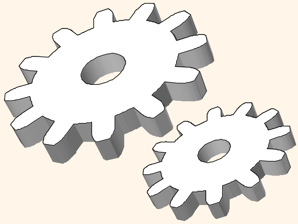
Overview of Query Evaluation

Chapter 12

Join:



```
SELECT  S.sid, S.name, R.bid
FROM    Sailors S, Reserves R
WHERE   S.sid=R.sid
```

- Join is the most *common* and most *expensive* query operator
- Joins are widely studied and systems support several join algorithms
- A straightforward way for the join is an exhaustive nested loop

```
For each tuple r in R do
        For each tuple s in S
                if r.sid == s.sid do
                        add <r, s> to result
```

Schema for Examples

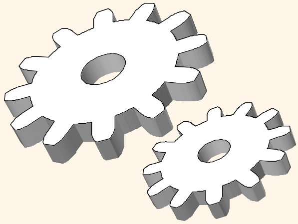
Sailors (*sid*: integer, *sname*: string, *rating*: integer, *age*: real)
Reserves (*sid*: integer, *bid*: integer, *day*: dates, *rname*: string)

- Sailors:
  - No. of tuples: 40,000
  - No. of pages N: 500
  - No. of tuples/page p_S : 80
- Reserves:
  - No. of tuple: 100,000
  - No. of pages M: 1,000
  - No. of tuples/page p_R : 100

	S	R
Pages	N=500	M=1,000
Tuples/page	p_S = 80	p_R = 100

- Retrieving a page through hashing costs 1.2 I/O
- *Cost metric*: # of I/Os. We will ignore output costs.

Simple *Nested Loops Join*

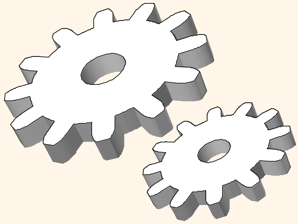


For each tuple r in R do
    for each tuple s in S do
        if $r_i == s_j$ then add <r, s> to result

- For each tuple in the *outer* relation R, we scan the entire *inner* relation S.
  - Cost: $M + p_R * M * N$ = 1000 + 100*1000*500 I/Os.
    = 50,001,000 I/Os.

	S	R
Pages	N=500	M=1,000
Tuples/page	$p_S = 80$	$p_R = 100$

Page-Oriented Nested Loops Join



foreach tuple r in R do
    foreach tuple s in S do
        if $r_i == s_j$ then add <r, s> to result

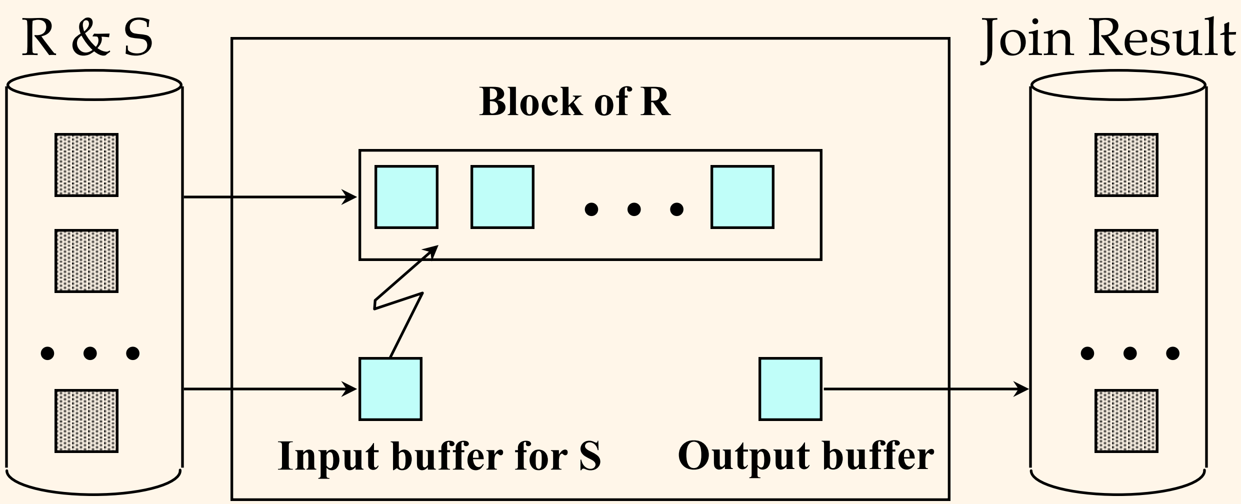
- For each *page* of R, get each *page* of S, and write out matching pairs of tuples <r, s>, where r is in R-page and S is in S-page.
  - Cost: M + M*N = 1000 + 1000*500 = 501,000

- If smaller relation (S) is outer:
  - Cost: N + M*N = 500 + 1000*500 = 500,500

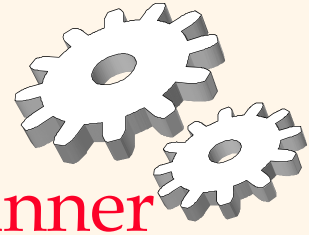
	S	R
Pages	N=500	M=1,000
Tuples/page	$p_S = 80$	$p_R = 100$

Block Nested Loops Join

- Use one page as an input buffer for scanning the inner S, one page as the output buffer, and use all remaining pages to hold ``block'' of outer R.
  - For each matching tuple r in R-block, s in S-page, add <r, s> to result. Then read next R-block, scan S, etc.



Cost of Block Nested Loops



- Cost: Scan of outer + #outer blocks * scan of inner
  - #outer blocks = $\lceil \# \textit{ of pages of outer} / \textit{blocksize} \rceil$
- With Reserves (R) as outer
  - Block size 100 ➔ 1,000 + (1,000/100) * 500 = 6,000
  - Block size 90 ➔ 1,000 + Ceil(1,000/90) * 500 =7,000
- With 100-page block of Sailors as outer:
  - Block size 100: ➔ 500 + (500/100) * 1,000 = 5,500
  - Block size 90: ➔ 500 + (500/90) * 1,000 = 6,500
- With *sequential reads* considered, analysis changes: may be best to divide buffers evenly between R and S.

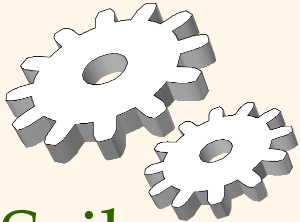
	S	R
Pages	N=500	M=1,000
Tuples/page	$p_S = 80$	$p_R = 100$

Index Nested Loops

- If there is an index on the join column of one relation (say S), can make it the inner and exploit the index.

- For each R tuple, cost of probing S index is about 1.2 for hash index, 2-4 for B+ tree. Cost of then finding S tuples (assuming Alt. (2) or (3) for data entries) depends on clustering.
  - Clustered index: 1 I/O (typical), unclustered: upto 1 I/O per matching S tuple.

Cost of Index Nested Loops



- Reserve is outer, Hash-index (Alt. 2) on *sid* of Sailors (as inner):
  - Scan Reserves: 1000 page I/Os.
  - For each Reserves tuple (100*1000 tuples): 1.2 I/Os to get data entry in index, plus 1 I/O to get (the exactly one) matching Sailors tuple.
  - Cost: 1000 + 100,000 * 2.2 = 221,000 I/Os.

- Does it matter if the index is clustered or not?

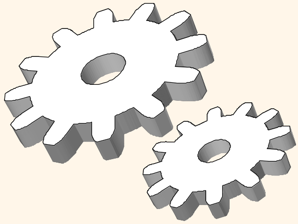
	S	R
Pages	N=500	M=1,000
Tuples/page	p_S = 80	p_R = 100

Cost of Index Nested Loops

- Sailors is outer, Hash-index (Alt. 2) on *sid* of Reserves (as inner):
  - Scan Sailors: 500 page I/Os
  - For each Sailors tuple (80*500 tuples): 1.2 I/Os to find index page with data entries, plus cost of retrieving matching Reserves tuples.
  - Assuming uniform distribution, 2.5 reservations per sailor (100,000 / 40,000).
  - Cost of retrieving them is 1 or 2.5 I/Os depending on whether the index is clustered.
  - Clustered Index ➔ 50 + 40,000 * 2.2 = 88,500
  - Unclustered Index ➔ 500 + 40,000 * 3.7 = 148,500

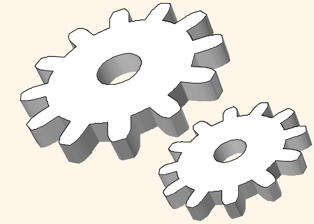
	S	R
Pages	N=500	M=1,000
Tuples/page	$p_S = 80$	$p_R = 100$

Sort-Merge Join $(R \bowtie_{i=j} S)$



- Sort R and S on the join column, then scan them to do a ``merge'' (on join col.), and output result tuples.
  - Advance scan of R until current R-tuple >= current S tuple, then advance scan of S until current S-tuple >= current R tuple; do this until current R tuple = current S tuple.
  - At this point, all R tuples with same value in Ri (*current R group*) and all S tuples with same value in Sj (*current S group*) *match*; output <r, s> for all pairs of such tuples.
  - Then resume scanning R and S.
- R is scanned once; each S group is scanned once per matching R tuple. (Multiple scans of an S group are likely to find needed pages in buffer.)

Join: Sort-Merge ($R \bowtie_{i=j} S$)



- Sort R and S on the join column, then scan them to do a ``merge'' (on join col.), and output result tuples.

sid	sname	rating	age
22	dustin	7	45.0
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

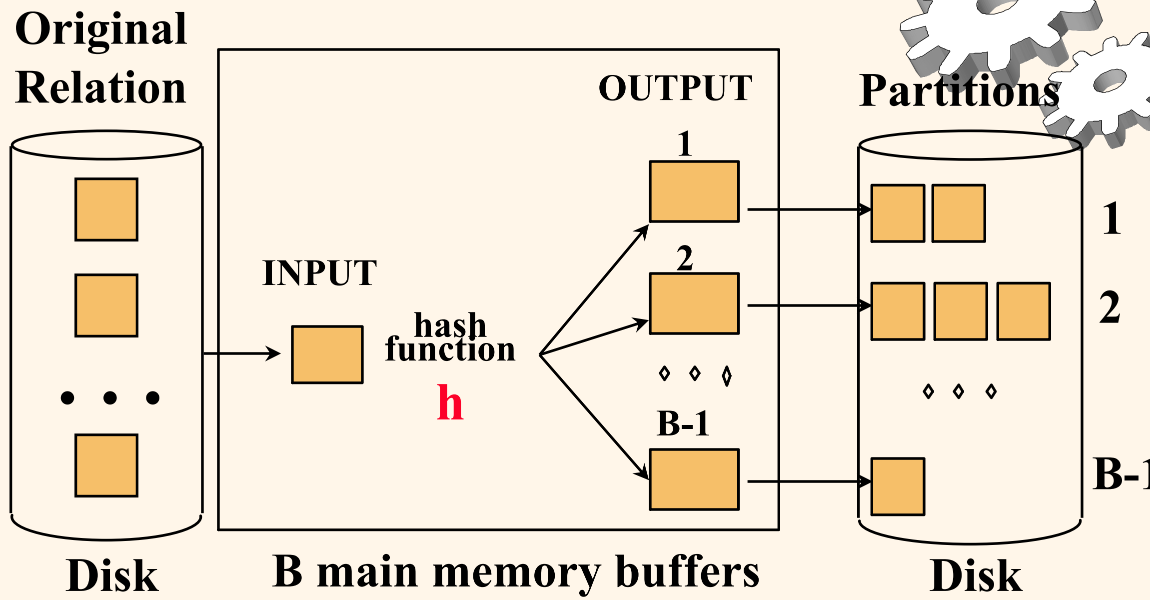
sid	bid	day	rname
28	103	12/4/96	guppy
28	103	11/3/96	yuppy
31	101	10/10/96	dustin
31	102	10/12/96	lubber
31	101	10/11/96	lubber
58	103	11/12/96	dustin

Cost of Sort-Merge Join

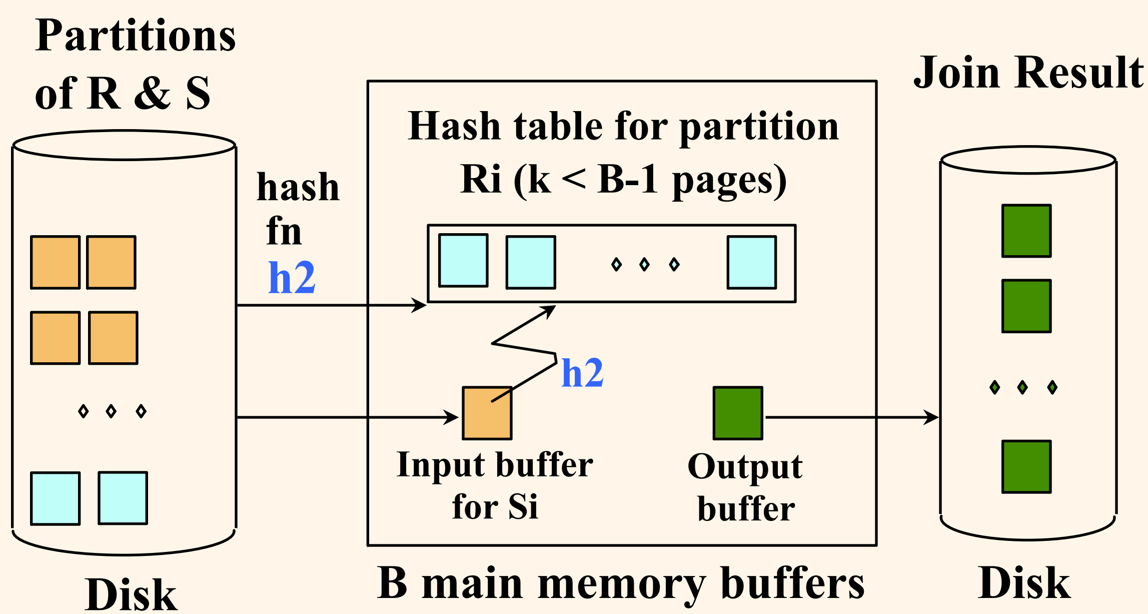
- *If sorting* takes two passes, for each pass, we need to scan (read and write) each data record:
  - Cost for sorting Reserves: 2 * 2 * 1000 = 4000
  - Cost for sorting Sailors: 2 * 2 * 500 = 2000
- *Merging* needs only one global pass over the two tables with read only
  - Merging cost = 1000+500 = 1500
- Total cost = 4000 + 2000 + 1500 = 7500

Hash-Join

- Partition both relations using hash fn **h**: R tuples in partition i will only match S tuples in partition i.



- Read in a partition of R, hash it using **h2** (<> **h**!). Scan matching partition of S, search for matches.



Cost of Hash-Join

- In partitioning phase, read+write both relns; 2(M+N). In matching phase, read both relns; M+N I/Os.
- In our running example, this is a total of 4500 I/Os.
- Sort-Merge Join vs. Hash Join:
  - Hash Join superior if relation sizes differ greatly. Also, Hash Join shown to be highly parallelizable.
  - Sort-Merge less sensitive to data skew; result is sorted.

General Join Conditions

- Equalities over several attributes (e.g., *R.sid=S.sid* AND *R.rname=S.sname*):
  - For Index NL, build index on <*sid, sname*> (if S is inner); or use existing indexes on *sid* or *sname*.
  - For Sort-Merge and Hash Join, sort/partition on combination of the two join columns.
- Inequality conditions (e.g., *R.rname* < *S.sname*):
  - For Index NL, need (clustered!) B+ tree index.
    - Range probes on inner; # matches likely to be much higher than for equality joins.
  - Hash Join, Sort Merge Join not applicable.
  - Block NL quite likely to be the best join method here.