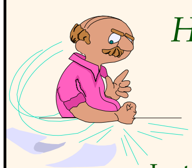

Hash Join Algorithms

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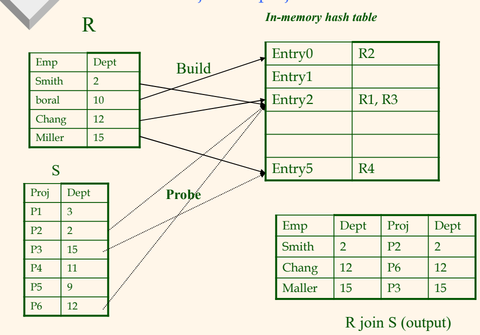
Hash-Join Algorithms

- In-memory Hash join
  - When you can hold one of the 2 relations in memory
- Simple hash-based join
  - Efficient when memory is large
  - Too many I/O operations when memory is small
- GRACE hash-based join
  - Separate partitioning and join phases
  - Easy to parallelize
  - Avoids bucket overflow
- Hybrid hash-based join
  - Combines Basic and Grace hash-join
  - Better memory usage

In-memory hash-join Algorithm

This is used for The map-side join. We are using the reduce-side join for project 3



Complexity

- Build phase
  - Read R once and construct in-memory hash table
  - I/Os: M (# of pages of R)
- Probe phase
  - Read all of S and search for matching tuples
  - I/Os: N (# of pages of S)
- Total Cost: O(M+N) if we have enough memory to hold one relation in memory
- How do you choose the relation for Build?
- How do you choose the relation for probe?
- What if we do not have enough memory?

Simple Hash Join algorithm

- Use whatever memory is available as buckets of one in-memory hash table and write the rest to disk
- Repeat this process until the entire join is performed
- Disadvantages: introduces too many I/O operations when the memory is not too large!
- Cost: O(b*(M+N)) where b is the number of buckets (range of hash function)!

Simple Hash Join Algorithm

```
            /* h is the hash function; h[0..n] is the range of hash function */
            /* R[0..n] and S[0..n] are buckets */
i=0; do
for ( each tuple r in R){
    if (h(r) in current_range)
            insert r into the in-memory hash table;
    else write r into R_temp;}
for (each tuple s in S){
    if (h(s) is in current_range{
            use s to probe the in-memory hash table;
            If (any match is found) output the matching tuples;
    else write s into S_temp; }
    R = R_temp;
    S = S_temp;
    current_range = h[i+1];
}
While (R_temp is not empty and S_temp is not empty);
```


Complexity

- Let size of R be M pages; size of S be N pages
- Let the hash function divide them uniformly into b buckets
- If you have b hash buckets for the simple hash join algorithms, then you need b* (M+N) I/O's (Try to derive this expression!)
- You read and write each relation b times!
- Typically, b ranges from 10 to 1024 or even larger
- How can we reduce it further?
- How many buffer pages do we need

GRACE Hash Join Algorithm

Partitioning phase

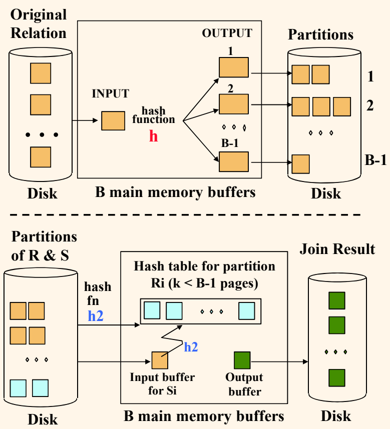
- Apply a hash function h(x) to the join attributes of the tuples in both R and S. Assume b buckets
- According to the hash value, each tuple is put into a corresponding bucket. Write these buckets to disk as separate files.

Joining phase:

- Use the basic hash-join algorithm
- Get one partition of R and the corresponding partition of S and apply the basic hash algorithm using a different hash function. Why?

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.



Grace Hash Join

- Range of H(x) is 1, …, N
- R1, …, Rn and S1, …, Sn are disjoint subsets of R and S
- R is the Union (R1, …, Rn) and S is the union(S1, …, Sn)
- We need to join only Ri with Si. Why?
- The efficiency comes from the reduction in work load which is illustrated below.

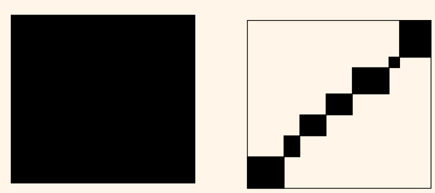
Grace Hash Join Algorithm

```
/* h[1..n]: range of hash function;  R[1..n] and S[1..n] are buckets */
for ( each tuple r in R){
    apply hash function to the join attributes of r;
    put r into the appropriate bucket R[i]}

for (each tuple s in S){
    apply hash function to the join attributes of s;
    put r into the appropriate bucket S[i]}

for (i=1; i <= n; i++){
    build the hash table for R[i]; /* using a different hash function  h2*/
    for (each tuple s in  S[i]){
          apply the hash function h2 to the join attributes of S;
          use s to probe the hash table;
          output any matches to the result relation;}
}
```


Workload in hash join



Nested loop join

Grace hash join

Observations on Hash-Join

- Given B buffer pages, the maximum # of partitions is B-1
- Assuming that partitions are of equal size, the size of each R partition is M/(B-1)
- The number of pages in the (in-memory) hash table built during the building phase is f*M/(B-1) where f is the fudge factor
- During the probing phase, in addition to the hash table for the R partition, we require a buffer page for scanning the S partition, and an output buffer.
- Therefore, we require B > f*M/(B-1) +2
- Approximately, we need B > $\sqrt{M}$ for the hash join algorithm to perform well.

Observations on Hash-Join

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 Grace Hash Join

- In partitioning phase,
  - read+write both relations; that is, 2(M+N).
  - In matching phase, read both relations; that is, M+N I/Os.
  - Total: 3*(M+N) linear instead of log or quadratic!
- In our running example, this is a total of 4500 I/Os.

Sort-merge join vs. Hash Join

- If partitions in hash join are not uniformly sized, hash join could cost more
- If the available number of buffers falls between $\sqrt{M}$ and $\sqrt{N}$, hash join costs less than sort-merge, since we need enough memory to hold partitions of the smaller relation. Sort-merge buffer needs are based on the larger relation.
- Hash Join is 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.

Hybrid Hash Join Algorithm

```
/* H[0..n] is the range of hash; R[0..n] and S[0..n] are buckets */
for ( each tuple in R){
    if (hash value of r is in H[0])
            insert r into the in-memory hash table;
    else   put r into the appropriate bucket R[i];}
for (each tuple s in S){
    if (hash value of s is in H[0]{
            use s to probe the hash table;
            put any matching tuples into the result relation;}
    else   put s into appropriate bucket S[i];}
for (i=1; i<=n; i++){
    build the hash table from R[i];
    for (each tuple s in S[i]){
            apply hash function to the join attributes of s;
            use s to probe the hash table;
            output any matches to the result  relation;}
}
```


Pointer Based Joins

1. Links represent a limited form of pre-computed results (OO has rekindled this concept)
2. Modeled as TID joins in Ingres
3. Shekita and Carey experiment – 3 pointer based join methods: Nested Loops, Merge-Join and Hybrid-Hash Join
   1. Tuples of R has a pointer to an embedded S tuple
      - Scan R and retrieve S
      - Sort R on the pointers (according to the disk address they point to) and then retrieve all S items in one elevator pass over the disk, reading S page at most once

Pointer based Joins(contd)

- Hybrid-hash join: Partitions relation R on the pointer values ensuring that R tuples with S pointers to the same page are bought together, and then retrieve S pages and tuples

- Direction of pointers fix the role of relations! (usually, the smaller relation is used for the build phase)
- Maintenance effort is to be taken into account as well.

Alternative Join methods

- S is 10 times R, Memory size 100Kb
- Cluster Size is 8Kb, Merge fan-in and partitioning fan-out are 10, # of R records/cluster is 20

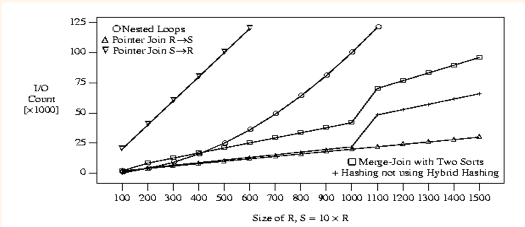


Figure 16. Performance of Alternative Join Methods.

Conclusions

- Nested Loop joins are unsuitable for medium size and large relations
- sort based join is not as fast as hash join (merge levels are determined individually for each file, but only the smaller relation determines partition depth)
- The step is because additional partitioning or merge levels become necessary at that point

Aggregation and Duplicate Removal

- Surprisingly, a lot in common
- In one, duplicates are discarded whereas in the other, some computation (e.g., COUNT, SUM, AVG) is performed before discarding the tuple

Aggregation and Duplicate Removal

- Scalar aggregates compute a single scalar value; from a unary input relation (count of all employees)
  - requires only one pass over data set
  - indices can be exploited where possible (for max, min, count)
- Aggregate functions determine a set of values from a binary input relation; e.g., sum of salaries for each department
- The result is a relation (closure property)

"Duality" of Sorting and Hashing

- Both do approx the same amount of I/O
- Mirror-images in terms of sequentiality of phase 2
- Sort-based algorithms
  - Large data sets are divided into subsets using physical rule (into chunks as large as memory)
- Hash-based algorithms
  - Large data sets are divided into subsets using a logical rule (hash values)
- Handling large inputs
  - Multi-pass sort vs. recursive partitioning hash
- It actually goes deeper than this