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

Schema for Examples

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

- 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 pages for R, p_R tuples per page, N pages for S, p_S tuples per page.
  - In our examples, R is Reserves and S is Sailors.
- *Cost metric*: # of I/Os. We will ignore output costs.

Join Algorithms to Consider

- Nested loop join
- Sort-merge join
- Hash join
- Index nested loop join

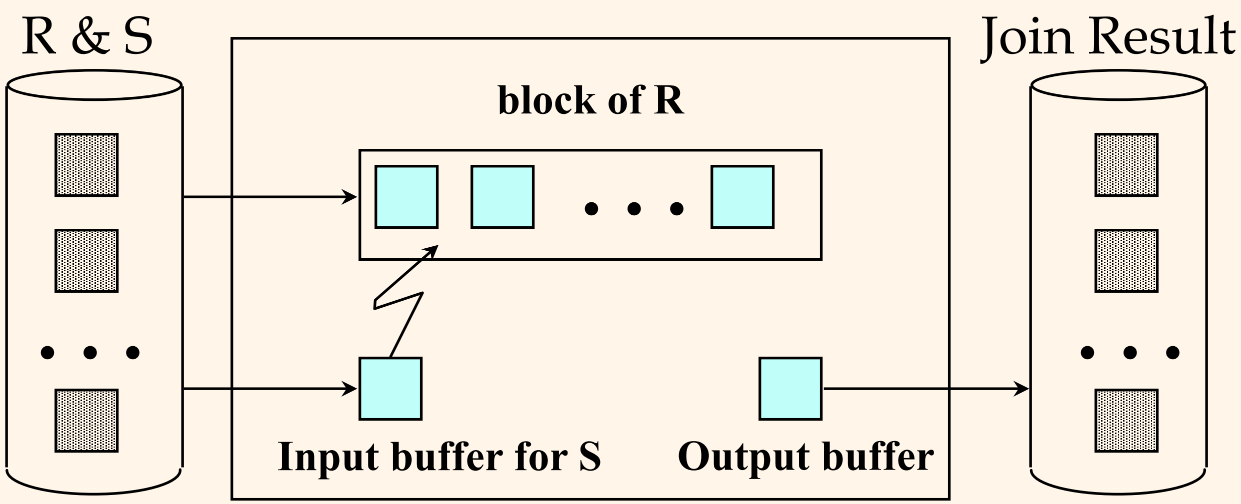
Simple Nested Loops Join

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

- Tuple-oriented NLJ: 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 NLJ: 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: $M + M*N = 1000 + 1000*500$
  - If smaller relation (S) is outer, cost = 500 + 500*1000

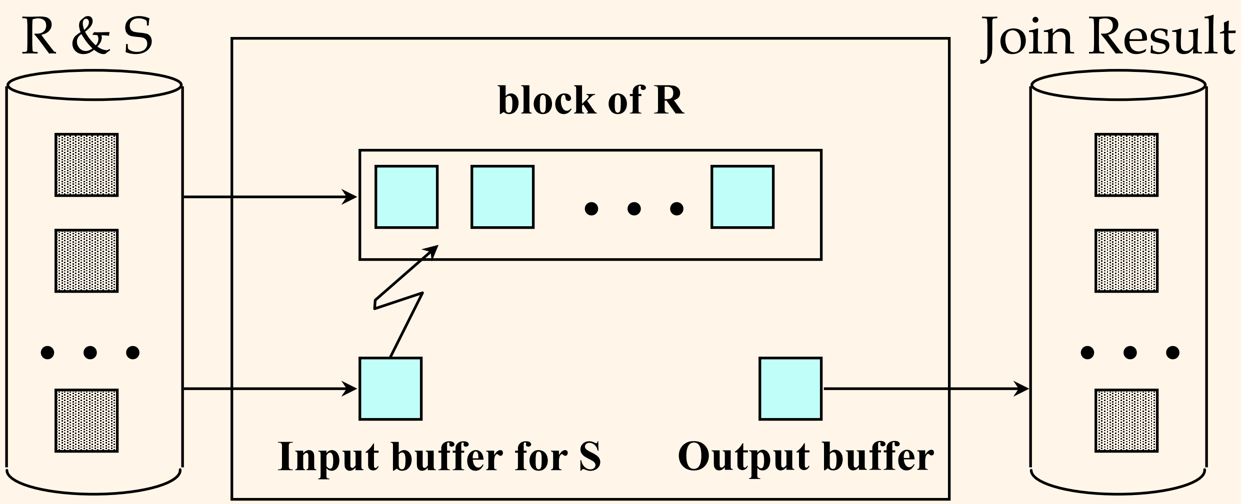
Block Nested Loops Join

- 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.



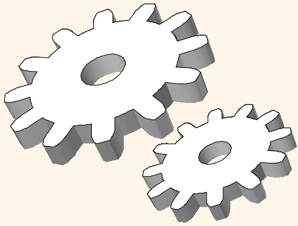
Block Nested Loops Join

- R is scanned once, cost = M pages
- Each block has size B-2 (B is # of buffer pages), so need to read S a total of ceiling(M/[B-2]) times
- Total cost: M + N * ceiling(M/[B-2])



Examples of Block Nested Loops

- Cost: Scan of outer + #outer blocks * scan of inner
  - #outer blocks = $\left\lceil \# \textit{ of pages of outer} / \textit{blocksize} \right\rceil$
- 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.



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.)

Example of Sort-Merge Join

<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

<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

Example of Sort-Merge Join

sid	sname	rating	age
22	dustin	7	45.0
28	yuppy	9	35.0
31	lubber	8	55.5
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31	101	10/11/96	lubber
58	103	11/12/96	dustin

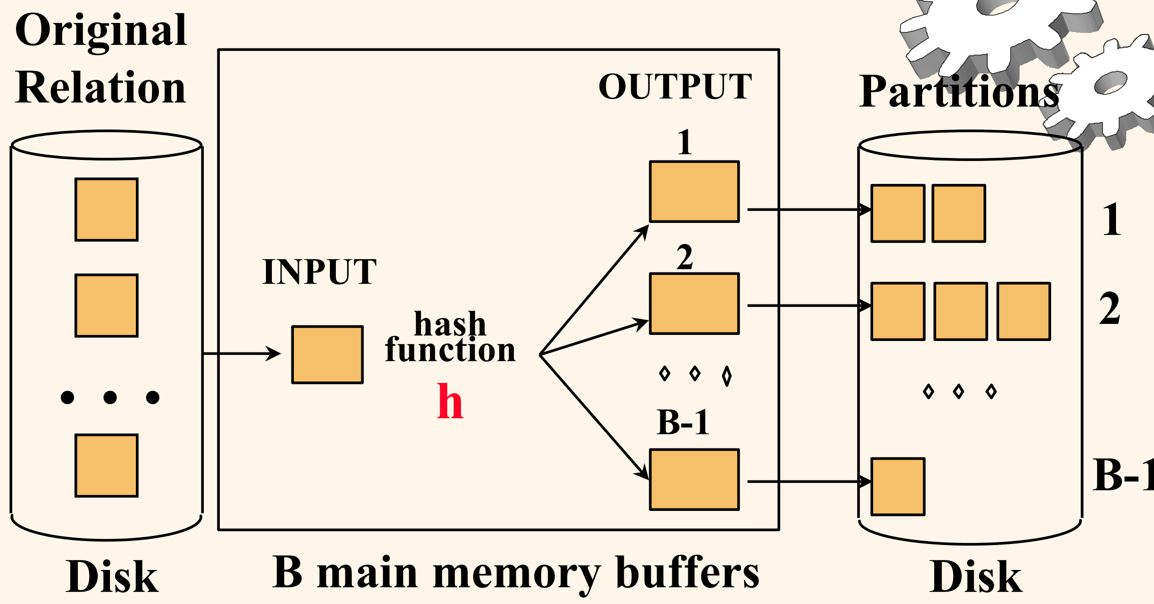
- Cost: M log M + N log N + (M+N) [this is incorrect!]
  - The cost of scanning, M+N, could be M*N (very unlikely!)

Cost of Sort-Merge Join

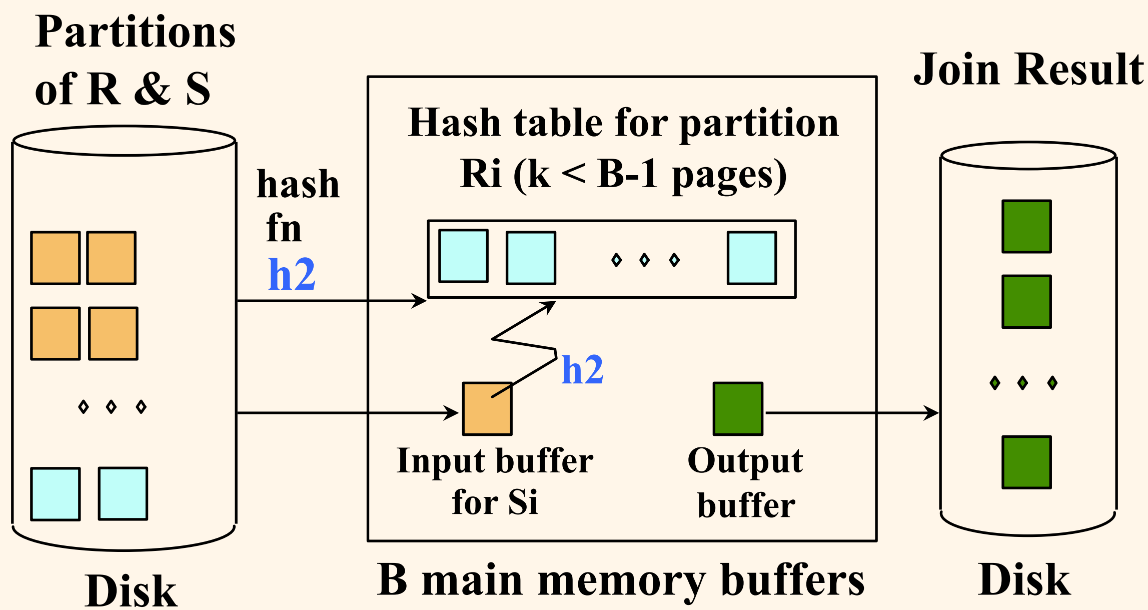
- Start by sorting both R and S on the join attribute:
  - Assumption: $M <= B^2$, $N <= B^2$
  - Cost: 4M + 4N
- Read both relations in sorted order, match tuples
  - Typical cost: M + N (but can be as high as M*N)
- Difficulty: many tuples in R may match many in S
  - If at least one set of tuples fits in memory, we are OK
  - Otherwise need nested loop, higher cost
- Total cost: 5M + 5N

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.



Observations on Hash-Join

- #partitions k < B-1 (why?), and B-2 > 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.

Index Nested Loops Join

foreach tuple r in R do
  foreach tuple s in S where $r_i == s_j$ do
    add <r, s> 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: $M + ((M*p_R) *$ 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.

General Join Conditions [See Textbook]

- 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.

Key Things to Remember

- Joins are very common, and very expensive
- Need to bring similar tuples together
- Can do this in a few ways
  - sort
  - hash
  - using an index
  - or just enumerate all pairs (nested loop joins)