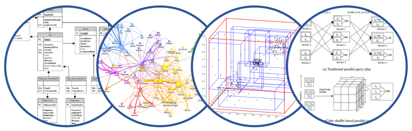

Database System Internals

Query Optimization (part 1)

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Announcements

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

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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

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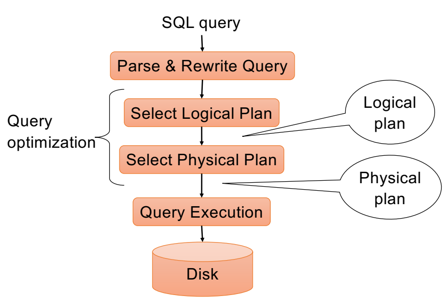
Query Optimization Overview



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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...

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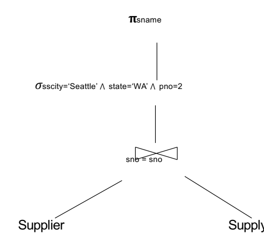
Example Query: Logical Plan 1



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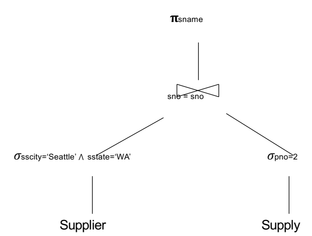
Example Query: Logical Plan 2



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What We Also Know

- For each logical plan…
- There exist many physical plans

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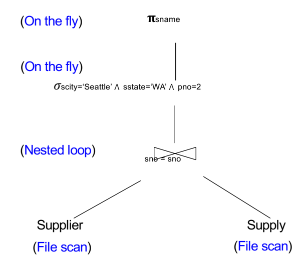
Example Query: Physical Plan 1



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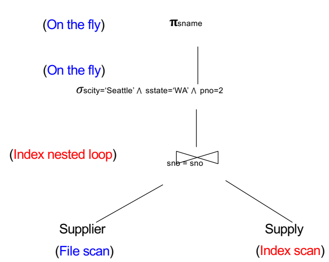
Example Query: Physical Plan 2



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Query Optimizer Overview

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

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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

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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

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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.

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Key Decisions for Implementation

Search Space

Optimization rules

Optimization algorithm

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Key Decisions for Implementation

Search Space

What form of plans do we consider?

Optimization rules

Optimization algorithm

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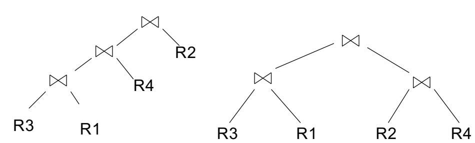
Search Space – Type of Plan



Left-deep plan

Bushy plan

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

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Key Decisions for Implementation

Search Space

Optimization rules

Which algebraic laws do we apply?

Optimization algorithm

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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 $(R \bowtie S) \bowtie T$

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Example: Simple Algebraic Laws

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

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

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

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Example: Simple Algebraic Laws

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

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

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

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Example: Simple Algebraic Laws

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

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

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

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Commutativity, Associativity, Distributivity

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

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

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

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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

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

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

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Laws for grouping and aggregation

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

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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

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Laws Involving Constraints

Foreign key

Product(pid, pname, price, cid)
Company(cid, cname, city, state)

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

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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

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Key Decisions

Search Space

Optimization rules

Optimization algorithm

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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*

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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*

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Two Types of Optimizers

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Approaches to Search Space Enumeration

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

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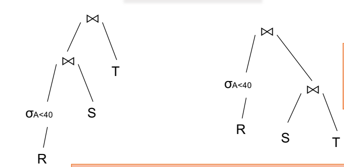
Complete Plans

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

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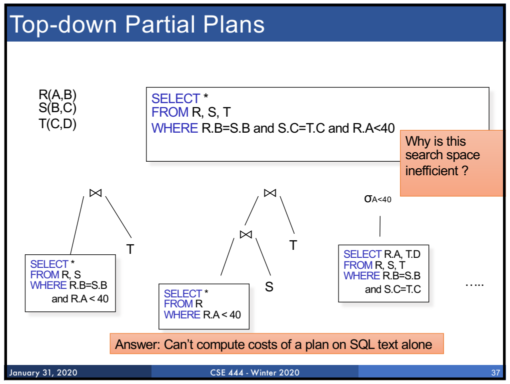

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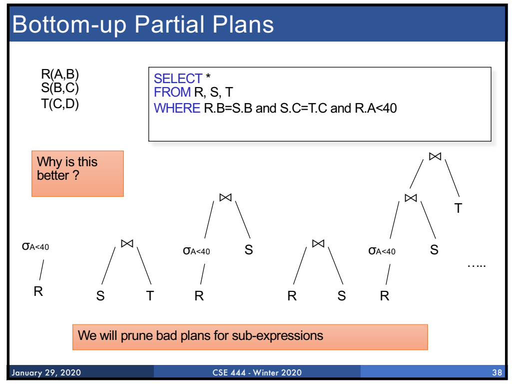

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Two Types of Plan Enumeration Algorithms

- 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

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