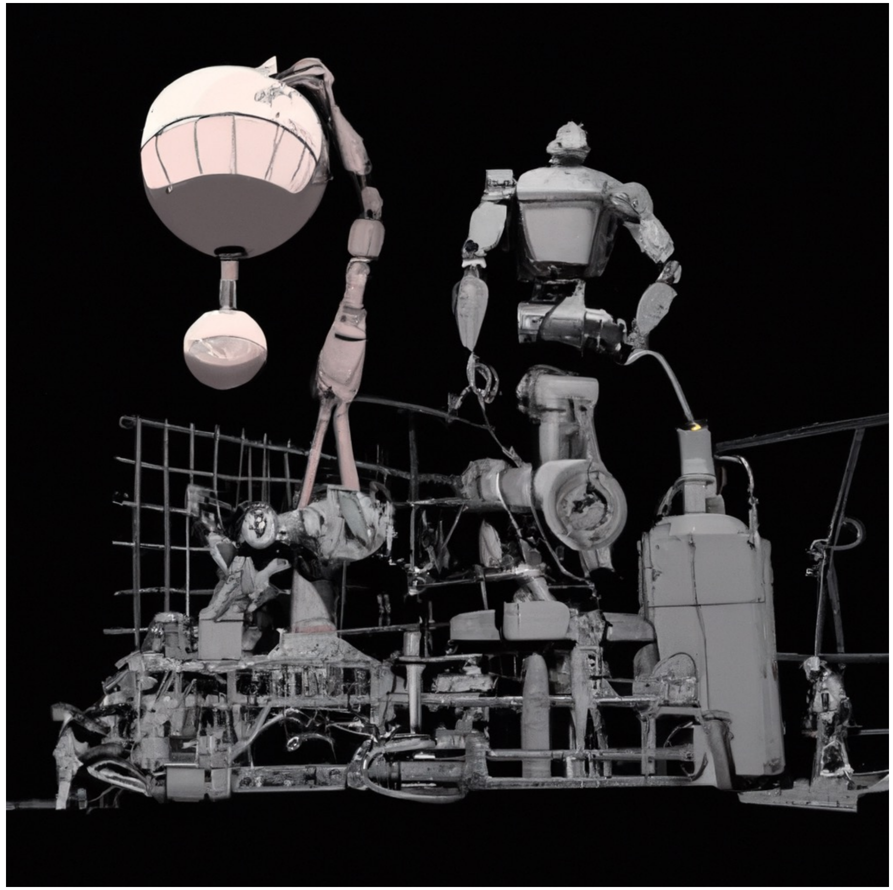
6.5830 Lecture 8



Query Optimization

October 2, 2023

Join Algo Summary

Algo	I/O cost	CPU cost	In Mem?
Nested loops	|R|+|S|	O({R}x{S})	R in mem
Nested loops	{S}|R| + |S|	O({R}x{S})	No
Index nested loops (R index)	|S| + {S}c (c <5)	O({S}log{R})	No
Block nested loops	|S| + B|R| (B=|S|/M)	O({R}x{S})	No
Sort-merge	|R|+|S|	O({S}log{S})	Both
Hash (Hash R)	|R|+|S|	O({S} + {R})	R in mem
Blocked hash (Hash S)	|S| + B|R| (B=|S|/M)	O({S} + B{R}) (*)	No
External Sort-merge	3(|R| + |S|)	O(P x {S}/P log {S}/P)	No
Simple hash (not covered '23)	P(|R|+|S|) (P=|S|/M)	O({R} + {S})	No
Grace hash	3(|R| + |S|)	O({R} + {S})	No

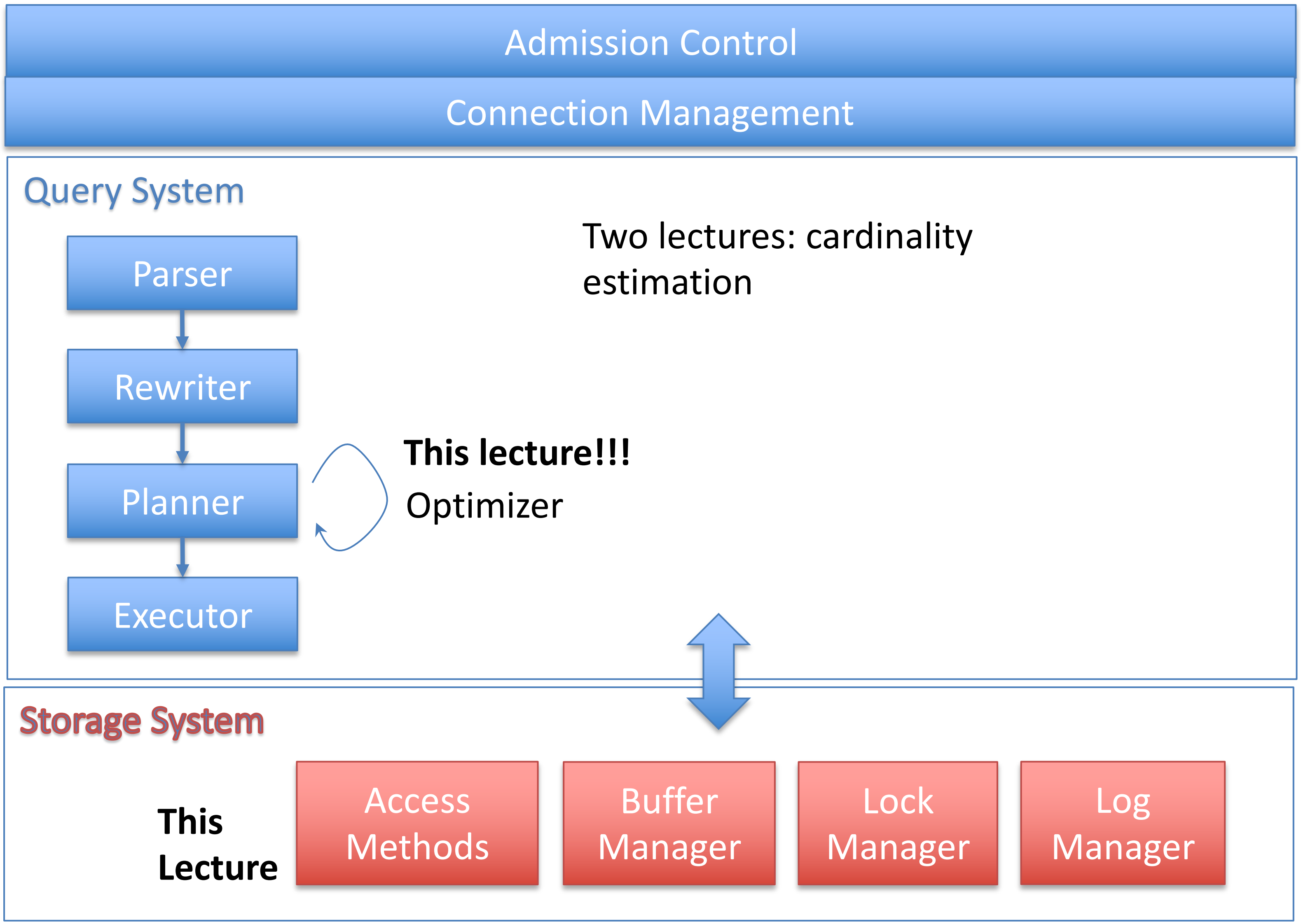
Grace hash is generally a safe bet, unless memory is close to size of tables, in which case simple can be preferable

Extra cost of sorting makes sort merge unattractive unless there is a way to access tables in sorted order (e.g., a clustered index), or a need to output data in sorted order (e.g., for a subsequent ORDER BY)

Postgres Demo

- Try running joins with hash vs merge join

Database Internals Outline



Query Optimization Objective

- Find the query plan of minimum cost
  - Many possible cost functions, as we’ve discussed
- Requires a way to:
  - Evaluate cost of a plan
  - Enumerate (iterate through) plan options

Cost Estimation

- Cost Plan = ∑(Cost Plan Operators)
- Cost Plan Operator ∝ Size of Operator Input

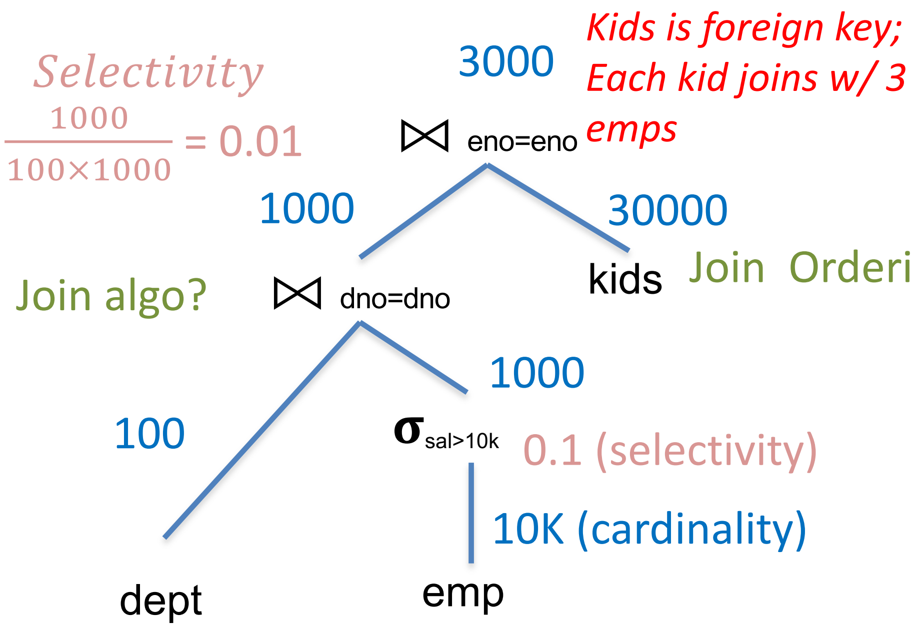
- Determining Size of Operator Input
  - For base tables, equal to size on disk
    - Tables with indexes may support predicate push down
  - For other operators, equal to “selectivity” x size of children
    - **Selectivity** is fraction of input size that the operator emits
    - Join selectivity defined relative to the size of the cross product

Example (Lec 5)

SELECT * FROM emp, dept, kids
WHERE sal > 10k
AND emp.dno = dept.dno
AND emp.eid = kids.eid

100 tuples/page
10 pages RAM
10 KB/page

|dept| = 100 records = 1 page = 10 KB
|emp| = 10K = 100 pages = 1 MB
|kids| = 30K = 300 pages = 3 MB



Join Ordering? Why not kids / emp first?

Index vs scan?

Steps:

For each plan alternative:

1. Estimate sizes of relations
2. Estimate selectivities
3. Compute intermediate sizes
4. Evaluate cost of plan operations

5. Select best plan

Steps:

1. Estimate sizes of relations
2. Estimate selectivities
3. Compute intermediate sizes
4. Evaluate cost of plan operations
5. Find best overall plan

Selinger Statistics

NCARD(R) - "relation cardinality" - number of records in R

TCARD(R) - # pages R occupies

ICARD(I) - # keys (distinct values) in index I

NINDX(I) - pages occupied by index I

Min and max keys in indexes

Modern databases use much more sophisticated stats – will look at Postgres and learn about some research techniques in 2 lectures

Steps:
1. Estimate sizes of relations
2. Estimate selectivities
3. Compute intermediate sizes
4. Evaluate cost of plan operations
5. Find best overall plan

Selinger Selectivities

F(pred) = Selectivity of predicate = Fraction of records that a predicate does not filter

NCARD(R) - "relation cardinality" - number of records in R

TCARD(R) - # pages R occupies

ICARD(I) - # keys (distinct values) in index I

NINDX(I) - pages occupied by index I

Min and max keys in indexes

Predicate types

1. col = val

Clicker (http://clicker.mit.edu/6.5830)

Which is the best estimate for the selectivity of *col = val*?

A. 1/TCARD(R)

B. ICARD(I)/NCARD(I)

C. 1/ICARD(I)

D. (max key – val) / (ICARD(I))

Steps:

1. Estimate sizes of relations
2. Estimate selectivities
3. Compute intermediate sizes
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Min and max keys in indexes

Predicate types

1. col = val

F = 1/ICARD() *(if index available)*

F = 1/10 otherwise

Modern DBs use fancier stats!

2. col > val

(max key - value) / (max key - min key) *(if index available)*

1/3 otherwise

3. col1 = col2

1/MAX(ICARD(col1), ICARD(col2)) *(if index available)*

1/10 otherwise

Assumes key-foreign key join

Note a better estimate is 1/ICARD(PK table)

Steps:

1. Estimate sizes of relations
2. Estimate selectivities
3. Compute intermediate sizes
4. Evaluate cost of plan operations
5. Find best overall plan

Complex Predicates

F(pred) = Selectivity of predicate = Fraction of records that a predicate does not filter

- P1 and P2

  F(P1) x F(P2)

- P1 or P2

  1 – P(neither predicate is satisfied) =

  1 – (1-F(P1)) x (1-F(P2))

Note uniformity assumption

Steps:

1. Estimate sizes of relations
2. Estimate selectivities
3. Compute intermediate sizes
4. Evaluate cost of plan operations
5. Find best overall plan

Intermediate Sizes

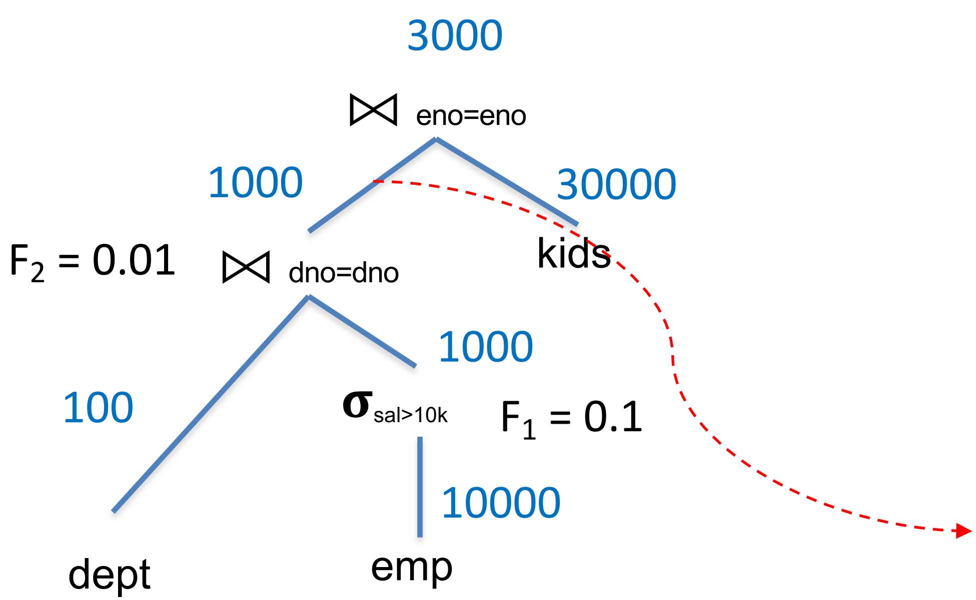
NCARD(R) - "relation cardinality" - number of records in R

TCARD(R) - # pages R occupies

ICARD(I) - # keys (distinct values) in index I

NINDX(I) - pages occupied by index I

Min and max keys in indexes



$NCARD_d$=100 $NCARD_e$=10000

$$NCARD_d \times NCARD_e \times F_1 \times F_2 = 100 \times 10000 \times 0.1 \times 0.01 = 1000$$

Steps:
1. Estimate sizes of relations
2. Estimate selectivities
3. Compute intermediate sizes
4. Evaluate cost of plan operations
5. Find best overall plan

Cost of Base Table Operations

NCARD(R) - "relation cardinality" - number of records in R

TCARD(R) - # pages R occupies

ICARD(I) - # keys (distinct values) in index I

NINDX(I) - pages occupied by index I

Min and max keys in indexes

W: weight of CPU operations

Cost = pages read + weight x (records evaluated)

Heap File lookup

Equality predicate with unique index: 1 + 1 + W

B+Tree lookup

Predicate evaluation

Clustered index, range w/ selectivity F: F x (NINDX + TCARD) + W x (tuples read)

One I/O per page

Unclustered index, range w/ selectivity F : F x (NINDX + NCARD) + W x (tuples read)

One I/O per record

Seq (segment) scan: TCARD + W x (NCARD)

Steps:

1. Estimate sizes of relations
2. Estimate selectivities
3. Compute intermediate sizes
4. Evaluate cost of plan operations
5. Find best overall plan

Cost of Joins

NCARD(R) - "relation cardinality" - number of records in R

TCARD(R) - # pages R occupies

ICARD(I) - # keys (distinct values) in index I

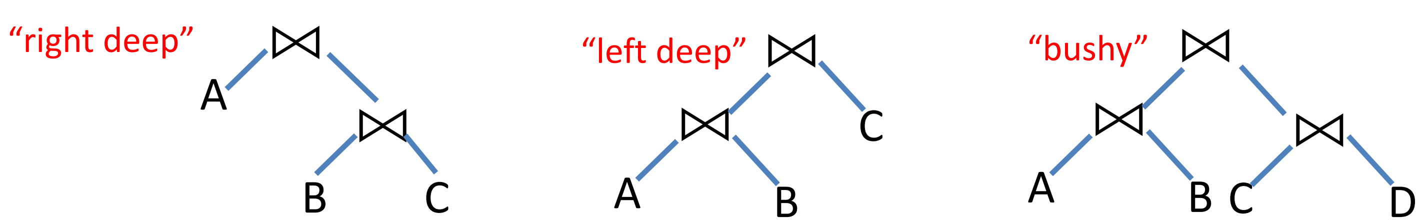
W: weight of CPU operations

NestedLoops(A,B,pred)

Cost(A) + NCARD(A) x Cost(B)

Outer Plan — Inner Plan

- Selinger only considers "left deep" plans, i.e., B is always a base table T_{right}
- <u>In an index on T_{right}</u>, Cost(B) = 1 + 1 + W
- <u>If no index</u>, Cost(B) = TCARD(T_{right}) + W x NCARD(T_{right})
- Cost(A) is just cost of outer subtree



Steps:

1. Estimate sizes of relations
2. Estimate selectivities
3. Compute intermediate sizes
4. Evaluate cost of plan operations
5. Find best overall plan

Cost of Joins

Merge(A,B,pred)

Cost(A) + Cost(B) + sort cost

Varies depending on whether sort is in memory or on disk, and whether one or both tables are already sorted

If either table is a base table, cost is just the sequential scan cost

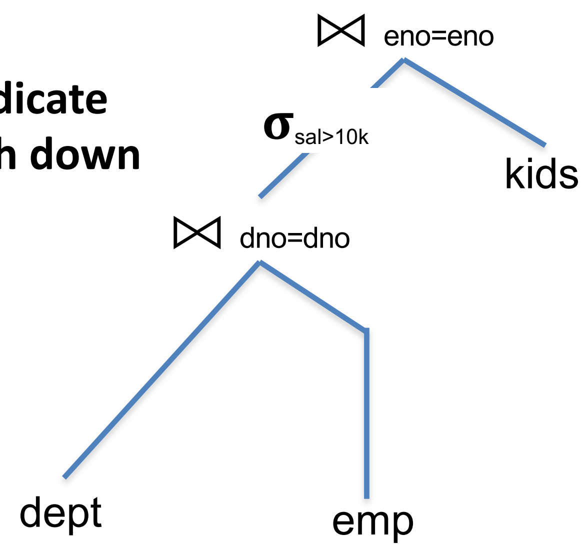
Steps:

1. Estimate sizes of relations
2. Estimate selectivities
3. Compute intermediate sizes
4. Evaluate cost of plan operations
5. Find best overall plan

Enumerating Plans

- Selinger combines several heuristics with a search over join orders
- Heuristics
  - Push down selections
  - Don't consider cross products
  - Only "left deep" plans
    - Right side of all joins is base relation
- Still have to order joins!

Predicate push down

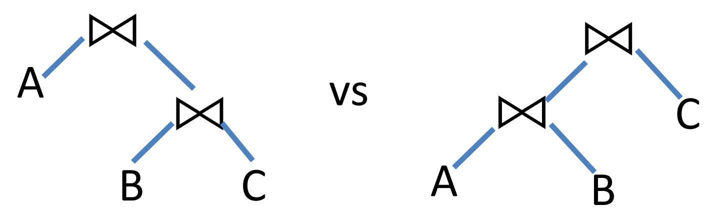


Join ordering

- Suppose I have 3 tables, A $\bowtie$ B $\bowtie$ C
  - Predicates between all 3 (no cross products)
- How many orderings?

ABC	A(BC)	(AB)C
ACB	A(CB)	(AC)B
BAC	B(AC)	(BA)C
BCA	B(CA)	(BC)A
CAB	C(AB)	(CA)B
CBA	C(BA)	(CB)A

n!



This plan is not left deep!

Left deep plans are all of the form (…(((AB)C)D)E)…)

n! left deep plans
10! = 3.6 M
15! = 1.3 T

Can we do better?

Dynamic Programming Algorithm

- **Idea**: compute the best way to join each sub-plan, from smallest to largest
  - Don’t need to reconsider subplans in larger plans
- For example, if the best way to join ABC is (AC)B, that will always be the best way to join ABC, whenever* these three relations occur as a part of a subplan.

* *Except when considering interesting orders*

Postgres example

*explain select * from emp join kids using (eno);*

```
Hash Join  (cost=34730.02..132722.07 rows=3000001 width=35)
 Hash Cond: (kids.eno = emp.eno)
 ->  Seq Scan on kids  (cost=0.00..49099.01 rows=3000001 width=18)
 ->  Hash  (cost=16370.01..16370.01 rows=1000001 width=21)
       ->  Seq Scan on emp  (cost=0.00..16370.01 rows=1000001 width=21)
```

*explain select * from dept join emp using(dno) join kids using (eno);*

```
Hash Join  (cost=35000.04..140870.43 rows=3000001 width=39)
 Hash Cond: (emp.dno = dept.dno)
 ->  Hash Join  (cost=34730.02..132722.07 rows=3000001 width=35)
       Hash Cond: (kids.eno = emp.eno)
       ->  Seq Scan on kids  (cost=0.00..49099.01 rows=3000001 width=18)
       ->  Hash  (cost=16370.01..16370.01 rows=1000001 width=21)
             ->  Seq Scan on emp  (cost=0.00..16370.01 rows=1000001 width=21)
 ->  Hash  (cost=145.01..145.01 rows=10001 width=8)
       ->  Seq Scan on dept  (cost=0.00..145.01 rows=10001 width=8)
```

Identical subplans

Selinger Algorithm

R ← set of relations to join

For i in {1...|R|}:

  for S in {all length i subsets of R}:

    $optcost_s = \infty$

    $optjoin_S = \emptyset$

    for a in S: //a is a relation

      c_{sa} = $optcost_{s-a}$ +

        min. cost to join (S-a) to a +

        min. access cost for a

      Cached in previous step!

      if $c_{sa} < optcost_s$:

        $optcost_s = c_{sa}$

        $optjoin_s$ = optjoin(S-a) joined optimally w/ a

Example

4 Relations: ABCD

Optjoin:

A = best way to access A

(e.g., sequential scan,

or predicate pushdown into index...)

B = "   "   "   " B

C = "   "   "   " C

D = "   "   "   " D

{A,B} = AB or BA

{A,C} = AC or CA

{B,C} = BC or CB

{A,D}

{B,D}

{C,D}

Relations	Best Plan	Cost

Dynamic Programming Table

Example (con't)

Already computed!

Optjoin

{A,B,C} = remove A: compare A({B,C}) to ({B,C})A

remove B: compare ({A,C})B to B({A,C})

remove C: compare C({A,B}) to ({A,B})C

{A,C,D} = …

{A,B,D} = …

{B,C,D} = …

…

{A,B,C,D} = remove A: compare A({B,C,D}) to ({B,C,D})A

remove B: compare B({A,C,D}) to ({A,C,D})B

remove C: compare C({A,B,D}) to ({A,B,D})C

remove D: compare D({A,C,C}) to ({A,B,C})D

Relations	Best Plan	Cost
A	Index Scan	5
B	Seq Scan	15
…		
{A,B}	BA	75
{A,C}	AC	12
{B,C}	CB	22
..		

Complexity

- Have to enumerate all sets of size 1…n

$$\binom{n}{1} + \binom{n}{2} \ldots + \binom{n}{n}$$

- Number of subsets of set of size n =

  |power set of n| =

  2^n (here, n is number of relations)

Equivalent to all binary strings of length N, where a 1 in the ith position indicates that relation i is included:

001, 010, 100, … , 011, 111

Complexity (cont.)

2^n Subsets

How much work per subset?

Have to iterate through each element of each subset, so this at most n

$n2^n$ complexity (vs n!)

n=12 ➔ 49K vs 479M

Interesting Orders

- Some query plans produce data in sorted order – E.g scan over a primary index, merge-join
  – Called an *interesting order*
- Next operator may use this order – E.g. can be another merge-join
- For each subset of relations, compute multiple optimal plans, one for each interesting order
- Increases complexity by factor k+1, where k=number of interesting orders

Summary

- Selinger Optimizer is the foundation of modern cost-based optimizers
  - Simple statistics
  - Several heuristics, e.g., left-deep
  - Dynamic programming algo for join ordering
- Easy to extend, e.g., with:
  - More sophisticated statistics
  - Fewer heuristics