Join algorithms

- (Block) Nested Loop Join - two-level for-loop
- Hash Join - compute a hash table of one input; probe the hash table with the other input
- Sort-Merge Join - sort both tables on one of the join conditions, then merge sorted lists

Indexes

- B-Tree index - supports point and range lookup.
- Hashtable - supports point lookup.

Clustered indexes are the way the data is stored in the “original” table; they are almost always B-trees. Unclustered indexes define secondary tables that reference the main table via pointers.

Cardinality estimation - the problem of estimating the number of tuples after an operation, such as a selection or join. Good estimates are critical to cost modeling; the larger the cardinality; the larger the cost. Here we use assumptions: that the values of a table are uniformly distributed among its distinct values, and that all joins are foreign key-primary key joins.

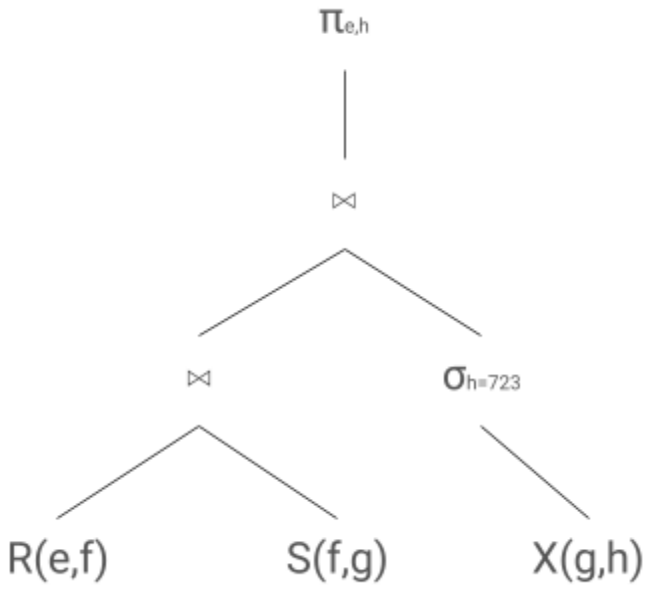
Cost Modeling

- B(R) - the number of blocks used to store the relation R on disk
- T(R) - the number of tuples in R (also known as R's cardinality)
- V(R, a) - the number of unique values of attribute a in relation R
- M - the number of pages that fit in memory

Cost-based Query Optimization compares plans by computing their estimated cost, then chooses the one with the cheapest estimated cost to execute.

Query execution - we learned about the iterator method (iterator interface) of executing the operators in a query plan. You may see it called the "pull-based model of query execution", because each operator "pulls" data from its child operators by calling next(). The three methods used are open(), next(), and close().

Problems



1. (Adapted from 414 SP 17 Final)
Consider the relations R(e, f), S(f, g), and X(g, h) in the query plan depicted above.
- Joins are natural joins.
- Every attribute is integer-valued.
- Assume that **every intermediate result is materialized** (i.e., written to disk).
- Assume that we are executing queries on a machine that has **11 memory pages** available.
- Assume uniform distributions on the attributes for the purpose of computing estimates.

Consider the following statistics:

Table	#tuples	#blocks
R	1,000	100
S	5,000	200
X	100,000	10,000

Attribute	# distinct values	Minimum	Maximum
R.f	100	1	1,000
S.f	1,000	1	2,000
S.g	5,000	1	2,000
X.g	1,000	1	10,000
X.h	1,000	1	500,000

A. Estimate the number of tuples and blocks in the selection $\sigma_{h=723}(X)$.

$T(\sigma_{h=723}(X)) \approx T(X) / V(X, h) = 100,000 / 1,000 = 100$
$B(\sigma_{h=723}(X)) \approx B(X) / V(X, h) = 10,000 / 1,000 = 10$

B. Estimate the number of tuples and blocks in the join $R \bowtie S$.

This is a HARD question. Cardinality estimation of joins has been an active research topic for many years. We don't have enough statistics on R and S to make a good estimate. Here is a common estimate:

$T(R \bowtie S) \approx T(R) * T(S) / \max\{V(R, f), V(S, f)\} = 1{,}000 * 5{,}000 / \max\{100,1000\} = 5{,}000$
Assume about 300 blocks, since the estimated number of tuples does not differ from S but the number of attributes has increased by 50%. This uses the foreign key-primary key join assumption.

C. What is the estimated I/O cost of $R \bowtie S$ if implemented by a block nested loop join?

$B(R) + \lceil B(R) / (M-1) \rceil * B(S) = 100 + 100 * 200 / (11 - 1) = 2{,}100$

Why? First we add B(R) because we must read all of R. Then, for each set of the blocks of R that fit into memory… we stream through the blocks of S, one block at a time. We can fit M-1 blocks of R into memory, since we must reserve 1 block for streaming through S.
Remember that we assume the size of a block equals the size of a page.

D. What is the estimated I/O cost of $R \bowtie S$ if implemented by an indexed join?
Assume that we have an unclustered index on S(f).

$B(R) + T(R) * (T(S) / V(S, f)) = 100 + 1{,}000 * 5{,}000 / 1000 = 5{,}100$

Why? First we add B(R) because we must read all of R. Then, for each *tuple* of R, we lookup the matching tuples in S via the index. How many tuples match? By the uniformity assumption, T(S) / V(S, f) of them match.

2. Create the index that is easiest to create that will make the following queries run faster. Assume there are no previous indexes.

a.
```
SELECT * FROM R
WHERE R.f > 100 AND R.f < 700
```

Use a clustered B-Tree index on R.f to deal with range selection.

b.
```
SELECT * FROM S
WHERE S.g = 344
```

Use a hash index on S.g, since only a point lookup is called for.
No need for clustering.

3. We have the relation V(m, n, p), W(p, q, r) and the following two queries. For each of the unclustered indexes below identify which queries will run faster under that index versus no index. Assume all attributes range from 0 to 1000 and are distributed uniformly.

```
(A) SELECT * FROM V
    WHERE V.m = 344

(B) SELECT * FROM V
    WHERE V.m = 344 AND V.p = 311

(C) SELECT * FROM V, W        (assume nested loop join)
    WHERE V.p = W.p
```

1. `INDEX idx1 on V(m)` ANSWER: A, B
2. `INDEX idx2 on V(m,p)` ANSWER: A, B
3. `INDEX idx3 on V(p,m)` ANSWER: B, C

4. (344 AU16 MT)

Consider the relations

Purchase(pid, custId, quantity, price)

Customer(custId, name, city)

with the statistics

T(Purchase) = 1000 T(Customer) = 3000

B(Purchase) = 100 B(Customer) = 200

V(Purchase, price) = 100 V(Customer, custId) = 3000

Price range = [0, 200)

V(Purchase, custId) = 500

Number of memory pages available = 20

a. Consider the query below and circle the indexes that will produce a speed up:

```
SELECT * FROM Purchase P, Customer C
WHERE P.custId = C.custId
  AND P.price < 100 AND C.custId = 42
```

(1) Hashtable index on Purchase(price) Answer: no

(2) B-tree index on Purchase(pid, price) Answer: no

(3) Hashtable index on Customer(custId) Answer: yes

(4) Hashtable index on Purchase(custId) Answer: yes

(5) B-tree index on Purchase(price, pid) Answer: yes

(6) Hashtable index on Purchase(price, pid) Answer: no

b. Write the optimal query plan that implements this query, including when you would perform selections and what algorithm you would use for the join. Assume that there are no indexes available. Briefly explain why your plan is the cheapest.

Observe that custId is a key of Customer. Selecting C.custId = 42 produces exactly one tuple.

On the Purchase side, it is better to select P.custId = 42 (selectivity 1/500) first because it is more selective than selecting P.price < 100 (selectivity 1/2).

A simple block nested loops join suffices, with C in the outer loop, because the selection from C produces a single tuple.