Database Systems
CSE 414

Lectures 9: Relational Algebra (part 2) and Query Evaluation

(Ch. 5.2 & 16.3 (skim 16.3.2))

Announcements

- Should have used SQL / Azure now
  - let us know if you had any setup problems
- WQ3 is due on Sunday
- HW3 is due one week from Tuesday
- HW1 grades *should* be posted tonight

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)
```

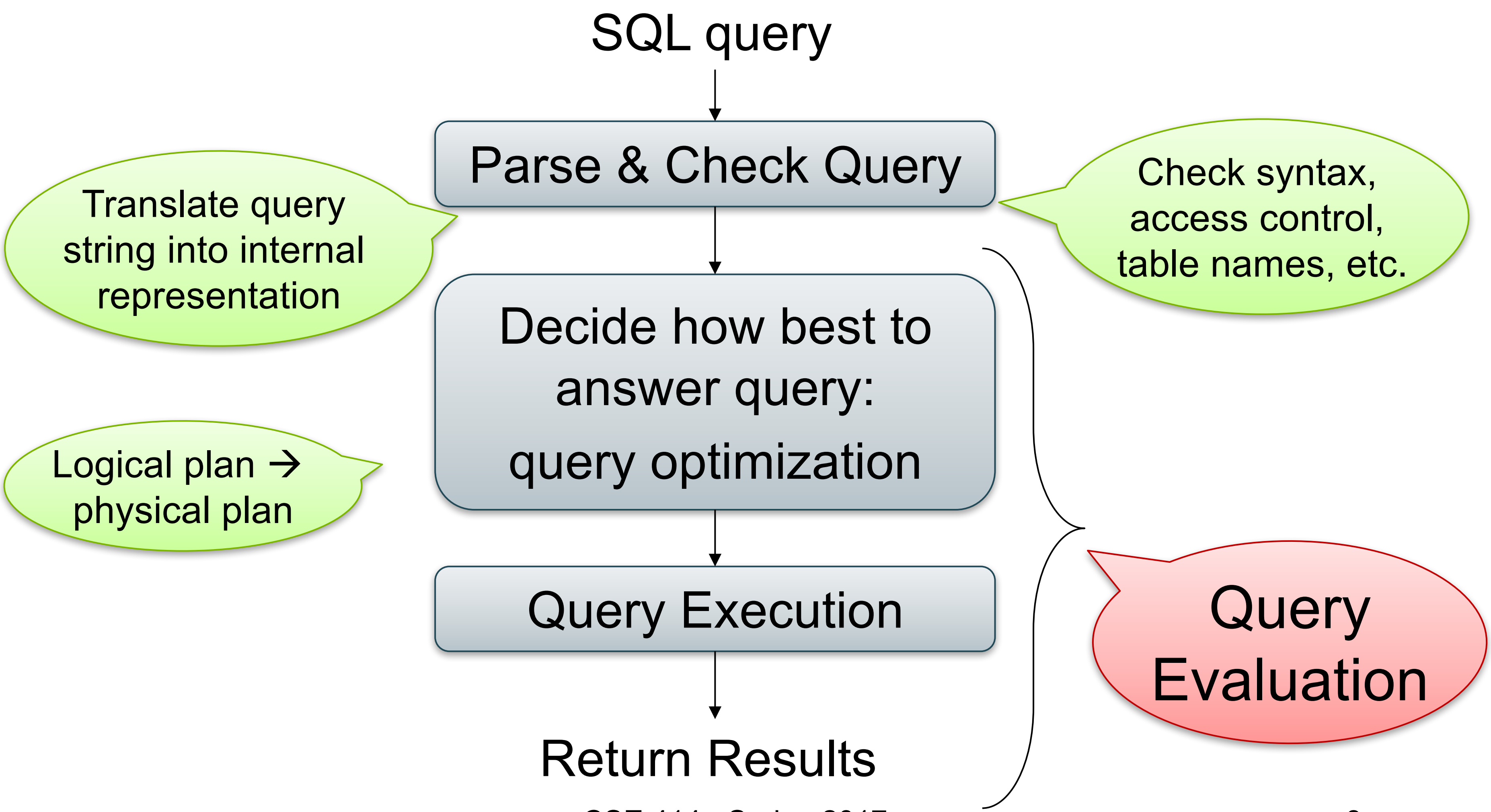
Name of supplier of parts with size greater than 10

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

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

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

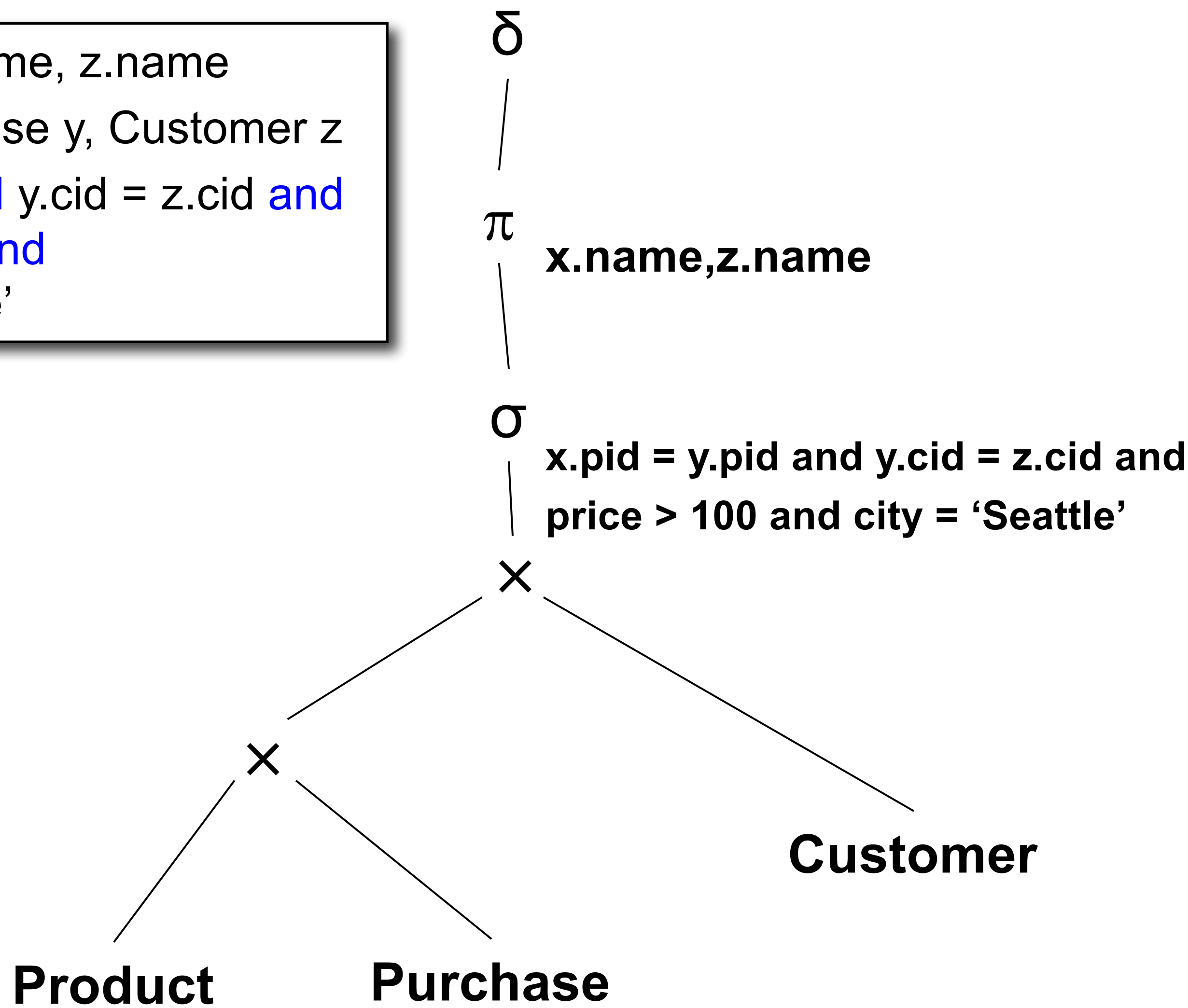
Query Evaluation Steps



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

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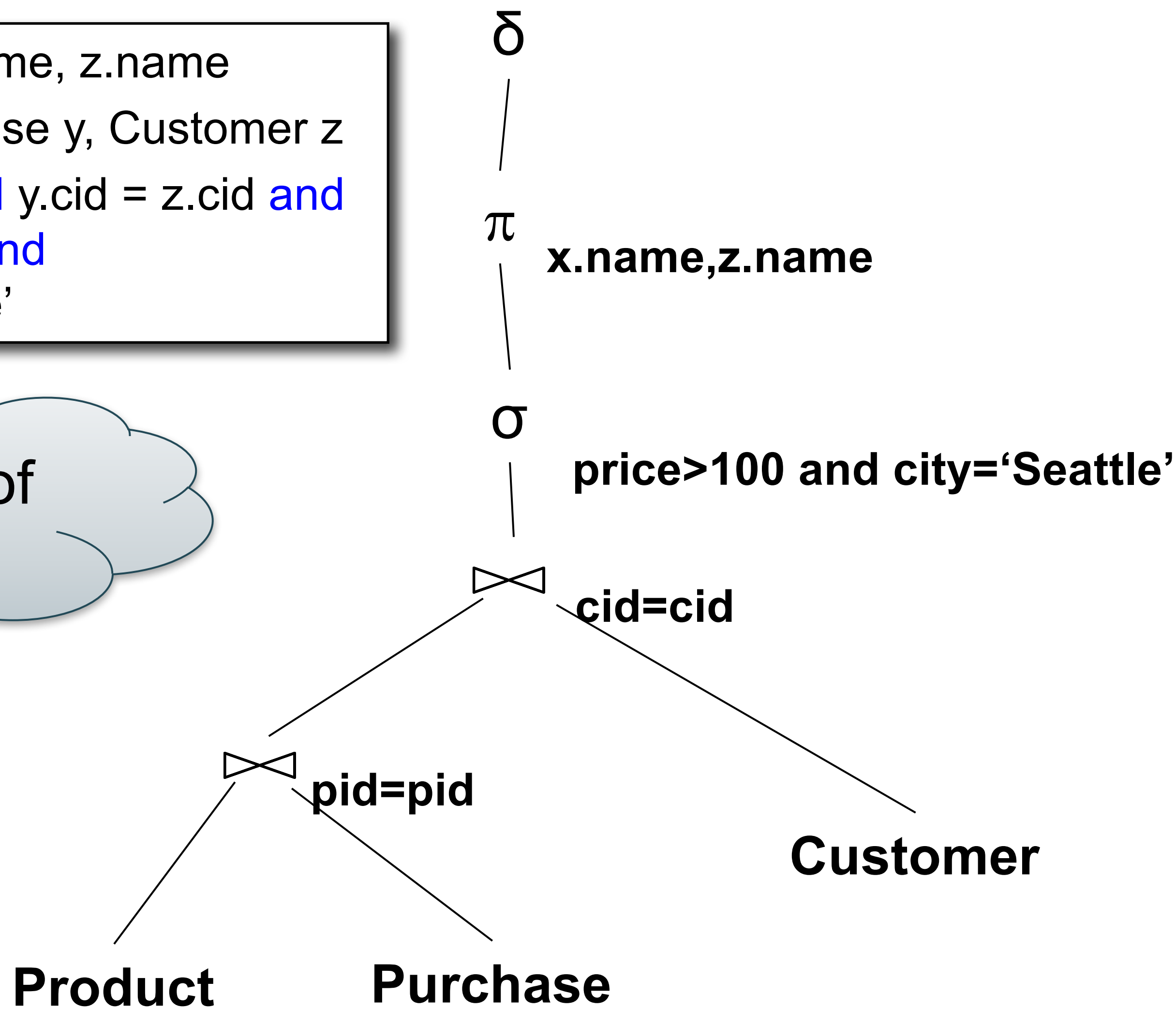

Can you think of another plan?

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
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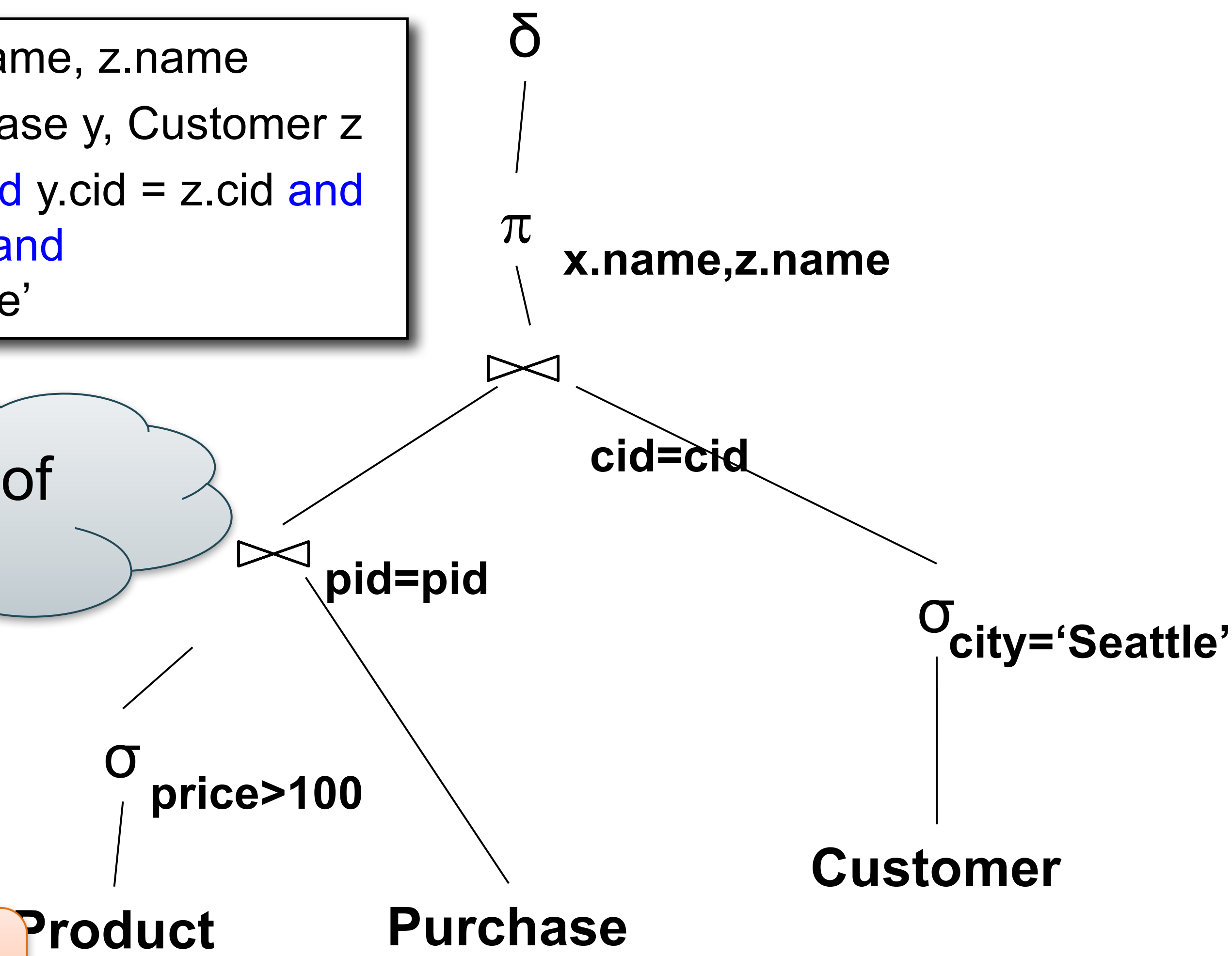


Can you think of another plan?

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
```

T3(city, c)

$\pi_{\text{city, c}}$

T2(city,p,c)

$\sigma_{\text{p > 100}}$

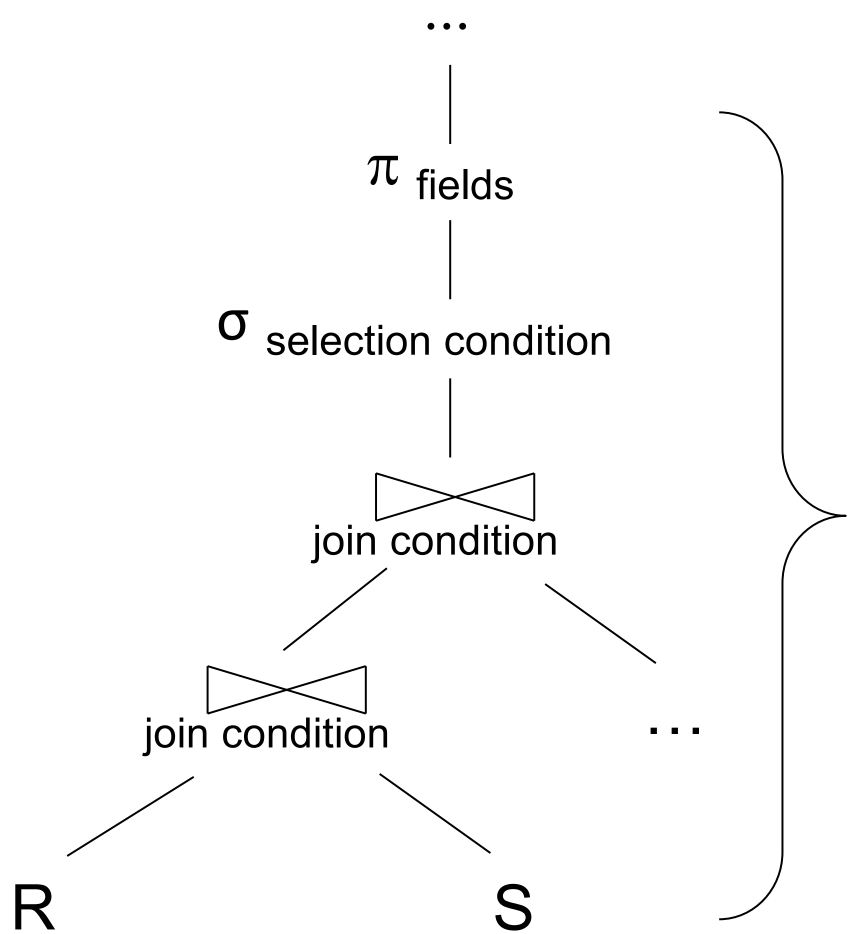
T1(city,p,c)

$\gamma_{\text{city, sum(price)} \rightarrow \text{p, count(*)} \rightarrow \text{c}}$

sales(product, city, price)

T1, T2, T3 = temporary tables

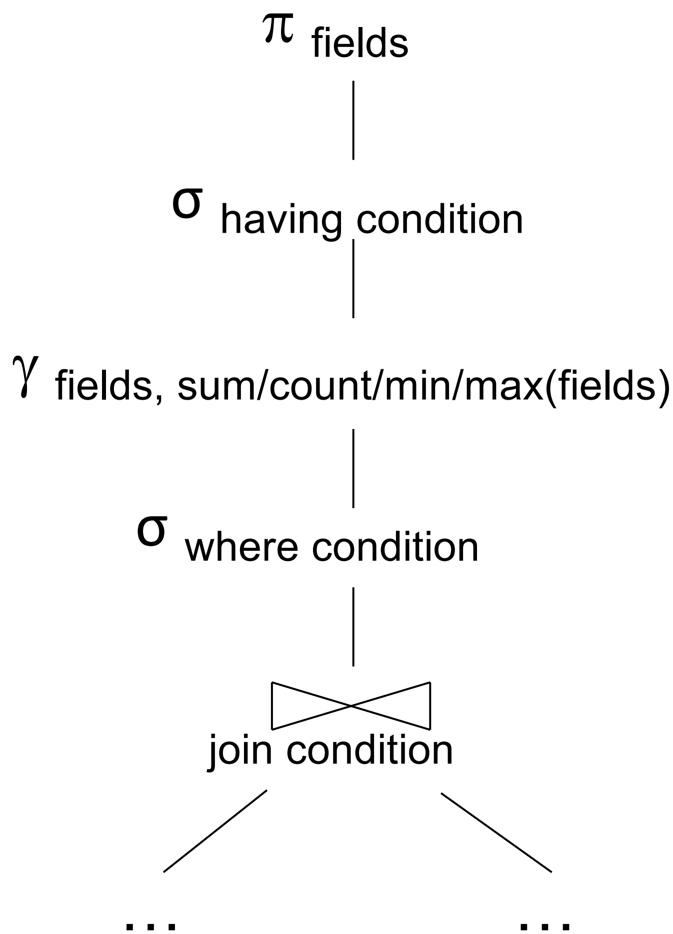
Typical Plan for Block (1/2)



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)
```

```
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)
```

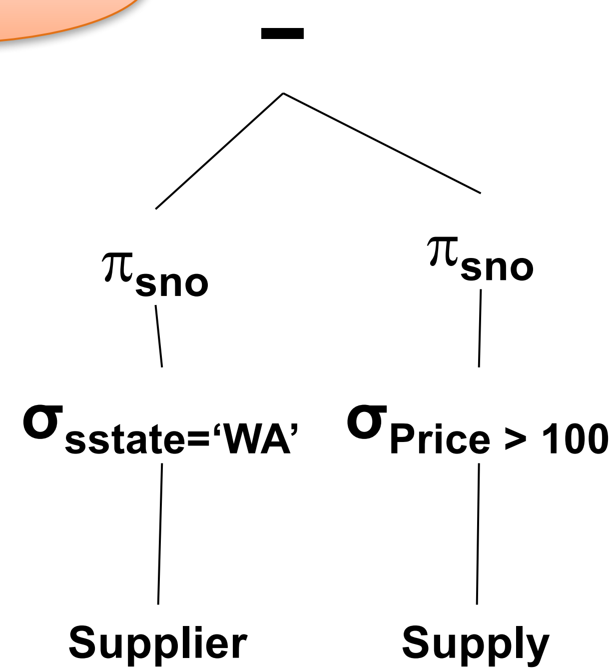
EXCEPT = set difference

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 $O(n \log n)$
3. Hash join $O(\ ??\ )$

sort both – $O(n \log n)$
merge – $O(n)$

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 $O(n) \ldots O(n^2)$

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

BRIEF Review of Hash Tables

A (naïve) hash function:

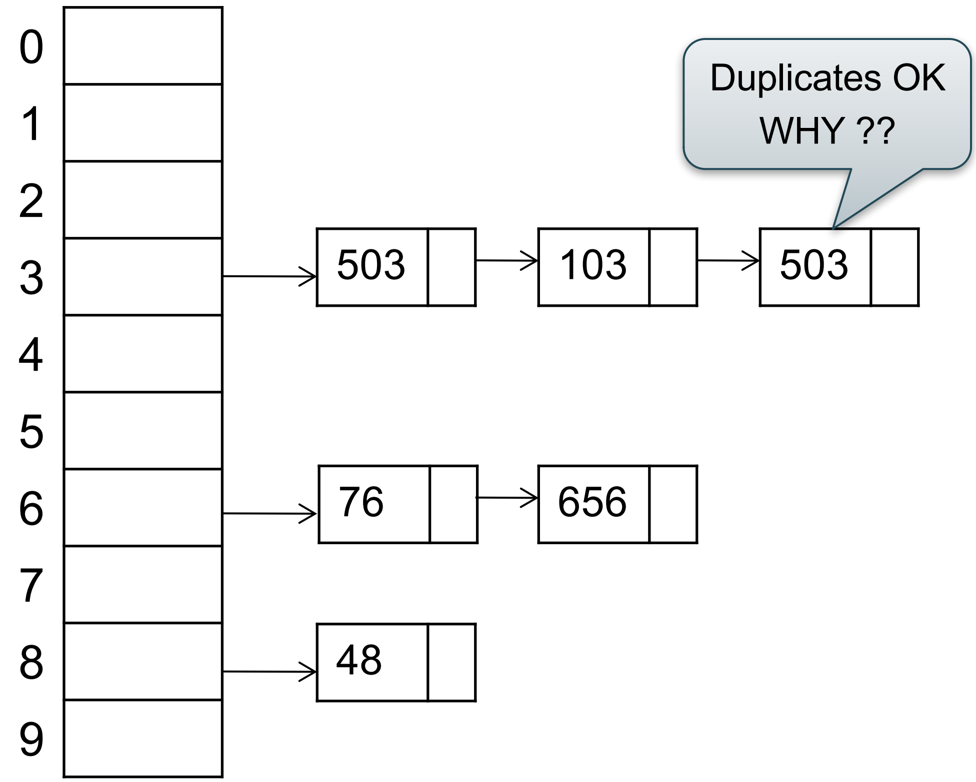
$h(x) = x \bmod 10$

Operations:

find(103) = ??

insert(488) = ??

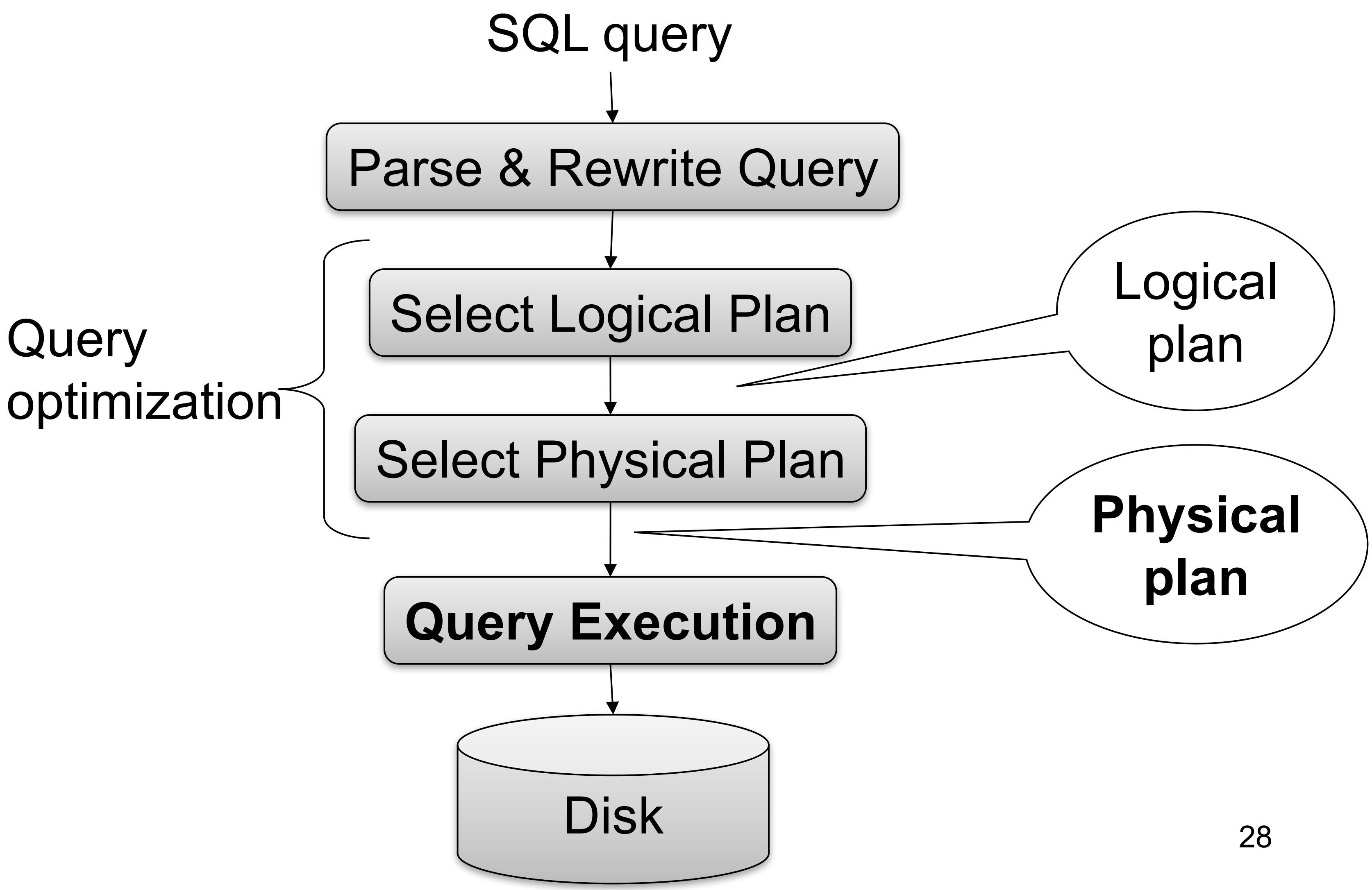
Separate chaining:



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(<u>sid</u>, sname, scity, sstate)
Supply(<u>sid, pno</u>, 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(<u>sid</u>, sname, scity, sstate)
Supply(<u>sid, pno</u>, 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(<u>sid</u>, sname, scity, sstate)
Supply(<u>sid, pno</u>, quantity)

Relational Algebra

```
SELECT sname
FROM Supplier x, Supply y
WHERE x.sid = y.sid
   and  y.pno = 2
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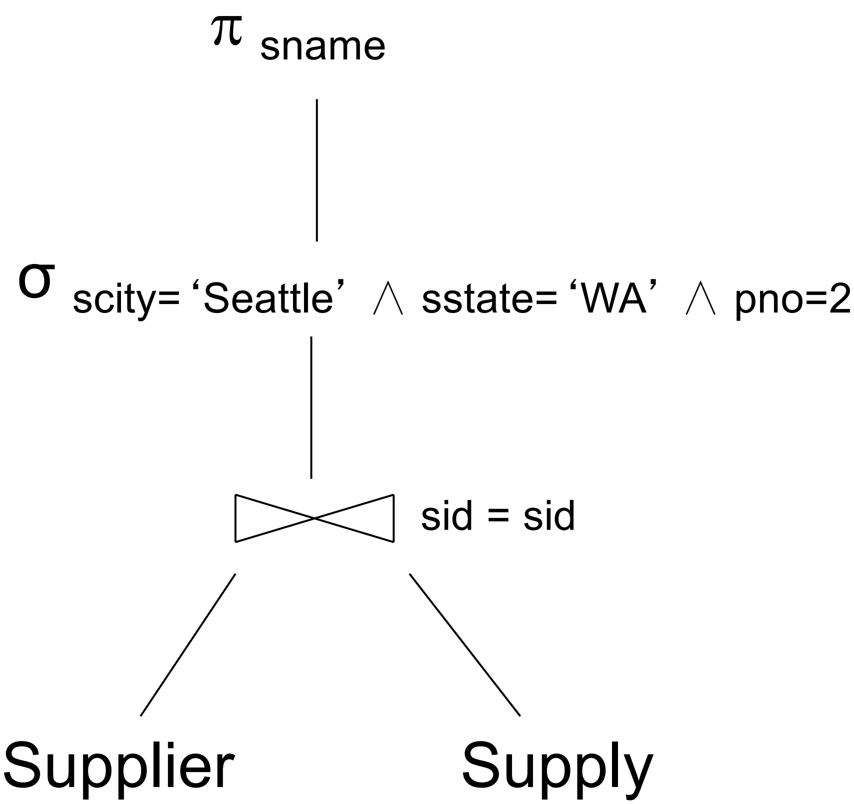
```



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

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

Physical Query Plan 1

(On the fly) π_{sname}

(On the fly) $\sigma_{\text{scity='Seattle'} \wedge \text{sstate='WA'} \wedge \text{pno=2}}$

(Nested loop) $\bowtie_{\text{sid = sid}}$

Supplier (File scan)

Supply (File scan)

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(<u>sid</u>, sname, scity, sstate)

Supply(<u>sid, pno</u>, quantity)

Physical Query Plan 2

(On the fly) π_{sname}

(On the fly) $\sigma_{\text{scity= 'Seattle'} \wedge \text{sstate= 'WA'} \wedge \text{pno=2}}$

(Hash join) $\bowtie_{\text{sid = sid}}$

Supplier (File scan)

Supply (File scan)

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'
```

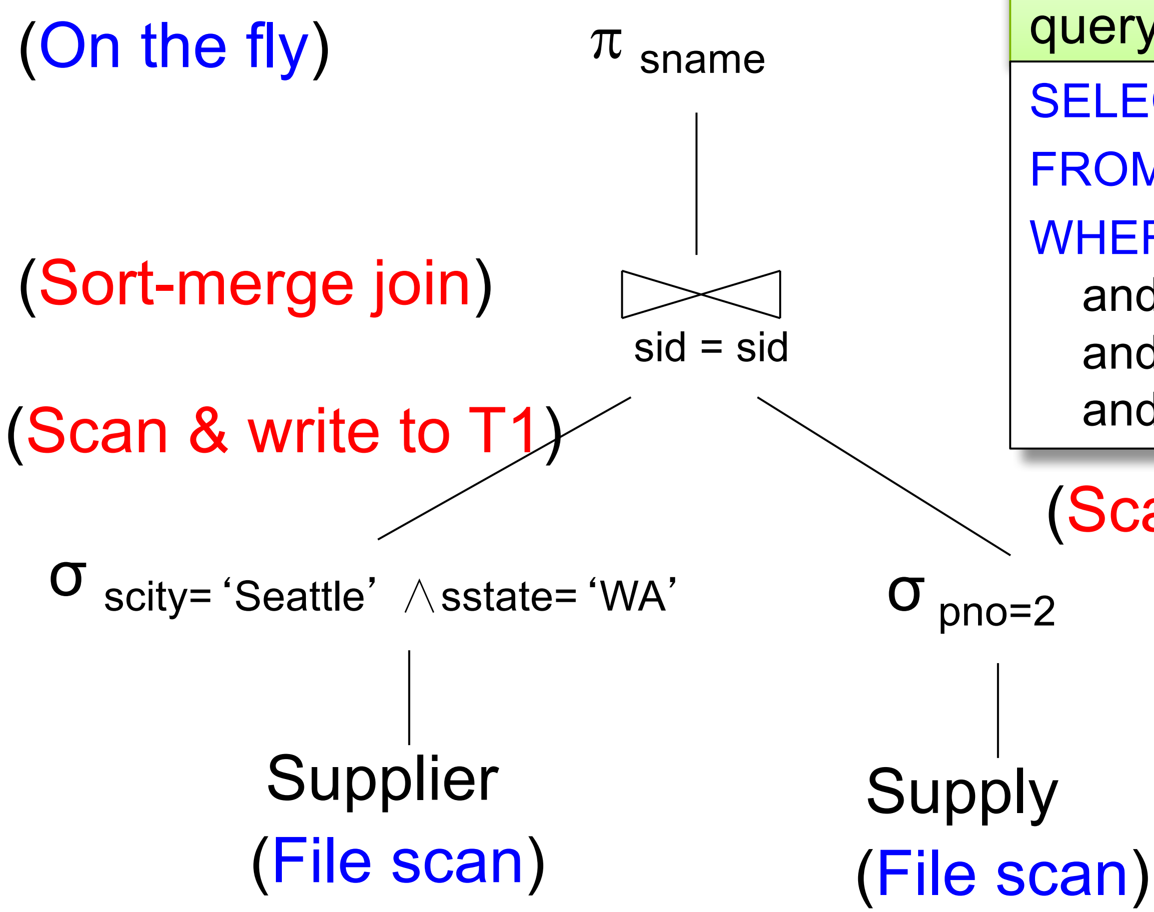
Supplier(<u>sid</u>, sname, scity, sstate)

Supply(<u>sid, pno</u>, 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 do find a fast physical plan?
  - Will discuss in a few lectures