Lecture 18 — Query Evaluation and Optimization

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Query Evaluation

The strategies we have looked at thus far have explained how to perform individual parts of a query.

If a simple select statement or a select-join is needed then we just have to carry it out using an evaluation plan.

Choosing which evaluation plan, as we saw, is not trivial.

Soon we will examine how we can “guess” about which plan is likely to be best.

But first we need to think about what order in which to perform a compound expression.

Evaluation of Expressions

Our normal expectation of how a composite operation works is that we do a subpart and then store the resulting relation temporarily for further use.

This is called materialization and usually results in the temporary relation being written to disk.

That seems undesirable but it may be necessary.

The other option is a pipeline which would allow us to immediately forward on the partial results from a particular operation.

Materialization

In the example from earlier where there is a three way join $r_1 \bowtie r_2 \bowtie r_3$ we will choose one of the ways to group this.

Then temporarily store the output in some temporary relation r_4 which is then used in the join with the third relation.

Compile This!

Think back to compilers!

When presented with a complex statement, we need to parse it and form a tree.

Then, we work from the bottom level of the tree up to complete the expression.

The code to be compiled is `x = (y * 5) + z;`

Low Level Operations

In the database, we again, need to work on our low level operations and execute those operations (fetch rows, compute joins, whatever it is).

Then take the output and put this in a temporary relation.

A temporary relation will be created at each step until all operations are complete.

At that point we have the final result and can return it.

Materialization Has Costs

The cost of materialization is the sum of the individual operations, plus the cost of writing all intermediate steps to disk.

How large those intermediate costs are depends very heavily on how much data is to be written to disk at each step.

However many tuples of each intermediate step fit into a block is important because it determines how many blocks are needed at each step.

Once again, we get a hint that says if we get some choices about which operations to do sooner rather than later.

We want the ones that result in the fewest result tuples in the output relation...

Pipelining

The idea behind pipelining is to reduce or avoid the costs of storing those temporary files.

Without pipelining, the first data item to finish stage 1 just kind of sits around waiting for the last item to finish stage 1 before the first item can start stage 2.

It accordingly needs a place to wait.

Eliminating that place of waiting is the goal of pipelining.

Types of Pipeline

There are two approaches for how pipelines may execute.

1. Demand-driven (or consumer-driven, pull) pipeline, the system requests at the output end the “next” chunk when it is ready to receive it.

2. Supply-driven (or producer-driven, push) pipeline, each stage of the pipeline is always trying to pick up the next chunk and process it.

Think Producer-Consumer Problem

A push-driven pipeline since it rather resembles the type of producer-consumer problem discussed in earlier courses.

Each stage of the pipeline can be its own thread, and threads can be both a producer and a consumer.

Buffer sizes will be limited, of course, so there can be different stages that are blocked awaiting space in a buffer or waiting their turn to access a buffer

Pipelining Problems

The catch, when it comes to pipelining, is that there are some operations that don't work very well with it.

Sorting is the most obvious example: you cannot send the first chunk of the sorted file on to the next stage until the entire file has been sorted.

Our choice of evaluation algorithm for a select or join operation may also limit the ability to pipeline.

These sorts of things are just limitations we cannot easily get around and may need to be accounted for in our plan for how to evaluate a query.

Query Optimization

The database server is responsible for choosing how to carry out the requested query and it is preferable to do it efficiently.

When we put some numbers to early examples, we saw that there can be orders of magnitude difference in how long it takes to execute a query.

Conclusion: it is worth while for the database server to make the effort to decide what is optimal.

Estimate Blocks

We have looked at techniques for evaluation of how long we think a certain plan is going to take to execute.

They concentrated primarily on how many disk operations we expected to take place.

These typically included numbers like the number of tuples or the number of blocks.

That left open the question of how did we know how many tuples or blocks are in this relation?

Use Metadata

One way that might have immediately come to mind is the metadata kept by the database system.

If it does provide us with some useful information like relation r has 10592 tuples and is currently stored in 2591 blocks then we have some values to go on.

Those are the easy values to get.

But how do we determine how many tuples we think will match the condition that some attribute A is greater than some value x?

And how many blocks will those tuples be in?

Heuristics

The answer lies mostly in heuristics, or perhaps less charitably, educated guessing.

A heuristic is a guideline or “rule of thumb” the gives us some hints.

Suppose we know some statistics about *A*. If we do, then it can help us make some important decisions about what execution plans we choose.

Rule 1: Always Have Rules

In fact, one of the main heuristic rules we should always try to follow is to cut down the size of intermediate relations whenever possible.

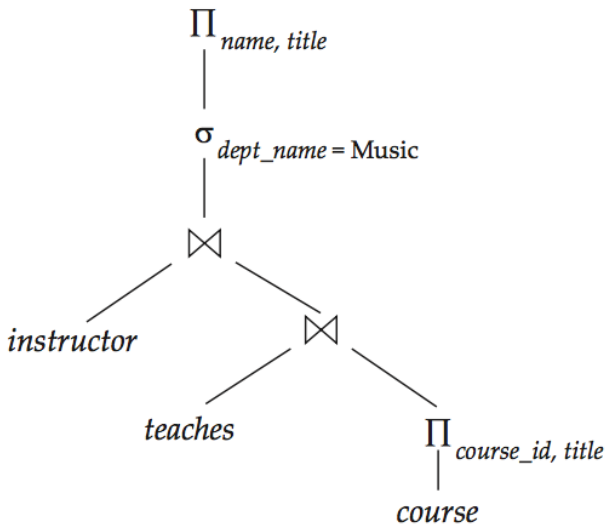
That means select and project operations should be done early and certainly before a join.

A join operation can result in a file size that is some multiple of the size of the input file so it is preferable to cut things down first.

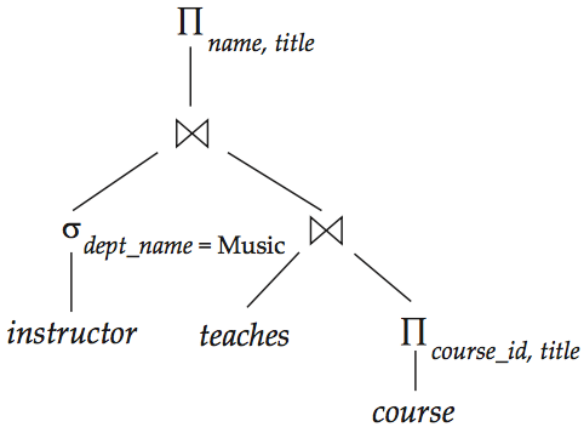
Tree Structure Map

We previously introduced the idea of turning the input query into a tree structure which was then evaluated from the bottom up.

We will often transform the input expression to a faster, better equivalent.



(a) Initial expression tree



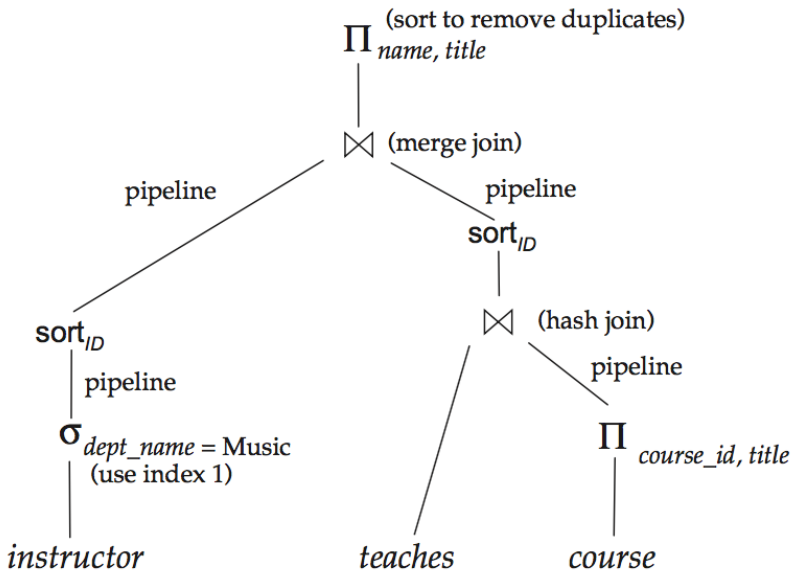
(b) Transformed expression tree

Draw Up Battle Plans

Depending on the nature of the query, 0, 1, or multiple equivalents may exist.

It may be practical to write off some of those immediately, without assessing them, because we know they will be an inferior variant of a plan we have.

The next step is then to draw up the plans for how we would execute the expressions.



Don’t Overthink This

There may be many options for annotating each of the steps in the expression tree.

A totally thorough approach would, once again, consider every possibility, but we realistically can eliminate some options.

Then we may affix cost estimates to each plan as the sum of each part.

The final step is then to choose the the plan with the lowest cost.

Tell Me Your Plan

As a practical note, in SQL you may ask the database server to tell you how it would carry out a query.

First you write the query as you normally would and prefix this query with the keyword `EXPLAIN`.

EXPLAIN!!!!!

Expression Transformation

There are some rules for how exactly to transform a query to an equivalent alternative.

These are a little bit like some things you may have learned in mathematics.

We should remember that database operations do not, unless there is an explicit order-by clause, specify an order in which tuples appear in the output.

Order does not matter in the output.

Notation Chart

To spare a lot of repetition of what things mean, the notation will be centralized here.

θ_x denotes a predicate (as part of a selection or join, for example).

L_x denotes lists of attribute.,

E denotes a relational algebra expression (a sub-expression or a relation r).

All our other symbols from relational algebra remain the same as when they were first introduced.

Rule 1: Conjunctive Selection

Conjunctive selection can be turned into a sequence of individual selections.

Suppose we have a selection from address where province is “ON” and city is “Kitchener”.

We can do this as a selection on address where city is “Kitchener”, producing a temporary relation.

Then we do a selection where province is “ON” on that temporary relation.

That is sometimes called a cascade of selection.

In relational algebra: $\sigma_{\theta_1 \wedge \theta_2}(E) = \sigma_{\theta_1}(\sigma_{\theta_2}(E))$

Rule 2: Selection Commutes

Suppose the original selection is on address where city is “Kitchener”, producing a temporary relation.

Then we do a selection where province is “ON” on that temporary relation.

This is equivalent to the opposite order, because the results are identical in both cases.

In relational algebra: $\sigma_{\theta_1}(\sigma_{\theta_2}(E)) = \sigma_{\theta_2}(\sigma_{\theta_1}(E))$

Rule 3: Projection Redundancy Elimination

Only the last projection operation is needed.

All other projection operations do not do anything.

This should be pretty logical given that projection reduces the returned attributes to just those that are specified in the projection.

In relational algebra: $\Pi_{L_1}(\Pi_{L_2}(\Pi_{L_3}(E))) = \Pi_{L_1}(E)$

Rule 4: Commuting Selection and Projection

If a selection involves the same attributes as a projection list, we can commute the two operations.

That is, if L contains exactly the same set of attributes $A_1, A_2 \ldots$ that are referenced in θ then:

$$\Pi_L(\sigma_\theta(E)) = \sigma_\theta(\Pi_L(E))$$

Rule 5: Selection Combination

Selection may be combined with both cartesian product.

This is, as you will recall, how a theta join works.

If a selection being combined with what is already a theta join, that is the same as a theta join with a conjunctive predicate/

a. $\sigma_\theta(E_1 \times E_2) = E_1 \bowtie_\theta E_2$

b. $\sigma_{\theta_1}(E_1 \bowtie_{\theta_2} E_2) = E_1 \bowtie_{\theta_1 \wedge \theta_2} E_2$

Rule 6: Theta Joins Commute

Theta (and natural) joins commute, so the operands can be swapped in order and the same result is produced.

That is a relief, considering our previous discussion of what blocks need to get moved into memory to complete the operation.

This does potentially change the order of the attributes in the output, but we should not actually care.

Rule 6: Theta Joins Commute

Normally a selection statement, for example, specifies some attributes to be returned, meaning there is a projection operation to be done.

If there is a select $*$ operation, no order is guaranteed in the output anyway.

In relational algebra: $E_1 \bowtie_\theta E_2 = E_2 \bowtie_\theta E_1$

The natural join is a special case of the theta join, so $E_1 \bowtie E_2 = E_2 \bowtie E_1$

Rule 7: Natural Join Associates

When discussing joins, we actually already covered this rule, that they are associative.

For theta joins, it looks a little more complicated, but the outcome is the same.

a. $(E_1 \bowtie E_2) \bowtie E_3 = E_1 \bowtie (E_2 \bowtie E_3)$.

b. $(E_1 \bowtie_{\theta_1} E_2) \bowtie_{\theta_2 \wedge \theta_3} E_3 = E_1 \bowtie_{\theta_1 \wedge \theta_3} (E_2 \bowtie_{\theta_2} E_3)$.

c. Because cartesian product is an empty theta join,
$(E_1 \times E_2) \times E_3 = E_1 \times (E_2 \times E_3)$.

Rule 8: Selection Distribution

Selection distributes over theta join if the following conditions hold:

a. It distributes if all the attributes in θ_0 involve only the attributes of one of the expressions E being joined.

In this example, if θ_0 applies only to E_1:

$$\sigma_{\theta_0}(E_1 \bowtie_\theta E_2) = (\sigma_{\theta_0}(E_1)) \bowtie_\theta E_2$$

Rule 8: Selection Distribution

b. It distributes when θ_1 involves only the attributes of E_1 and θ_2 only the attributes of E_2.

This would mean cutting down both relations before performing the join.

$$\sigma_{\theta_1 \wedge \theta_2}(E_1 \bowtie_\theta E_2) = (\sigma_{\theta_1}(E_1)) \bowtie_\theta (\sigma_{\theta_2}(E_2))$$

Both of these scenarios apply also for the cartesian product.

Rule 9: Projection Distribution

The projection operation can be distributed over theta join if the following conditions hold:

a. If L_1 and L_2 are attributes of E_1 and E_2 respectively, and θ contains only attributes in $L_1 \cup L_2$, then we can distribute.

$$\Pi_{L_1 \cup L_2}(E_1 \bowtie_\theta E_2) = (\Pi_{L_1}(E_1)) \bowtie_\theta (\Pi_{L_2}(E_2))$$

Rule 9: Projection Distribution

b. If L_1 and L_2 are attributes of E_1 and E_2 respectively, and L_3 are join attributes of E_1 not $L_1 \cup L_2$ and L_4 are join attributes of E_2 not $L_1 \cup L_2$:

$$\Pi_{L_1 \cup L_2}(E_1 \bowtie_\theta E_2) = \Pi_{L_1 \cup L_2}((\Pi_{L_1 \cup L_3}(E1)) \bowtie_\theta (\Pi_{L_2 \cup L_4}(E_2)))$$

Again, this can also be applied to cartesian product.

Rule 10: Set Operations Commute

The set operations union and intersection commute (difference does not).

a. $E_1 \cup E_2 = E_2 \cup E_1$

b. $E_1 \cap E_2 = E_2 \cap E_1$

Rule 11: Set Operations Associate

Union and intersection are associative:

a. $(E_1 \cup E_2) \cup E_3 = E_1 \cup (E_2 \cup E_3)$

b. $(E_1 \cap E_2) \cap E_3 = E_1 \cap (E_2 \cap E_3)$

Rule 12: Selection Distribution II

Selection distributes over union, intersection, and difference operations:

a. $\sigma_\theta(E_1 \cup E_2) = \sigma_\theta(E_1) \cup \sigma_\theta(E_2)$

b. $\sigma_\theta(E_1 \cap E_2) = \sigma_\theta(E_1) \cap \sigma_\theta(E_2)$

c. $\sigma_\theta(E_1 - E_2) = \sigma_\theta(E_1) - \sigma_\theta(E_2)$

Rule 13: Projection Distribution II

The projection operation distributes over a union operation.

In relational algebra: $\Pi_L(E_1 \cup E_2 = (\Pi_L(E_1)) \cup (\Pi_L(E_2))$

Rules Review

These rules are (sadly) neither a complete set nor minimal.

There are other potential transformations that can be done, including various rules from boolean algebra (e.g., $\neg(a \wedge b) = \neg a \vee \neg b$)...

Having learned a bit about equivalence rules and what they are for, next time we will work on putting them to use and affixing cost estimates.