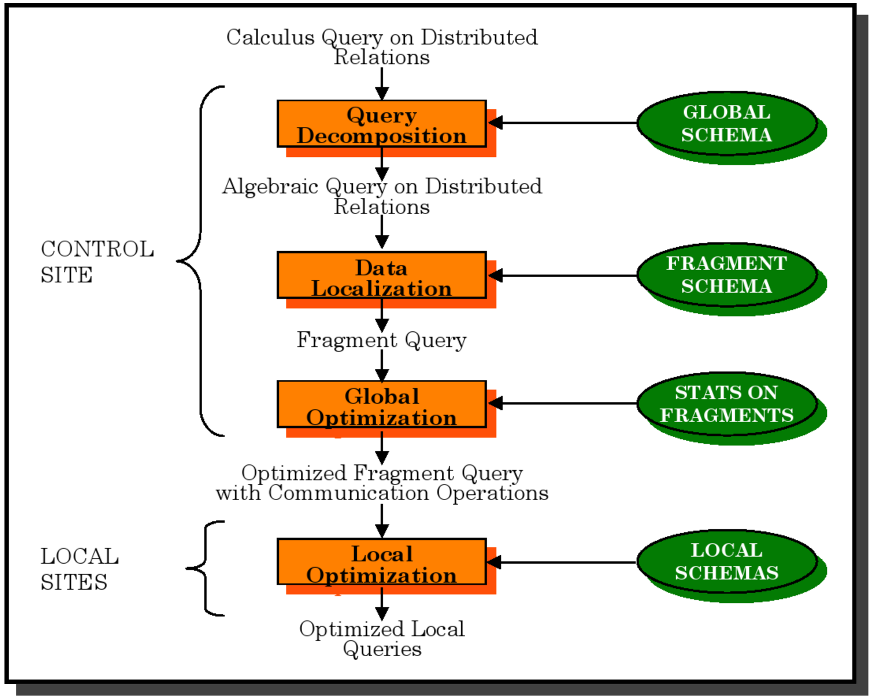
Chapter 6: Query Decomposition and Data Localization

- Query Decomposition
- Data Localization

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

Query Decomposition

- **Query decomposition:** Mapping of calculus query (SQL) to algebra operations (select, project, join, rename)
- Both input and output queries refer to global relations, without knowledge of the distribution of data.
- The output query is semantically correct and good in the sense that redundant work is avoided.



- Query decomposistion consists of 4 steps:
  1. **Normalization**: Transform query to a normalized form
  2. **Analysis**: Detect and reject "incorrect" queries; possible only for a subset of relational calculus
  3. **Elimination of redundancy**: Eliminate redundant predicates
  4. **Rewriting**: Transform query to RA and optimize query

Query Decomposition – Normalization

- **Normalization:** Transform the query to a normalized form to facilitate further processing. Consists mainly of two steps.
  1. **Lexical** and **syntactic** analysis
     - Check validity (similar to compilers)
     - Check for attributes and relations
     - Type checking on the qualification
  2. Put into **normal form**
     - With SQL, the query qualification (WHERE clause) is the most difficult part as it might be an arbitrary complex predicate preceeded by quantifiers ($\exists, \forall$)
     - Conjunctive normal form

$$(p_{11} \vee p_{12} \vee \cdots \vee p_{1n}) \wedge \cdots \wedge (p_{m1} \vee p_{m2} \vee \cdots \vee p_{mn})$$

     - Disjunctive normal form

$$(p_{11} \wedge p_{12} \wedge \cdots \wedge p_{1n}) \vee \cdots \vee (p_{m1} \wedge p_{m2} \wedge \cdots \wedge p_{mn})$$

     - In the disjunctive normal form, the query can be processed as independent conjunctive subqueries linked by unions (corresponding to the disjunction)

- **Example:** Consider the following query: *Find the names of employees who have been working on project P1 for 12 or 24 months?*

- The query in SQL:

```
SELECT ENAME
FROM   EMP, ASG
WHERE  EMP.ENO = ASG.ENO AND
       ASG.PNO = ‘‘P1’’ AND
       DUR = 12 OR DUR = 24
```

- The qualification in conjunctive normal form:

$$EMP.ENO = ASG.ENO \wedge ASG.PNO = "P1" \wedge (DUR = 12 \vee DUR = 24)$$

- The qualification in disjunctive normal form:

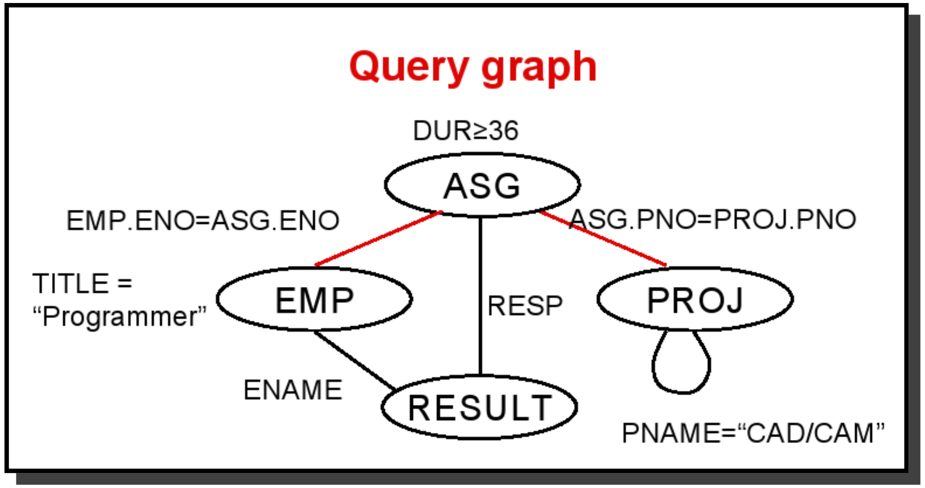
$$(EMP.ENO = ASG.ENO \wedge ASG.PNO = "P1" \wedge DUR = 12) \vee$$
$$(EMP.ENO = ASG.ENO \wedge ASG.PNO = "P1" \wedge DUR = 24)$$

Query Decomposition – Analysis

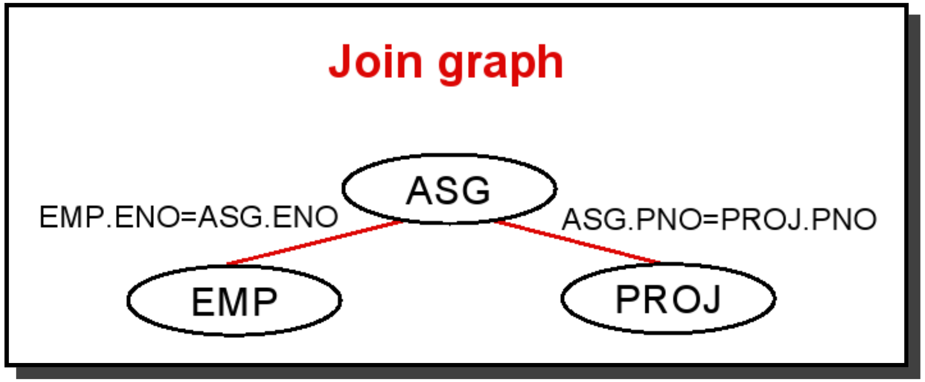
- **Analysis:** Identify and reject type incorrect or semantically incorrect queries
- Type incorrect
  - Checks whether the attributes and relation names of a query are defined in the global schema
  - Checks whether the operations on attributes do not conflict with the types of the attributes, e.g., a comparison $>$ operation with an attribute of type string
- Semantically incorrect
  - Checks whether the components contribute in any way to the generation of the result
  - Only a subset of relational calculus queries can be tested for correctness, i.e., those that do not contain disjunction and negation
  - Typical data structures used to detect the semantically incorrect queries are:
    - ∗ Connection graph (query graph)
    - ∗ Join graph

- **Example:** Consider a query:

```
SELECT  ENAME,RESP
FROM    EMP, ASG, PROJ
WHERE   EMP.ENO = ASG.ENO
AND     ASG.PNO = PROJ.PNO
AND     PNAME = "CAD/CAM"
AND     DUR ≥ 36
AND     TITLE = "Programmer"
```



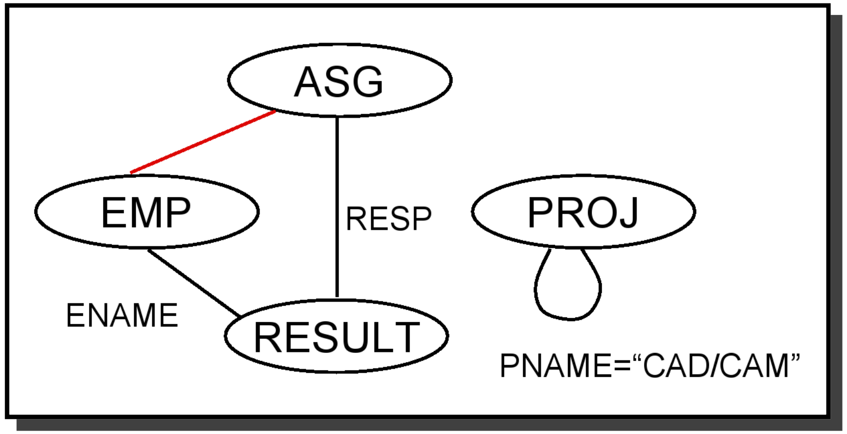
- Query/connection graph
  - Nodes represent operand or result relation
  - Edge represents a join if both connected nodes represent an operand relation, otherwise it is a projection



- Join graph
  - a subgraph of the query graph that considers only the joins
- Since the query graph **is connected**, the query is semantically correct

- **Example:** Consider the following query and its query graph:

```
SELECT  ENAME,RESP
FROM    EMP, ASG, PROJ
WHERE   EMP.ENO = ASG.ENO
AND     PNAME = "CAD/CAM"
AND     DUR ≥ 36
AND     TITLE = "Programmer"
```



- Since the graph **is not connected**, the query is semantically incorrect.
- 3 possible solutions:
  - Reject the query
  - Assume an implicit Cartesian Product between ASG and PROJ
  - Infer from the schema the missing join predicate ASG.PNO = PROJ.PNO

Query Decomposition – Elimination of Redundancy

- **Elimination of redundancy:** Simplify the query by eliminate redundancies, e.g., redundant predicates
  - Redundancies are often due to semantic integrity constraints expressed in the query language
  - e.g., queries on views are expanded into queries on relations that satiesfy certain integrity and security constraints
- Transformation rules are used, e.g.,
  - $p \wedge p \iff p$
  - $p \vee p \iff p$
  - $p \wedge true \iff p$
  - $p \vee false \iff p$
  - $p \wedge false \iff false$
  - $p \vee true \iff true$
  - $p \wedge \neg p \iff false$
  - $p \vee \neg p \iff true$
  - $p_1 \wedge (p_1 \vee p_2) \iff p_1$
  - $p_1 \vee (p_1 \wedge p_2) \iff p_1$

- **Example:** Consider the following query:

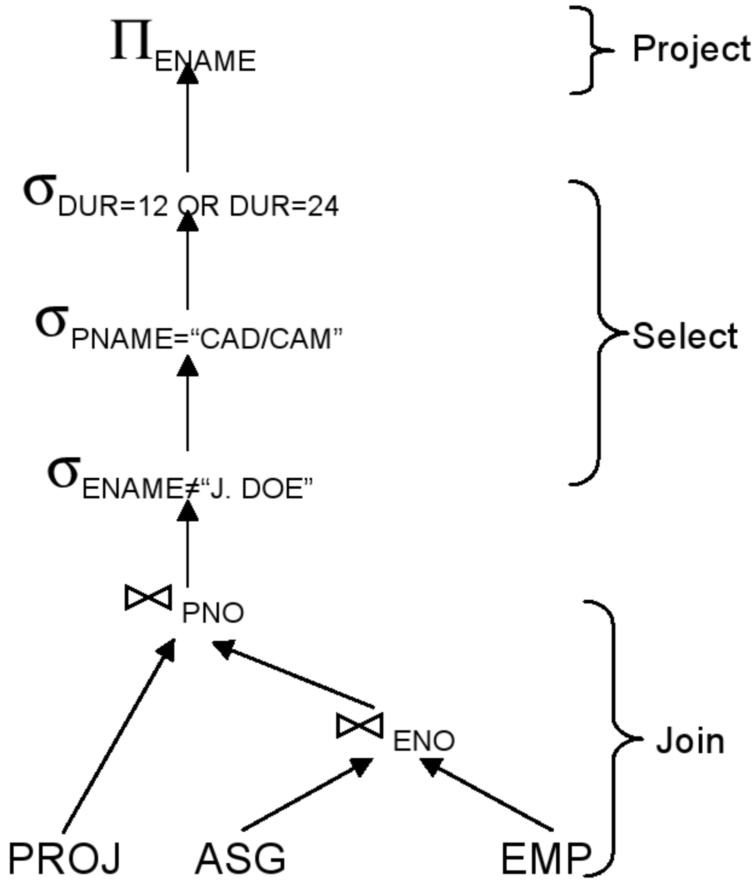
```
SELECT  TITLE
FROM    EMP
WHERE   EMP.ENAME = "J. Doe"
OR      (NOT(EMP.TITLE = "Programmer")
AND     ( EMP.TITLE = "Elect. Eng."
OR        EMP.TITLE = "Programmer" )
AND     NOT(EMP.TITLE = "Elect. Eng."))
```

- Let p_1 be ENAME = "J. Doe", p_2 be TITLE = "Programmer" and p_3 be TITLE = "Elect. Eng."
- Then the qualification can be written as $p_1 \vee (\neg p_2 \wedge (p_2 \vee p_3) \wedge \neg p_3)$ and then be transformed into p_1
- Simplified query:

```
SELECT  TITLE
FROM    EMP
WHERE   EMP.ENAME = "J. Doe"
```

Query Decomposition – Rewriting

- **Rewriting:** Convert relational calculus query to relational algebra query and find an **efficient** expression.
- **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)

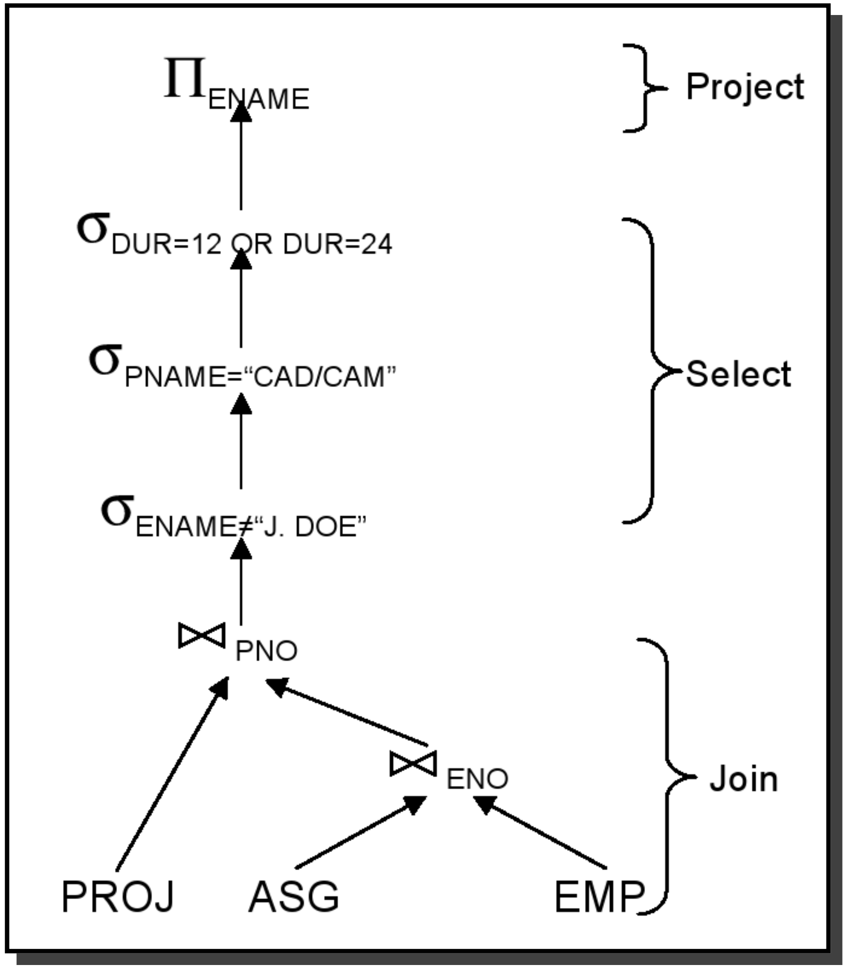


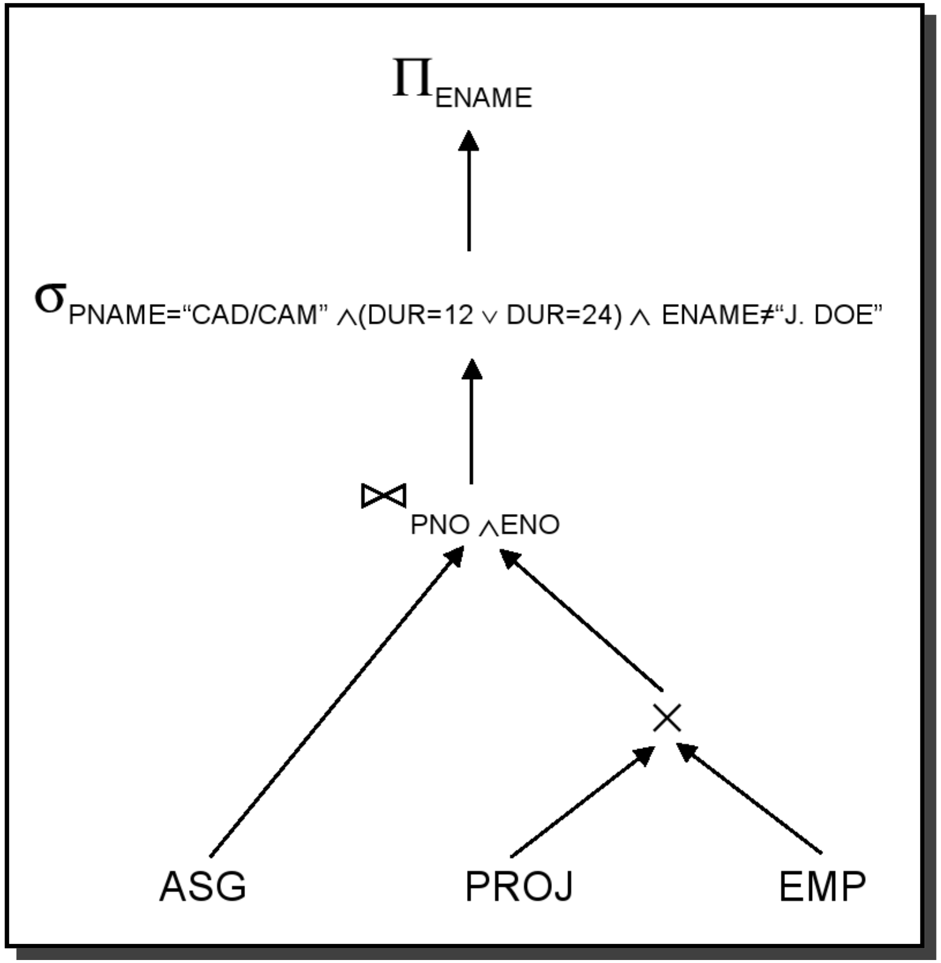
- A **query tree** represents the RA-expression
  – Relations are leaves (FROM clause)
  – Result attributes are root (SELECT clause)
  – Intermediate leaves should give a result from the leaves to the root

- By applying **transformation rules**, many different trees/expressions may be found that are **equivalent** to the original tree/expression, but might be more efficient.
- In the following we assume relations $R(A_1, \ldots, A_n)$, $S(B_1, \ldots, B_n)$, and T which is union-compatible to R.
- **Commutativity** of binary operations
  - $R \times S = S \times R$
  - $R \bowtie S = S \bowtie R$
  - $R \cup S = S \cup R$
- **Associativity** of binary operations
  - $(R \times S) \times T = R \times (S \times T)$
  - $(R \bowtie S) \bowtie T = R \bowtie (S \bowtie T)$
- **Idempotence** of unary operations
  - $\Pi_A(\Pi_A(R)) = \Pi_A(R)$
  - $\sigma_{p1(A1)}(\sigma_{p2(A2)}(R)) = \sigma_{p1(A1) \wedge p2(A2)}(R)$

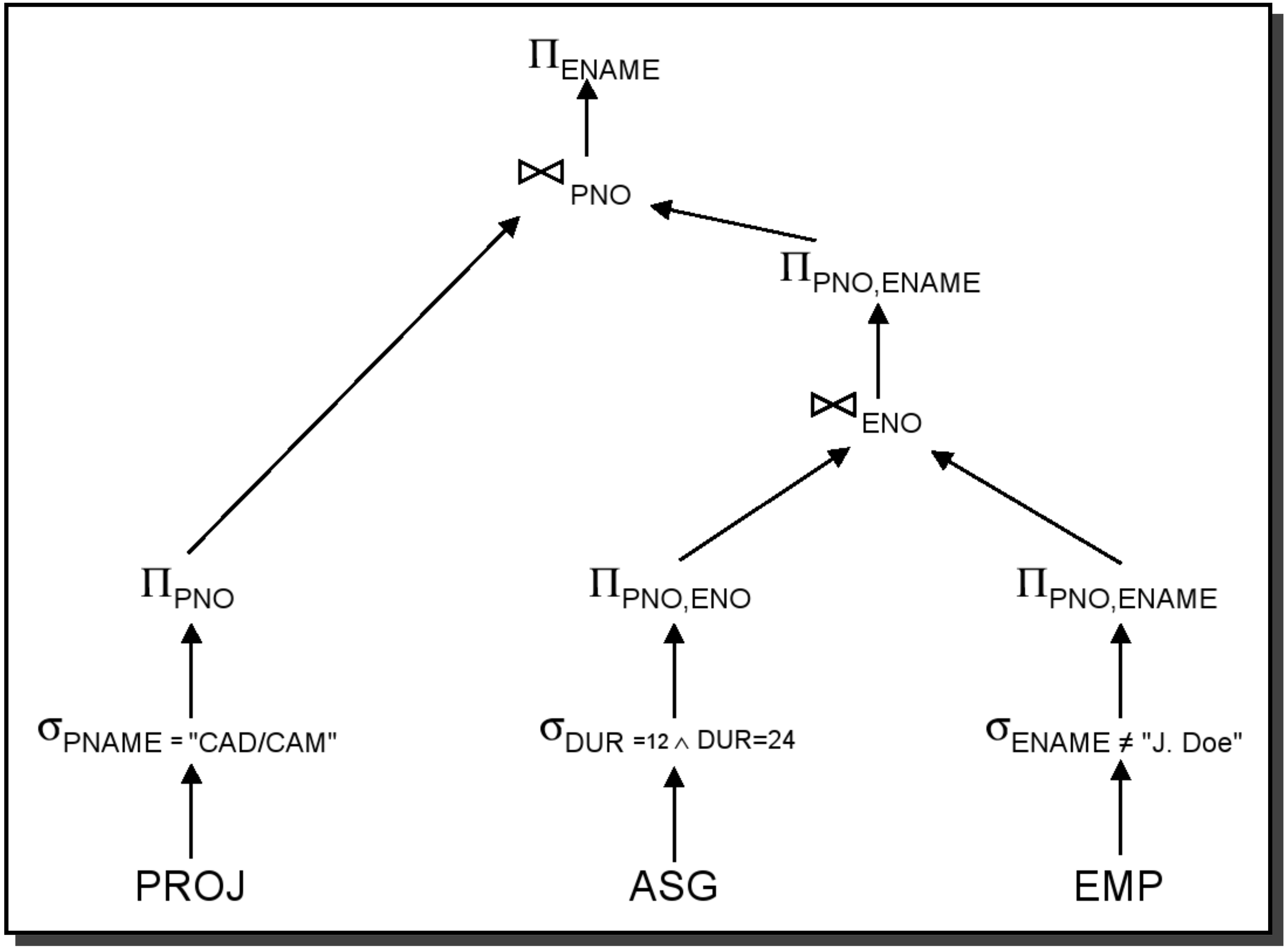
- **Commuting selection** with binary operations
  - $\sigma_{p(A)}(R \times S) \iff \sigma_{p(A)}(R) \times S$
  - $\sigma_{p(A_1)}(R \bowtie_{p(A_2,B_2)} S) \iff \sigma_{p(A_1)}(R) \bowtie_{p(A_2,B_2)} S$
  - $\sigma_{p(A)}(R \cup T) \iff \sigma_{p(A)}(R) \cup \sigma_{p(A)}(T)$
    - (A belongs to R and T)
- **Commuting projection** with binary operations (assume $C = A' \cup B'$, $A' \subseteq A, B' \subseteq B$)
  - $\Pi_C(R \times S) \iff \Pi_{A'}(R) \times \Pi_{B'}(S)$
  - $\Pi_C(R \bowtie_{p(A',B')} S) \iff \Pi_{A'}(R) \bowtie_{p(A',B')} \Pi_{B'}(S)$
  - $\Pi_C(R \cup S) \iff \Pi_C(R) \cup \Pi_C(S)$

- **Example:** Two equivalent query trees for the previous example
  - Recall the schemas: EMP(ENO, ENAME, TITLE)
    PROJ(PNO, PNAME, BUDGET)
    ASG(ENO, PNO, RESP, DUR)



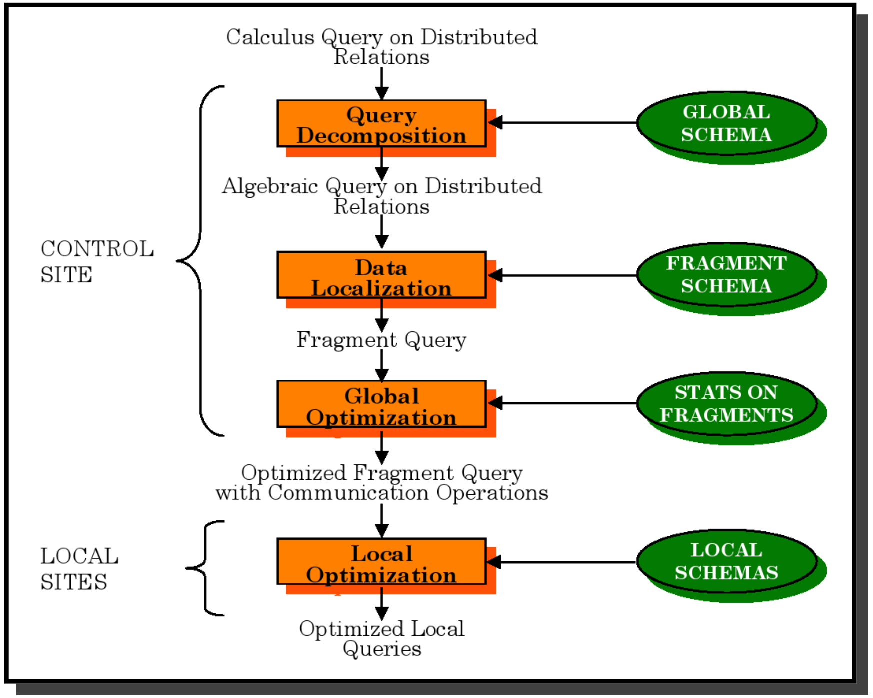


- **Example (contd.):** Another equivalent query tree, which allows a more efficient query evaluation, since the most selective operations are applied first.



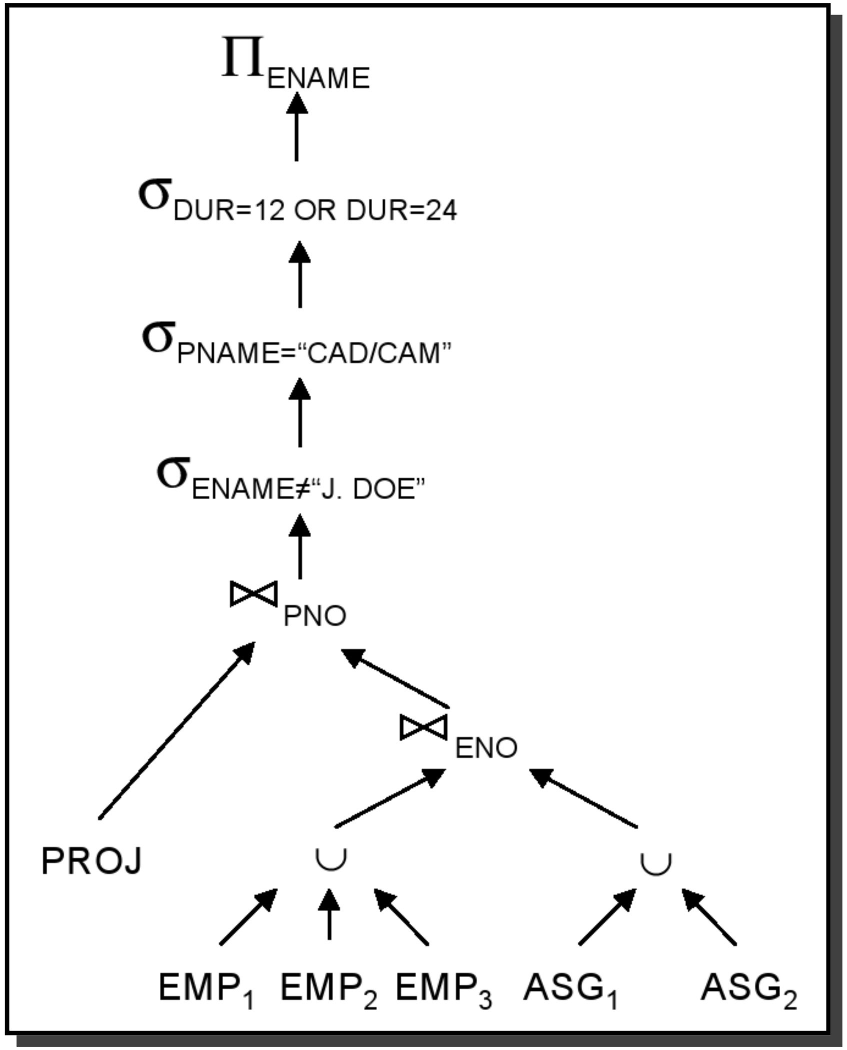
Data Localization

- **Data localization**
  - **Input:** Algebraic query on global conceptual schema
  - **Purpose:**
    - ∗ Apply data distribution information to the algebra operations and determine which fragments are involved
    - ∗ Substitute global query with queries on fragments
    - ∗ Optimize the global query



Data Localization ...

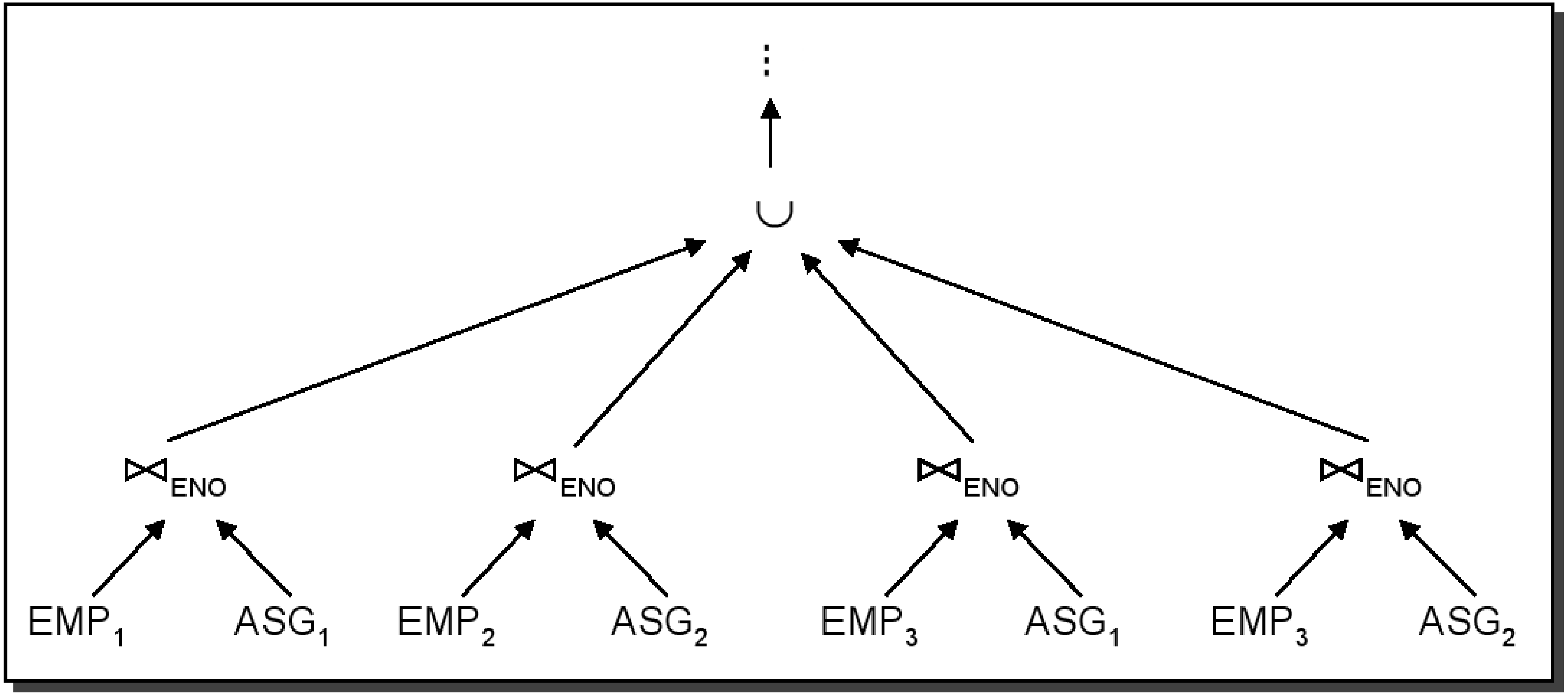
- **Example:**
  - Assume EMP is horizontally fragmented into EMP1, EMP2, EMP3 as follows:
    - $EMP1 = \sigma_{ENO \leq \text{"}E3\text{"}}(EMP)$
    - $EMP2 = \sigma_{\text{"}E3\text{"} < ENO \leq \text{"}E6\text{"}}(EMP)$
    - $EMP3 = \sigma_{ENO > \text{"}E6\text{"}}(EMP)$
  - ASG fragmented into ASG1 and ASG2 as follows:
    - $ASG1 = \sigma_{ENO \leq \text{"}E3\text{"}}(ASG)$
    - $ASG2 = \sigma_{ENO > \text{"}E3\text{"}}(ASG)$
- Simple approach: Replace in all queries
  - EMP by (EMP1∪EMP2∪ EMP3)
  - ASG by (ASG1∪ASG2)
  - Result is also called **generic query**



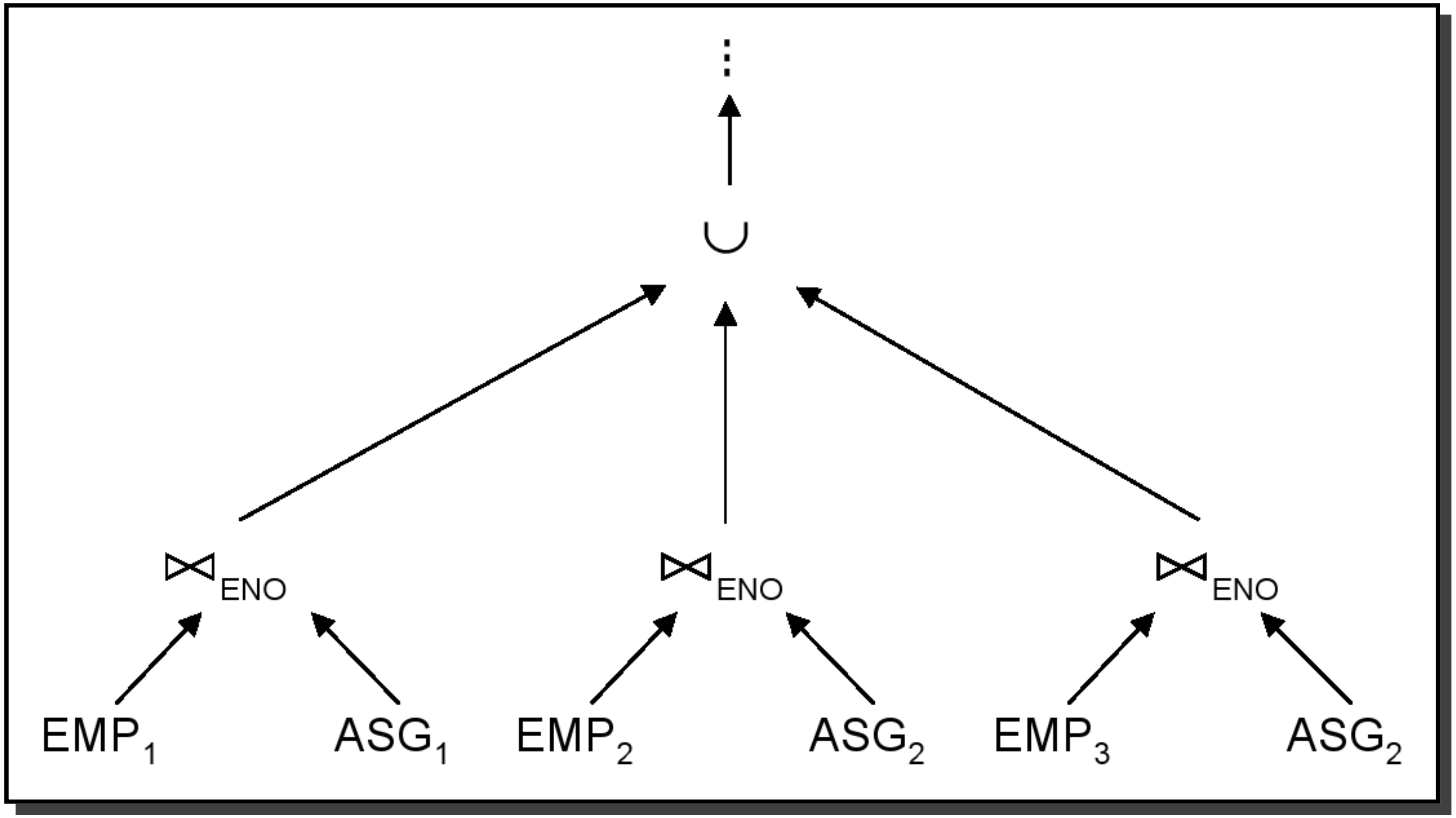
- In general, the **generic query is inefficient** since important restructurings and simplifications can be done.

Data Localization . . .

- **Example (contd.)**: Parallelsim in the evaluation is often possible
  - Depending on the horizontal fragmentation, the fragments can be joined in parallel followed by the union of the intermediate results.



- **Example (contd.)**: Unnecessary work can be eliminated
  - e.g., $EMP_3 \bowtie ASG_1$ gives an empty result
    - $EMP3 = \sigma_{ENO > "E6"}(EMP)$
    - $ASG1 = \sigma_{ENO \leq "E3"}(ASG)$



Data Localizations Issues

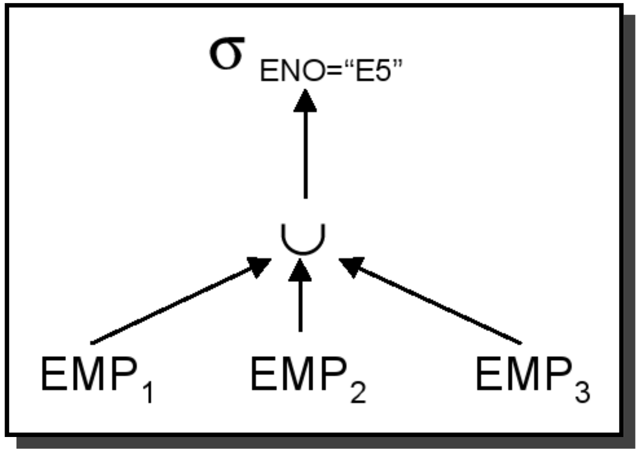
- Various more advanced **reduction techniques** are possible to generate simpler and optimized queries.
- Reduction of horizontal fragmentation (HF)
  - Reduction with selection
  - Reduction with join
- Reduction of vertical fragmentation (VF)
  - Find empty relations

- **Reduction with selection for HF**
  - Consider relation R with horizontal fragmentation $F = \{R_1, R_2, \ldots, R_k\}$, where $R_i = \sigma_{p_i}(R)$
  - **Rule1:** Selections on fragments, $\sigma_{p_j}(R_i)$, that have a qualification contradicting the qualification of the fragmentation generate empty relations, i.e.,

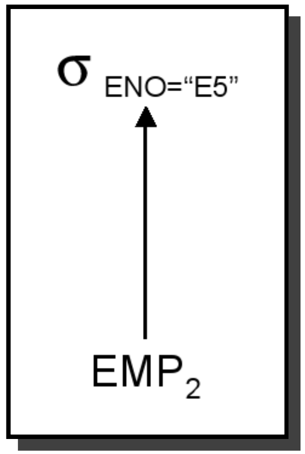
$$\sigma_{p_j}(R_i) = \emptyset \iff \forall x \in R(p_i(x) \wedge p_j(x) = false)$$

  - Can be applied if fragmentation predicate is inconsistent with the query selection predicate.

- **Example:** Consider the query: **SELECT** * **FROM** EMP **WHERE** ENO=”E5”



After commuting the selection with the union operation, it is easy to detect that the selection predicate contradicts the predicates of EMP_1 and EMP_3.

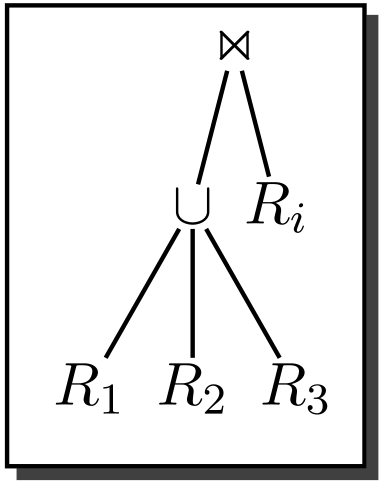


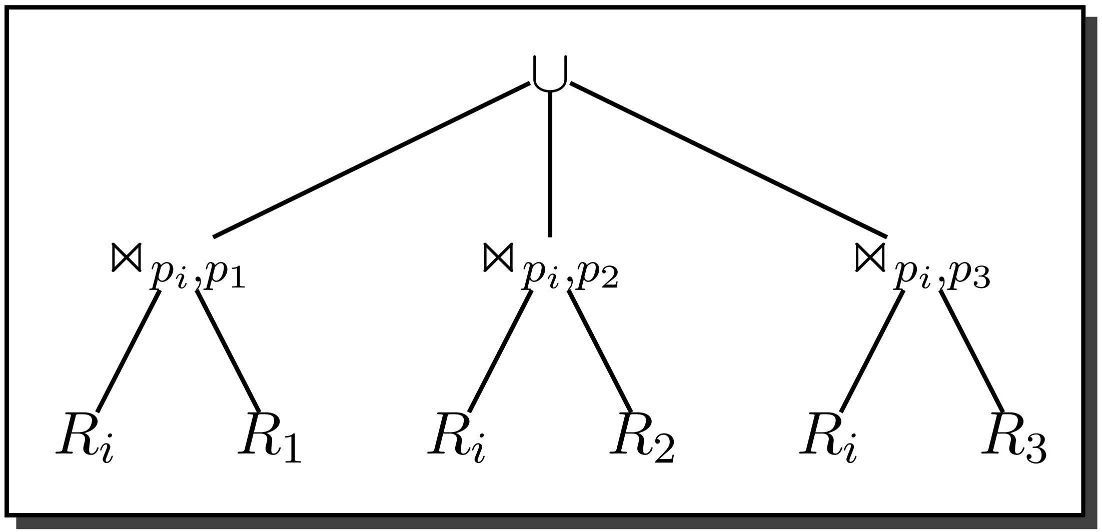
- **Reduction with join for HF**
  - Joins on horizontally fragmented relations can be simplified when the joined relations are fragmented according to the join attributes.
  - Distribute join over union

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

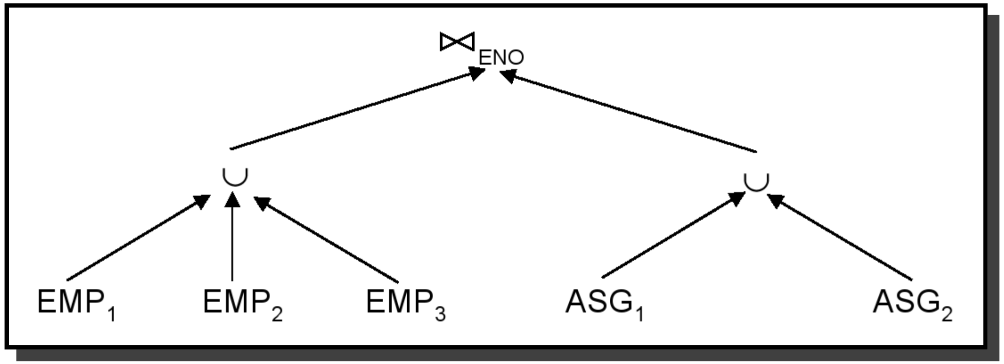
  - **Rule 2**: Useless joins of fragments, $R_i = \sigma_{p_i}(R)$ and $R_j = \sigma_{p_j}(R)$, can be determined when the qualifications of the joined fragments are contradicting, i.e.,

$$R_i \bowtie R_j = \emptyset \iff \forall x \in R_i, \forall y \in R_j (p_i(x) \wedge p_j(y) = false)$$

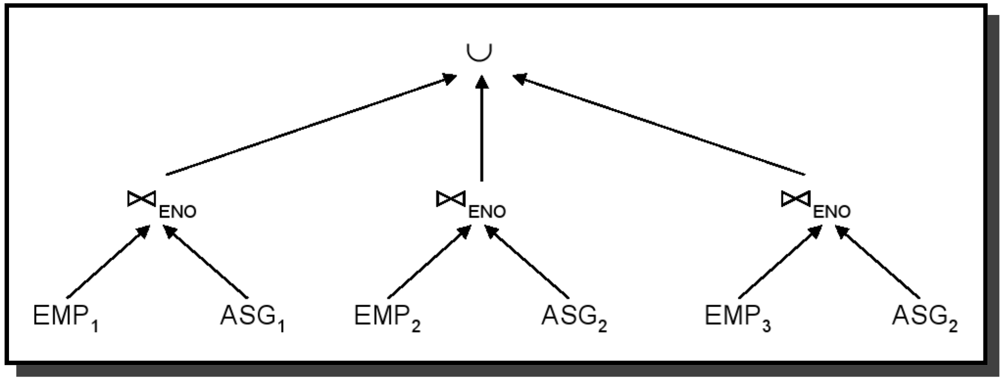




- **Example:** Consider the following query and fragmentation:
  - Query: **SELECT** * **FROM** EMP, ASG **WHERE** EMP.ENO=ASG.ENO
  - Horizontal fragmentation:
    - $EMP1 = \sigma_{ENO \leq "E3"}(EMP)$
    - $EMP2 = \sigma_{"E3" < ENO \leq "E6"}(EMP)$
    - $EMP3 = \sigma_{ENO > "E6"}(EMP)$
    - $ASG1 = \sigma_{ENO \leq "E3"}(ASG)$
    - $ASG2 = \sigma_{ENO > "E3"}(ASG)$
  - Generic query



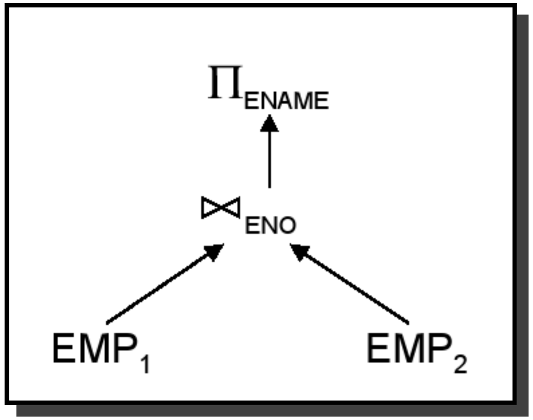
  - The query reduced by distributing joins over unions and applying rule 2 can be implemented as a union of three partial joins that can be done in parallel.



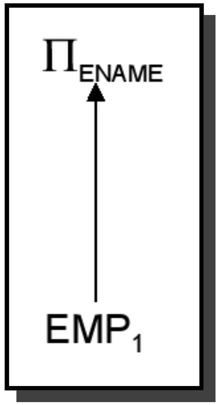
- **Reduction with join for derived HF**
  - The horizontal fragmentation of one relation is **derived** from the horizontal fragmentation of another relation by using semijoins.
- If the fragmentation is not on the same predicate as the join (as in the previous example), derived horizontal fragmentation can be applied in order to make efficient join processing possible.
- **Example:** Assume the following query and fragmentation of the EMP relation:
  - Query: **SELECT** * **FROM** EMP, ASG **WHERE** EMP.ENO=ASG.ENO
  - Fragmentation (**not** on the join attribute):
    - EMP1 = $\sigma_{\text{TITLE=“Prgrammer”}}(\text{EMP})$
    - EMP2 = $\sigma_{\text{TITLE}\neq\text{“Prgrammer”}}(\text{EMP})$
  - To achieve efficient joins ASG can be fragmented as follows:
    - ASG1= ASG$\rtimes_{ENO}$EMP1
    - ASG2= ASG$\rtimes_{ENO}$EMP2
  - The fragmentation of ASG is derived from the fragmentation of EMP
  - Queries on derived fragments can be reduced, e.g., $ASG_1 \bowtie EMP_2 = \emptyset$

- **Reduction for Vertical Fragmentation**
  - Recall, VF distributes a relation based on projection, and the reconstruction operator is the join.
  - Similar to HF, it is possible to identify useless intermediate relations, i.e., fragments that do not contribute to the result.
  - Assume a relation $R(A)$ with $A = \{A_1, \ldots, A_n\}$, which is vertically fragmented as $R_i = \pi_{A'_i}(R)$, where $A'_i \subseteq A$.
  - **Rule 3**: $\pi_{D,K}(R_i)$ is useless if the set of projection attributes D is not in A'_i and K is the key attribute.
  - Note that the result is not empty, but it is useless, as it contains only the key attribute.

- **Example:** Consider the following query and vertical fragmentation:
  - Query: **SELECT** ENAME **FROM** EMP
  - Fragmentation:
    - $EMP1 = \Pi_{ENO,ENAME}(EMP)$
    - $EMP2 = \Pi_{ENO,TITLE}(EMP)$
- Generic query



- Reduced query
  - By commuting the projection with the join (i.e., projecting on ENO, ENAME), we can see that the projection on EMP_2 is useless because ENAME is not in EMP_2.



Conclusion

- Query decomposition and data localization maps calculus query into algebra operations and applies data distribution information to the algebra operations.
- Query decomposition consists of normalization, analysis, elimination of redundancy, and rewriting.
- Data localization reduces horizontal fragmentation with join and selection, and vertical fragmentation with joins, and aims to find empty relations.