COMP 3311
DATABASE MANAGEMENT SYSTEMS

TUTORIAL 9
QUERY OPTIMIZATION

COST ESTIMATION INFORMATION

- The DBMS system catalog stores statistics for each relation r:

  n_r the number of tuples in r.

  B_r the number of pages containing tuples of r.

  l_r the size of a tuple of r in bytes.

  bf_r the blocking factor of r (i.e., the number of tuples of r that fit into one disk page).

  HT_i the number of levels in the index i (i.e., the height of i).

  - For a B$^+$-tree index on attribute A of relation r, $HT_i = \lceil \log_{fi}(V(A, r)) \rceil$.
  - For a hash index, HT_i is 1 (or 1.2 if there are overflow buckets).

  $V(A, r)$ the number of distinct values that appear in r for attribute A.

  - Equivalent to $\pi_A(r)$.

  ☞ If tuples of r are stored together physically in a file, then

  $$B_r = \lceil n_r / bf_r \rceil.$$

SELECTION CARDINALITY: REVIEW

$SC(\theta, r)$, the selection cardinality of predicate θ for relation r, is the *average number of tuples that satisfy the predicate* θ.

Selectivity(θ, r) = $SC(\theta, r) / n_r$ (i.e., the fraction of tuples that satisfy θ)

Equality selection: $\sigma_{A=v}(r)$

$SC(A=v, r) = n_r / V(A, r) \Longrightarrow$ number of r tuples / number of distinct A values

Selectivity($A=v$, r) = 1 / $V(A, r) \Longrightarrow$ 1 / number of distinct A values

Range selection: $\sigma_{A \leq v}(r)$

$SC(A \leq v, r) = 0$ if $v < \min(A, r)$ (since no tuples will qualify)

$SC(A \leq v, r) = n_r$ if $v \geq \max(A, r)$ (since all tuples will qualify)

$SC(A \leq v, r) = n_r * \frac{v - \min(A,r)}{\max(A,r) - \min(A,r)}$ (assumes uniform distribution of tuples over the values)

SELECTION CARDINALITY: REVIEW

Conjunction: $\sigma_{\theta 1 \wedge \theta 2 \wedge \ldots \wedge \theta n}(r)$

$$SC(\sigma_{\theta 1 \wedge \theta 2 \wedge \ldots \wedge \theta n}, r) = n_r * \frac{s_1}{n_r} * \frac{s_2}{n_r} * \cdots * \frac{s_n}{n_r} = n_r * \frac{s_1 * s_2 * \cdots * s_n}{n_r^n}$$

Disjunction: $\sigma_{\theta 1 \vee \theta 2 \vee \ldots \vee \theta n}(r)$

$$SC(\sigma_{\theta 1 \vee \theta 2 \vee \ldots \vee \theta n}, r) = n_r * (1 - (1 - \frac{s_1}{n_r}) * (1 - \frac{s_2}{n_r}) * \ldots * (1 - \frac{s_n}{n_r}))$$

Projection: $SC(\pi_A(r)) = V(A, r)$

Aggregation: SC(group-by A) $= V(A, r)$

Set Operations

$SC(r \cup s)$ = size of r + size of s

$SC(r \cap s)$ = minimum (size of r , size of s)

$SC(r - s) = r$

SELECTION CARDINALITY: REVIEW

Join: $SC(r \bowtie s)$

If $r \cap s = \varnothing$ (no common attribute)

- same as $r \times s$

If $r \cap s = A$ is a key for r

- no greater than number of tuples in s

If $r \cap s = A$ is a (*not null*) foreign key *in* s referencing r

- same as the number of tuples in s

If $r \cap s = A$ is *not a key* for r or s

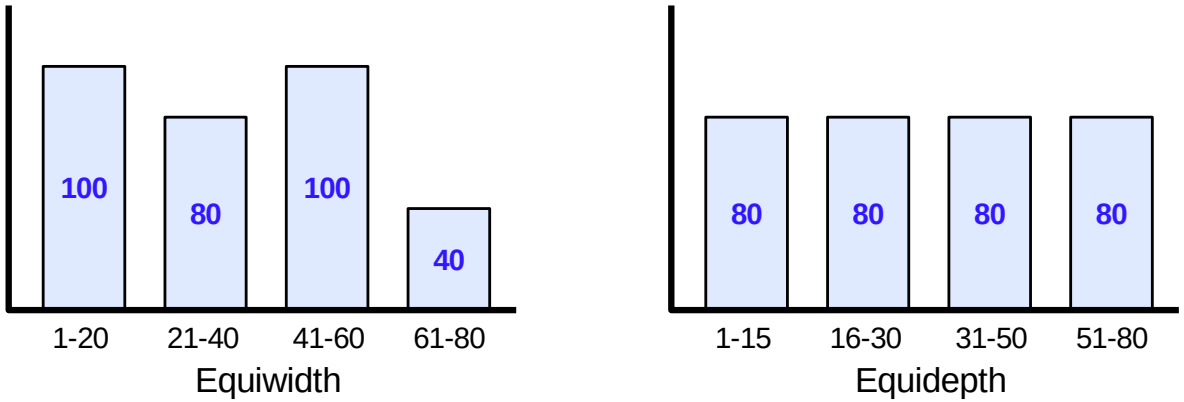
- $n_r * \frac{n_s}{V(A,s)}$ or $n_s * \frac{n_r}{V(A,r)}$ (select the lower estimate)

HISTOGRAM: REVIEW

- The previous estimates assume that each value of *A* has the same probability (i.e., that the values of *A* are uniformly distributed over the tuples).

  ☞ **The uniformity assumption rarely holds in practice.**

- A histogram assumes local uniformity within each partition (but not global uniformity).



The numbers in the bars indicate the total number of tuples that fall into that range.
For equiwidth, the ranges are the same, but each partition contains a different number of tuples.
For equidepth, each partition contains exactly 80 tuples, but the ranges are different for each bucket.

EXERCISE 1

Sailor(sailorId, sName, rating, age)	6,000 tuples	10 tuples/page
Reserves(*sailorId*, *boatId*, rDate)	1,500 tuples	15 tuples/page
Boat(boatId, bName, color)	3,000 tuples	20 tuples/page

There is no index on any relation. 15% of boats are red.

All foreign keys are not null.

a) Estimate the size of $\pi_{boatId}(\sigma_{color='red'}Boat)$.

b) Estimate the size of (Sailor Join Reserves Join Boat). Briefly explain the reason(s) for your answer.

c) Which of the following two join strategies is better? Briefly explain the reason(s) for your choice.

   i. (Sailor Join Boat) Join Reserves

   ii. (Sailor Join Reserves) Join Boat

EXERCISE 1 (cont'd)

Sailor tuples: 6,000
Reserves tuples: 1,500
Boat tuples: 3,000
bf_{Sailor}: 10 tuples/page
$bf_{Reserves}$: 15 tuples/page
bf_{Boat}: 20 tuples/page
15% red boats

a) Estimate the size of $\pi_{boatId}(\sigma_{color='red'}Boat)$.

Size of $\pi_{boatId}(\sigma_{color='red'}Boat)$: 15% * 3000 = 450 tuples

b) Estimate the size in tuples of (Sailor Join Reserves Join Boat). Briefly explain the reason(s) for your answer

Since sailorId in Reserves is a not null foreign key referencing Sailor, one tuple in Reserves will join with exactly one tuple in Sailor. Therefore, Sailor Join Reserves has exactly 1500 tuples.

Since boatId in Reserves is a not null foreign key referencing Boat, each tuple in the preceding intermediate result will join with exactly one tuple in Boat. Therefore, the final join also contains exactly 1500 tuples.

Size of the query result: 1500 tuples

EXERCISE 1 (cont'd)

Sailor tuples: 6,000
Reserves tuples: 1,500
Boat tuples: 3,000
bf_{Sailor}: 10 tuples/page
$bf_{Reserves}$: 15 tuples/page
bf_{Boat}: 20 tuples/page
15% red boats

c) i. Calculate the result size in tuples of the join order (Sailor JOIN Boat) JOIN Reserves

In this strategy, since there is no common attribute, Sailor JOIN Boat is equal to the cross-product of the two relations and the size of the join result is 6000 * 3000 = 18,000,000 tuples.

This intermediate result is very large and later, when joining this intermediate result with Reserves, the cost is also large to read all the tuples of the intermediate result. The query result has 1500 tuples.

ii. Calculate the result size in tuples of the join order (Sailor JOIN Reserves) JOIN Boat

In this strategy, since the common attribute, sailorId, is a not null foreign key in Reserves that references Sailor, Sailor JOIN Reserves has only 1500 tuples.

When joining this intermediate result with Boat, the cost is also small, and the query result has 1500 tuples.

iii. Which join order is better and why?

The second strategy is better since the size of the intermediate results is smaller.

EXERCISE 2

For the query $\pi_{A,B,C,D}(R \bowtie_{A=C} S)$ assume that the projection routine uses external sorting, eliminates all unwanted attributes during the initial sort pass and removes duplicate tuples on-the-fly during the merge passes. Furthermore, assume the following:

R is 10 pages; each R tuple is 300 bytes.

S is 100 pages; each S tuple is 500 bytes.

The combined size of attributes A, B, C and D is 450 bytes.

A and B are in R and have combined size of 200 bytes; C and D are in S.

A is a key for R.

Each S tuple joins with exactly one R tuple.

The page size is 1024 bytes.

The buffer size *M* is 3 pages.

Only the (optimized) block nested-loop join method is implemented.

Number of R tuples: [1024/300] * 10 = 30 tuples

Number S tuples: [1024/500] * 100 = 200 tuples

Query: $\pi_{A,B,C,D}(R \bowtie_{A=C} S)$

EXERCISE 2 (CONT'D)

n_R: 30 tuples
B_R: 10 pages
bf_R: 3 tuples/page
n_S: 200 tuples
B_S: 100 pages
bf_S: 2 tuples/page
page size: 1024 bytes
M: 3 pages

What is the query processing page I/O cost?

a) **Join Cost** (using (optimized) block nested-loop and eliminating unwanted attributes during the join)

Use R (the smaller relation as the outer relation; eliminate unwanted attributes)

Join page I/O cost: $\lceil B_r / (M-2) \rceil * B_s + B_r = \lceil 10 / (3-2) \rceil * 100 + 10 = 1{,}010$

Since each S tuple joins with exactly one R tuple, the join produces 200 tuples. Keeping only the attributes A, B, C, and D, the size of each join tuple is 450 bytes. Thus, [1024 / 450] = 2 tuples fit on a page.

Write join result page I/O cost: $\lceil 200 / 2 \rceil = 100$

b) **Projection Cost** (using external sorting)

The sort pass reads the 100 pages of the join result and writes 100 sorted pages. $\lceil 100 / 3 \rceil = 34$ runs are produced (33 runs of 3 pages each and 1 run of 1 page).

Sort page I/O cost pass 0: $100_r + 100_w = 200$

The 34 runs are merged in $\lceil \log_2(100 / 3) \rceil = 6$ additional passes.

Merge page I/O cost: $(100 * 2 * 6) - 100 = 1{,}100$

The page I/O cost of 100, to write the query result, is subtracted from the merge page I/O cost since the cost of writing the query result is never included.

Query processing page I/O cost: $1010 + 100 + 200 + 1100 = 2{,}410$

Query: $\pi_{A,B,C,D}(R \bowtie_{A=C} S)$

EXERCISE 3

n_R: 30 tuples
B_R: 10 pages
bf_R: 3 tuples/page
n_S: 200 tuples
B_S: 100 pages
bf_S: 2 tuples/page
page size: 1024 bytes
M: 3 pages

What is the query processing page I/O cost if merge join is used for Exercise 2 instead of block-nested loop using a buffer of 3 pages?

Using merge join, the projection can be done on-the-fly as the relations are joined. So, the projection cost is 0 and the only cost is for the join. Moreover, when initially sorting R and S, unwanted attributes can be removed, which reduces the number of pages written after sorting.

a) **Cost to sort R** (A and B are in R and have size 200 bytes)

Sort pass

Read 3 R pages into the buffer and eliminate unwanted attributes. Each R page contains 3 tuples. After eliminating unwanted attributes, these tuples occupy $\lceil 9 / \lfloor 1024 / 200 \rfloor \rceil = 2$ pages. Therefore, read one more page into the buffer and sort 4 R pages at once creating a sorted run of 3 pages containing 3 * 4 = 12 tuples.

We do the same with the next 4 pages creating a second sorted run of 3 pages containing 12 tuples.

Finally, we read the final 2 R pages containing 6 tuples and create a third sorted run of 2 pages containing 6 tuples. (Not all pages are full.)

Sort pass page I/O cost: $\underset{r}{4} + \underset{w}{3} + \underset{r}{4} + \underset{w}{3} + \underset{r}{2} + \underset{w}{2} = 18$

Query: $\pi_{A,B,C,D}(R \bowtie_{A=C} S)$

EXERCISE 3 (CONT'D)

n_R: 30 tuples
B_R: 10 pages
bf_R: 3 tuples/page
n_S: 200 tuples
B_S: 100 pages
bf_S: 2 tuples/page
page size: 1024 bytes
M: 3 pages

Merge pass 1 (2 input pages; 1 output page)

Merge a sorted run of 3 pages (12 tuples) and one of 2 pages (6 tuples) creating a sorted run of $\lceil 18 / \lfloor 1024 / 200 \rfloor \rceil = 4$ pages.

Merge pass 2 (2 input pages; 1 output page)

Merge the run of 4 pages (18 tuples) with the remaining sorted run of 3 pages (12 tuples) creating a final sorted output of $\lceil 30 / \lfloor 1024 / 200 \rfloor \rceil = 6$ pages.

Merge pass page I/O cost: $3 + 2 + 4 + 4 + 3 + 6 = 22$
(3: read pass 1; 2: write pass 1; 4: read pass 2; 6: write pass 2)

(The cost to first merge the 3 pages and then the 2 pages would be: pass 1 (read 3 + 3; write 5) + pass 2 (read 5 + 2; write 6) = 24).

Page I/O cost to sort R: $18 + 22 = 40$

b) **Cost to sort S** (C and D are in S and have size 450-200=250 bytes)

Sort pass

Read 3 S pages into memory and eliminate unwanted attributes. Each S page contains 2 tuples. After eliminating unwanted attributes, these tuples occupy $\lceil 6 / \lfloor 1024 / 250 \rfloor \rceil = 2$ pages.

Therefore, read one more page into memory. After removing unwanted attributes, the 8 tuples will still fit in $\lceil 8 / \lfloor 1024 / 250 \rfloor \rceil = 2$ pages.

Query: $\pi_{A,B,C,D}(R \bowtie_{A=C} S)$

EXERCISE 3 (CONT'D)

n_R: 30 tuples
B_R: 10 pages
bf_R: 3 tuples/page
n_S: 200 tuples
B_S: 100 pages
bf_S: 2 tuples/page
page size: 1024 bytes
M: 3 pages

Therefore, read one more page into memory. After removing unwanted attributes, the 10 tuples will fit in $\lceil 10 / \lfloor 1024 / 250 \rfloor \rceil = 3$ pages.

We sort these 10 tuples and create a sorted run of 3 pages.

We do the same for each of the remaining 95 pages creating 20 sorted runs of 3 pages each containing 10 tuples. (Not all pages are full.)

Sort pass page I/O cost: $100_r + 60_w = 160$

Merge pass 1

Merge 20 sorted runs of 3 pages each creating 10 runs of $\lceil 20 / \lfloor 1024 / 250 \rfloor \rceil = 5$ pages containing 20 tuples each. Read 60, write 50 pages. (We note that the first merge pass creates more full pages.)

Merge pass 2

Merge 10 sorted runs of 5 pages each creating 5 runs of $\lceil 40 / \lfloor 1024 / 250 \rfloor \rceil = 10$ pages containing 40 tuples each. Read 50, write 50 pages.

Merge pass 3

Merge 4 sorted runs of 10 pages each creating 2 runs of $\lceil 80 / \lfloor 1024 / 250 \rfloor \rceil = 20$ pages containing 80 tuples each. Read 40, write 40 pages. (We leave the extra run of 10 pages for later merging.)

Query: $\pi_{A,B,C,D}(R \bowtie_{A=C} S)$

EXERCISE 3 (CONT'D)

n_R: 30 tuples
B_R: 10 pages
bf_R: 3 tuples/page
n_S: 200 tuples
B_S: 100 pages
bf_S: 2 tuples/page
page size: 1024 bytes
M: 3 pages

Merge pass 4

Merge 1 run of 20 pages and one run of 10 pages creating 1 run of 30 pages containing 120 tuples. Read 30, write 30 pages.

Merge pass 5

Merge one run of 20 pages and one run of 30 pages to create the final sorted run of $\lceil 200 / \lfloor 1024 / 250 \rfloor \rceil = 50$ pages containing 200 tuples. Read 50 pages, write 50 pages.

Merge pass page I/O cost: $60 + 50 + 50 + 50 + 40 + 40 + 30 + 30 + 50 + 50$

($^{r}_{\text{pass 1}}$ ^{w} $^{r}_{\text{pass 2}}$ ^{w} $^{r}_{\text{pass 3}}$ ^{w} $^{r}_{\text{pass 4}}$ ^{w} $^{r}_{\text{pass 5}}$ ^{w})

$= 450$

Page I/O cost to sort S: $160 + 450 = 610$

c) **Cost to join**

Join page I/O cost: $B_r + B_s = 6 + 50 = 56$

Query processing page I/O cost: $40 + 610 + 56 = 706$