CSE 444: Database Internals

Lecture 11
Query Optimization (part 2)

Reminders

- Lab 2 is due on Wednesday
- HW 5 is due on Friday

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

The Three Parts of an Optimizer

- Cost estimation
  - Based on cardinality estimation
- Search space
  - Algebraic laws, restricted types of join trees
- Search algorithm
  - Will discuss next

Search Algorithm

- 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

Dynamic Programming

Originally proposed in System R [1979]

- Only handles single block queries:

```
SELECT list
FROM   R1, …, Rn
WHERE  cond_1 AND cond_2 AND . . . AND cond_k
```

- Some heuristics for search space enumeration:
  - Selections down
  - Projections up
  - Avoid cartesian products

SELECT list
FROM R1, …, Rn
WHERE $cond_1$ AND $cond_2$ AND . . . AND $cond_k$

Dynamic Programming

- For each subquery Q ⊆{R1, …, Rn} compute the following:
  - T(Q) = the estimated size of Q
  - Plan(Q) = a best plan for Q
  - Cost(Q) = the estimated cost of that plan

SELECT list
FROM R1, …, Rn
WHERE $cond_1$ AND $cond_2$ AND . . . AND $cond_k$

Dynamic Programming

- **Step 1**: For each $\{R_i\}$ do:
  - $T(\{R_i\}) = T(R_i)$
  - $Plan(\{R_i\})$ = access method for R_i
  - $Cost(\{R_i\})$ = cost of access method for R_i

SELECT list
FROM R1, …, Rn
WHERE $cond_1$ AND $cond_2$ AND . . . AND $cond_k$

Dynamic Programming

- **Step 2**: For each $Q \subseteq \{R_1, …, R_n\}$ of size k do:
  - T(Q) = use estimator
  - Consider all partitions Q = Q' ∪ Q''
    compute cost(Plan(Q') ⋈ Plan(Q''))
  - Cost(Q) = the smallest such cost
  - Plan(Q) = the corresponding plan
- Note
  - If we restrict to left-linear trees: Q'' = single relation
  - May want to avoid cartesian products

SELECT list
FROM R1, …, Rn
WHERE $cond_1$ AND $cond_2$ AND . . . AND $cond_k$

Dynamic Programming

- **Step 3**: Return $Plan(\{R_1, …, R_n\})$

SELECT *
FROM R, S, T, U
WHERE $cond_1$ AND $cond_2$ AND . . .

Example

- R ⋈ S ⋈ T ⋈ U
- Assumptions:

  T(R) = 2000
  T(S) = 5000
  T(T) = 3000
  T(U) = 1000

- Every join selectivity is 0.001

T(R) = 2000
T(S) = 5000
T(T) = 3000
T(U) = 1000

Assume
B(..) = T(..)/10

Join selectivity is 0.001

Subquery	T	Plan	Cost
R	2000		
S	5000		
T	3000		
U	1000		
RS			
RT			
RU			
ST			
SU			
TU			
RST			
RSU			
RTU			
STU			
RSTU			

T(R) = 2000
T(S) = 5000
T(T) = 3000
T(U) = 1000

Assume
B(..) = T(..)/10

Join selectivity
is 0.001

Subquery	T	Plan	Cost
R	2000		
S	5000		
T	3000		
U	1000		
RS	10000		
RT	6000		
RU	2000		
ST	15000		
SU	5000		
TU	3000		
RST	30000		
RSU	10000		
RTU	6000		
STU	15000		
RSTU	30000		

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T(R) = 2000
T(S) = 5000
T(T) = 3000
T(U) = 1000

Assume
B(..) = T(..)/10

Join selectivity
is 0.001

Subquery	T	Plan	Cost
R	2000	Clustered index scan R.A	200
S	5000		
T	3000		
U	1000		
RS	10000		
RT	6000		
RU	2000		
ST	15000		
SU	5000		
TU	3000		
RST	30000		
RSU	10000		
RTU	6000		
STU	15000		
RSTU	30000		

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T(R) = 2000
T(S) = 5000
T(T) = 3000
T(U) = 1000

Assume
B(..) = T(..)/10

Join selectivity
is 0.001

Subquery	T	Plan	Cost
R	2000	Clustered index scan R.A	200
S	5000	Table scan	500
T	3000		
U	1000		
RS	10000		
RT	6000		
RU	2000		
ST	15000		
SU	5000		
TU	3000		
RST	30000		
RSU	10000		
RTU	6000		
STU	15000		
RSTU	30000		

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T(R) = 2000
T(S) = 5000
T(T) = 3000
T(U) = 1000

Assume
B(..) = T(..)/10

Join selectivity
is 0.001

Subquery	T	Plan	Cost
R	2000	Clustered index scan R.A	200
S	5000	Table scan	500
T	3000	Table scan	300
U	1000	Unclustered index scan U.F	1000
RS	10000		
RT	6000		
RU	2000		
ST	15000		
SU	5000		
TU	3000		
RST	30000		
RSU	10000		
RTU	6000		
STU	15000		
RSTU	30000		

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T(R) = 2000
T(S) = 5000
T(T) = 3000
T(U) = 1000

Assume
B(..) = T(..)/10

Join selectivity
is 0.001

Subquery	T	Plan	Cost
R	2000	Clustered index scan R.A	200
S	5000	Table scan	500
T	3000	Table scan	300
U	1000	Unclustered index scan U.F	1000
RS	10000	R ⋈ S nested loop join	…
RT	6000		
RU	2000		
ST	15000		
SU	5000		
TU	3000		
RST	30000		
RSU	10000		
RTU	6000		
STU	15000		
RSTU	30000		

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T(R) = 2000
T(S) = 5000
T(T) = 3000
T(U) = 1000

Assume
B(..) = T(..)/10

Join selectivity
is 0.001

Subquery	T	Plan	Cost
R	2000	Clustered index scan R.A	200
S	5000	Table scan	500
T	3000	Table scan	300
U	1000	Unclustered index scan U.F	1000
RS	10000	R ⋈ S nested loop join	…
RT	6000	R ⋈ T index join	…
RU	2000		
ST	15000		
SU	5000		
TU	3000		
RST	30000		
RSU	10000		
RTU	6000		
STU	15000		
RSTU	30000		

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T(R) = 2000
T(S) = 5000
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T(U) = 1000

Assume
B(..) = T(..)/10

Join selectivity is 0.001

Subquery	T	Plan	Cost
R	2000	Clustered index scan R.A	200
S	5000	Table scan	500
T	3000	Table scan	300
U	1000	Unclustered index scan U.F	1000
RS	10000	R ⋈ S nested loop join	…
RT	6000	R ⋈ T index join	…
RU	2000	R ⋈ U index join	
ST	15000	S ⋈ T hash join	
SU	5000	. . .	
TU	3000	. . .	
RST	30000		
RSU	10000		
RTU	6000		
STU	15000		
RSTU	30000		

T(R) = 2000
T(S) = 5000
T(T) = 3000
T(U) = 1000

Assume
B(..) = T(..)/10

Join selectivity is 0.001

Subquery	T	Plan	Cost
R	2000	Clustered index scan R.A	200
S	5000	Table scan	500
T	3000	Table scan	300
U	1000	Unclustered index scan U.F	1000
RS	10000	R ⋈ S nested loop join	…
RT	6000	R ⋈ T index join	…
RU	2000	R ⋈ U index join	
ST	15000	S ⋈ T hash join	
SU	5000	. . .	
TU	3000	. . .	
RST	30000	(RT) ⋈ S hash join	…
RSU	10000	(SU) ⋈ R merge join	
RTU	6000	…	
STU	15000		
RSTU	30000		

T(R) = 2000
T(S) = 5000
T(T) = 3000
T(U) = 1000

Assume
B(..) = T(..)/10

Join selectivity is 0.001

Subquery	T	Plan	Cost
R	2000	Clustered index scan R.A	200
S	5000	Table scan	500
T	3000	Table scan	300
U	1000	Unclustered index scan U.F	1000
RS	10000	R ⋈ S nested loop join	…
RT	6000	R ⋈ T index join	…
RU	2000	R ⋈ U index join	
ST	15000	S ⋈ T hash join	
SU	5000	. . .	
TU	3000	. . .	
RST	30000	(RT) ⋈ S hash join	…
RSU	10000	(SU) ⋈ R merge join	
RTU	6000	…	
STU	15000		
RSTU	30000	(RT) ⋈ (SU) hash join	…

Discussion

- Need to consider both R ⋈ S and S ⋈ R
  - Because the cost may be different!
- When computing the cheapest plan for (Q) ⋈ R, we may consider new access methods for R, e.g. an index look-up that makes sense only in the context of the join


```
SELECT list
FROM   R1, …, Rn
WHERE cond1 AND cond2 AND . . . AND condk
```

Discussion

Given a query with n relations R1, …, Rn

- How many entries do we have in the dynamic programming table?
- For each entry, how many alternative plans do we need to inspect?


```
SELECT list
FROM   R1, …, Rn
WHERE cond1 AND cond2 AND . . . AND condk
```


Discussion

Given a query with n relations R1, …, Rn

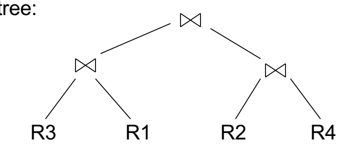
- How many entries do we have in the dynamic programming table?
  - A: $2^n - 1$
- For each entry, how many alternative plans do we need to inspect?
  - A: for each entry with k tables, examine $2^k - 2$ plans

Reducing the Search Space

- Left-linear trees
- No cartesian products

Join Trees

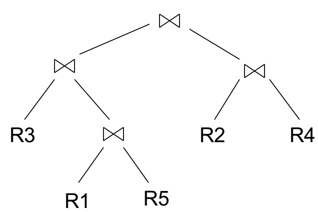
- R1 ⋈ R2 ⋈ …. ⋈ Rn
- Join tree:



- A plan = a join tree
- A partial plan = a subtree of a join tree

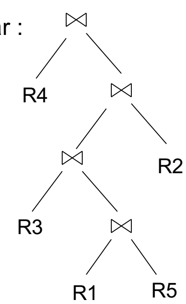
Types of Join Trees

- Bushy:



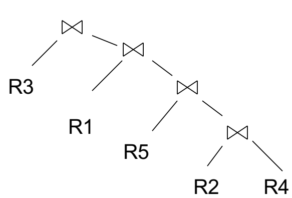
Types of Join Trees

- Linear :



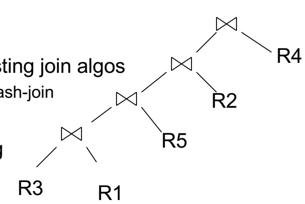
Types of Join Trees

- Right deep:



Types of Join Trees

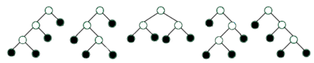
- Left deep:
  - Work well with existing join algos
    - Nested-loop and hash-join
  - Facilitate pipelining



  - Dynamic programming can be used with all trees

Number of Join Trees

- Number of bushy join trees: $C_{n-1} \times n!$
  - Catalan number $C_n = \frac{1}{n+1}\binom{2n}{n}$
  - Counts the number of trees with n internal nodes
  - E.g. n = 3



- Number of left linear join trees: n!

No Cartesian Products

R(A,B) ⋈ S(B,C) ⋈ T(C,D)

Plan: (R(A,B)⋈T(C,D)) ⋈ S(B,C)
has a cartesian product.
Most query optimizers will not consider it

Number of Join Trees

How many join trees without cartesian products?

- Star query:
  $S(K,A_1,\ldots, A_n) \bowtie R_1(A_1,B) \bowtie R_2(A_2,B) \bowtie \ldots R_n(A_n,B)$
- Chain query:
  $R_1(A_0,A_1) \bowtie R_2(A_1,A_2) \bowtie \ldots R_n(A_{n-1},A_n)$

Number of Join Trees

How many join trees without cartesian products?

- Star query:
  $S(K,A_1,\ldots, A_n) \bowtie R_1(A_1,B) \bowtie R_2(A_2,B) \bowtie \ldots R_n(A_n,B)$
  - n! instead of (n+1)!
- Chain query:
  $R_1(A_0,A_1) \bowtie R_2(A_1,A_2) \bowtie \ldots R_n(A_{n-1},A_n)$
  - 2^n instead of n! why?

Selinger Algorithm

Selinger enumeration algorithm considers

- Different logical and physical plans *at the same time*
- Cost of a plan is IO + CPU
- Concept of *interesting order* during plan enumeration
  - Same order as that requested by ORDER BY or GROUP GY
  - Attributes that appear in eq-join predicates

More about the Selinger Algorithm

- Step 1: Enumerate all access paths for a single relation
  - File scan or index scan
  - Keep the cheapest for each *interesting order*
- Step 2: Consider all ways to join two relations
  - Use result from step 1 as the outer relation
  - Consider every other possible relation as inner relation
  - Estimate cost when using sort-merge or nested-loop join
  - Keep the cheapest for each *interesting order*
- Steps 3 and later: Repeat for three relations, etc.

Example on the Board

- You can find this example in the Selinger paper posted on the course website
  - Look under "Readings"