CS460: Intro to Database Systems

Class 18: Relational Query Optimization (cont’d)

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https://bu-disc.github.io/CS460/

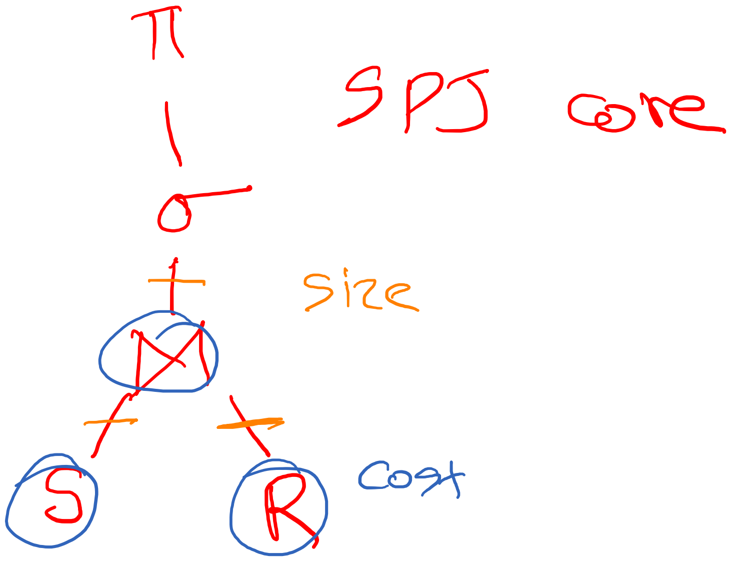
Last time

→ Query Plans / Blocks

→ SPJ equivalences

→ Query Rewriting

→ De-correlation & Flattening



→ Cost Estimation (use cost functions of all algorithms)

→ Result size estimation

Query Optimization

Overview

Query optimization

Cost estimation

Plan enumeration and costing

Readings: Chapter 15.4

System R strategy

Enumeration of Alternative Plans

There are two main cases:

- Single-relation plans
- Multiple-relation plans

For queries over a single relation:

- Each available access path (file scan / index) is considered, and the one with the least estimated cost is chosen
- The different operations are essentially carried out together (e.g., if an index is used for a selection, projection is done for each retrieved tuple)

Cost Estimates for Single-Relation Plans

Index I on primary key matches selection:

- *Cost is Height(I)+1 for a B+ tree, about 2.2 for hash index*

Clustered index I matching one or more selects:

- *(NPages(I)+NPages(R)) * product of RF's of matching selects.*

Non-clustered index I matching one or more selects:

- *(NPages(I)+NTuples(R)) * product of RF's of matching selects*

Sequential scan of file:

- *NPages(R)*

- ***Note:*** *Must also charge for duplicate elimination if required*

Example

```
SELECT S.sid
FROM Sailors S
WHERE S.rating=8
```

Reminder: Sailors has 500 pages, 40000 tuples, and index page holds 800 sids.

NPages(I) = 40000 tuples / 800 sids per page = 50.

RF because we have 10 ratings

If we have an index on *rating*:

- Cardinality: (1/NKeys(I)) * NTuples(S) = (1/10)*40000 tuples retrieved
- Clustered index: cost = (1/NKeys(I)) * (NPages(I)+NPages(S)) = (1/10) * (50+500) = 55 pages retrieved.
- Unclustered index: cost = (1/NKeys(I)) * (NPages(I)+NTuples(S)) = (1/10) * (50+40000) = 4005 pages.

If we have an index on *sid*:

- Would have to retrieve all tuples/pages.
  With a clustered index, the cost is 50+500 / with unclustered index, 50+40000

Doing a file scan:

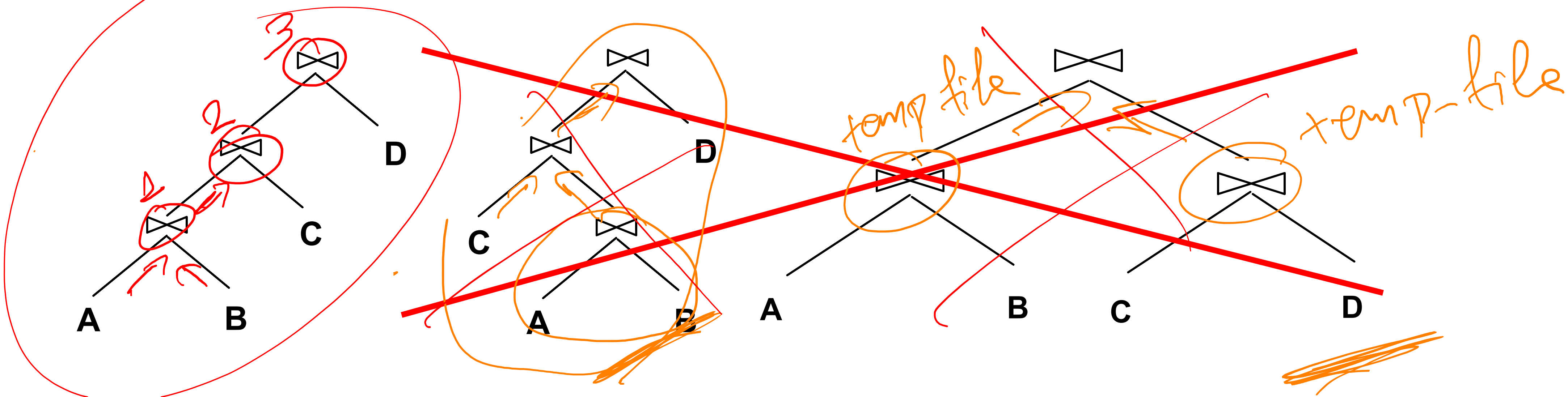
- We retrieve all file pages (500)

Queries Over Multiple Relations

As number of joins increases, number of alternative plans grows rapidly → *need to restrict search space*

Fundamental decision in System R:
only left-deep join trees are considered

- Left-deep trees allow us to generate all *fully pipelined* plans
  - Intermediate results are not written to temporary files
  - Not all left-deep trees are fully pipelined (e.g., SM join)



Plan Enumeration – The Hard Way

1. Select order of relations (the only degree of freedom for left-deep plans)
   – maximum possible orderings = N! (but no X-products)
2. For each join, select join algorithm ← NLJ / HS / SMJ
3. For each input relation, select access method ← scan / idx on A / idx B

Q: How many plans for a query over N relations?

Back-of-envelope calculation:

- With 3 join algorithms, I indexes per relation:
  # plans ≈ [N!] * [$3^{(N-1)}$] * [$(I + 1)^N$]
- Suppose N = 3, I = 2: # plans ≈ 3! * 3^2 * 3^3 = 1458 plans

  For each candidate plan, must estimate cost

Query optimization is NP-complete

Plan Enumeration Example

```
SELECT  S.sname, B.bname, R.day
FROM  Sailors S, Reserves R, Boats B
WHERE  S.sid = R.sid AND R.bid = B.bid
```

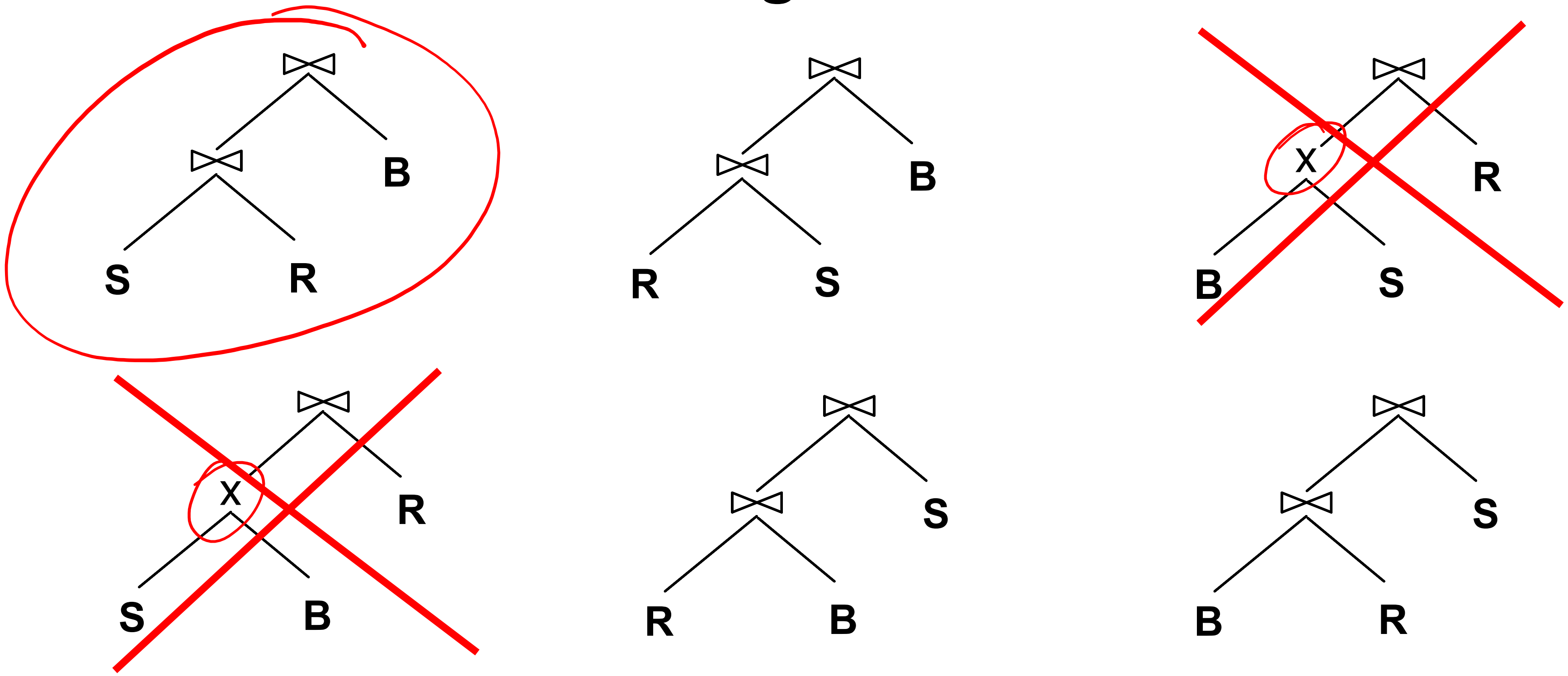
Let's assume:

- Two join algorithms to choose from:
  - Hash-Join / NL-Join (page-oriented or Index-NL-Join)
- Unneeded columns removed at each stage ← after join we keep only the needed columns
- Non-clustered B+Tree index on R.sid; no other indexes
- R.sid index has 50 pages
- S has 500 pages, 80 tuples/page
- R has 1000 pages, 100 tuples/page
- B has 10 pages
- 100 R ⋈ S tuples fit on a page ← important to calculate result size in #pages

Candidate Plans

SELECT S.sname, B.bname, R.day
FROM Sailors S, Reserves R, Boats B
WHERE S.sid = R.sid AND R.bid = B.bid

1. Enumerate relation orderings:



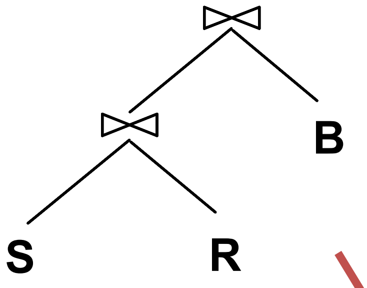
Prune plans with cross-products immediately!

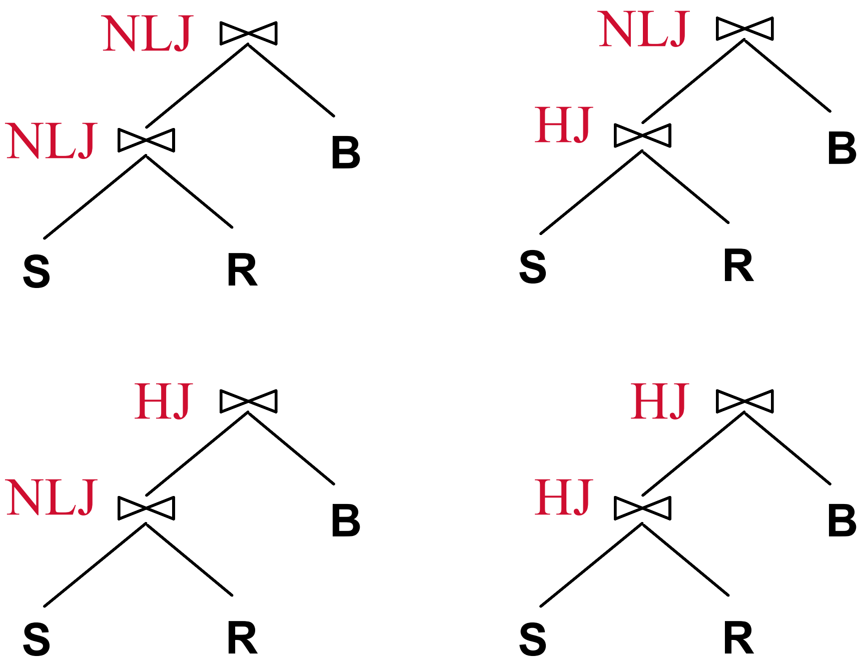
Candidate Plans

```
SELECT S.sname, B.bname, R.day
FROM Sailors S, Reserves R, Boats B
WHERE S.sid = R.sid AND R.bid = B.bid
```

NLJ / HJ

2. Enumerate join algorithm choices:





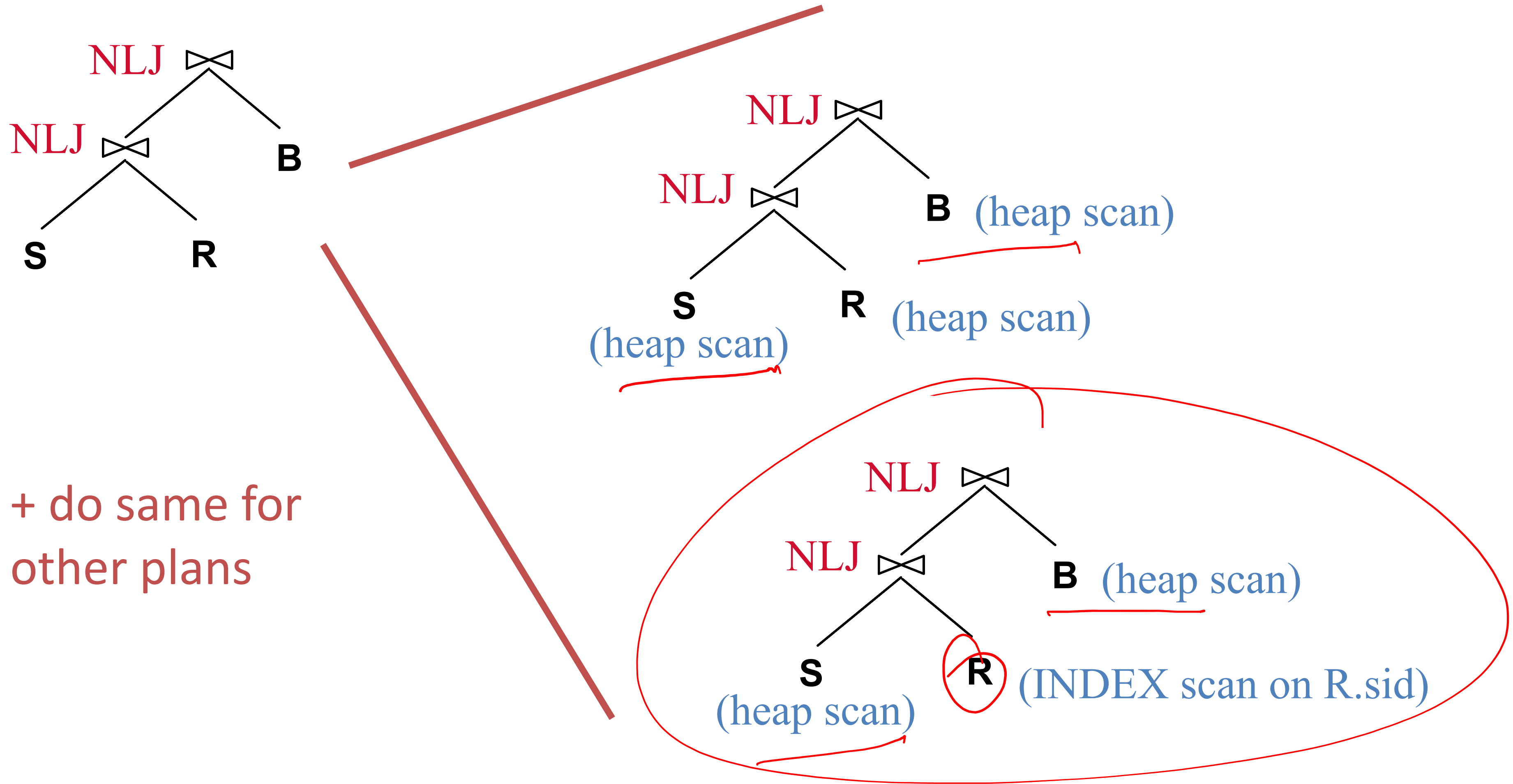
+ do same for
3 other plans

→ 4*4 = 16 plans so far..

Candidate Plans

SELECT S.sname, B.bname, R.day
FROM Sailors S, Reserves R, Boats B
WHERE S.sid = R.sid AND R.bid = B.bid

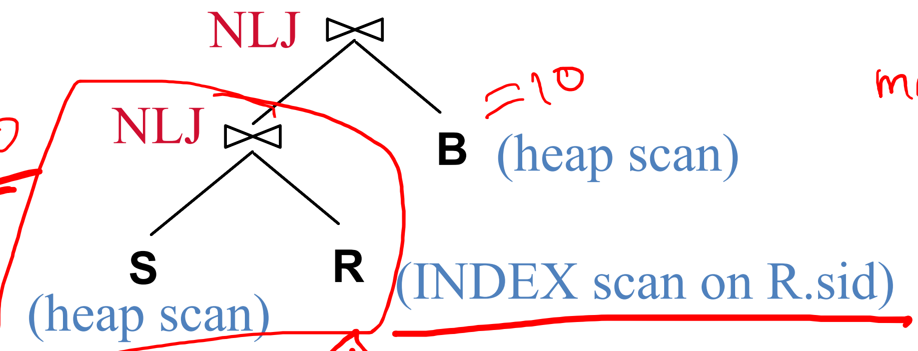
3. Enumerate access method choices:



+ do same for other plans

Now estimate the cost of each plan

Example:



R.sid index has 50 pages
|S|= 500 pg, 80 tuples/pg
|R|= 1000 pg, 100 tuples/pg
|B|= 10 pages
100 R ⋈ S tuples fit on a page
There are 40000 sids

Cost to join S with R

|S| + ((|S| *p_s) * cost of finding matching R tuples)

500 + 500*80 * (1/40000)(50[idx]+100,000) = 100,050

Size of S ⋈ R = NTuples(S)*NTuples(R)/distinct keys(sid) =100,000 tuples; 100,000/100 = 1000 pages

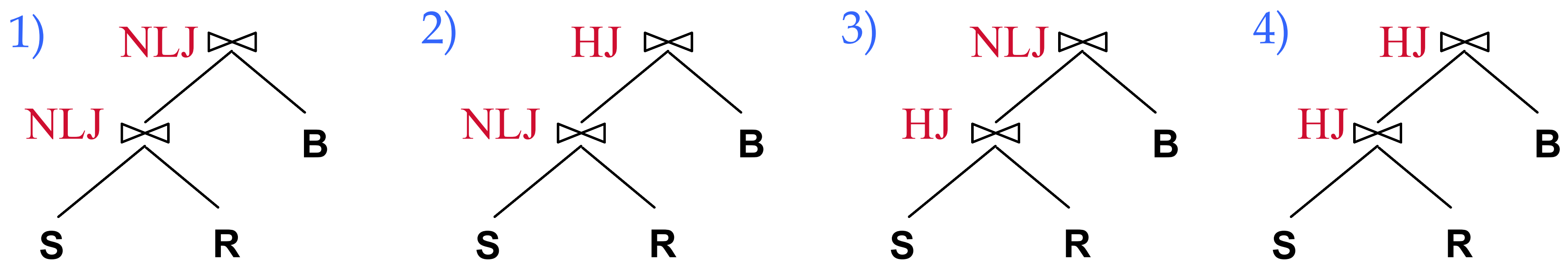
Cost to NL join with B = 1000 * 10 = 10000 (pipelined)

→ Total estimated cost = 500 + 100,050 + 10000 = 110,550

Now You Try …

S = Sailors
R = Reserves
B = Boats

Estimate the cost of each of these plans:



Relevant stats:

- S has 500 pages, 80 tuples/page
- R has 1000 pages, 100 tuples/page
- B has 10 pages
- 100 S ⋈ R tuples fit on a page

Join algorithms:

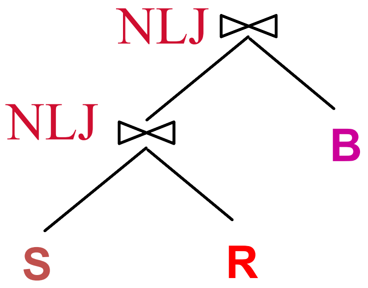
NLJ = page-oriented NL Join

- Scan left input + scan right input once per page in left input

HJ = hash-join (assume 2 passes)

- Scan both inputs + write both inputs in buckets + read all buckets

Answers …

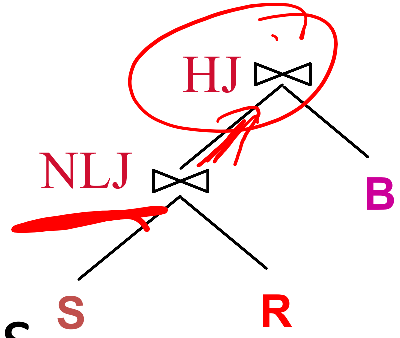


Plan 1:

$S \bowtie R$ size = 100,000 tuples; 1000 pages

Estimated cost = 500 + 500(1000) + 1000(10) = 510,500

scan S join w/R join w/B



Plan 2:

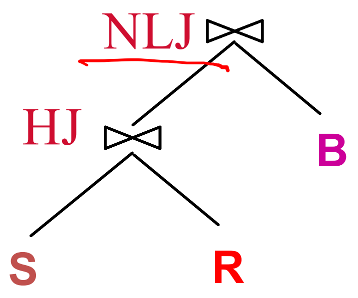
$S \bowtie R$ size = 100,000 tuples; 1000 pages

Estimated cost = 500 + 500(1000) + 2*1000 + 3*10 = 502,530

scan S join w/R join w/B

3(M+N)

Answers …



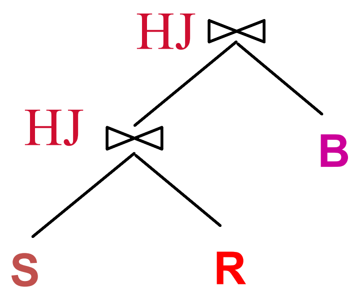
Plan 3:

S ⋈ R size = 100,000 tuples; 1000 pages

Cost = 500 + 2*500 + 3*1000 + 1000(10) = 14500

scan S | join w/R | join w/B

Plan 4:

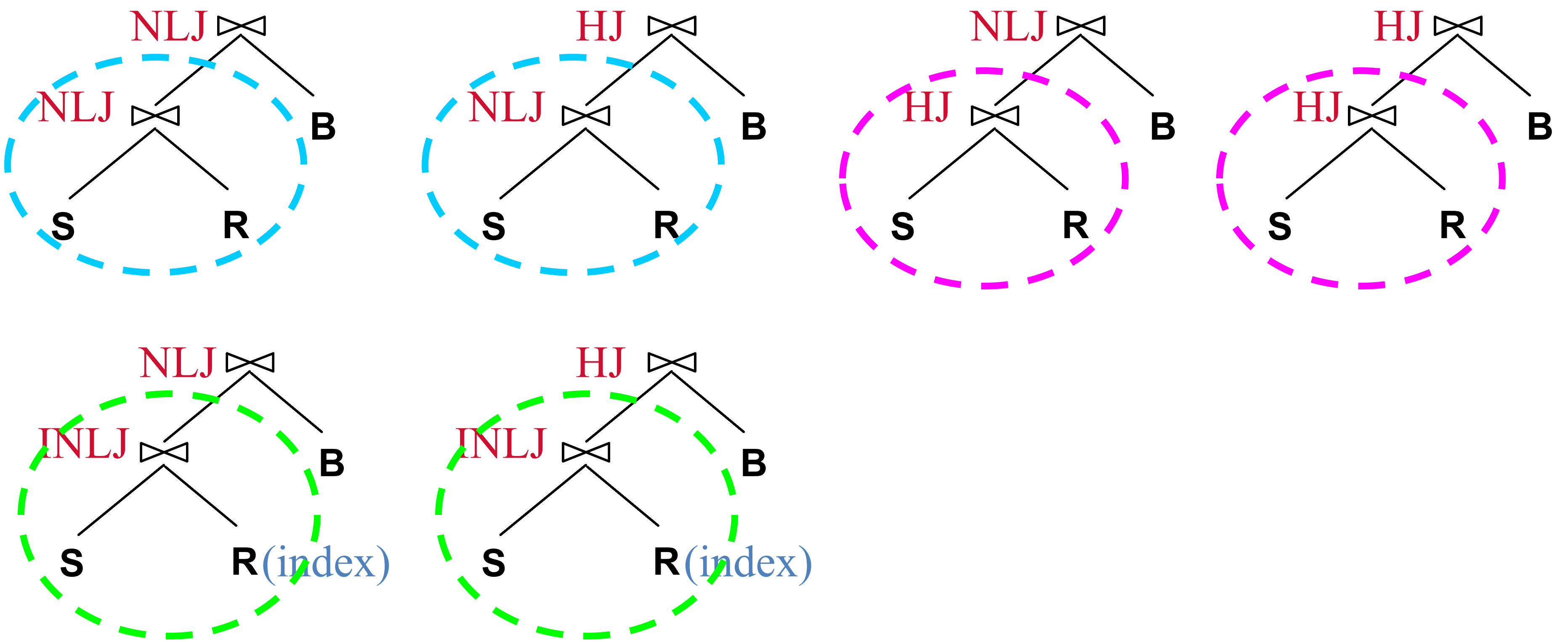


S ⋈ R size = 100,000 tuples; 1000 pages

Cost = 500 + 2*500 + 3*1000 + 2*1000 + 3*10 = 6530

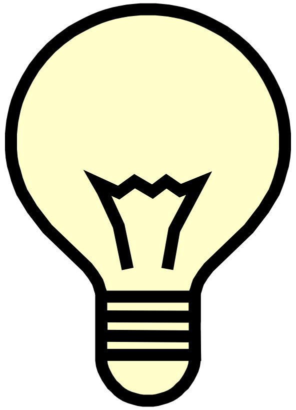
scan S | join w/R | join w/B

Enumerated Plans (just the S-R-B ones)



Observe that many plans share common sub-plans
(i.e., only upper part differs)

Notice Anything?



Much of the computation is redundant

Idea: when we estimate costs & result sizes of sub-plans, remember them.

Query Optimization

Overview

Query optimization

Cost estimation

Plan enumeration and costing

System R strategy

Readings: Chapter 15.6

Improved Strategy (used in System R)

Shared sub-plan observation suggests a better strategy:

Enumerate plans using N passes (N = # relations joined):

- Pass 1: Find best 1-relation plans for each relation
- Pass 2: Find best ways to join result of each 1-relation plan as outer to another relation *(All 2-relation plans.)*
- Pass N: Find best ways to join result of a (N-1)-relation plan as outer to the Nth relation *(All N-relation plans.)*

For each subset of relations, retain only:

- Cheapest subplan overall (possibly unordered), plus
- Cheapest subplan for each *interesting order* of the tuples

For each subplan retained, remember cost and result size estimates

A Note on ”Interesting Orders”

An intermediate result has an “interesting order” if it is sorted by any of:

- ORDER BY attributes
- GROUP BY attributes
- Join attributes of other joins

System R Plan Enumeration

A N-1 way plan is not combined with an additional relation unless there is a join condition between them (unless all predicates in WHERE have been used up)

- i.e., avoid Cartesian products if possible

Always push all selections & projections as far down in the plans as possible

- Usually a good strategy, as long as these operations are cheap

System R Plan Enumeration Example

```
SELECT  S.sname, B.bname, R.day
FROM  Sailors S, Reserves R, Boats B
WHERE  S.sid = R.sid AND R.bid = B.bid
```

This time let's assume:

- Two join algorithms to choose from:
  - Sort-Merge-Join / NL-Join (page-oriented or Index-NL-Join)
- Clustered B+Tree on S.sid (height=3; 500 leaf pages)
- S has 10,000 pages, 5 tuples/page
- R has 10 pages, 10 tuples/page
- B has 10 pages, 20 tuples/page
- 10 R $\bowtie$ S tuples fit on a page
- 10 R $\bowtie$ B tuples fit on a page

Pass 1 (single-relation subplans)

S: (a) heap scan or (b) scan index on S.sid

a) heap scan cost = 10,000

b) index scan cost = 500 + 10,000 = 10,500

Retain both, since (b) has "interesting order" by sid

Two join algorithms to choose from:
Sort-Merge-Join / NL-Join (page-oriented or Index-NL-Join)
Clustered B+Tree on S.sid (height=3; 500 leaf pages)

S has 10,000 pages, 5 tuples/page
R has 10 pages, 10 tuples/page
B has 10 pages, 20 tuples/page

R: heap scan only option

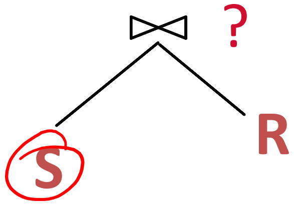
Cost = 10

B: heap scan only option

Cost = 10

Pass 2 (2-relation subplans)

Starting with S as outer



Two join algorithms to choose from:
Sort-Merge-Join / NL-Join (page-oriented or Index-NL-Join)
Clustered B+Tree on S.sid (height=3; 500 leaf pages)

S has 10,000 pages, 5 tuples/page
R has 10 pages, 10 tuples/page
B has 10 pages, 20 tuples/page

Heap scan-S as outer:

a) NL-Join with R, cost = 10,000 + 10,000(10) = 110,000

b) SM-Join with R, cost = 10,000 + 2*10,000 + 3*10 = 30,030

Index scan-S as outer:

c) NL-Join with R, cost = 10,500 + 10,000(10) = 110,500

d) SM-Join with R, cost = 10,500 + 3*10 = 10,530

Retain (d) only

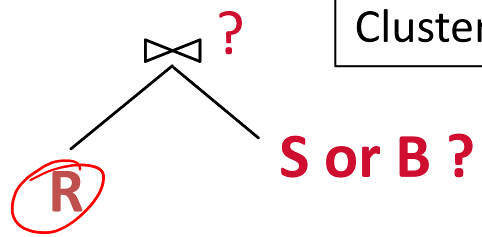
Note: best S⋈ R plan exploits "interesting order" of non-optimal subplan !

Pass 2 (continued)

Two join algorithms to choose from:
Sort-Merge-Join / NL-Join (page-oriented or Index-NL-Join)
Clustered B+Tree on S.sid (height=3; 500 leaf pages)

S has 10,000 pages, 5 tuples/page
R has 10 pages, 10 tuples/page
B has 10 pages, 20 tuples/page

Starting with R as outer



Join with S:

a) NL-Join with S, cost = 10 + 10(10,000) = 100,010

b) Index-NL-Join with Index-S, cost = 10 + 100*4 = 410

c) SM-Join with S, cost = 10 + 2*10 + 3*10,000 = 30,030

Join with B:

a) NL-Join with B, cost = 10 + 10(10) = 110

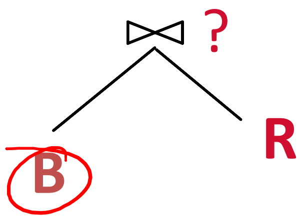
b) SM-Join with B, cost = 10 + 2*10 + 3*10 = 60

Pass 2 (continued)

Two join algorithms to choose from:
Sort-Merge-Join / NL-Join (page-oriented or Index-NL-Join)
Clustered B+Tree on S.sid (height=3; 500 leaf pages)

S has 10,000 pages, 5 tuples/page
R has 10 pages, 10 tuples/page
B has 10 pages, 20 tuples/page

Starting with B as outer

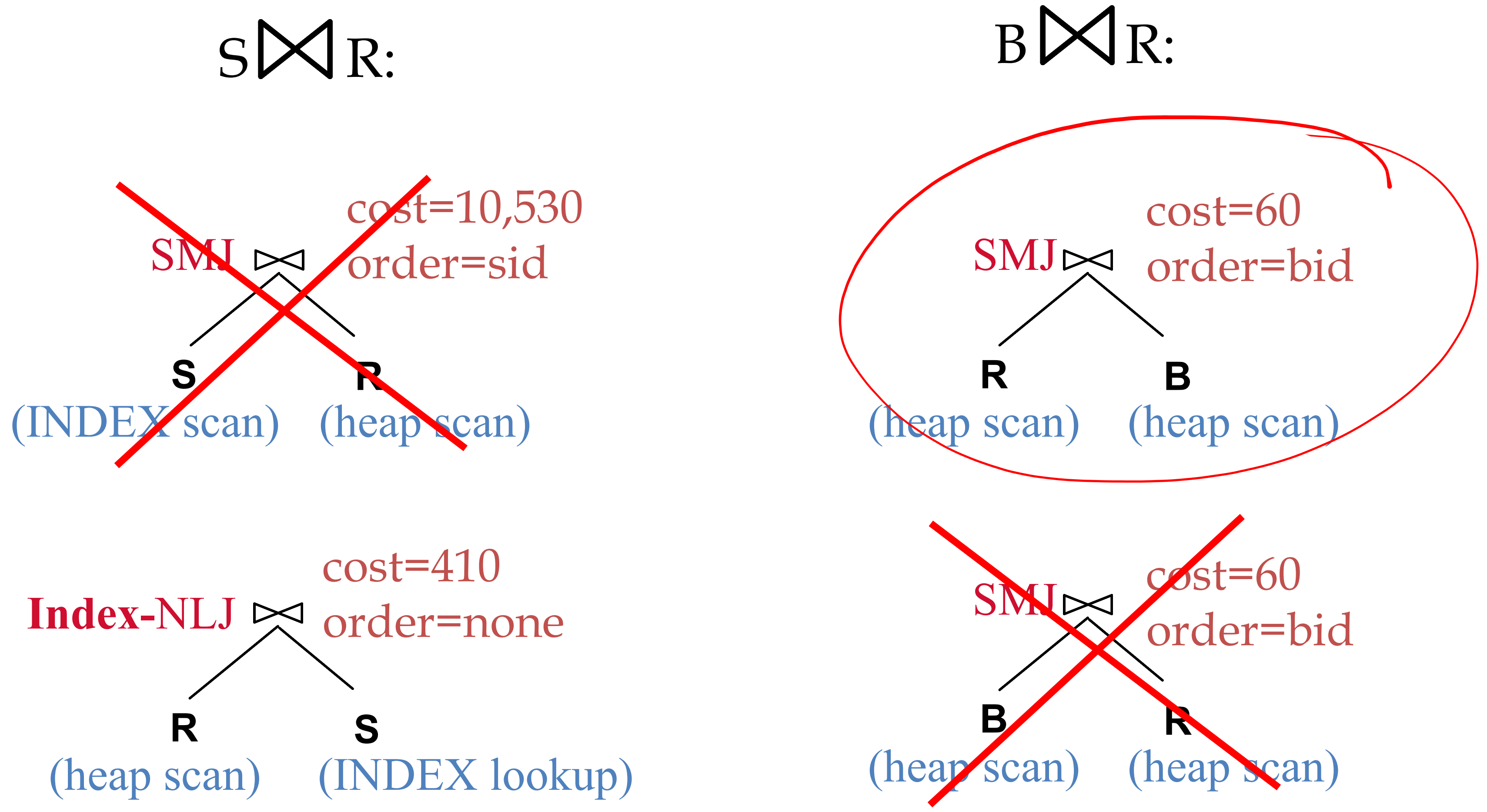


Join with R:

a) NL-Join with R, cost = 10 + 10(10) = 110

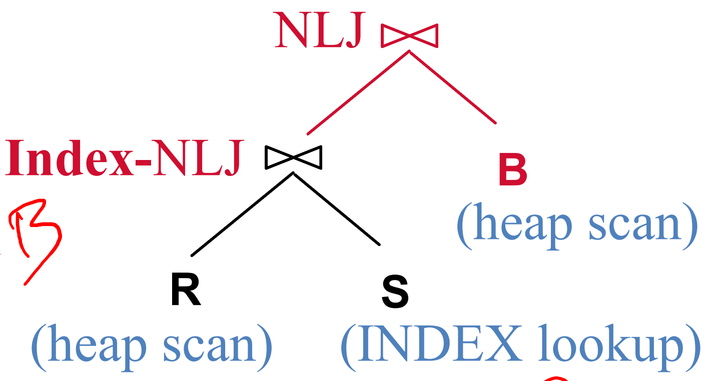
b) SM-Join with R, cost = 10 + 2*10 + 3*10 = 60

Further pruning of 2-relation subplans

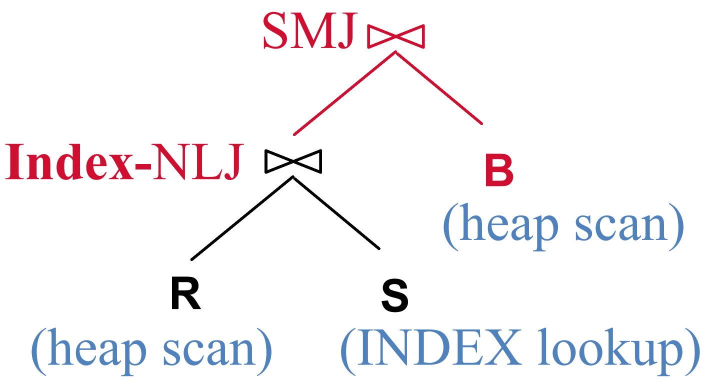


Pass 3 (3-relation subplans)

S ⋈ R subplan:
cost=410
order=none
result size = 10 pages



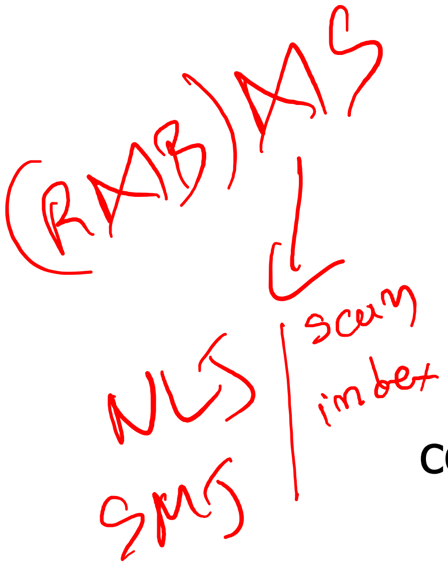
cost = 410 + 10(10) = 510

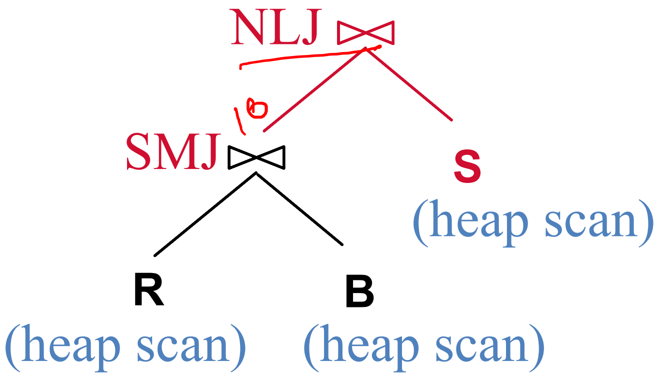


cost = 410 + 2*10 + 3*10 = 460

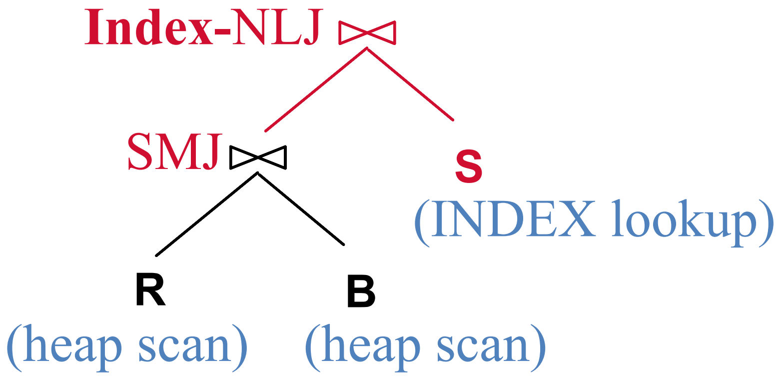
Pass 3 (continued)

B⋈R subplan:
cost=60, order=bid
result size = 100 tuples (10 pages)

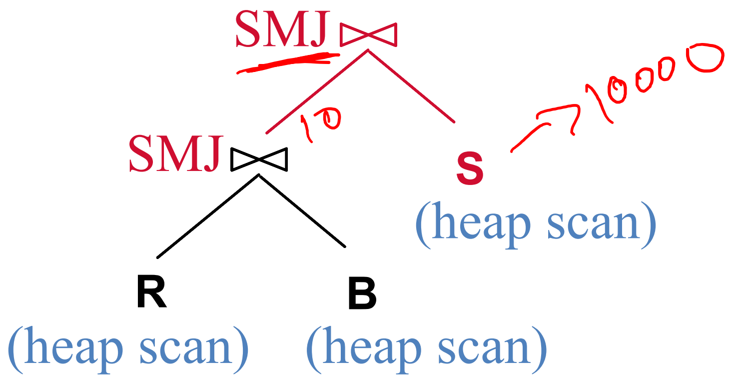




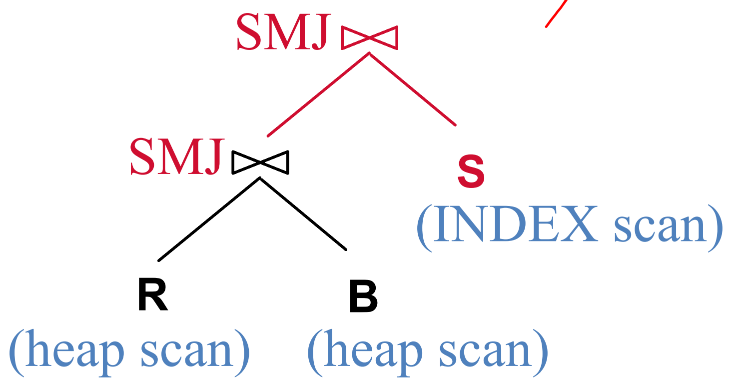
cost = 60 + 10(10,000) = 100,060



cost = 60 + 100*4 = 460

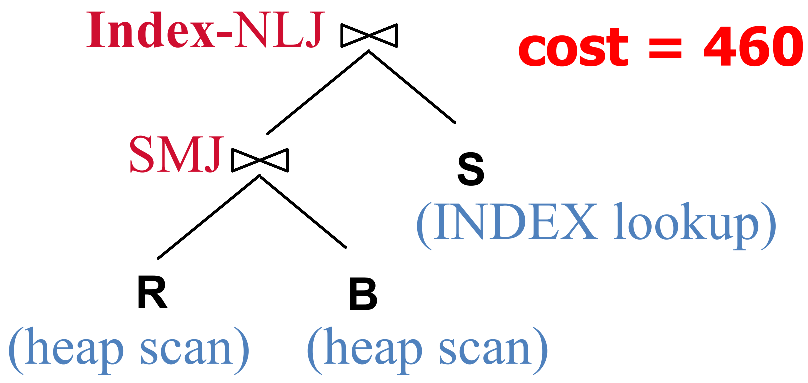


cost = 60 + 10*2 + 3*10,000 = 30,080



cost = 60 + 10*2 + 10,500 = 10,580

And the Winner is …



cost = 460

worst plan was: 510K

Observations:

- Best plan mixes join algorithms
- Worst plan had cost > 100,000

  (exact cost unknown due to pruning)

Optimization yielded ~ **1000-fold improvement** over worst plan!

Some notes w.r.t. reality…

In spite of pruning plan space, this approach is still exponential in the # of tables

– Rule of thumb: works well for < 10 joins

In real systems, COST considered is:

#IOs + *factor* * #CPU Instructions

System R strategy: Summary

Enumerate plans using N passes (N = # relations joined):

For each subset of relations, retain only:

- Cheapest subplan overall (possibly unordered), plus
- Cheapest subplan for each *interesting order* of the tuples

For each subplan retained, remember cost and result size estimates