Optimization Overview

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Lecture and activity contents are based on what Prof Chris Ré of Stanford used in his CS 145 in the fall 2016 term with permission

Today's Lecture

1. Logical Optimization
2. Physical Optimization

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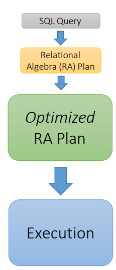
Logical vs. Physical Optimization

- **Logical optimization:**
  - Find equivalent plans that are more efficient
  - *Intuition: Minimize # of tuples at each step by changing the order of RA operators*
- **Physical optimization:**
  - Find algorithm with lowest IO cost to execute our plan
  - *Intuition: Calculate based on physical parameters (buffer size, etc.) and estimates of data size (histograms)*



1. Logical Optimization

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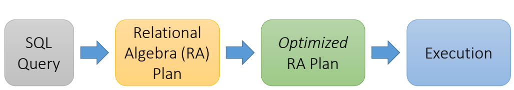
RDBMS Architecture

How does a SQL engine work ?



Declarative query (from user)

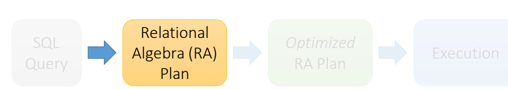
Translate to relational algebra expressions

Find logically equivalent- but more efficient- RA expression

Execute each operator of the optimized plan!

RDBMS Architecture

How does a SQL engine work ?



Relational Algebra allows us to translate declarative (SQL) queries into precise and optimizable expressions!

Recall: Relational Algebra (RA)

- Five **basic** operators:
  1. Selection: σ
  2. Projection: Π
  3. Cartesian Product: $\times$
  4. Union: $\cup$
  5. Difference: -
- Derived or auxiliary operators:
  - Intersection, complement
  - Joins (natural,equi-join, theta join, semi-join)
  - Renaming: ρ
  - Division

We'll look at these first!

And also at one example of a derived operator (natural join) and a special operator (renaming)

Recall: Converting SFW Query -> RA

Students(sid,sname,gpa)
People(ssn,sname,address)

```
SELECT DISTINCT
  gpa,
  address
FROM Students S,
     People P
WHERE gpa > 3.5 AND
  sname = pname;
```

$$\Pi_{gpa,address}(\sigma_{gpa>3.5}(S \bowtie P))$$

How do we represent this query in RA?

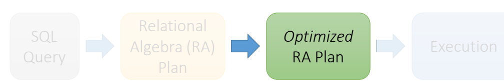
Recall: Logical Equivalece of RA Plans

- Given relations R(A,B) and S(B,C):
  - Here, projection & selection commute:
    - $\sigma_{A=5}(\Pi_A(R)) = \Pi_A(\sigma_{A=5}(R))$
  - What about here?
    - $\sigma_{A=5}(\Pi_B(R)) ?= \Pi_B(\sigma_{A=5}(R))$

We'll look at this in more depth later in the lecture…

RDBMS Architecture

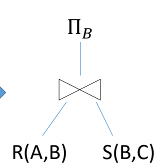
How does a SQL engine work ?



We'll look at how to then optimize these plans now

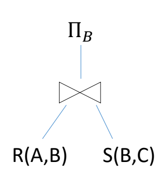
Note: We can visualize the plan as a tree

$$\Pi_B(R(A,B) \bowtie S(B,C))$$



Bottom-up tree traversal = order of operation execution!

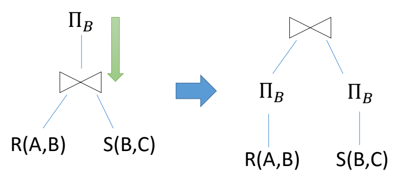
A simple plan



What SQL query does this correspond to?

Are there any logically equivalent RA expressions?

"Pushing down" projection



Why might we prefer this plan?

Takeaways

- This process is called logical optimization
- Many equivalent plans used to search for "good plans"
- Relational algebra is an important abstraction.

RA commutators

- The basic commutators:
  - Push **projection** through **(1) selection**, **(2) join**
  - Push **selection** through **(3) selection, (4) projection, (5) join**
  - *Also:* Joins can be re-ordered!
- Note that this is not an exhaustive set of operations
  - This covers *local re-writes; global re-writes possible but much harder*

This simple set of tools allows us to greatly improve the execution time of queries by optimizing RA plans!

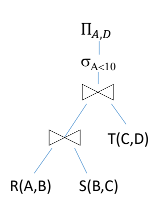
Optimizing the SFW RA Plan

Translating to RA

R(A,B) S(B,C) T(C,D)

```
SELECT R.A,S.D
FROM R,S,T
WHERE R.B = S.B
  AND S.C = T.C
  AND R.A < 10;
```

$\Pi_{A,D}(\sigma_{A<10}(T \bowtie (R \bowtie S)))$



Logical Optimization

- Heuristically, we want selections and projections to occur as early as possible in the plan
  - Terminology: "push down **selections**" and "pushing down **projections.**"
- **Intuition:** We will have fewer tuples in a plan.
  - Could fail if the selection condition is very expensive (say runs some image processing algorithm).
  - Projection could be a waste of effort, but more rarely.

Optimizing RA Plan

R(A,B) S(B,C) T(C,D)

```
SELECT R.A,S.D
FROM R,S,T
WHERE R.B = S.B
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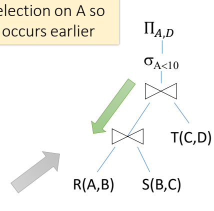
$$\Pi_{A,D}(\sigma_{A<10}(T \bowtie (R \bowtie S)))$$

Push down selection on A so it occurs earlier



Optimizing RA Plan

R(A,B) S(B,C) T(C,D)

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SELECT R.A,S.D
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WHERE R.B = S.B
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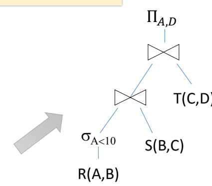
$$\Pi_{A,D}\left(T \bowtie (\sigma_{A<10}(R) \bowtie S)\right)$$

Push down selection on A so it occurs earlier



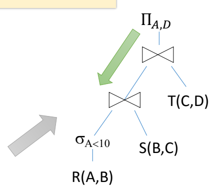
Optimizing RA Plan

R(A,B) S(B,C) T(C,D)

```
SELECT R.A,S.D
FROM R,S,T
WHERE R.B = S.B
  AND S.C = T.C
  AND R.A < 10;
```

$$\Pi_{A,D}\left(T \bowtie (\sigma_{A<10}(R) \bowtie S)\right)$$

Push down projection so it occurs earlier



Optimizing RA Plan

R(A,B) S(B,C) T(C,D)

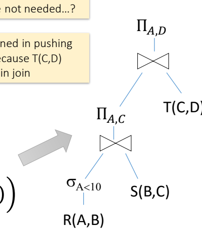
```
SELECT R.A,S.D
FROM R,S,T
WHERE R.B = S.B
  AND S.C = T.C
  AND R.A < 10;
```

$$\Pi_{A,D}\left(T \bowtie \Pi_{A,c}(\sigma_{A<10}(R) \bowtie S)\right)$$

We eliminate B earlier!

In general, when is an attribute not needed…?

C is retained in pushing down because T(C,D) needs it in join



2. Physical Optimization

What you will learn about in this section

1. Index Selection
2. Histograms

Index Selection

Input:
- Schema of the database
- **Workload description:** set of (query template, frequency) pairs

Goal: Select a set of indexes that minimize execution time of the workload.
- Cost / benefit balance: Each additional index may help with some queries, but requires updating

This is an optimization problem!

Example

Workload description:

Query	Frequency
SELECT pname FROM Product WHERE year = ? AND category = ?	Frequency 10,000,000
SELECT pname, FROM Product WHERE year = ? AND Category = ? AND manufacturer = ?	Frequency 10,000,000

Which indexes might we choose?

Example

Workload description:

Query	Frequency
SELECT pname FROM Product WHERE year = ? AND category =?	Frequency 10,000,000
SELECT pname FROM Product WHERE year = ? AND Category =? AND manufacturer = ?	Frequency 100

Now which indexes might we choose? Worth keeping an index with manufacturer in its search key around?

Simple Heuristic

- Can be framed as standard optimization problem: Estimate how cost changes when we add index.
  - We can ask the optimizer!
- Search over all possible space is too expensive, optimization surface is really nasty.
  - Real DBs may have 1000s of tables!
- Techniques to exploit *structure* of the space.
  - In SQLServer Autoadmin.

NP-hard problem, but can be solved!

Estimating index cost?

- Note that to frame as optimization problem, we first need an estimate of the ***cost*** of an index lookup
- Need to be able to estimate the costs of different indexes / index types…

We will see this mainly depends on getting estimates of result set size!

Ex: Clustered vs. Unclustered

Cost to do a range query for M entries (records) over N-page file (P per page):

- Clustered:
  - To traverse: $\text{Log}_f(1.5N)$
  - To scan: 1 random IO + $\left\lceil \frac{M-1}{P} \right\rceil$ sequential IO
- Unclustered:
  - To traverse: $\text{Log}_f(1.5N)$
  - To scan: ~ M random IO

Suppose we are using a B+ Tree index with:
- Fanout f
- Fill factor 2/3

Plugging in some numbers

To simplify:
- Random IO = ~10ms
- Sequential IO = free

- Clustered:
  - To traverse: $Log_F(1.5N)$
  - **To scan: 1 random IO +** $\left\lceil \frac{M-1}{P} \right\rceil$ **sequential IO**

~ 1 random IO = 10ms

- Unclustered:
  - To traverse: $Log_F(1.5N)$
  - **To scan: ~ M random IO**

~ ***M*** random IO = M*10ms

- If M = 1, then there is no difference!
- If M = 100,000 records, then difference is ~10min. Vs. 10ms!

If only we had good estimates of M…

Histograms & IO Cost Estimation

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IO Cost Estimation via Histograms

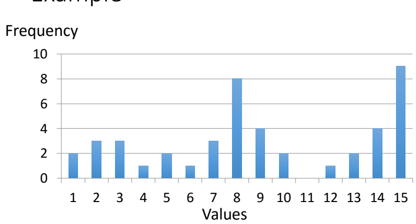
- For **index selection**:
  - What is the cost of an index lookup?
- Also for **deciding which algorithm to use**:
  - Ex: To execute $R \bowtie S$, which join algorithm should DBMS use?
  - **What if we want to compute** $\boldsymbol{\sigma_{A>10}(R) \bowtie \sigma_{B=1}(S)}$**?**
- In general, we will need some way to ***estimate intermediate result set sizes***

Histograms provide a way to efficiently store estimates of these quantities

Histograms

- A histogram is a set of value ranges ("buckets") and the frequencies of values in those buckets occurring
- How to choose the buckets?
  - Equiwidth & Equidepth
- Turns out high-frequency values are **very** important

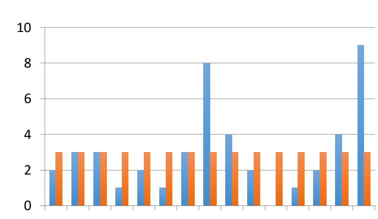
Example



How do we compute how many values between 8 and 10?
(Yes, it's obvious)

Problem: counts take up too much space!

Full vs. Uniform Counts



How much space do the full counts (bucket_size=1) take?

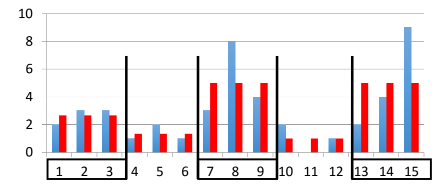
How much space do the uniform counts (bucket_size=ALL) take?

Fundamental Tradeoffs

- Want high resolution (like the full counts)
- Want low space (like uniform)
- Histograms are a compromise!

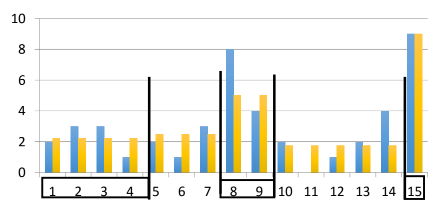
So how do we compute the “bucket” sizes?

Equi-width



All buckets roughly the same width

Equi-depth



All buckets contain roughly the same number of items (total frequency)

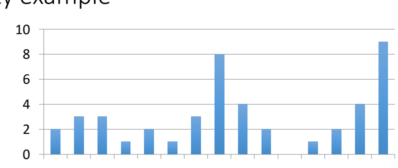
Histograms

- Simple, intuitive and popular
- Parameters: # of buckets and type
- Can extend to many attributes (multidimensional)

Maintaining Histograms

- Histograms require that we update them!
  - Typically, you must run/schedule a command to update statistics on the database
  - Out of date histograms can be terrible!
- There is research work on self-tuning histograms and the use of query feedback
  - Oracle 11g

Nasty example



1. we insert many tuples with value > 16
2. we do **not** update the histogram
3. we ask for values > 20?

Compressed Histograms

- One popular approach:
  1. Store the most frequent values and their counts explicitly
  2. Keep an equiwidth or equidepth one for the rest of the values

People continue to try all manner of fanciness here
wavelets, graphical models, entropy models,…