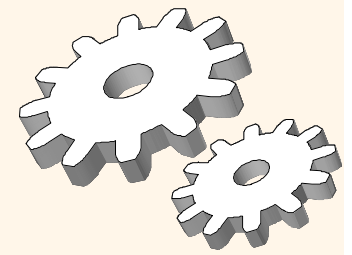


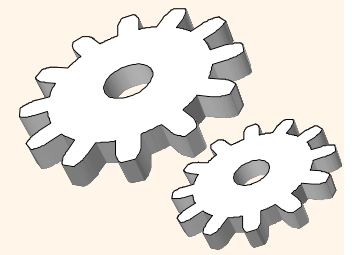
Evaluation of Relational Operations

Chapter 14, Part A (Joins)



Relational Operations

- ❖ We will consider how to implement:
 - Selection (σ) Selects a subset of rows from relation.
 - Projection (π) Deletes unwanted columns from relation.
 - Join (\bowtie) Allows us to combine two relations.
 - Set-difference ($-$) Tuples in reln. 1, but not in reln. 2.
 - Union (\cup) Tuples in reln. 1 and in reln. 2.
 - Aggregation (SUM, MIN, etc.) and GROUP BY
- ❖ Since each op returns a relation, ops can be *composed*!
After we cover the operations, we will discuss how to *optimize* queries formed by composing them.



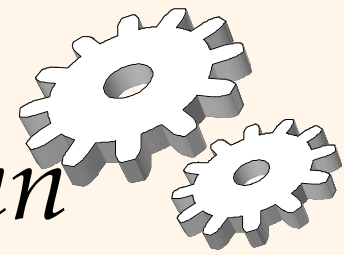
Schema for Examples

Sailors (*sid*: integer, *sname*: string, *rating*: integer, *age*: real)

Reserves (*sid*: integer, *bid*: integer, *day*: dates, *rname*: string)

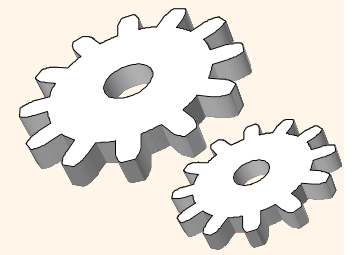
- ❖ Similar to old schema; *rname* added for variations.
- ❖ Reserves:
 - Each tuple is 40 bytes long, 100 tuples per page, 1000 pages.
- ❖ Sailors:
 - Each tuple is 50 bytes long, 80 tuples per page, 500 pages.

Equality Joins With One Join Column



```
SELECT *  
FROM   Reserves R1, Sailors S1  
WHERE  R1.sid=S1.sid
```

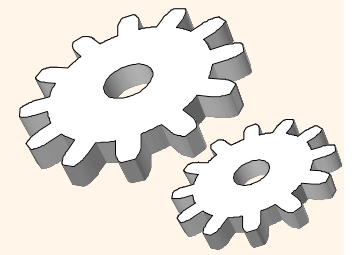
- ❖ In algebra: $R \bowtie S$. Common! Must be carefully optimized. $R \times S$ is large; so, $R \times S$ followed by a selection is inefficient.
- ❖ Assume: M tuples in R , p_R tuples per page, N tuples in S , p_S tuples per page.
 - In our examples, R is Reserves and S is Sailors.
- ❖ We will consider more complex join conditions later.
- ❖ *Cost metric*: # of I/Os. We will ignore output costs.



Simple Nested Loops Join

```
foreach tuple r in R do
    foreach tuple s in S do
        if  $r_i == s_j$  then add  $\langle r, s \rangle$  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.
- ❖ Page-oriented Nested Loops join: For each *page* of R, get each *page* of S, and write out matching pairs of tuples $\langle r, s \rangle$, where r is in R-page and S is in S-page.
 - Cost: $M + M * N = 1000 + 1000 * 500$
 - If smaller relation (S) is outer, cost = $500 + 500 * 1000$

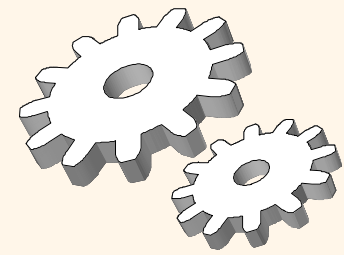


Index Nested Loops Join

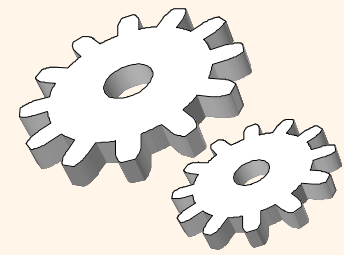
```
foreach tuple r in R do
    foreach tuple s in S where  $r_i == s_j$  do
        add  $\langle r, s \rangle$  to result
```

- ❖ If there is an index on the join column of one relation (say S), can make it the inner and exploit the index.
 - Cost: $M + (M * p_R) * \text{cost of finding matching S tuples}$
- ❖ 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.

Examples of Index Nested Loops

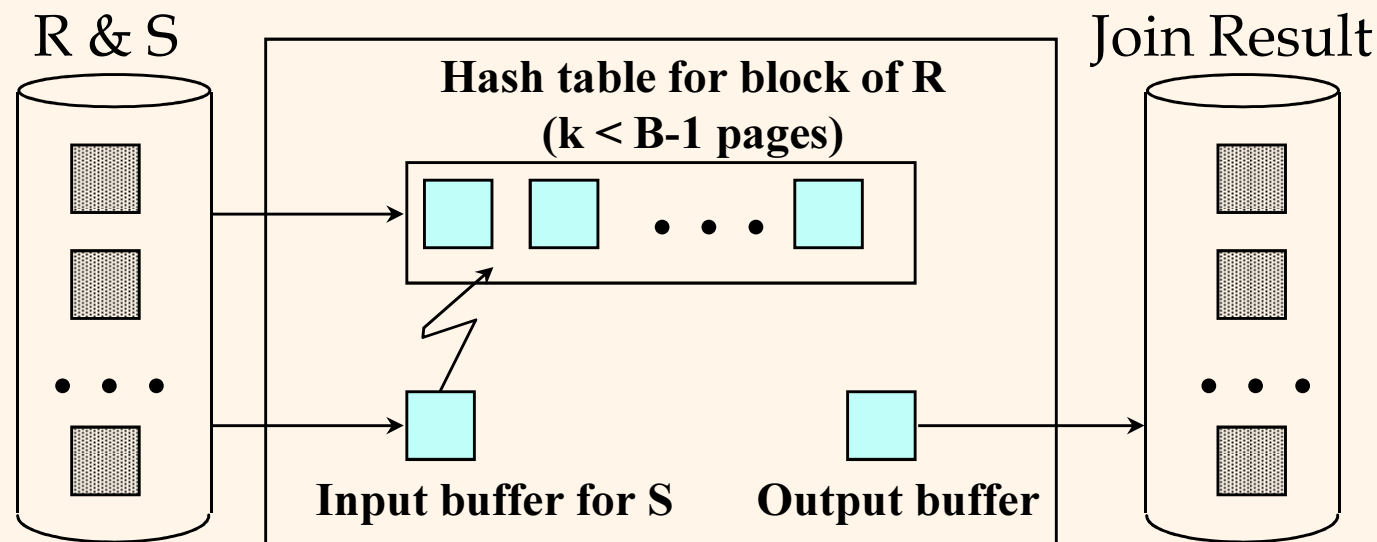


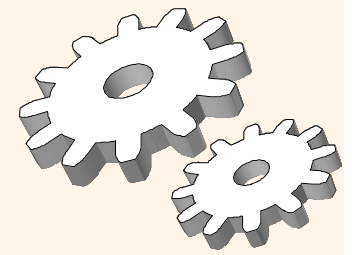
- ❖ Hash-index (Alt. 2) on *sid* of Sailors (as inner):
 - Scan Reserves: 1000 page I/Os, 100*1000 tuples.
 - For each Reserves tuple: 1.2 I/Os to get data entry in index, plus 1 I/O to get (the exactly one) matching Sailors tuple. Total: 220,000 I/Os.
- ❖ Hash-index (Alt. 2) on *sid* of Reserves (as inner):
 - Scan Sailors: 500 page I/Os, 80*500 tuples.
 - For each Sailors tuple: 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.



Block Nested Loops Join

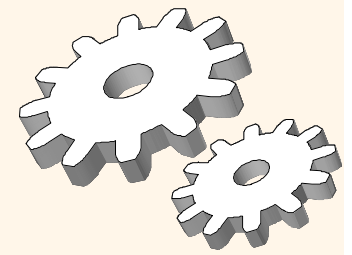
- ❖ Use one page as an input buffer for scanning the inner S, one page as the output buffer, and use all remaining pages to hold ``block'' of outer R.
 - For each matching tuple r in R-block, s in S-page, add $\langle r, s \rangle$ to result. Then read next R-block, scan S, etc.





Examples of Block Nested Loops

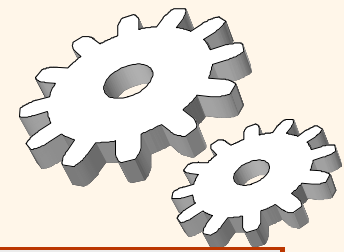
- ❖ **Cost: Scan of outer + #outer blocks * scan of inner**
 - #outer blocks = $\lceil \# \text{ of pages of outer} / \text{blocksize} \rceil$
- ❖ With Reserves (R) as outer, and 100 pages of R:
 - Cost of scanning R is 1000 I/Os; a total of 10 *blocks*.
 - Per block of R, we scan Sailors (S); 10*500 I/Os.
 - If space for just 90 pages of R, we would scan S 12 times.
- ❖ With 100-page block of Sailors as outer:
 - Cost of scanning S is 500 I/Os; a total of 5 blocks.
 - Per block of S, we scan Reserves; 5*1000 I/Os.
- ❖ With sequential reads considered, analysis changes:
may be best to divide buffers evenly between R and S.



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 \geq current S tuple, then advance scan of S until current S-tuple \geq current R tuple; do this until current R tuple = current S tuple.
 - At this point, all R tuples with same value in R_i (*current R group*) and all S tuples with same value in S_j (*current S group*) match; output $\langle r, s \rangle$ 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.)

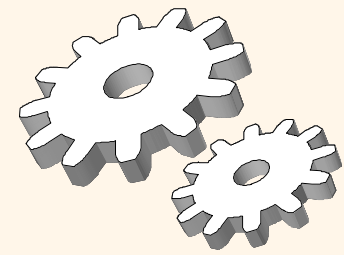
Example of Sort-Merge Join



<u>sid</u>	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

<u>sid</u>	<u>bid</u>	<u>day</u>	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: $M \log M + N \log N + (M+N)$**
 - The cost of scanning, $M+N$, could be $M*N$ (very unlikely!)
- ❖ With 35, 100 or 300 buffer pages, both Reserves and Sailors can be sorted in 2 passes; total join cost: 7500.
(BNL cost: 2500 to 15000 I/Os)

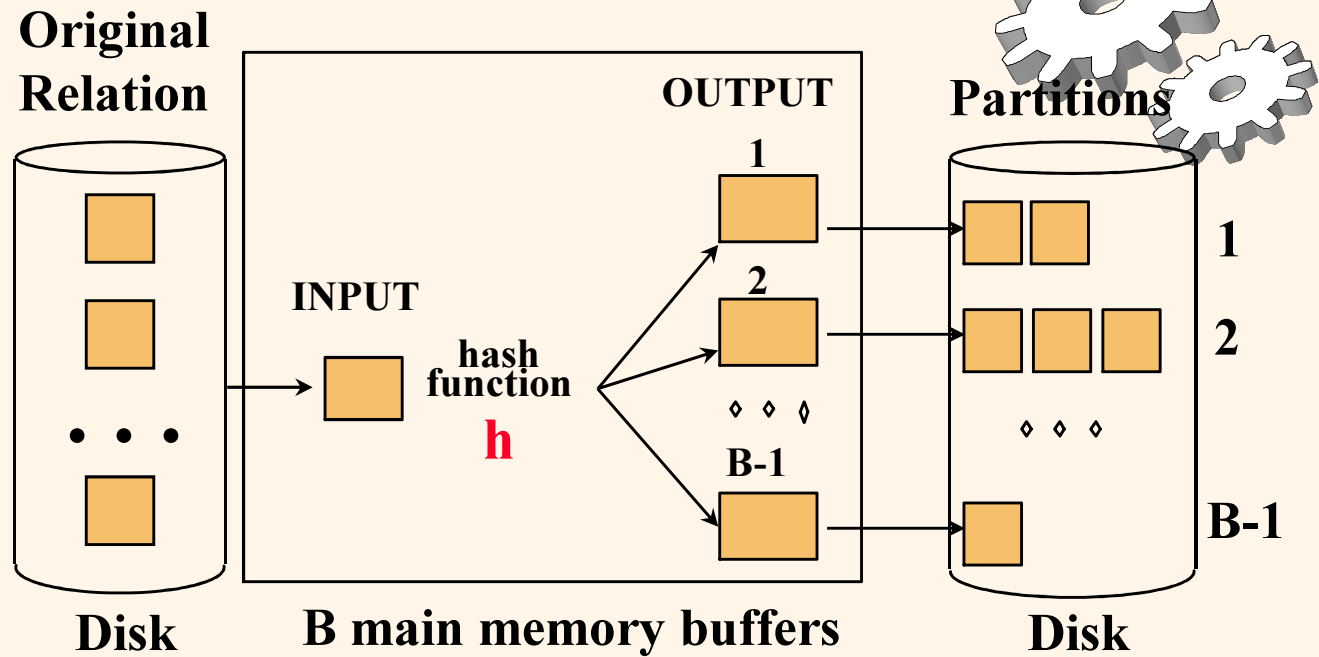


Refinement of Sort-Merge Join

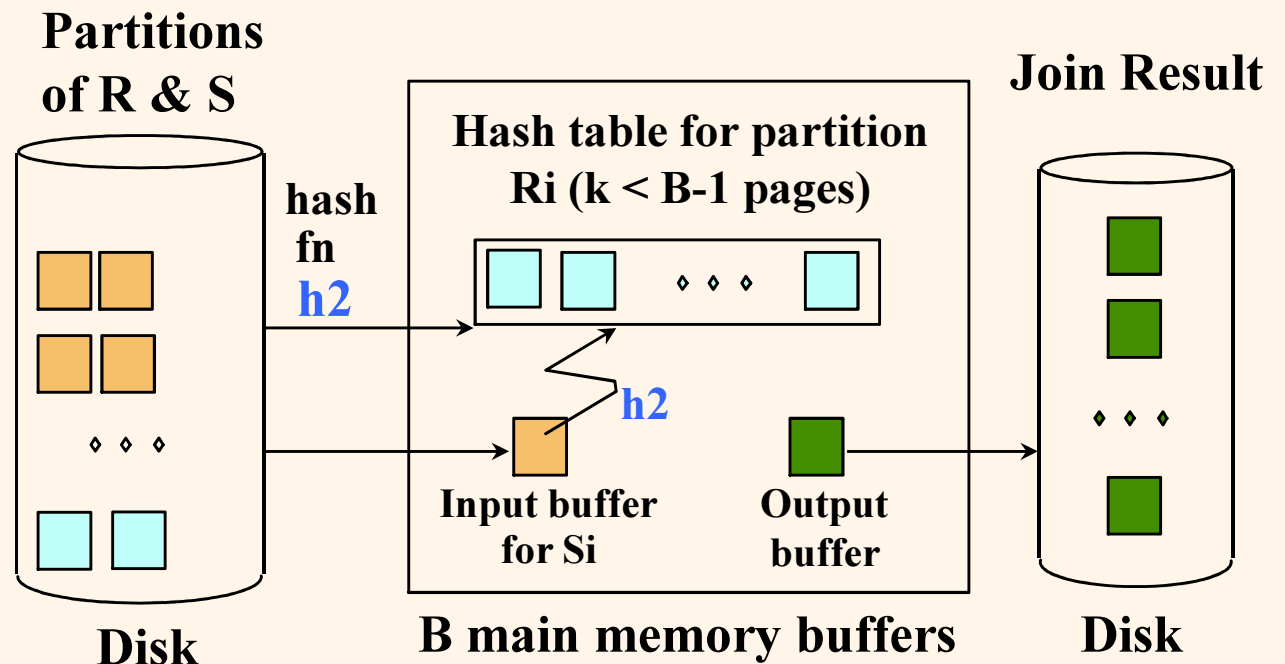
- ❖ We can combine the merging phases in the *sorting* of R and S with the merging required for the join.
 - With $B > \sqrt{L}$, where L is the size of the larger relation, using the sorting refinement that produces runs of length $2B$ in Pass 0, #runs of each relation is $< B/2$.
 - Allocate 1 page per run of each relation, and ‘merge’ while checking the join condition.
 - **Cost:** read+write each relation in Pass 0 + read each relation in (only) merging pass (+ writing of result tuples).
 - In example, cost goes down from 7500 to 4500 I/Os.
- ❖ In practice, cost of sort-merge join, like the cost of external sorting, is *linear*.

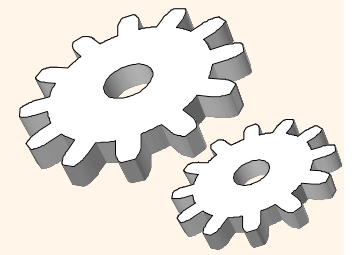
Hash-Join

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



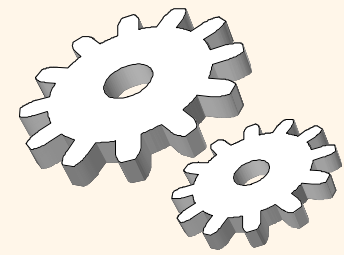
- ❖ Read in a partition of *R*, hash it using **h2** (\neq **h**!). Scan matching partition of *S*, search for matches.





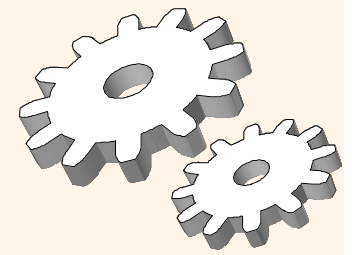
Observations on Hash-Join

- ❖ #partitions $k < B-1$ (why?), and $B-2 > \text{size of largest partition}$ to be held in memory. Assuming uniformly sized partitions, and maximizing k , we get:
 - $k = B-1$, and $M/(B-1) < B-2$, i.e., B must be $> \sqrt{M}$
- ❖ If we build an in-memory hash table to speed up the matching of tuples, a little more memory is needed.
- ❖ If the hash function does not partition uniformly, one or more R partitions may not fit in memory. Can apply hash-join technique recursively to do the join of this R -partition with corresponding S -partition.



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:
 - Given a minimum amount of memory (*what is this, for each?*) both have a cost of $3(M+N)$ I/Os. Hash Join superior on this count 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.