribute joins over unions
  - Apply the join reduction for horizontal fragmentation
- Example

  ASG_1: $ASG \ltimes_{ENO} EMP_1$

  ASG_2: $ASG \ltimes_{ENO} EMP_2$

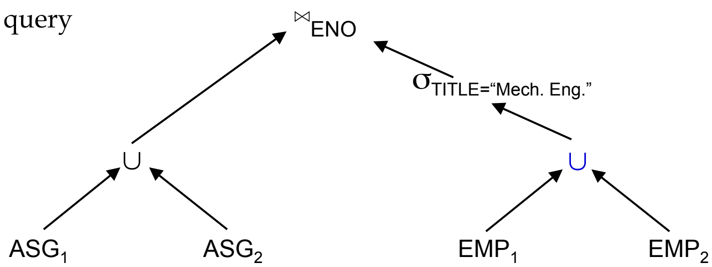
  EMP_1: $\sigma_{TITLE=\text{"Programmer"}}(EMP)$

  EMP_2: $\sigma_{TITLE=\text{"Programmer"}}(EMP)$
- Query

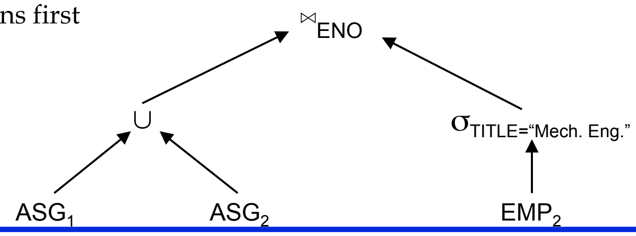
```
SELECT  *
FROM    EMP, ASG
WHERE   ASG.ENO = EMP.ENO
AND     EMP.TITLE = "Mech. Eng."
```

Reduction for DHF

Generic query

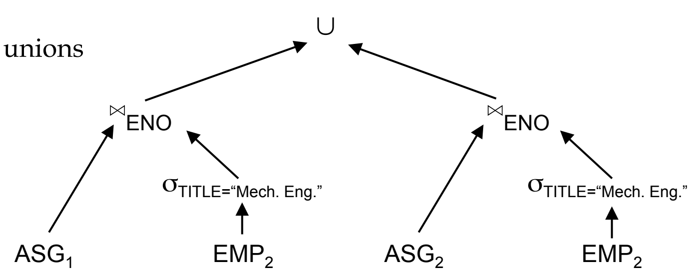


Selections first



Reduction for DHF

Joins over unions



Elimination of the empty intermediate relations (left sub-tree)