CSE544
Data Management

Lecture 11

Query Optimization – Part 1

Announcements

- Project proposal is due Friday
  - Submit via gitlab
  - If needed, update title on the spreadsheet
- Monday: Moe’s lecture on HW3
  - Don’t miss!!!
- Review 5 is due on ~~Monday~~ Wednesday
  - Advanced topic, you may skip parts

Snowflake: Recap

- SaaS = software as a service
- Other cloud services:
  - Platform as a service (PaaS): Amazon’s EC
  - Infrastructure as a service (virtual machines)
  - Software as a Service
  - Function as a Service: Amazon’s Lambda

Snowflake: Recap

Snowflake’s Data Storage:

In class:

- S3:PUT/GET/DELETE
- Table → horizontal partition in *files*
- Blobs+PAX
- Temp storage→S3

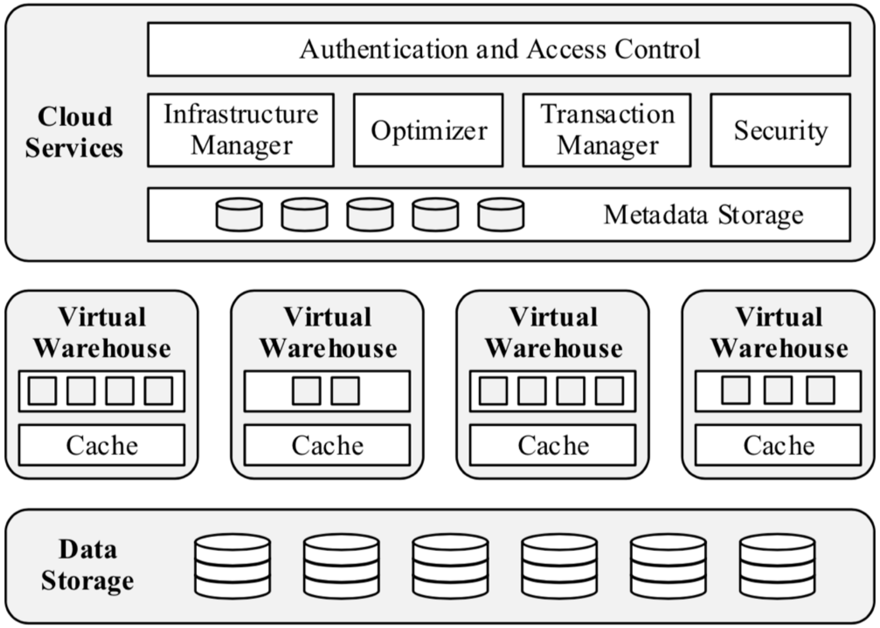

Figure 1: Multi-Cluster, Shared Data Architecture

Snowflake: Recap

- Describe Elasticity in Snowflake
  - Virtual Warehouse (VW) serves one user
  - T-Shirt sizes: X-Small … XX-Large
  - Small query may run on subset of VW
- Describe failure handling in Snowflake
  - Restart the query
  - No partial retries (like MapReduce or Spark)

Snowflake: Recap

- Column-oriented (in class)
- Vectorized (“tuple batches” – in class)
- Push-based (in class)

Snowflake: Recap

- What does Snowflake use instead of indexes?

- “Pruning”: for each file (recall: this is a horizontal partition of a table) and each attribute, it stores the min/max values in that column in that file; may skip files when not needed.

Query Optimization

Query Optimization

Three major components:

1. Search space

2. Cardinality and cost estimation

3. Plan enumeration algorithms

Search Space

Refers to the set of all possible alternate plans that the optimizers may explore

- Access Path Selection: how to use indices
- Rewrite Rules: what identities the optimizer applies
- Scheduling: pipeline or blocking

Database Statistics

- B(R) = # of blocks that store R
- T(R) = # of records in R
- V(R,A) = # of distinct values of R.A

Access Path

Access path: implements a selection $\sigma_P(R)$
(P is sometimes called *search argument* SARG)

- A file scan, or

- An index *plus* a matching selection condition

Access Path Selection

```
SELECT * FROM Supplier
WHERE sid > 300 ∧ scity='Seattle'
```

Indices:

B+-tree on sid; clustered

B+-tree on scity; unclustered

Access Path Selection

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Which access path should we use?

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Which access path should we use? Depends on stats

Access Path Selection

```
SELECT * FROM Supplier
WHERE sid > 300 ∧ scity='Seattle'
```

B(Supplier) = 100
T(Supplier) = 1000
V(Supplier,scity) = 20
Max(Supplier, sid) = 1000
Min(Supplier,sid) =1

Indices:

- B+-tree on sid; clustered
- B+-tree on scity; unclustered

Which access path should we use? Depends on stats

Supplier(sid, sname, scity, sstate)

Access Path Selecti

Number of distinct values of scity

```
SELECT * FROM Supplier
WHERE sid > 300 ∧ scity='Seattle'
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Which access path should we use? Depends on stats

1. Sequential scan: cost = 100

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Indices:

B+-tree on sid; clustered
B+-tree on scity; unclustered

Which access path should we use? Depends on stats

1. Sequential scan: cost = 100
2. Index scan on sid: cost = 7/10 * 100 = 70

Supplier(sid, sname, scity, sstate)

Access Path Selection

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Indices:

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Which access path should we use? Depends on stats

1. Sequential scan: cost = 100
2. Index scan on sid: cost = 7/10 * 100 = 70
3. Index scan on scity: cost = 1000/20 = 50

Access Path Selection

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SELECT * FROM Supplier
WHERE sid > 300 ∧ scity='Seattle'
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B(Supplier) = 100
T(Supplier) = 1000
V(Supplier,scity) = 20
Max(Supplier, sid) = 1000
Min(Supplier,sid) =1

Indices:

B+-tree on sid; clustered
B+-tree on scity; unclustered

Which access path should we use? Depends on stats

1. Sequential scan: cost = 100
2. Index scan on sid: cost = 7/10 * 100 = 70
3. Index scan on scity: cost = 1000/20 = 50

Optimal

Rewrite Rules

Search space is defined by the set of rewrite rules that the optimizer implements

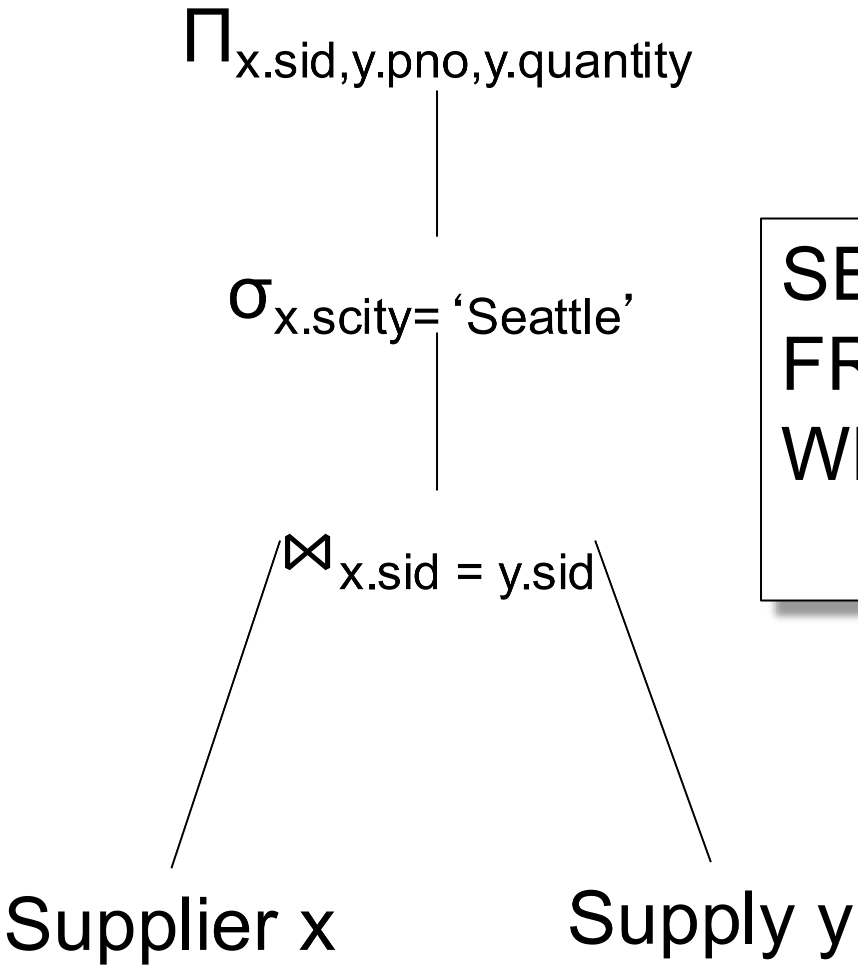
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Example Optimization

```
SELECT x.sid, y.pno, y.quantity
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




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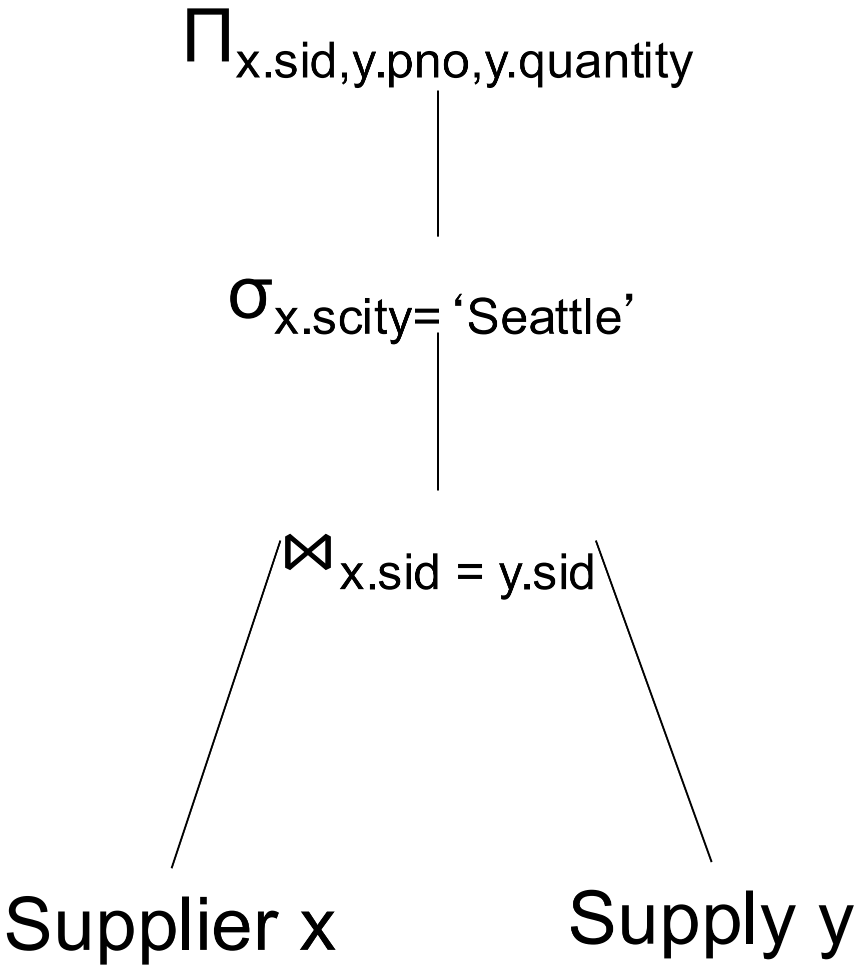
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

Push Selections Down



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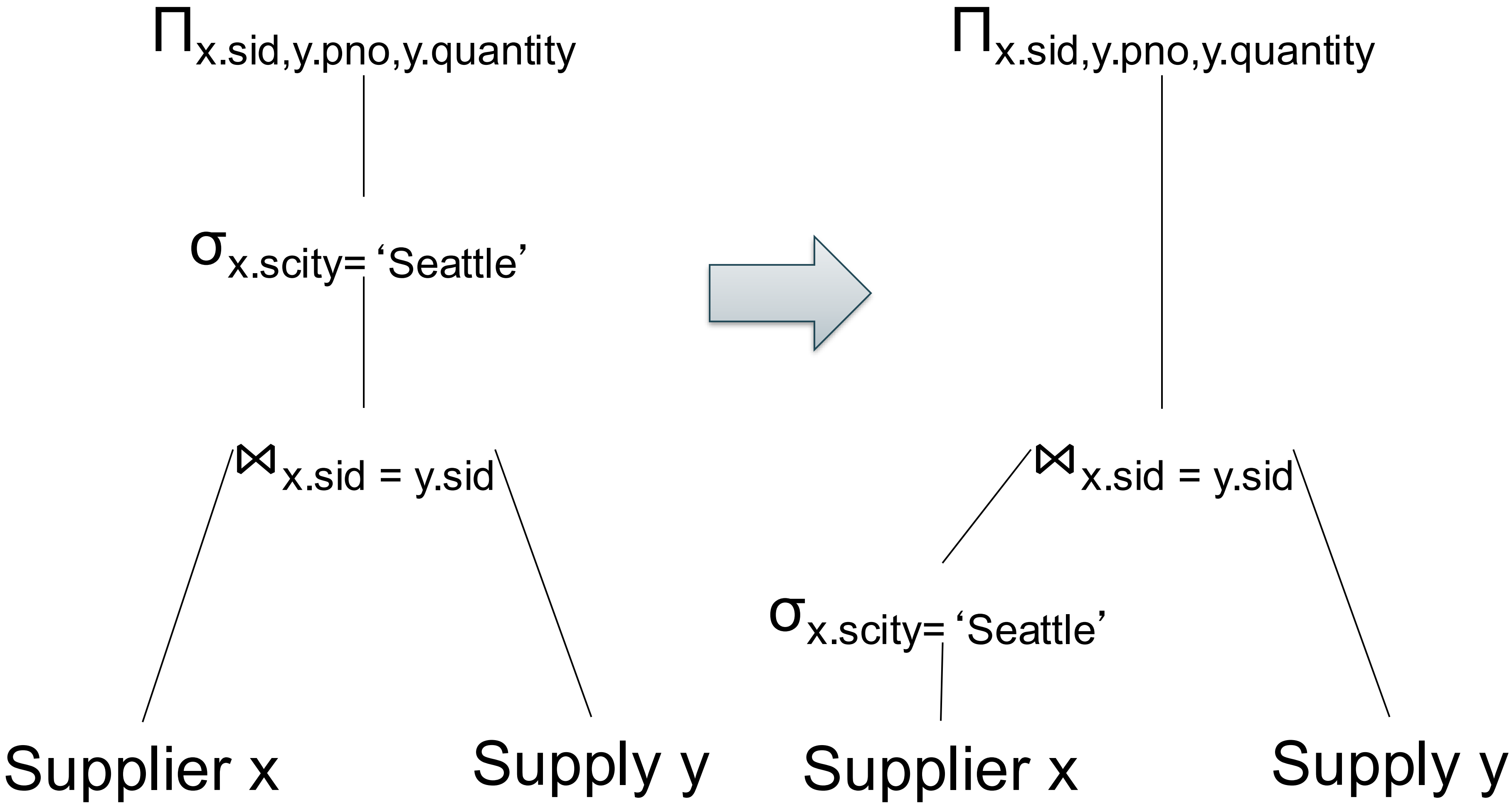

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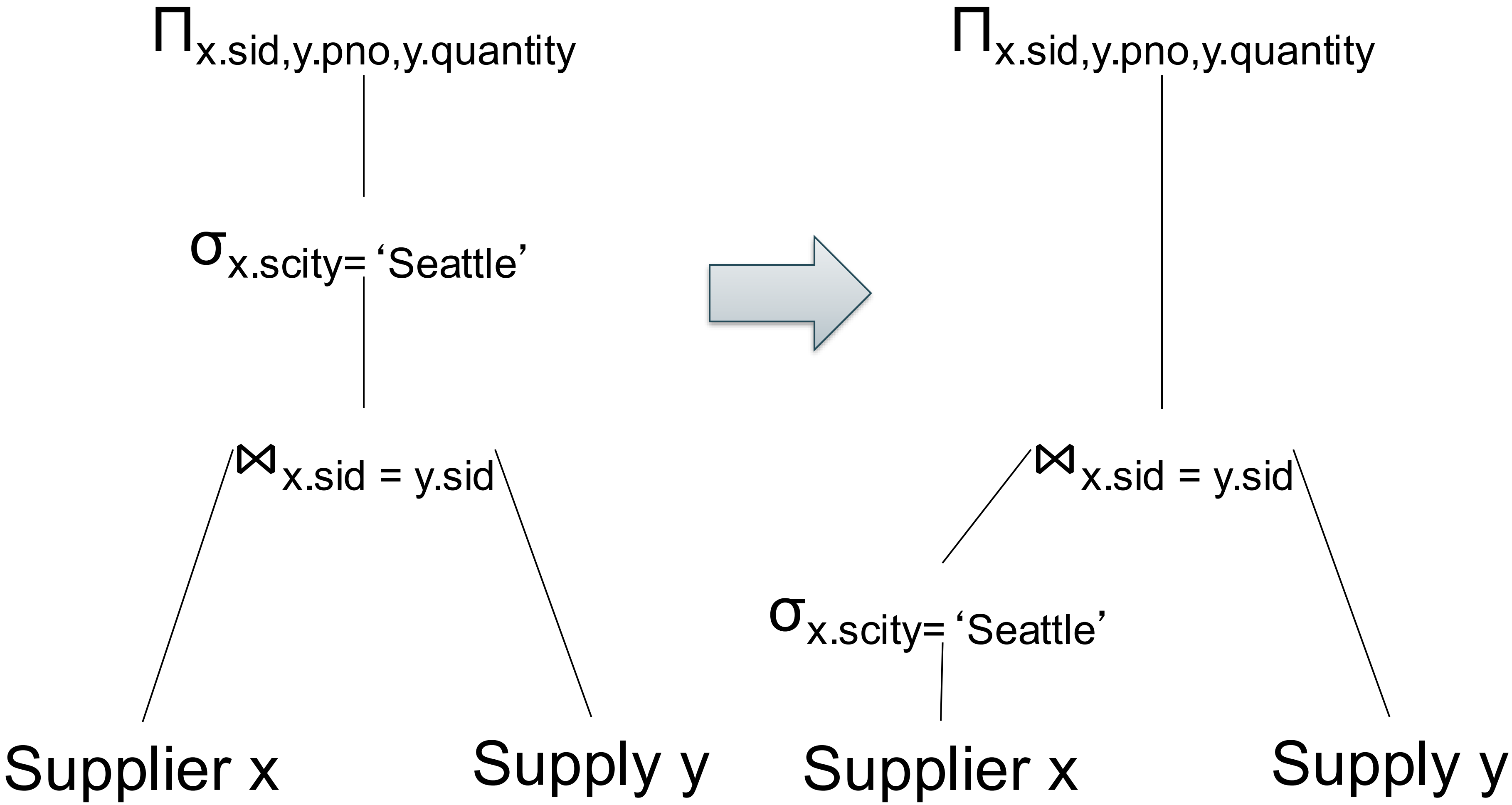


$\sigma_C(R \bowtie S) = \sigma_C(R) \bowtie S$ when C refers only to R

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

Push Selections Down

$\Pi_{x.sid,y.pno,y.quantity}$

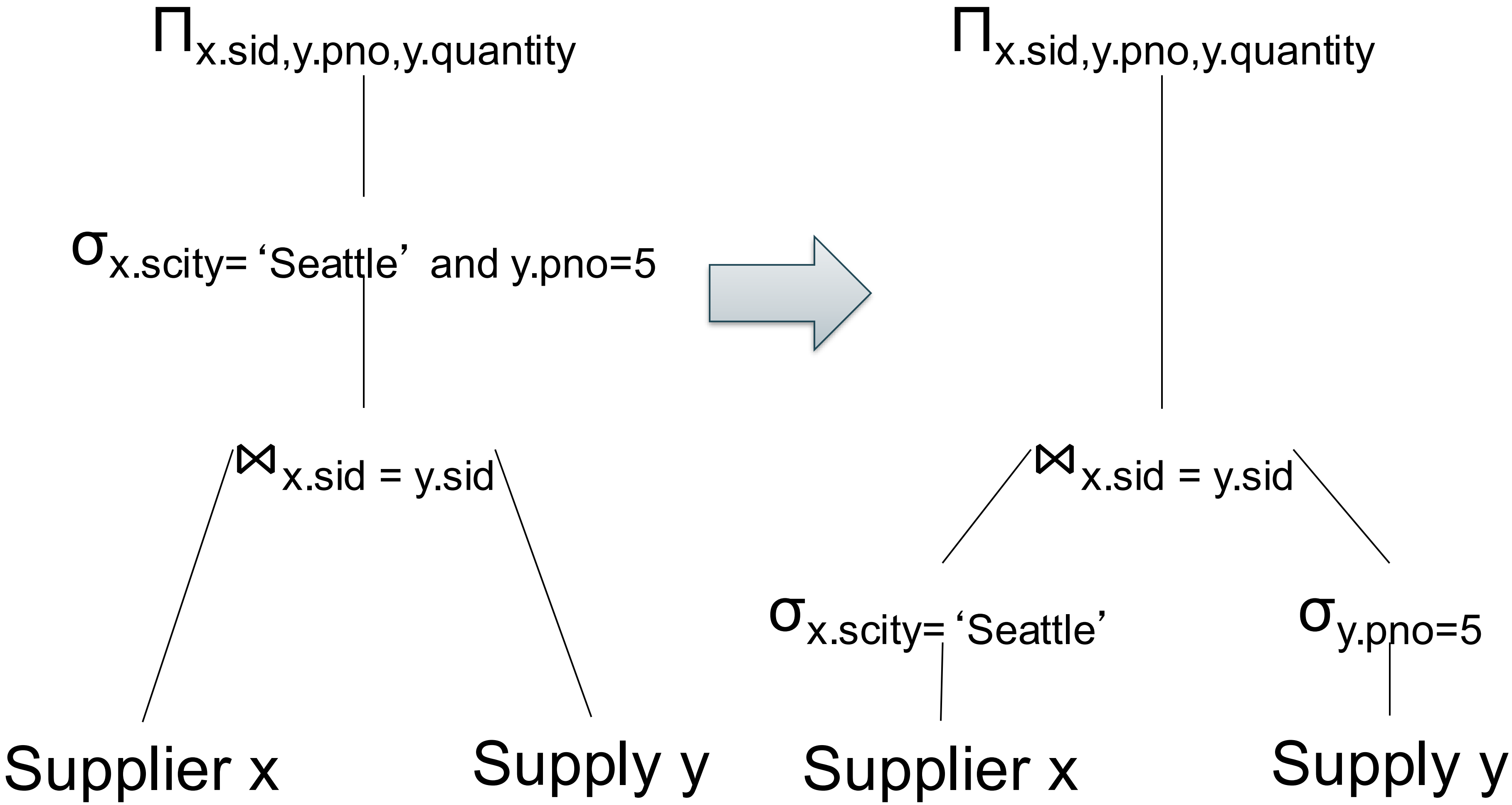
$\sigma_{x.scity=\text{'Seattle'} \text{ and } y.pno=5}$

$\bowtie_{x.sid = y.sid}$

Supplier x   Supply y

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

Push Selections Down



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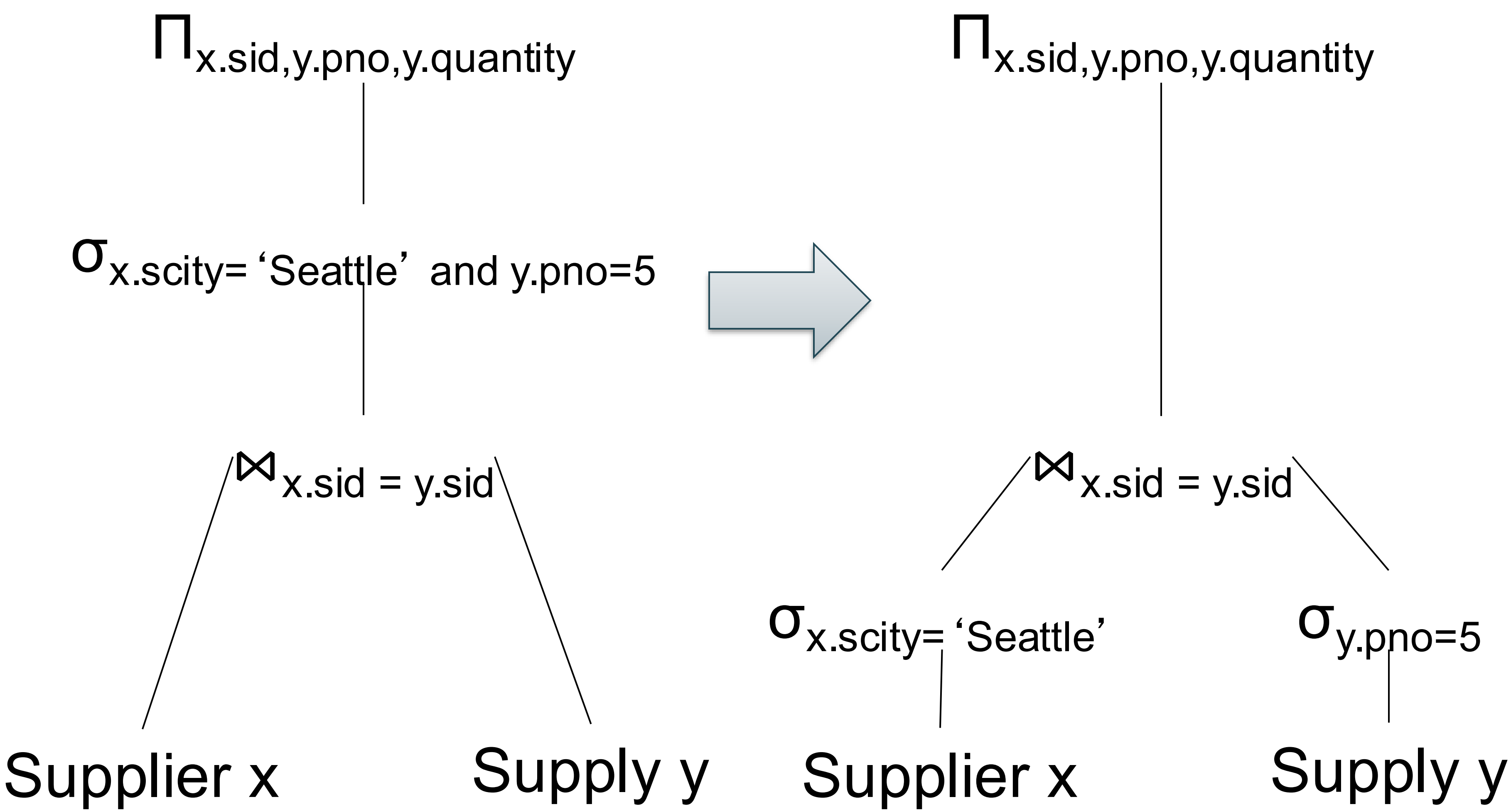
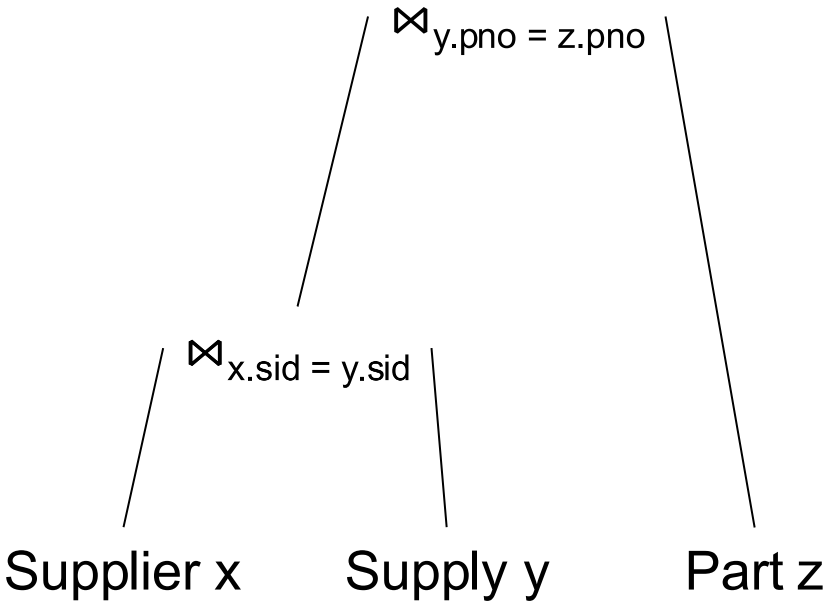
Push Selections Down



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

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

Join Reorder



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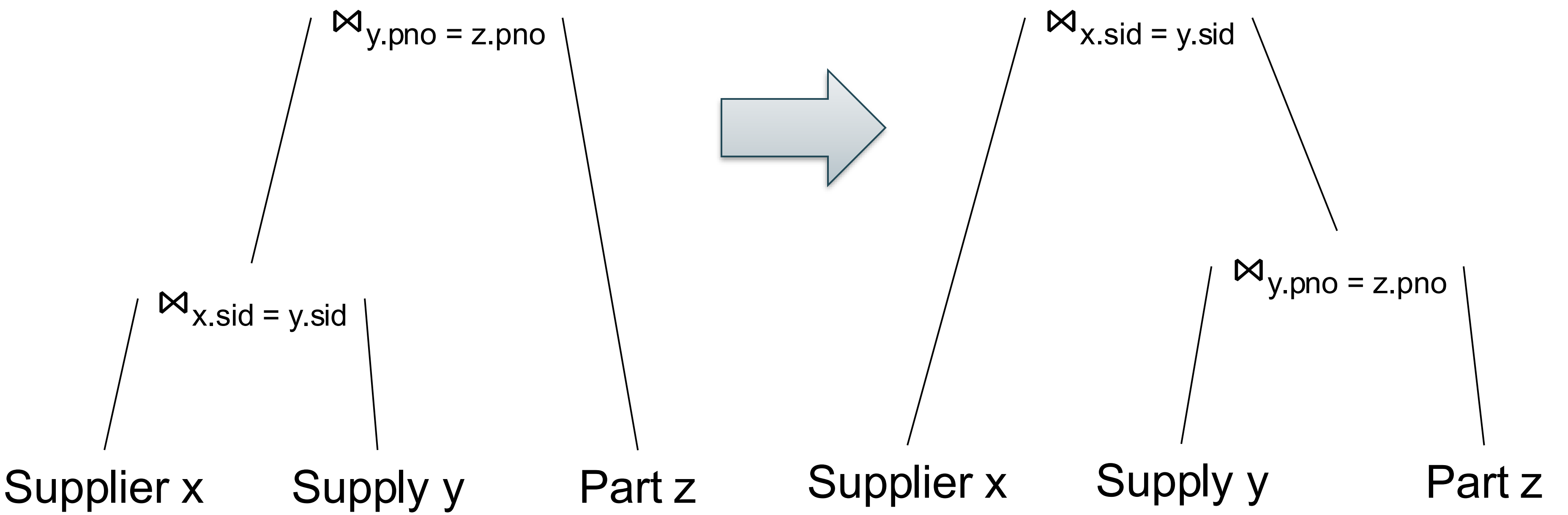

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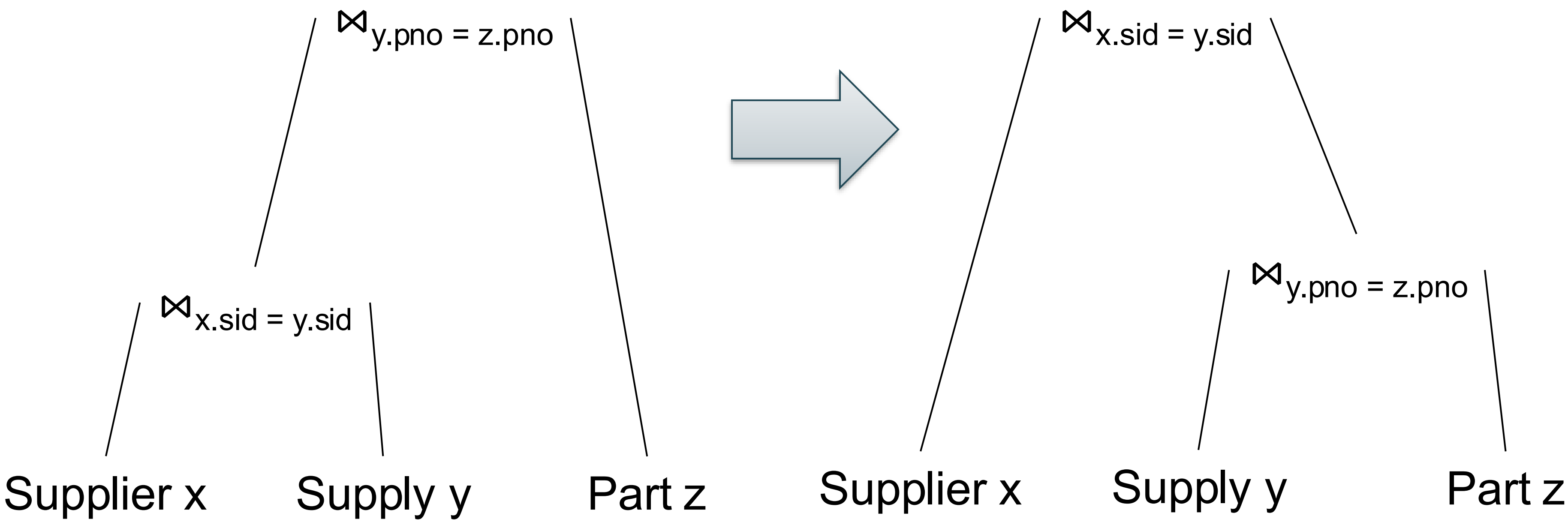


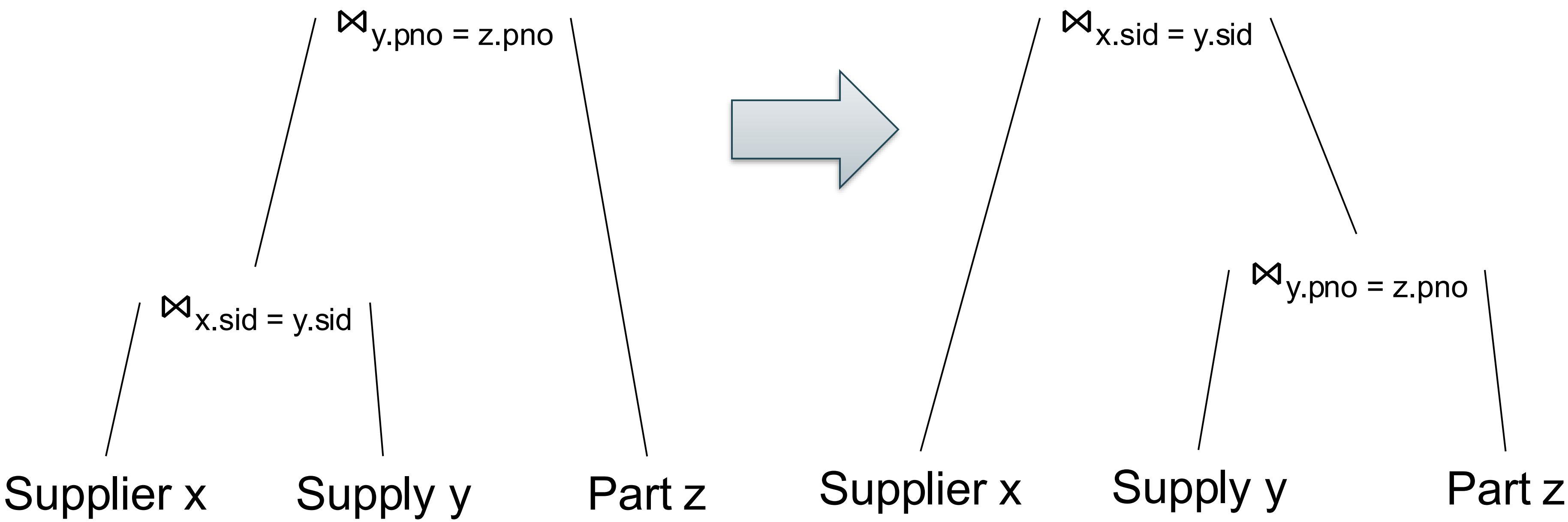
$$(R \bowtie S) \bowtie T = R \bowtie (S \bowtie T)$$

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

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

Join Reorder

Which plan is better?



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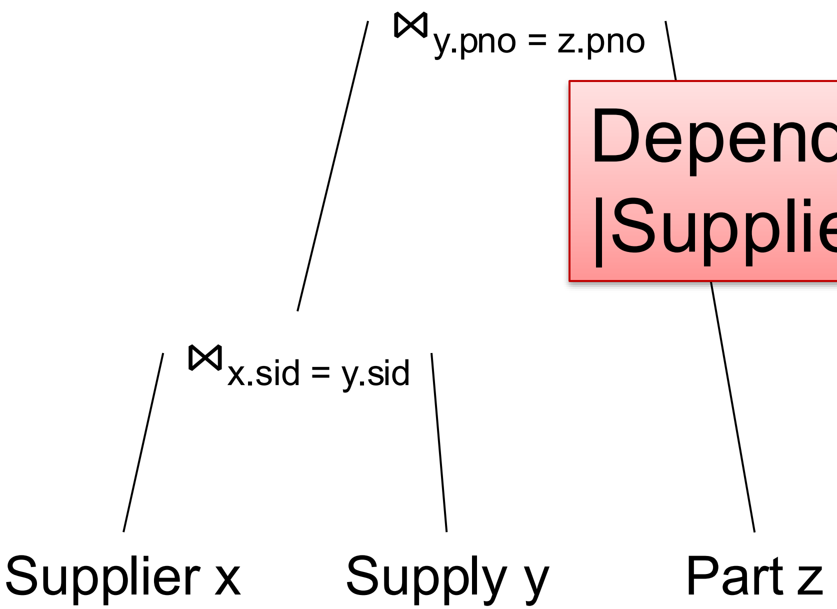

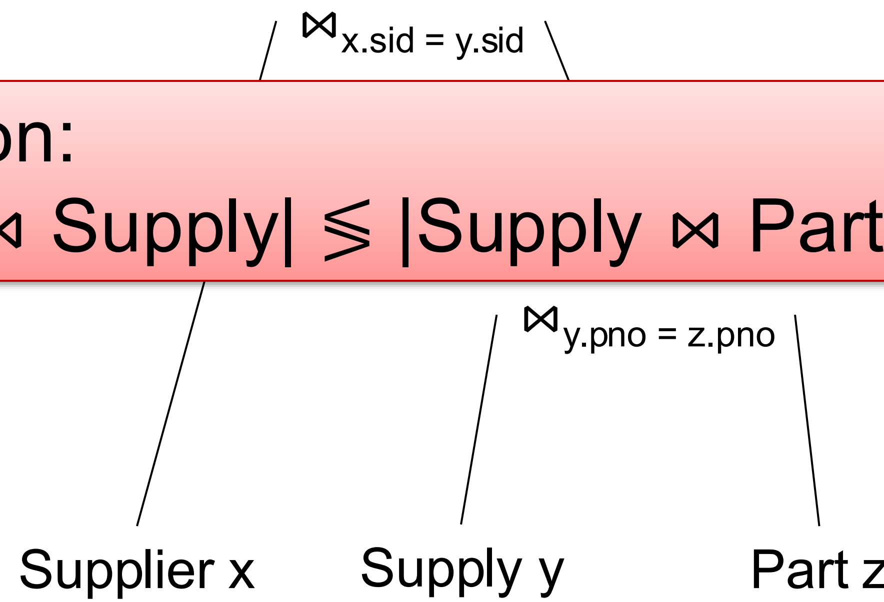

Depends on:
$|\text{Supplier} \bowtie \text{Supply}| \lesseqgtr |\text{Supply} \bowtie \text{Part}|$

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

$R \bowtie S = S \bowtie R$

Supplier(sid, sname, scity, sstate)
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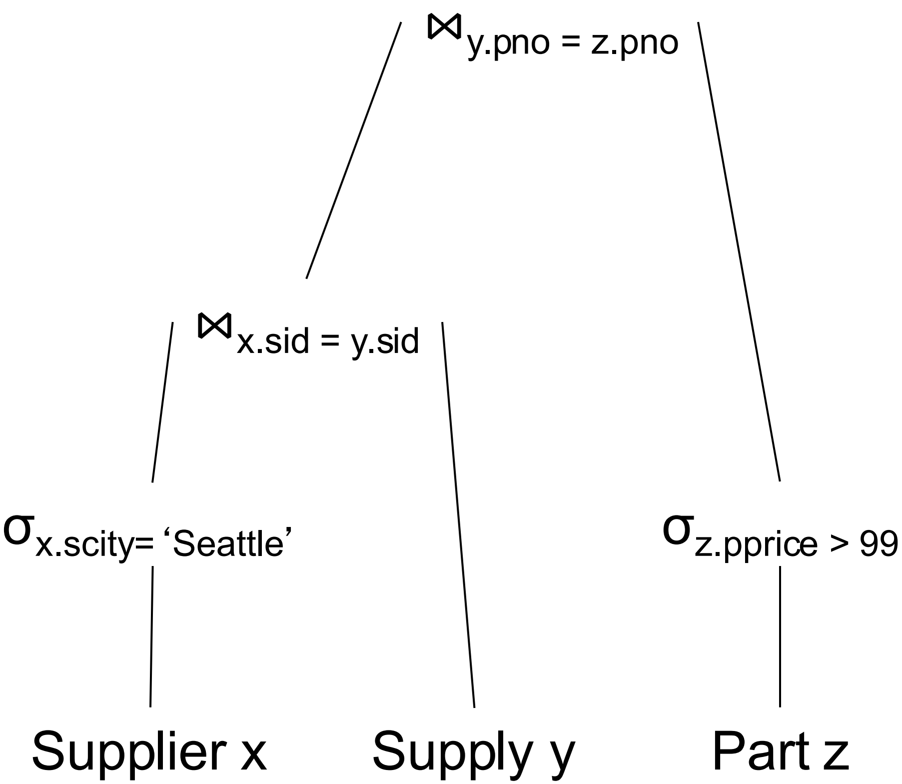

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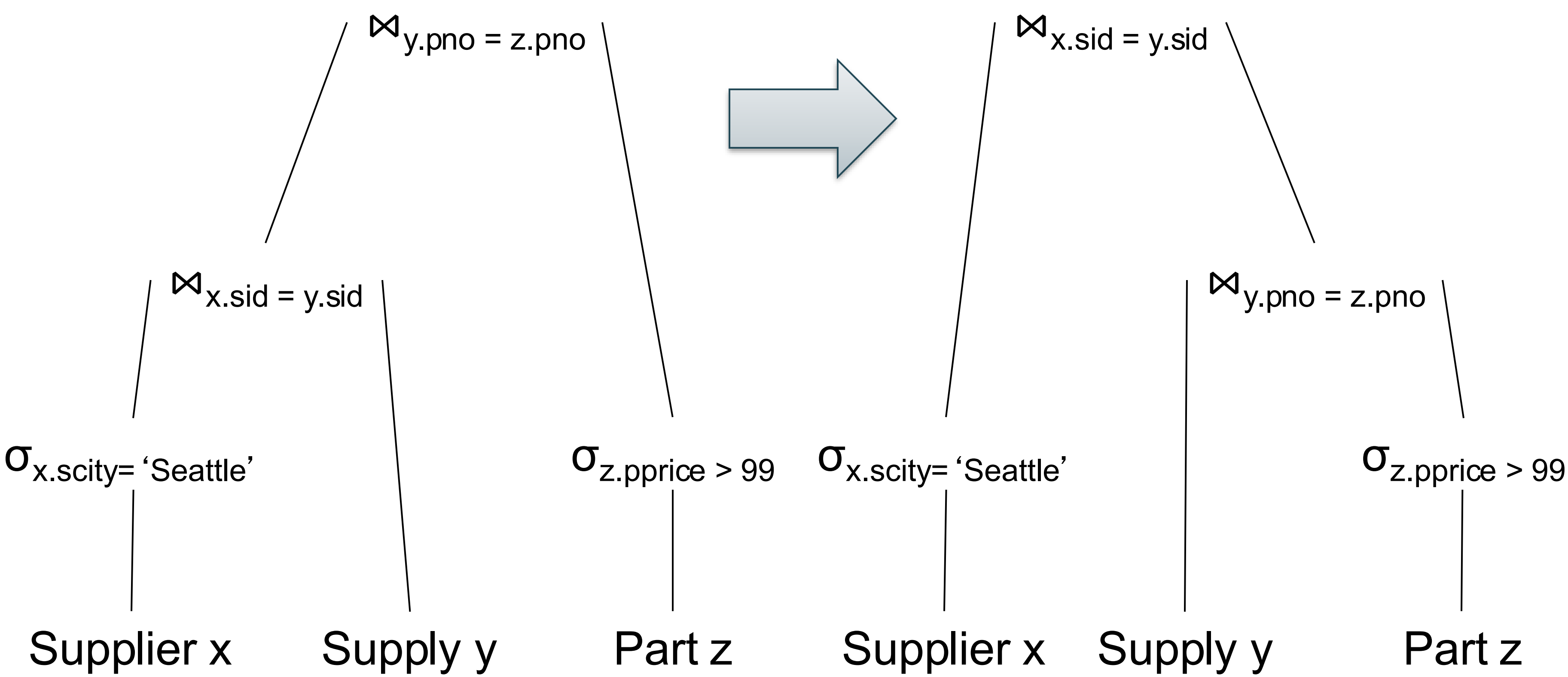

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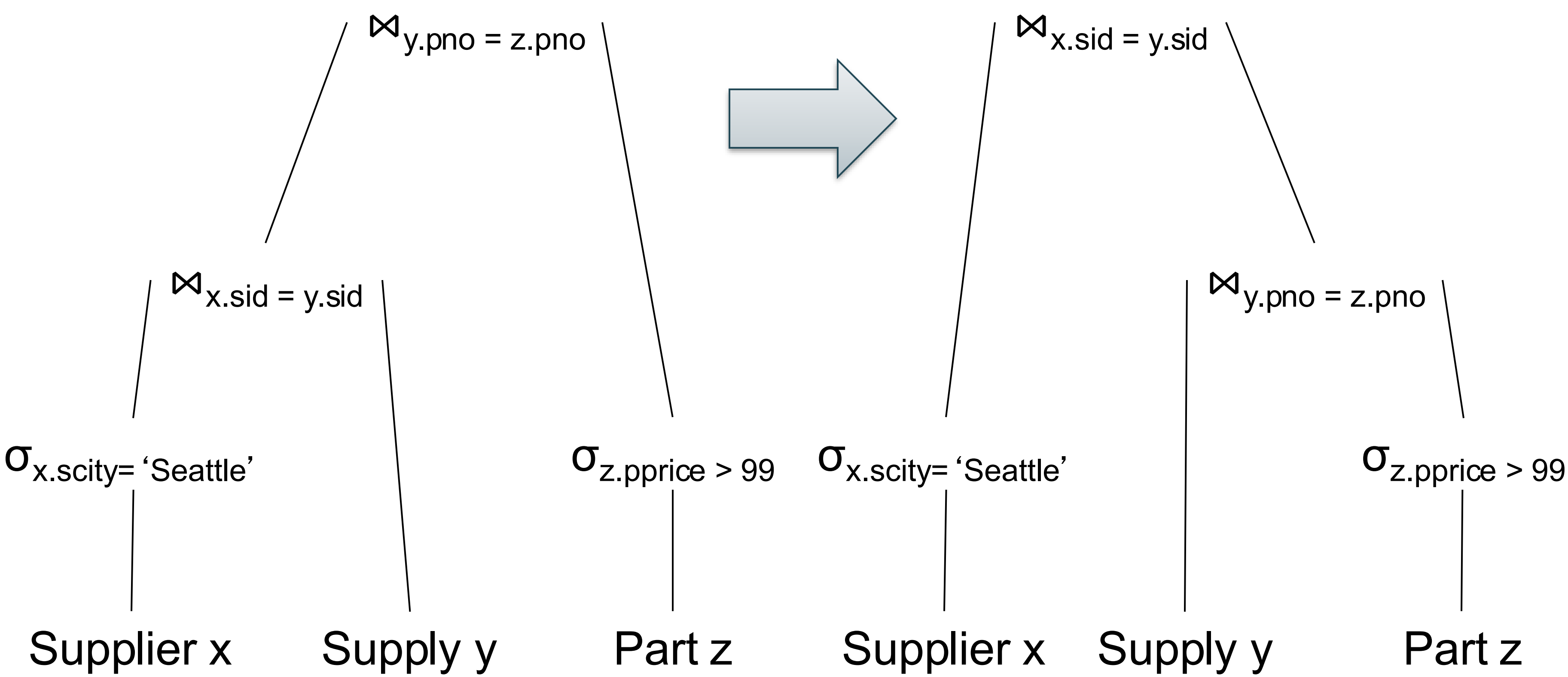

Lesson: need sizes of $\sigma_{x.scity= 'Seattle'}$(Supplier), $\sigma_{z.pprice > 99}$(Part)

Discussion

- Both rewrite rules **and** cardinality estimations are needed for optimization
- They can be developed independently

- Next: a powerful optimization rule: aggregate pushdown or better known as generalized distributivity law

Motivation

- Try this in postgres

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

Answer: 2652053
Time: 0.058 s

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select count(*) from author;
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Answer: 2652053
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select count(*) from publication;
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Answer: 5120896
Time: 0.062 s

Motivation

- Try this in postgres

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

Timeout!!!

Motivation

- Try this in postgres

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select count(*) from author;
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```
select count(*) from publication;
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Answer: 5120896
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```
select count(*) from author, publication;
```

Timeout!!!

But 3rd query is simply the **product** of the first two!

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)
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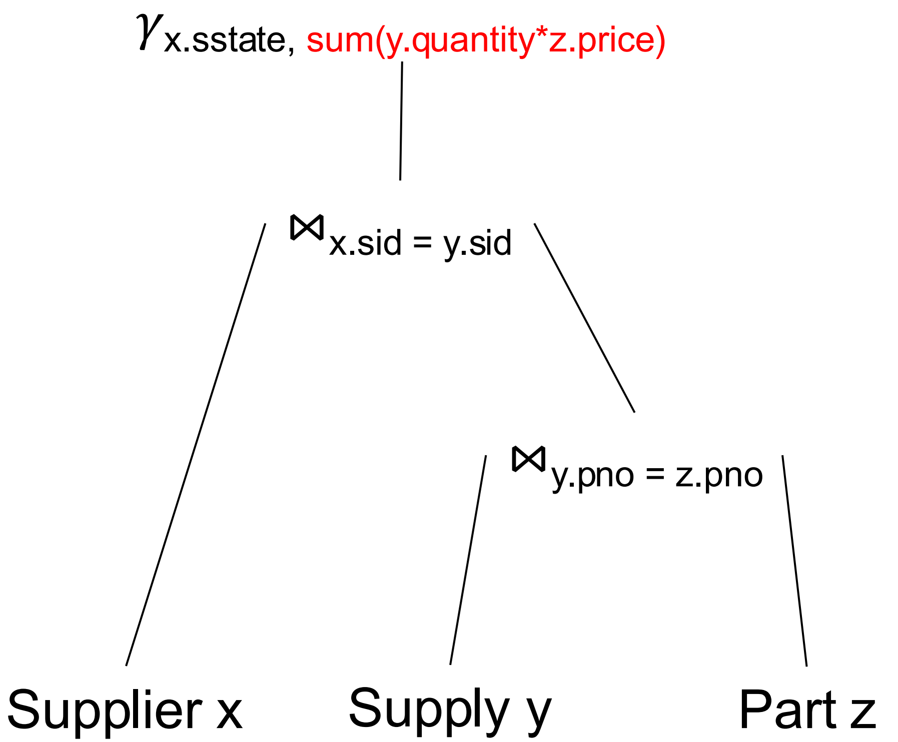
Aggregate Push-down

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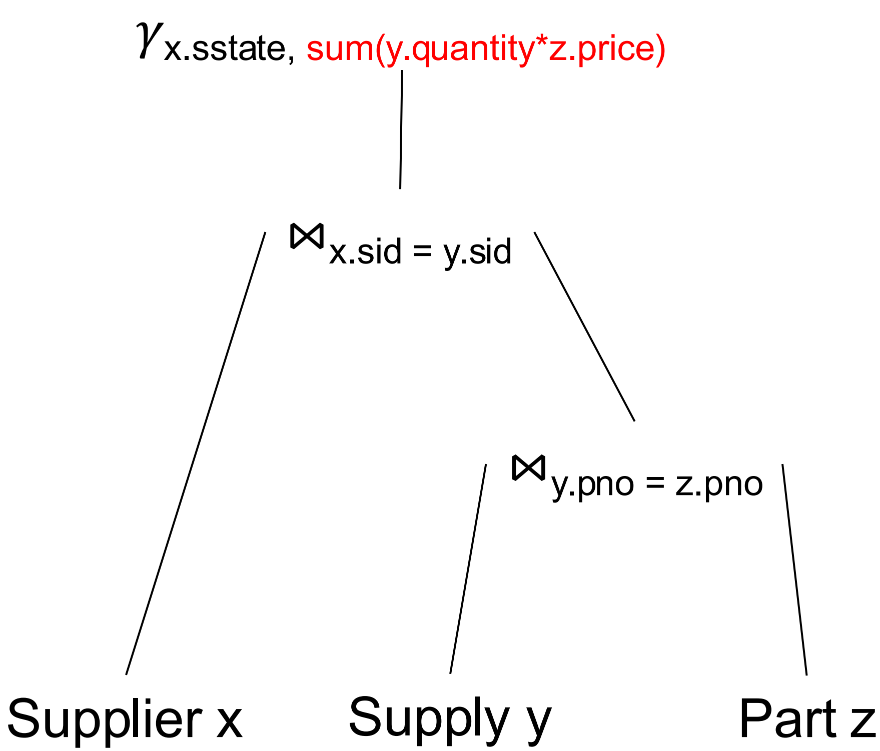

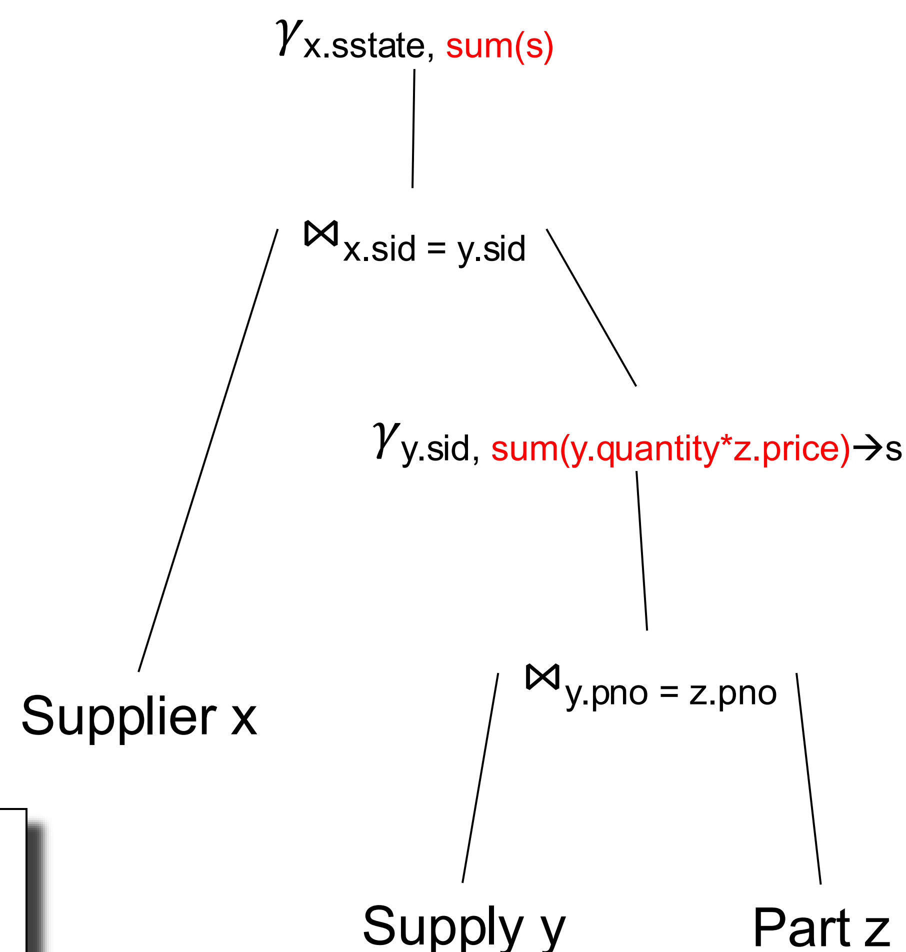


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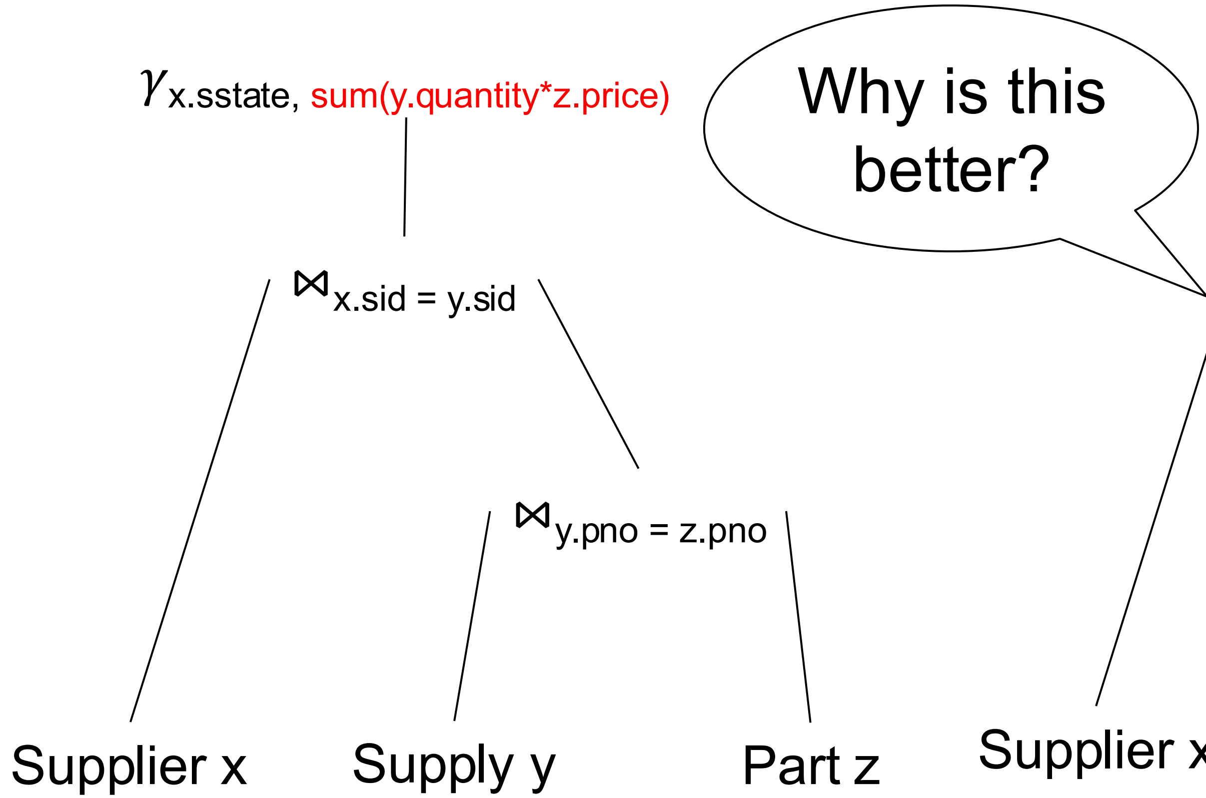

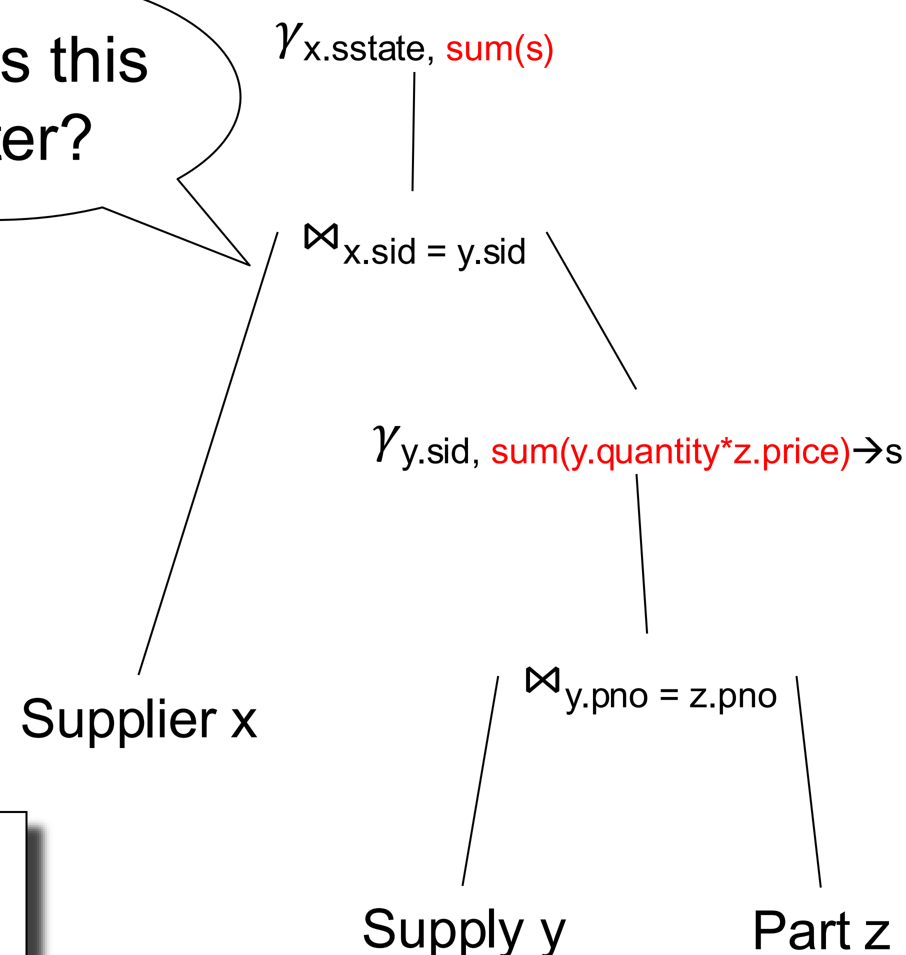


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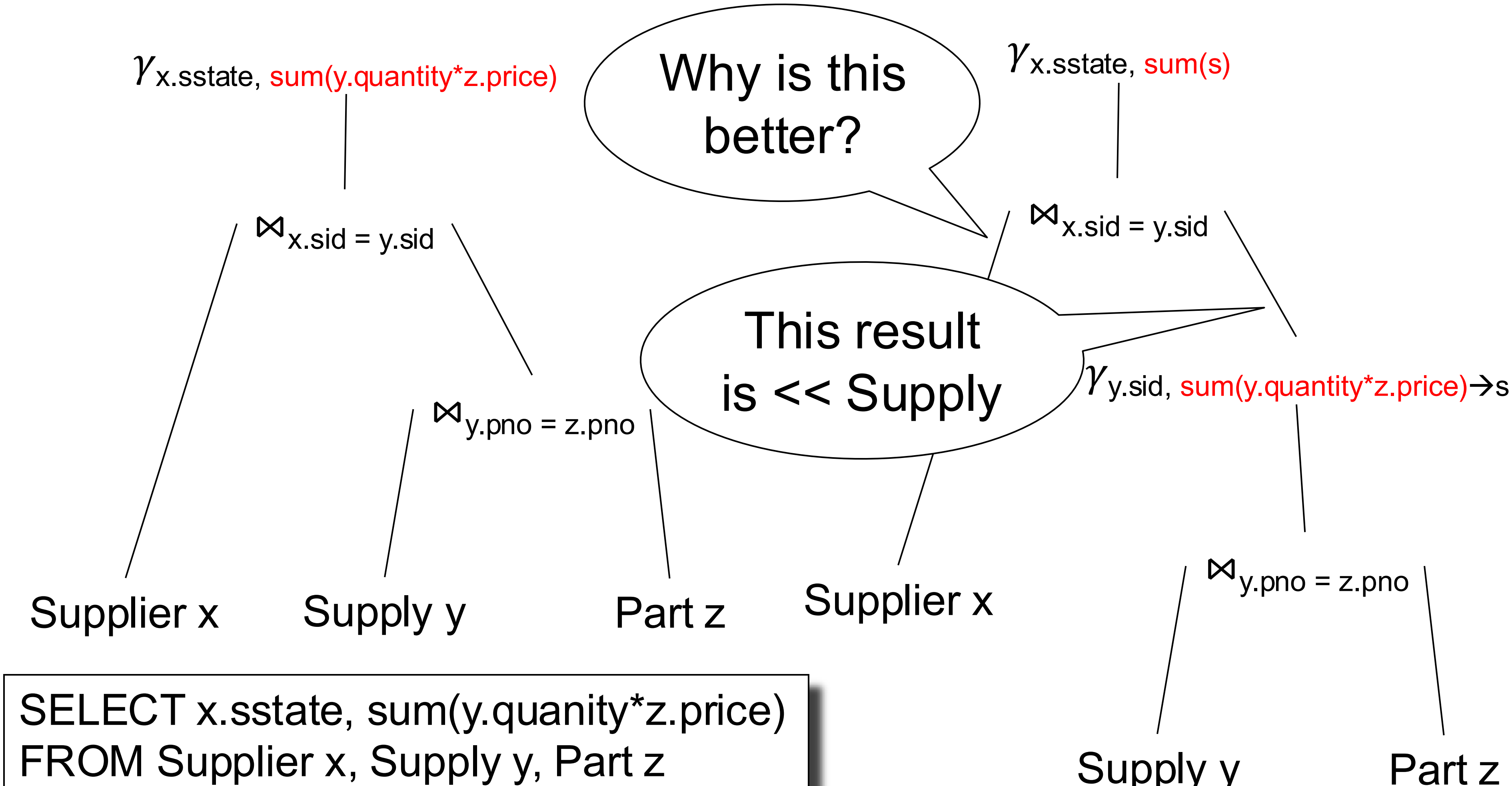


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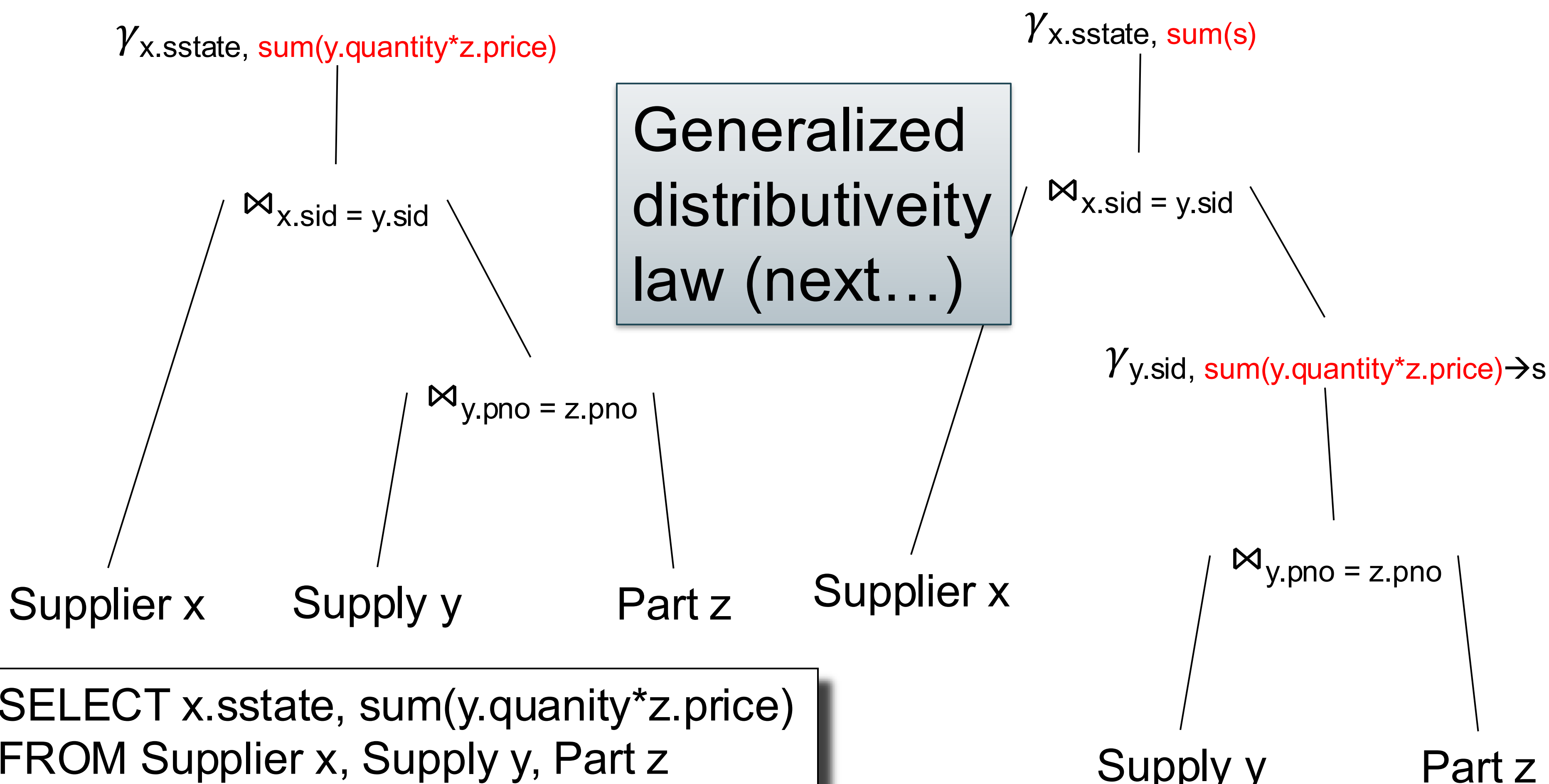

Generalized distributiveity law (next…)

```
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FROM Supplier x, Supply y, Part z
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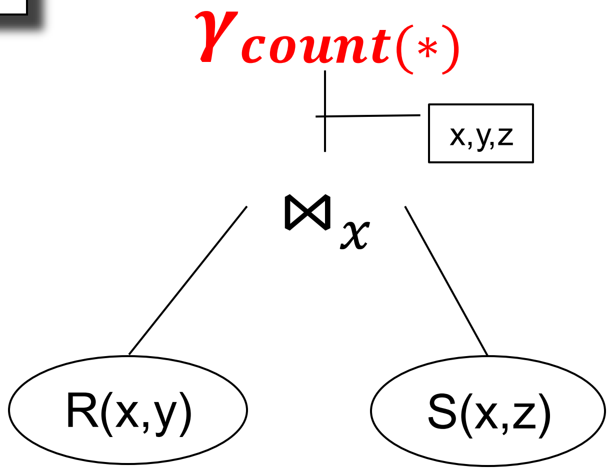
```

Generalized Distributivity Law

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



Generalized Distributivity Law

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

R:

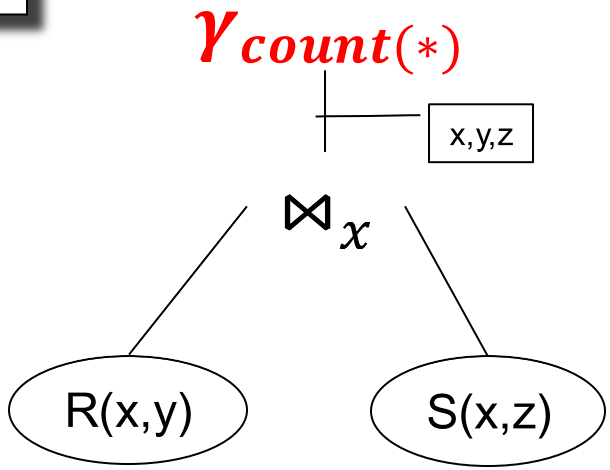
x	y
b	a
b	c
f	d
h	g

S:

x	z
b	g
b	k
h	m

Answer = 5

Runtime = ?????



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R:

x	y
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S:

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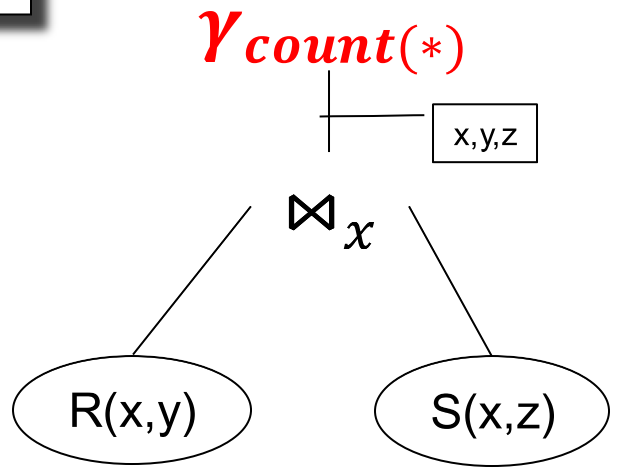
b	k
h	m

Answer = 5

Runtime = $O(N^2)$



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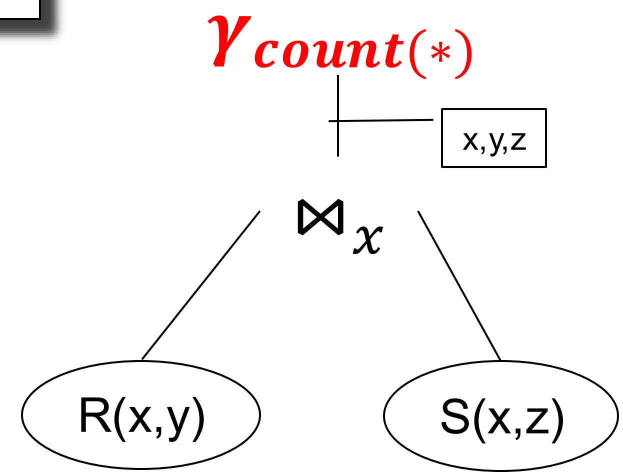

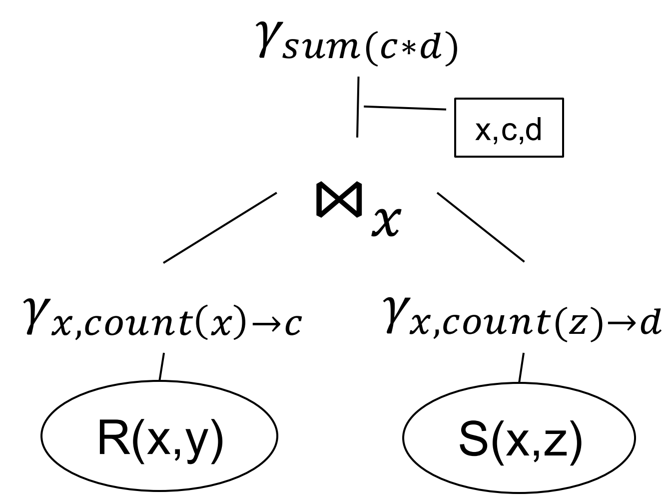

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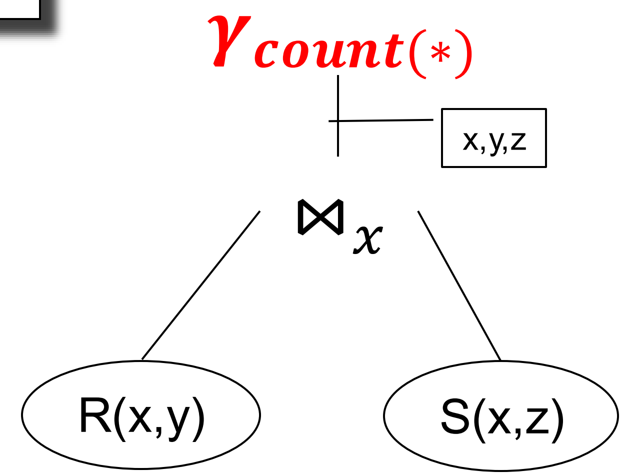

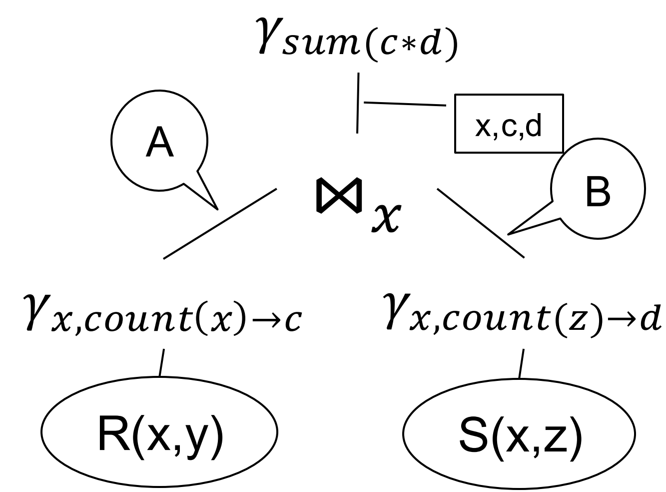

Generalized Distributivity Law

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R:

x	y
b	a
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x	z
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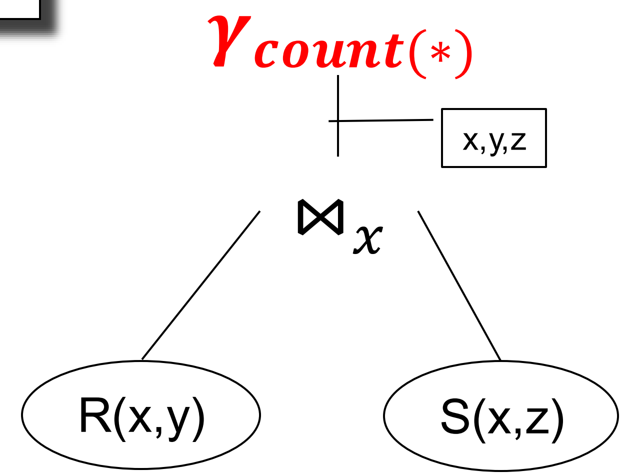
Answer = 5

Runtime = O(N^2)



A:

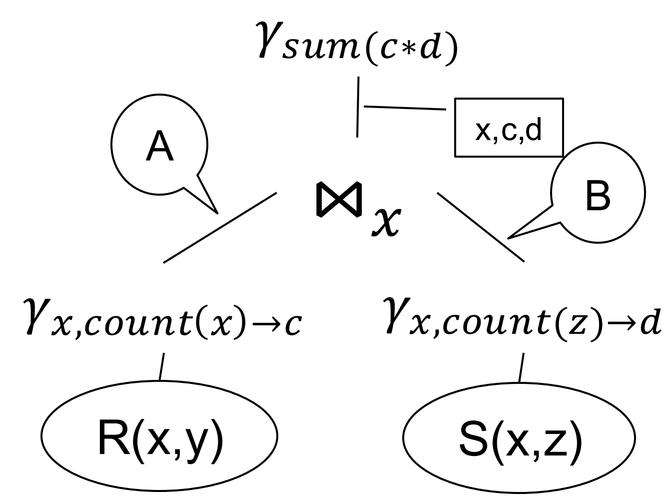
x	c
b	2
f	1
h	1

B:

x	d
b	2
h	1

A⋈B

x	c	d
b	2	2
h	1	1



Generalized Distributivity Law

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

R:

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b	c
f	d
h	g

S:

x	z
b	g
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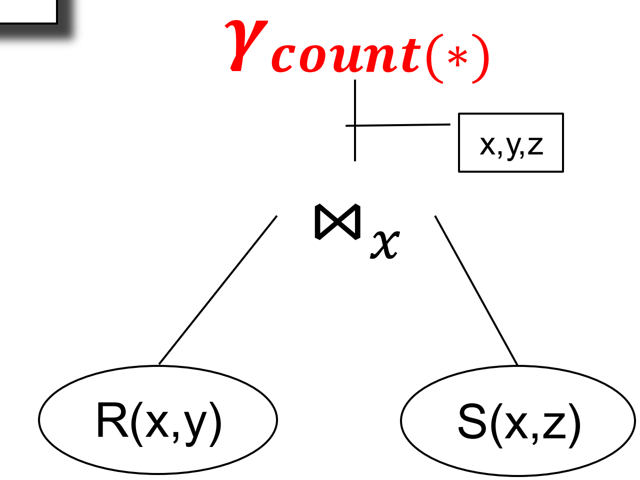
h	m

Answer = 5

Runtime = O(N^2)



Runtime = ????

A:

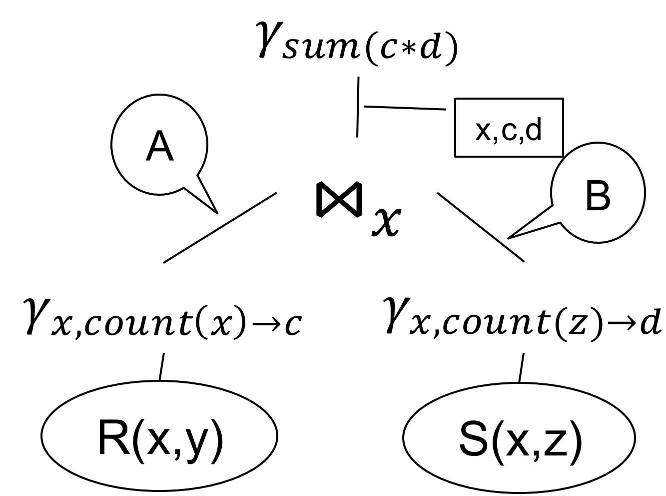
x	c
b	2
f	1
h	1

B:

x	d
b	2
h	1

A⋈B

x	c	d
b	2	2
h	1	1



Generalized Distributivity Law

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

R:

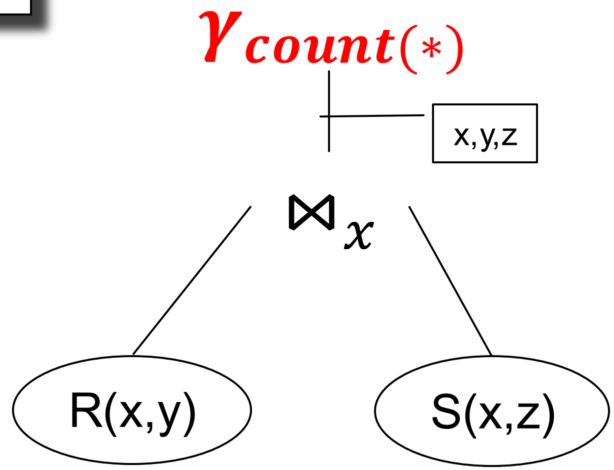
x	y
b	a
b	c
f	d
h	g

S:

x	z
b	g
b	k
h	m

Answer = 5

Runtime = $O(N^2)$



Runtime = O(N)

A:

x	c
b	2
f	1
h	1

B:

x	d
b	2
h	1

A⋈B

x	c	d
b	2	2
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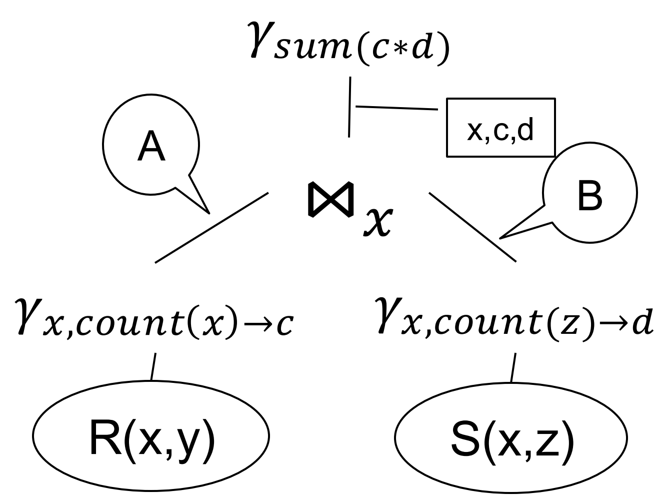


Generalized Distributivity Law

$$\gamma_{Y,Z,sum(A*B*C*\cdots)}$$

$$\bowtie_X$$

$\cdots$ $\cdots$

Generalized Distributivity Law

$\gamma_{Y,Z,sum(A*B*C*\cdots)}$

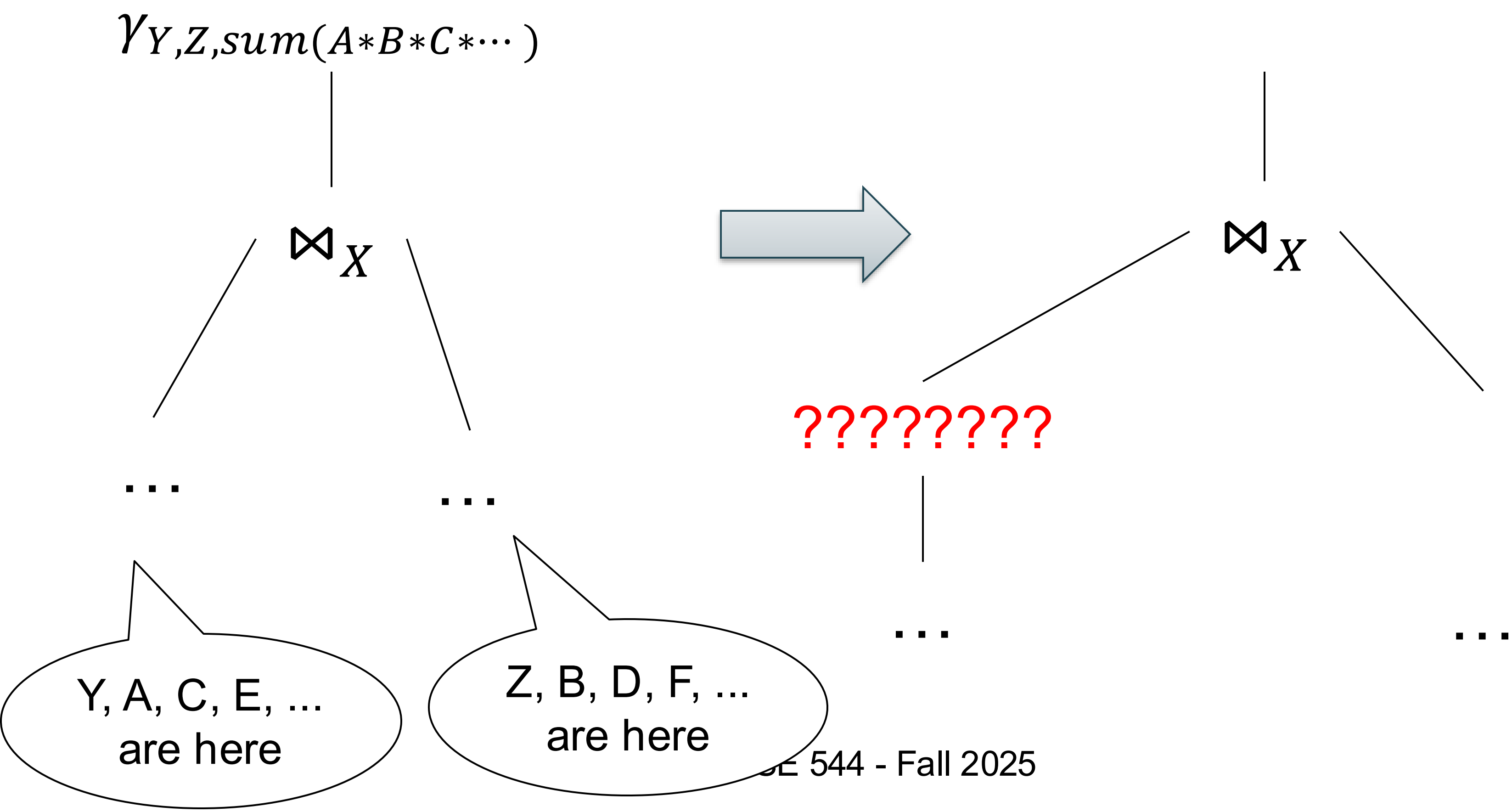
$\bowtie_X$

$\ldots$ $\ldots$

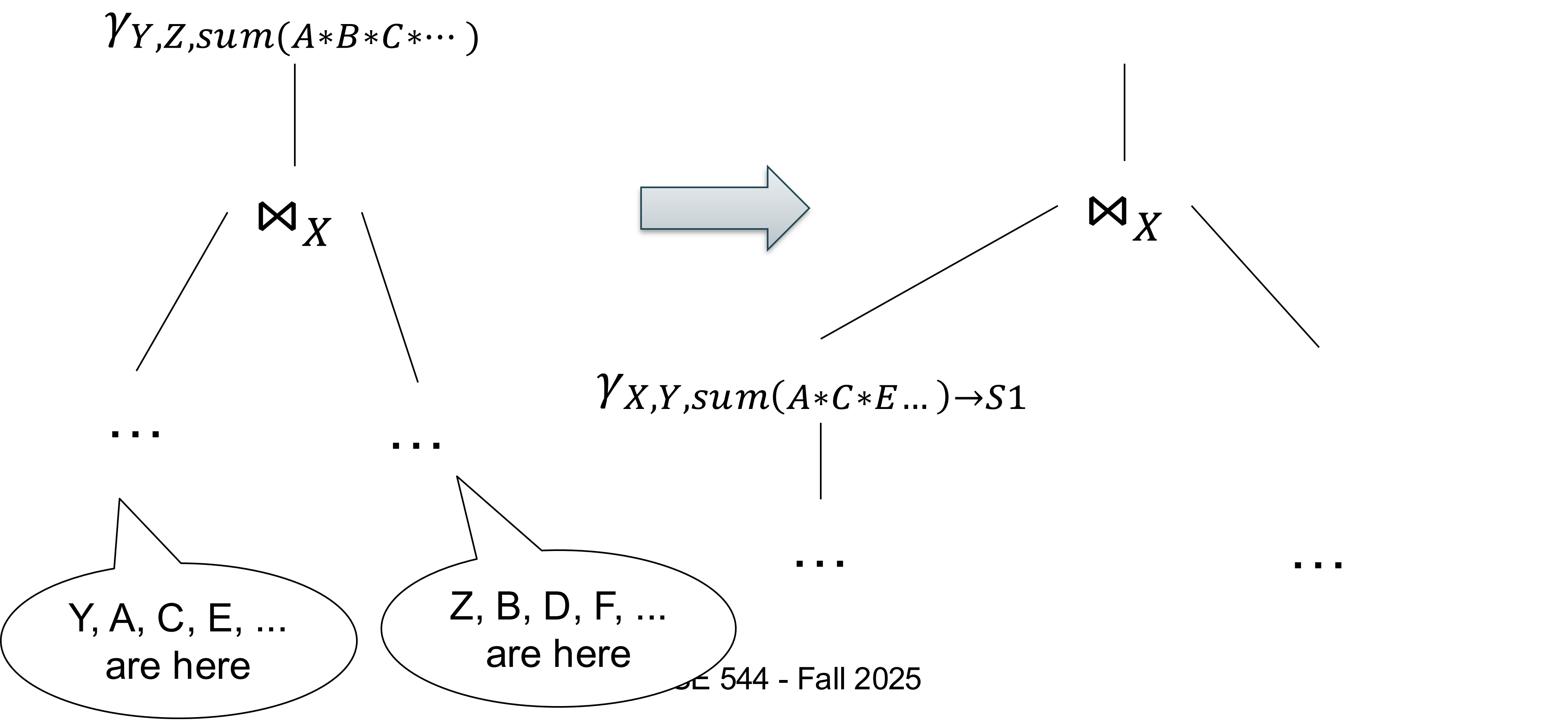
Y, A, C, E, ...
are here

Z, B, D, F, ...
are here

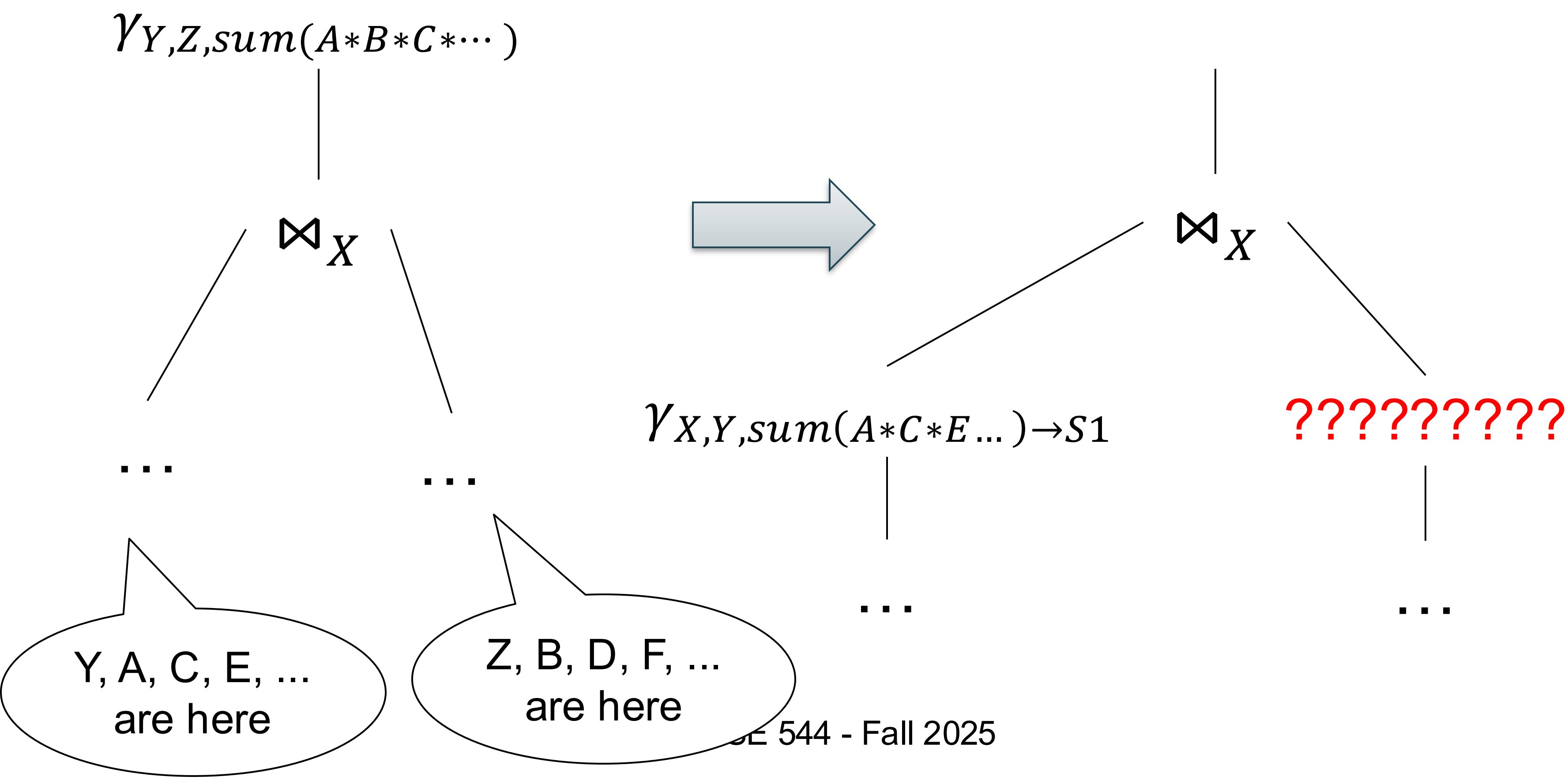
Generalized Distributivity Law



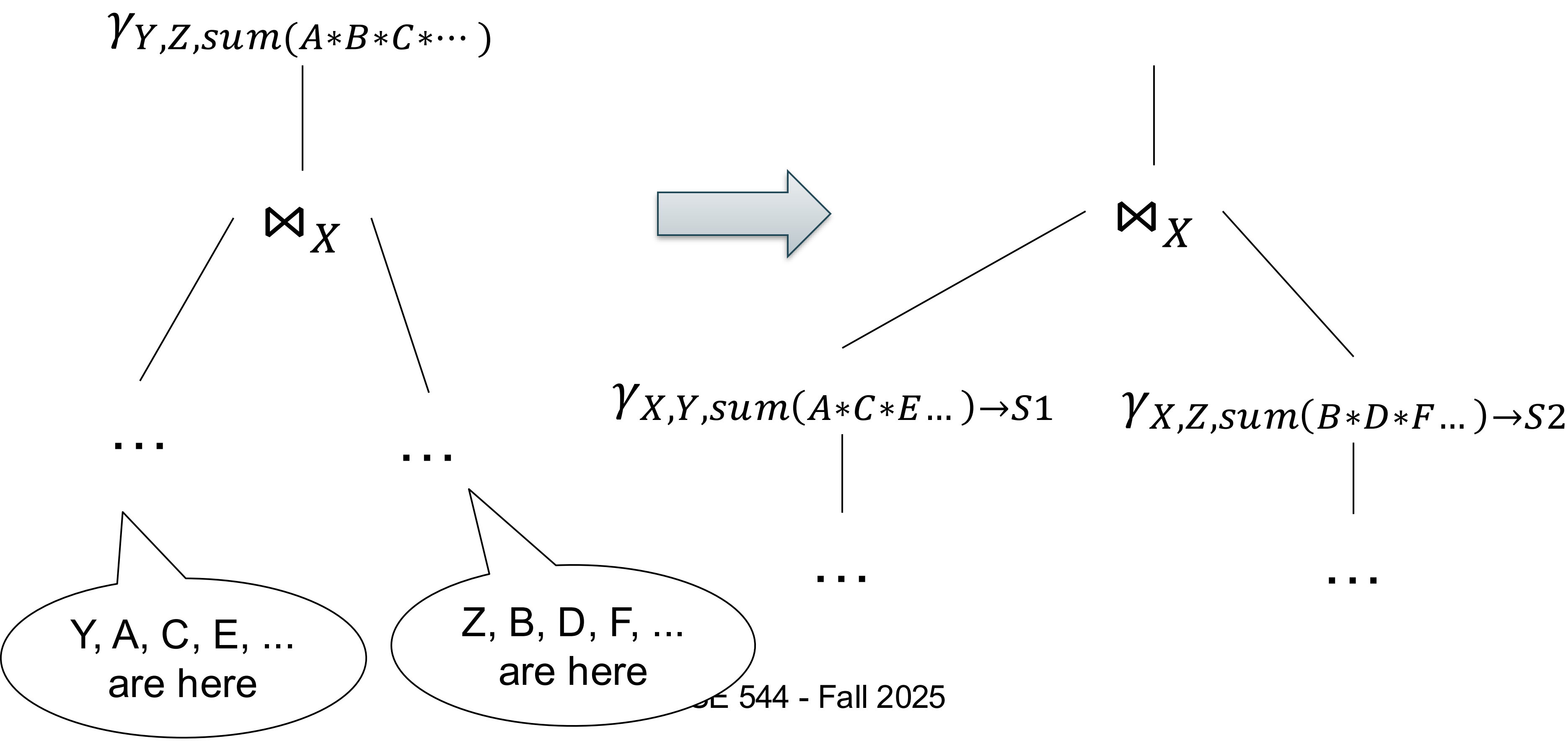
Generalized Distributivity Law



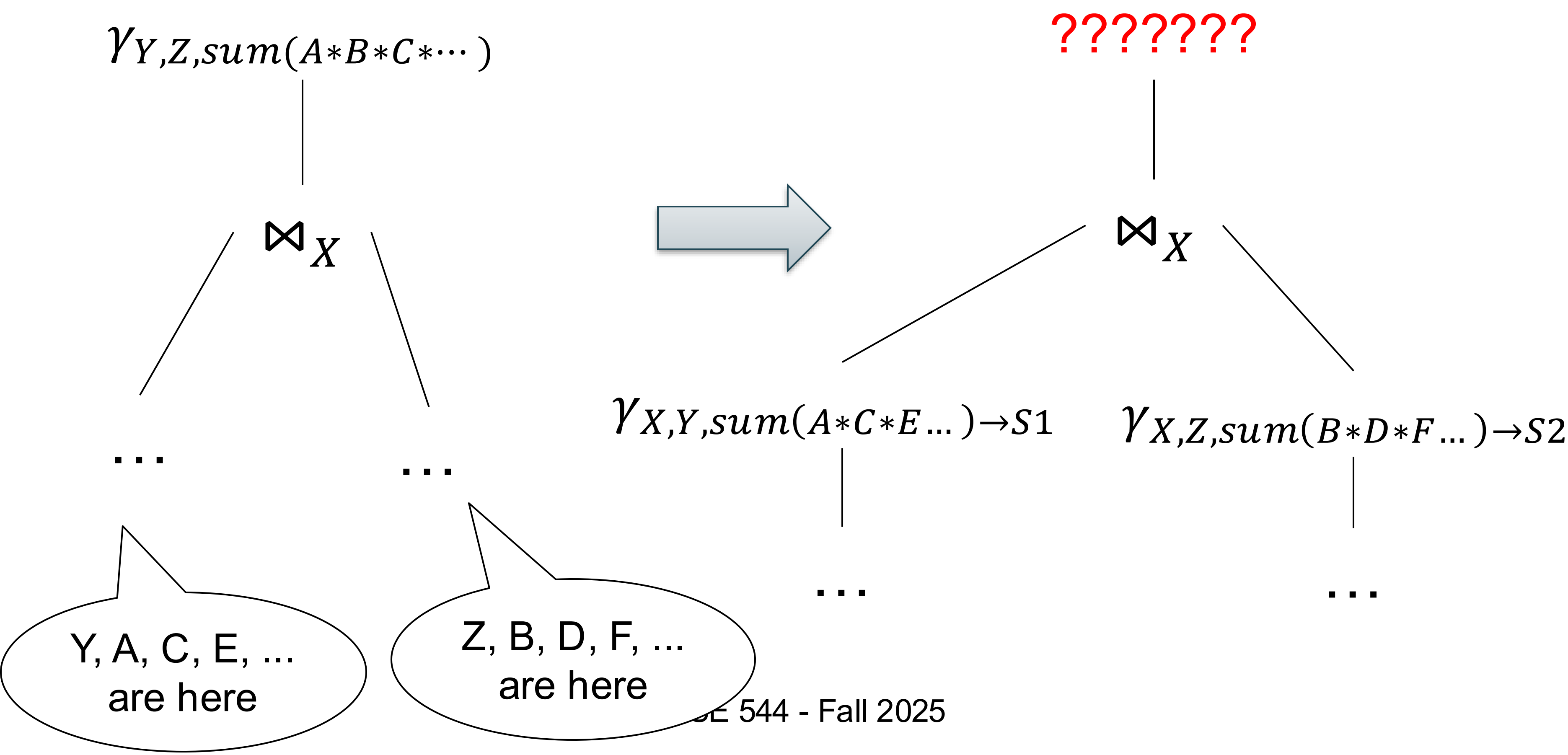
Generalized Distributivity Law



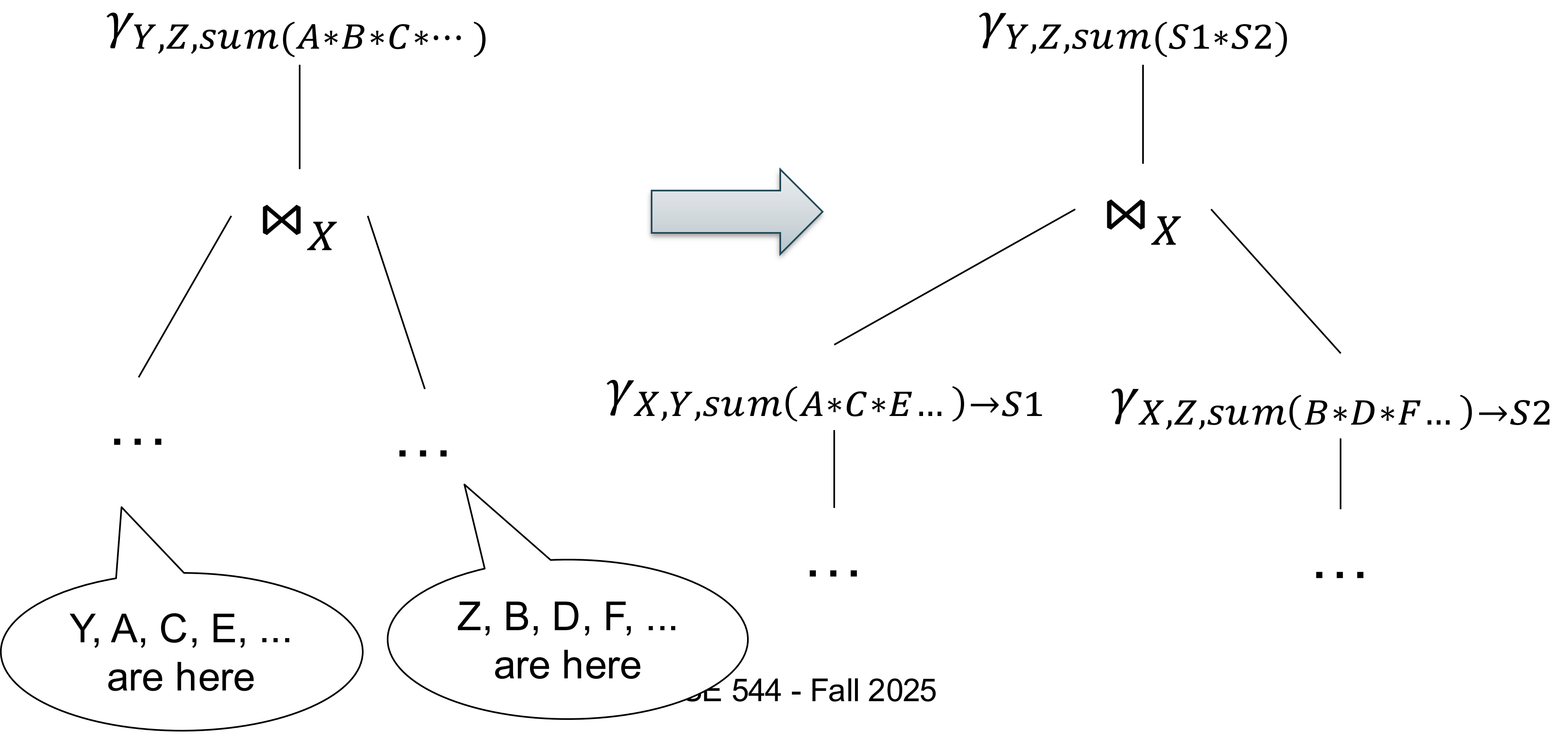
Generalized Distributivity Law



Generalized Distributivity Law



Generalized Distributivity Law



Discussion

- Most DBMS support only some subset of the generalized distributivity law
- Fun activity: check if your favorite DBMS supports it
- Next: a rewrite rule that most DBMS support

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

Key / Foreign-Key

```
Select x.pno, x.quantity
From Supply x, Supplier y
Where x.sid = y.sid
```

?

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

Key / Foreign-Key

```
Select x.pno, x.quantity
From Supply x, Supplier y
Where x.sid = y.sid
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```
Select x.pno, x.quantity
From Supply x
```

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

Key / Foreign-Key

```
Select x.pno, x.quantity
From Supply x, Supplier y
Where x.sid = y.sid
```

```
Select x.pno, x.quantity
From Supply x
```

Only if these constraints hold:

1. Supplier.sid = key
2. Supply.sid = foreign key
3. Supply.sid NOT NULL

Summary: Rules

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

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

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

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$$\gamma_{X,sum(B)}\left(\gamma_{X,Y,sum(A)\rightarrow B}(R)\right) = \gamma_{X,sum(A)}(R)$$

Summary: Rules

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

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

In particular,
$\delta(\delta(R) = \delta(R)$

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$$\gamma_{X,sum(B)}\left(\gamma_{X,Y,sum(A)\to B}(R)\right) = \gamma_{X,sum(A)}(R)$$

$$\gamma_{X,sum(A*B)}(R \bowtie_{Y=Z} S) =$$
$$\gamma_{X,sum(C*D)}\left(\gamma_{X,Y,sum(A)\to C}(R) \bowtie_{Y=Z} \gamma_{X,Z,sum(B)\to D}(S)\right)$$

Summary: Rules

$R \bowtie S = S \bowtie R$

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

In particular,
$\delta(\delta(R) = \delta(R)$

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$\gamma_{X,sum(A*B)}(R \bowtie_{Y=Z} S) =$
$\quad \gamma_{X,sum(C*D)}(\gamma_{X,Y,sum(A)\to C}(R) \bowtie_{Y=Z} \gamma_{X,Z,sum(B)\to D}(S))$

$\Pi_{attr(R)}(R \bowtie_{X=Y} S) = R$ if S.Y key, R.X fk not null

…

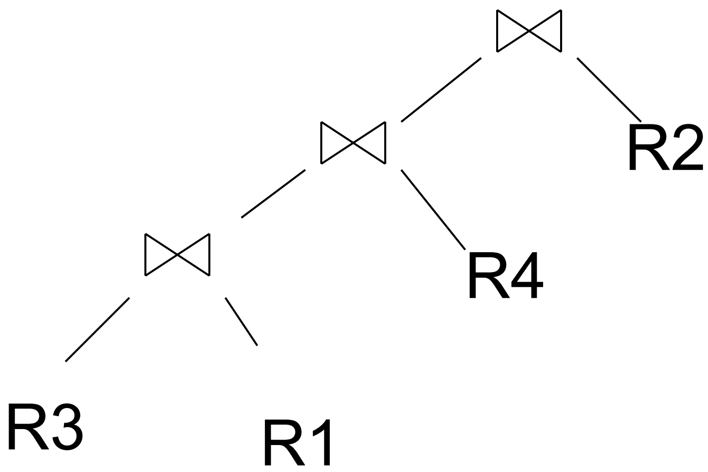
Practice

- Database optimizers typically have a database of rewrite rules
- E.g. SQL Server: about 500 rules
- Rules become complex as they need to serve specialized types of queries

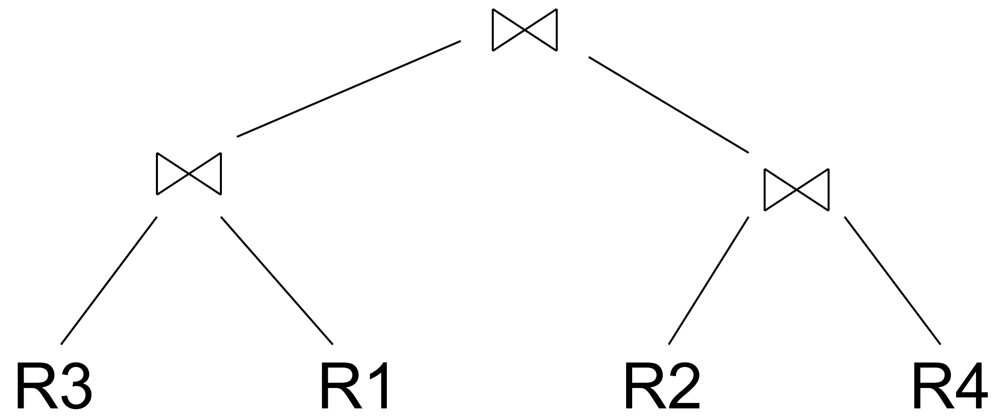
Search Space Challenges

- Search space is huge
- Typical compromises:
  - Left-deep plans
  - Plans without cartesian products

Left-Deep Plans and Bushy Plans



Left-deep plan



Bushy plan

Cartesian Product

- Plan without cartesian product:
  $$(R(A,B) \bowtie S(B,C)) \bowtie T(C,D)$$
- Plan with cartesian product
  $$\big(R(A,B) \bowtie T(C,D)\big) \bowtie S(B,C)$$
- Some optimizers avoid cartesian products

Recap: Search Space

Refers to the set of all possible alternate plans that the optimizers may explore

- Access Path Selection: how to use indices
- Rewrite Rules: what identities the optimizer applies
- Scheduling: pipeline/blocking next week

Recap: Query Optimization

<u>Three major components</u>:

1. Search space

Discussed today
(less scheduling)

2. Cardinality and cost estimation

Continued
next week

3. Plan enumeration algorithms