Nested Loop Algorithms

II. Nested loop algorithms.

• Join

Nested-Loop joins

One-pass join algorithm can only be used if one of the the relations is small enough to fit in main memory.

If both relations are large, then, one pass will not be enough. However, we can devise algorithms that read one of the two relations only once. This family of algorithms is called Nested-Loop algorithms.

 Tuple-based Nested-Loop Join

Assume we are computing natural join $R(X,Y) \bowtie S(Y,Z)$. Tuple-based nested-loop join accesses relations in a tuple by tuple fashion, and for each pair of tuples checks if the join condition holds. It can be represented as follows:

Algorithm TupleJoin(R,S)

for each s in S do
  for each r in R do
    if (s.Y == r.Y) output (r.X,r.Y,s.Z);
  end Algorithm

We can build iterators based on tuple-based join.
Algorithm Open(R,S)
Open(S);
Open(R);
s: = GetNext(s); // set the first tuple from S
end Algorithm

Algorithm GetNext(R,S)

do
r:= GetNext(R);
if (NOT found) // if R is at the end, advance the tuple in S
{ Close(R);
s:= GetNext(S);
if (NOT found) return; // if at the end of S, return
Open(R); // restart R for the new tuple from S
}
while (s.Y != r.Y);
return (r.X, r.Y, s.Z); // return the next joined tuple
end Algorithm

Algorithm Close(R,S)
Close(R);
Close(S);
end Algorithm

Block Nested-Loop Join

Tuple-based nested-loop join “pretends” to load tuples one-by-one into main memory. If it is allowed to proceed this way, its cost is $O(T(R) \cdot T(S))$ — very high.

Block Nested-Loop Join reads data in blocks to fill as much main memory as possible. This allows for computations of large portions of the final join without any extra I/O manipulation.

Let us assume that $B(R) > B(S) > M$, i.e., neither $R$ nor $S$ fits main memory. The block nested-loop join approach is as follows:

- Break $S$ into “chunks” of size $M - 1$ each\(^1\).
- organize the algorithm as a nested loop.
- The outer loop loads the next chunk from $S$ into main memory.
- The inner loop scans $R$ and joins tuples from $R$ with tuples from $S$.

\(^1\)The last chunk may have a smaller size.
The pseudocode for this algorithm is below.

**Algorithm BlockNestedLoopJoin(R,S)**

```plaintext
NumChunks := (B(S) div (M-1)) + 1; // compute the number of chunks
for i = 1 to NumChunks do
    read M-1 blocks of S into buffer; // load next chunk of S
    index these blocks on S.Y; // index it
for j = 1 to B(R) do // read next block from R
    read block Block_j from R;
    for each tuple r in Block_j do
        for each tuple s in main memory, s.t. s.Y == r.Y do // use indexing to find
            output (r.X, r.Y, s.Z); // these tuples
    end for;
end for;
end Algorithm
```

**Evaluation**

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>TupleJoin</th>
<th>BlockNestedLoopsJoin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constraints</td>
<td>NONE!</td>
<td></td>
</tr>
<tr>
<td>I/O Cost</td>
<td>T(R)·T(S)</td>
<td>O(B(S)·B(R) / M)</td>
</tr>
<tr>
<td>Memory Footprint</td>
<td>O(1)</td>
<td>M</td>
</tr>
</tbody>
</table>

**Notes.** For the tuple nested-loop join, we provide the worst-case estimate. For the block nested-loop join, the actual estimate of I/O costs is $B(S) + \frac{B(S)·B(R)}{M-1}$. This formula explains why the smaller relation should be in the *outer loop*.