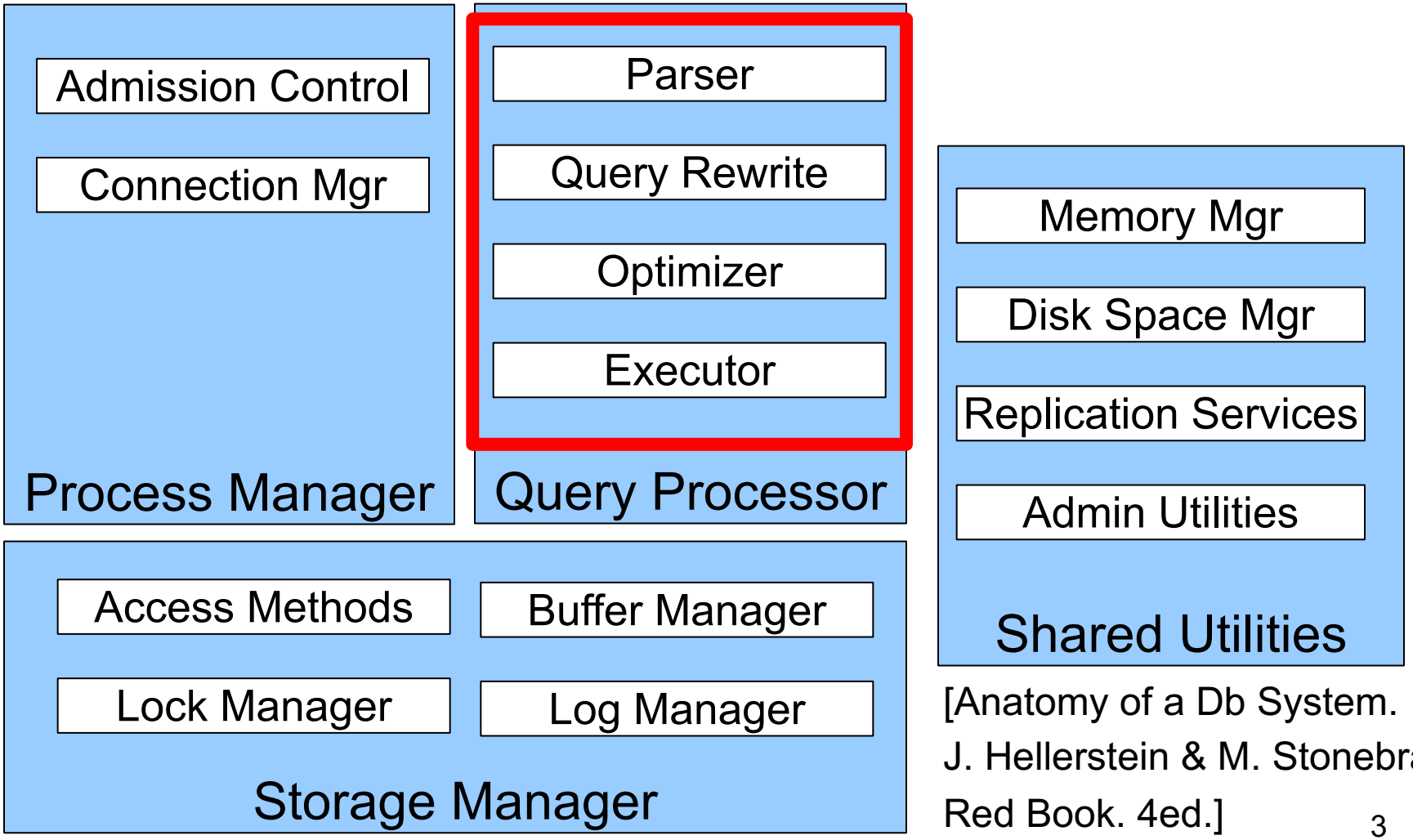
DATA516/CSED516
Scalable Data Systems and Algorithms

Lecture 2 Query Execution and Optimization

Announcements

- Paper reviews are due before the beginning of the class
- HW1 is due next Tuesday
- Please start thinking about the project

DBMS Architecture



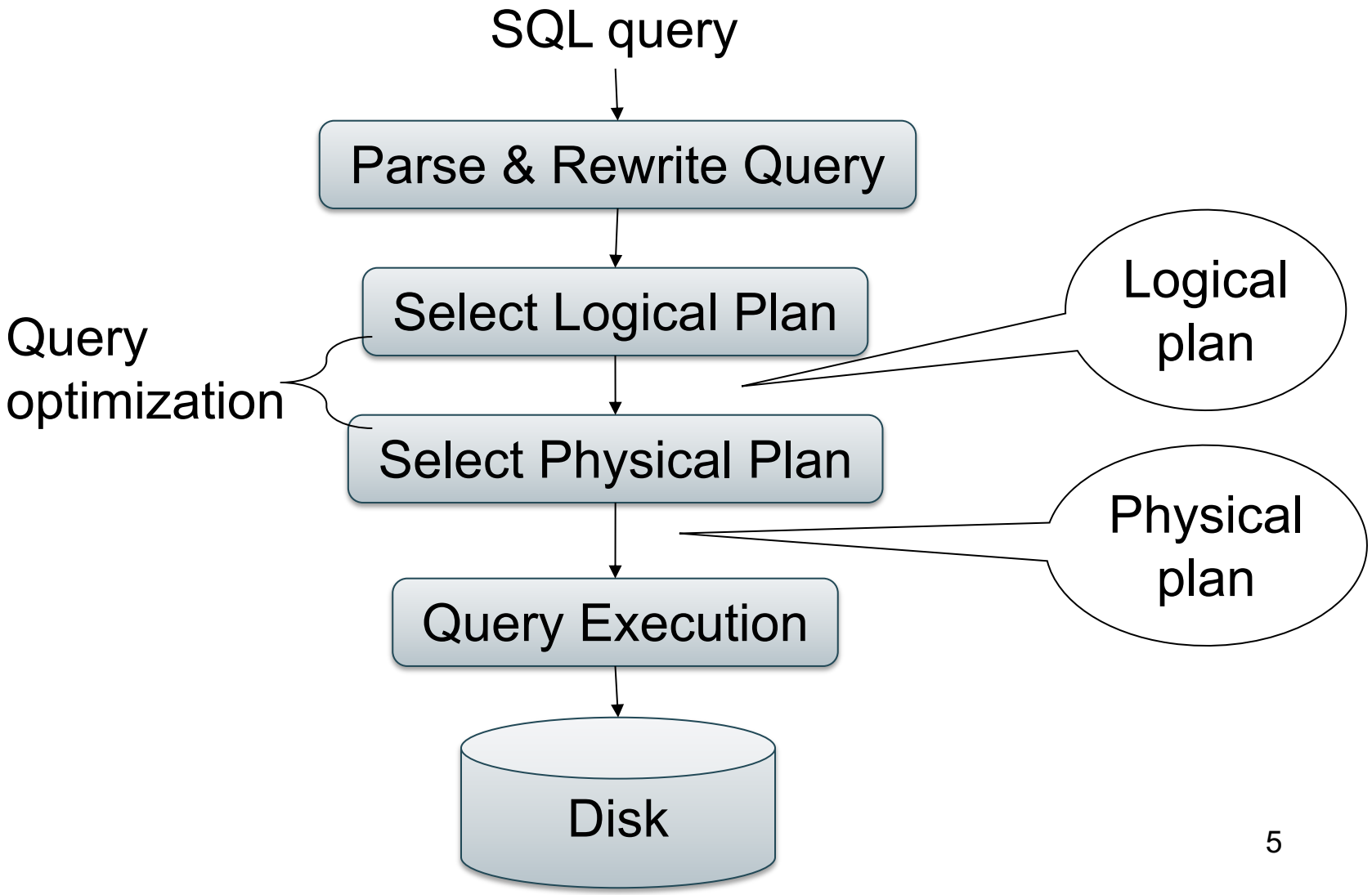
[Anatomy of a Db System. J. Hellerstein & M. Stonebraker. Red Book. 4ed.]

Warning: it will be confusing…

DBMS are monoliths: all components must work together and cannot be isolated

- Good news:
  - Hole system has rich functionality and is efficient
- Bad news:
  - Hard to discuss components in isolation
  - Impossible to use components in isolation

Lifecycle of a Query



Example Database Schema

Supplier(sno,sname,scity,sstate)

Part(pno,pname,psize,pcolor)

Supply(sno,pno,price)

View: Suppliers in Seattle

```
CREATE VIEW NearbySupp AS
SELECT sno, sname
FROM Supplier
WHERE scity='Seattle' AND sstate='WA'
```

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

Example Query

- Find the names of all suppliers in Seattle who supply part number 2

```
SELECT sno, sname FROM NearbySupp
WHERE sno IN (     SELECT sno
                   FROM Supply
                   WHERE pno = 2 )
```

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

View Rewriting, Flattening

Original query:

```
SELECT sno, sname
FROM NearbySupp
WHERE sno IN (SELECT sno
              FROM Supply
              WHERE pno = 2 )
```

View rewriting
= view inlining
= view expansion

Flattening
= unnesting

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

View Rewriting, Flattening

Original query:

```
SELECT sno, sname
FROM NearbySupp
WHERE sno IN (SELECT sno
              FROM Supply
              WHERE pno = 2 )
```

Rewritten query:

```
SELECT DISTINCT S.sno, S.sname
FROM Supplier S, Supply U
WHERE S.scity='Seattle' AND S.sstate='WA'
AND S.sno = U.sno
AND U.pno = 2;
```

View rewriting
= view inlining
= view expansion

Flattening
= unnesting

Reasoning about sets/bags

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

Decorrelation

```
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)
```

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

Decorrelation

```
SELECT  Q.sno
FROM Supplier Q
WHERE  Q.sstate = 'WA'
   and not exists
      (SELECT *
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Supplier(sno,sname,scity,sstate)
Part(pno,pname,psize,pcolor)
Supply(sno,pno,price)

Decorrelation

```
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)

Decorrelation

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

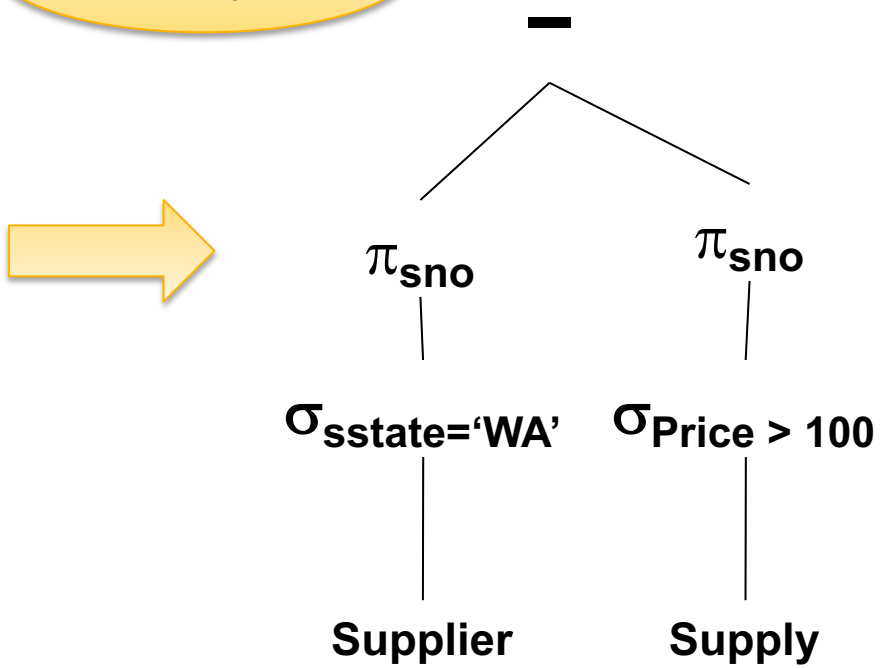
```
SELECT  Q.sno
FROM Supplier Q
WHERE  Q.sstate = 'WA'
   and Q.sno not in
      (SELECT P.sno
       FROM Supply P
       WHERE P.price > 100)
```

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

Decorrelation

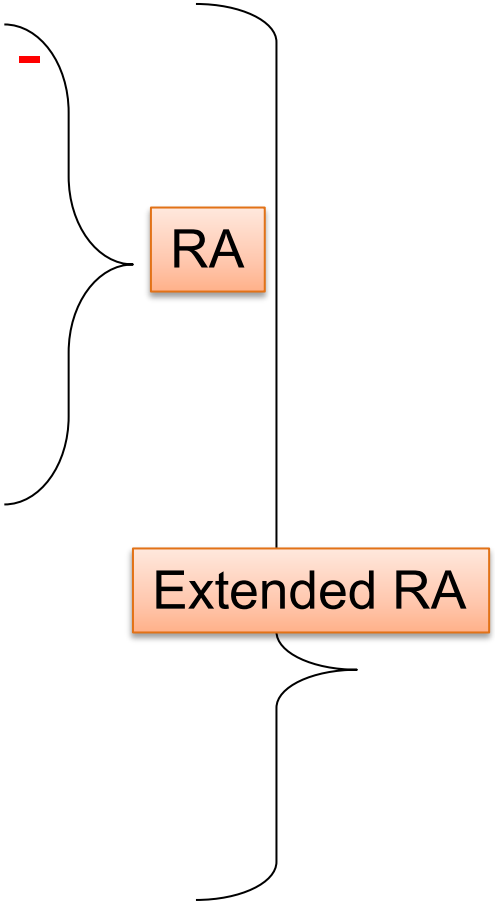
```
(SELECT  Q.sno
 FROM Supplier Q
 WHERE  Q.sstate = 'WA')
   EXCEPT
 (SELECT P.sno
  FROM Supply P
  WHERE P.price > 100)
```

Finally…

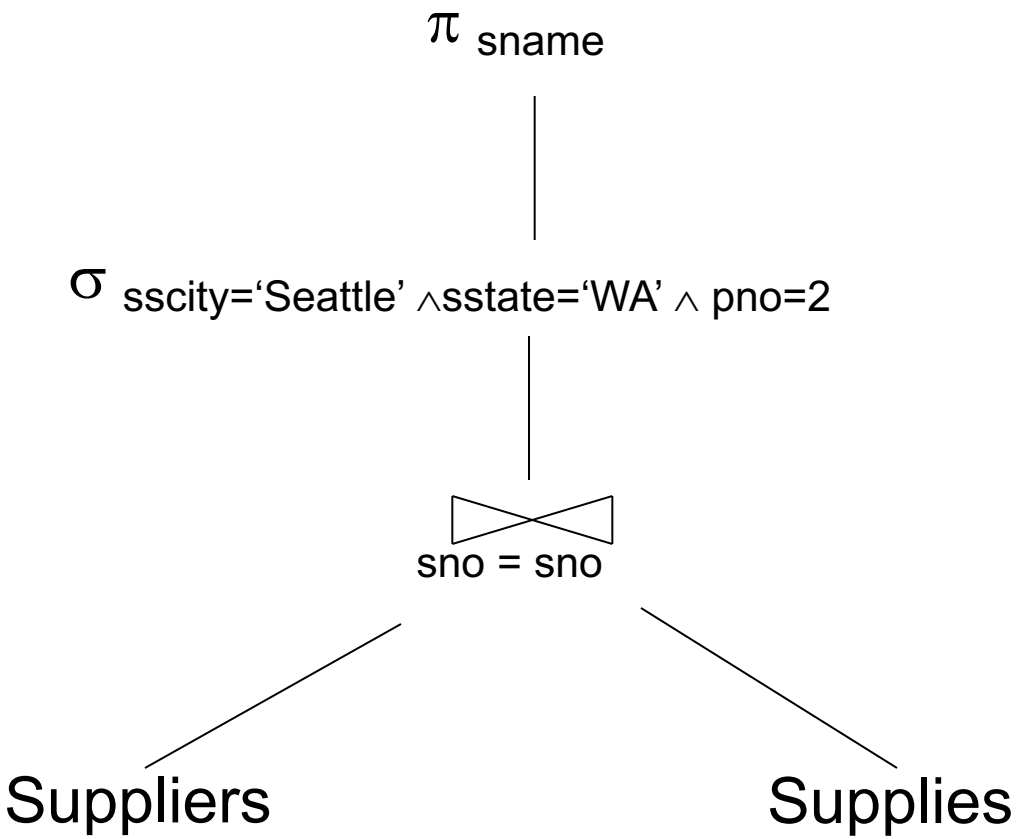


Relational Algebra Operators

- Union ∪, ~~intersection ∩~~, difference -
- Selection σ
- Projection π
- Cartesian product ×, join ⋈
- (Rename ρ)
- Duplicate elimination δ
- Grouping and aggregation γ
- Sorting τ



Logical Query Plan

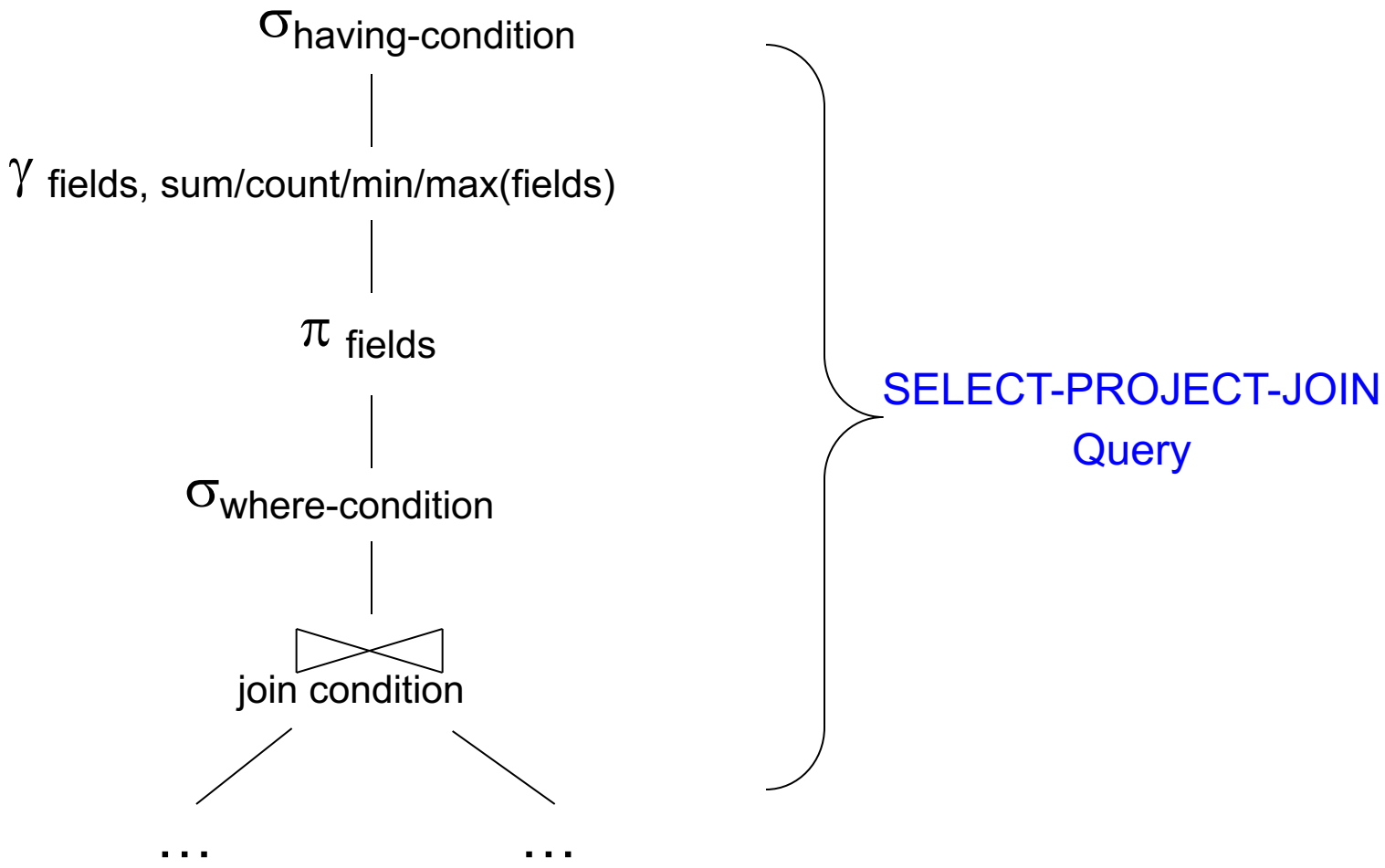


Query Block

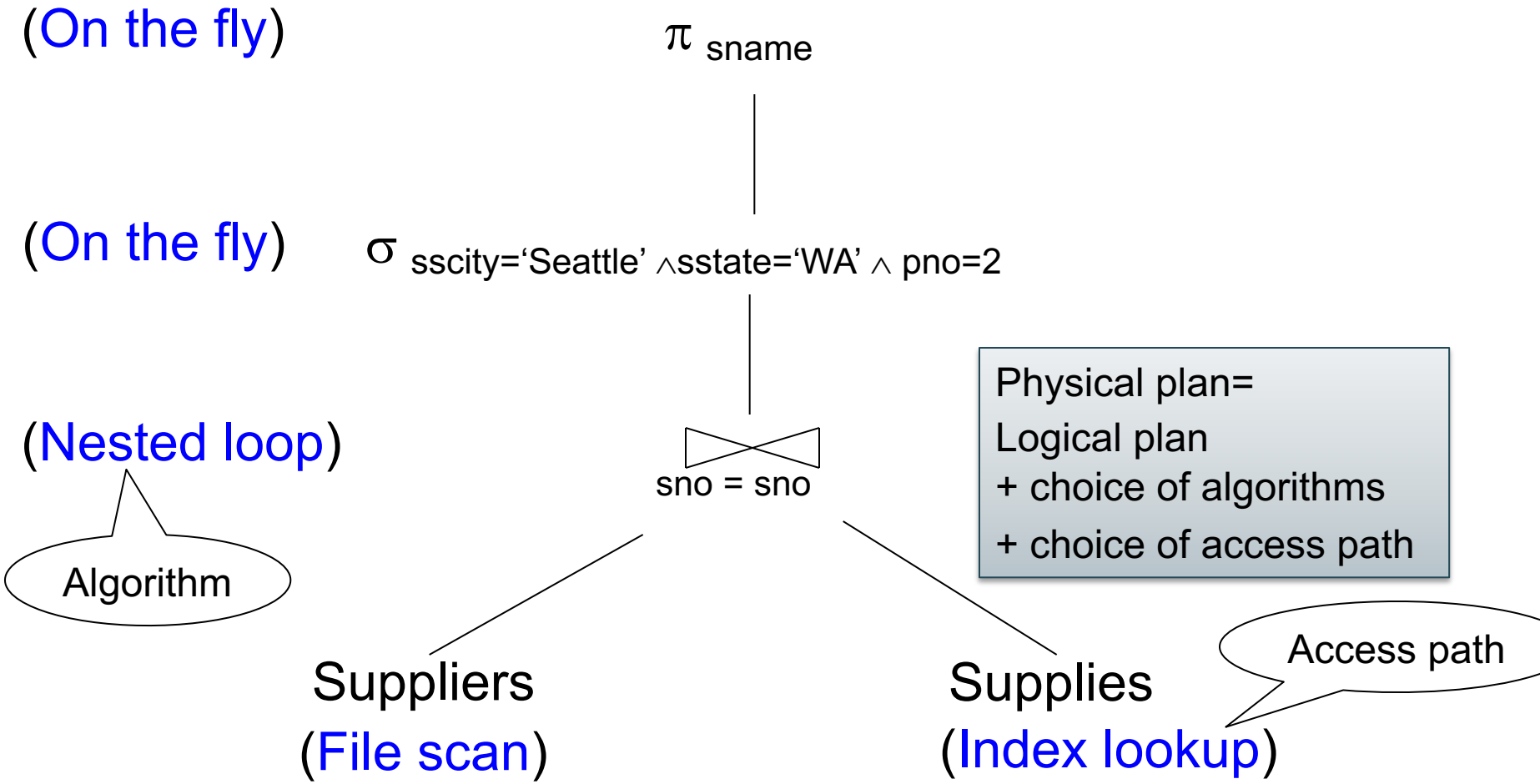
- Most optimizers operate on individual query blocks

- A query block is an SQL query with **no nesting**
  - **Exactly one**
    - SELECT clause
    - FROM clause
  - **At most one**
    - WHERE clause
    - GROUP BY clause
    - HAVING clause

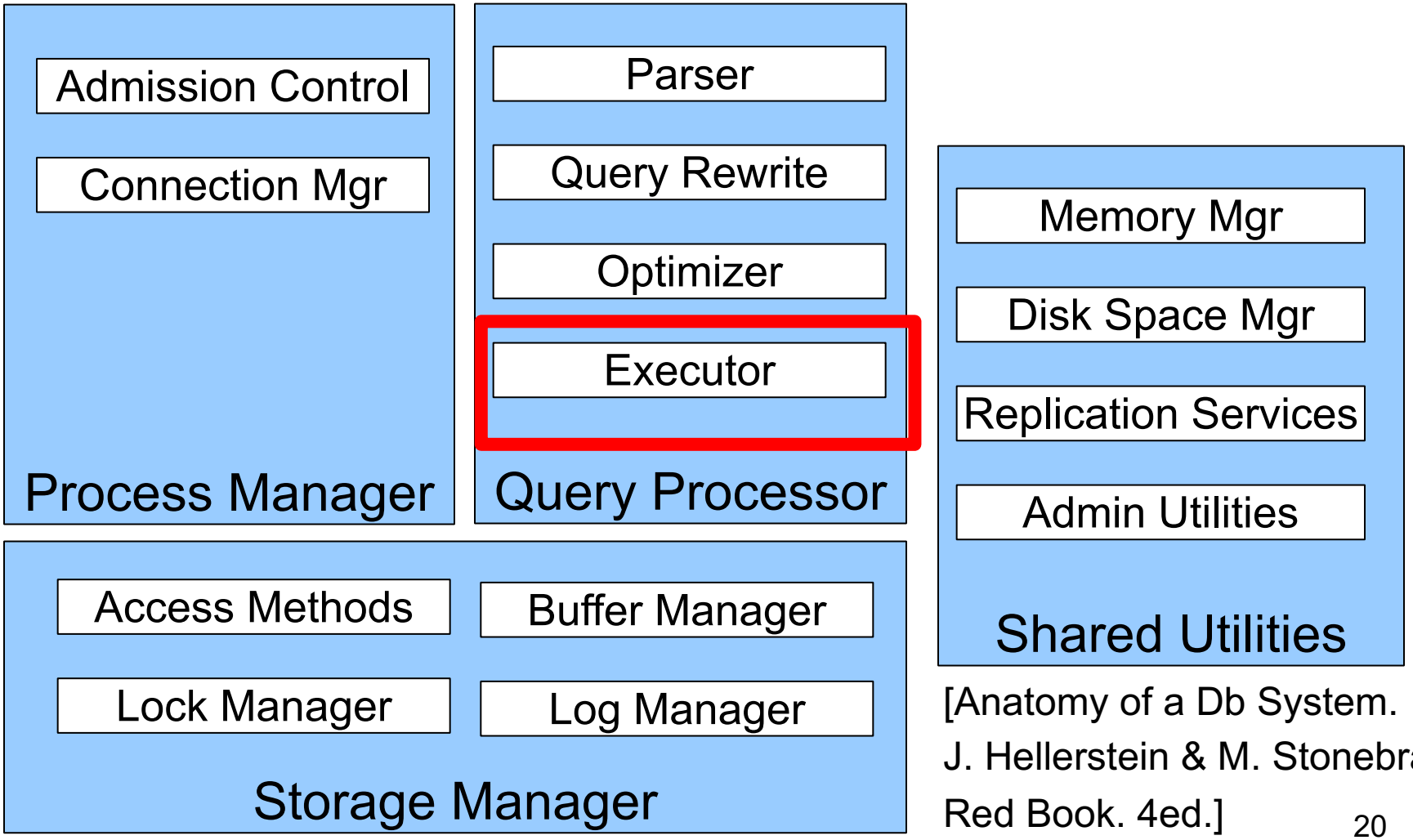
Query Plan For A Block



Physical Query Plan

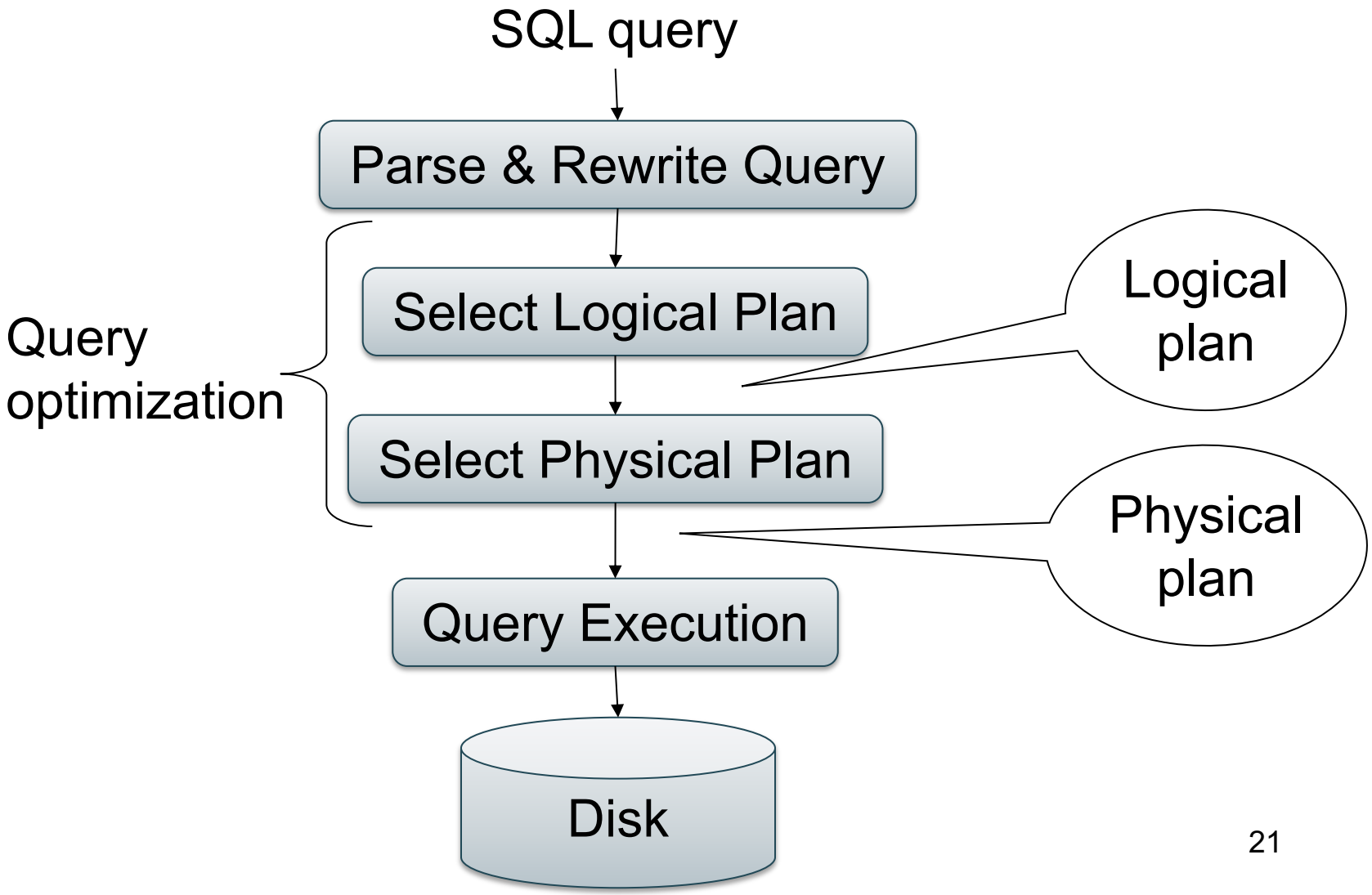


DBMS Architecture



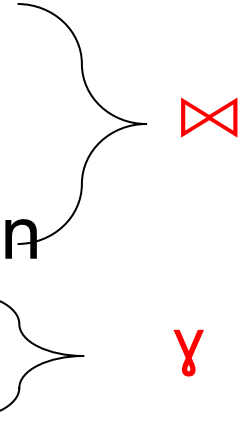
[Anatomy of a Db System. J. Hellerstein & M. Stonebraker. Red Book. 4ed.]

Lifecycle of a Query



Physical Operators

- For each operator, several algorithms
- Main memory or external memory
- Examples:
  - Main memory hash join
  - External memory merge join
  - External memory partitioned hash join
  - Sort-based group by
  - Hash-based group by



Supplier(sid, sname, scity, sstate)

Supply(sid, pno, quantity)

Main Memory Algorithms

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

Three algorithms:

1. Nested Loops
2. Hash-join
3. Merge-join

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

1. Nested Loop Join

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

```
for x in Supplier do
   for y in Supply do
      if x.sid = y.sid
         then output(x,y)
```

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

1. Nested Loop Join

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

```
for x in Supplier do
   for y in Supply do
      if x.sid = y.sid
         then output(x,y)
```

If |R|=|S|=n,
what is the runtime?

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

1. Nested Loop Join

Logical operator:

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```
for x in Supplier do
   for y in Supply do
      if x.sid = y.sid
         then output(x,y)
```

If |R|=|S|=n,
what is the runtime?

$O(n^2)$

BRIEF Review of Hash Tables

A (naïve) hash function:

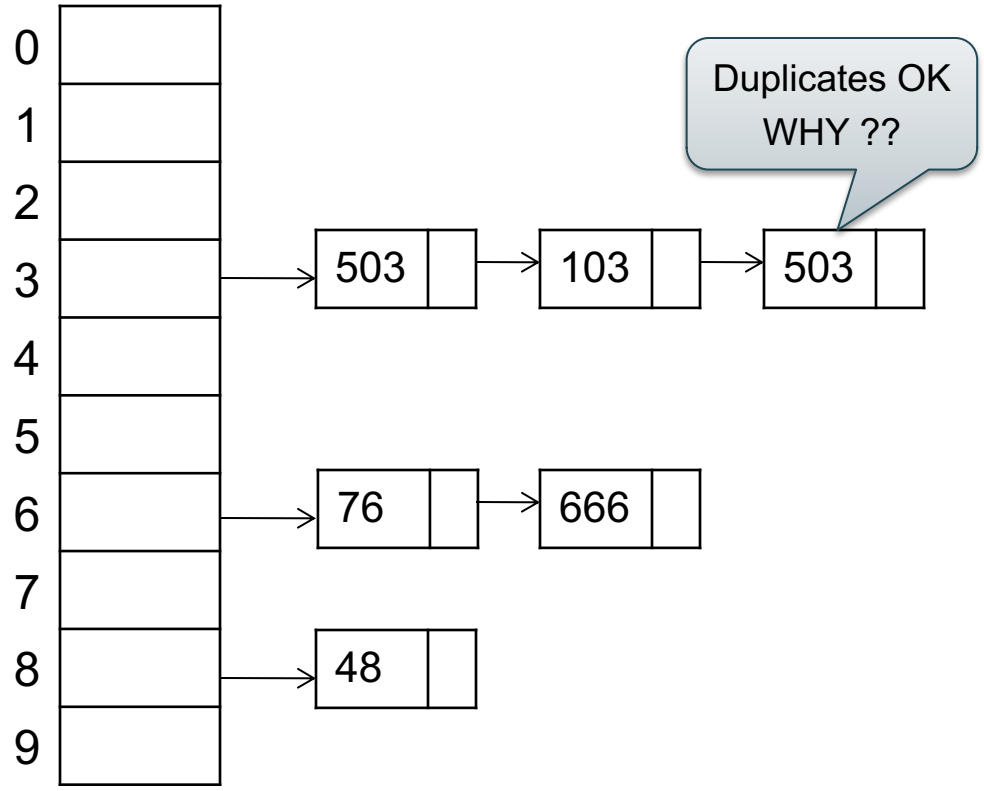
$$h(x) = x \bmod 10$$

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

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

2. Hash Join

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

Build phase

```
for x in Supplier do
    insert(x.sid, x)
```

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

2. Hash Join

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

Build phase

```
for x in Supplier do
    insert(x.sid, x)
```

Probe phase

```
for y in Supply do
    x = find(y.sid);
    output(x,y);
```

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

2. Hash Join

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

Build phase

```
for x in Supplier do
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for y in Supply do
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Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

2. Hash Join

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for x in Supplier do
    insert(x.sid, x)
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Probe phase

```
for y in Supply do
    x = find(y.sid);
    output(x,y);
```

If |R|=|S|=n,
what is the runtime?

O(n)

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

2. Hash Join

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

Change join order

```
for y in Supply do
      insert(y.sid, y)

for x in Supplier do ??
```

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

2. Hash Join

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

Change join order

```
for y in Supply do
      insert(y.sid, y)

for x in Supplier do
    for y in find(x.sid) do
          output(x,y);
```

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

2. Hash Join

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

Change join order

```
for y in Supply do
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for x in Supplier do
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If |R|=|S|=n,
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Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

2. Hash Join

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

Change join order

```
for y in Supply do
    insert(y.sid, y)

for x in Supplier do
    for y in find(x.sid) do
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If |R|=|S|=n,
what is the runtime?

O(n)

But can be $O(n^2)$ why?

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

2. Hash Join

Why would we change the order?

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

Change join order

```
for y in Supply do
    insert(y.sid, y)

for x in Supplier do
    for y in find(x.sid) do
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If |R|=|S|=n,
what is the runtime?

O(n)

But can be $O(n^2)$ why?

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

2. Hash Join

Why would we change the order?

When |Supply| << |Supplier|

Change join order

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

```
for y in Supply do
    insert(y.sid, y)

for x in Supplier do
    for y in find(x.sid) do
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If |R|=|S|=n,
what is the runtime?

O(n)

But can be $O(n^2)$ why?

Supplier(sid, sname, scity, sstate)

Supply(sid, pno, quantity)

3. Merge Join

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

```
Sort(Supplier); Sort(Supply);
x = Supplier.first();
y = Supply.first();
```

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

3. Merge Join

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

```
Sort(Supplier); Sort(Supply);
x = Supplier.first();
y = Supply.first();
while y != NULL do
  case:
    x.sid < y.sid: ???
    x.sid = y.sid: ???
    x.sid > y.sid: ???
```

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

3. Merge Join

Logical operator:

Supplier $\bowtie_{sid=sid}$ Supply

```
Sort(Supplier); Sort(Supply);
x = Supplier.first();
y = Supply.first();
while y != NULL do
  case:
    x.sid < y.sid: x = x.next()
    x.sid = y.sid: ???
    x.sid > y.sid: ???
```

Supplier(sid, sname, scity, sstate)
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    x.sid > y.sid: ???
```

Supplier(sid, sname, scity, sstate)

Supply(sid, pno, quantity)

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Supplier(sid, sname, scity, sstate)
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```

If |R|=|S|=n,
what is the runtime?

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

3. Merge Join

Logical operator:

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while y != NULL do
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    x.sid < y.sid: x = x.next()
    x.sid = y.sid: output(x,y); y = y.next();
    x.sid > y.sid: y = y.next();
```

If |R|=|S|=n,
what is the runtime?

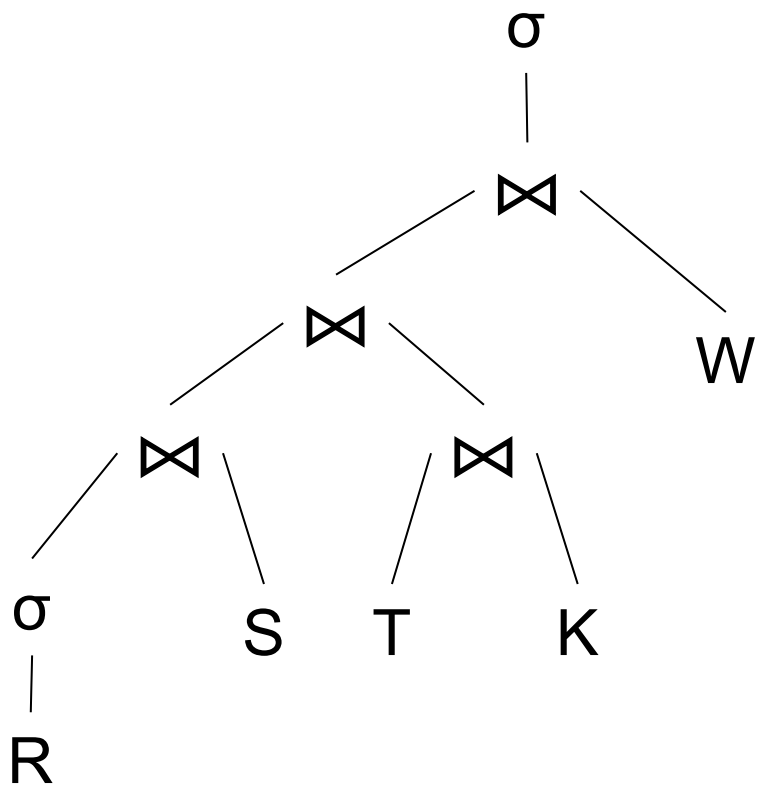
O(n log(n))

(because sorting…)

Main Memory Algorithms

- Join ⋈:
  - Nested loop join
  - Hash join
  - Merge join
- Selection σ
  - "on-the-fly"
- Group by γ
  - Hash–based
  - Merge-based

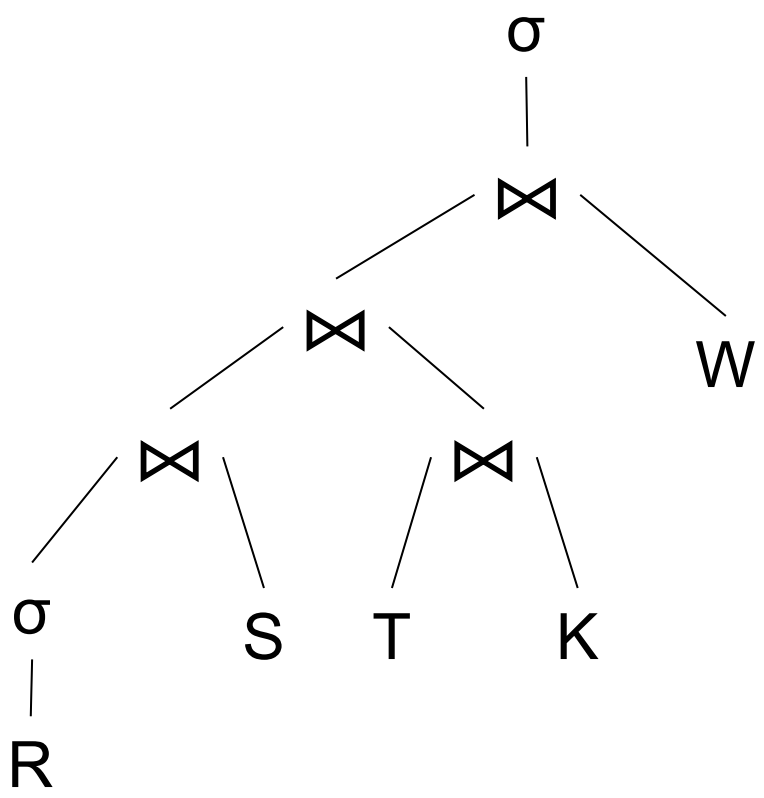
How Do We Combine Them?



How Do We Combine Them?

The *Iterator Interface*

- open()
- next()
- close()



Implementing Query Operators with the Iterator Interface

```
interface Operator {









}
```

Implementing Query Operators with the Iterator Interface

```
interface Operator {

  // initializes operator state
  // and sets parameters
  void open (...);









}
```

Implementing Query Operators with the Iterator Interface

```
interface Operator {

  // initializes operator state
  // and sets parameters
  void open (...);


  // calls next() on its inputs
  // processes an input tuple
  // produces output tuple(s)
  // returns null when done
  Tuple next ();




}
```

Implementing Query Operators with the Iterator Interface

```
interface Operator {

  // initializes operator state
  // and sets parameters
  void open (...);


  // calls next() on its inputs
  // processes an input tuple
  // produces output tuple(s)
  // returns null when done
  Tuple next ();


  // cleans up (if any)
  void close ();
}
```

Implementing Query Operators with the Iterator Interface

Example “on the fly” selection operator

```
interface Operator {

  // initializes operator state
  // and sets parameters
  void open (...);


  // calls next() on its inputs
  // processes an input tuple
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Implementing Query Operators with the Iterator Interface

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  // cleans up (if any)
  void close ();
}
```

Example “on the fly” selection operator

```
class Select implements Operator {...
  void open (Predicate p,
             Operator c) {
    this.p = p; this.c = c; c.open();
    }

}
```

Implementing Query Operators with the Iterator Interface

```
interface Operator {

  // initializes operator state
  // and sets parameters
  void open (...);


  // calls next() on its inputs
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    }
  Tuple next () {

    }

}
```

Implementing Query Operators with the Iterator Interface

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interface Operator {

  // initializes operator state
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  void open (...);


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  Tuple next ();


  // cleans up (if any)
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}
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class Select implements Operator {...
  void open (Predicate p,
             Operator c) {
    this.p = p; this.c = c; c.open();
    }
  Tuple next () {
    boolean found = false;
    Tuple r = null;
    while (!found) {
       r = c.next();
       if (r == null) break;
       found = p(r);
    }

  }

}
```

Implementing Query Operators with the Iterator Interface

```
interface Operator {

  // initializes operator state
  // and sets parameters
  void open (...);


  // calls next() on its inputs
  // processes an input tuple
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  // cleans up (if any)
  void close ();
}
```

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       if (r == null) break;
       found = p(r);
    }
    return r;
  }

}
```

Implementing Query Operators with the Iterator Interface

```
interface Operator {

  // initializes operator state
  // and sets parameters
  void open (...);


  // calls next() on its inputs
  // processes an input tuple
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  // cleans up (if any)
  void close ();
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Example “on the fly” selection operator

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class Select implements Operator {...
  void open (Predicate p,
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    Tuple r = null;
    while (!found) {
       r = c.next();
       if (r == null) break;
       found = p(r);
    }
    return r;
  }
  void close () { c.close(); }
}
```

Implementing Query Operators with the Iterator Interface

```
interface Operator {

  // initializes operator state
  // and sets parameters
  void open (...);


  // calls next() on its inputs
  // processes an input tuple
  // produces output tuple(s)
  // returns null when done
  Tuple next ();


  // cleans up (if any)
  void close ();
}
```

Query plan execution

```
Operator q = parse("SELECT ...");
q = optimize(q);

q.open();
while (true) {
  Tuple t = q.next();
  if (t == null) break;
  else printOnScreen(t);
}
q.close();
```

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

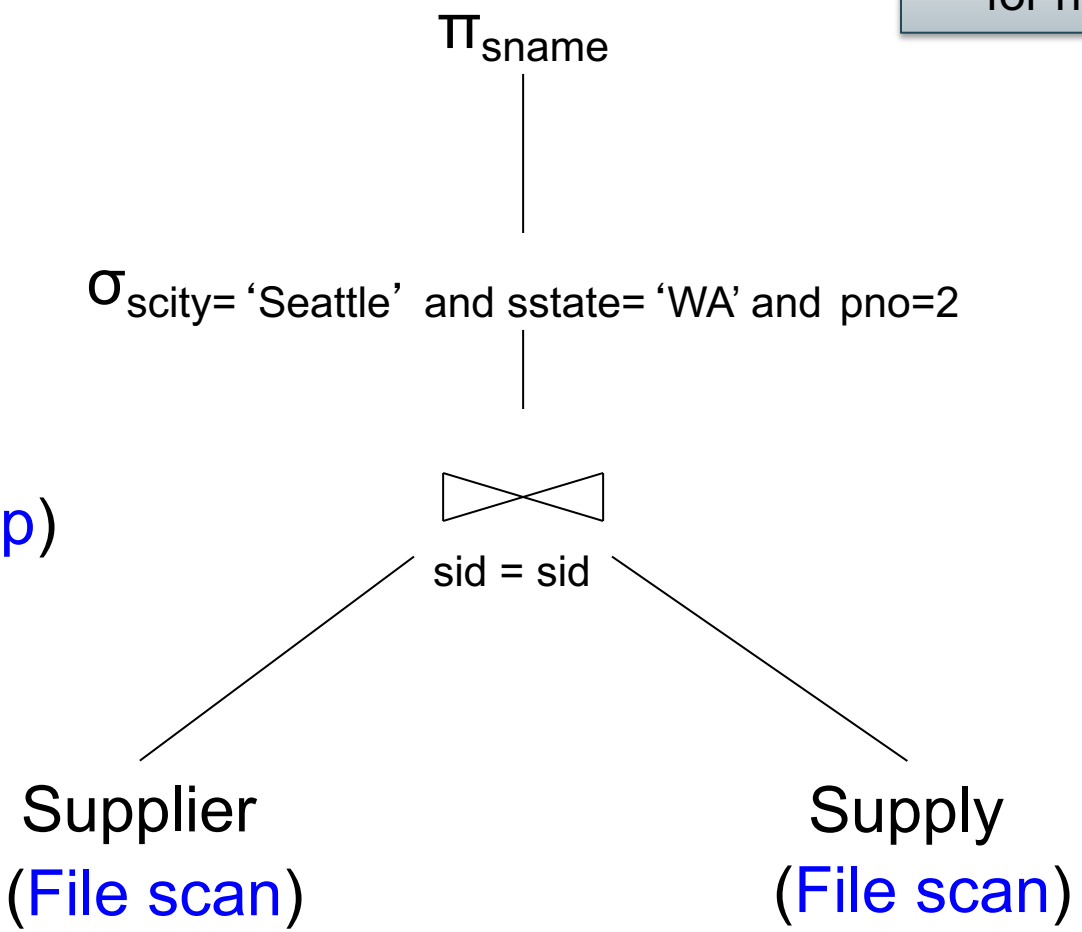
Pipelining

Discuss: open/next/close for nested loop join

(On the fly)

(On the fly)

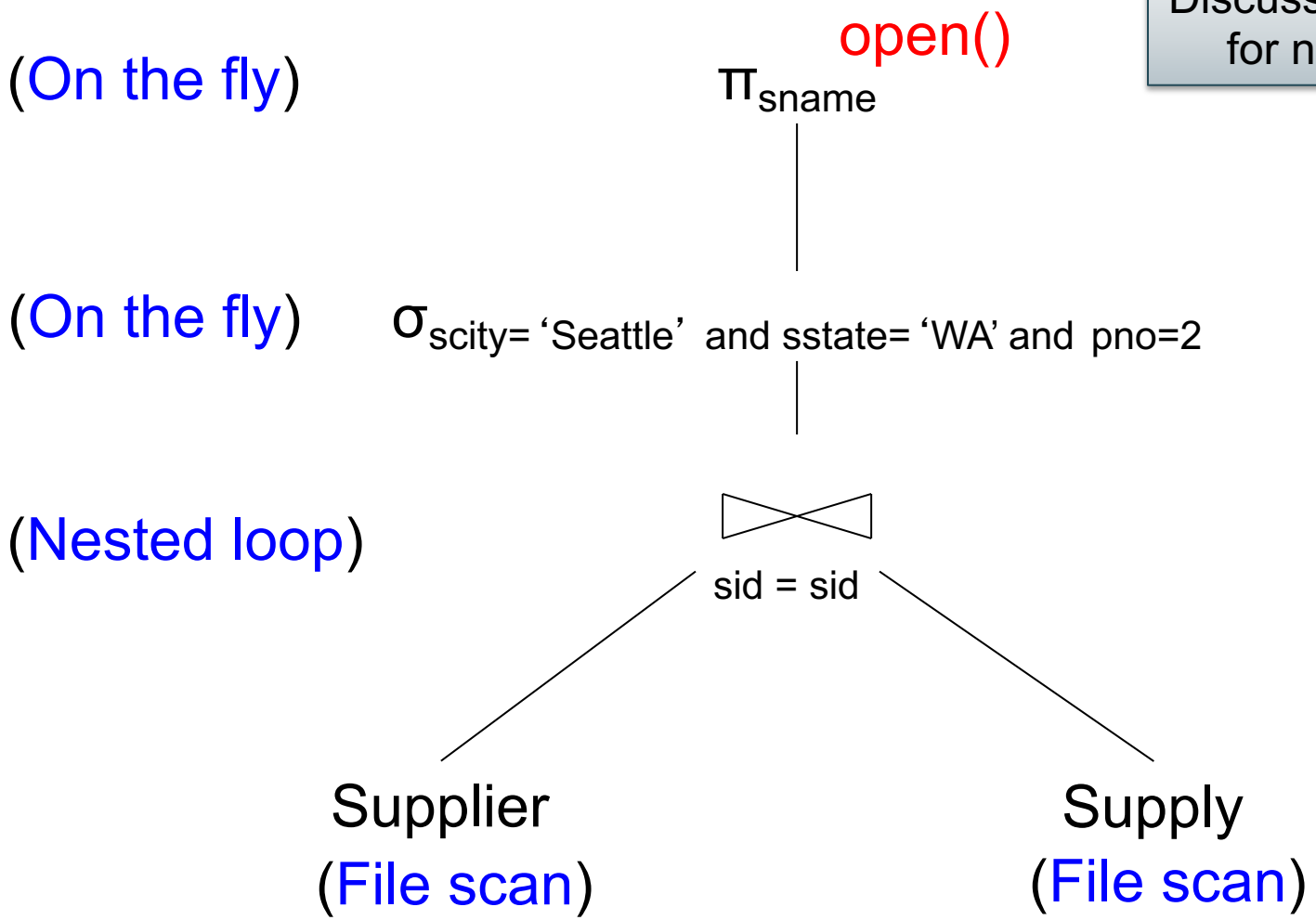
(Nested loop)



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

Pipelining

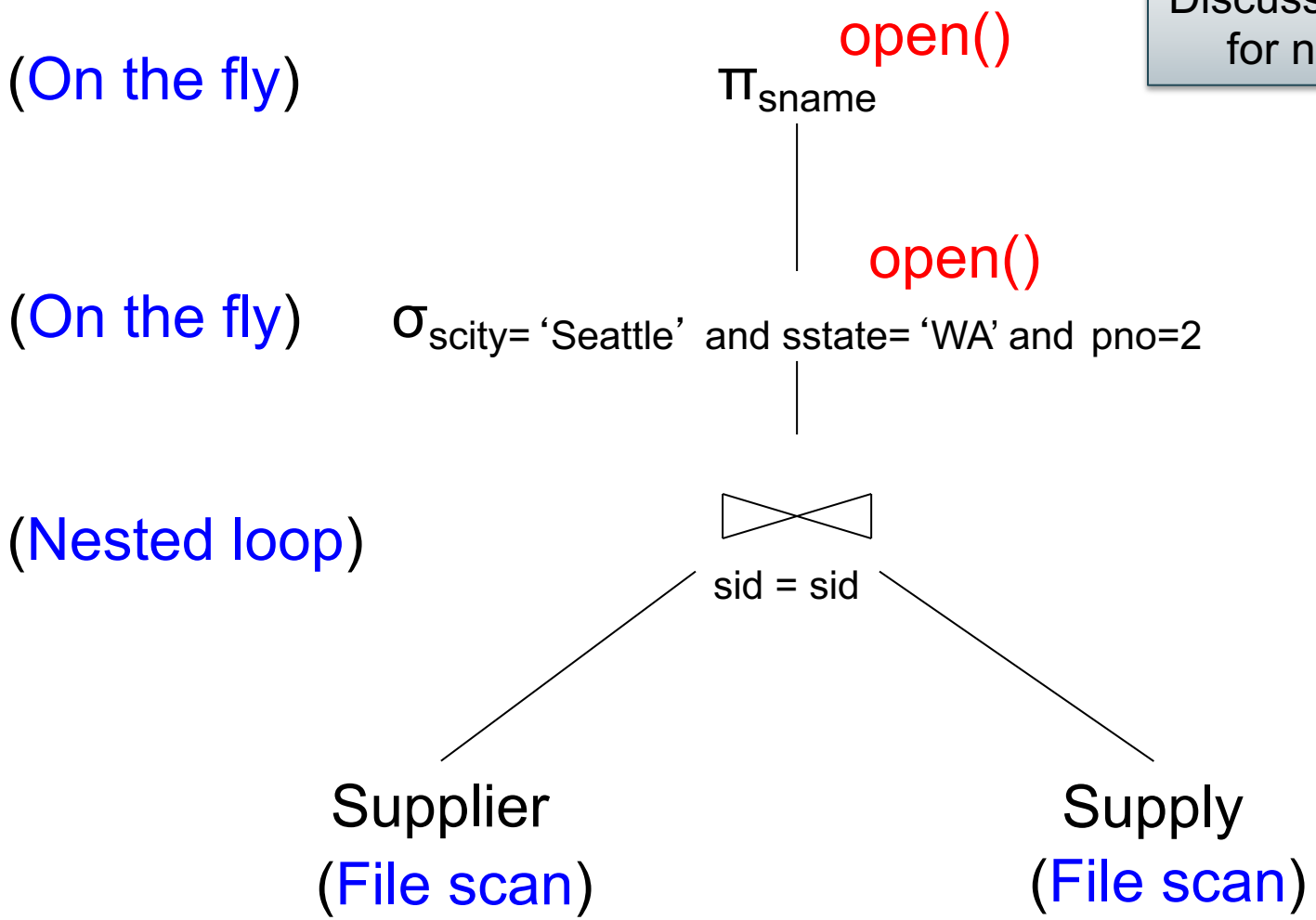
Discuss: open/next/close for nested loop join



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

Pipelining

Discuss: open/next/close for nested loop join



Supplier(sid, sname, scity, sstate)
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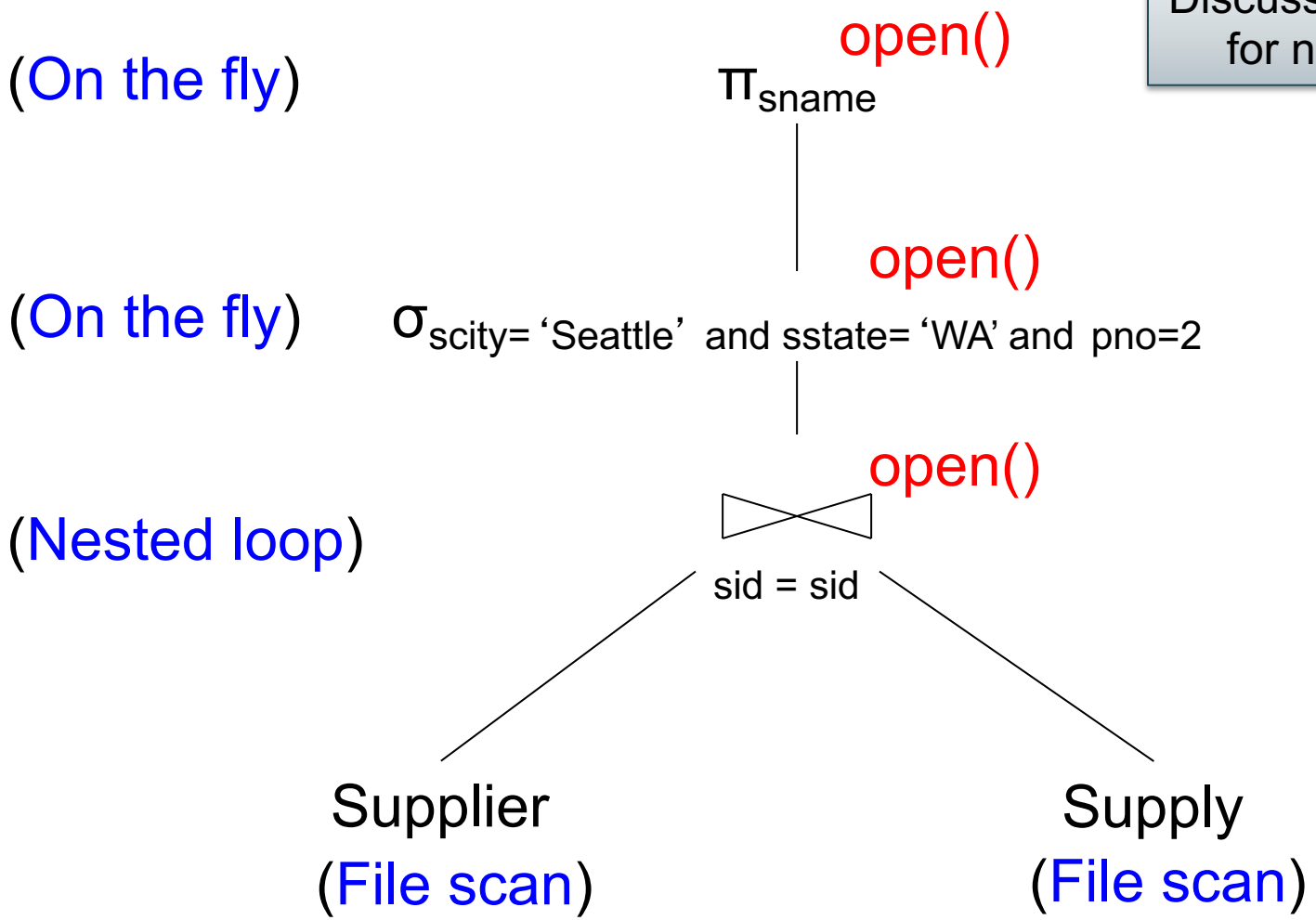
Pipelining

Discuss: open/next/close for nested loop join



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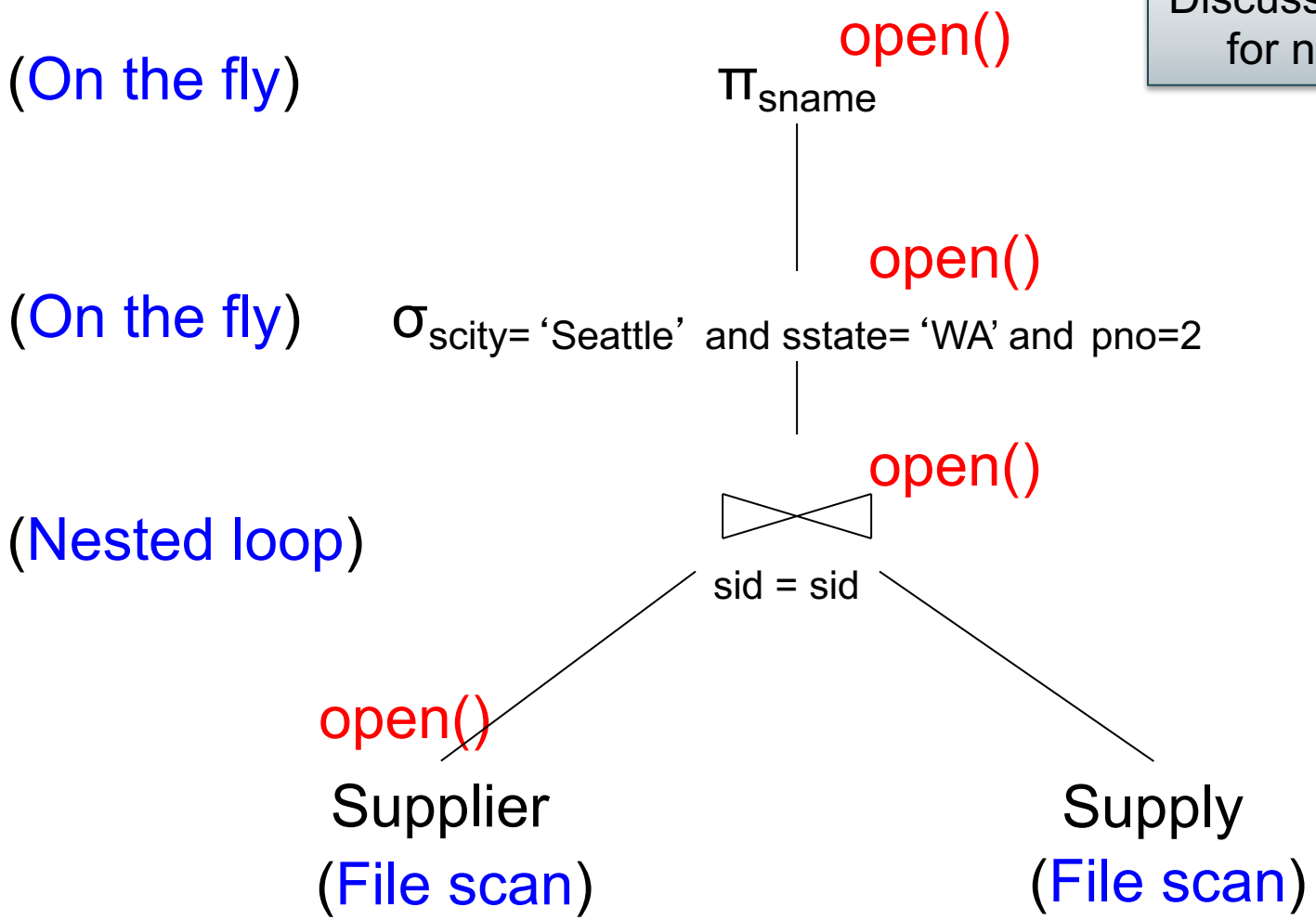
Pipelining

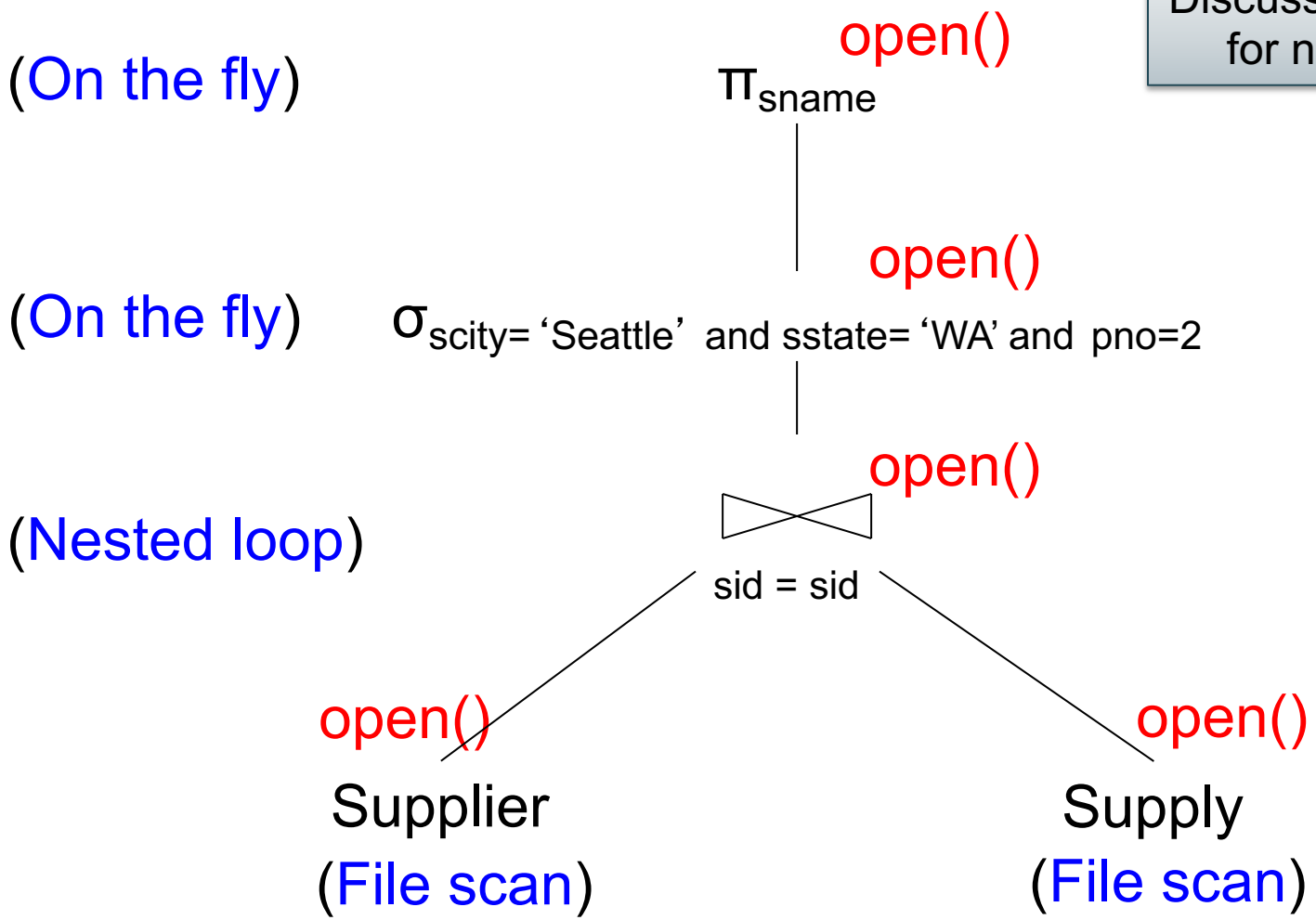
Discuss: open/next/close for nested loop join



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

Pipelining

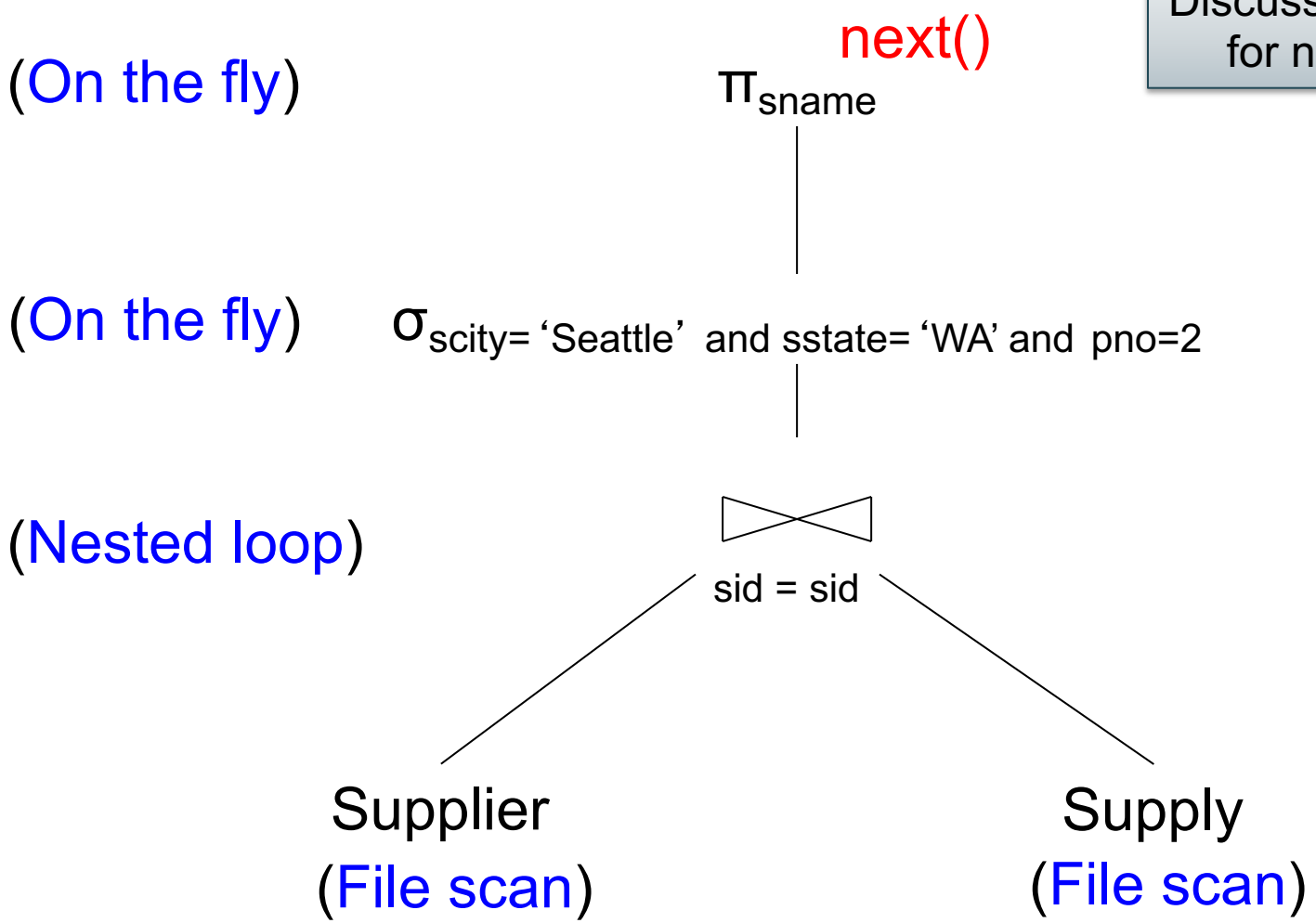
Discuss: open/next/close for nested loop join



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

Pipelining

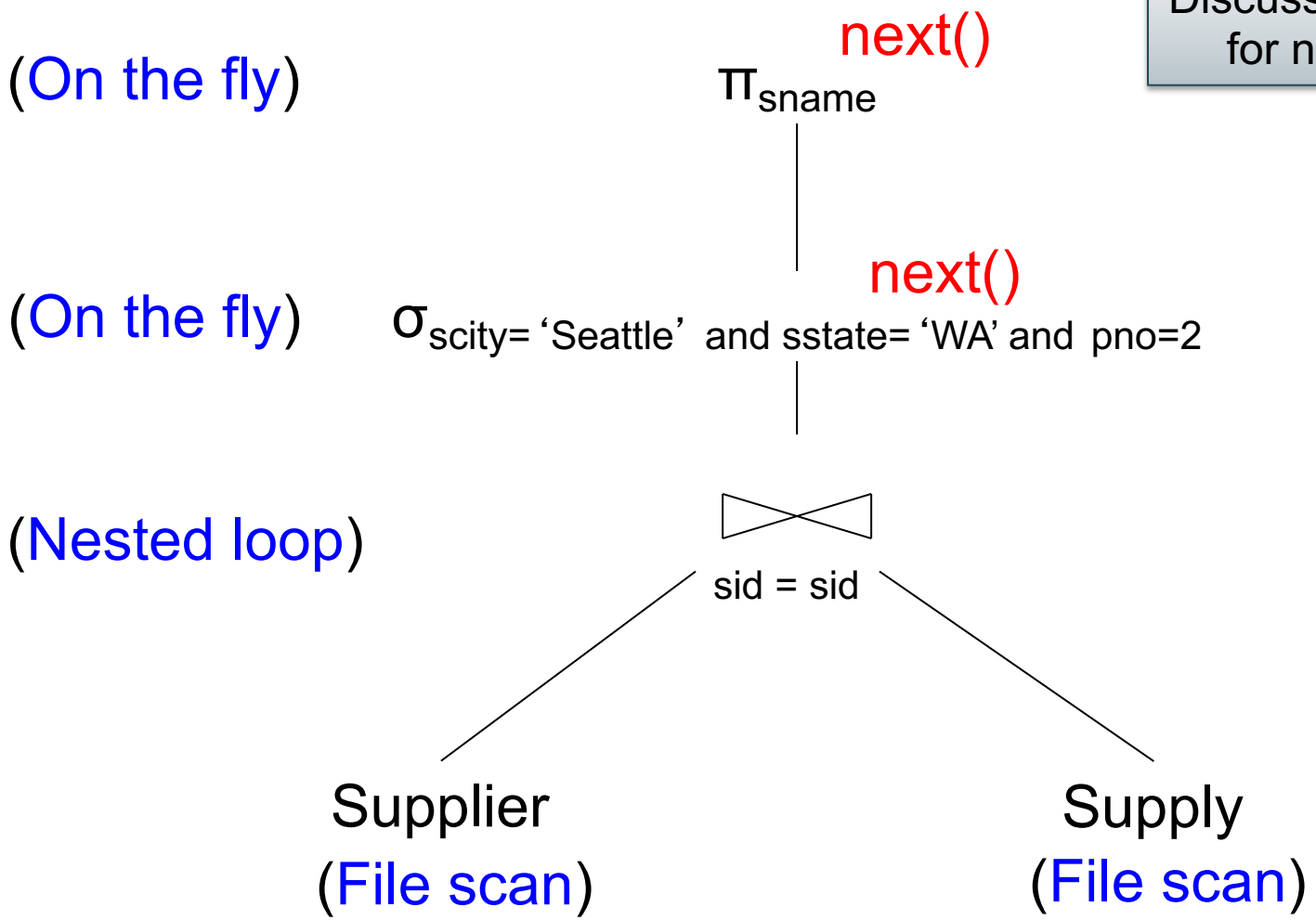
Discuss: open/next/close for nested loop join



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

Pipelining

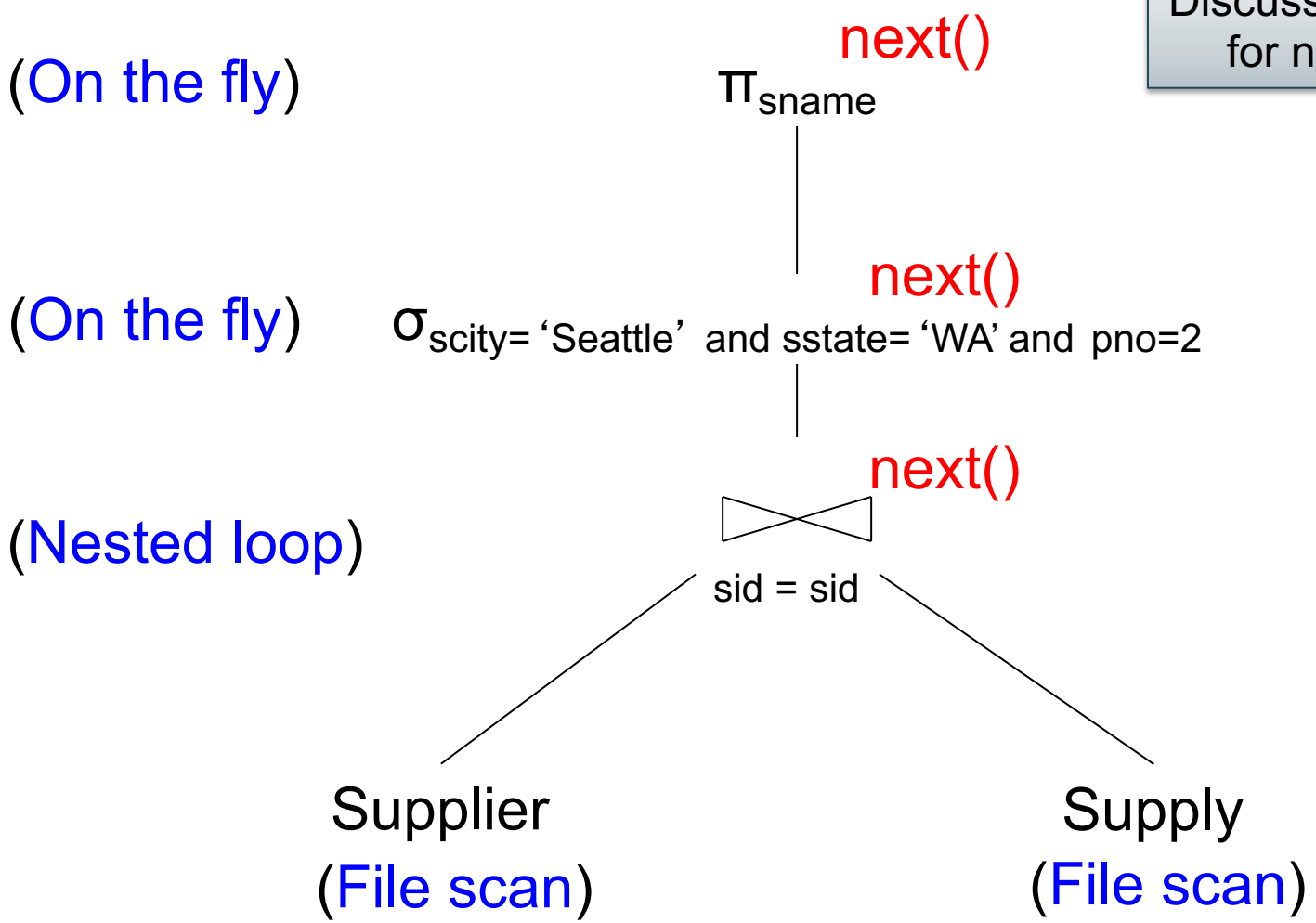
Discuss: open/next/close for nested loop join



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

Pipelining

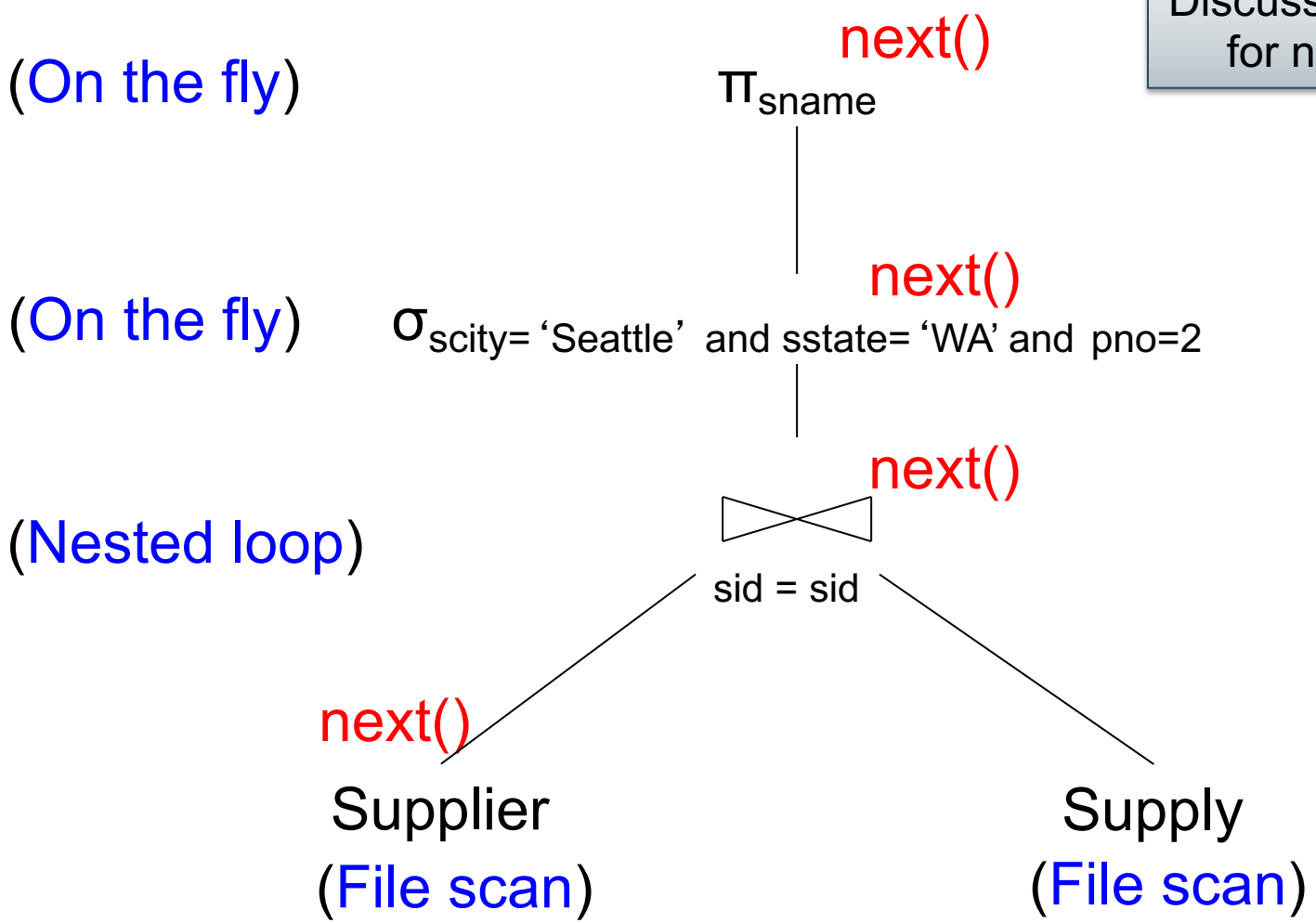
Discuss: open/next/close for nested loop join



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

Pipelining

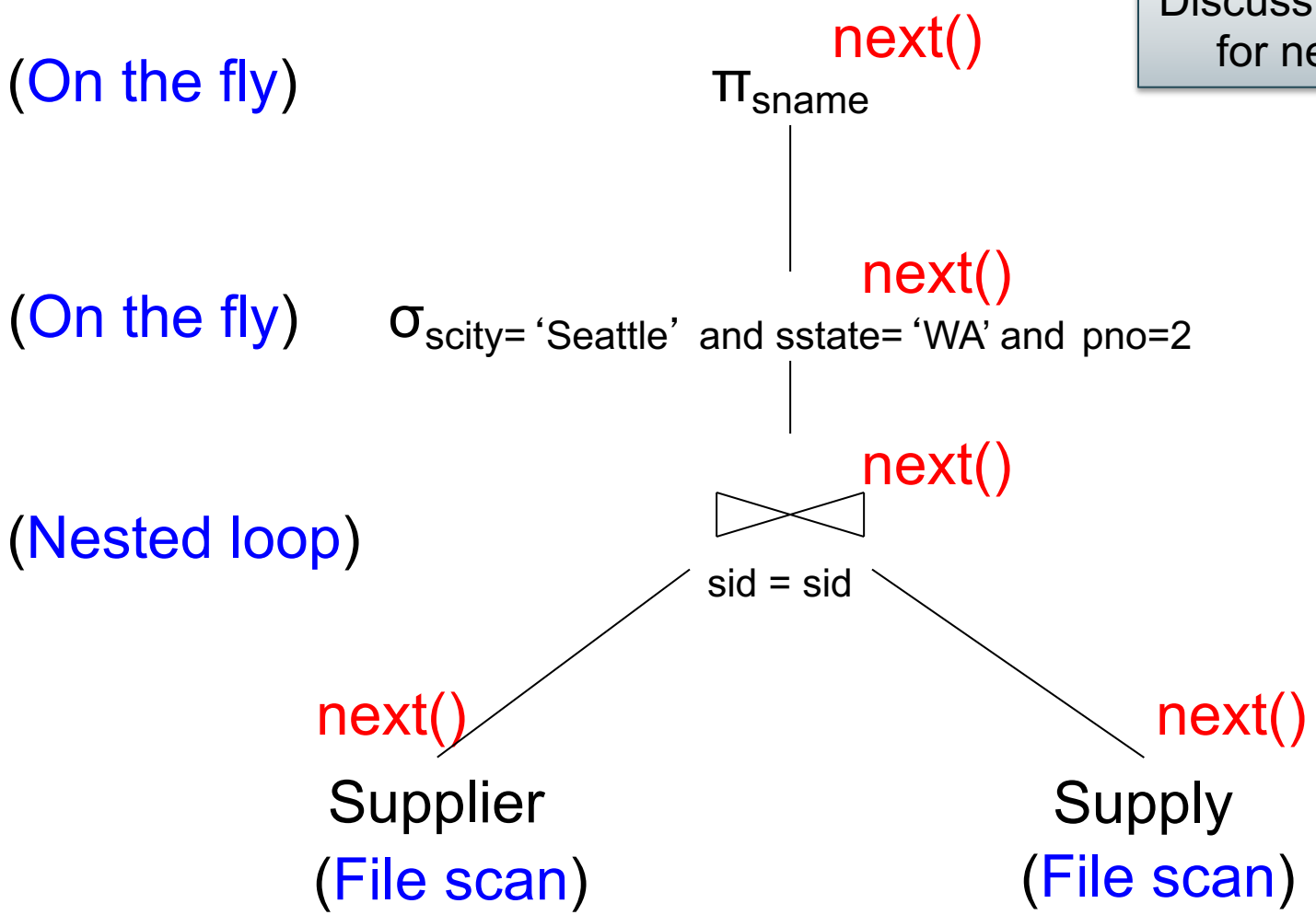
Discuss: open/next/close for nested loop join



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

Pipelining

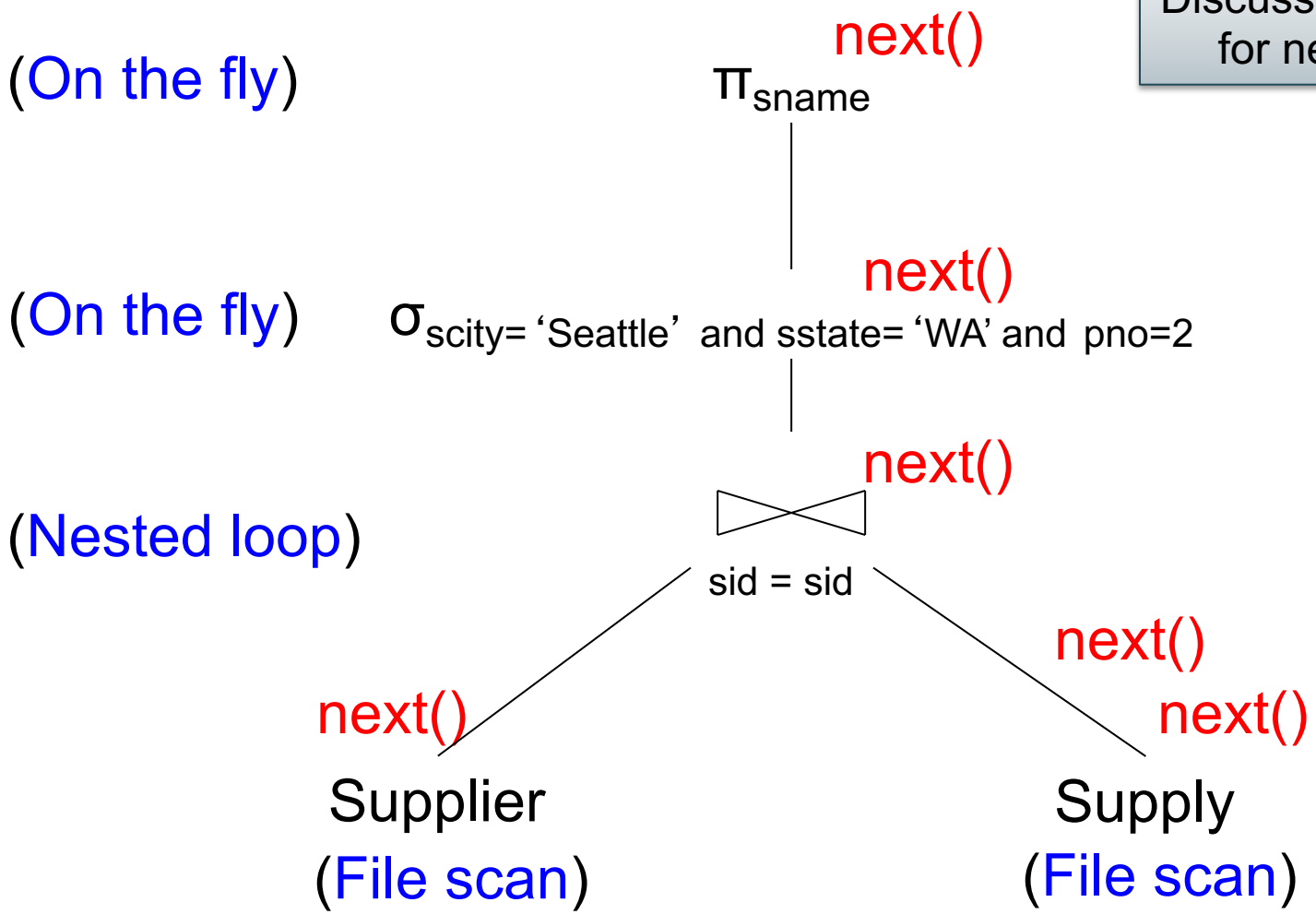
Discuss: open/next/close for nested loop join



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

Pipelining

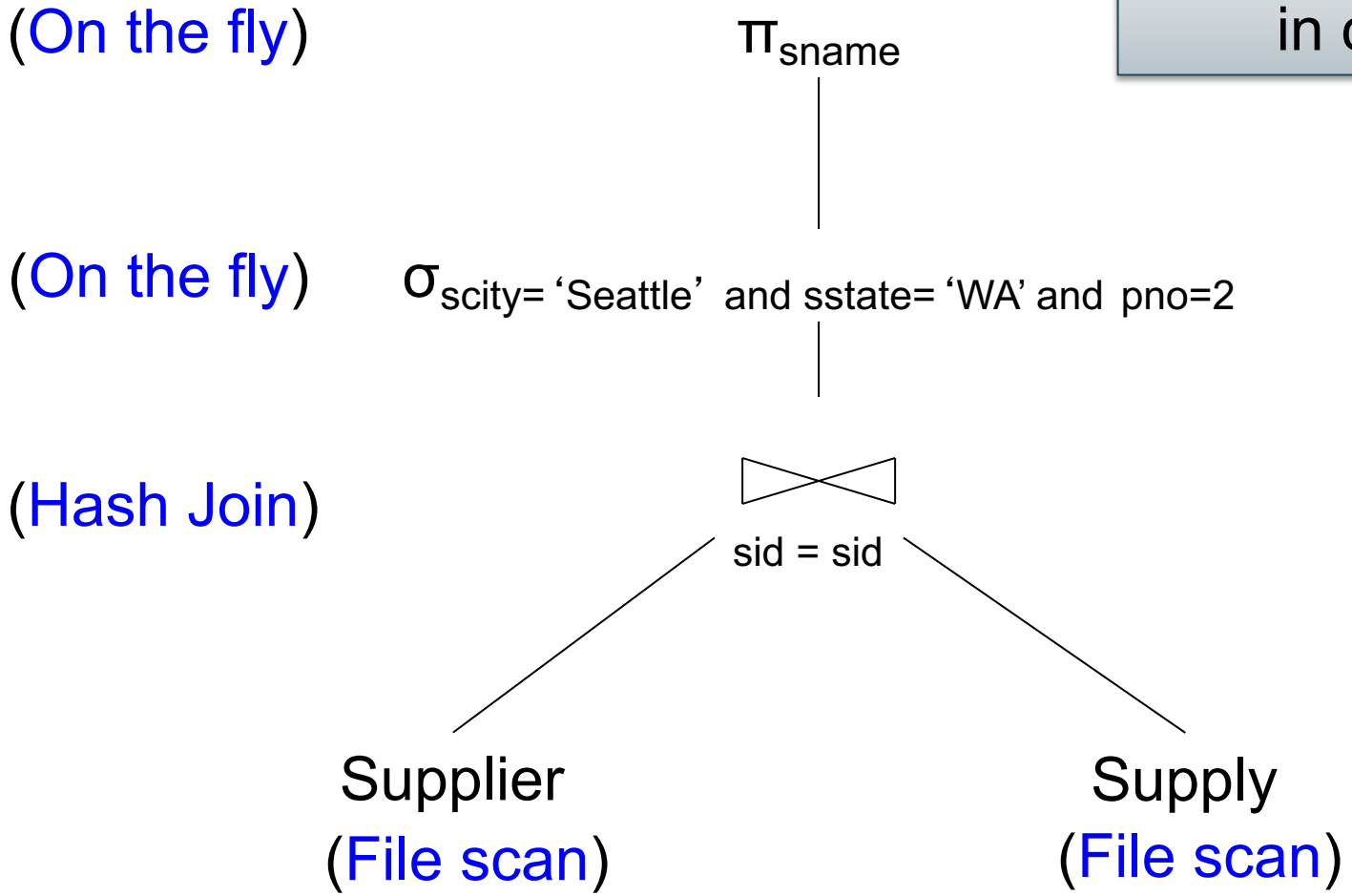
Discuss: open/next/close for nested loop join



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

Pipelining

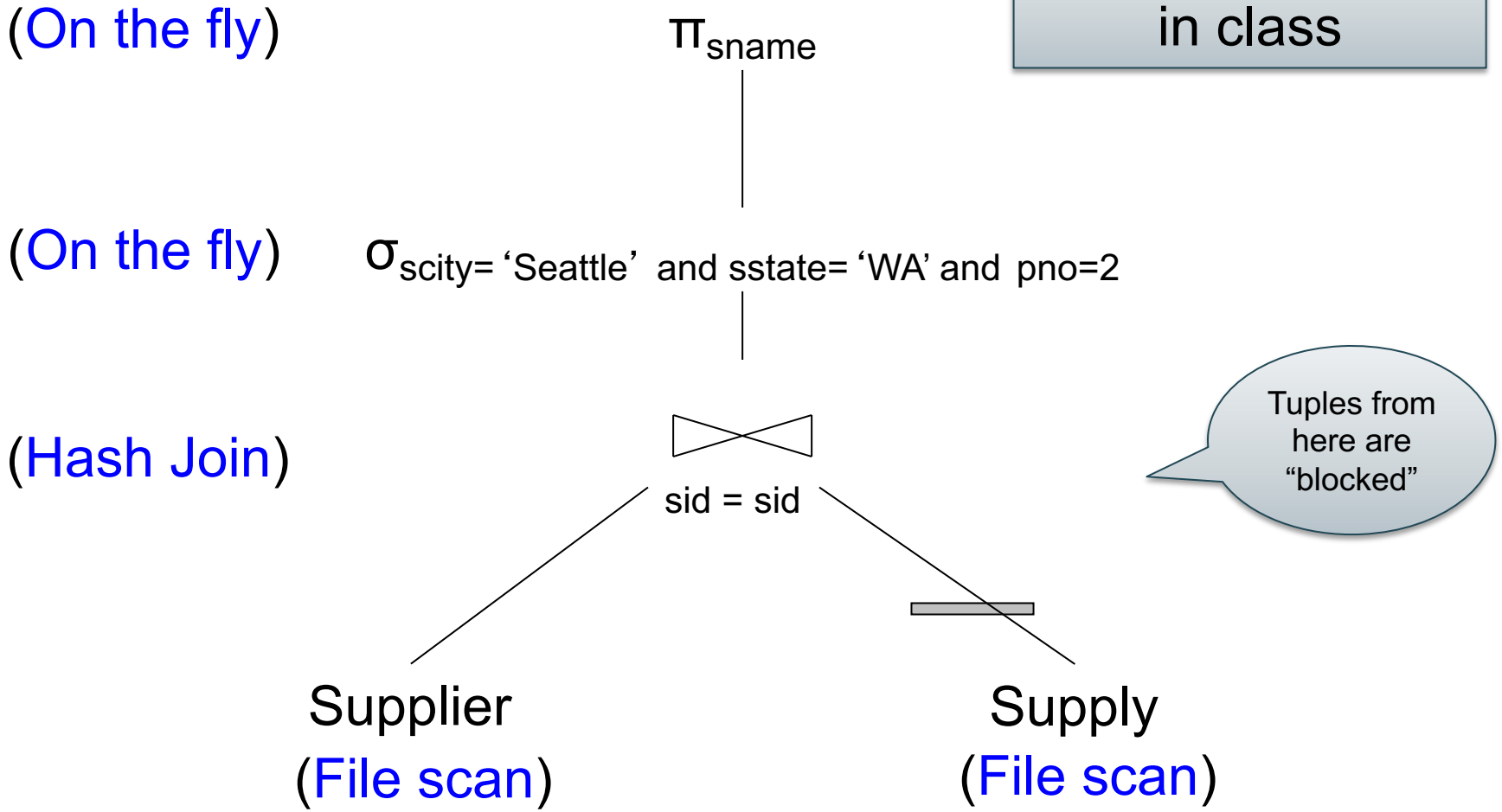
Discuss hash-join in class



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

Pipelining

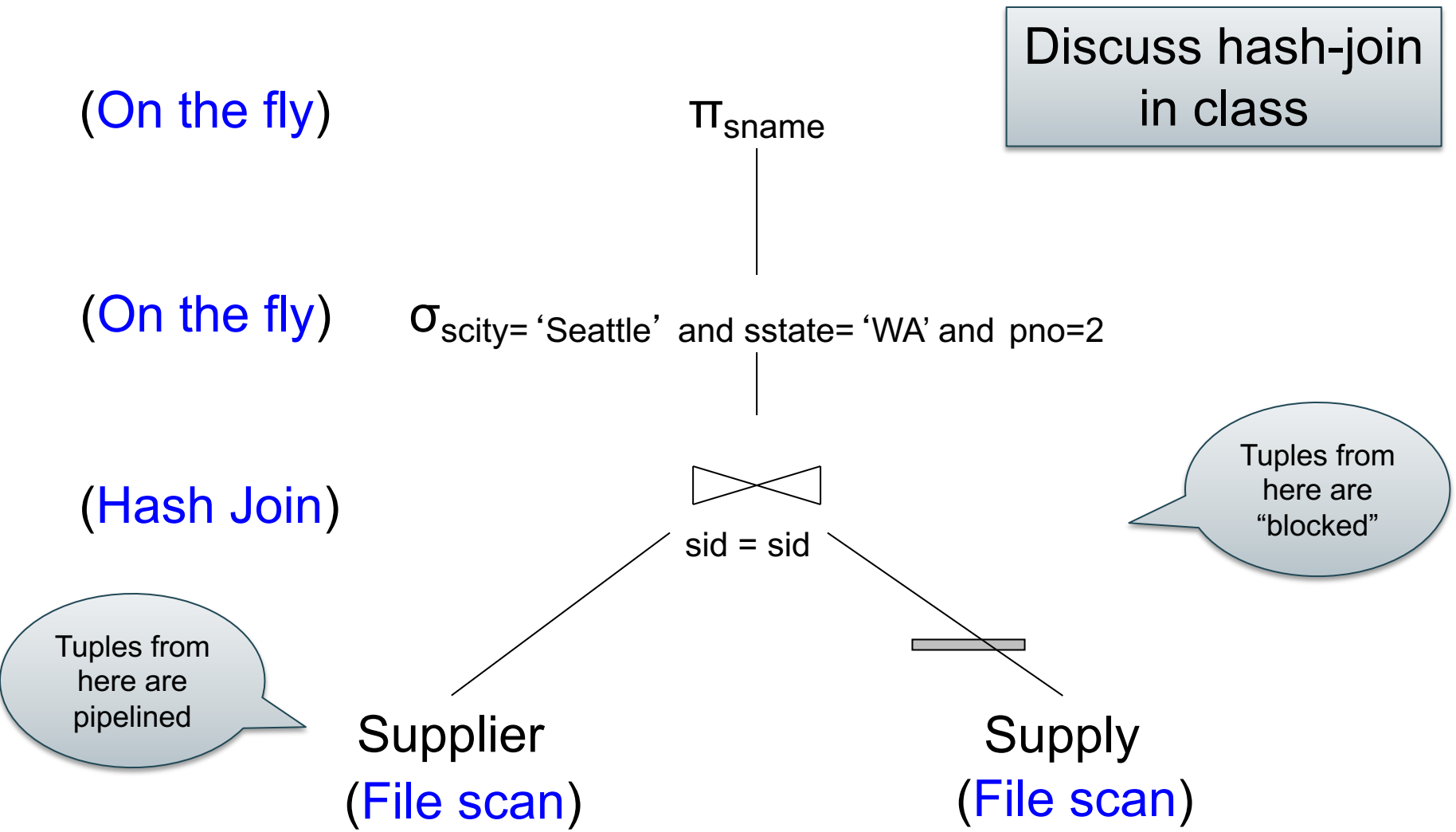
Discuss hash-join in class



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

Pipelining

Discuss hash-join in class



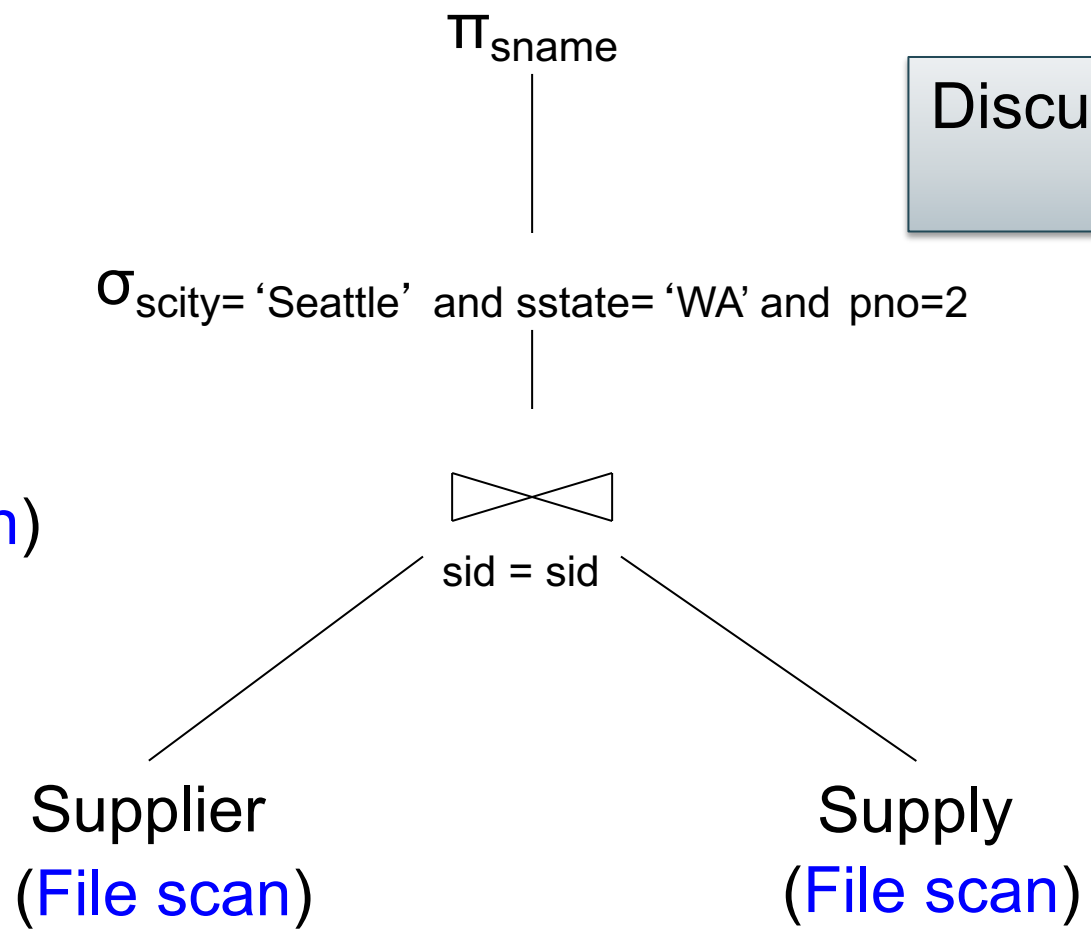
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Blocked Execution

(On the fly)

(On the fly)

(Merge Join)



Discuss merge-join in class

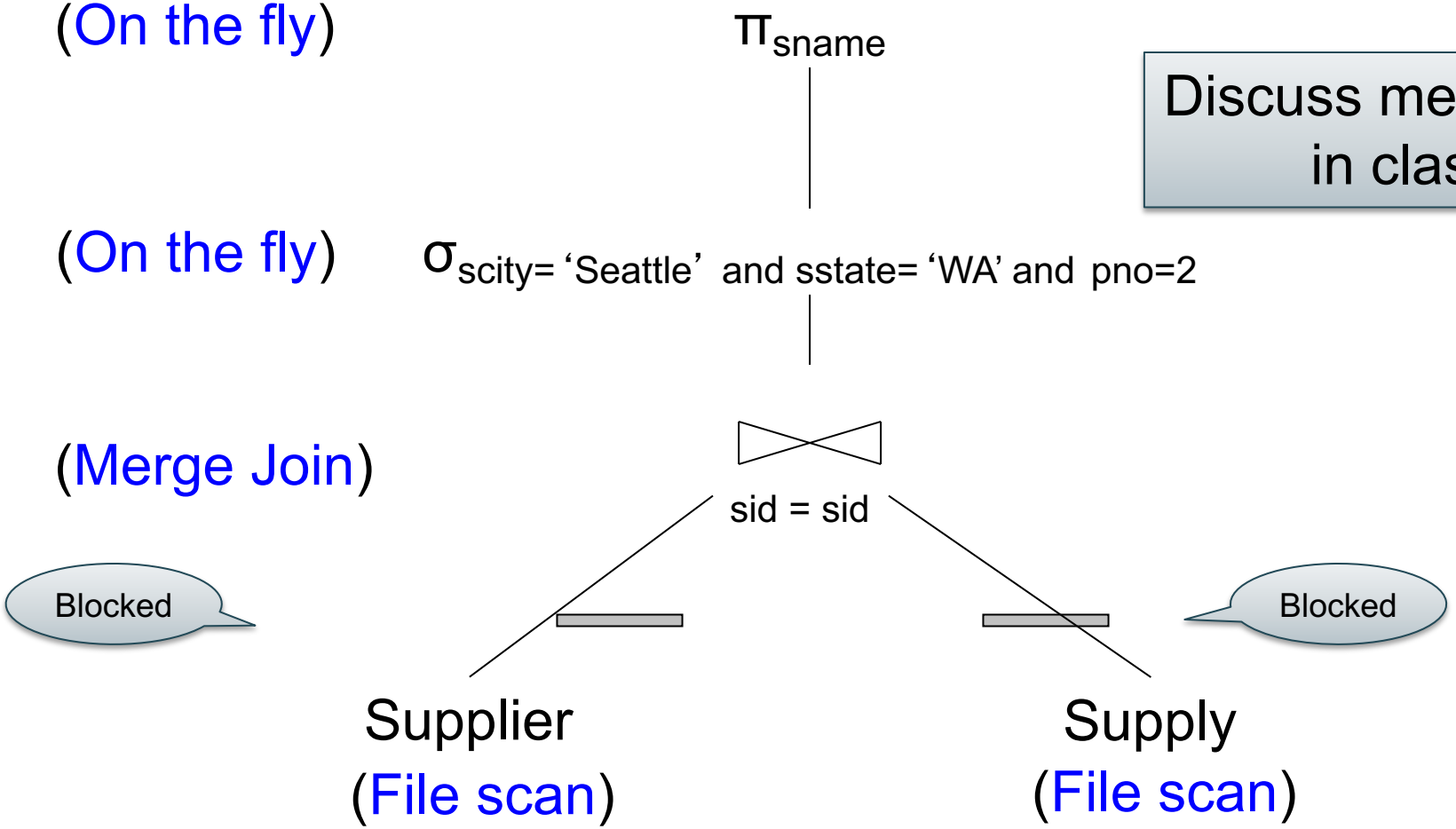
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Blocked Execution

(On the fly)

(On the fly)

(Merge Join)

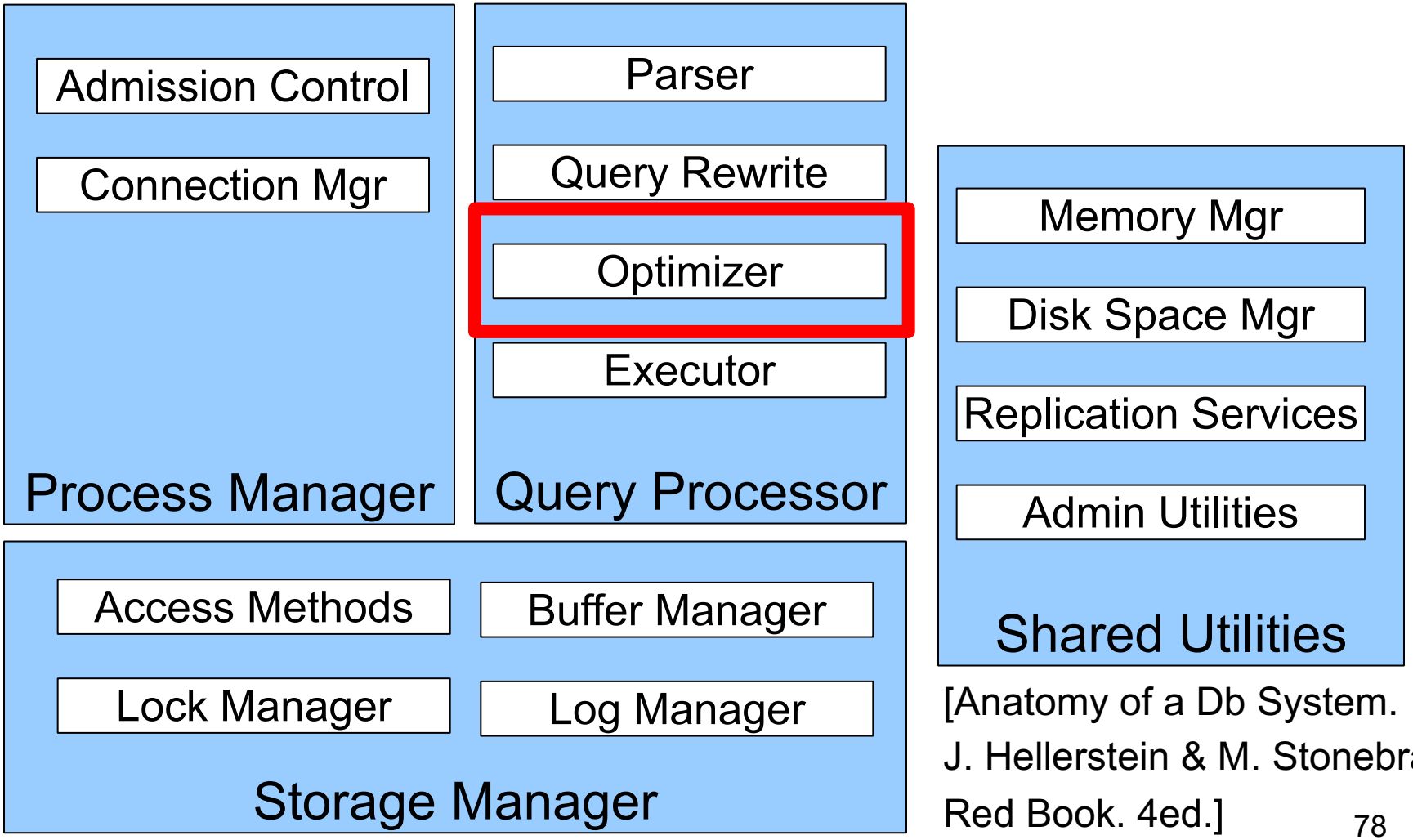


Discuss merge-join in class

Pipeline v.s. Blocking

- Pipeline
  - A tuple moves all the way through up the query plan
  - Advantages: speed
  - Disadvantage: need all hash at the same time in memory
- Blocking
  - The entire result of the subplan is computed (and stored to disk) before the first tuple is sent up the plan
  - Advantage: saves memory
  - Disadvantage: slower

DBMS Architecture



[Anatomy of a Db System. J. Hellerstein & M. Stonebraker. Red Book. 4ed.]

Query Optimizer

- SQL → Relational Algebra Plan (RA)
- RA → Optimized RA
- Algebraic identities of RA; examples:
  1. Pushing selections down
  2. Join reorder
  3. Pushing aggregates down

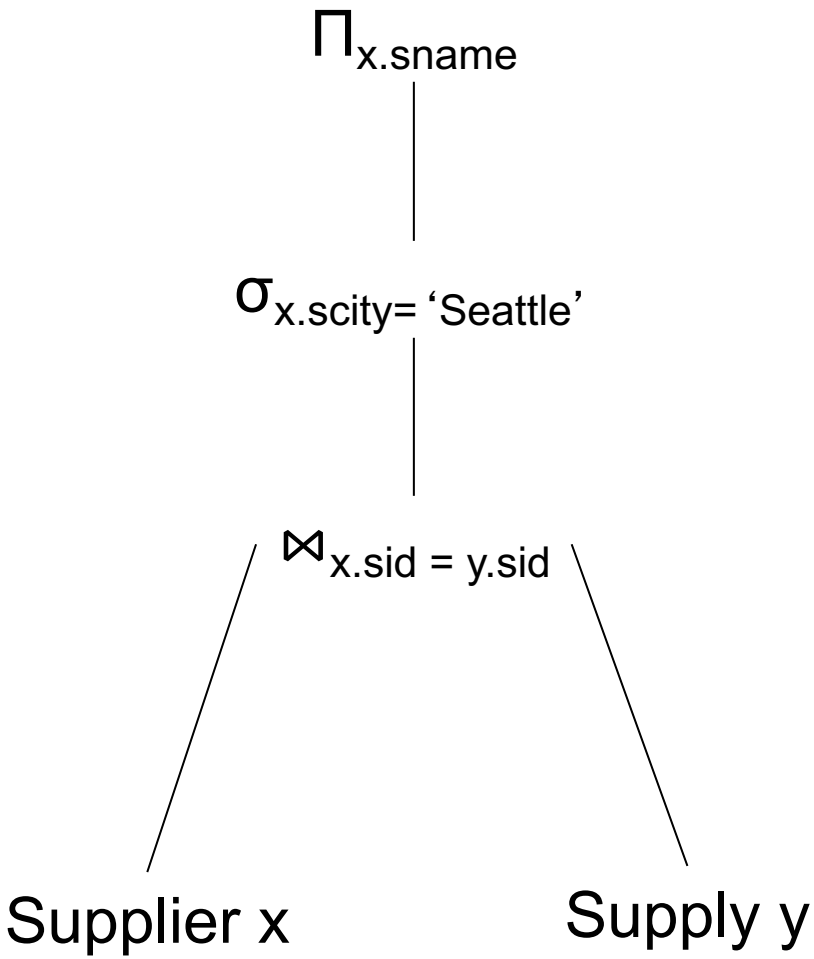
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Example Optimization

```
SELECT x.name
FROM.   Supplier x, Supply y
WHERE x.sid = y.sid
        and x.scity = 'Seattle'
```

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

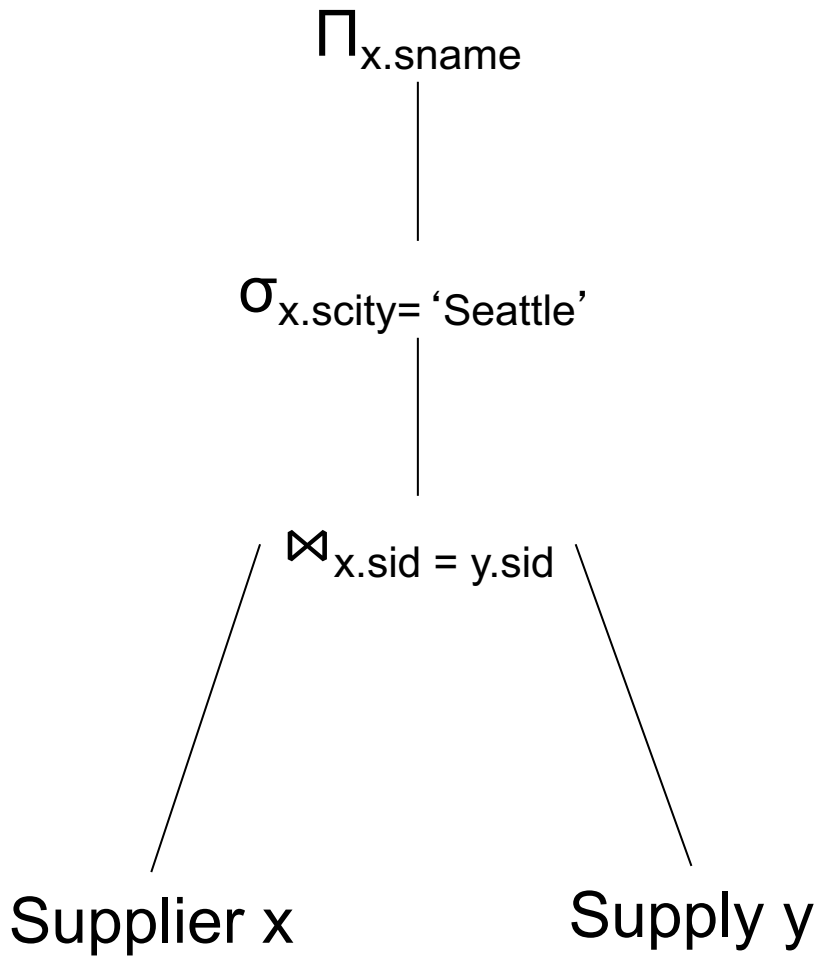
Example Optimization




```
SELECT x.name
FROM.   Supplier x, Supply y
WHERE x.sid = y.sid
        and x.scity = 'Seattle'
```

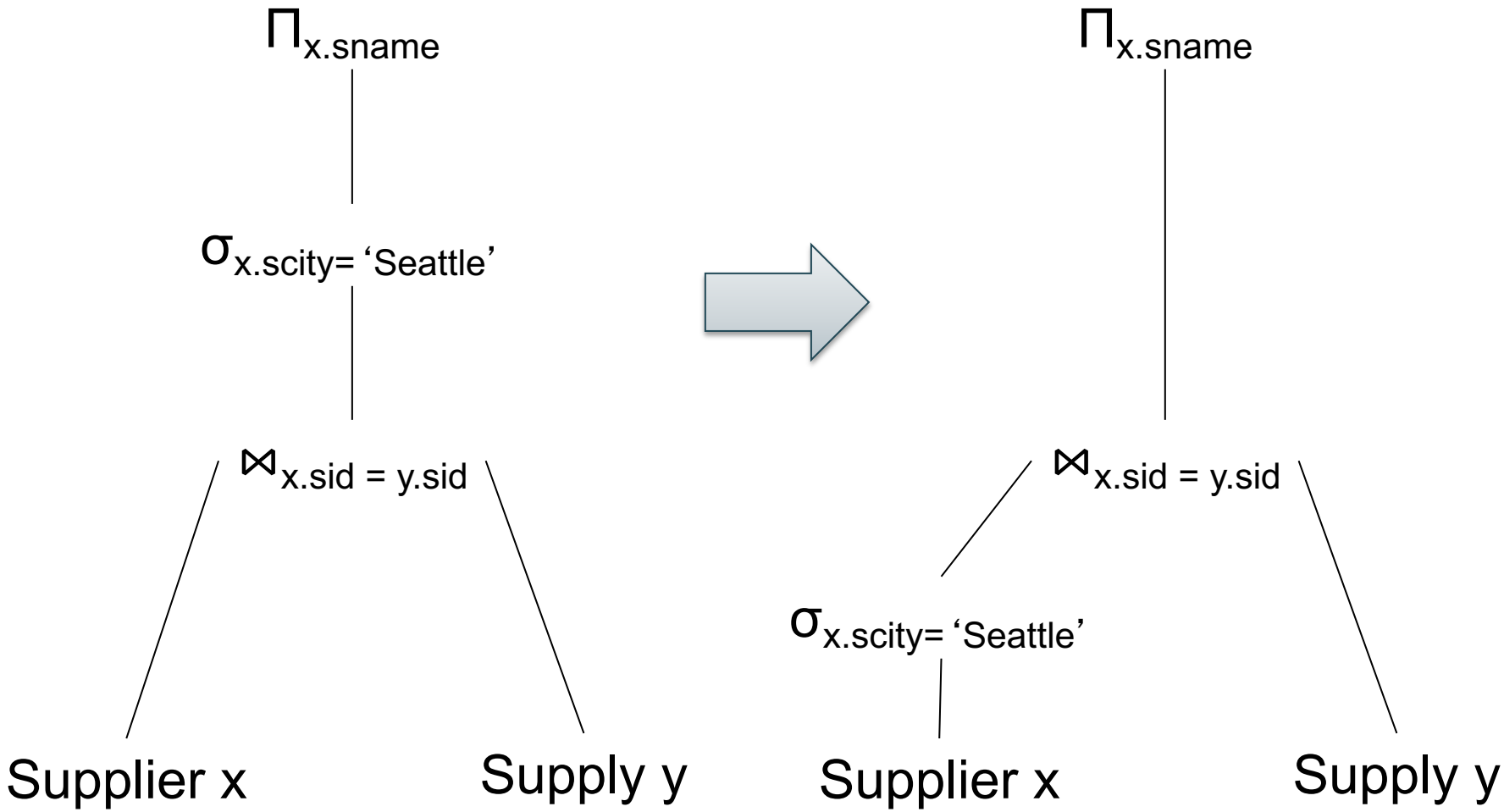
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Push Selections Down



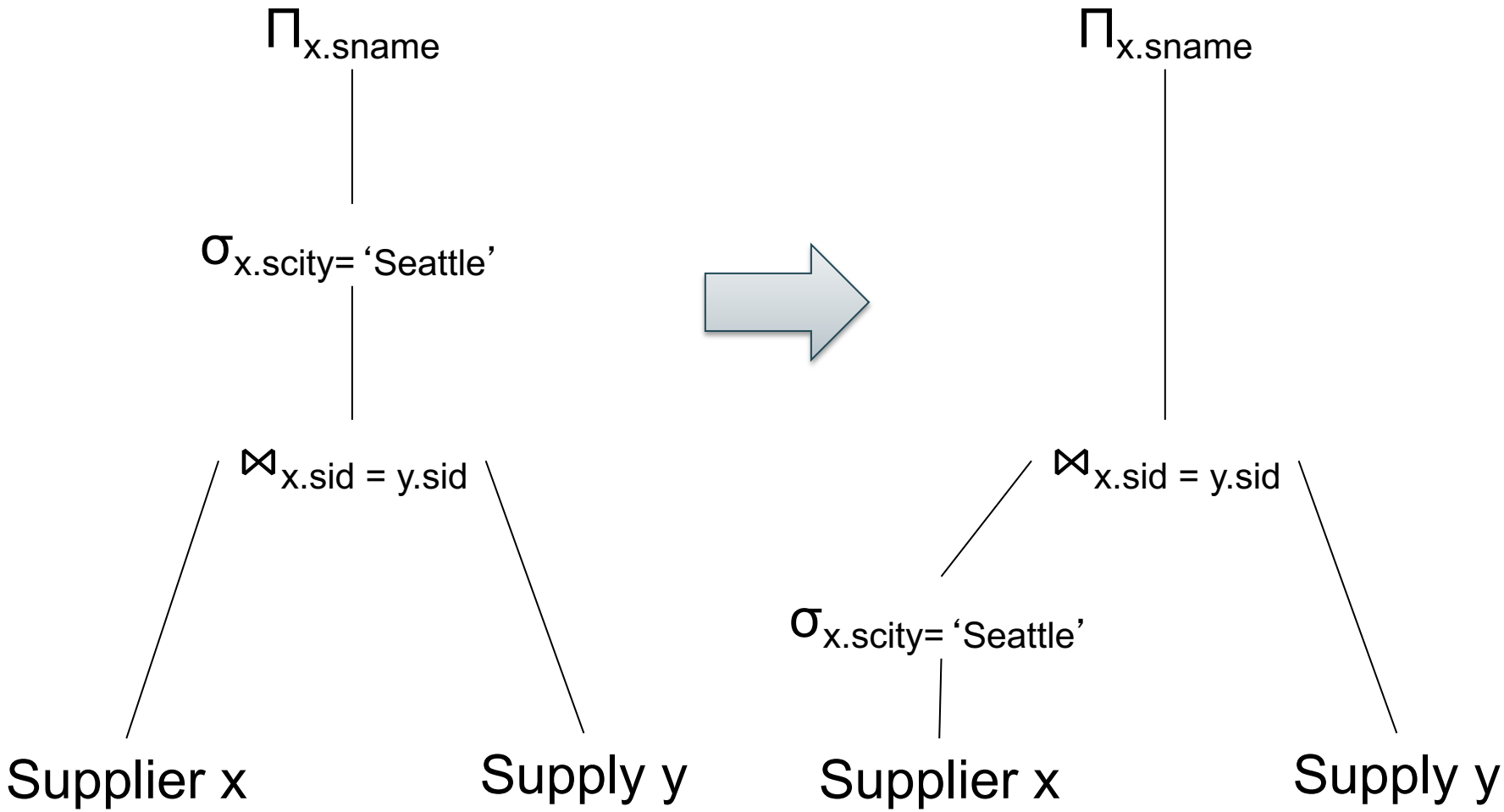
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Push Selections Down



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

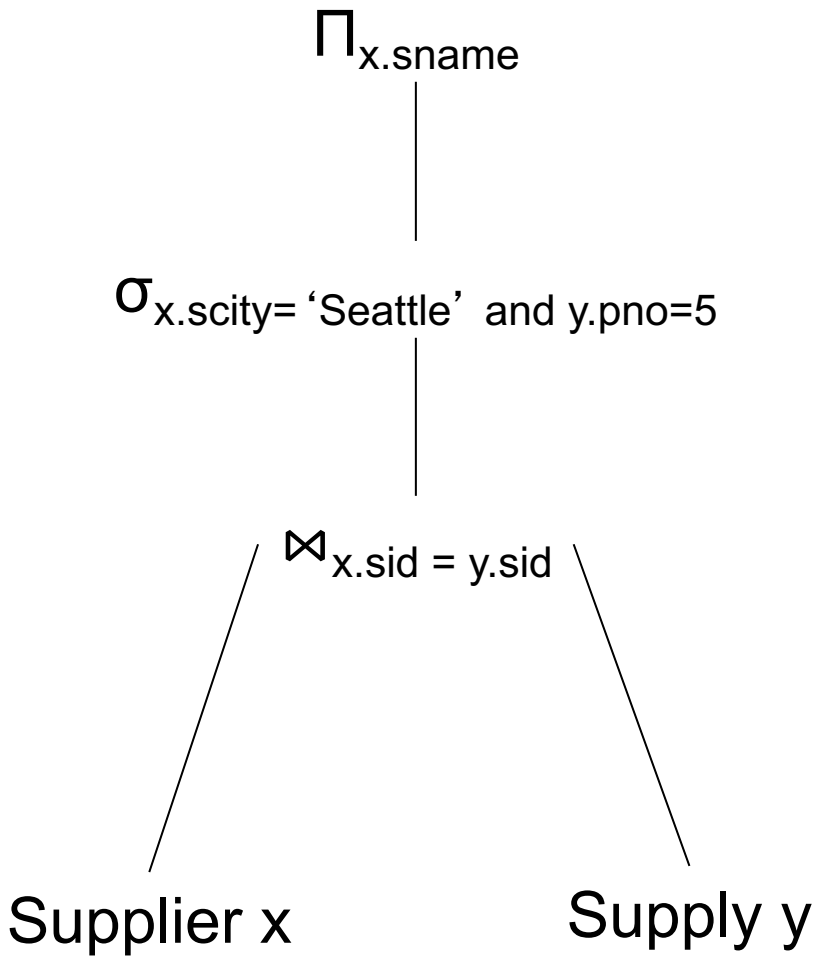
Push Selections Down



$\sigma_C(R \bowtie S) = \sigma_C(R) \bowtie S$ when C refers only to R

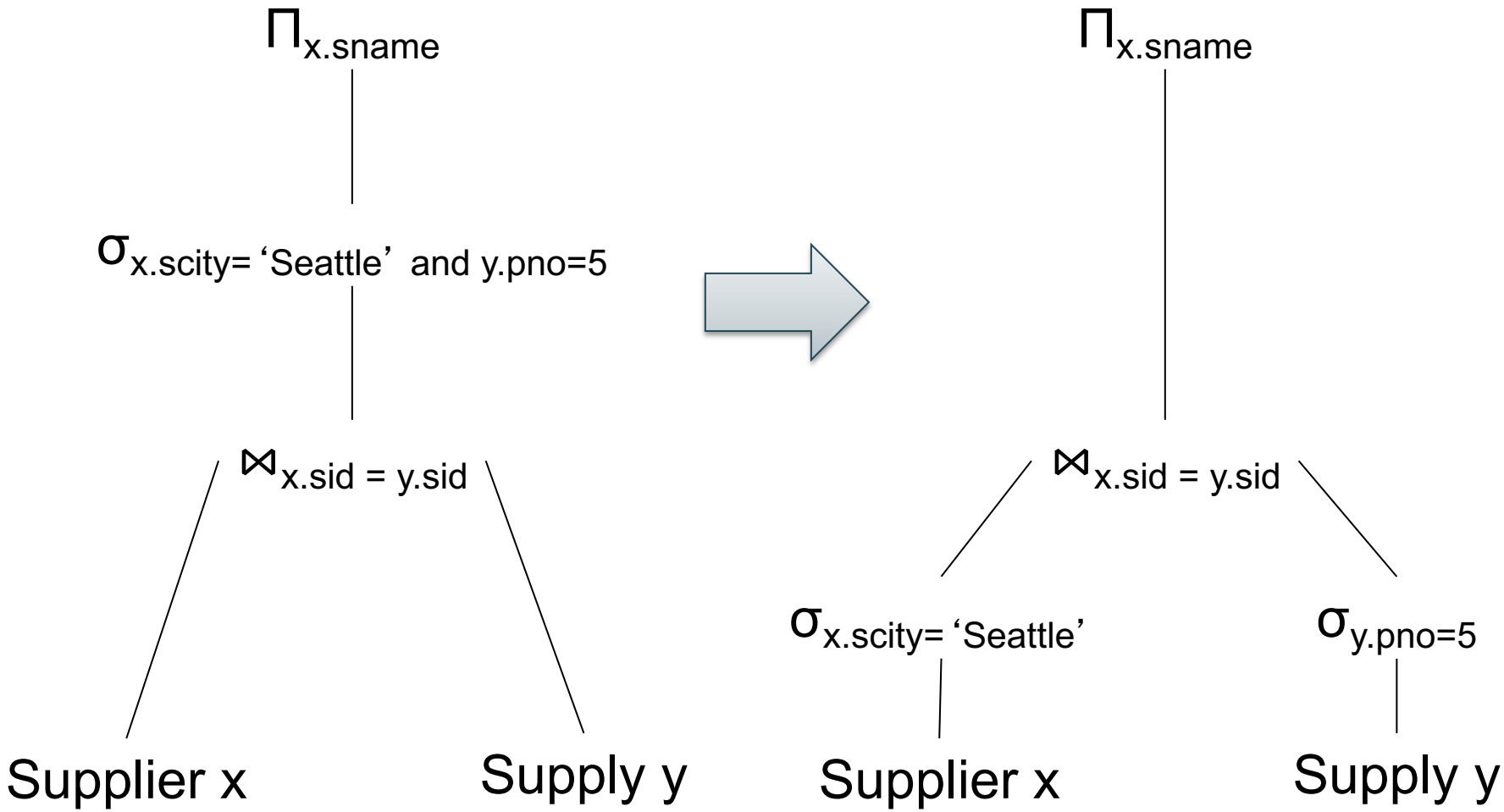
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Push Selections Down



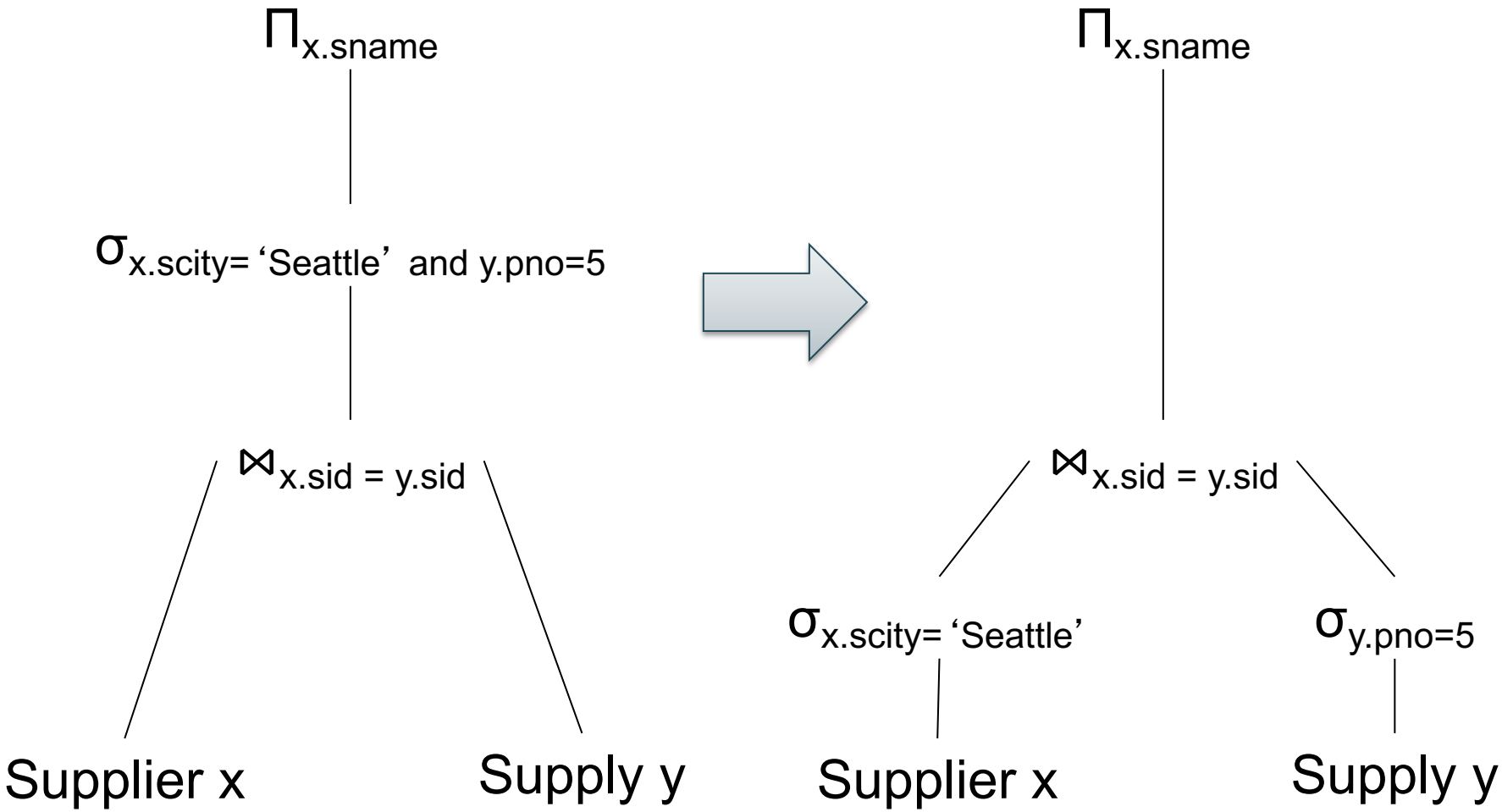
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Push Selections Down



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

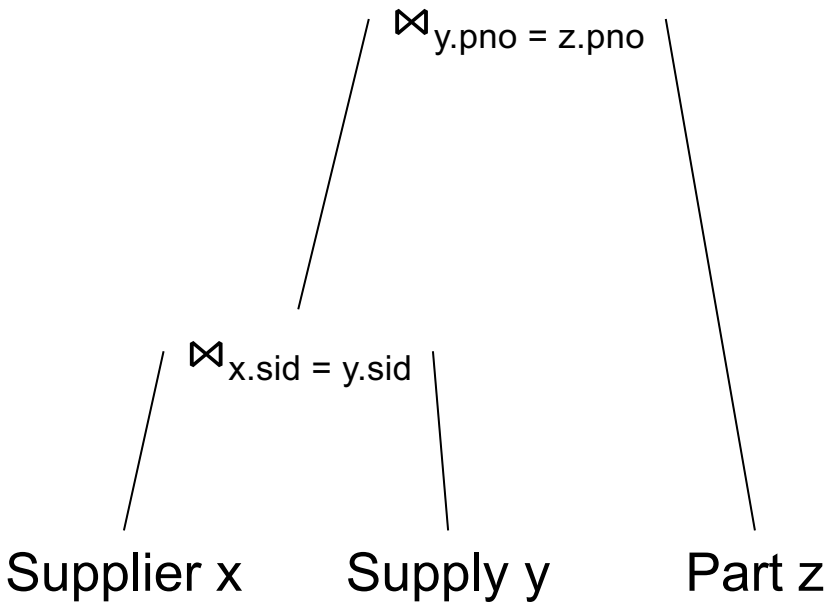
Push Selections Down



$$\sigma_{C1 \text{ and } C2}(R \bowtie S) = \sigma_{C1}(\sigma_{C2}(R \bowtie S)) = \sigma_{C1}(R \bowtie \sigma_{C2}(S)) = \sigma_{C1}(R) \bowtie \sigma_{C2}(S)$$

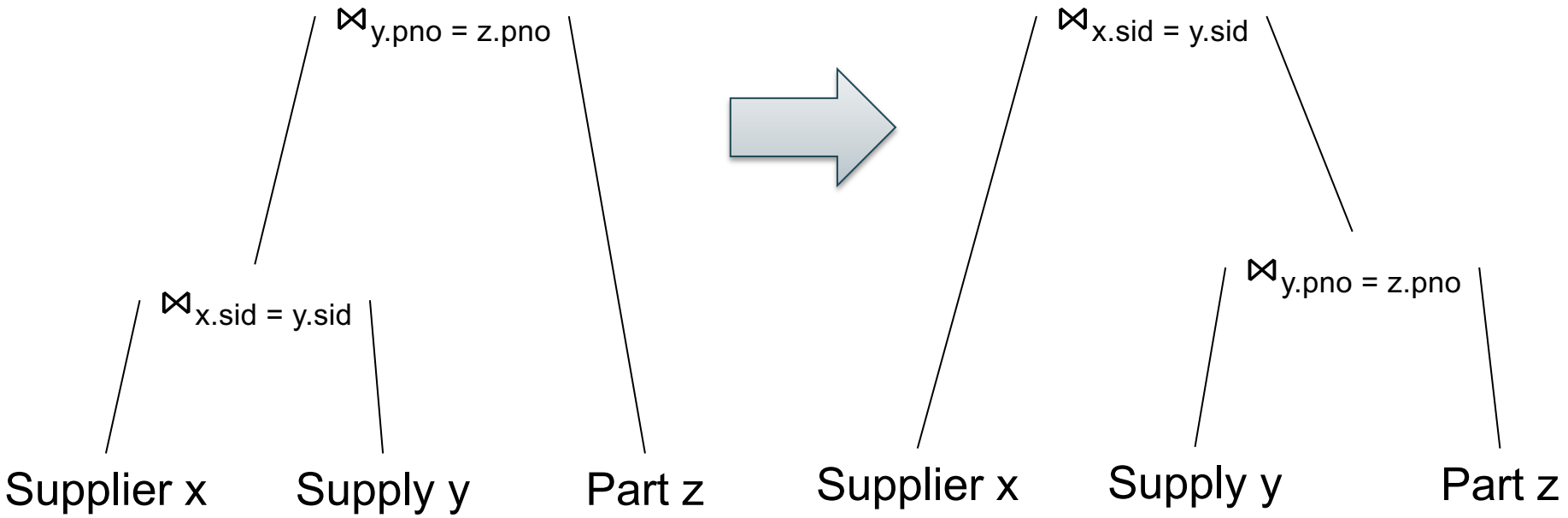
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
Part(pno, pname, pprice)

Join Reorder



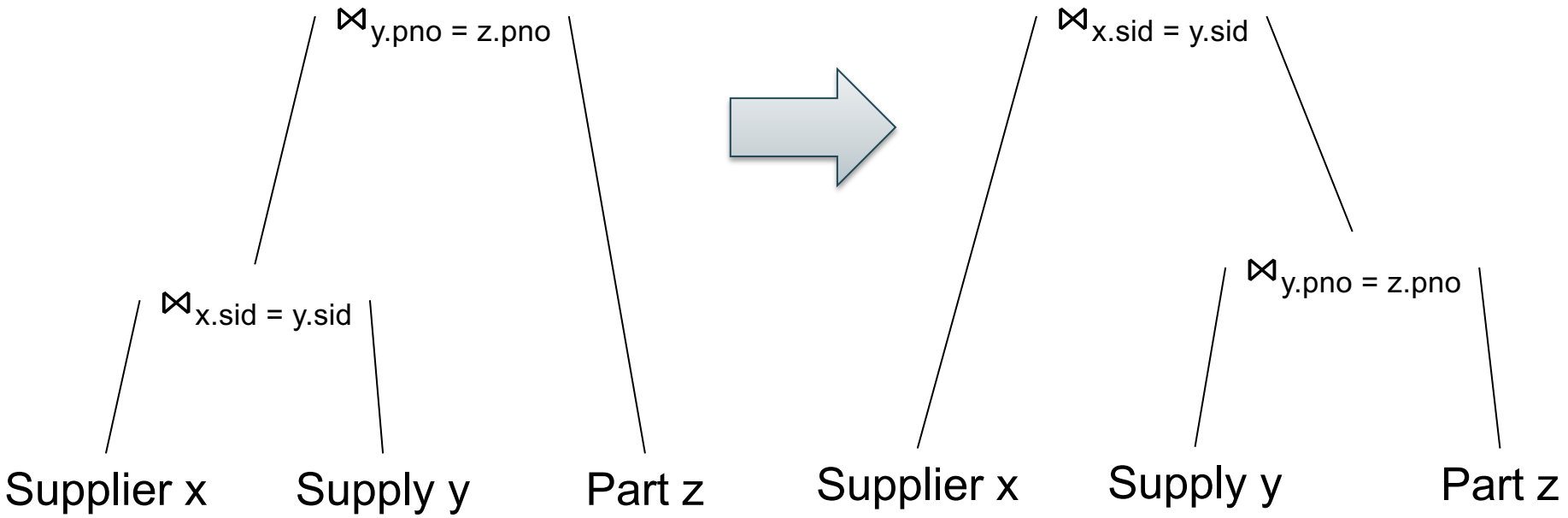
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
Part(pno, pname, pprice)

Join Reorder



Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
Part(pno, pname, pprice)

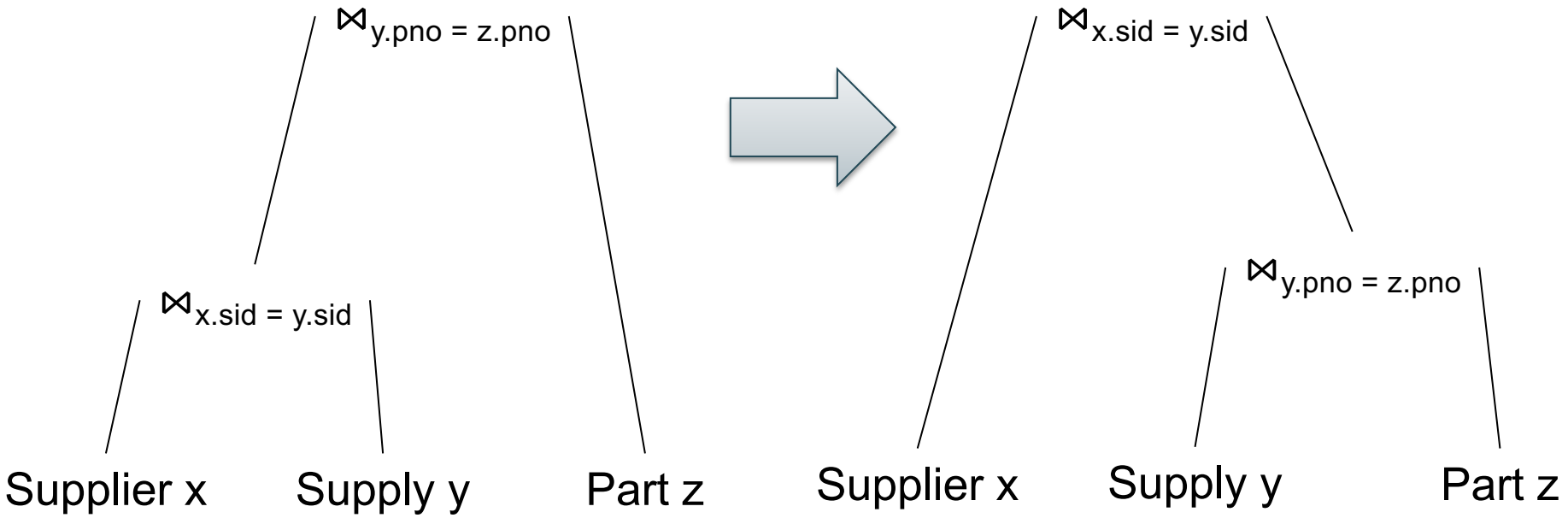
Join Reorder



$$(R \bowtie S) \bowtie T = R \bowtie (S \bowtie T)$$

Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
Part(pno, pname, pprice)

Join Reorder



$$(R \bowtie S) \bowtie T = R \bowtie (S \bowtie T)$$

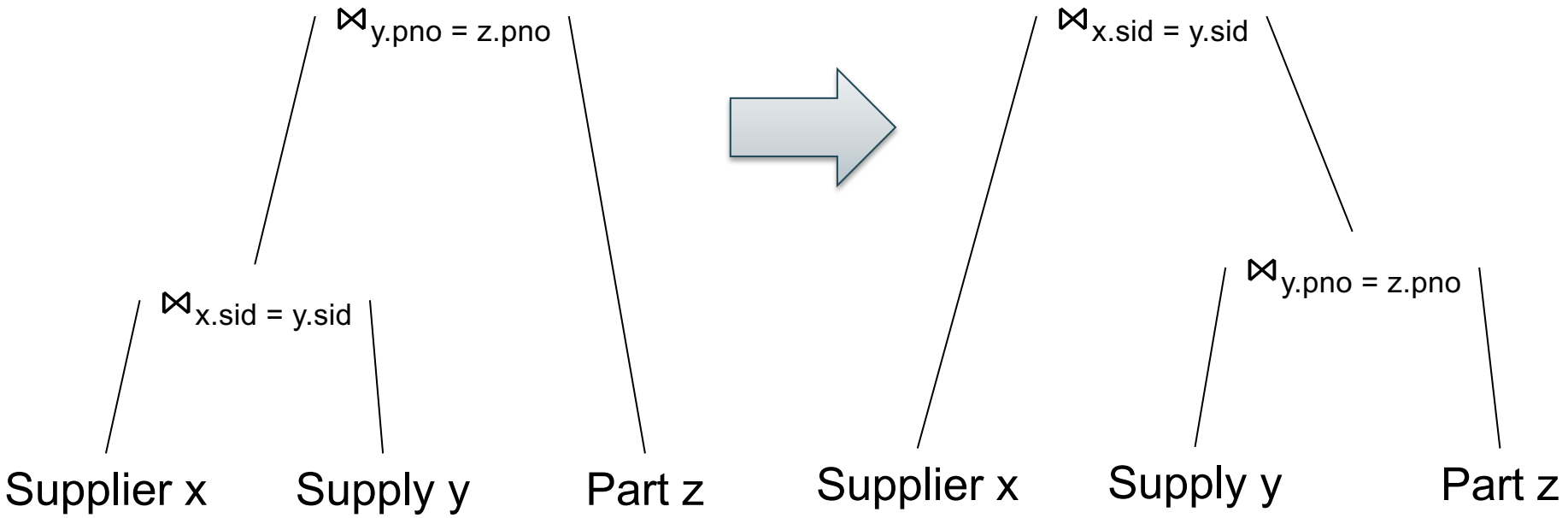
Also:

$$R \bowtie S = S \bowtie R$$

Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
Part(pno, pname, pprice)

Join Reorder

When is one plan better than the other?



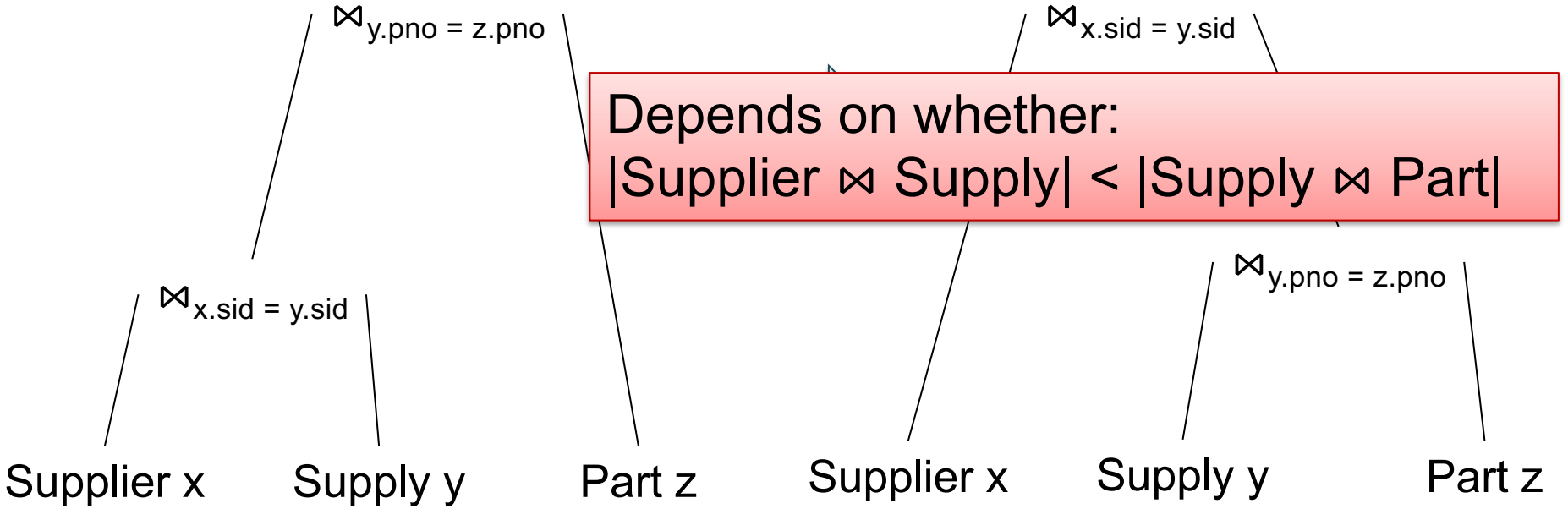
$(R \bowtie S) \bowtie T = R \bowtie (S \bowtie T)$

Also: $R \bowtie S = S \bowtie R$

Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
Part(pno, pname, pprice)

Join Reorder

When is one plan better than the other?

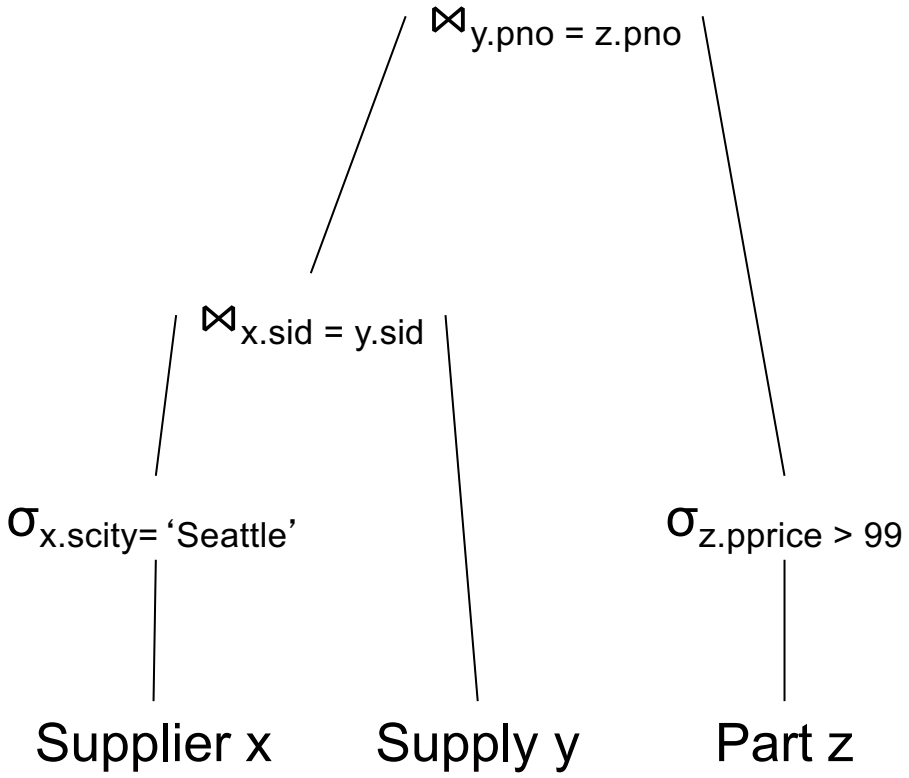


$(R \bowtie S) \bowtie T = R \bowtie (S \bowtie T)$

Also: $R \bowtie S = S \bowtie R$

Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
Part(pno, pname, pprice)

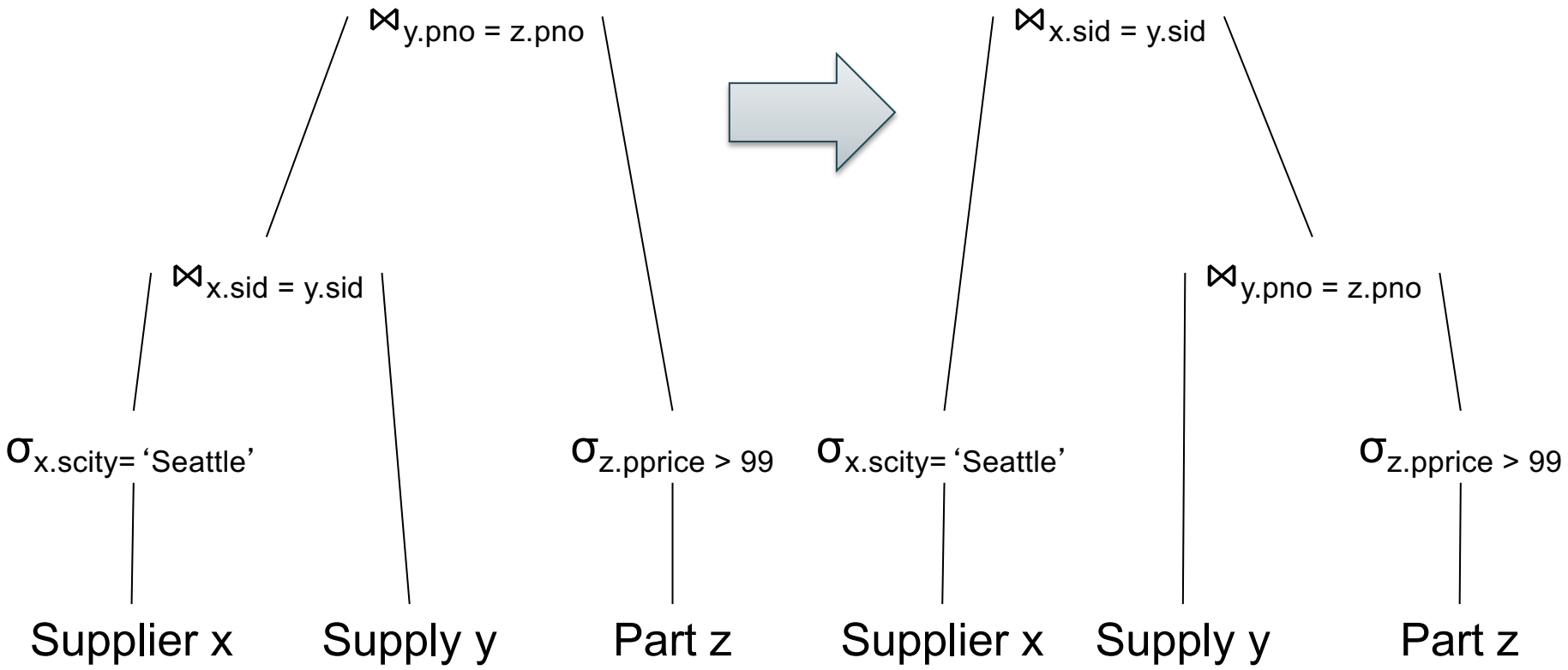
Join Reorder



Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
Part(pno, pname, pprice)

Join Reorder

When is one plan better than the other?



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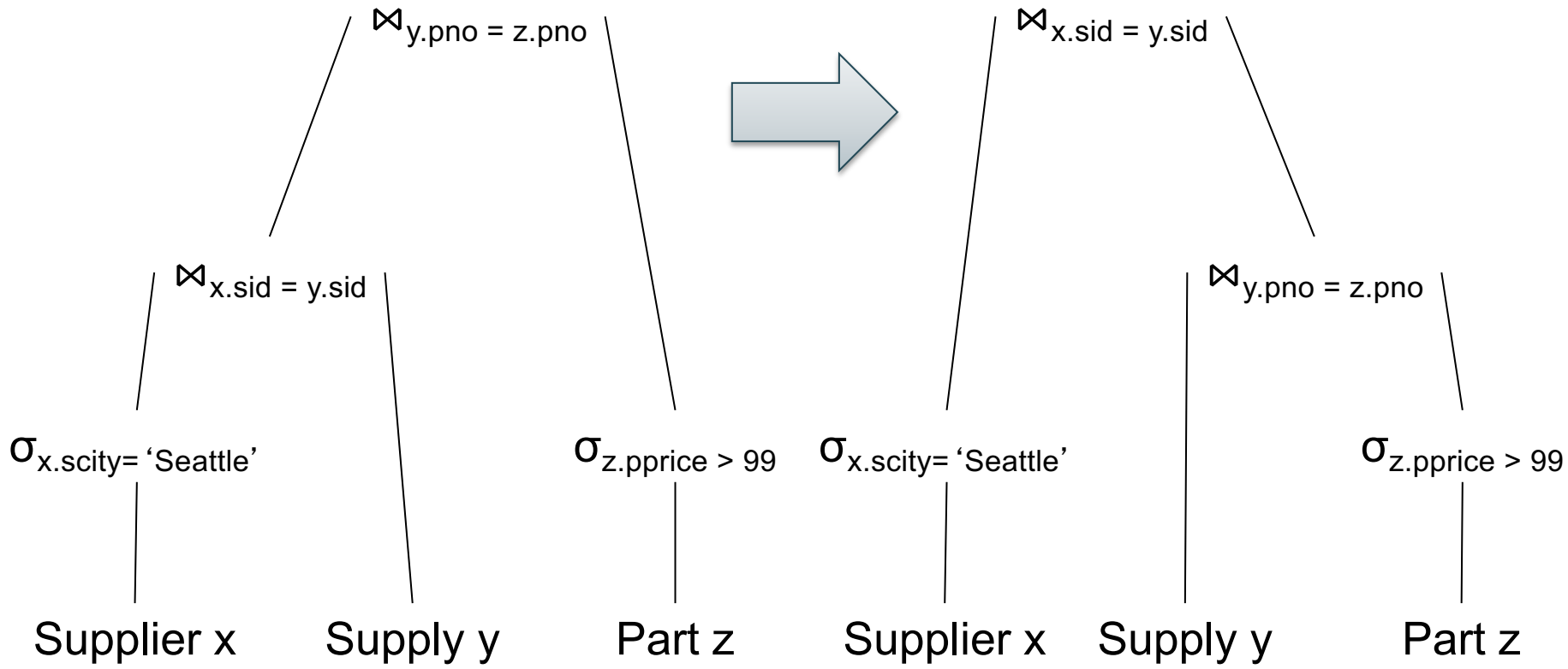
Join Reorder

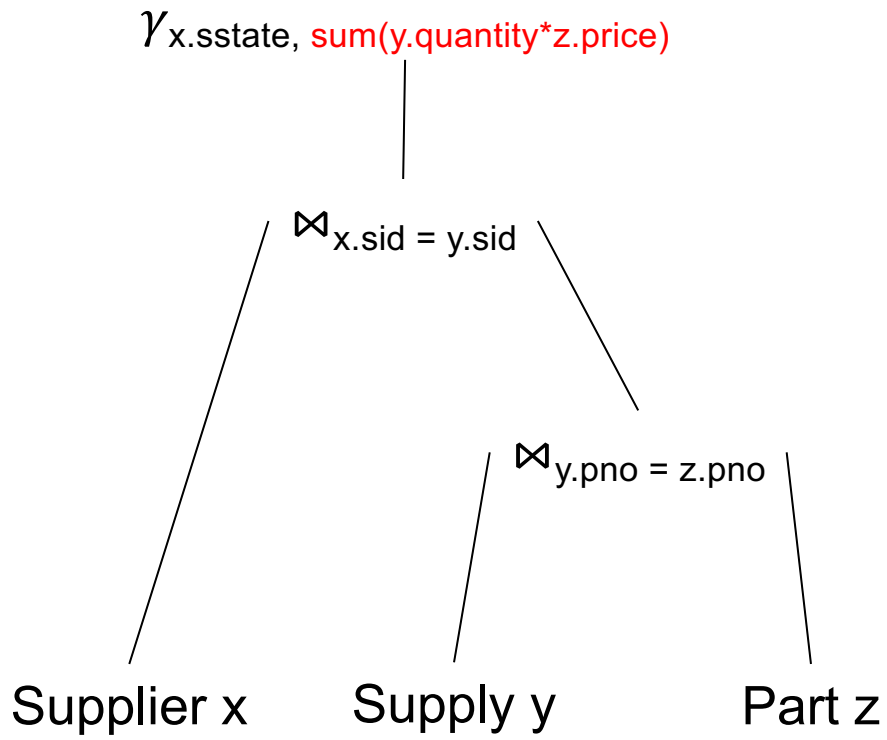
When is one plan better than the other?



Lesson: need sizes of $\sigma_{x.scity= \text{'Seattle'}}$(Supplier), $\sigma_{z.pprice > 99}$(Part)

Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
Part(pno, pname, pprice)

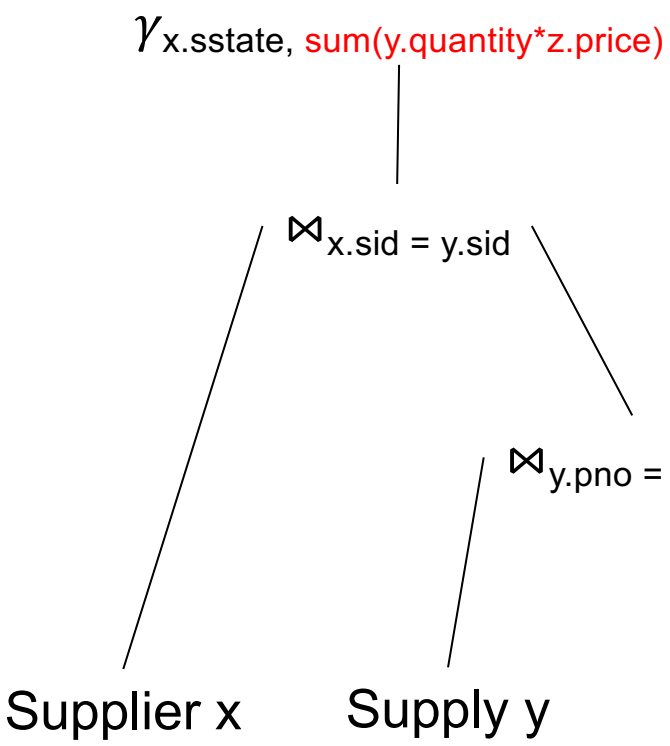
Aggregate Push-down

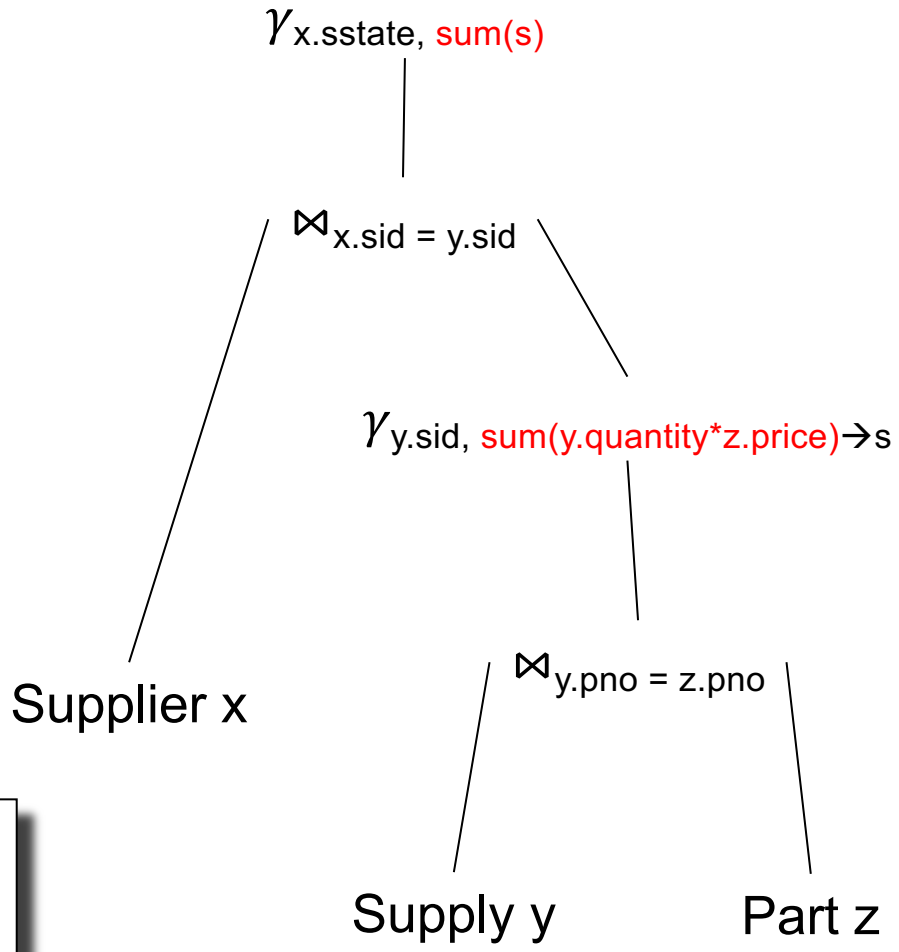



```
SELECT x.sstate, sum(y.quanity*z.price)
FROM Supplier x, Supply y, Part z
WHERE x.sid = y.sid and y.pno = z.pno
GROUP BY x.sstate
```

Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
Part(pno, pname, pprice)

Aggregate Push-down

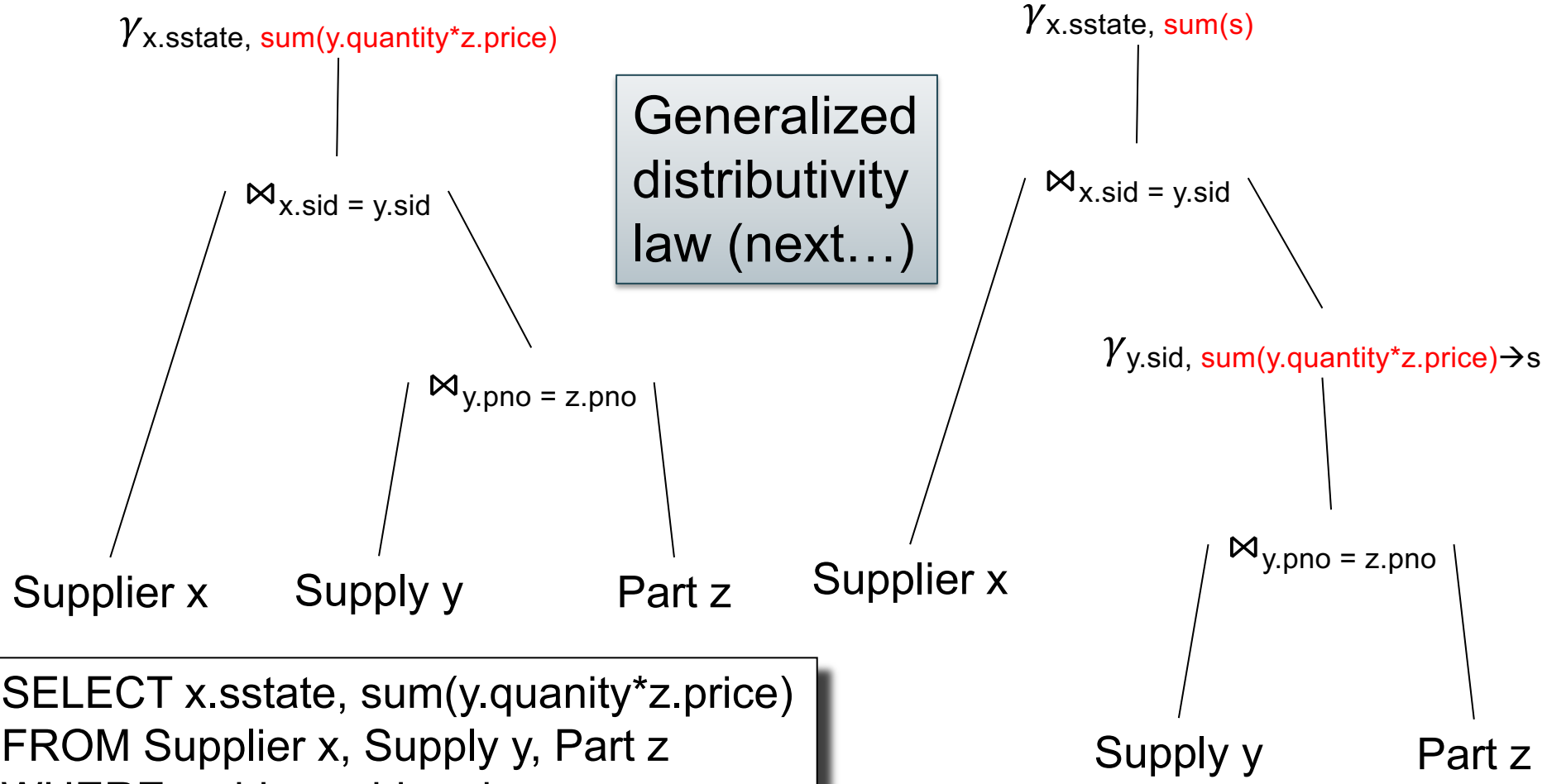





```
SELECT x.sstate, sum(y.quanity*z.price)
FROM Supplier x, Supply y, Part z
WHERE x.sid = y.sid and y.pno = z.pno
GROUP BY x.sstate
```

Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
Part(pno, pname, pprice)

Aggregate Push-down




```
SELECT x.sstate, sum(y.quanity*z.price)
FROM Supplier x, Supply y, Part z
WHERE x.sid = y.sid and y.pno = z.pno
GROUP BY x.sstate
```

Aggregate Push-Down

- Is an instance of the *generalized distributivity law* (next)
- Motivation: try this in postgres

```
select count(*) from author;
```

Answer: 2652053

Time: 58.974 ms

Aggregate Push-Down

- Is an instance of the *generalized distributivity law* (next)
- Motivation: try this in postgres

```
select count(*) from author;
```

Answer: 2652053

Time: 58.974 ms

```
select count(*) from publication;
```

Answer: 5120896

Time: 62.465 ms

Aggregate Push-Down

- Is an instance of the *generalized distributivity law* (next)
- Motivation: try this in postgres

```
select count(*) from author;
```

Answer: 2652053

Time: 58.974 ms

```
select count(*) from publication;
```

Answer: 5120896

Time: 62.465 ms

```
select count(*) from author, publication;
```

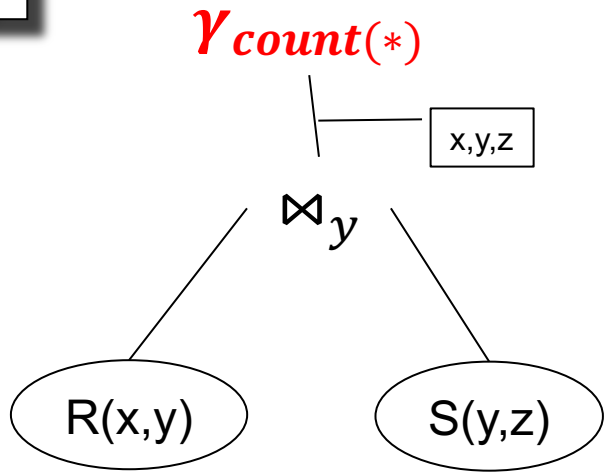
Timeout!!!

Generalized Distributivity Law

```
SELECT count(*) from R, S where R.y=S.y
```

Generalized Distributivity Law

SELECT count(*) from R, S where R.y=S.y



Generalized Distributivity Law

SELECT count(*) from R, S where R.y=S.y

R:

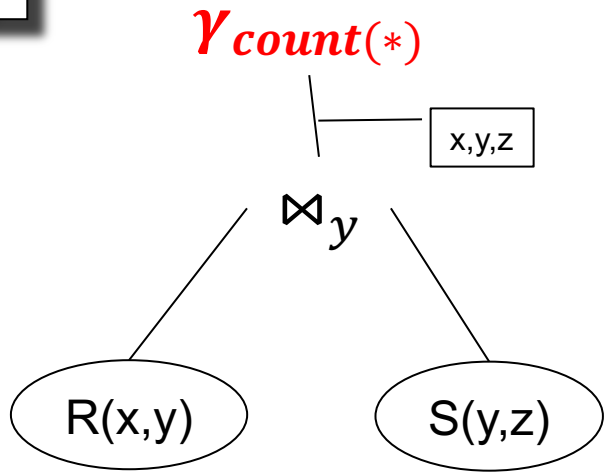
x	y
a	b
c	b
d	f
g	h

S:

y	z
b	g
b	k
h	m

Answer = 5

Runtime = $O(N^2)$



Generalized Distributivity Law

SELECT count(*) from R, S where R.y=S.y

R:

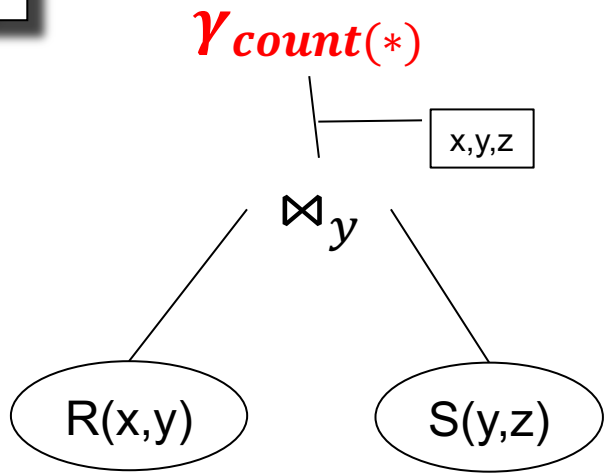
x	y
a	b
c	b
d	f
g	h

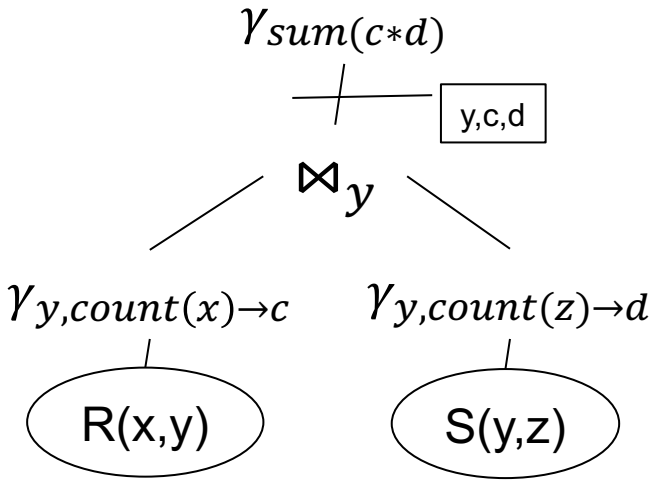
S:

y	z
b	g
b	k
h	m

Answer = 5

Runtime = $O(N^2)$





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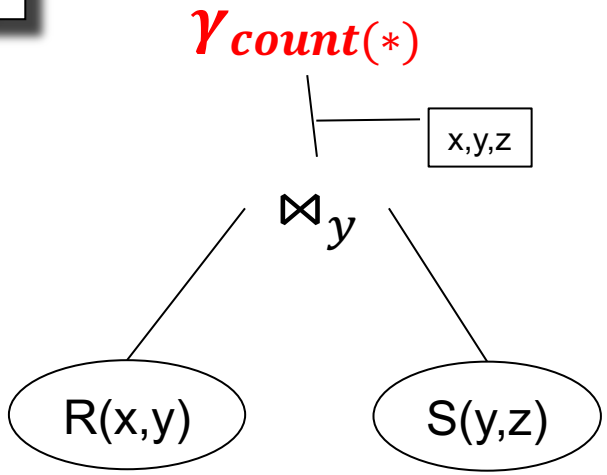


A:

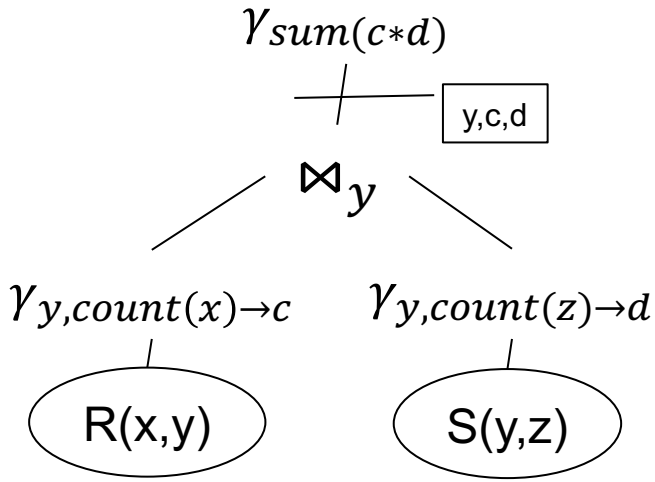
y	c
b	2
f	1
h	1

B:

y	c
b	2
h	1

A⋈B

y	c	d
b	2	2
h	1	1



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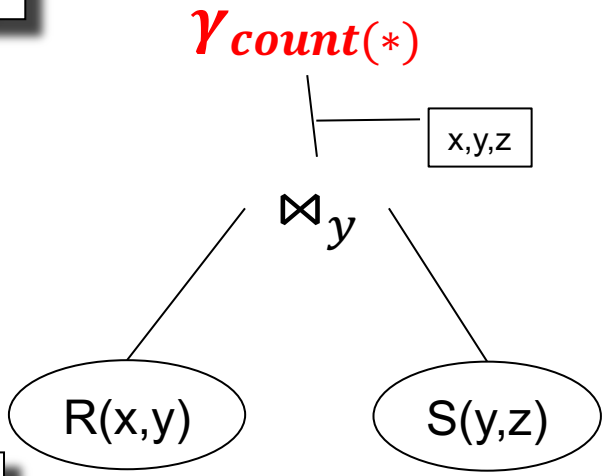
Runtime = $O(N)$



A=select y,count(*) as c from R group by y

B=select y,count(*) as d from S group by y

select sum(c*d) from A, B where A.y=B.y

A:

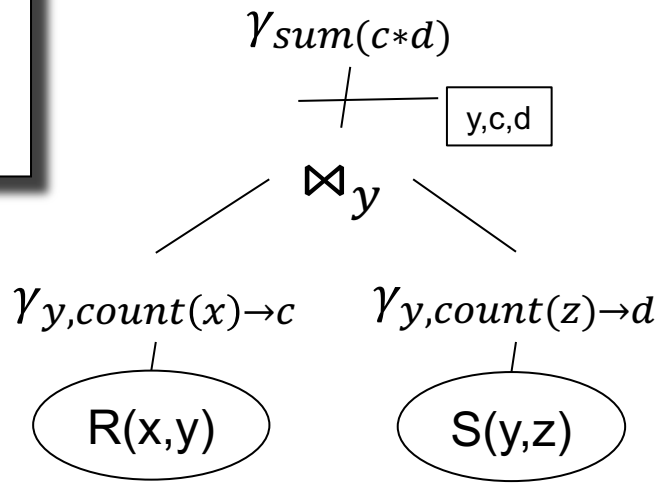
y	c
b	2
f	1
h	1

B:

y	c
b	2
h	1

A⋈B

y	c	d
b	2	2
h	1	1



Cardinality Estimation

Problem: given statistics on base tables and a query, estimate size of the answer

Very difficult, because:

- Need to do it very fast
- Need to use very little memory

Statistics on Base Data

Statistics on base tables

- Number of tuples (cardinality) T(R)
- Number of physical pages B(R)
- Indexes, number of keys in the index V(R,a)
- Histogram on single attribute (1d)
- Histogram on two attributes (2d)

Computed periodically, often using sampling

Assumptions

- Uniformity
- Independence
- Containment of values
- Preservation of values

Selectivity of a Predicate

Selection: size decreases by *selectivity factor* θ

$$T(\sigma_{pred}(R)) = T(R) * \theta_{pred}$$

Uniformity assumption

Selectivity Factors

- A = c /* $\sigma_{A=c}(R)$ */
  - Selectivity = 1/V(R,A)

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- A = c /* $\sigma_{A=c}(R)$ */
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- c1 < A < c2 /* $\sigma_{c1<A<c2}(R)$*/
  - Selectivity = (c2 – c1)/(max(R,A) - min(R,A))

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Multiple predicates:

- A = c and B = d /* $\sigma_{A=c \text{ and } B=d}(R)$ */

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Multiple predicates: *independence assumption*

- A = c and B = d /* $\sigma_{A=c \text{ and } B=d}(R)$ */
  - Selectivity = 1/V(R,A) * 1/V(R,B)

Estimating Result Sizes

Join R $\bowtie_{R.A=S.B}$ S

- Take product of cardinalities of R and S
- Apply this selectivity factor:
  1/ (MAX(V(R,A), V(S,B))
- Why? Will explain next...

Assumptions

Containment of values: if V(R,A) ≤ V(S,B), then the set of A values of R is included in the set of B values of S

- Note: this indeed holds when A is a foreign key in R, and B is a key in S

Selectivity of $R \bowtie_{A=B} S$

Assume $V(R,A) \leq V(S,B)$

- Each tuple t in R joins with $T(S)/V(S,B)$ tuples in S

- Hence $T(R \bowtie_{A=B} S) = T(R)\ T(S) / V(S,B)$

In general:

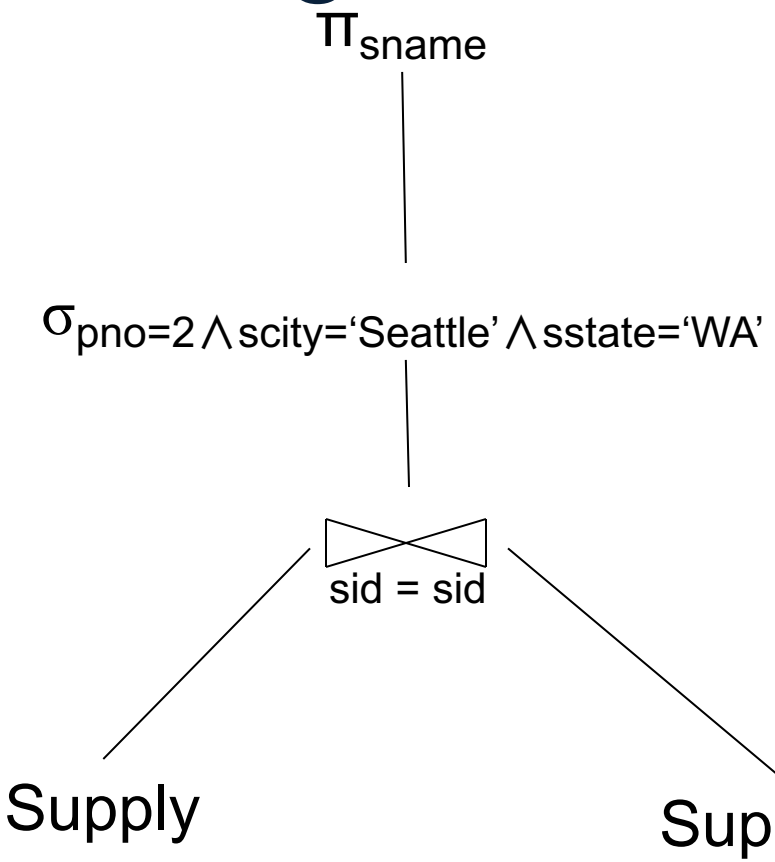
$T(R \bowtie_{A=B} S) = T(R)\ T(S) / \max(V(R,A),V(S,B))$

Computing the Cost of a Plan

- Estimate cardinality in a bottom-up fashion
  - Cardinality is the size of a relation (nb of tuples)
  - Compute size of *all* intermediate relations in plan
- Estimate cost by using the estimated cardinalities
- Extensive example next...

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

Logical Query Plan 1

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SELECT sname
FROM Supplier x, Supply y
WHERE x.sid = y.sid
    and y.pno = 2
    and x.scity = 'Seattle'
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T(Supply) = 10000
B(Supply) = 100
V(Supply, pno) = 2500

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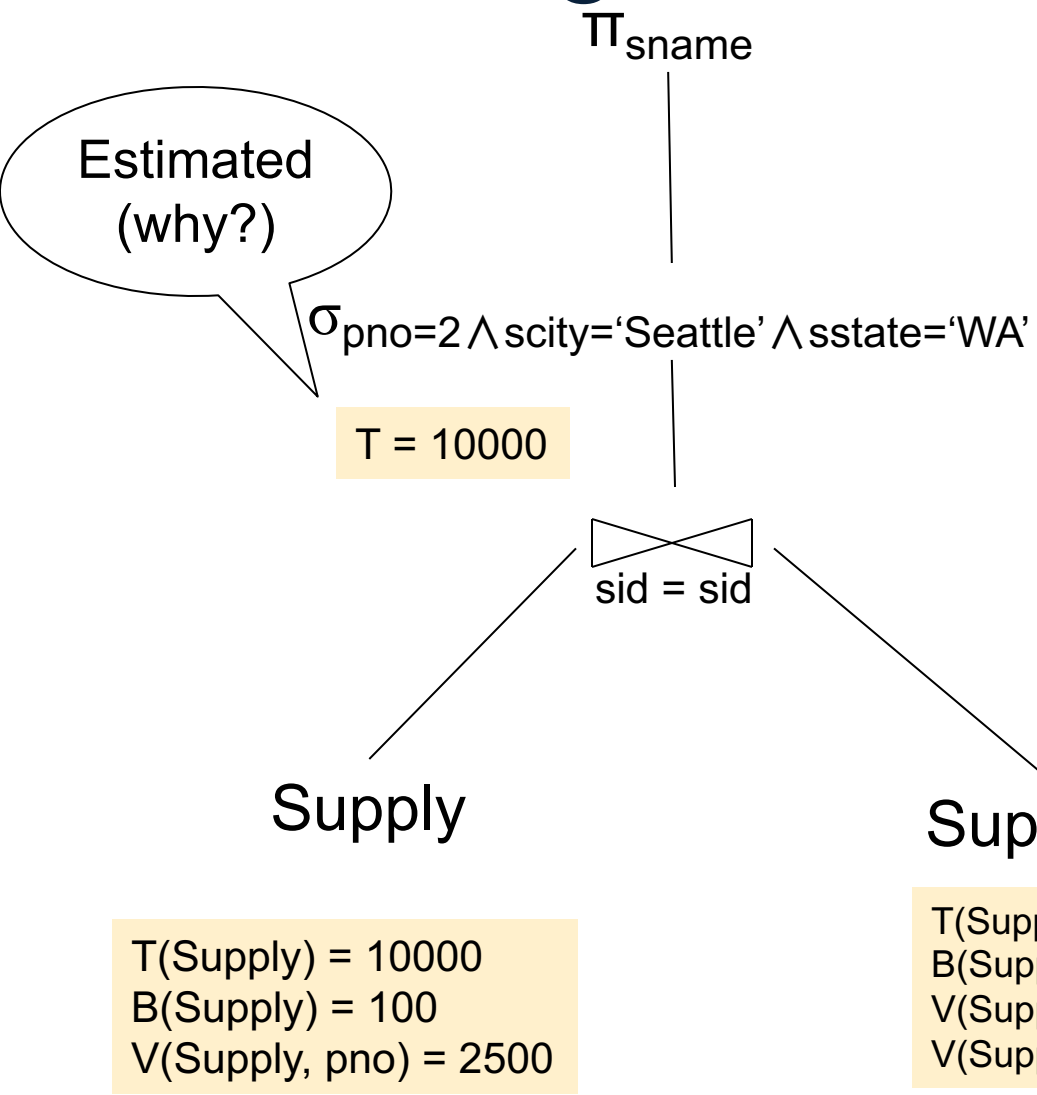


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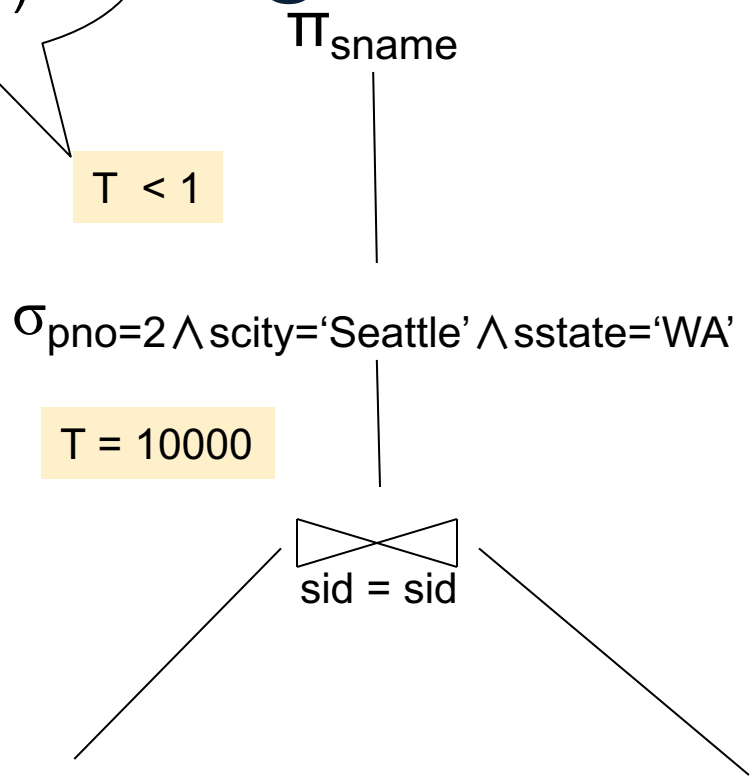
Logical Query Plan 1

Estimated (why?)

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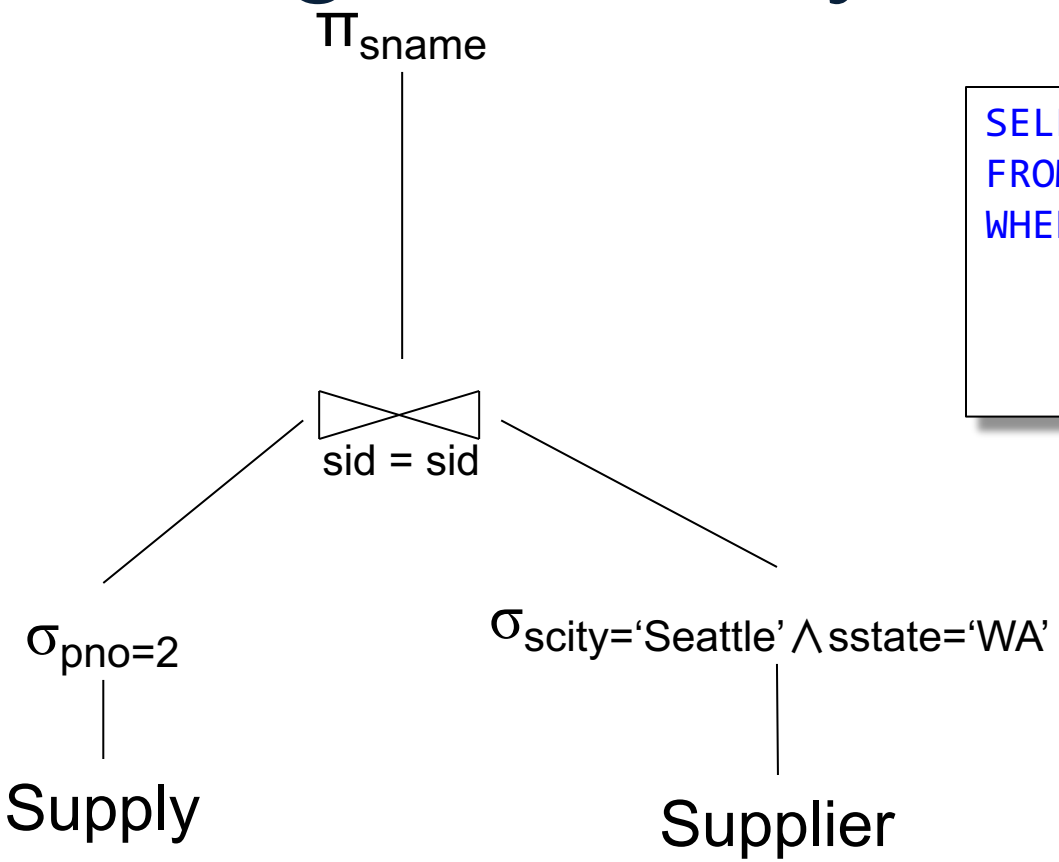
Logical Query Plan 2

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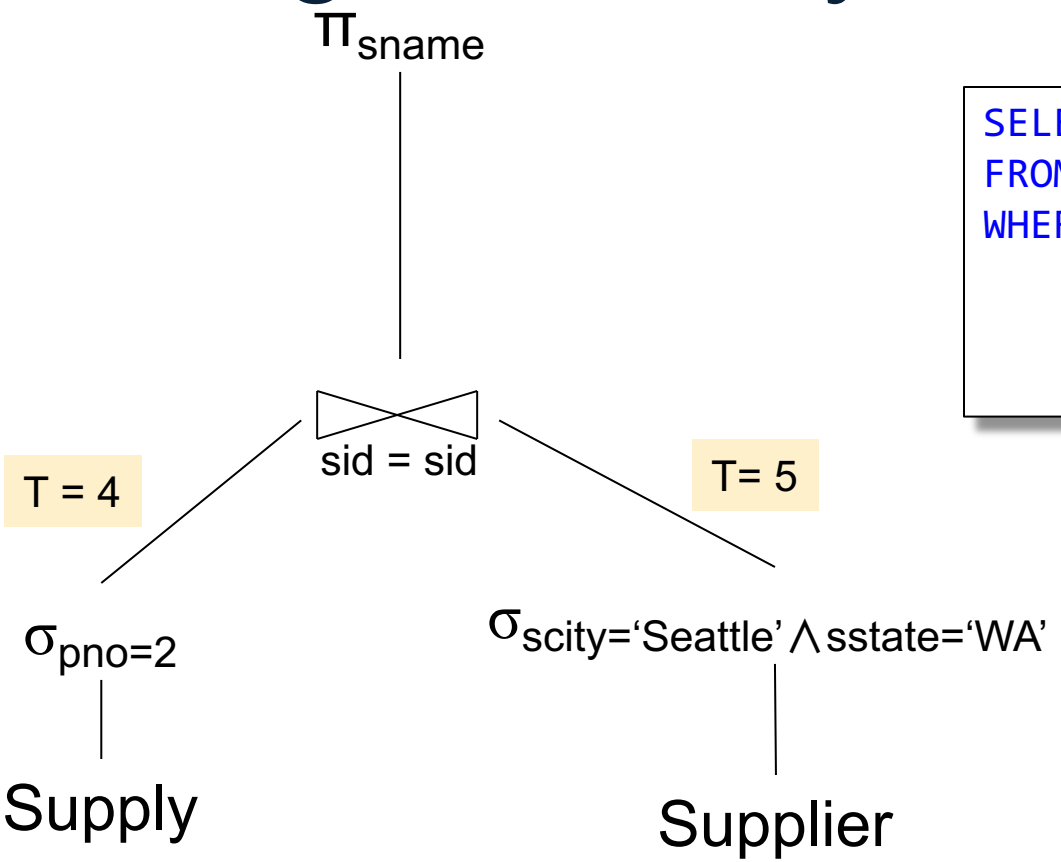


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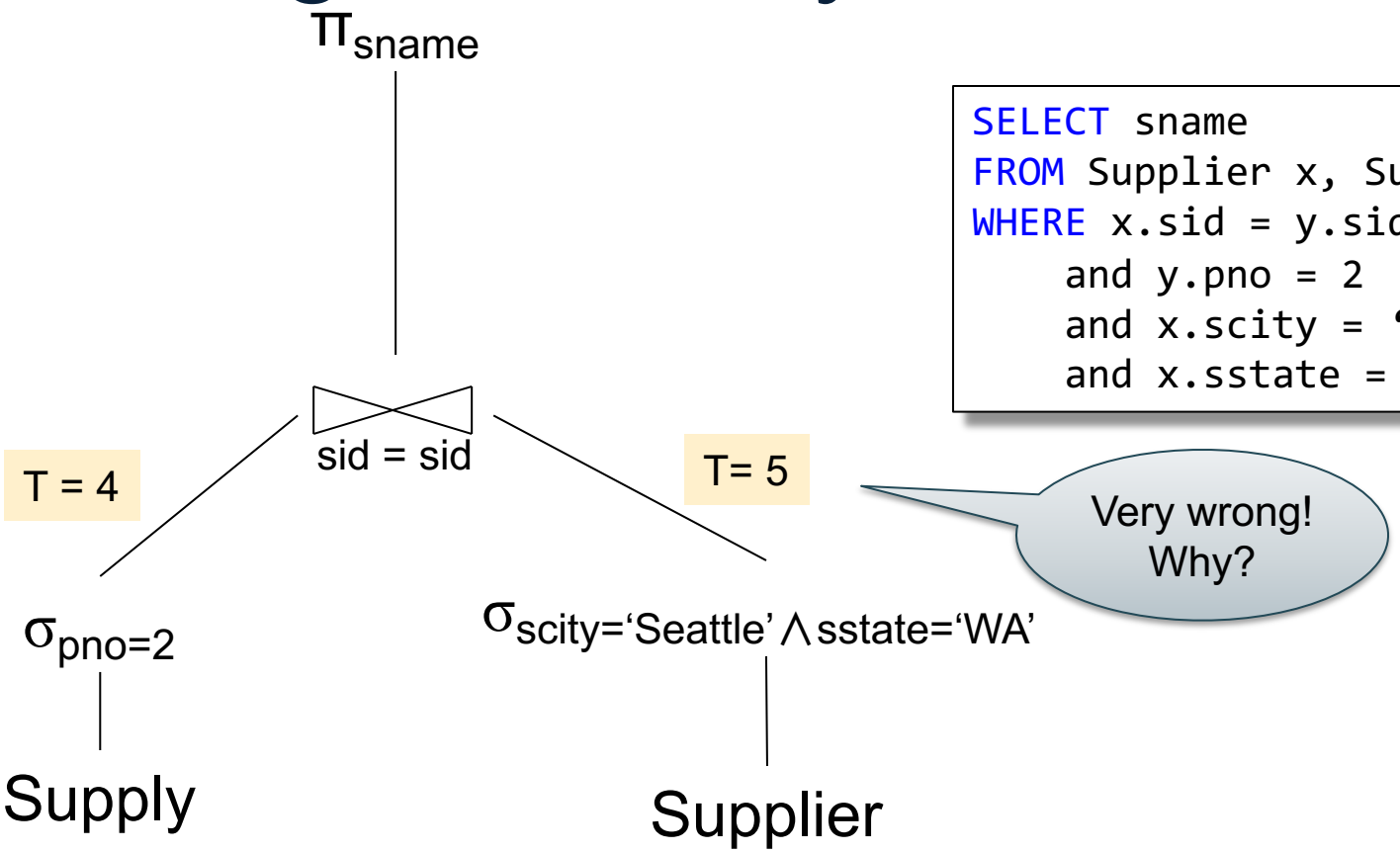


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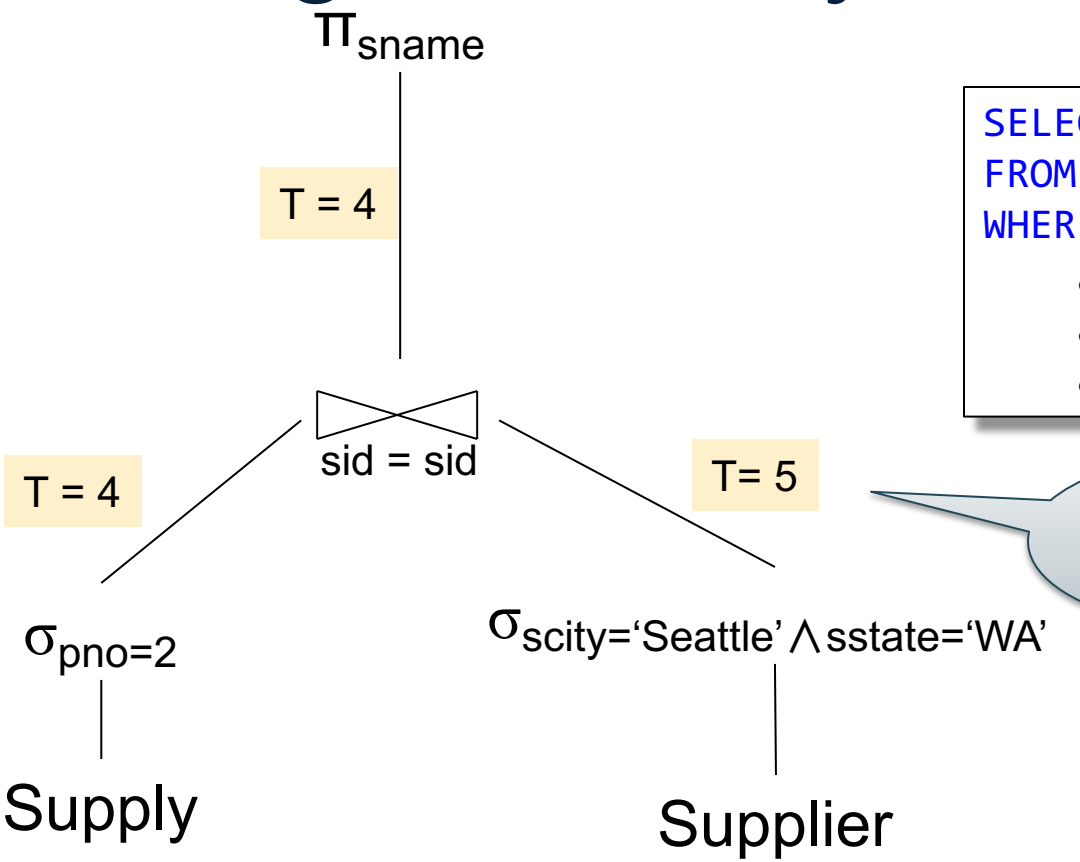


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Very wrong!
Why?

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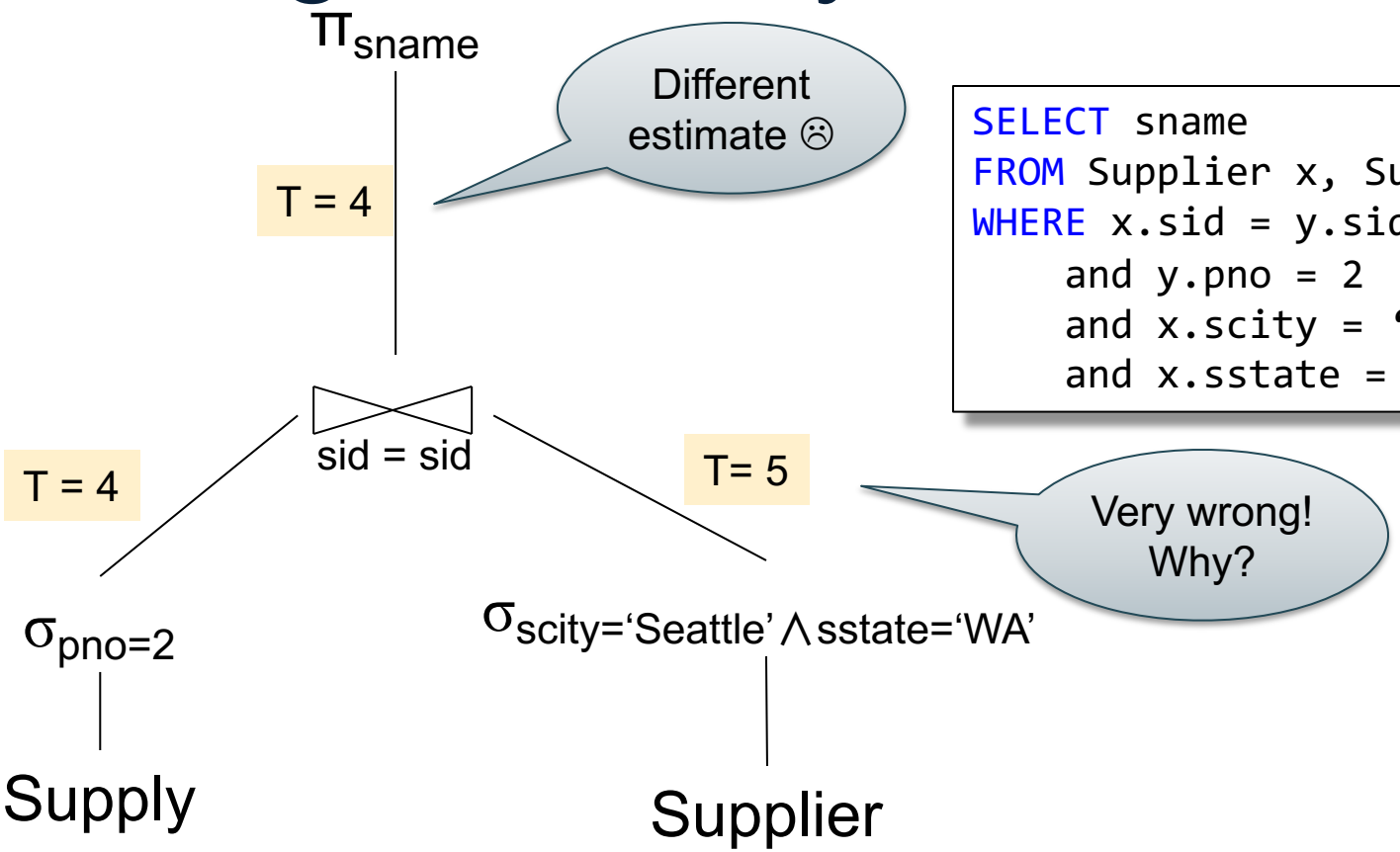


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Viktor Leis, Andrey Gubichev, Atanas Mirchev, Peter A. Boncz, Alfons Kemper, Thomas Neumann: How Good Are Query Optimizers, Really?, VLDB 2015

Joins (0 to 6)

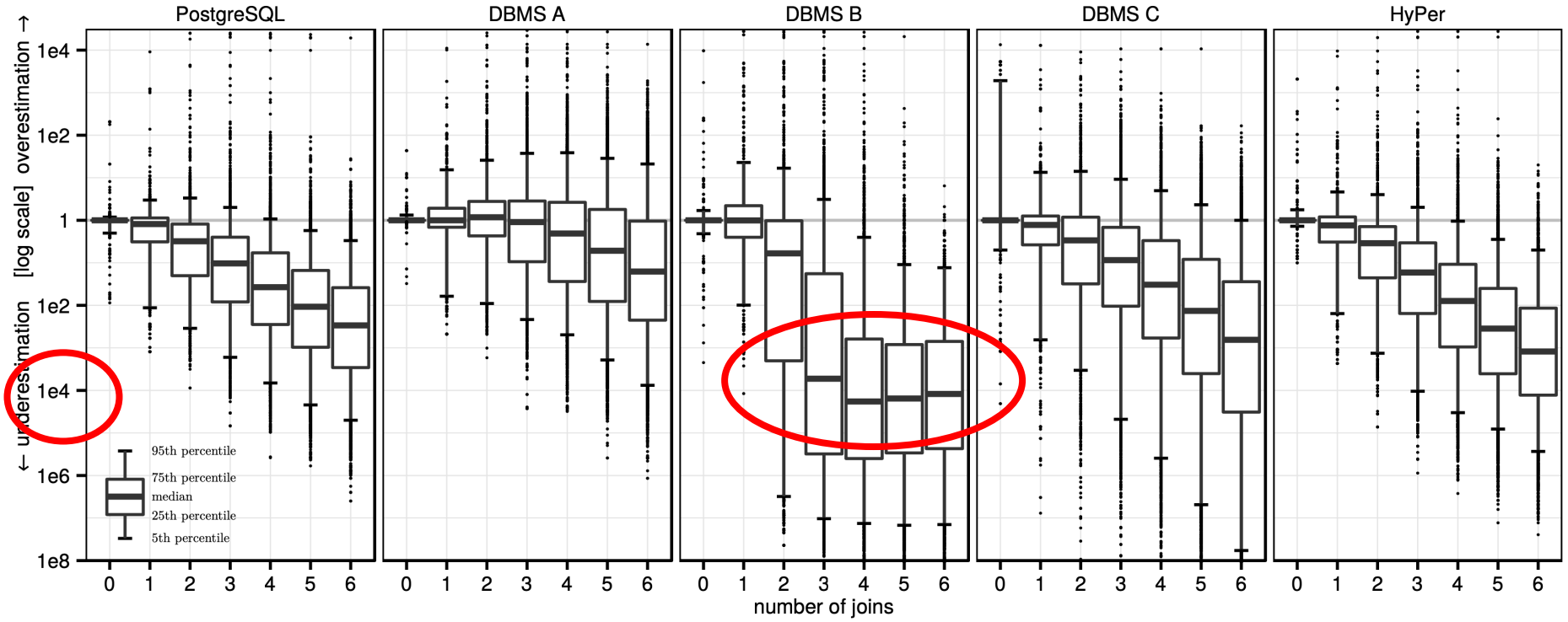


Figure 3: Quality of cardinality estimates for multi-join queries in comparison with the true cardinalities. Each boxplot summarizes the error distribution of all subexpressions with a particular size (over all queries in the workload)

Discussion

Physical data independence recap:

- Users think of the data as a *relations*, SQL is declarative = *what*
- Real data is stored in physical format (on disk, or distributed, etc), real queries are answered by algorithms=*how*
- Query optimizer maps *what* to *how*

Parallel Query Processing

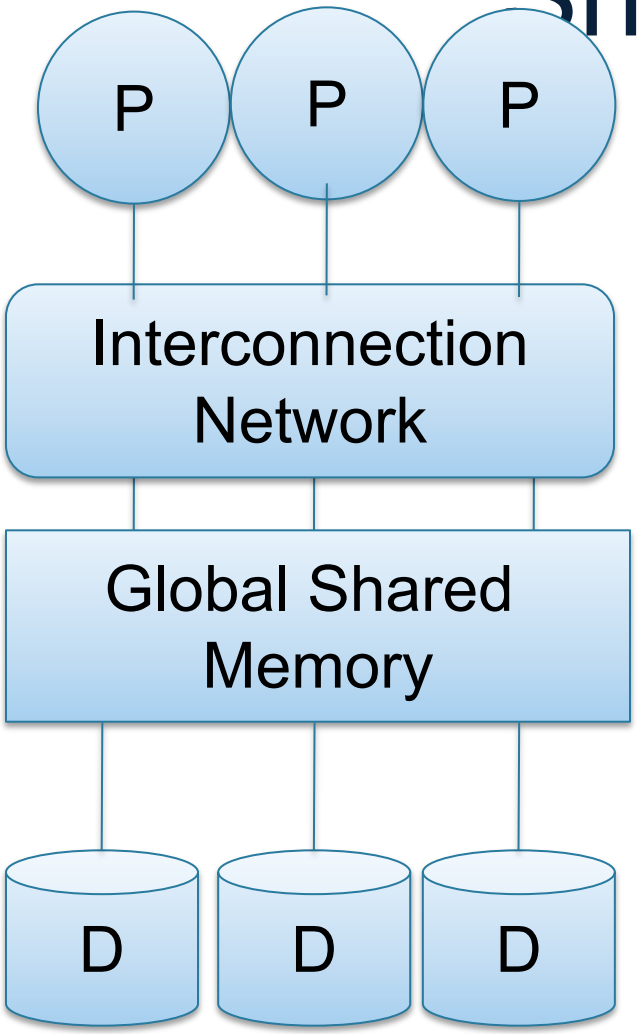
Parallel Query Processing

- Clusters:
  - More servers → more likely to fit data in main memory
  - More servers → more computing power
  - Clusters are now cheaply available in the cloud
  - A.k.a. *distributed* query procesing
- Multicores: the end of Moore's law

Architectures for Parallel Databases

- Shared memory
- Shared disk
- Shared nothing

Shared Memory

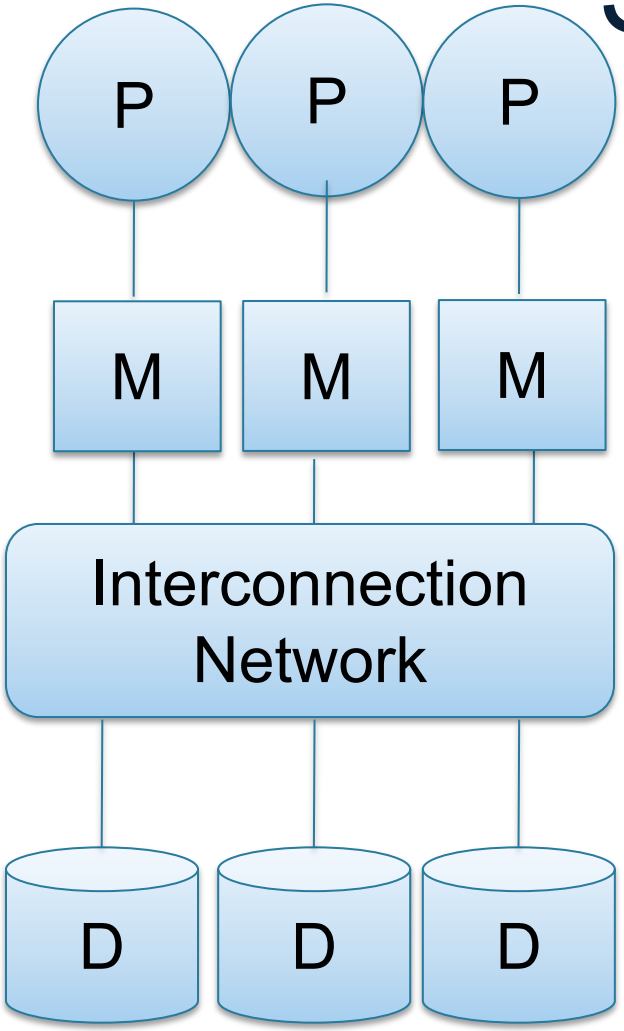


- SMP = symmetric multiprocessor
- Nodes share RAM and disk
- 10x … 100x processors

- Example: SQL Server runs on a single machine and can leverage many threads to speed up a query

- Easy to use and program
- Expensive to scale

Shared Disk



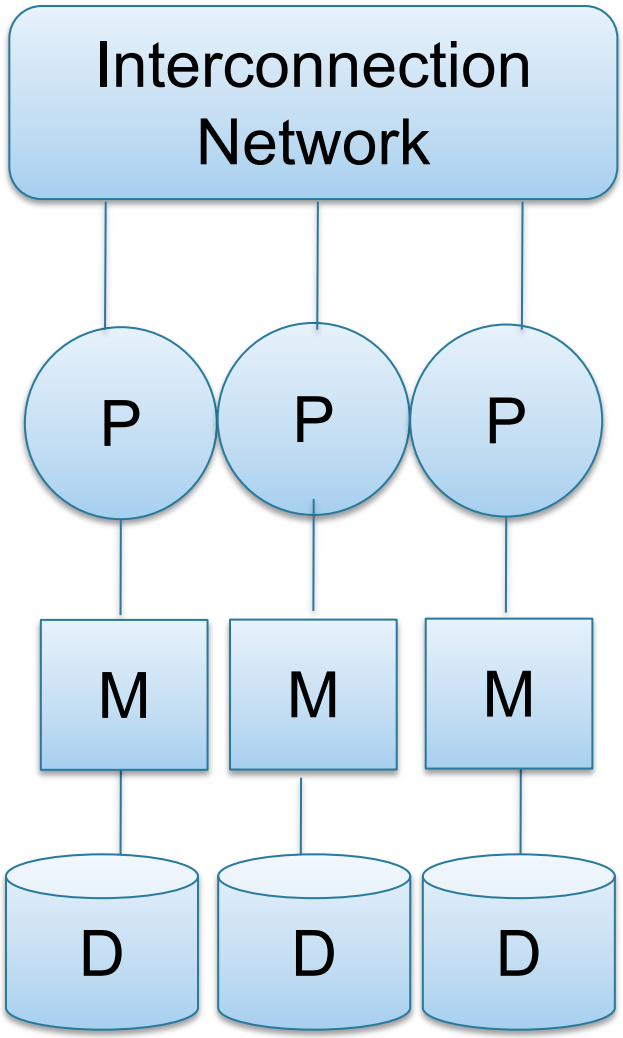
- All nodes access same disks
- 10x processors

- Example: Oracle

- No more memory contention

- Harder to program
- Still hard to scale

Shared Nothing



- Cluster of commodity machines
- Called "clusters" or "blade servers"
- Each machine: own memory&disk
- Up to x1000-x10000 nodes
- Example: redshift, spark, etc, etc

Because all machines today have many cores and many disks, shared-nothing systems typically run many "nodes" on a single physical machine.

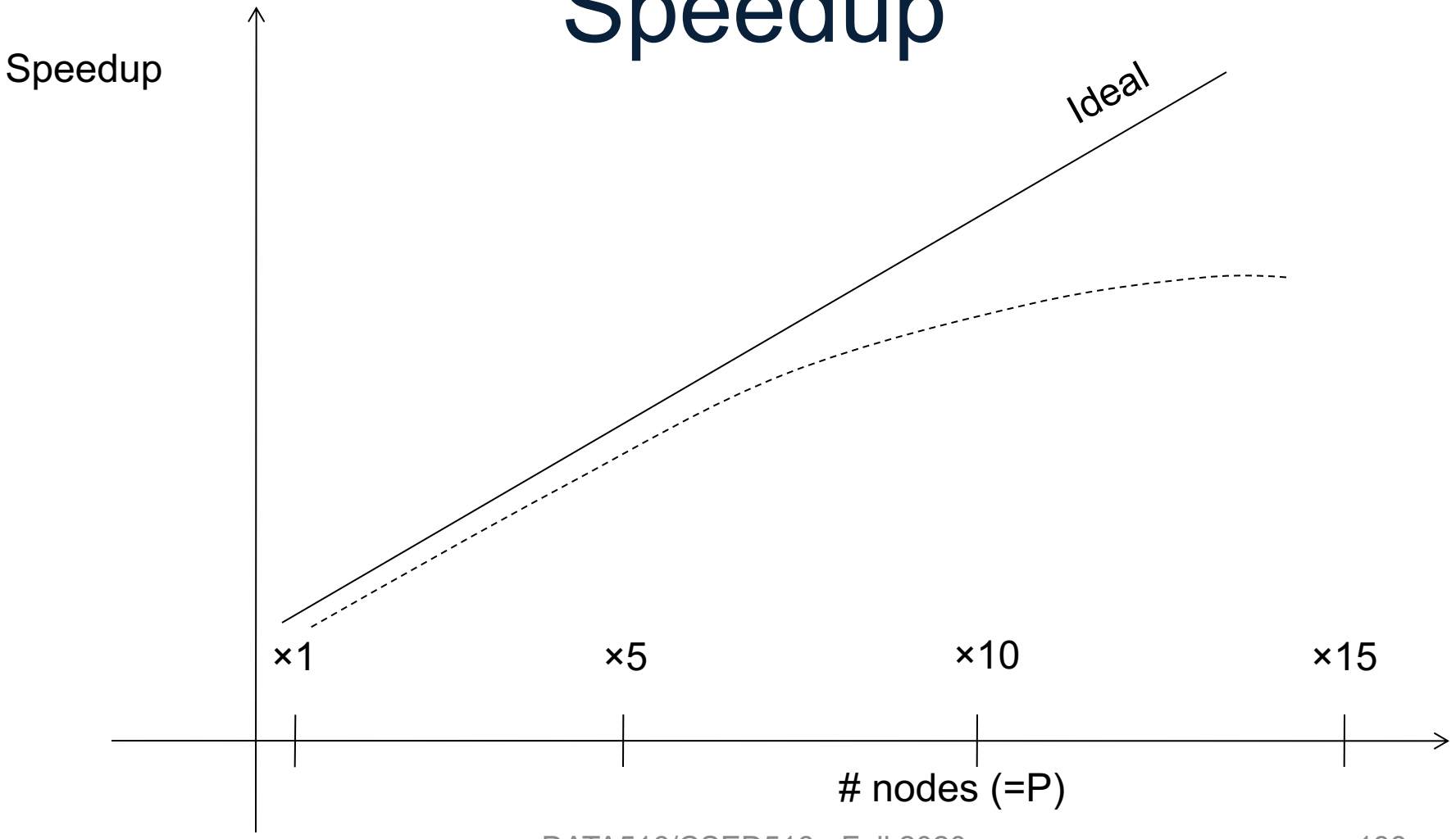
- Easy to maintain and scale
- Most difficult to administer and tune.

Performance Metrics

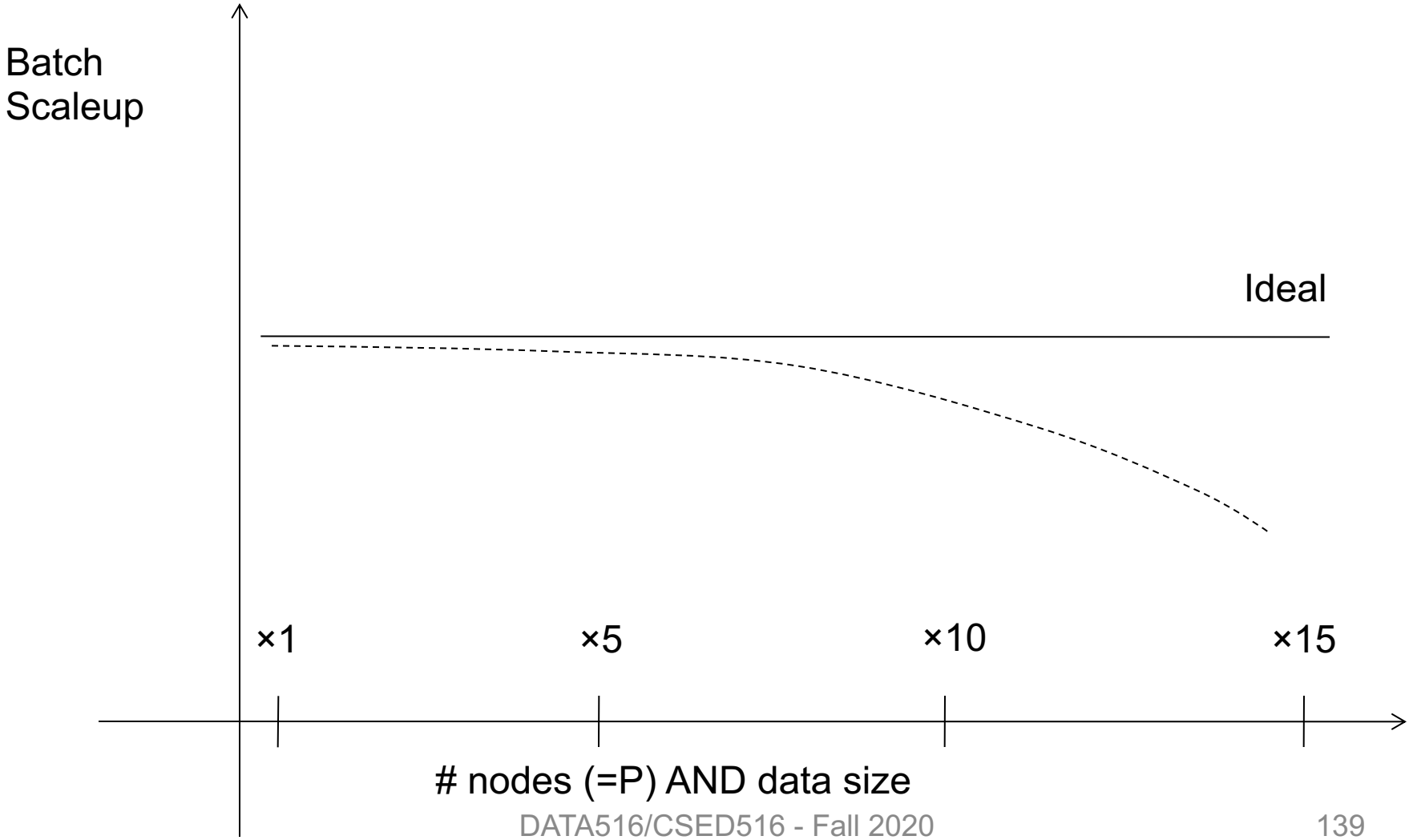
Nodes = processors = computers

- Speedup:
  - More nodes, same data ➔ higher speed
- Scaleup:
  - More nodes, more data ➔ same speed

Linear v.s. Non-linear Speedup



Linear v.s. Non-linear Scaleup



Why Sub-linear?

- Startup cost
  - Cost of starting an operation on many nodes
- Interference
  - Contention for resources between nodes
- Skew
  - Slowest node becomes the bottleneck

Horizontal Data Partitioning

- Distribute the n data on the p servers, such that each server only needs to process n/p data items.

- Called *horizontal data partitioning*

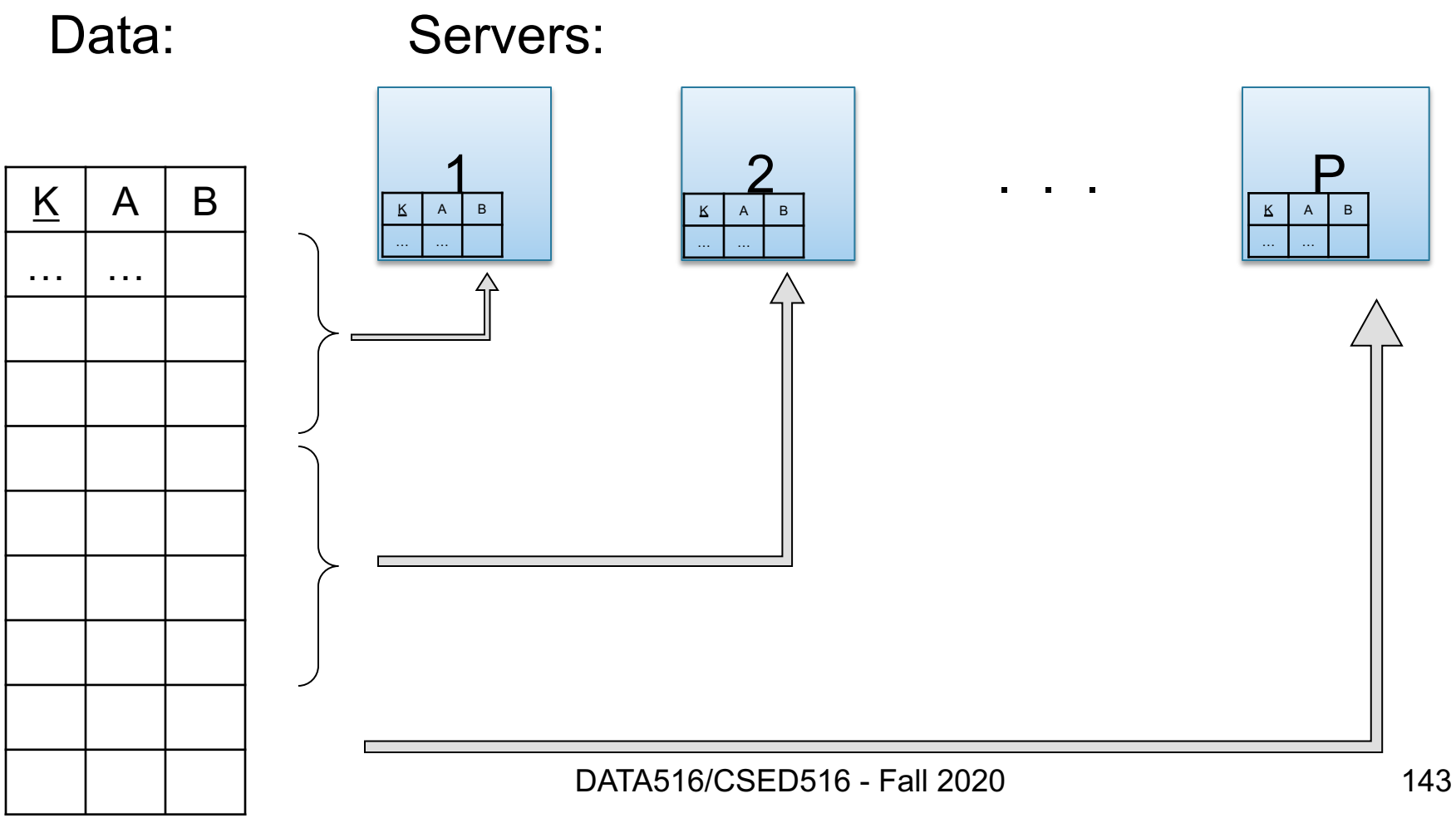
Horizontal Data Partitioning

Data:

K	A	B
…	…	

Servers:

Horizontal Data Partitioning



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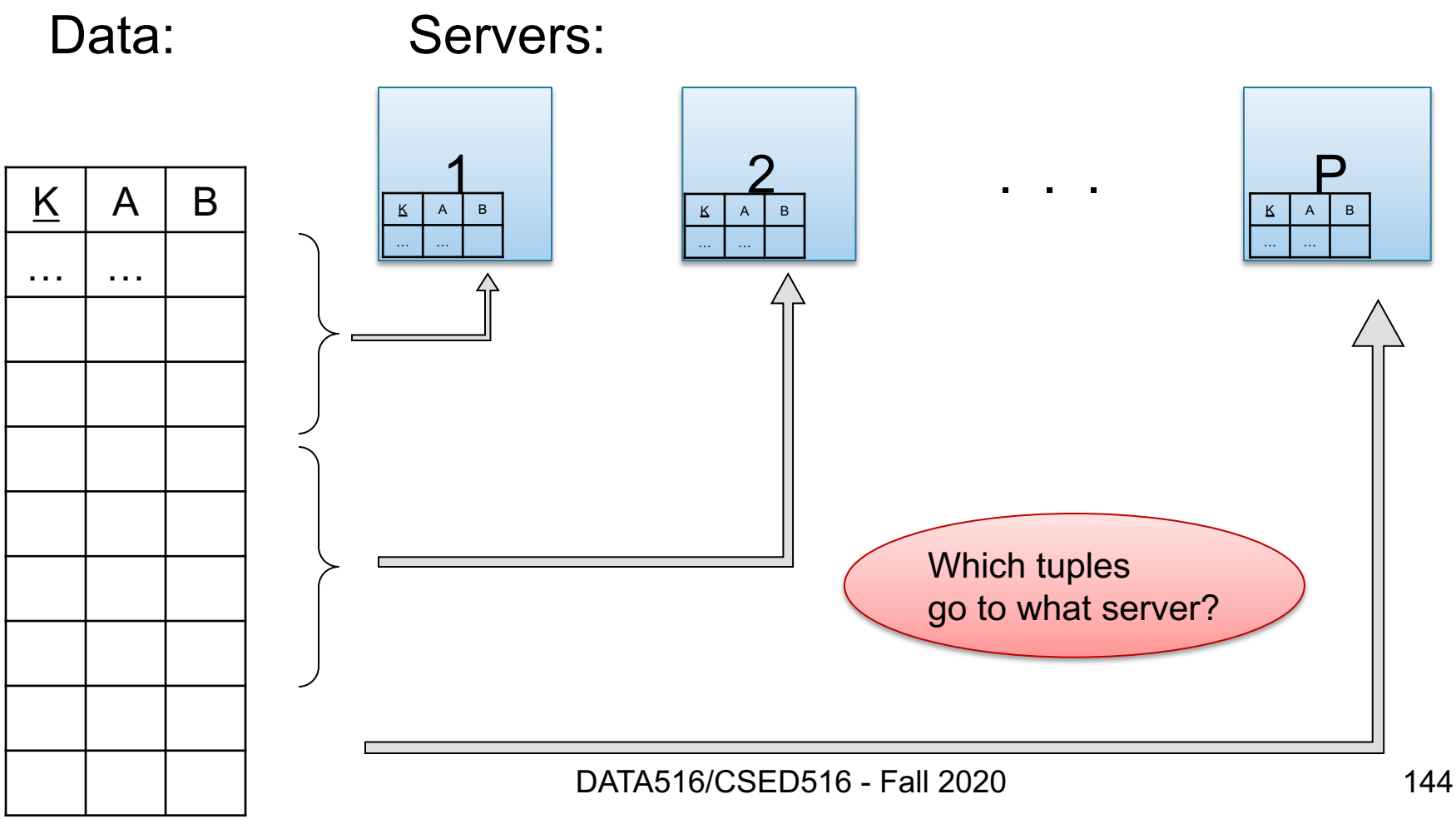

Horizontal Data Partitioning

- Block Partition, a.k.a. Round Robin:
  - Partition tuples arbitrarily s.t. size(R_1)≈ … ≈ size(R_P)
- Hash partitioned on attribute A:
  - Tuple t goes to chunk i, where i = h(t.A) mod P + 1
- Range partitioned on attribute A:
  - Partition the range of A into $-\infty = v_0 < v_1 < \ldots < v_P = \infty$
  - Tuple t goes to chunk i, if $v_{i-1} < t.A < v_i$

Brent's Theorem

Suppose we can solve a problem in time T using P servers:

Brent's Theorem

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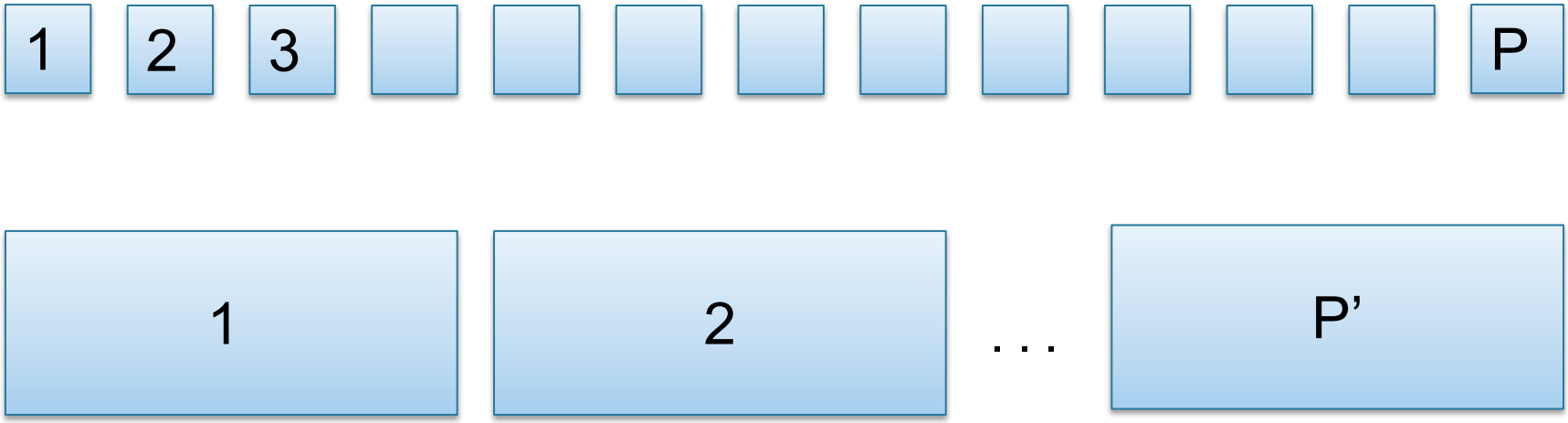

Then we can solve the same problem in time T*P/P' using P' < P servers

Brent's Theorem

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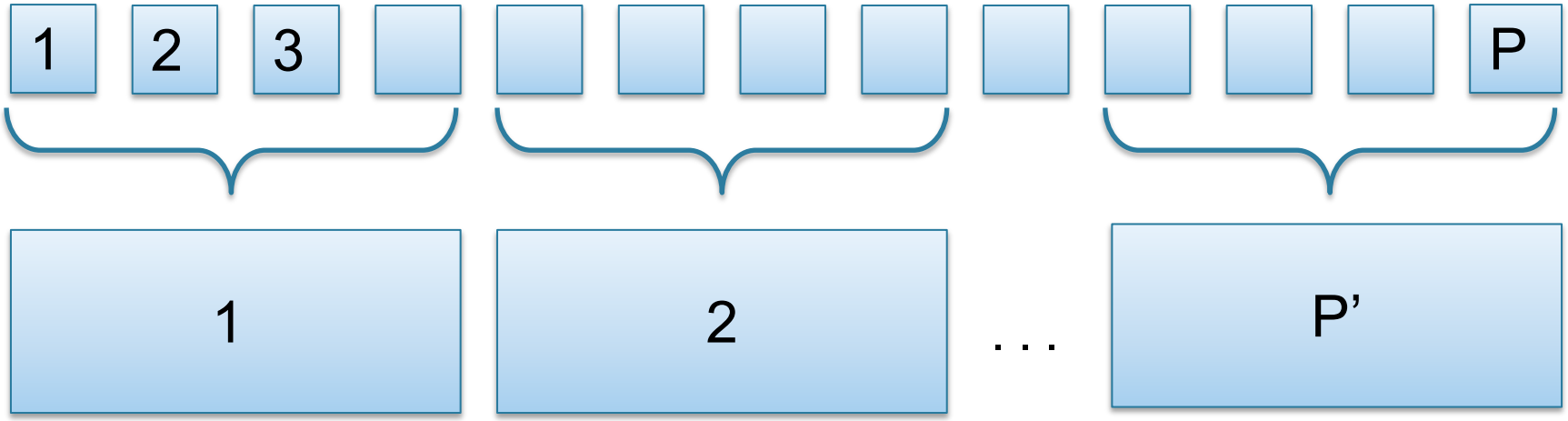

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Next Lecture

- MapReduce+Spark
  - Big consumers of Brent's theorem
- Algorithm for parallel Query Processing