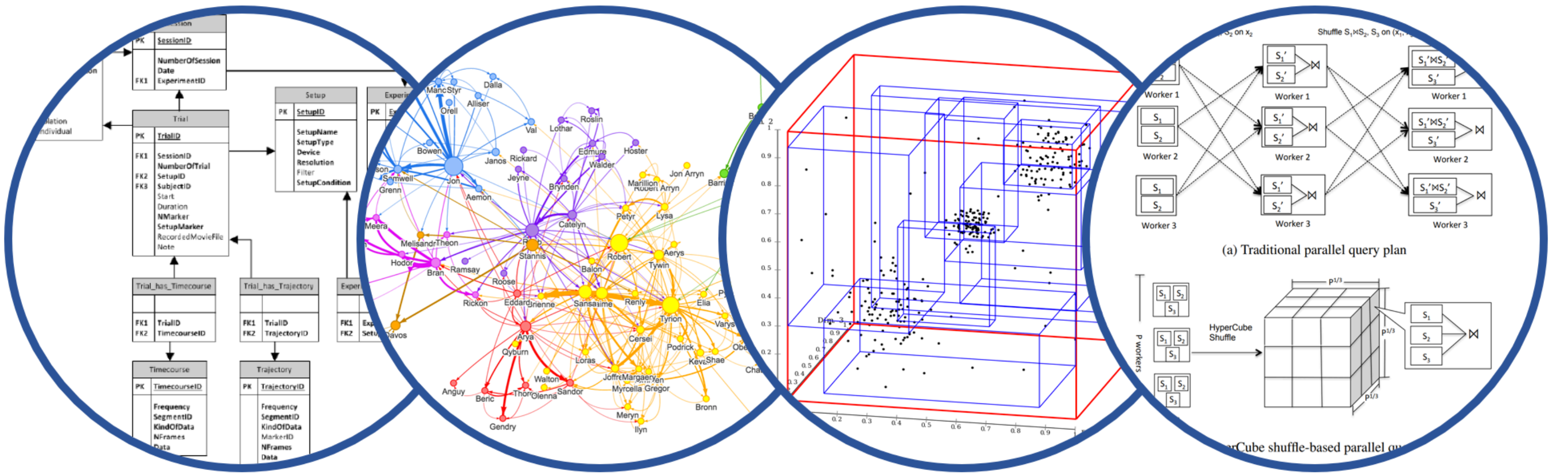

Database System Internals

Query Optimization (part 1)

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Announcements

- Lab 2 part 1 due Today
- Homework 2 due Monday

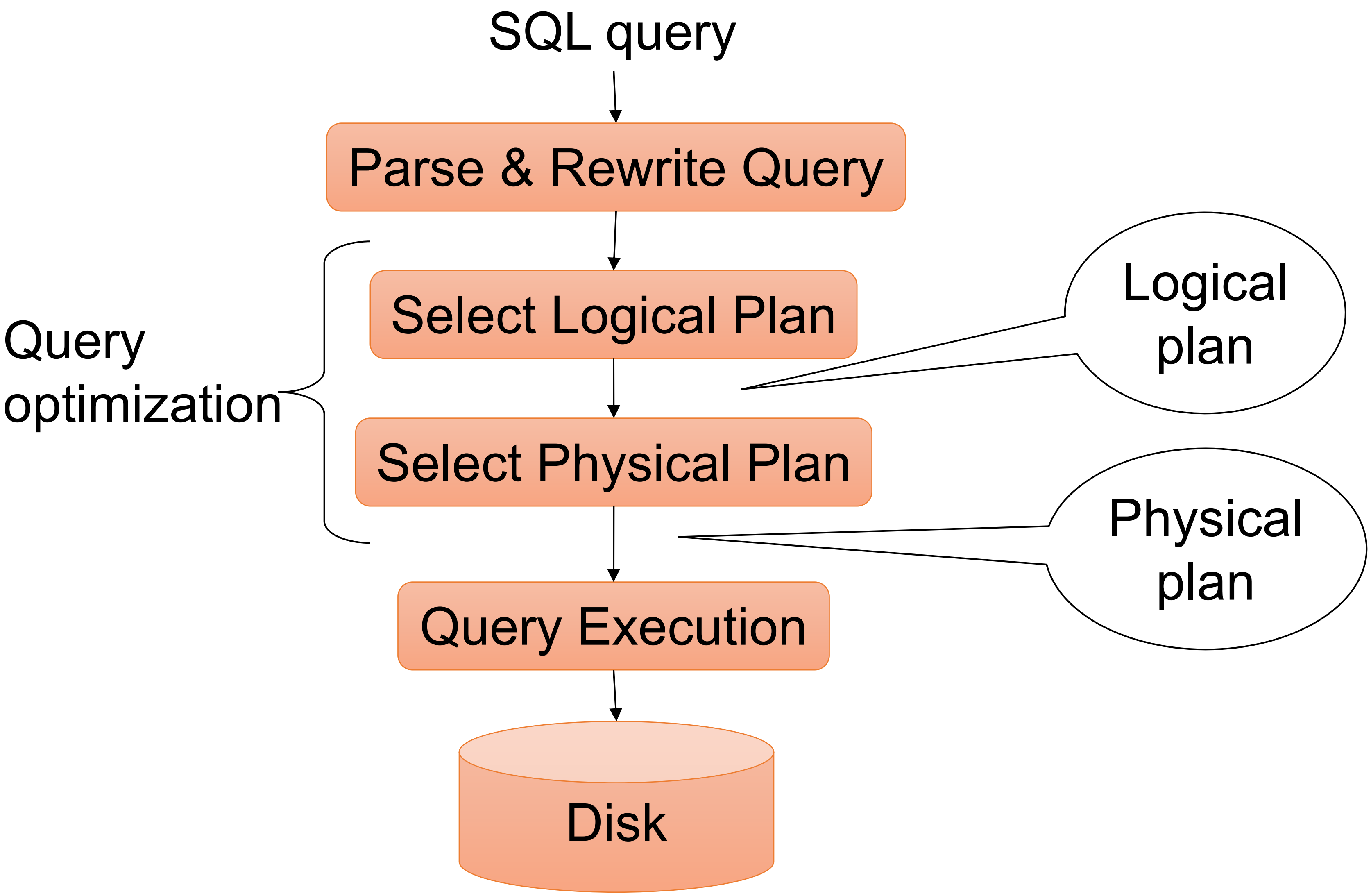
Query Optimization Overview

We know how to compute the cost of a plan

Next: Find a good plan automatically?

This is the role of the query optimizer

Query Optimization Overview



What We Already Know...

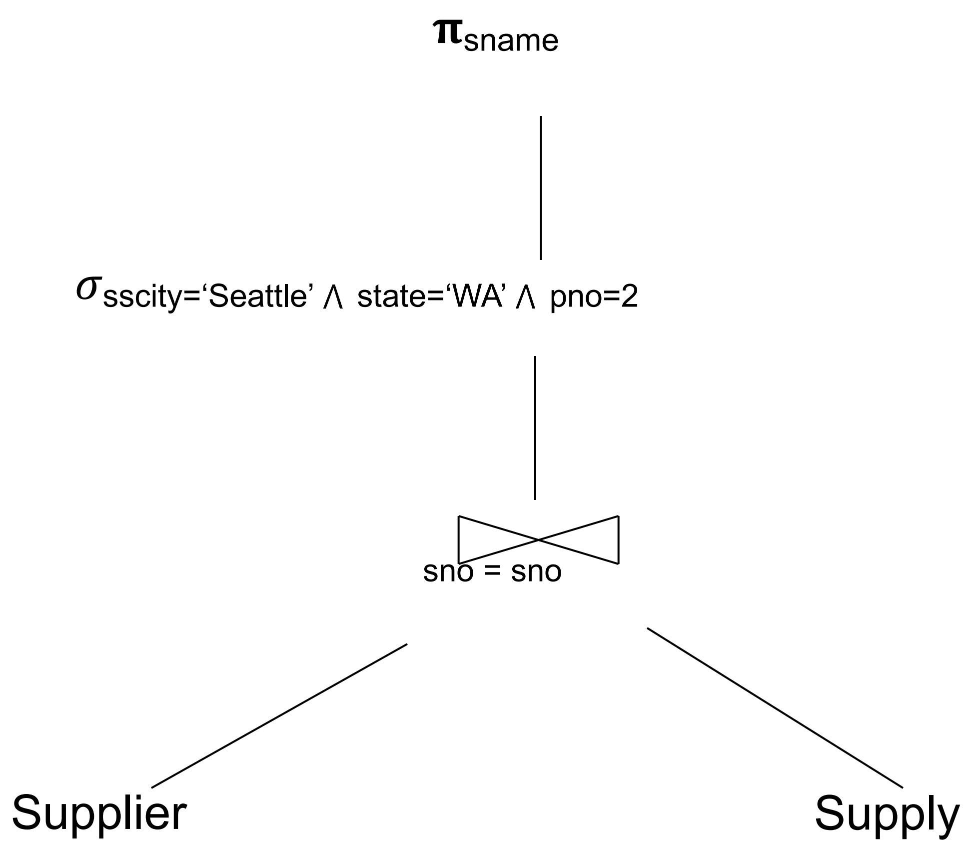
```
Supplier(sno,sname,scity,sstate)
Part(pno,pname,psize,pcolor)
Supply(sno,pno,price)
```

For each SQL query....

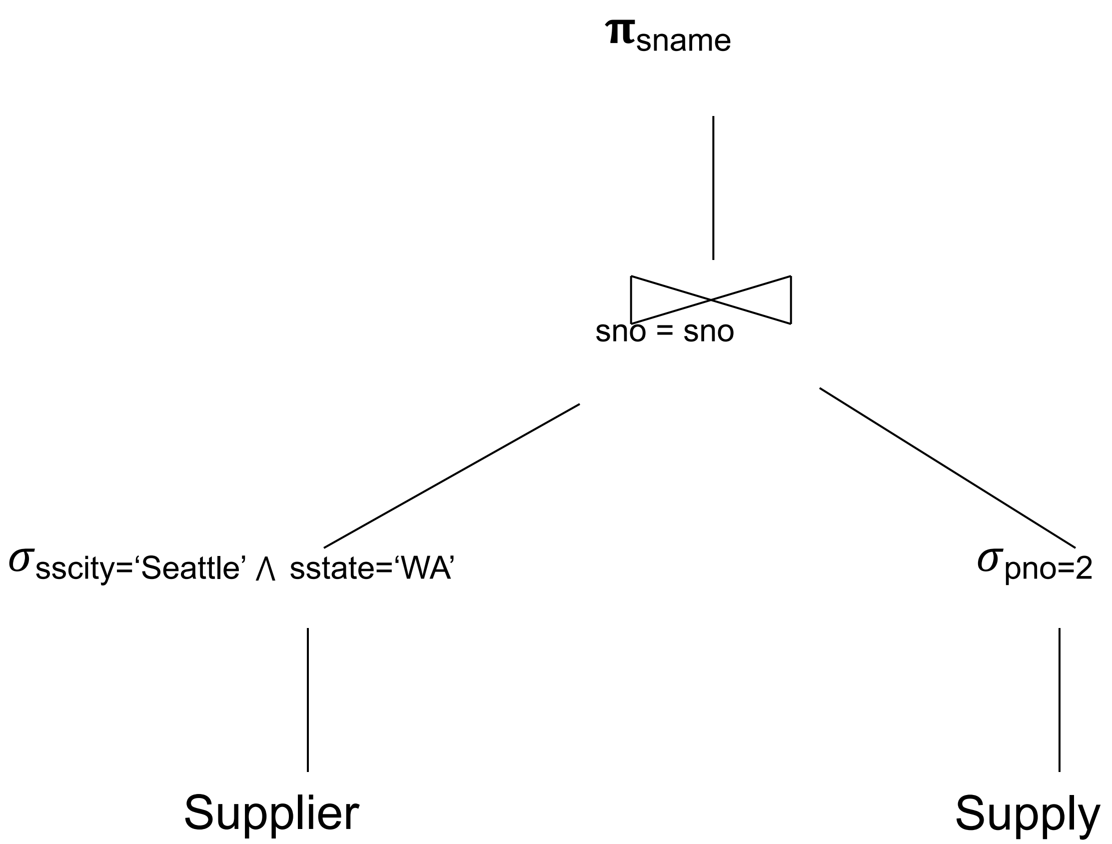
```
SELECT S.sname
FROM Supplier S, Supply U
WHERE S.scity='Seattle' AND S.sstate='WA'
AND S.sno = U.sno
AND U.pno = 2
```

There exist many logical query plans...

Example Query: Logical Plan 1



Example Query: Logical Plan 2

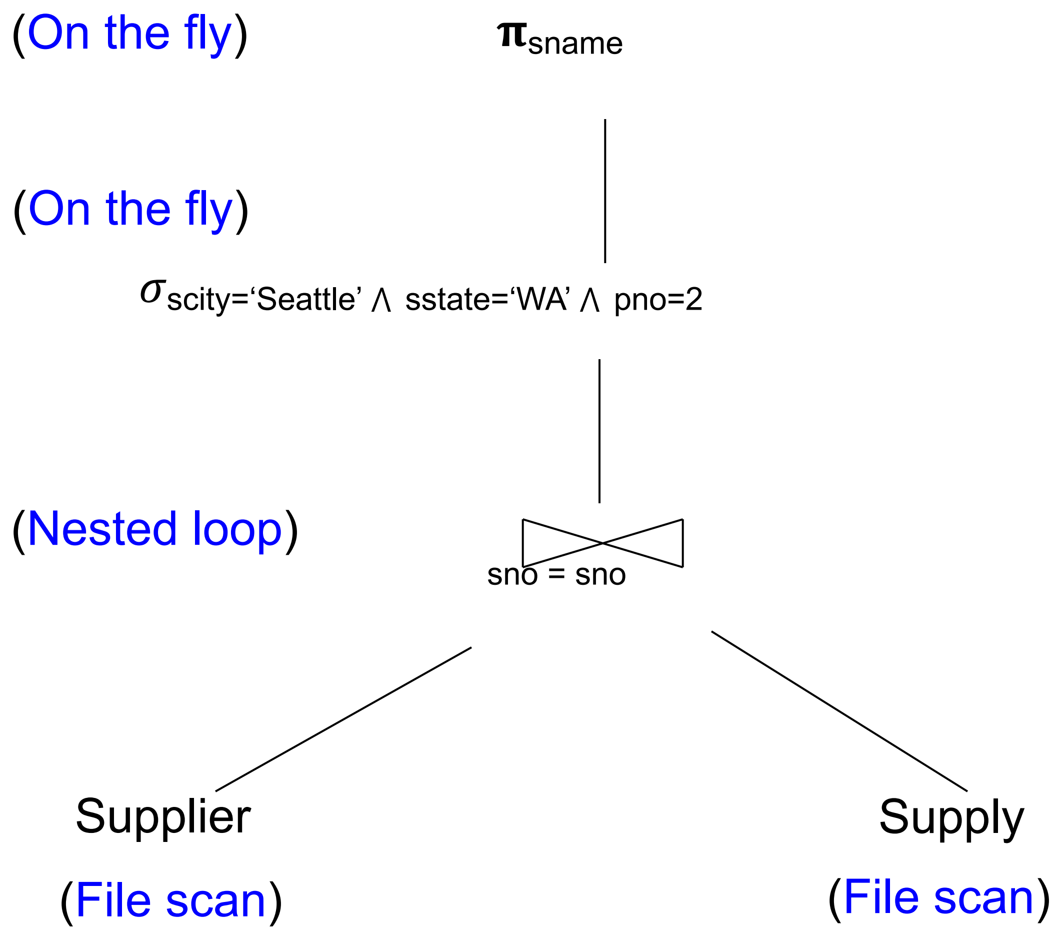


What We Also Know

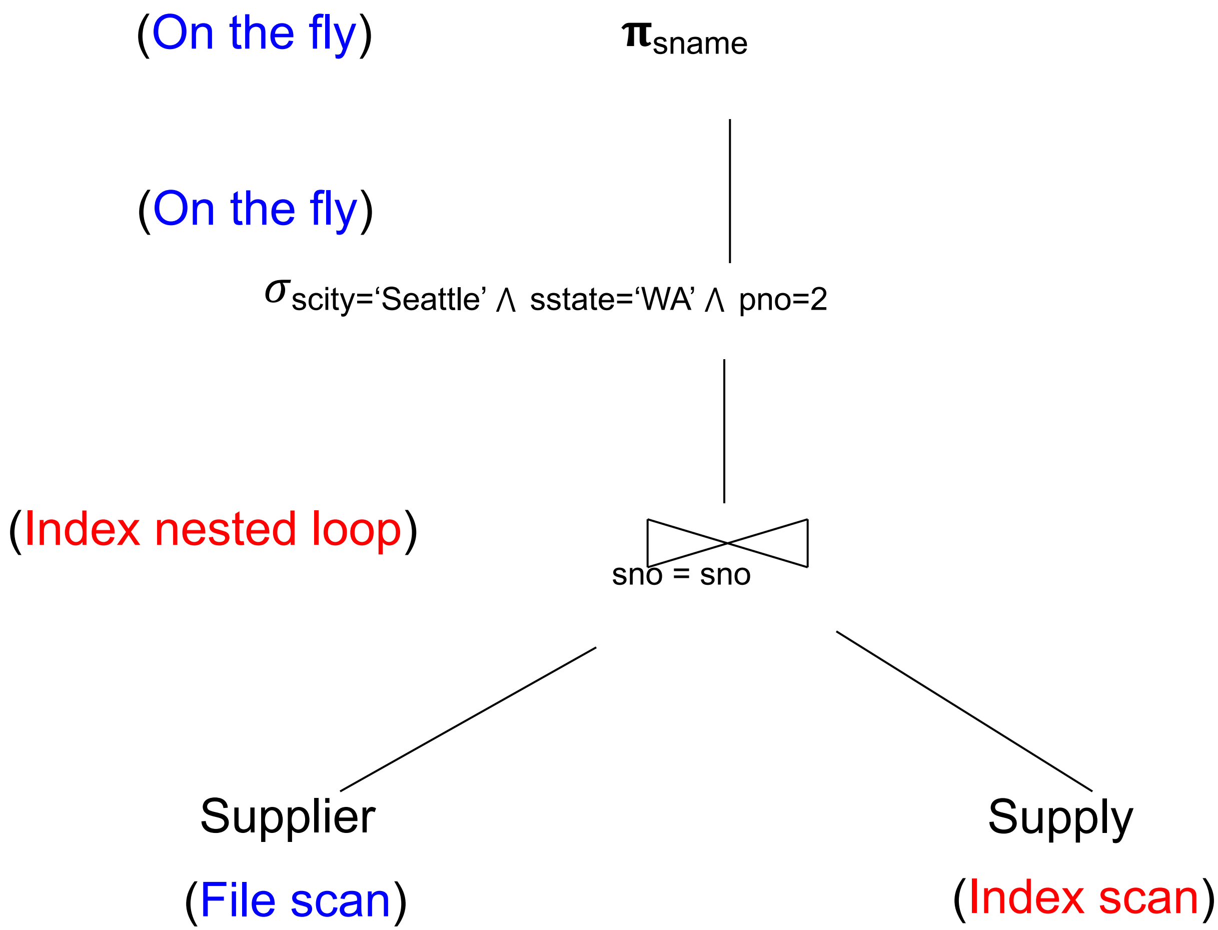
- For each logical plan…

- There exist many physical plans

Example Query: Physical Plan 1



Example Query: Physical Plan 2



Query Optimizer Overview

- **Input**: A logical query plan
- **Output**: A good physical query plan

Query Optimizer Overview

- **Input**: A logical query plan
- **Output**: A good physical query plan
- **Basic query optimization algorithm**
  - Enumerate alternative plans (logical and physical)
  - Compute estimated cost of each plan
    - Compute number of I/Os
    - Optionally take into account other resources
  - Choose plan with lowest cost
  - This is called cost-based optimization

Two Types of Optimizers

- Rule-based (heuristic) optimizers:
  - Apply greedily rules that always improve plan
    - Typically: push selections down
  - Very limited: no longer used today

- Cost-based optimizers:
  - Use a cost model to estimate the cost of each plan
  - Select the “cheapest” plan
  - We focus on cost-based optimizers

Observations

- No magic “best” plan: depends on the data

- In order to make the right choice
  - Need to have ***statistics*** over the data
  - The B’s, the T’s, the V’s
  - Commonly: histograms over base data
    - In SimpleDB as well… lab 5.

Key Decisions for Implementation

Search Space

Optimization rules

Optimization algorithm

Key Decisions for Implementation

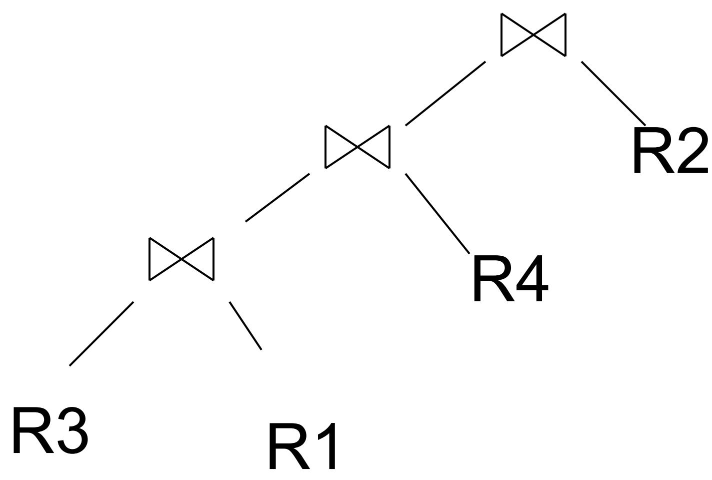
Search Space

What form of plans do we consider?

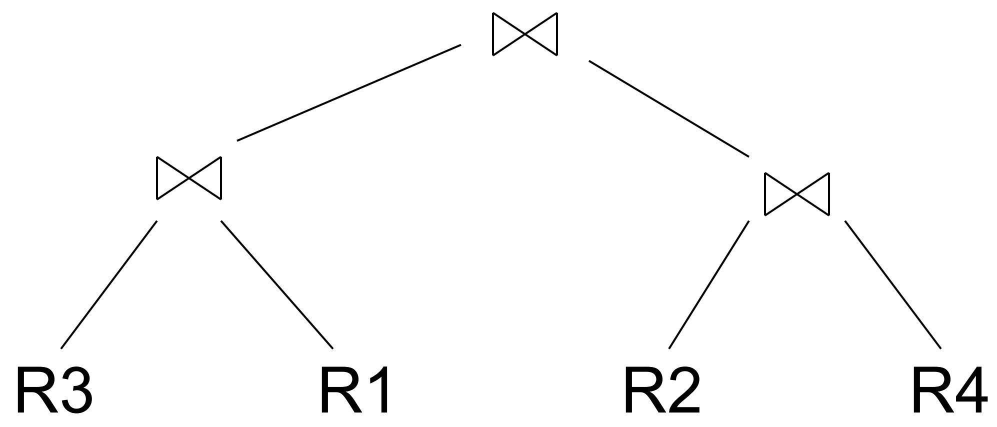
Optimization rules

Optimization algorithm

Search Space – Type of Plan



Left-deep plan



Bushy plan

Linear plan: One input to each join is a relation from disk
Can be either left or right input

Key Decisions for Implementation

Search Space

Optimization rules

Which algebraic laws do we apply?

Optimization algorithm

Optimization Rules – RA equivalencies

- Selections
  - Commutative: $\sigma_{c1}(\sigma_{c2}(R))$ same as $\sigma_{c2}(\sigma_{c1}(R))$
  - Cascading: $\sigma_{c1 \wedge c2}(R)$ same as $\sigma_{c2}(\sigma_{c1}(R))$

- Projections
  - Cascading

- Joins
  - Commutative : $R \bowtie S$ same as $S \bowtie R$
  - Associative: $R \bowtie (S \bowtie T)$ same as $(R \bowtie S) \bowtie T$

Example: Simple Algebraic Laws

- Example: R(A, B, C, D), S(E, F, G)

$\sigma_{F=3} (R \bowtie_{D=E} S) =$

$\sigma_{A=5 \text{ AND } G=9} (R \bowtie_{D=E} S) =$

Example: Simple Algebraic Laws

- Example: R(A, B, C, D), S(E, F, G)

$$\sigma_{F=3}(R \bowtie_{D=E} S) = R \bowtie_{D=E} \sigma_{F=3}(S)$$

$$\sigma_{A=5 \text{ AND } G=9}(R \bowtie_{D=E} S) =$$

Example: Simple Algebraic Laws

- Example: R(A, B, C, D), S(E, F, G)

$$\sigma_{F=3}(R \bowtie_{D=E} S) = R \bowtie_{D=E} \sigma_{F=3}(S)$$

$$\sigma_{A=5 \text{ AND } G=9}(R \bowtie_{D=E} S) = \sigma_{A=5}(R) \bowtie_{D=E} \sigma_{G=9}(S)$$

Commutativity, Associativity, Distributivity

$$R \cup S = S \cup R, \quad R \cup (S \cup T) = (R \cup S) \cup T$$
$$R \bowtie S = S \bowtie R, \quad R \bowtie (S \bowtie T) = (R \bowtie S) \bowtie T$$

$$R \bowtie (S \cup T) = (R \bowtie S) \cup (R \bowtie T)$$

Laws Involving Selection

$$\sigma_{C \text{ AND } C'}(R) = \sigma_C(\sigma_{C'}(R)) = \sigma_C(R) \cap \sigma_{C'}(R)$$
$$\sigma_{C \text{ OR } C'}(R) = \sigma_C(R) \cup \sigma_{C'}(R)$$
$$\sigma_C(R \bowtie S) = \sigma_C(R) \bowtie S$$

$$\sigma_C(R - S) = \sigma_C(R) - S$$
$$\sigma_C(R \cup S) = \sigma_C(R) \cup \sigma_C(S)$$
$$\sigma_C(R \bowtie S) = \sigma_C(R) \bowtie S$$

Assuming C on attributes of R

Laws Involving Projections

$$\Pi_M(R \bowtie S) = \Pi_M(\Pi_P(R) \bowtie \Pi_Q(S))$$

$$\Pi_M(\Pi_N(R)) = \Pi_M(R)$$

/* note that $M \subseteq N$ */

- Example R(A,B,C,D), S(E, F, G)

$$\Pi_{A,B,G}(R \bowtie_{D=E} S) = \Pi_{?}(\Pi_{?}(R) \bowtie_{D=E} \Pi_{?}(S))$$

Laws Involving Projections

$$\Pi_M(R \bowtie S) = \Pi_M(\Pi_P(R) \bowtie \Pi_Q(S))$$

$$\Pi_M(\Pi_N(R)) = \Pi_M(R)$$

/* note that $M \subseteq N$ */

- Example R(A,B,C,D), S(E, F, G)

  $\Pi_{A,B,G}(R \bowtie_{D=E} S) = \Pi_{A,B,G}(\Pi_{A,B,D}(R) \bowtie_{D=E} \Pi_{E,G}(S))$

Laws for grouping and aggregation

$$\gamma_{A,\ agg(D)}(R(A,B) \bowtie_{B=C} S(C,D)) =$$
$$\gamma_{A,\ agg(D)}(R(A,B) \bowtie_{B=C} (\gamma_{C,\ agg(D)} S(C,D)))$$

Laws for grouping and aggregation

$$\delta(\gamma_{A,\ agg(B)}(R)) = \gamma_{A,\ agg(B)}(R)$$

$$\gamma_{A,\ agg(B)}(\delta(R)) = \gamma_{A,\ agg(B)}(R)$$

if agg is "duplicate insensitive"

Which of the following are "duplicate insensitive" ?
sum, count, avg, min, max

Laws Involving Constraints

Foreign key

Product(<u>pid</u>, pname, price, cid)
Company(<u>cid</u>, cname, city, state)

$$\Pi_{\text{pid, price}}(\text{Product} \bowtie_{\text{cid=cid}} \text{Company}) = \Pi_{\text{pid, price}}(\text{Product})$$

Search Space Challenges

- Search space is huge!
  - Many possible equivalent trees
  - Many implementations for each operator
  - Many access paths for each relation
    - File scan or index + matching selection condition
- Cannot consider ALL plans
  - Heuristics: only partial plans with “low” cost

Key Decisions

Search Space

Optimization rules

Optimization algorithm

Key Decisions

Logical plan

- What logical plans do we consider (left-deep, bushy?) *Search Space*
- Which algebraic laws do we apply, and in which context(s)? *Optimization rules*
- In what order do we explore the search space? *Optimization algorithm*

Even More Key Decisions!

Physical plan

- What physical operators to use?
- What access paths to use (file scan or index)?
- Pipeline or materialize intermediate results?

These decisions also affect the *search space*

Two Types of Optimizers

- Heuristic-based optimizers:
  - Apply greedily rules that always improve plan
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- Cost-based optimizers:
  - Use a cost model to estimate the cost of each plan
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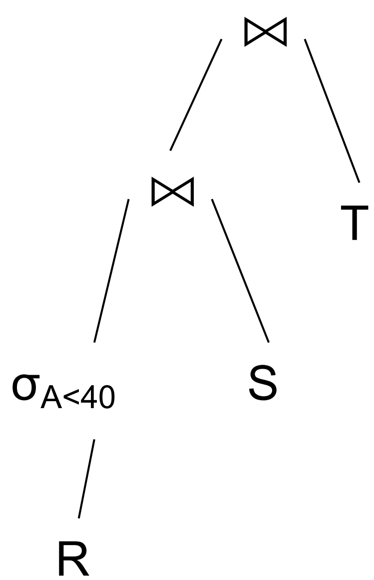
Approaches to Search Space Enumeration

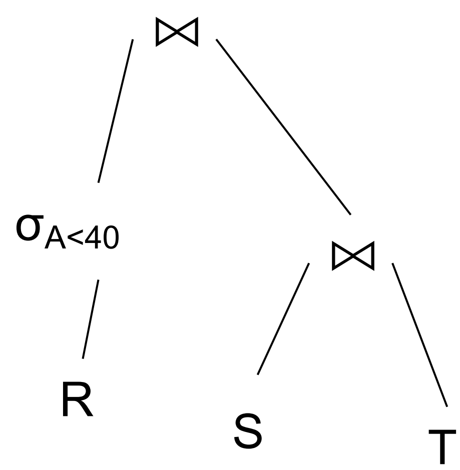
- Complete plans
- Bottom-up plans
- Top-down plans

Complete Plans

R(A,B)
S(B,C)
T(C,D)

```
SELECT *
FROM R, S, T
WHERE R.B=S.B and
      S.C=T.C and
      R.A<40
```





Why is this search space inefficient ?

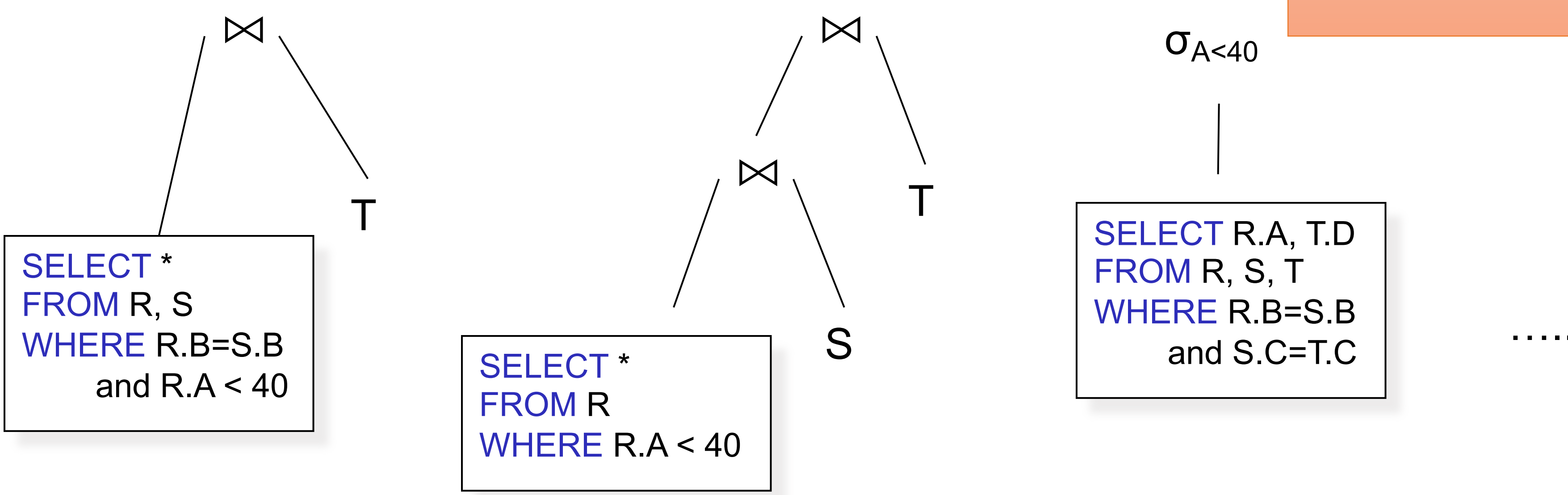
Answer: No way to do early pruning

Top-down Partial Plans

R(A,B)
S(B,C)
T(C,D)

```
SELECT *
FROM R, S, T
WHERE R.B=S.B and S.C=T.C and R.A<40
```

Why is this search space inefficient ?



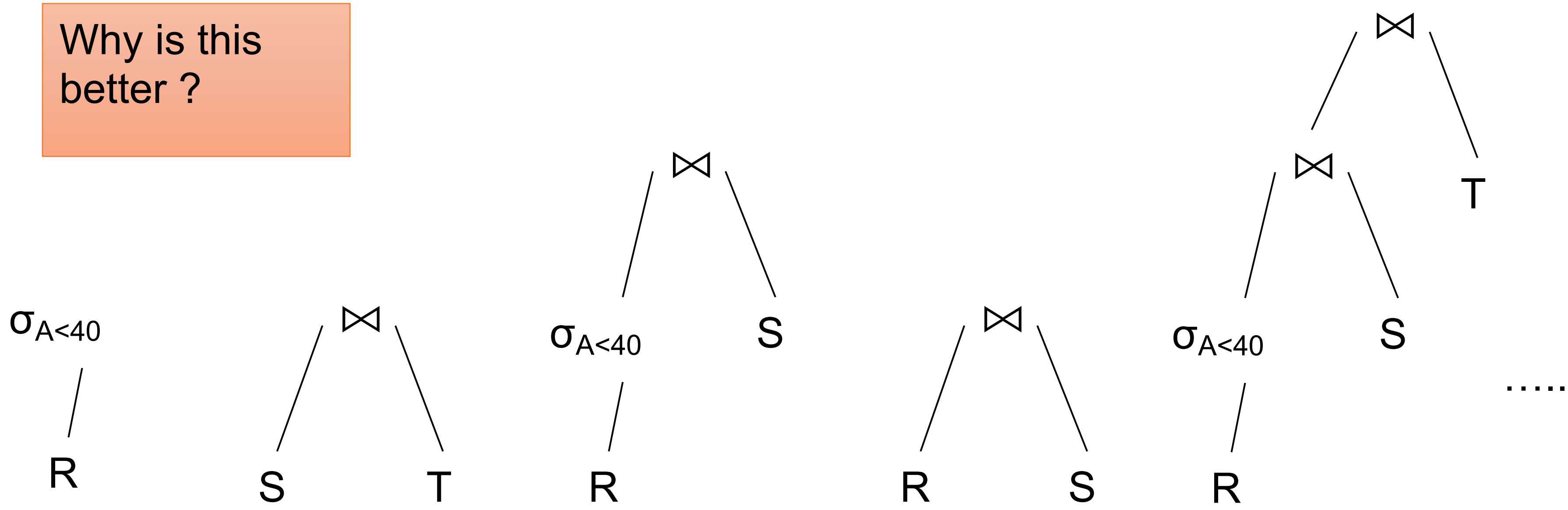
Answer: Can’t compute costs of a plan on SQL text alone

Bottom-up Partial Plans

R(A,B)
S(B,C)
T(C,D)

```
SELECT *
FROM R, S, T
WHERE R.B=S.B and S.C=T.C and R.A<40
```

Why is this better ?



We will prune bad plans for sub-expressions

Two Types of Plan Enumeration Algorithms

- Dynamic programming (in class)
  - Based on System R (aka Selinger) style optimizer[1979]
  - Limited to joins: *join reordering algorithm*
  - Bottom-up

- Rule-based algorithm (will not discuss)
  - Database of rules (=algebraic laws)
  - Usually: dynamic programming
  - Usually: top-down