COSC-4411: Assignment #3 & #4

Due: Friday 26 November 2004

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1. (5 points) **External Sorting.** *A better sort of sort?*

   Dr. Datta Bas has developed an "improved" version of the standard external sort routine. External sorting is usually quite efficient as few passes over the records are required. However, when the buffer pool is small and/or the file to sort is huge, a more significant number of passes may be needed, requiring a read and write of every page every pass.

   Dr. Bas has made the observation that we might improve performance as follows: we do not need to keep *all* the fields of the records during the sort, but just the fields that are part of the sort key (and the *rid*)!

   For Dr. Bas's external sort routine, pass 0 (the initial sorting pass) and the final (merge) pass are modified. Pass 0 is modified to "project" the records, removing the unneeded fields. The final (merge) pass—call it pass f—is modified to "join" back the removed fields. Merge passes $1 \ldots f-1$ proceed just as in the regular external sort routine. The only difference is that the number of pages in the "file" for these runs is much smaller because we have removed the fields unneeded for the sorting.

   Assume the buffer pool allocation is B. Pass 0 uses one buffer frame as *input* to read sequentially each page of the file to sort. It projects each record in the input frame to a record with just *search key* + *page#* + *slot#* and places it sequentially in the array of the remaining $B-1$ frames. The *page#* + *slot#* here represent the record's *rid* in the original file. When the $B-1$ frames allocated for sorting become full, the projected records are then sorted, and written out as a $B-1$ page sorted run.

   Pass f must have only $B-2$ runs remaining to merge. One frame is reserved for *output* as before. $B-2$ frames are used as input to merge the (potentially) $B-2$ runs. The last frame is reserved to be used to fetch the page with the original record (from the original file) for each projected record in the merge stream, in order to retrieve the missing fields and add them back. (Recall that each projected record includes the *rid* of the original record for this purpose.)

   Assume that you have file **F** to sort. File **F** is 400 pages and 5 records fit per page. The "projected" records for Dr. Bas's routine fit 50 records to a page, so after pass 0 of his routine, the "file" fits in 40 pages. Your buffer pool allocation (B) for the sort is 6 frames.

   a. (2 points) First, calculate the I/O cost of sorting **F** using the basic external sort routine. (Assume that pass 0 produces runs of size B, so 6 in this case.)

- ***Pass 0**: 67 runs of length 6 in each case (except last run at length 4)*
- ***Pass 1**: 14 runs via 5-way merges*
- ***Pass 2**: 3 runs via 5-way merges*
- ***Pass 3**: 1 runs via one 3-way merges*

So $4 \cdot 2 \cdot 400 = 3200$.

b. (2 points) Now calculate the I/O cost of sorting **F** using Dr. Bas's external sort routine. (Note that Bas's pass 0 produces runs of size $B - 1$, so 5 in this case.)

- ***Pass 0**: 8 runs of length 5 in each case of projected records. 400 pages read, 40 written, for 440 I/O's.*
- ***Pass 1**: 2 runs via 5-way merges, one of length 25, the other of 15.* $40+40 =$ 80 *I/O's.*
- ***Pass f**: one run. Each record fetched at an I/O each, for 2,000 I/O's. 40 pages read, 400 written, for 440 I/O's.*

Total: 2,960 I/O's. Okay, saves a little.

c. (1 point) Under what conditions, if any, is Dr. Bas's sort routine advantageous? If none, briefly explain why not.

May help if the records are huge and few pack per page, and the sort will take more than a couple of passes.
This is an unusual case though. Usually there are many more than 5 records per page, and we have enough BP allocation to sort in a couple of passes. So generally, Dr. Bas's technique will not help.

2. (5 points) **Few Sort.** *The few, the proud, the sort routine.*

   Dr. Bas has noted that for many queries for which the query optimizer uses sorting in the query plan the input table is large, but the number of distinct values over the sort key is small.

   For instance, consider that table **T** has one million records (10^6) over 10,000 pages, we want to sort it on **T**.A, but there are only 70 distinct values of A in **T**. Given eleven buffer frames for the job, running the basic external sort routine on it would take four passes.

   Describe an external sorting routine, *few sort*, that could sort a large table with few distinct values more efficiently than the regular external sort. You can assume you have some auxiliary memory (in main memory) beyond the buffer pool for bookkeeping purposes.

   Cost out how expensive your routine would be sorting **T** given eleven buffer frames.

   The idea is that we want to partition the data so that each partition contains the records for a single value of A.
   We can partition like in HJ: one frame for input and $B-1$ (10) buckets for partitioning. Scan **T**. *The first value of A we see, we assign to bucket 0; the second, to bucket 1; etc. When we see the Bth A value, it is also assigned to bucket 0, etc. We keep track of which A's are assigned to which buckets via a main-memory hash. Each record is written to the bucket its A is assigned.*
   We also keep track (in main-memory) of how many A's are assigned to a given partition run.
   At the end of pass 0, we have 10 partition runs. Each contains records of just 7 different A values.
   In pass 1, we repartition each of these. Since we have ten buckets, the resulting partitions will just have a single A value each.
   We have tracked in main-memory which A values are attached to which partition runs. We sort in main-memory the A's. Now is it simply bookkeeping by the file manager to append the partition runs in the right order. This can be done really without reading them.
   So we effectively sorted in two passes, for 40,000 I/O's. Regular external sort would have required 4 passes here at twice the cost.

3. (5 points) **Sorting.** *Over doing it.*

   We want to re-implement the sort-merge join algorithm to handle *over-sorting*.

   Consider table **R** with attributes A and B, table **S** with attributes B and C, and **R** $\bowtie_{\mathsf{B}}$ **S**. Normally for the sort-merge join, both **R** and **S** would be sorted on B. However, we could sort **R** on B, A—a nested sort over both attributes, as in order by B, A—and the merge could still work.

   Call this *over-sorting* when we sort one or the other table, or both, on more attributes than just the join attributes.

   What changes would need to be made to the basic sort-merge join algorithm to accommodate *over-sorting*, and what restrictions, if any, would we need to place on what *over-sorting* is permitted?

Would a sort-merge join implementation that accommodates *over-sorting* be potentially useful? Why or why not?

There is no problem that the outer and inner streams are sorted with respect to more fields for the SMJ. It works the same. The question is whether the over-sorted order will be maintained by the SMJ.
In this case, if **R** *is the outer, yes. If* **S** *is the outer instead, then not necessarily, If B is not unique in* **S**. *This is because of how the inner-stream is buffered to account for possible multiple matches with the outer.*
*There is no easy way to change the SMJ routine to avoid the non-working case. We can place the restriction that the table owning the extra columns being added to the sort (*R*'s* **A** *in this case) is made the outer. Or if the table not owning the extra columns (*S*) is unique on the join key (B), there are no restrictions.*
Note that if we want to oversort but with extra columns coming from both *tables, life is yet more difficult! How?*

4. (5 points) **Evaluating the relational operators.**
Selecting the join and joining the Selection.

Consider tables **R** with attributes A and B and **S** with attributes B and C. Column B is unique in **S**. Values of B in **R** are the same as the values of B in **S**. Assume that there are no indexes available.

Consider the sort-merge join to be the efficient *two-pass* version discussed in the textbook (in which the sort-merge's merge steps are integrated with the external sort's merge steps) and not the more general version. (In the more general version, the external sort is *entirely* done before the merge-join. Furthermore, assume that the sort-merge join algorithm produces runs of length $2B$ in "pass 0" of sorting.) Consider that there may be problems with skew.

For each of the following, choose which of the following join algorithms is likely to be best. In each case, there are 250 buffer frames allocated for the join.

A. A block nested loops join with **R** as the outer and with **S** as the inner.
B. A block nested loops join with **S** as the outer and with **R** as the inner.
C. A (2-pass) sort-merge join with **R** as the outer and with **S** as the inner.
D. A (2-pass) sort-merge join with **S** as the outer and with **R** as the inner.
E. A hash join with **R** as the outer and with **S** as the inner.
F. A hash join with **S** as the outer and with **R** as the inner.

Table **R** is 3,000,000 pages with 80 records a page, and table **S** is 40,000 pages with 100 records a page. Which would be the most cost effective method to evaluate $\mathbf{R} \bowtie_{\mathsf{B}} \mathbf{S}$?

> *The SMJ's cannot be done. We don't have the BP allocation. Either BNL will be too expensive: each is a little more than* $3,000,000 \cdot 4,000$ *I/O's.*
> *So that leaves the HJ's. We do have the BP allocation for that. Either costs* $3 \cdot (3,000,000 + 4,000) = 9,012,000$ *I/O's But which one?* **S** *has to be the outer for the partitions to fit in the BP on the second pass. So* ***F****.*

5. (5 points) **Reduction Factors and Access Paths.** *The path less worn.*

Consider table **T** with attributes A, B, C, D, & E. Table **T** has 1,000,000 records and **T** has no key.

- Column A has 10 values, $1 \ldots 10$.
- Column B has 100 values, $1 \ldots 100$.
- Column C has 1,000 values, $1 \ldots 1,000$.
- Column D has 10,000 values, $1 \ldots 10,000$.
- Column E has 100,000 values, $1 \ldots 100,000$.

Assume independence of the attributes, and a uniform distribution for each.

The following are possible indexes for **T**.

1) B+ tree unclustered index on D + C + B.

2) B+ tree clustered index on D + B + C.
3) B+ tree clustered index on C + A + B + D.
4) hash unclustered index on A + B + D + E.
5) hash clustered index on A + B + E.
6) hash clustered index on D + A + B + E.

Assume that the depth of each B+ tree above is four: so it costs four I/O's from the root to the *data entry* page. Assume the hash indexes are extendible hashes, so one I/O to get the directory page and one I/O to get the data entry page, so two I/O's.

We are interested to retrieve records from **T** that satisfy

where A = 7 and B = 53 and D <= 1,000 and E >= 40,000 and E <= 41,000

Estimate how many records will be retrieved.

Which index provides the best access path? What is its I/O cost?

Assuming that many tuples are returned, which index provides the best access path *and* preserves an *interesting order* on D? What is its I/O cost?

We estimate 1 record will be returned!
None of the hash indexes can be applied. Each has a key that covers one of the range conditions.
3) is not applicable because there is no condition on C.
1) and 2) can only match on D, as this is a range condition. The conditions on B and C cannot help here. So they both fetch the same records, and $\frac{1{,}000}{10{,}000} = \frac{1}{10}$ *of them. 2) clearly beats 1) since it is clustered.*
2)'s cost? Reading the depth of the index: guessing 2 index pages, and a DE page (so alt#2). Then reading $\frac{1}{10}$ *of the number of data-record pages of* **T**. *If 300 records per page,* **T** *has 3,334 pages, so we read 334 of them. So 337 I/O's?*

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6. (5 points) **Query Planning.** *Yo! Optimize this!*

Consider the schema

Sailors(sid, sname, rating, age)
Reserves(sid, bid, day, ...)
FK (sid) refs **Sailors**
FK (bid) refs **Boats**
Boats(bid, bname, color, size, maint)
FK (maint) refs **Sailors** (sid)

This is the same as the textbook's usual "Yacht Club" database, but with one addition: there is a foreign key from **Boats** referencing **Sailors** to indicate which sailor is in charge of maintaining that boat.

The underlined attributes indicate the primary key for each table, and the FK's the foreign keys. Assume no columns are nullable.

The following catalog information is available.

- **Sailors**: 1000 records on 50 pages
  - **Sailors**.rating: 10 values (1..10)
- **Reserves**: 10,000 records on 250 pages
  - **Reserves**.bid: 100 values
  - **Reserves**.day: 500 values
- **Boat** has 100 records on 10 pages.
  - **Boat**.size: 10 values (3..12 meters)

Available indexes are as follows. Each follows alternative #2, with data entries.

- A unique, hash index on sid for **Sailors** (10 data-entry pages / buckets). Assume this is a linear hash.
- A unique, hash index on bid for **Boat** (2 data-entry pages / buckets). Assume this is a linear hash.
- A unique, clustered B+ tree index on sid + bid + day (in that order) for **Reserves** (75 data-entry pages / leaves). Assume two levels of index pages. At level three are the data entry pages.
- An unclustered hash index on day for **Reserves** (25 data-entry pages / buckets). Assume this is a linear hash.

Consider the following query.

```
select S.sid, S.sname, B.bname, R.day
    from Sailor S, Reserves R, Boat B
    where S.sid = R.sid and R.bid = B.bid and
          B.maint = S.sid;
```

a. (1 point) Using the assumptions of uniform distributions and column independence that System R—the type of optimizer the textbook presents—makes, estimate how many tuples this query returns.

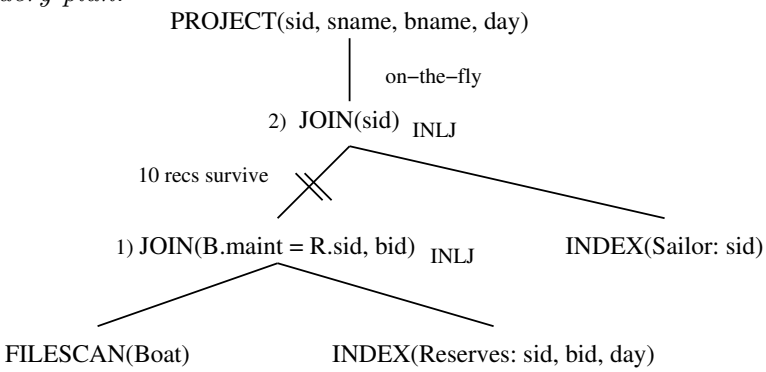
Since there is a foreign key from **R** *to* **S** *and a foreign key from* **R** *to* **B** *(and the joins are over the FKs), we can start our estimate with* $|\mathbf{R}|$*, or 10,000.*
Any reduction factors? Yes. Any boat has some maintainer. So a reservation involves one maintainer. The chance that that maintainer matches the reserver (sailor)? There are 1,000 possible reservers, so $\frac{1}{1000}$*. So* $10,000 \cdot \frac{1}{1000} = 10$*.*
Works out perfectly well too if we do it longhand starting with $1000 \cdot 10,000 \cdot 100$ *and apply the three reduction factors.*

b. (4 points) Design a query plan that System R might find. (So do not do anything outside of System R's search space. You do not have to mimic System R's steps, but you should stay within the plan space it explores.)

Ideally, your query plan's estimated cost should be under 300 I/O's. The query plan has 10 buffer-pool frames available.

In your answer, show your query plan clearly as an annotated tree (as in the textbook examples). Calculate the cost estimation of your query step-by-step clearly.

Here is one query plan.



$\bowtie_1$ *There are 100 probes, one for each boat record. Each probe: 2 index pages, 1 DE page. 10% of the time, there is a matching data entry, so we fetch the DR page. So 310 I/O's. But we can assume the root index page is in the BP across all probes. So 211 I/O's.*
It cost 10 I/O's to read **Boat**. *Total: 221 I/O's.*

$\bowtie_2$ *Only 10 records are estimated to survive* $\bowtie_1$. *Probe* **Sailor** *10 times. Is a hash index, so estimate* 2.2 *I/O's per, for 22 I/O's.*

Total: 243 I/O's.