# SQL

Part-**III**

# SQL - Part 3

1. SQL Sets operators
2. When are two queries equivalent?
3. How does SQL work?
   - Intro to Relational Algebra
   - A basic RDBMS query optimizer

# Preview

# SQL queries

[sqltutorial.org/sql-cheat-sheet](sqltutorial.org/sql-cheat-sheet)

## SQL CHEAT SHEET http://www.sqltutorial.org

### QUERYING DATA FROM A TABLE

```
SELECT c1, c2 FROM t;
```
Query data in columns c1, c2 from a table

```
SELECT * FROM t;
```
Query all rows and columns from a table

```
SELECT c1, c2 FROM t
WHERE condition;
```
Query data and filter rows with a condition

```
SELECT DISTINCT c1 FROM t
WHERE condition;
```
Query distinct rows from a table

```
SELECT c1, c2 FROM t
ORDER BY c1 ASC [DESC];
```
Sort the result set in ascending or descending order

```
SELECT c1, c2 FROM t
ORDER BY c1
LIMIT n OFFSET offset;
```
Skip *offset* of rows and return the next n rows

```
SELECT c1, aggregate(c2)
FROM t
GROUP BY c1;
```
Group rows using an aggregate function

```
SELECT c1, aggregate(c2)
FROM t
GROUP BY c1
HAVING condition;
```
Filter groups using HAVING clause

### QUERYING FROM MULTIPLE TABLES

```
SELECT c1, c2
FROM t1
INNER JOIN t2 ON condition;
```
Inner join t1 and t2

```
SELECT c1, c2
FROM t1
LEFT JOIN t2 ON condition;
```
Left join t1 and t1

```
SELECT c1, c2
FROM t1
RIGHT JOIN t2 ON condition;
```
Right join t1 and t2

```
SELECT c1, c2
FROM t1
FULL OUTER JOIN t2 ON condition;
```
Perform full outer join

```
SELECT c1, c2
FROM t1
CROSS JOIN t2;
```
Produce a Cartesian product of rows in tables

```
SELECT c1, c2
FROM t1, t2;
```
Another way to perform cross join

```
SELECT c1, c2
FROM t1 A
INNER JOIN t2 B ON condition;
```
Join t1 to itself using INNER JOIN clause

### USING SQL OPERATORS

```
SELECT c1, c2 FROM t1
UNION [ALL]
SELECT c1, c2 FROM t2;
```
Combine rows from two queries

```
SELECT c1, c2 FROM t1
INTERSECT
SELECT c1, c2 FROM t2;
```
Return the intersection of two queries

```
SELECT c1, c2 FROM t1
MINUS
SELECT c1, c2 FROM t2;
```
Subtract a result set from another result set

```
SELECT c1, c2 FROM t1
WHERE c1 [NOT] LIKE pattern;
```
Query rows using pattern matching %, _

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SELECT c1, c2 FROM t
WHERE c1 [NOT] IN value_list;
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Query rows in a list

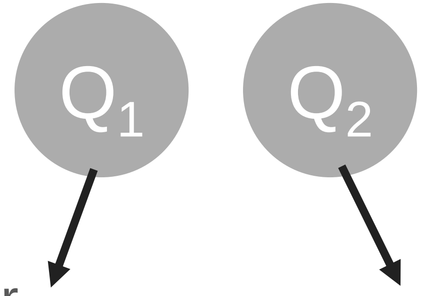
```
SELECT c1, c2 FROM t
WHERE c1 BETWEEN low AND high;
```
Query rows between two values

```
SELECT c1, c2 FROM t
WHERE c1 IS [NOT] NULL;
```
Check if values in a table is NULL or not

1. Multiset operators in SQL

2. Nested queries

What you will learn about in this section



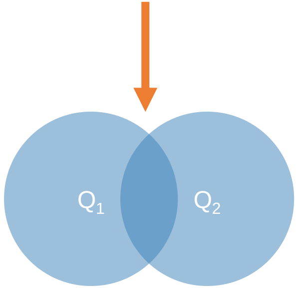

Result for Query Q1

Result for Query Q2

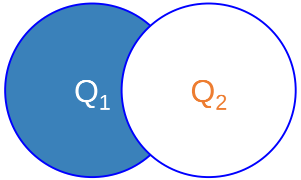
# Explicit Set Operators:

## INTERSECT, UNIONS on results of Queries Q1, Q2

```
SELECT R.A
FROM   R, S
WHERE  R.A=S.A          Q1
INTERSECT
SELECT R.A
FROM   R, T             Q2
WHERE  R.A=T.A
```

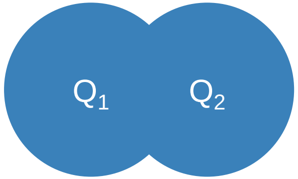



```
SELECT R.A
FROM   R, S
WHERE  R.A=S.A
EXCEPT
SELECT R.A
FROM   R, T
WHERE  R.A=T.A
```




$$\{r.A \mid r.A = s.A\} \setminus \{r.A \mid r.A = t.A\}$$

```
SELECT  R.A
FROM   R, S
WHERE  R.A=S.A
UNION
SELECT R.A
FROM   R, T
WHERE  R.A=T.A
```



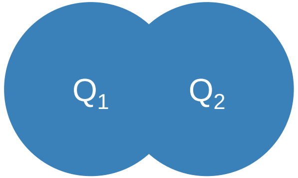

By default:

SQL retains Set semantics for Set Operators

What if we want duplicates?

# ALL indicates Multiset

```
SELECT  R.A
FROM    R, S
WHERE   R.A=S.A
UNION ALL
SELECT R.A
FROM    R, T
WHERE   R.A=T.A
```




*ALL indicates Multiset operations*

# Recall Multisets

$\lambda(X)$= *"Count of tuple in X"*
*(Items not listed have implicit count 0)*

**Multiset X**

| Tuple |
|---|
| (1, a) |
| (1, a) |
| (1, b) |
| (2, c) |
| (2, c) |
| (2, c) |
| (1, d) |
| (1, d) |

Equivalent Representations of a **Multiset**

**Multiset X**

| Tuple | $\lambda(X)$ |
|---|---|
| (1, a) | 2 |
| (1, b) | 1 |
| (2, c) | 3 |
| (1, d) | 2 |

*Note: In a set all counts are {0,1}.*

# Generalizing Set Operations to Multiset Operations

**Multiset X**

| Tuple | $\lambda(X)$ |
|---|---|
| (1, a) | 2 |
| (1, b) | 0 |
| (2, c) | 3 |
| (1, d) | 0 |

$\cap$

**Multiset Y**

| Tuple | $\lambda(Y)$ |
|---|---|
| (1, a) | 5 |
| (1, b) | 1 |
| (2, c) | 2 |
| (1, d) | 2 |

$=$

**Multiset Z**

| Tuple | $\lambda(Z)$ |
|---|---|
| (1, a) | 2 |
| (1, b) | 0 |
| (2, c) | 2 |
| (1, d) | 0 |

$$\lambda(Z) = min(\lambda(X), \lambda(Y))$$

# Generalizing Set Operations to Multiset Operations

**Multiset X**

| Tuple | $\lambda(X)$ |
|---|---|
| (1, a) | 2 |
| (1, b) | 0 |
| (2, c) | 3 |
| (1, d) | 0 |

$\cup$

**Multiset Y**

| Tuple | $\lambda(Y)$ |
|---|---|
| (1, a) | 5 |
| (1, b) | 1 |
| (2, c) | 2 |
| (1, d) | 2 |

$=$

**Multiset Z**

| Tuple | $\lambda(Z)$ |
|---|---|
| (1, a) | 7 |
| (1, b) | 1 |
| (2, c) | 5 |
| (1, d) | 2 |

$$\lambda(Z) = \lambda(X) + \lambda(Y)$$

# SQL is compositional

Key concept

Can construct powerful query chains (e.g., f(g(...(x)))

Inputs / outputs are multisets

⇒ Output of one query can be input to another (nesting)!

⇒ Including on same table (e.g., self correlation)

# Nested queries: Sub-queries Return Relations

Company(<u>name</u>, city)
Product(<u>name</u>, maker)
Purchase(<u>id</u>, product, buyer)

```
        SELECT pr.maker
FROM    Purchase p, Product pr
WHERE   p.product = pr.name
            AND p.buyer = 'Mickey')
```

"

- Companies making products bought by Mickey"
- Location of companies?

"

# Subqueries Return Relations

You can also use operations of the form:

- s > ALL R
- s < ANY R
- EXISTS R

Ex: Product(name, price, category, maker)

```
SELECT name
FROM   Product
WHERE  price > ALL(
    SELECT price
    FROM   Product
    WHERE  maker = 'Gizmo-Works')
```

Find products that are more expensive than all those produced by "Gizmo-Works"

```
SELECT p1.name
FROM   Product p1
WHERE  p1.maker = 'Gizmo-Works'
  AND EXISTS(
        SELECT p2.name
        FROM   Product p2
        WHERE  p2.maker <> 'Gizmo-Works'
          AND p1.name = p2.name)
```

<> means !=

Find 'copycat' products, i.e. products made by competitors with the same names as products made by "Gizmo-Works"

Note the scoping of the variables!

# Example: Complex Correlated Query

Product(name, price, category, maker, year)

```
SELECT DISTINCT  x.name, x.maker
FROM             Product AS x
WHERE            x.price > ALL(
        SELECT y.price
        FROM   Product AS y
        WHERE  x.maker = y.maker
                         AND y.year < 1972)
```

Find products (and their manufacturers) that are more expensive than all products made by the same manufacturer before 1972

Can be very powerful (also much harder to optimize)

# SQL is compositional

Key concept

Can construct powerful query chains (e.g., f(g(x)))

Inputs / outputs are multisets

⇒ Output of one query can be input to another (nesting)!

⇒ Including on same table (e.g., self correlation)

# Equivalent SQL queries

Key concept

Can write different SQL queries to solve same problem

Key:

-- Be careful with sets and multisets

-- Go back to semantics (1st principles)

# Example1: Two equivalent queries?

Product(name, price, company)
Company(name, city)

Find all companies with products having price < 100

VS

Find all companies that make only products with price < 100

'Similar' but non-equivalent'

```
SELECT DISTINCT Company.cname
FROM    Company, Product
WHERE  Company.name = Product.company
       AND Product.price < 100
```

```
SELECT DISTINCT Company.cname
FROM     Company
WHERE   Company.name NOT IN(
                  SELECT Product.company
                  FROM Product.price >= 100)
```

A universal quantifier is of the form "for all"

# Example 2: Headquarters of companies which make gizmos in US AND China

```
Company(name, hq_city)
Product(pname, maker, factory_loc)
```

Company

| Name | hq_city |
|---|---|
| X Co. | Seattle |
| Y Inc. | Seattle |

Product

| pname | maker | factory_loc |
|---|---|---|
| X | X Co. | U.S. |
| Y | Y Inc. | China |

Option 1: With Nested queries

```
SELECT DISTINCT hq_city
FROM   Company, Product
WHERE  maker = name
     AND name IN (
                    SELECT maker
                    FROM   Product
                    WHERE  factory_loc = 'US')
          AND name IN (
                    SELECT maker
                    FROM   Product
                    WHERE  factory_loc = 'China')
```

Note: If we hadn't used DISTINCT here, how many copies of each hq_city would have been returned?

Option 2: With Intersections

```
SELECT hq_city
FROM   Company, Product
WHERE  maker = name
       AND factory_loc='US'
INTERSECT
SELECT hq_city
FROM   Company, Product
WHERE  maker = name
       AND factory_loc='China'
```

X Co has a factory in the US (but not China)
Y Inc. has a factory in China (but not US)
But Seattle is returned by the query!
⇒ Option 1 and Option 2 are **NOT** equivalent

# Example 3: Are these equivalent?

```
SELECT c.city
FROM   Company c, Product pr, Purchase p
WHERE  c.name = pr.maker
   AND  pr.name = p.product
   AND  p.buyer = ‘Mickey’
```

```
SELECT c.city
FROM   Company c
WHERE  c.name  IN (
        SELECT pr.maker
        FROM   Purchase p, Product pr
        WHERE  p.name = pr.product
               AND p.buyer = ‘Mickey‘)
```

Step 1: Construct some examples

| Company | | | Product | | | Purchase | |
|---|---|---|---|---|---|---|---|
| Name | City | | Name | Maker | | Product | Buyer |
| Tesla | Palo Alto | | Model X | Tesla | | Kindle | Mickey |
| Amazon | Seattle | | Kindle | Amazon | | Model X | Mickey |
| | | | Kindle Fire | Amazon | | Kindle Fire | Mickey |
| | | | Books | Amazon | | Book | Mickey |

Step 2: Test examples

| |
|---|
| Seattle |
| Palo Alto |
| Seattle |
| Seattle |

| |
|---|
| Palo Alto |
| Seattle |

Beware of duplicates!

# Example 3: Are these equivalent?

```
SELECT c.city
FROM   Company c, Product pr, Purchase p
WHERE  c.name = pr.maker
    AND  pr.name = p.product
    AND  p.buyer = 'Mickey'
```

```
SELECT c.city
FROM   Company c
WHERE  c.name  IN (
       SELECT pr.maker
       FROM   Purchase p, Product pr
       WHERE  p.name = pr.product
              AND p.buyer = 'Mickey')
```

Fix duplicates!

```
SELECT DISTINCT c.city
FROM   Company c, Product pr, Purchase p
WHERE  c.name = pr.maker
     AND  pr.name = p.product
     AND  p.buyer = 'Mickey'
```

```
SELECT DISTINCT c.city
FROM   Company c
WHERE  c.name  IN (
     SELECT pr.maker
     FROM   Purchase p, Product pr
     WHERE  p.product = pr.name
              AND p.buyer = 'Mickey')
```

Now they are equivalent (both use set semantics)

# Example 4: Are these equivalent?

Students(sid, name, gpa)
Enrolled(student_id, cid, grade)

- Find students enrolled in > 5 classes

Attempt 1: with nested queries

```
SELECT DISTINCT Students.sid
FROM    Students
WHERE (
    SELECT COUNT (cid)
    FROM    Enrolled
    WHERE  Students.sid = Enrolled.student_id) > 5
```

SQL by a novice

Attempt 2: with GROUP BYs

```
SELECT    Students.sid
FROM       Students, Enrolled
WHERE     Students.sid = Enrolled.student_id
GROUP BY Students.sid
HAVING    COUNT(Enrolled.cid) > 5
```

1. SQL by an expert
2. No need for DISTINCT: automatic from GROUP BY

# Group-by vs. Nested Query

Which way is more efficient?

- Attempt #1- *With nested:* How many times do we do a SFW query over all of the Enrolled relations?

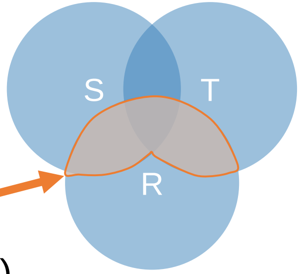
- Attempt #2- *With group-by*: How about when written this way?

With GROUP BY can be **much** more efficient!

# Example 5: An Unintuitive Query

```
SELECT DISTINCT R.A
FROM   R, S, T
WHERE  R.A=S.A OR R.A=T.A
```

What does it compute?




Computes R $\cap$ (S $\cup$ T)

But what if S = $\phi$ ?

Go back to the semantics!

# What does this look like in Python?

```
SELECT DISTINCT R.A
FROM   R, S, T
WHERE  R.A=S.A OR R.A=T.A
```

Semantics:

1. Take <u>cross-product</u>

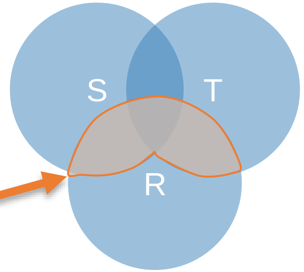
*Joins / cross-products* are just nested for loops (in simplest implementation)!

1. Apply <u>selections</u> / <u>conditions</u>

*If-then statements!*

1. Apply <u>projection</u>

$R \cap (S \cup T)$



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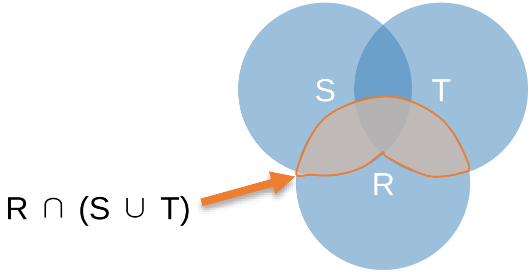


```
output = {}

for r in R:
   for s in S:
      for t in T:
         if r['A'] == s['A'] or r['A'] == t['A']:
            output.add(r['A'])
return list(output)
```

Can you see now what happens if S = []?

# Equivalent SQL queries

Key concept

Can write different SQL queries to solve same problem

Key:

-- Be careful with sets and multisets

-- Go back to semantics (1st principles)

# Basic SQL Summary

SQL is a high-level declarative language for manipulating data (DML)

- The workhorse is the SFW block
- Set operators are powerful but have some subtleties
- Powerful, nested queries also allowed

# Preview

# SQL queries

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Skip *offset* of rows and return the next n rows

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Group rows using an aggregate function

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Inner join t1 and t2

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RIGHT JOIN t2 ON condition;
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Perform full outer join

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Produce a Cartesian product of rows in tables

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Query rows using pattern matching %, _

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```
Query rows between two values

```
SELECT c1, c2 FROM t
WHERE c1 IS [NOT] NULL;
```
Check if values in a table is NULL or not

# How does it work?

# RDBMS Architecture

How does a SQL engine work ?

SQL Query → Relational Algebra (RA) Plan → *Optimized* RA Plan → Execution

Declarative query (from user)

Translate to relational algebra expression

*Find logically equivalent- but more **cost-efficient**- RA expression*

Execute each operator of the optimized plan!

# RDBMS Architecture

How does a SQL engine work ?

SQL Query → Relational Algebra (RA) Plan → *Optimized* RA Plan → Execution

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

# Relational Algebra (RA)

<u>Five **basic** operators:</u>

1. Selection: $\sigma$
2. Projection: $\Pi$
3. Cartesian Product: $\times$
4. Union: $\cup$
5. Difference: -

<u>Derived or auxiliary operators:</u>

- Intersection
- Joins: $\bowtie$ (natural, equi-join, semi-join)
- Renaming: $\rho$

What's an <u>Algebra</u>? Why?

- For ex, in Math

a) (x + y) + z   vs   x + y + z

b) (x + y) + 2*x  vs  (x + y + 2)*x

- Operators and rules

- Basic notation for operators ('+', '-', '*', '/', '^' etc.)
- Association, commutative, …

⇒ Why?

- What can you reorder, simplify?
- Express complex equations and expressions, and reason about them

# Converting SFW Query to 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;
```

$\Rightarrow$

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

How do we represent this query in RA?

# Logical Equivalence 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?
    - $\sigma_{A=5}(\Pi_B(R)) \, ?= \Pi_B(\sigma_{A=5}(R))$

# RDBMS Architecture

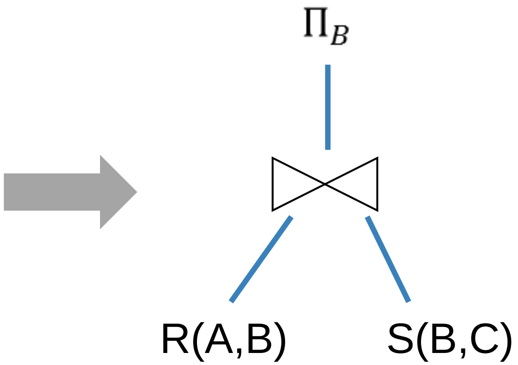
How does a SQL engine work ?

SQL Query → Relational Algebra (RA) Plan → *Optimized* RA Plan → Execution

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

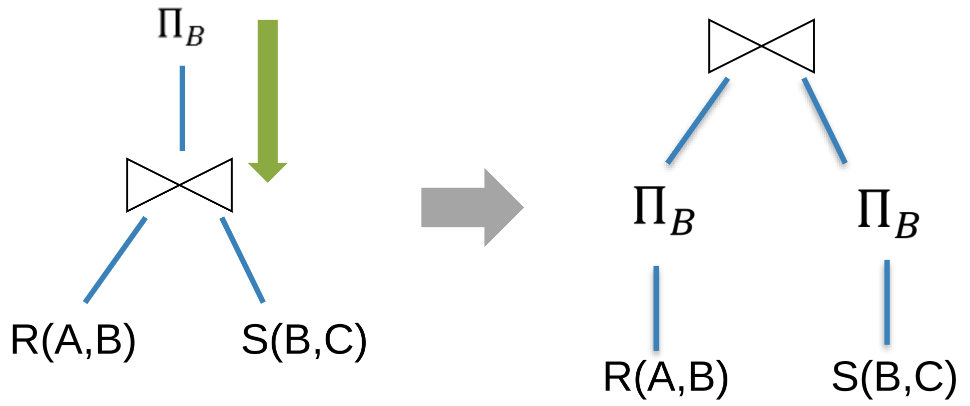
# Visualize the plan as a tree

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




Bottom-up tree traversal = order of operation execution!

# One simple plan -- "Push down" projection




What SQL query does this correspond to?

Are there any logically equivalent RA expressions?

Why might we prefer this plan?

# Logical Optimization

- Heuristically, we want selections and projections to occur as early as possible in the plan
  - Terminology: “push down **selections** and **projections”**

- **Intuition:** We will usually have fewer tuples in a plan.

  Exceptions
  - Could fail if the selection condition is very expensive (e.g, run image processing algorithm)
  - Projection could be a waste of effort, but more rarely

⇒ Cost-based Query Optimizers (e.g., Postgres/ BigQuery/ MySQL optimizers, SparkSQL’s Catalyst)

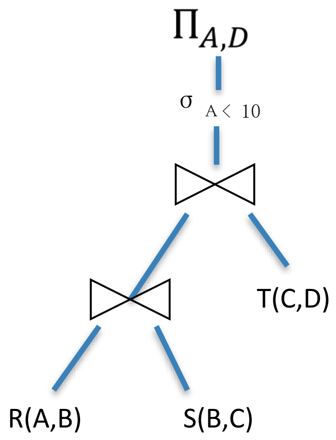
# Optimizing the SFW RA Plan

# 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;
```

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



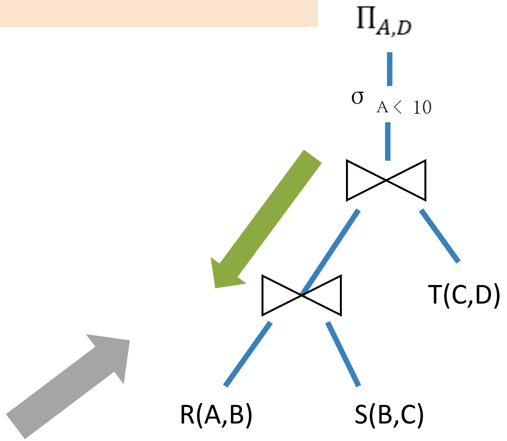
# Optimizing RA Plan

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;
```

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

Push down selection on A so it occurs earlier



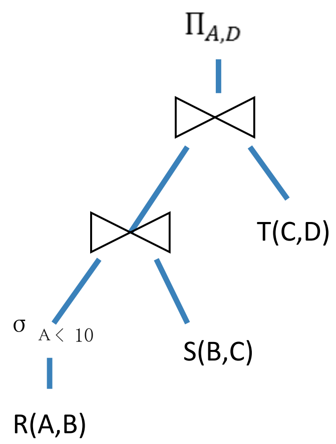
# Optimizing RA Plan

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

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

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

Push down selection on A so it occurs earlier



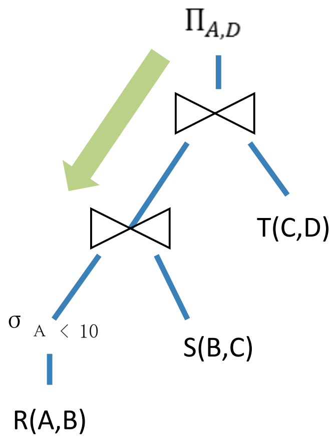
# Optimizing RA Plan

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;
```

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

Push down projection so it occurs earlier



# Optimizing RA Plan

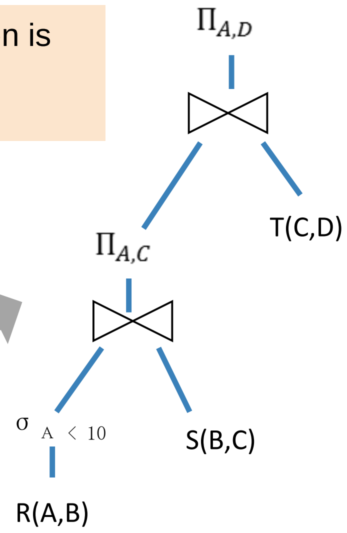
R(A,B)  S(B,C)  T(C,D)

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…?



# Basic RA 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!

# Takeaways

- This process is called logical optimization
- Many equivalent plans used to search for “good plans”
- Relational algebra is a simple and elegant abstraction

# THANK YOU!