

Query Processing and Query Optimization in Centralized Database Systems

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- ◆ **Query processing** is defined as the activities involved in parsing, validation, translation, optimization, and execution of a query.
- ◆ The aims of query processing process are to transform a query written in a high-level language, SQL, into a correct and efficient execution strategy expressed in low-level language, and to execute the strategy to generate the result.

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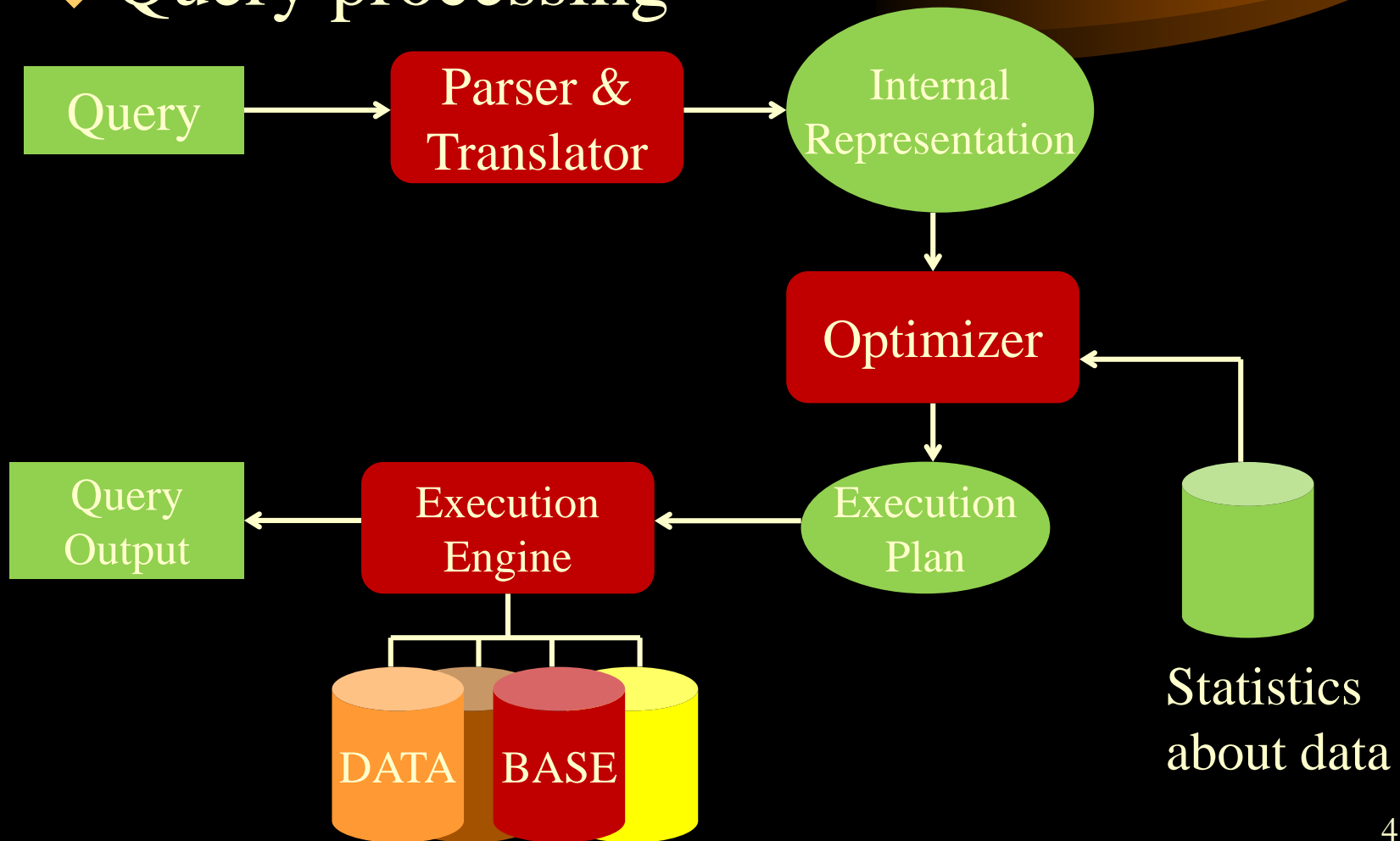
◆ Query processing

★ A query processing involves three steps:

- Parsing, validation, and Translation
- Optimization
- Evaluation (execution)

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◆ Query processing



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◆ Query processing – An Example

```
Select balance  
From account  
Where balance < 2,500
```

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◆ Query processing – An Example

$\sigma_{\text{balance} < 2500} (\Pi_{\text{balance}} (\text{account}))$

or

$\Pi_{\text{balance}} (\sigma_{\text{balance} < 2500} (\text{account}))$

- ◆ Note there might be different ways to define and execute a query. It is the role of **optimizer** to select an **efficient** way to execute a query. Therefore, the optimizer needs to determine different ways (plans) that one can execute a query, determine the **execution cost** of each plan, and then choose the most cost effective plan for execution.

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◆ Query processing — An Example

- ★ Factors such as **number of accesses to the disks** and **CPU time** must be taken into consideration to estimate cost of a plan.
- ★ In large databases, however, disk accesses (the number of data block transfers) are usually the most dominating cost factor. Hence, it can be used as a cost metric.

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◆ Query processing — An Example

- ★ To simplify the cost estimation, we can assume that all block transfers cost the same (i.e., variances in **rotational latency** and **seek time** are ignored).
- ★ For more accurate measure, one also need to distinguish the difference between **sequential I/O** and **random I/O** as well.

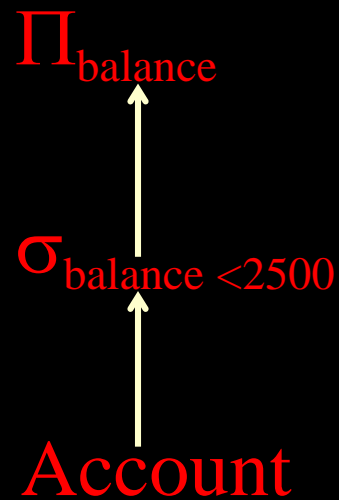
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◆ Query processing — An Example

- ★ One also needs to distinguish between the number of data blocks being read and written.
- ★ Techniques such as **pipelining** and **parallelism**, if possible, depending on the underlying platform, can be applied to execute basic operations.
- ★ **Different algorithms** can be developed to execute basic operations.

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◆ Query processing – An Example



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- ◆ **Query optimization** is the activity of choosing an efficient execution strategy for processing a query.
- ◆ Query optimization can be done in two fashion: Static or dynamic

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- ◆ There are two choices in carrying the first phases (i.e., parsing, validation, translation, and optimization) of query processing.
- ◆ One option is to **dynamically** carry out the decomposition and optimization every time the query is run.
- ◆ Alternative is **static** query optimization where the query is parsed, validated, and optimized once.

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◆ Query Optimization

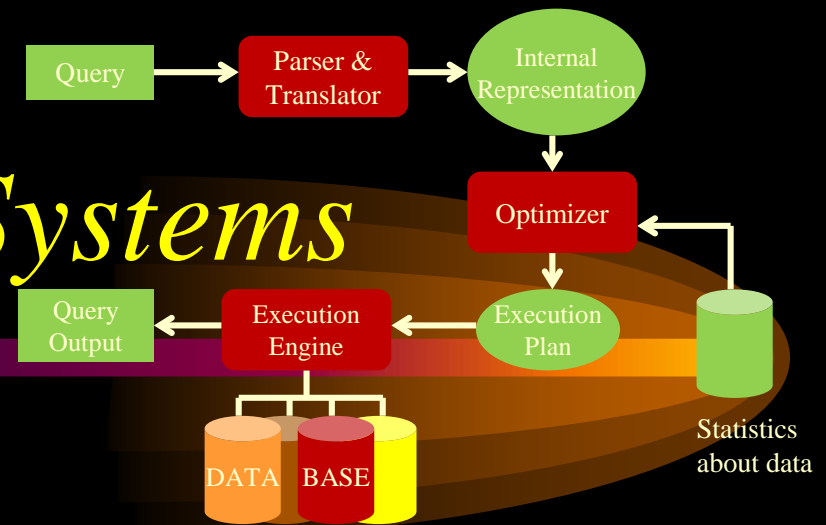
- ★ In general, **optimization** is required in such a system if the system is expected to achieve **acceptable objectives** (e.g., performance).
- ★ It is one of the strength of **relational algebra** that **optimization** can be done **automatically**, since relational expression are at a sufficiently high semantic level.

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◆ Query Optimization

- ★ The overall goal of an optimization is to choose an **efficient strategy** for evaluation of a given relational expression (i.e., a query).
- ★ An optimizer might actually do **better** than a **human programmer** since:

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◆ Query Optimization

- An optimizer will have a **wealth of information** available to it that human programmers typically do not have.
- If the data base **statistics changes** drastically, then an optimizer may choose a different strategy.
- Optimizer can potentially considers **several strategies** for a given request.
- Optimizer is written by an **expert**.

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◆ Running Example

EMPLOYEE

Fname	Minit	Lname	<u>Ssn</u>	Bdate	Address	Sex	Salary	Super_ssn	Dno
-------	-------	-------	------------	-------	---------	-----	--------	-----------	-----

DEPARTMENT

Dname	<u>Dnumber</u>	Mgr_ssn	Mgr_start_date
-------	----------------	---------	----------------

DEPT_Location

<u>Dnumber</u>	<u>Dlocation</u>
----------------	------------------

PROJECT

Pname	<u>Pnumber</u>	Plocation	Dnum
-------	----------------	-----------	------

WORKS_ON

<u>Essn</u>	<u>Pno</u>	Hours
-------------	------------	-------

DEPENDENT

<u>Essn</u>	<u>Dependent_name</u>	Sex	Bdate	Relationship
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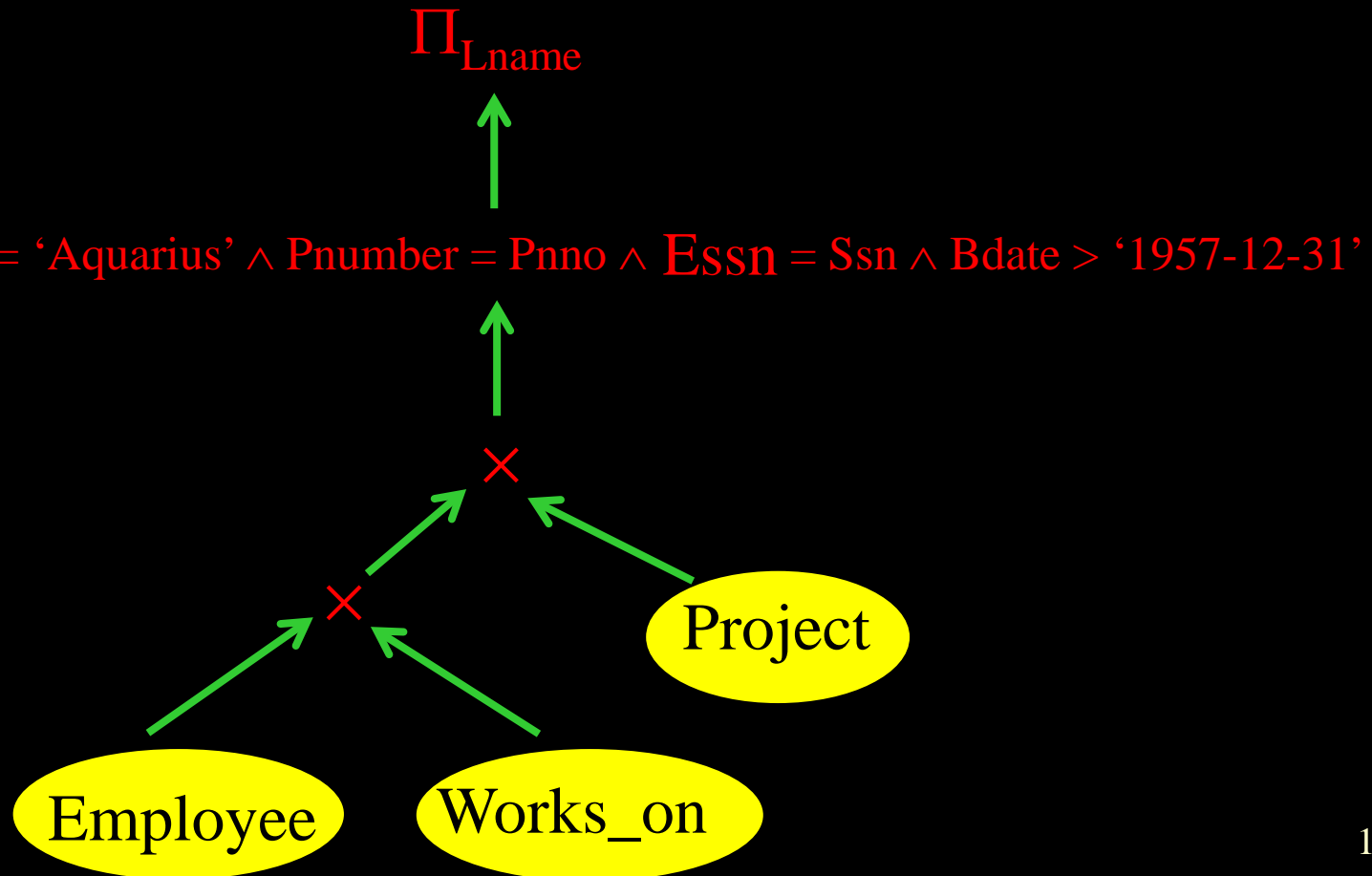
◆ Query Optimization — Running Example

- ★ Find the last name of employees born after 1957 and working on a project named “Aquarius”.

```
SELECT      Lname
FROM        EMPLOYEE, WORKS_ON, PROJECT
WHERE       P_name = 'Aquarius' AND Pnumber = Pno AND Essn
           = Ssn AND Bdate > '1957-12-31';
```

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◆ Query Optimization — Running Example



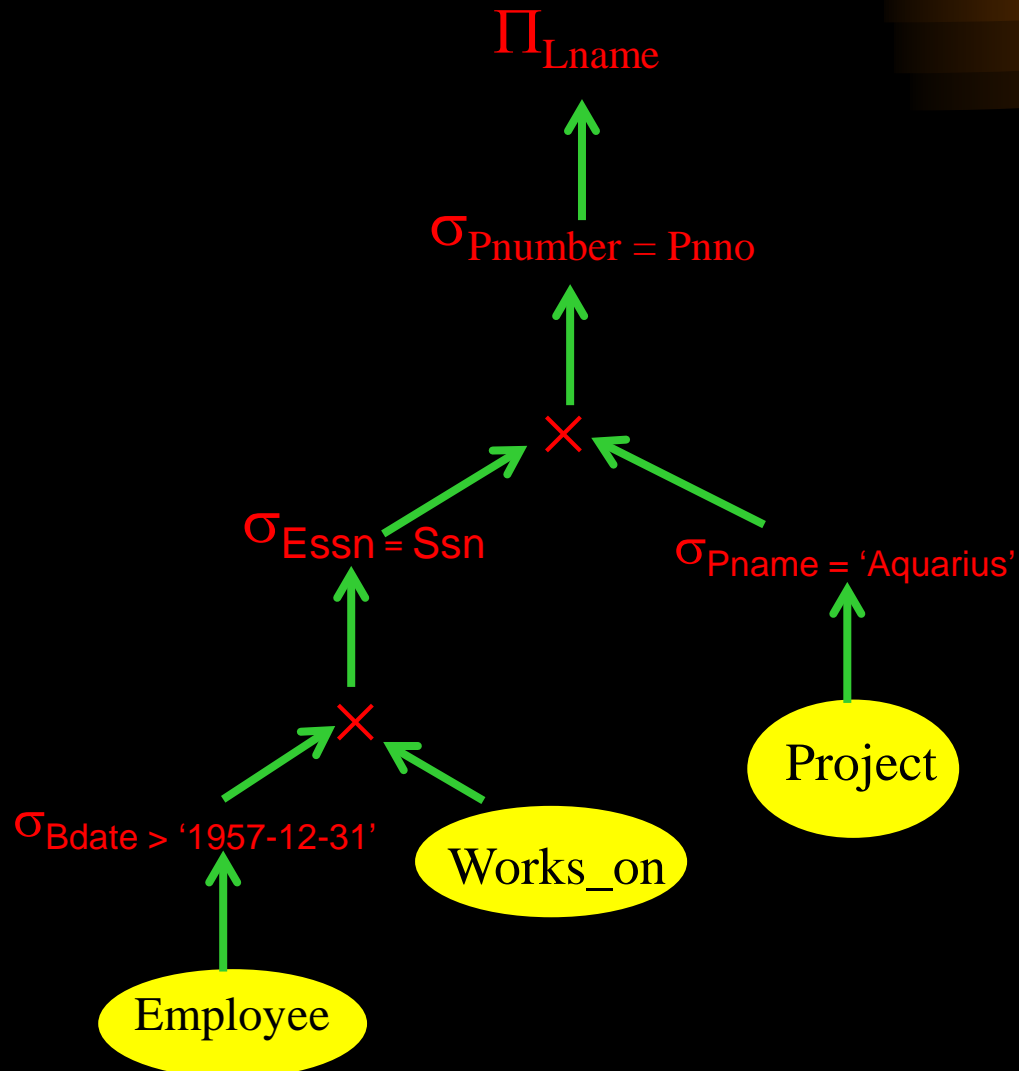
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◆ Query Optimization — An Example

- ★ Execution of the previous query tree generates a very large relation because of performing **Cartesian products** on input relations.
- ★ It makes sense to perform some **Select operations** on base relations before performing the Cartesian products.

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◆ Query Optimization — Running Example



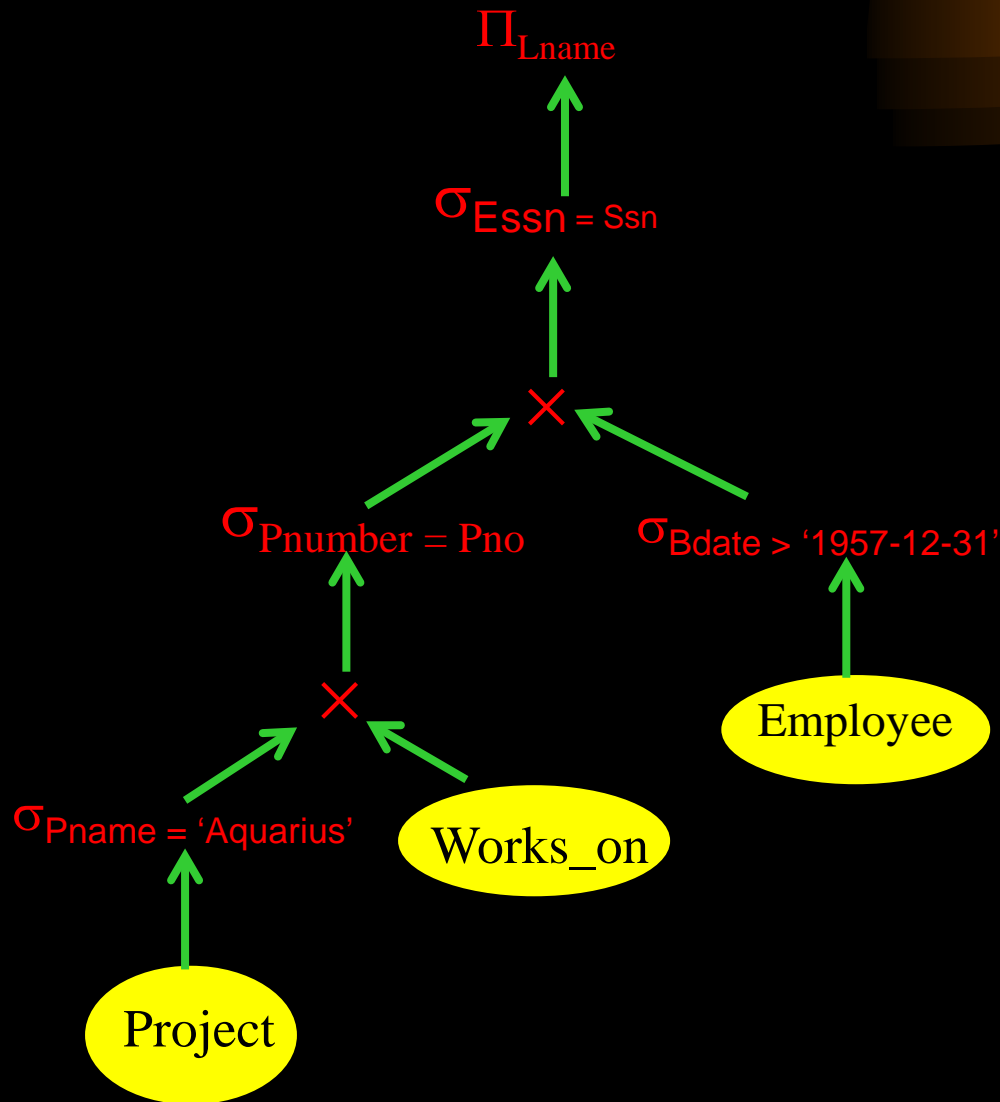
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◆ Query Optimization — Running Example

- ★ By closer observation, one should realize that just one tuple from the Project will be involved with the query. So it makes sense to switch the order of operations on input relations.

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◆ Query Optimization — Running Example



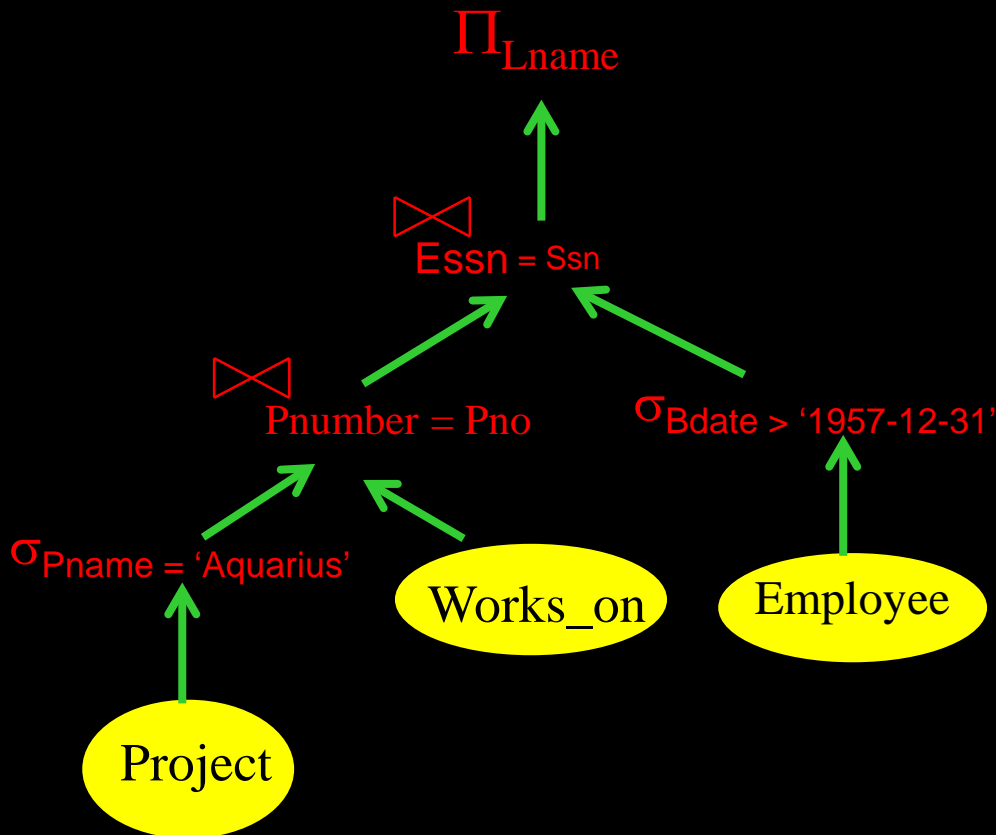
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◆ Query Optimization — *Running Example*

- ★ It also makes sense to replace any Cartesian product followed by a Select operation with a Join operation.

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◆ Query Optimization — Running Example



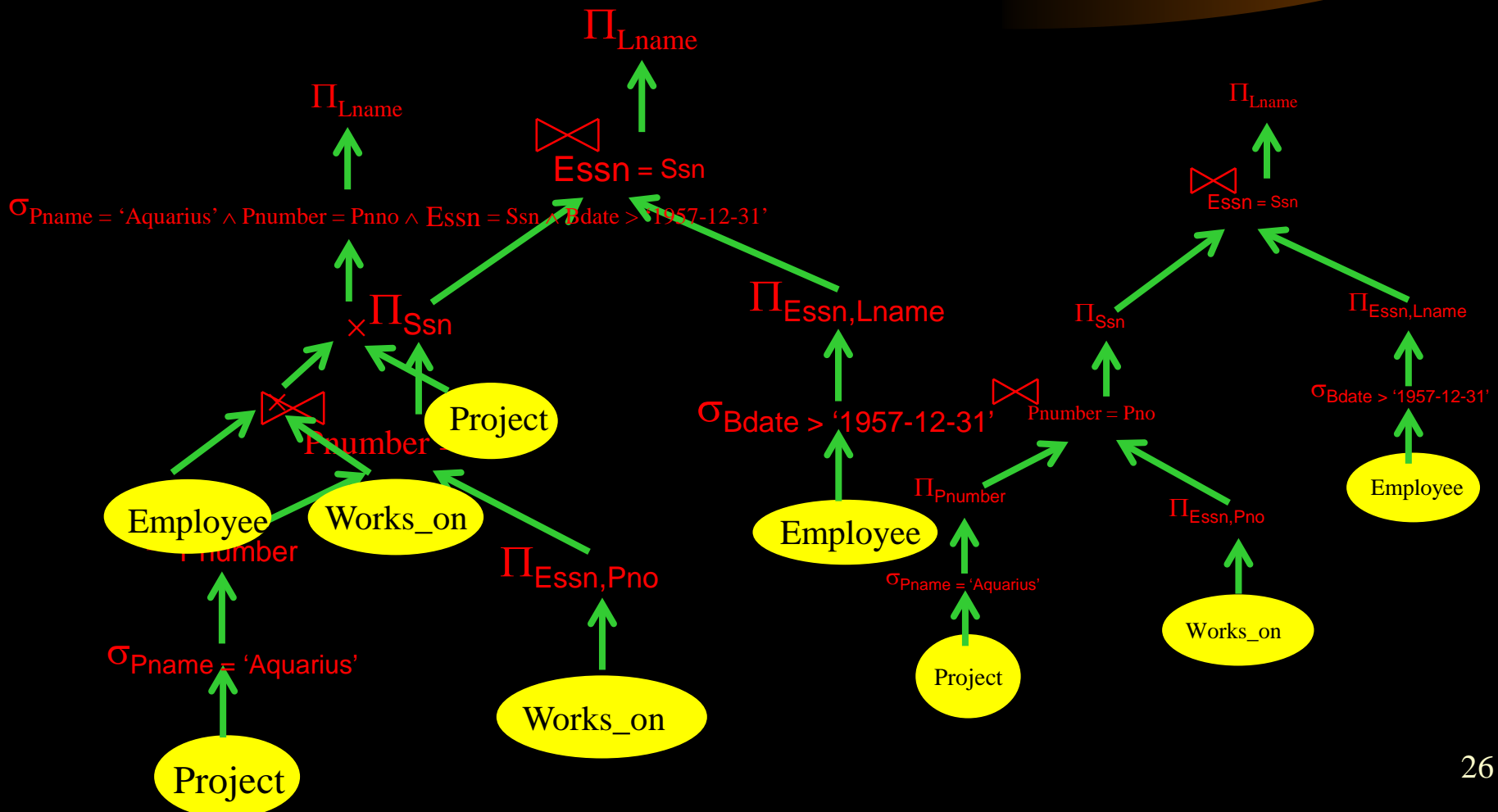
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◆ Query Optimization — Running Example

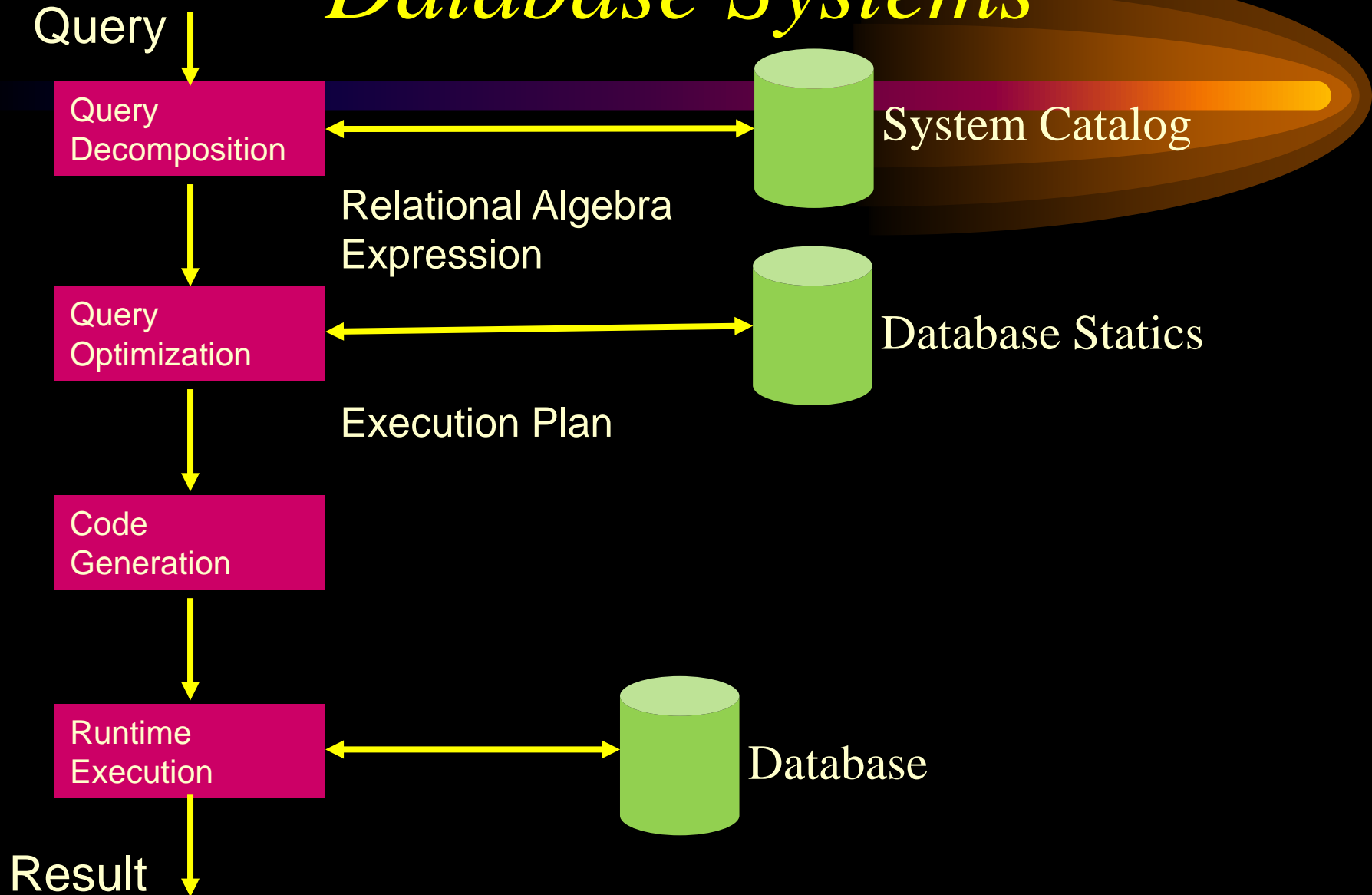
- ★ It also makes sense to reduce the size of intermediate results by keeping just attributes that are needed for correct execution of this query.

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◆ Query Optimization — Running Example



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◆ Query Optimization — A Simple Example

S

S#	Sname	Status	City
S ₁	Smith	20	London
S ₂	Jones	10	Paris
S ₃	Blake	30	Paris
S ₄	Clark	20	London
S ₅	Adams	30	Athens

SP

S#	P#	QTY
S ₁	P ₁	300
S ₁	P ₂	200
S ₁	P ₃	400
S ₁	P ₄	200
S ₁	P ₅	100
S ₁	P ₆	100
•		
•		
•		

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◆ Query Optimization — A Simple Example

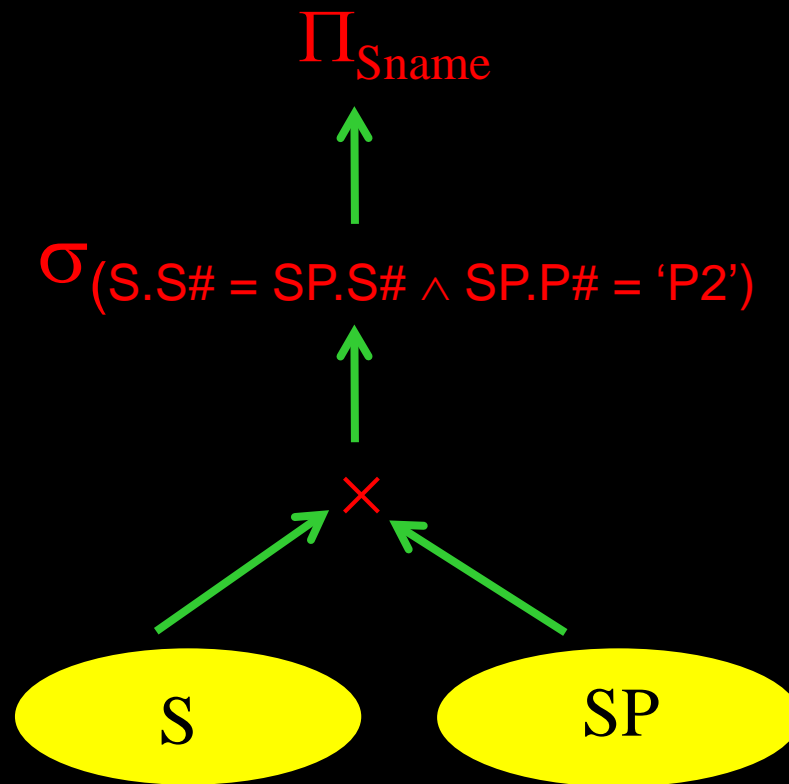
★ Get names of suppliers who supply part P_2 :

```
SELECT    DISTINCT Sname
FROM      S, SP
WHERE     S.S# = SP.S#
AND      SP.P# = 'P2';
```

★ Suppose that the cardinality of S and SP are 100 and 10,000, respectively. Furthermore, assume 50 tuples in SP are for part P_2 .

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◆ Query Optimization — A Simple Example



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◆ Query Optimization — A Simple Example

S#	Sname	Status	S.City	S#	P#	QTY
S ₁	Smith	20	London	S ₁	P ₁	300
S ₁	Smith	20	London	S ₁	P ₂	200
S ₁	Smith	20	London	S ₁	P ₃	400
S ₁	Smith	20	London	S ₁	P ₄	200
S ₁	Smith	20	London	S ₁	P ₅	100
S ₁	Smith	20	London	S ₁	P ₆	100
S ₂	Jones	10	Paris	S ₂	P ₁	300
S ₂	Jones	10	Paris	S ₂	P ₂	400
•						
•						

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◆ Query Optimization — A Simple Example

★ Without an optimizer, the system will:

- Generates **Cartesian product** of S and SP . This will generate a relation of size 1,000,000 tuples — Too large to be kept in the main memory.
- **Restricts** results of previous step as specified by **WHERE** clause. This means reading 1,000,000 tuples of which 50 will be selected.
- **Projects** the result of previous step over $Sname$ to produce the final result.

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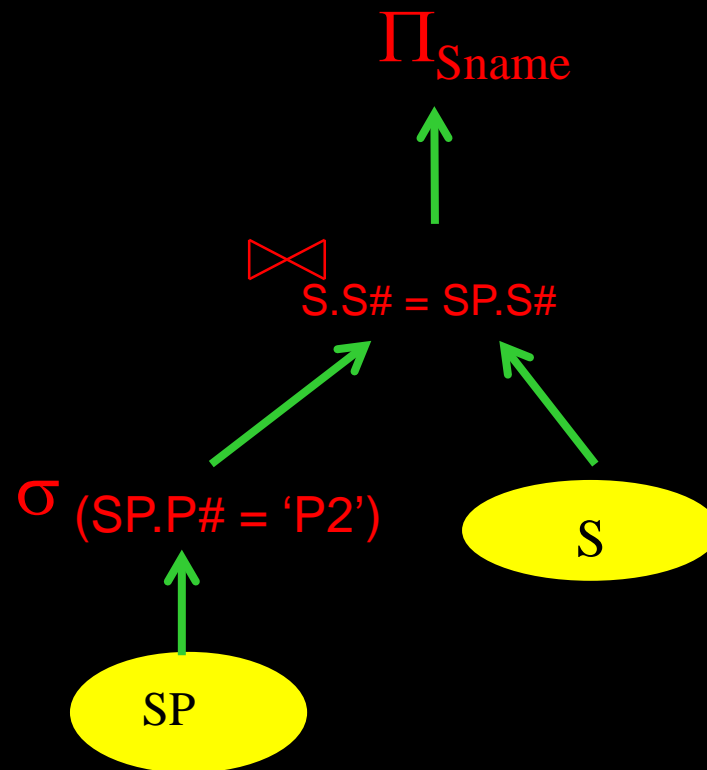
◆ Query Optimization — A Simple Example

★ An **Optimizer** on the other hand:

- **Restricts** SP to just the tuples for part P_2 . This will involve reading 10,000 tuples, but produces a relation with 50 tuples.
- **Joins** the result of the previous step with S relation over $S\#$. This involves the retrieval of only 100 tuples and the generation of a relation with at most 50 tuples.
- **Projects** the result of the last operation over $Sname$.

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◆ Query Optimization — A Simple Example



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◆ Query Optimization — A Simple Example

- ★ If the number of tuples I/O's is used as the performance measure, then it is clear that the second approach is far faster than the first approach. In the first case we read/write about 3,000,000 tuples and in the second case we read about 10,000 tuples.
- ★ So a simple policy — **doing restriction and then join instead of doing product and then a restriction** sounds a good heuristic.

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◆ Optimization Process

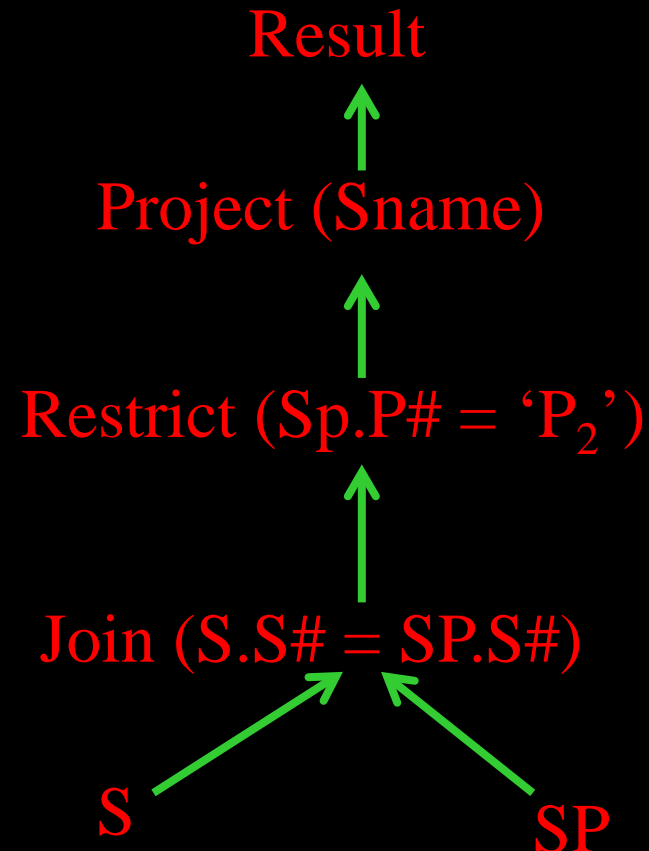
- ★ Cast the query into some **internal representation**
— Convert the query to some internal representation that is more suitable for machine manipulation, **relational algebra**.

$$\Pi_{(Sname)}(\sigma_{P\# = \text{"P2"}}(S \bowtie_{S.S\# = SP.S\#} SP))$$

- ★ Now we can build a **query tree** very easily.

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◆ Optimization Process



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◆ Optimization Process

- ★ Convert the result of the previous step into a **canonical form** — during this phase, optimizer performs a number of optimization that are “guaranteed to be good” regardless of the actual data value and the access paths. For Example:

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◆ Optimization Process

(A Join B) WHERE restriction-on-B

can be transformed into

(A Join (B WHERE restriction-on-B))

(A Join B) WHERE restriction-on-A AND restriction-on-B

can be transformed into

(A WHERE restriction-on-A) Join (B WHERE restriction-on-B)

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◆ Optimization Process

★ **General rule:** It is a good idea to perform the restriction before the join, because:

- It reduces the size of the input to the join operation,
- It reduces the size of the output from the join.

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◆ Optimization Process

WHERE p OR (q AND r)

can be converted into

WHERE (p OR q) AND (p OR r)

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◆ Optimization Process

★ **General rule:** Transform restriction condition into an equivalent condition in conjunctive normal form, because:

- A condition that is in conjunctive normal form evaluates to “true” only if every conjunct evaluates to “true”. Consequently, it evaluates to “false” if any conjunct evaluates to “false”. This is specially useful in the domain of parallel systems where conjuncts can be evaluated in parallel.

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◆ Optimization Process

(A **WHERE** restriction-1) **WHERE** restriction-2

can be converted into

A WHERE restriction-1 **AND** restriction-2

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◆ Optimization Process

- ★ **General rule:** A sequence of restrictions can be combined into a single restriction.

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◆ Optimization Process

(A [projection-1]) [projection-2]

can be converted into

A [projection-2]

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◆ Optimization Process

- ★ **General rule:** A sequence of projections can be transferred into a single projection.

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◆ Optimization Process

- ★ **General rule:** A restriction and projection can be converted into a projection and restriction.

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◆ Optimization Process

- ★ Finally, consider the following query:
- ★ Get the supplier numbers who supply at least one part;

(SP Join P) [S#]

- ★ However, we know that P# is the foreign key in SP, therefore the above query is **semantically** equivalent to:

SP [S#]

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◆ Optimization Process

- ★ An **equivalence rule** says that expressions in different forms are equivalent. In another words, an expression in one form can be replaced by its equivalent expression.
- ★ Since the computational cost of equivalent relations may vary, the **optimizer** can use equivalence rules to transform expression while satisfying **performance metrics**.

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◆ Optimization Process

- ★ **Rule 1:** Conjunctive selection operations (cascade of selections) can be deconstructed into a sequence of individual selections:

$$\sigma_{\theta_1 \wedge \theta_2}(E) = \sigma_{\theta_1}(\sigma_{\theta_2}(E))$$

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◆ Optimization Process

★ Rule 2: Selection operation is commutative:

$$\sigma_{\theta_1}(\sigma_{\theta_2}(E)) = \sigma_{\theta_2}(\sigma_{\theta_1}(E))$$

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◆ Optimization Process

★ **Rule 3:** A sequence of projections is the same as the last projection operation (cascade of projections):

$$\Pi_{L_1}(\Pi_{L_2}(\dots (\Pi_{L_n}(E))\dots)) = \Pi_{L_1}(E)$$

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◆ Optimization Process

- ★ **Rule 4:** A combination of selection and Cartesian product operations is equivalent to theta join operation:

$$\sigma_{\theta}(E_1 \times E_2) = E_1 \bowtie_{\theta} E_2$$

- ★ This can be extended to:

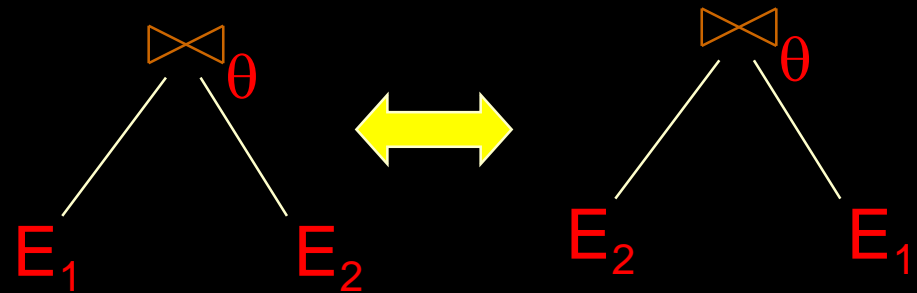
$$\sigma_{\theta_1}(E_1 \bowtie_{\theta_2} E_2) = E_1 \bowtie_{\theta_1 \wedge \theta_2} E_2$$

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◆ Optimization Process

★ Rule 5: Theta join operation is commutative:

$$E_1 \bowtie_{\theta} E_2 = E_2 \bowtie_{\theta} E_1$$

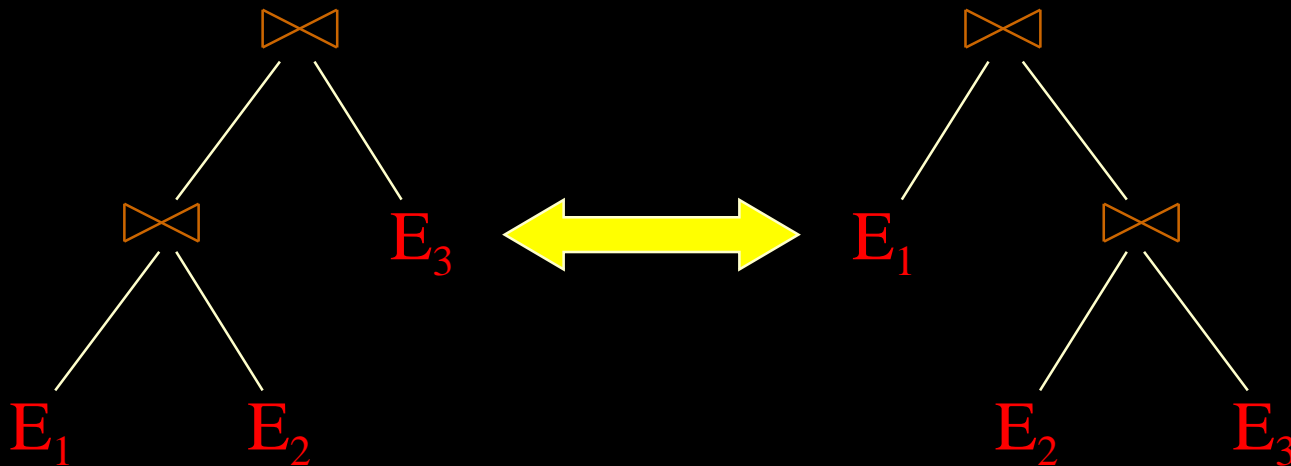


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◆ Optimization Process

★ Rule 6: Natural join is associative:

$$(E_1 \bowtie E_2) \bowtie E_3 = E_1 \bowtie (E_2 \bowtie E_3)$$



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◆ Optimization Process

★ **Rule 7:** Theta join is associative in the following manner:

$$(E_1 \bowtie_{\theta_1} E_2) \bowtie_{\theta_2 \wedge \theta_3} E_3 = E_1 \bowtie_{\theta_1 \wedge \theta_3} (E_2 \bowtie_{\theta_2} E_3)$$

Where θ_2 involves attributes from only E_2 and E_3 .

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◆ Definition

- ★ **Selectivity** is defined as the ratio of the number of tuples that satisfy the equality condition to the cardinality of the relation.

$$\text{selectivity} = \frac{\text{\#of tuples satisfying the search}}{|r(R)|}$$

- ★ Selectivity is used to estimate size of intermediate relation and hence number of accesses.

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- ◆ In practice selectivities of all conditions is not available so we use **estimated selectivity** as part of statistical data to aid query optimization.

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- ◆ Selectivity on **key attribute** and search on equality then:

$$s = \frac{1}{|r(R)|}$$

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- ◆ Selectivity on an attribute with i distinct values is:

$$s = \frac{|r(R)|}{i \cdot |r(R)|}$$

- ◆ Hence the number of tuples that satisfy an equality search is:

$$\frac{1}{i} * |r(R)|$$

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◆ Optimization Process

★ **Rule 8:** Selection operation distribute over the theta join under the following conditions:

■ When all attributes in selection condition θ_0 involve only the attributes of one relation (E_1 in this case):

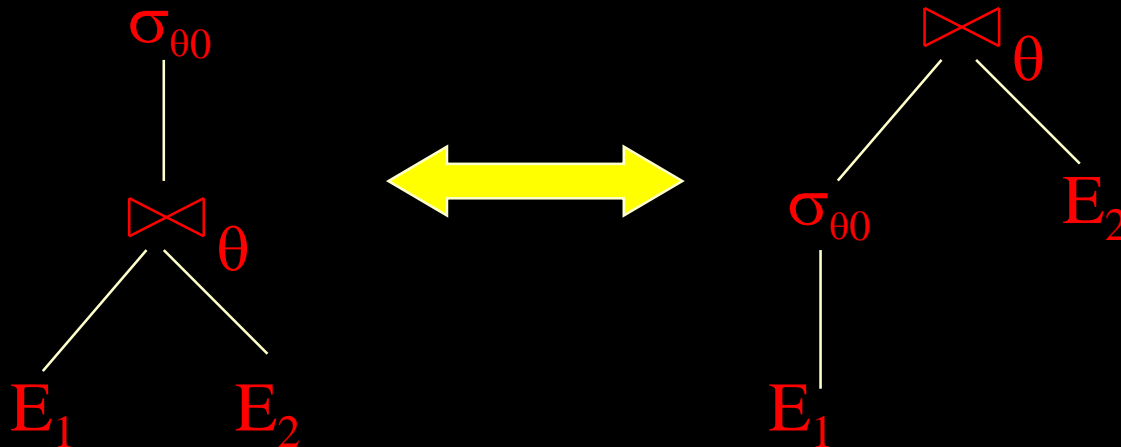
$$\sigma_{\theta_0}(E_1 \bowtie_{\theta} E_2) = (\sigma_{\theta_0}(E_1)) \bowtie_{\theta} E_2$$

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◆ Optimization Process

★ Rule 8:

$$\sigma_{\theta_0}(E_1 \bowtie_{\theta} E_2) = (\sigma_{\theta_0}(E_1)) \bowtie_{\theta} E_2$$



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◆ Optimization Process

★ **Rule 9:** The projection operation distributes over theta-join under the following condition:

■ Join condition θ only involves attributes in $L_1 \cup L_2$:

$$\Pi_{L_1 \cup L_2} (E_1 \bowtie_{\theta} E_2) = (\Pi_{L_1}(E_1)) \bowtie_{\theta} (\Pi_{L_2}(E_2))$$

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◆ Optimization Process

★ **Rule 10:** Set union and set intersection operations are commutative:

$$(E_1 \cup E_2) = (E_2 \cup E_1)$$

$$(E_1 \cap E_2) = (E_2 \cap E_1)$$

★ **Note,** set difference is not commutative.

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◆ Optimization Process

★ Rule 11: Set union and set intersection operations are associative:

$$(E_1 \cup E_2) \cup E_3 = E_1 \cup (E_2 \cup E_3)$$

$$(E_1 \cap E_2) \cap E_3 = E_1 \cap (E_2 \cap E_3)$$

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◆ Optimization Process

★ **Rule 12:** Selection operation distributes over the set union, set intersection, and set difference operations:

$$\sigma_p (E_1 \cup E_2) = \sigma_p (E_1) \cup \sigma_p (E_2)$$

$$\sigma_p (E_1 \cap E_2) = \sigma_p (E_1) \cap \sigma_p (E_2)$$

$$\sigma_p (E_1 - E_2) = \sigma_p (E_1) - \sigma_p (E_2)$$

$$\sigma_p (E_1 - E_2) = \sigma_p (E_1) - (E_2)$$

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◆ Optimization Process

★ Rule 12

$$\sigma_p(E_1 \cup E_2) = \sigma_p(E_1) \cup \sigma_p(E_2)$$

$$\sigma_p(E_1 \cup E_2) \neq \sigma_p(E_1) \cup (E_2)$$

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◆ Optimization Process

★ Rule 12

$$\sigma_p(E_1 \cap E_2) = \sigma_p(E_1) \cap \sigma_p(E_2)$$

$$\sigma_p(E_1 \cap E_2) = \sigma_p(E_1) \cap (E_2)$$

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◆ Optimization Process

★ **Rule 13:** Projection operation distributes over the set union, set intersection?, and set difference operations?:

$$\Pi_L(E_1 - E_2) = (\Pi_L(E_1)) - (\Pi_L(E_2))?$$

$$\Pi_L(E_1 \cup E_2) = \Pi_L(E_1) \cup \Pi_L(E_2)$$

$$\Pi_L(E_1 \cap E_2) = \Pi_L(E_1) \cap \Pi_L(E_2)?$$

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◆ Optimization Process

★ Choose candidate low-level procedure — After transferring the query into **more desirable form**, the optimizer must then decide how to **evaluate** the transformed query. At this stage issues such as:

- existence of indexes or other access paths — To reduce I/O cost, and
- physical clustering of records — To reduce I/O cost, ... comes into play.

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◆ Optimization Process

★ So, in short:

- after **scanning** and **parsing**,
- the query will be **translated** into an equivalent representation, this internal representation is in the form of a **query tree** or **query graph**,
- an execution strategy will be chosen. The **execution strategy** is a plan for accessing the data, executing the query, and storing the intermediate results.

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◆ Optimization Process

- ★ **Generate query plans** — The final stage of optimization involve the construction of a set of **candidate query plans** and the choice of “the best of these plans”.
- ★ Choosing the **cheapest plan**, naturally, requires a method for assigning a cost to any given plan — This cost formula should estimate the number of disk accesses, CPU utilization and execution time, space utilization,....

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◆ Optimization Process

- ★ There are two main techniques for query optimization:
 - Heuristic rules
 - Systematic estimation approach
- ★ In this course, as noted before, we will talk about the **heuristic rules**.

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◆ Optimization Process — heuristic rules

- ★ Perform selection operations as early as possible.
- ★ Perform projections early.
- ★ It is usually better to perform selections earlier than projections.

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- ◆ Optimization Process – heuristic rules
 - ★ Based on heuristic rules the optimizer uses equivalence relationships to reorder operations in a query for execution.

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◆ Definition:

- ★ **Materialized evaluation:** Generation of intermediate result (relation).
- ★ **Pipeline evaluation:** Combining several operations.

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- ◆ Assume we want to perform:

$$\Pi_{a_1, a_2}(r \bowtie s)$$

We can perform the join operation, materialize the resultant, and then apply projection.

Alternatively, we can do the following: When the join operation generates a tuple, it will be passed directly to the project operation for processing.

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◆ Assume the following relations:

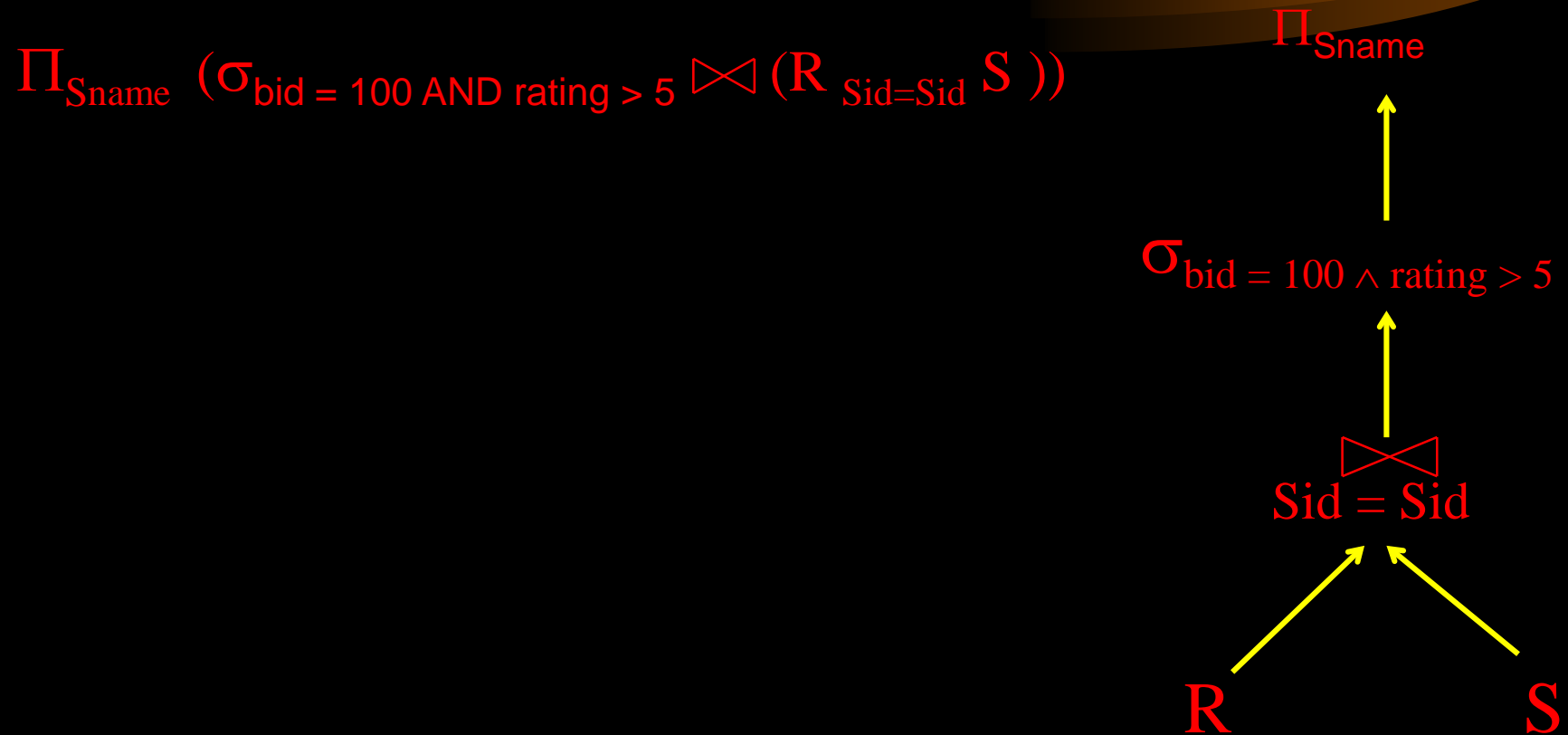
★ S (S_{id} : integer, S_{name} : string, rating: integer, age: real)

★ R (S_{id} : integer, bid: integer, day: dates, r_{name} : string)

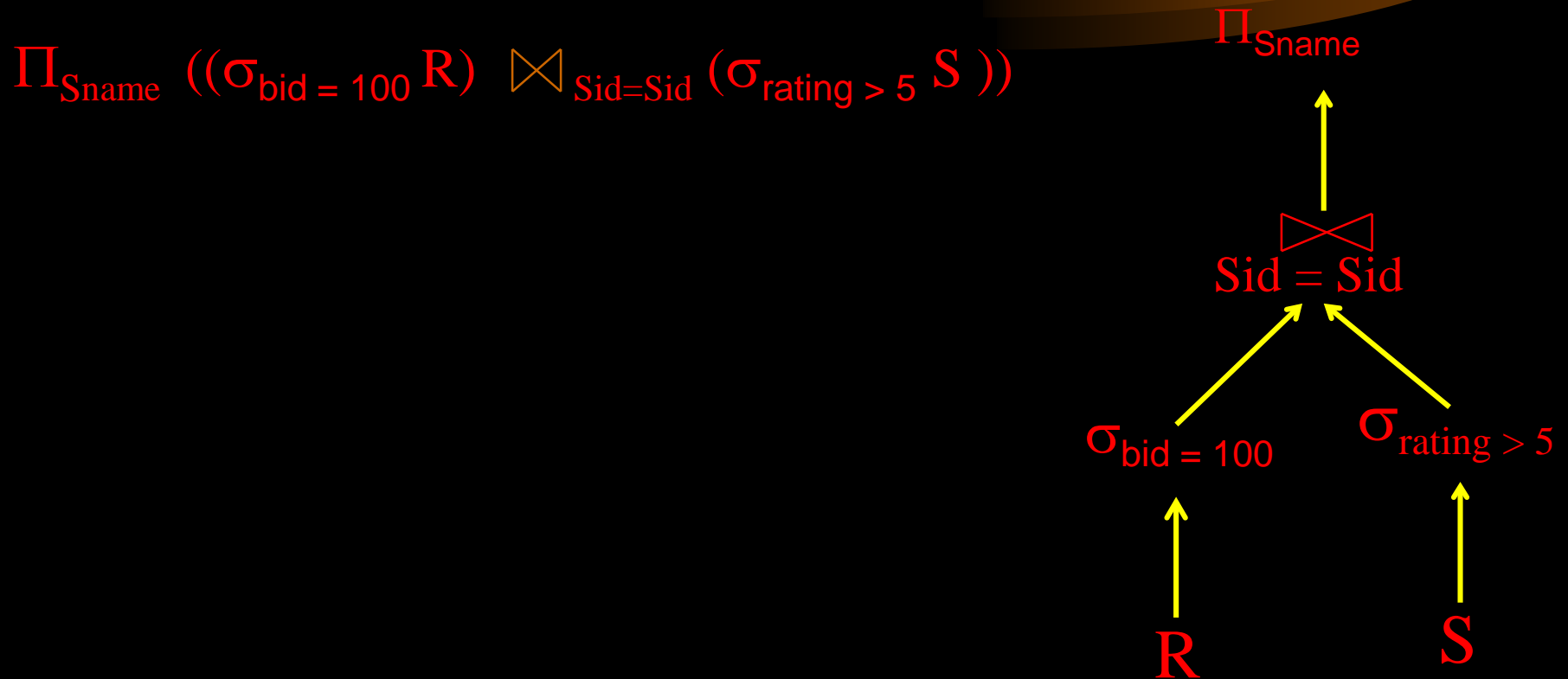
◆ Further assume the following query:

```
SELECT      S. $S_{name}$ 
FROM        R, S
WHERE       R. $S_{id}$  = S. $S_{id}$ 
           AND R.bid = 100  AND S.rating > 5
```

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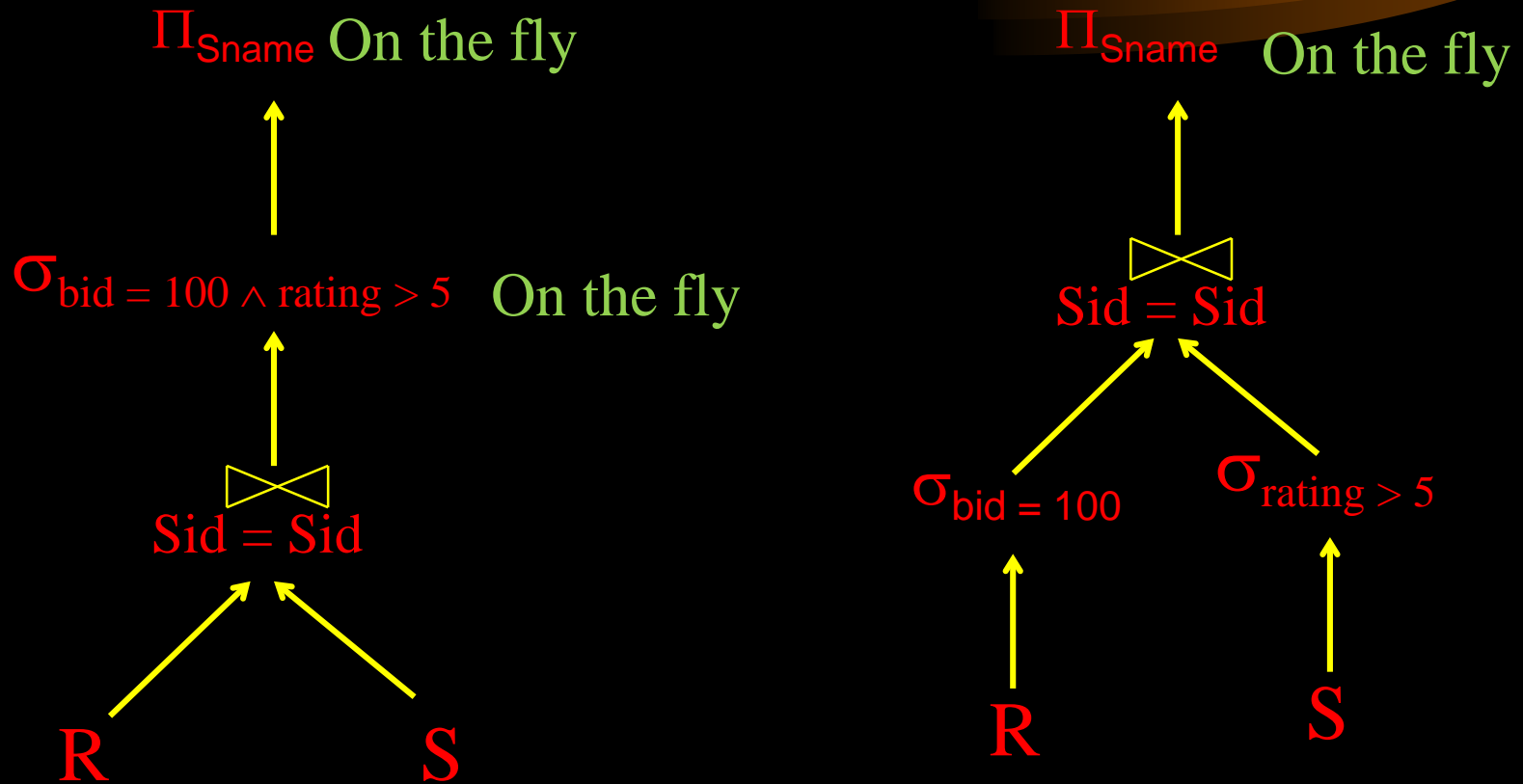
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- ◆ Assume the underlying platform can perform the basic relational operations in “**pipeline**” fashion – i.e., result of one operation is fed to another operation.
- ◆ In this case, articulate the way the previous query is going to be executed?

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◆ Cost of Plan

- ★ The cost associated with each plan needs to be estimated. This will be accomplished by estimating the cost of each operation.
- ★ Factors such as: size of relation (s), underlying architecture, buffer size, size of the memory, “reduction factor” for each operation, ... need to be taken into consideration.

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◆ Optimization Process — Search methods for Selection

- ★ **General Philosophy:** Make effort to reduce the search space.

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◆ Optimization Process — Search methods for Selection

- ★ **Linear search:** Retrieve every records in the file and test whether or not its attribute values satisfy the selection condition (In this case, data is not organized and no meta data is available).
- ★ **Binary search:** Use binary search method if the **selection condition** involves an **equality** comparison on a key attribute on which the file is ordered.

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◆ Optimization Process — Search methods for Selection

- ★ Using a primary index or hash key to retrieve a single record: Use the primary index or hash key to retrieve the record if the selection condition involves an equality comparison on a key attribute with a primary index or hash key (note in this case at most one record is retrieved).

$\sigma_{SSN = 123456789}(\text{EMPLOYEE})$

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◆ Optimization Process — Search methods for Selection

- ★ Using a primary index or hash key to retrieve multiple records: If the comparison condition is $>$, $<$, \leq , \geq on a key field with a primary index, use the index to find the record satisfying the corresponding equality condition and then retrieve all the subsequent records in the file (note in this case, data is also sorted).

$\sigma_{\text{DNUMBER} > 5}(\text{DEPARTMENT})$

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- ◆ Query Optimization — Search methods for Selection
 - ★ Using a clustering index to retrieve multiple records: If the selection condition involves an equality comparison on a non-key attribute with clustering index, use the clustering index to retrieve all the records satisfying the selection condition (clustered data).

$\sigma_{DNO = 5}(\text{EMPLOYEE})$

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◆ Query Optimization — Search methods for Selection

★ **Conjunctive selection:** conjunctive selection is of the following form;

$$\sigma_{\theta_1 \wedge \theta_2 \wedge \dots \wedge \theta_n}(\mathbf{r})$$

★ **Disjunctive selection:** disjunctive selection is of the following form;

$$\sigma_{\theta_1 \vee \theta_2 \vee \dots \vee \theta_n}(\mathbf{r})$$

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- ◆ **Query Optimization** — Search methods for Selection
 - ★ **Conjunctive selection:** If an attribute involved in any single simple condition in the **conjunctive condition** has an access path that allows the use of any aforementioned techniques, use that condition to retrieve the records and then apply the rest of the conditions.

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◆ Query Optimization — Search methods for Selection

- ★ **Disjunctive selection by union of record pointers:** If access path exists for **all** the attributes involved in disjunctive selection then each index is scanned for pointers to tuples that satisfy individual condition.
- ★ The **union** of all the retrieved pointers yields the set of pointers to tuples satisfying the disjunctive condition.
- ★ Note, even if one of the conditions does not have an access path, we will have to perform a linear scan of the relation.

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◆ Query Optimization — JOIN Operation

- ★ **Nested loop**: For each record $t \in R$ (outer loop), retrieve every record of $s \in S$ (inner loop) and then check the join condition $t[A] = s[B]$.

$R \bowtie_{A=B} S$

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◆ Query Optimization — JOIN Operation (nested loop)

★ Suppose we want to perform

$$r \bowtie_{r.A \Theta s.B} s$$

★ A and B are attributes or set of attributes (i.e., join attributes) of relations r and s . Further assume $n_r = |r|$ and $n_s = |s|$ are the cardinality of the relations. Finally assume b_r and b_s are the number of blocks of each relation.

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◆ Query Optimization — JOIN Operation (nested loop)

★ The following algorithm performs the nested loop join operation:

For each $t_r \in r$ do begin

 For each $t_s \in s$ do begin

 If $r.A \Theta s.B$ true then add $t_r \parallel t_s$ to the result

 end

end

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- ◆ Query Optimization — JOIN Operation (nested loop)
 - ★ Cost of nested loop algorithm is $n_r * n_s$.
 - ★ In **best case scenario**, both relations fit into the physical space and hence we need $b_s + b_r$ block accesses.

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- ◆ Query Optimization — JOIN Operation (nested loop)
 - ★ If one of the relations fits in the physical space then $b_s + b_r$ block accesses will be the cost.

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- ◆ Query Optimization — JOIN Operation (block nested loop)
 - ★ If the buffer is too small to hold either relation, entirely, we can still obtain a major saving in the number of block accesses.

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◆ Query Optimization — JOIN Operation (block nested loop)

For each block B_r of r do begin

 For each block B_s of s do begin

 For each $t_r \in B_r$ do begin

 For each $t_s \in B_s$ do begin

 If $r.A \Theta s.B$ true then add $t_r \parallel t_s$ to the result

 end

 end

 end

end

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- ◆ Query Optimization — JOIN Operation (block nested loop)
 - ★ Cost of block nested loop in term of number of block accesses is $b_r * b_s + b_r$.
 - ★ How can we improve block nested loop?

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◆ Query Optimization — JOIN Operation

- ★ Use of access structure to retrieve the matching record(s): If an index or hash key exists for one of the join attributes, say B of s , retrieve each record $t_r \in r$, one at a time, and then use the access structure to retrieve all the matching records $t_s \in S$ that satisfy $t_r[A] = t_s[B]$.



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◆ Query Optimization — JOIN Operation

- ★ **Sort-merge**: If the records of r and s are physically sorted by the value of the join attributes, then this technique can be applied by scanning r and s linearly.

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◆ Query Optimization — JOIN Operation (Merge)

- ★ 1 pointer, initially pointing to the first tuple, is assigned to each relation. As the algorithm proceeds, the pointers move through the relations.
- ★ Since the relations are sorted, each tuple is accessed once and hence the number of block accesses is:

$$b_s + b_r$$

Assuming that the set of all tuples with the same value for the join attributes fit in the main memory.

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◆ Query Optimization — JOIN Operation

- ★ **hash-join**: The records of both files r and s are hashed to the same hash file using the **same hashing function**. A **single pass** through each file hashes the records to the hash file buckets. Each bucket is then examined for records from r and s with matching join attribute values to produce a possible result for the join operation.

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- ◆ Query Optimization — Complex JOIN Operation
 - ★ Nested loop join can be used regardless of the join condition. The other join techniques, though more efficient than nested loop, can handle simple join conditions.
 - ★ Join with complex join conditions (i. e., conjunctive and disjunctive conditions) can be implemented using techniques discussed for conjunctive and disjunctive selections.

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◆ Query Optimization — Complex JOIN Operation

- ★ Consider the following join operation

$$r \bowtie_{\theta_1 \wedge \theta_2 \wedge \dots \wedge \theta_n} S$$

- ★ One or more of the join techniques may be applicable for joins on individual conditions.
- ★ We can perform the overall join by first computing one of the simpler joins, say $r \bowtie_{\theta_1} S$. The result of complete join consists of those tuples in the **intermediate result** that satisfy the remaining conditions.

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◆ Query Optimization — Complex JOIN Operation

★ Now consider the following join operation

$$r \bowtie_{\theta_1 \vee \theta_2 \vee \dots \vee \theta_n} S$$

★ The join can be performed as the **union** of the tuples in individual joins $r \bowtie_{\theta_i} S$.

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◆ Query Optimization — Project Operation

- ★ A project operation $\Pi_{\langle \text{attribute-list} \rangle}(\mathbf{R})$ is straightforward to implement if $\langle \text{attribute list} \rangle$ includes a key of relation R.
- ★ If $\langle \text{attribute list} \rangle$ does not include a key, then we may end up with duplicates. Duplicates can be eliminated by sorting the result and then eliminating the duplicate or by using hashing technique.

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◆ Query Optimization — Set Operations

- ★ **Cartesian product** is very expensive operation to perform. Hence, it is important to avoid it as much as possible.
- ★ The **other set operations** can be implemented by sorting the relations and then a single scan through each relation is sufficient to generate the result.
- ★ Hashing technique is another way to implement Union, intersection, and difference operations.

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◆ Questions

- ★ Devise algorithms to perform variation of outer join operations.
- ★ Devise algorithms to perform aggregate operations.

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◆ Query Optimization — An Example

★ Assume the following relations:

Department (Dname, Dnumber, Mgr-ssn, ...)

Project (Pname, Pnumber, Plocation, Dnum)

Employee (Fname, Lname, Ssn, Bdate, address, Dno, ...)

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◆ Query Optimization — An Example

```
SELECT    Pnumber, Dnum, Lname, Bdate,  
          Address  
  
FROM      Project, Department, Employee  
  
WHERE     Dnum = Dnumber  
  
AND       MGRSSN = SSN  
  
AND       Plocation = 'California';
```

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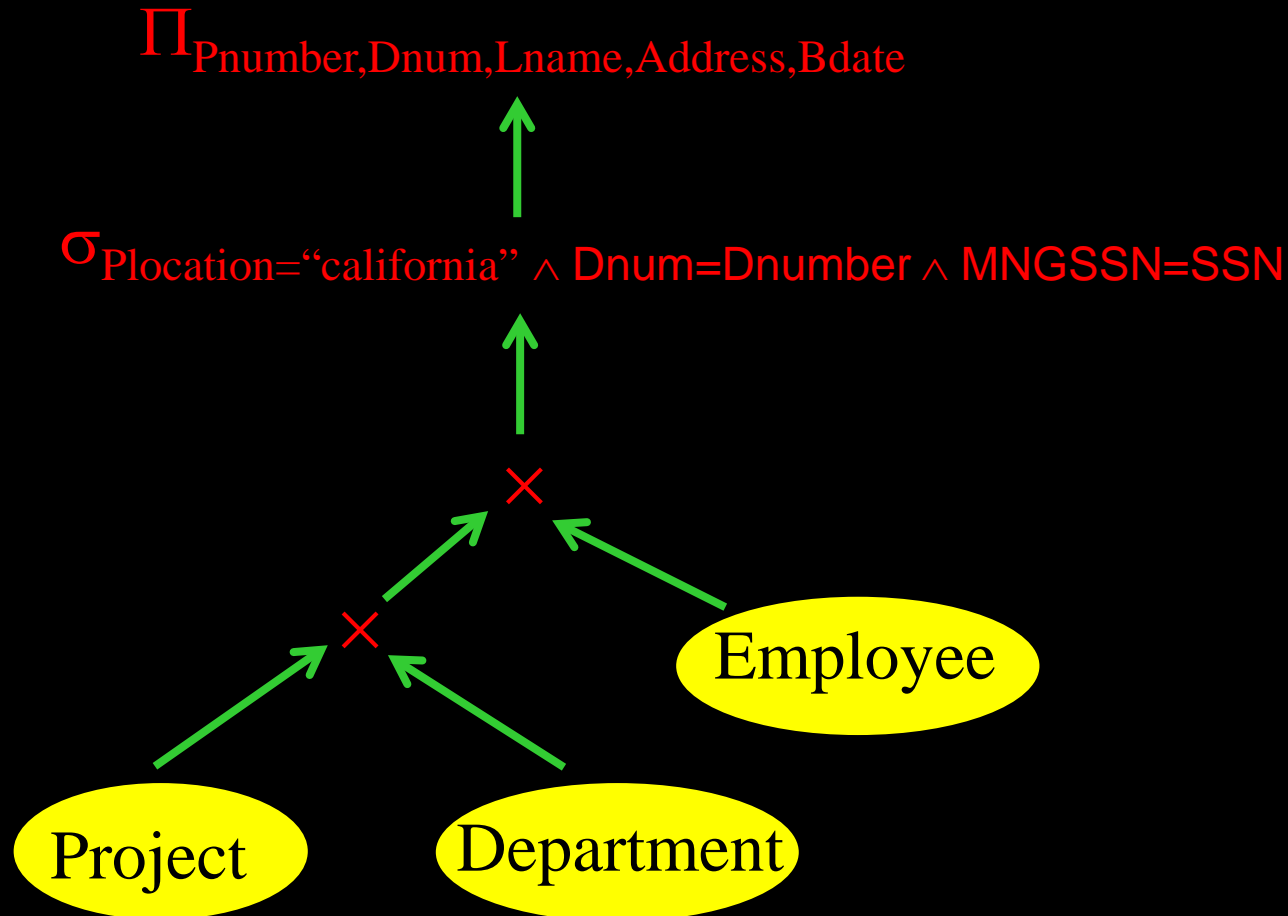
◆ Query Optimization — An Example

★ The above query can be translated into:

$\Pi_{Pnumber, Dnum, Lname, Address, Bdate} (\sigma_{Plocation="california" \wedge Dnum=Dnumber \wedge MNGSSN=SSN} (Project \times (Department \times Employee)))$

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◆ Query Optimization — An Example



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◆ Query Optimization — An Example

- ★ The previous scenario will result in an inefficient query processing. Assume **Project**, **Department**, and **Employee** relations had tuples sizes of 100, 50, and 150 bytes, and contained 100, 20, and 5,000 tuples, respectively. Then the Cartesian products would generate a relation of 10 million tuples each of 300 bytes.

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◆ Query Optimization — An Example

★ However, the above query based on the schemas of the relations can be translated into:

$$\Pi_{Pnumber, Dnum, Lname, Address, Bdate} \left(\left(\left(\sigma_{Plocation="california"} (Project) \right) \bowtie_{Dnum=Dnumber} (Department) \right) \bowtie_{MNGSSN=SSN} (Employee) \right)$$

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◆ Query Optimization — An Example

