Database Systems
CSE 414

Lectures 14: Relational Algebra (part 2) and Query Evaluation

(Ch. 5.2 & 16.3 (skim 16.3.2))

Join Summary

- **Theta-join**: $R \bowtie_\theta S = \sigma_\theta(R \times S)$
  - Join of R and S with a join condition θ
  - Cross-product followed by selection θ
- **Equijoin**: $R \bowtie_\theta S = \sigma_\theta(R \times S)$
  - Join condition θ consists only of equalities
- **Natural join**: $R \bowtie S = \pi_A (\sigma_\theta(R \times S))$
  - Equijoin
  - Equality on **all** fields with same name in R and in S
  - Projection π_A drops all redundant attributes

So Which Join Is It ?

When we write $R \bowtie S$ we usually mean an equijoin, but we often omit the equality predicate when it is clear from the context

More Joins

- **Outer join**
  - Include tuples with no matches in the output
  - Use NULL values for missing attributes
  - Does not eliminate duplicate columns
- Variants
  - Left outer join
  - Right outer join
  - Full outer join

Outer Join Example

AnonPatient P

age	zip	disease
54	98125	heart
20	98120	flu
33	98120	lung

AnonJob J

job	age	zip
lawyer	54	98125
cashier	20	98120

P ⟕ J

P.age	P.zip	disease	job	J.age	J.zip
54	98125	heart	lawyer	54	98125
20	98120	flu	cashier	20	98120
33	98120	lung	null	null	null

More Examples

```
Supplier(sno, sname, scity, sstate)
Part(pno, pname, psize, pcolor)
Supply(sno, pno, qty, price)
```

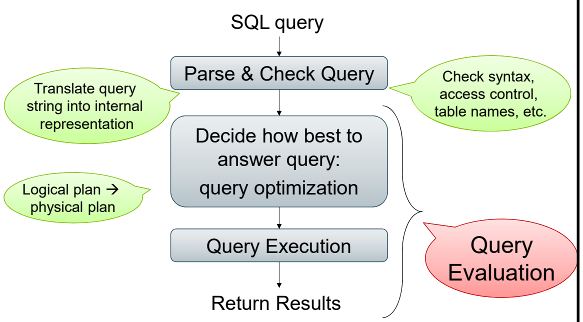
Name of supplier of parts with size greater than 10

$\pi_{sname}(Supplier \bowtie Supply \bowtie (\sigma_{psize>10}\ (Part))$

Name of supplier of red parts or parts with size greater than 10

$\pi_{sname}(Supplier \bowtie Supply \bowtie (\sigma_{psize>10}\ (Part) \cup \sigma_{pcolor='red'}\ (Part)\ )\ )$

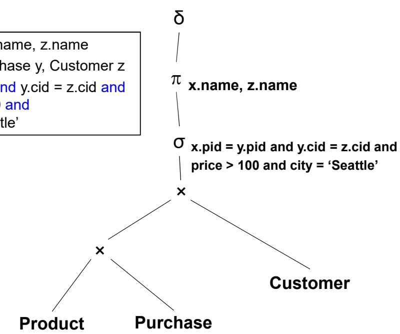
Query Evaluation Steps



Product(pid, name, price)
Purchase(pid, cid, store)
Customer(cid, name, city)

From SQL to RA

SELECT DISTINCT x.name, z.name
FROM Product x, Purchase y, Customer z
WHERE x.pid = y.pid and y.cid = z.cid and
x.price > 100 and
z.city = 'Seattle'

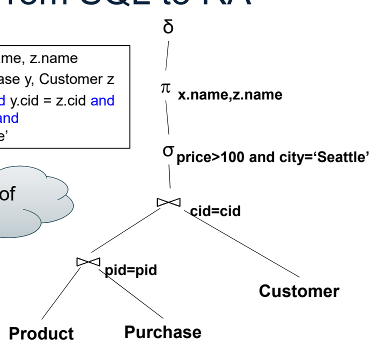


Product(pid, name, price)
Purchase(pid, cid, store)
Customer(cid, name, city)

From SQL to RA

SELECT DISTINCT x.name, z.name
FROM Product x, Purchase y, Customer z
WHERE x.pid = y.pid and y.cid = z.cid and
x.price > 100 and
z.city = 'Seattle'

Can you think of another plan?



Product(pid, name, price)
Purchase(pid, cid, store)
Customer(cid, name, city)

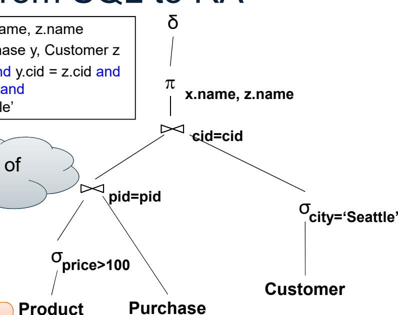
From SQL to RA

SELECT DISTINCT x.name, z.name
FROM Product x, Purchase y, Customer z
WHERE x.pid = y.pid and y.cid = z.cid and
x.price > 100 and
z.city = 'Seattle'

Can you think of another plan?

Push selections down the query plan!

Query optimization: find an equivalent optimal plan

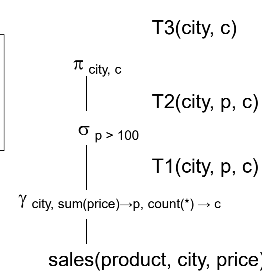


Extended RA: Operators on Bags

- Duplicate elimination δ
- Grouping & aggregation γ
- Sorting τ

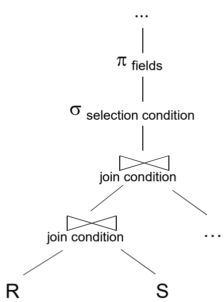
Logical Query Plan

SELECT city, count(*)
FROM sales
GROUP BY city
HAVING sum(price) > 100



T1, T2, T3 = temporary tables

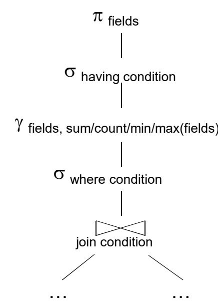
Typical Plan for Block (1/2)



SELECT fields
FROM R, S, …
WHERE condition

SELECT-PROJECT-JOIN Query

Typical Plan for Block (2/2)



SELECT fields
FROM R, S, …
WHERE condition
GROUP BY fields
HAVING condition

Supplier(sno, sname, scity, sstate)
Part(pno, pname, psize, pcolor)
Supply(sno, pno, price)

How about Subqueries?

```
SELECT  Q.sno
FROM Supplier Q
WHERE  Q.sstate = 'WA'
   and not exists
     (SELECT *
      FROM Supply P
      WHERE P.sno = Q.sno
         and P.price > 100)
```

Correlation !

Supplier(sno, sname, scity, sstate)
Part(pno, pname, psize, pcolor)
Supply(sno, pno, price)

How about Subqueries?

```
SELECT  Q.sno
FROM Supplier Q
WHERE  Q.sstate = 'WA'
   and not exists
     (SELECT *
      FROM Supply P
      WHERE P.sno = Q.sno
         and P.price > 100)
```

De-Correlation

```
SELECT  Q.sno
FROM Supplier Q
WHERE  Q.sstate = 'WA'
   and Q.sno not in
     (SELECT P.sno
      FROM Supply P
      WHERE P.price > 100)
```


Supplier(sno, sname, scity, sstate)
Part(pno, pname, psize, pcolor)
Supply(sno, pno, price)

How about Subqueries?

Un-nesting

```
(SELECT  Q.sno
 FROM Supplier Q
 WHERE  Q.sstate = 'WA')
   EXCEPT
 (SELECT P.sno
  FROM Supply P
  WHERE P.price > 100)
```

EXCEPT = set difference

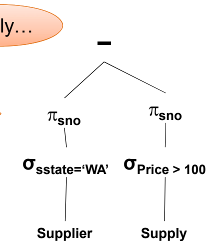
```
SELECT  Q.sno
FROM Supplier Q
WHERE  Q.sstate = 'WA'
   and Q.sno not in
     (SELECT P.sno
      FROM Supply P
      WHERE P.price > 100)
```


Supplier(sno, sname, scity, sstate)
Part(pno, pname, psize, pcolor)
Supply(sno, pno, price)

How about Subqueries?

```
(SELECT  Q.sno
 FROM Supplier Q
 WHERE  Q.sstate = 'WA')
   EXCEPT
 (SELECT P.sno
  FROM Supply P
  WHERE P.price > 100)
```

Finally…



From Logical Plans to Physical Plans

Physical Operators

Each of the logical operators may have one or more implementations = physical operators

Will discuss several basic physical operators, with a focus on join

Product(pid, name, price)
Purchase(pid, cid, store)

Main Memory Algorithms

Logical operator:

Product(pid, name, price) $\bowtie_{pid=pid}$ Purchase(pid, cid, store)

Propose three physical operators for the join, assuming the tables are in main memory:

1. Nested Loop Join O(??)
2. Merge join O(??)
3. Hash join O(??)

(note that pid is a key)

Product(pid, name, price)
Purchase(pid, cid, store)

Main Memory Algorithms

Logical operator:

Product(pid, name, price) $\bowtie_{pid=pid}$ Purchase(pid, cid, store)

Propose three physical operators for the join, assuming the tables are in main memory:

1. Nested Loop Join $O(n^2)$ — two nested loops
2. Merge join O(??)
3. Hash join O(??)

Product(pid, name, price)
Purchase(pid, cid, store)

Main Memory Algorithms

Logical operator:

Product(pid, name, price) $\bowtie_{pid=pid}$ Purchase(pid, cid, store)

Propose three physical operators for the join, assuming the tables are in main memory:

1. Nested Loop Join $O(n^2)$
2. Merge join O(n log n) — sort both – O(n log n); merge – O(n)
3. Hash join O(??)

Product(pid, name, price)
Purchase(pid, cid, store)

Main Memory Algorithms

Logical operator:

Product(pid, name, price) $\bowtie_{pid=pid}$ Purchase(pid, cid, store)

Propose three physical operators for the join, assuming the tables are in main memory:

1. Nested Loop Join $O(n^2)$
2. Merge join O(n log n)
3. Hash join O(n) … $O(n^2)$

add n to hash – O(n)?
lookup n in hash – O(n)?

BRIEF Review of Hash Tables

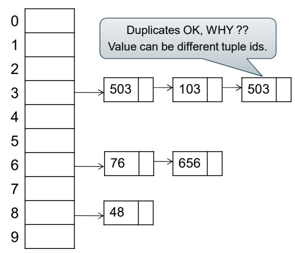
Separate chaining:

A (naïve) hash function:

h(x) = x mod 10

Operations:

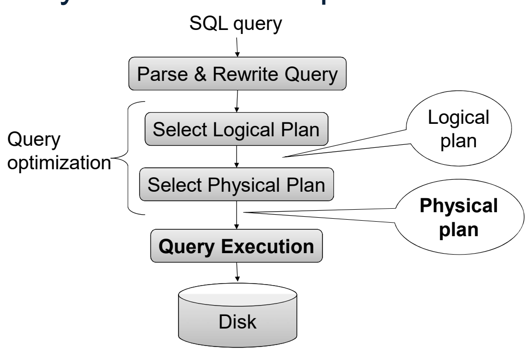
find(103) = ??
insert(488) = ??



BRIEF Review of Hash Tables

- insert(k, v) = inserts a key k with value v
- Many values for one key
  - Hence, duplicate k's are OK
- find(k) = returns the ***list*** of all values v associated to the key k

Query Evaluation Steps Review



Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Relational Algebra

```
SELECT sname
FROM Supplier x, Supply y
WHERE x.sid = y.sid
   and  y.pno = 2
   and x.scity = 'Seattle'
   and x.sstate = 'WA'
```

Give a relational algebra expression for this query

Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Relational Algebra

```
SELECT sname
FROM Supplier x, Supply y
WHERE x.sid = y.sid
   and  y.pno = 2
   and x.scity = 'Seattle'
   and x.sstate = 'WA'
```

$\pi_{sname}(\sigma_{scity='Seattle' \wedge sstate='WA' \wedge pno=2}(Supplier \bowtie_{sid=sid} Supply))$

Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Relational Algebra

```
SELECT sname
FROM Supplier x, Supply y
WHERE x.sid = y.sid
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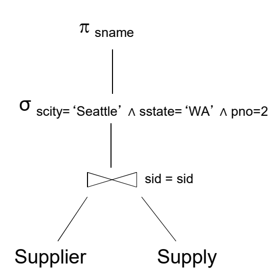
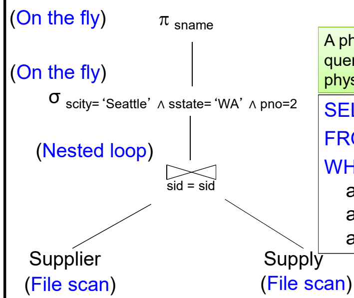


Relational algebra expression is also called the "logical query plan"

Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Physical Query Plan 1

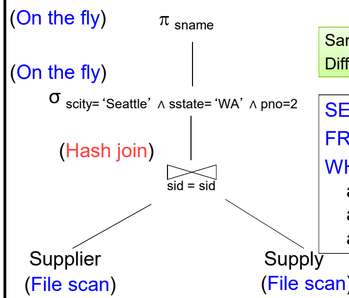


A physical query plan is a logical query plan annotated with physical implementation details

```
SELECT sname
FROM Supplier x, Supply y
WHERE x.sid = y.sid
   and  y.pno = 2
   and x.scity = 'Seattle'
   and x.sstate = 'WA'
```


Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Physical Query Plan 2



Same logical query plan
Different physical plan

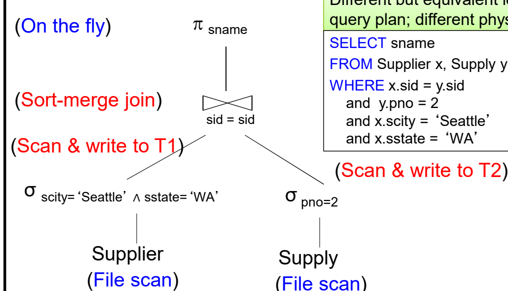
```
SELECT sname
FROM Supplier x, Supply y
WHERE x.sid = y.sid
   and  y.pno = 2
   and x.scity = 'Seattle'
   and x.sstate = 'WA'
```


Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Physical Query Plan 3

Different but equivalent logical query plan; different physical plan

```
SELECT sname
FROM Supplier x, Supply y
WHERE x.sid = y.sid
   and  y.pno = 2
   and x.scity = 'Seattle'
   and x.sstate = 'WA'
```



Query Optimization Problem

- For each SQL query… many logical plans
- For each logical plan… many physical plans
- How to find a fast physical plan?
  - Will discuss in a few lectures