Query Processing and Advanced Queries

Query Optimization (3)

Nested-Loop Joins

- We now consider algorithms for the join operator.
- The simplest one is the nested-loop join, a one-and-a-half pass algorithm.
- One table is read once, the other one multiple times.
- It is not necessary that one relation fits in main memory.
- Perform the join through two nested loops over the two input relations.

Nested-Loop Joins

- *Tuple-based nested-loop join*
  natural join R $\bowtie$ S, join attribute C

  for each r $\in$ R do
  for each s $\in$ S do
  if r.C = s.C then output (r,s)

- *Outer relation* R, *inner relation* S.
- One buffer for outer relation, one buffer for inner relation.
- M = 2.
- I/O cost is T(R) x T(S).

Nested-Loop Joins

- Example
- Relations not clustered
- T(R1) = 10,000 T(R2) = 5,000
- R1 as the outer relation
- Cost for each R1 tuple t1:

  read tuple t1 + read relation R2
- Total I/O cost is 10,000 (1+5,000)=50,010,000

Nested-Loop Joins

- Can do much better by organizing access to both relations by blocks.
- Use as much buffer space as possible (M-1) to store tuples of the outer relation.
- *Block-based nested-loop join*

```
for each chunk of M-1 blocks of R do
    read these blocks into the buffer;
    for each block b of S do
        read b into the buffer;
        for each tuple t of b do
            find the tuples of R that join
            with t and output the join results
```

Nested-Loop Joins

- Example
- R1 as the outer relation
- T(R1) = 10,000,   T(R2) = 5,000
- S(R1) = S(R2) = 1/10 block (each block 10 tuples)
- M = 101,   100 buffers for R1, 1 buffer for R2
- 10 R1 chunks
- cost for each R1 chunk:
  read chunk: 1,000 IOs
  read R2:   5,000 IOs
- total I/O cost is 10 x 6,000 = 60,000 IOs

Nested-Loop Joins

- Can do even better by reversing the join order.

  R2 $\bowtie$ R1
- T(R1) = 10,000, T(R2) = 5,000

  S(R1) = S(R2) = 1/10 block (each block 10 tuples)

  M = 101, 100 buffers for R2, 1 buffer for R1
- 5 R2 chunks
- cost for each R2 chunk:

  read chunk: 1,000 IOs

  read R1: 10,000 IOs
- total I/O cost is 5 x 11,000 = 55,000 IOs

Nested-Loop Joins

- Finally, performance is dramatically improved when input relations are clustered (read by block).
- With clustered relations, for each R2 chunk:

  read chunk: 100 IOs

  read R1: 1,000 IOs
- Total I/O is 5 x 1,100 = 5,500 IOs.
- Note that the IO cost for a one-pass join (which has the minimum IO of any join algorithm) in this example is 1,000 + 500 = 1,500 IOs.
- For a comparison, the one-pass join requires M=501 buffer blocks, which is optimal.

Back

Two-Pass Algorithms Based on Sorting

- If the input relations are sorted, the efficiency of duplicate elimination, set-theoretic operations and join can be greatly improved.
- Reserve one buffer for each of the input relations R and S and another buffer for the output.
- Scan both relations simultaneously in sort order, merging matching tuples.
- For example, for set intersection: repeatedly consider the tuple t that is least in the sort order (w.r.t. primary key) among all tuples in the input buffer. If it appears in both R and S, output t.

Two-Pass Algorithms Based on Sorting

- In the following, we present a simple *sort-merge join* algorithm.
- It is called *merge-join*, if step (1) can be skipped, since the input relations R1 and R2 are already sorted.

Sort-merge join

(1) if R1 and R2 not sorted, sort them

(2) $i \leftarrow 1$; $j \leftarrow 1$;

while $(i \leq T(R1)) \land (j \leq T(R2))$ do

if R1{ i }.C = R2{ j }.C then outputTuples

else if R1{ i }.C > R2{ j }.C then $j \leftarrow j+1$

else if R1{ i }.C < R2{ j }.C then $i \leftarrow i+1$

Two-Pass Algorithms Based on Sorting

- Procedure outputTuples produces all pairs of tuples from R1 and R2 with C = R1{ i }.C = R2{ j }.C.
- In the worst case, need to match each pairs of tuples from R1 and R2 (nested-loop join).

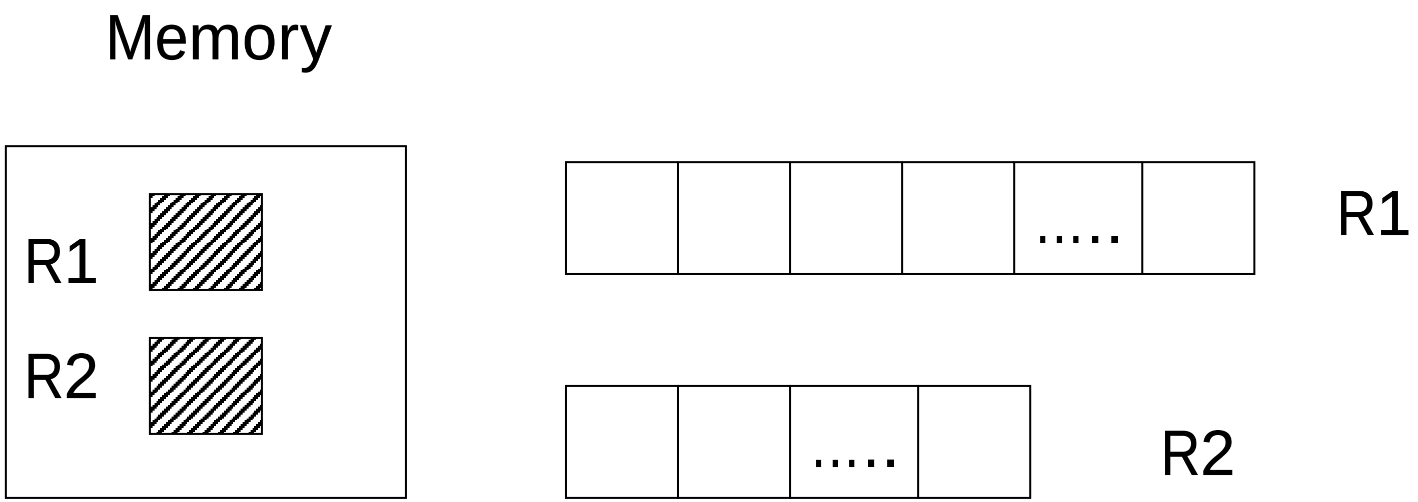
```
Procedure outputTuples
   While (R1{ i }.C = R2{ j }.C) ∧ (i ≤ T(R1)) do
      [jj ← j;
      while (R1{ i }.C = R2{ jj }.C) ∧ (jj ≤ T(R2)) do
                  [output pair R1{ i }, R2{ jj };
                   jj ← jj+1  ]
      i ← i+1  ]
```

Example

i	R1{i}.C	R2{j}.C	j
1	10	5	1
2	20	20	2
3	20	20	3
4	30	30	4
5	40	30	5
		50	6
		52	7

Two-Pass Algorithms Based on Sorting

- Example
- Both R1, R2 *ordered* by C; relations clustered.

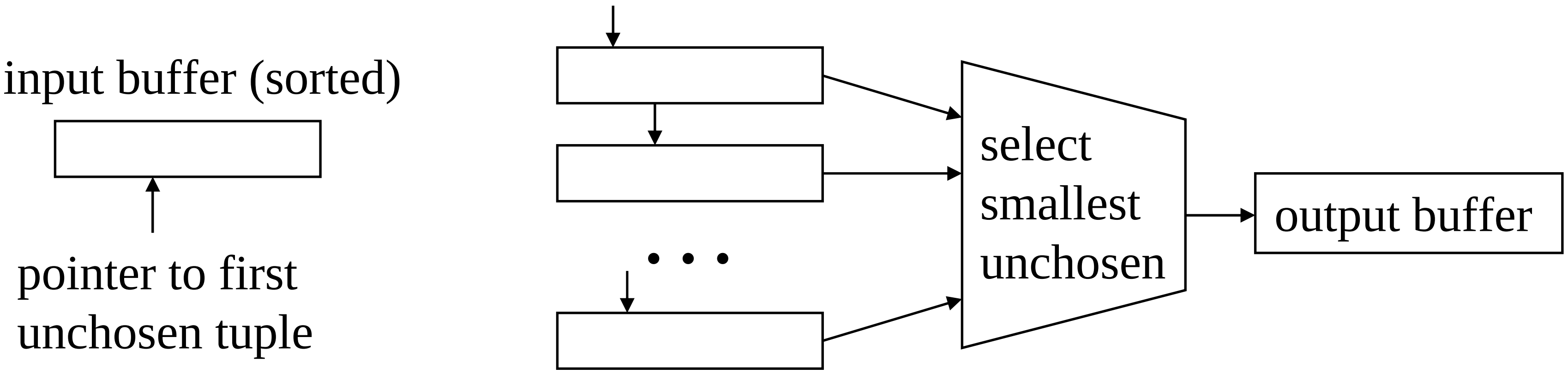


Total cost: read R1 cost + read R2 cost

= 1,000 + 500 = 1,500 IOs

Two-Pass Algorithms Based on Sorting

- What if input relations are not yet in the required sort order?
- Do *Two-Phase, Multiway Merge-Sort* (2PMMS).
- Phase 1: Sort each block of relation R separately in main memory, write sorted sublists back to disk.
- Phase 2: Merge all the B(R) sorted sublists.



Two-Pass Algorithms Based on Sorting

- Each sorted sublist has a length of M blocks.
- Number of sublists is B(R)/M.
- Therefore, $B(R)/M \le M - 1$, i.e. $B(R) \le M^2 - M \le M^2$.

  This means we require $M \ge \sqrt{B(R)}$.
- In phase 1, each tuple is read and written once. In phase 2, each tuple is read again. We ignore the cost of writing the results to disk.
- Thus, the IO cost is 3B(R).

Two-Pass Algorithms Based on Sorting

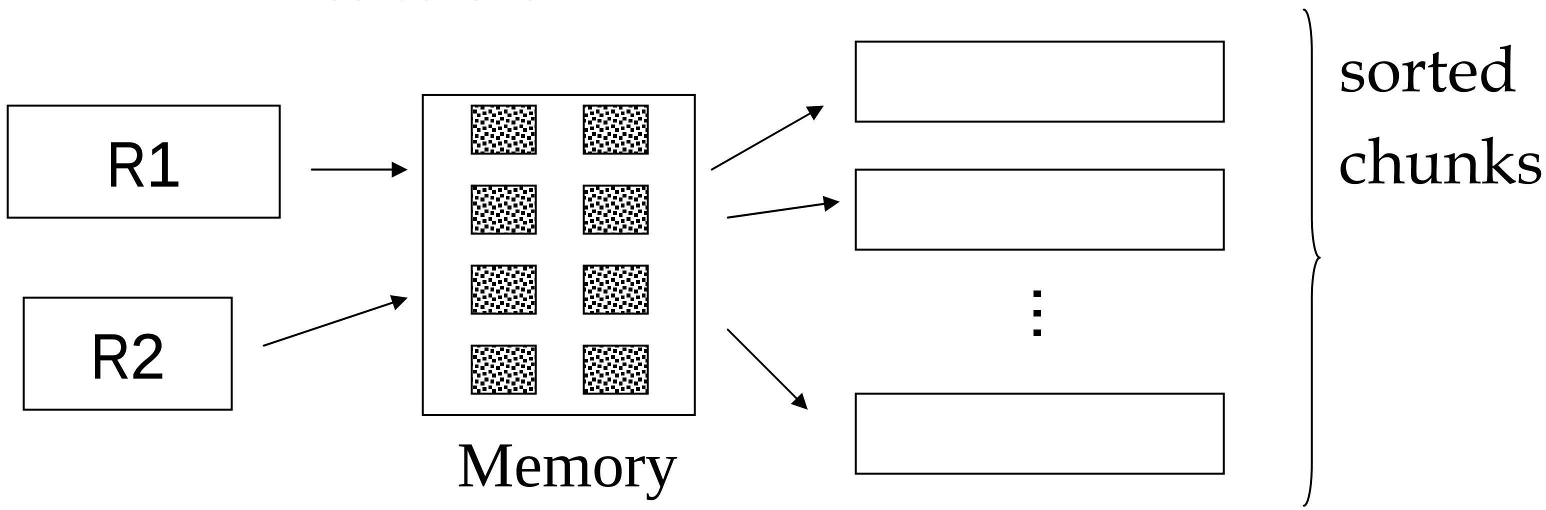
- IO cost is 4B(R), if sorting is used as a first step of sort-join and the results must be written to the disk.
- If relation R is too big, apply the idea recursively.
- Divide R into chunks of size M(M-1), use 2PMMS to sort each one, and take resulting sorted lists as input for a third (merge) phase.
- This leads to *Multi-Phase, Multiway Merge Sort*.

Two-Pass Algorithms Based on Sorting

- Example M=101

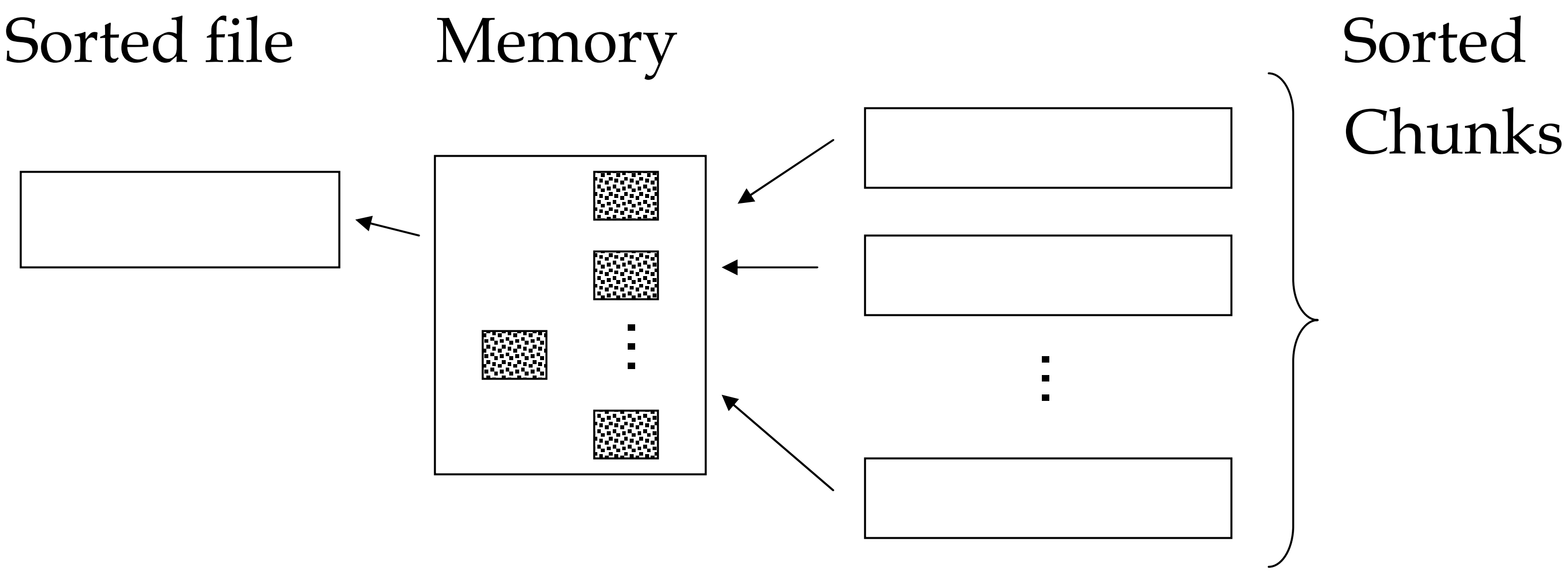
(i) For each 100 blk chunk of R:

- read chunk
- sort in memory
- write to disk



Two-Pass Algorithms Based on Sorting

(ii) Read all chunks + merge + write out



Two-Pass Algorithms Based on Sorting

Sort cost: each tuple is read, written,
read, written

Join cost: each tuple is read

Running Example:
T(R1) = 10,000
T(R2) = 5,000
S(R1) = S(R2) = 1/10 block
(each block 10 tuples)
M = 101
100 buffers for R2, 1 buffer for R1

Sort cost R1: 4 x 1,000 = 4,000

Sort cost R2: 4 x 500 = 2,000

Total cost = sort cost + join cost
= 6,000 + 1,500 = 7,500 IOs

Total IO Cost: 5(B(R1) + B(R2))

Two-Pass Algorithms Based on Sorting

- Nested loop join (best version discussed above) needs only 5,500 IOs, i.e. outperforms sort-join.
- However, the situation changes for the following scenario:

R1 = 10,000 blocks	clustered
R2 = 5,000 blocks	not ordered

- R1 is 10,000 blocks, sorting needs $M \geq 100$.
  R2 is 5,000 blocks, sorting needs $M \geq 70.7$.
  I.e., need at least M=71 buffers.

Two-Pass Algorithms Based on Sorting

- Nested-loops join:
  $\frac{5000}{100} \times (100+10{,}000) = 50 \times 10{,}100$ M=101
  $= 505{,}000$ IOs

- Sort-join:
  $5(10{,}000+5{,}000) = 75{,}000$ IOs

- Sort-join clearly outperforms nested-loop join!

Two-Pass Algorithms Based on Sorting

- Simple sort-join costs 5(B(R) + B(S)) IOs.
- It requires $M \geq \sqrt{B(R)}$ and $M \geq \sqrt{B(S)}$.
- It assumes that tuples with the same join attribute value fit in M blocks.
- If we do not have to worry about large numbers of tuples with the same join attribute value, then we can combine the second phase of the sort with the actual join (merge).
- We can save the writing to disk in the sort step and the reading in the merge step.

Two-Pass Algorithms Based on Sorting

- This algorithm is an advanced *sort-merge join*.
- Repeatedly find the least C-value c among the tuples in all input buffers.
- Instead of writing a sorted output buffer to disk, and reading it again later, identify all the tuples of both relations that have C=c.
- Cost is only 3(B(R) + B(S)) IOs.
- Since we have to simultaneously sort both input tables and keep them in memory, the memory requirements are getting larger:

$$M \geq \sqrt{B(R) + B(S)}.$$