CSE544
Data Management

Lecture 4
Data Models

Announcements

- Tomorrow (Thursday): makeup lecture at 10:30am, CSE2 371
- Homework 1 is due on Friday
- Start to think about class projects

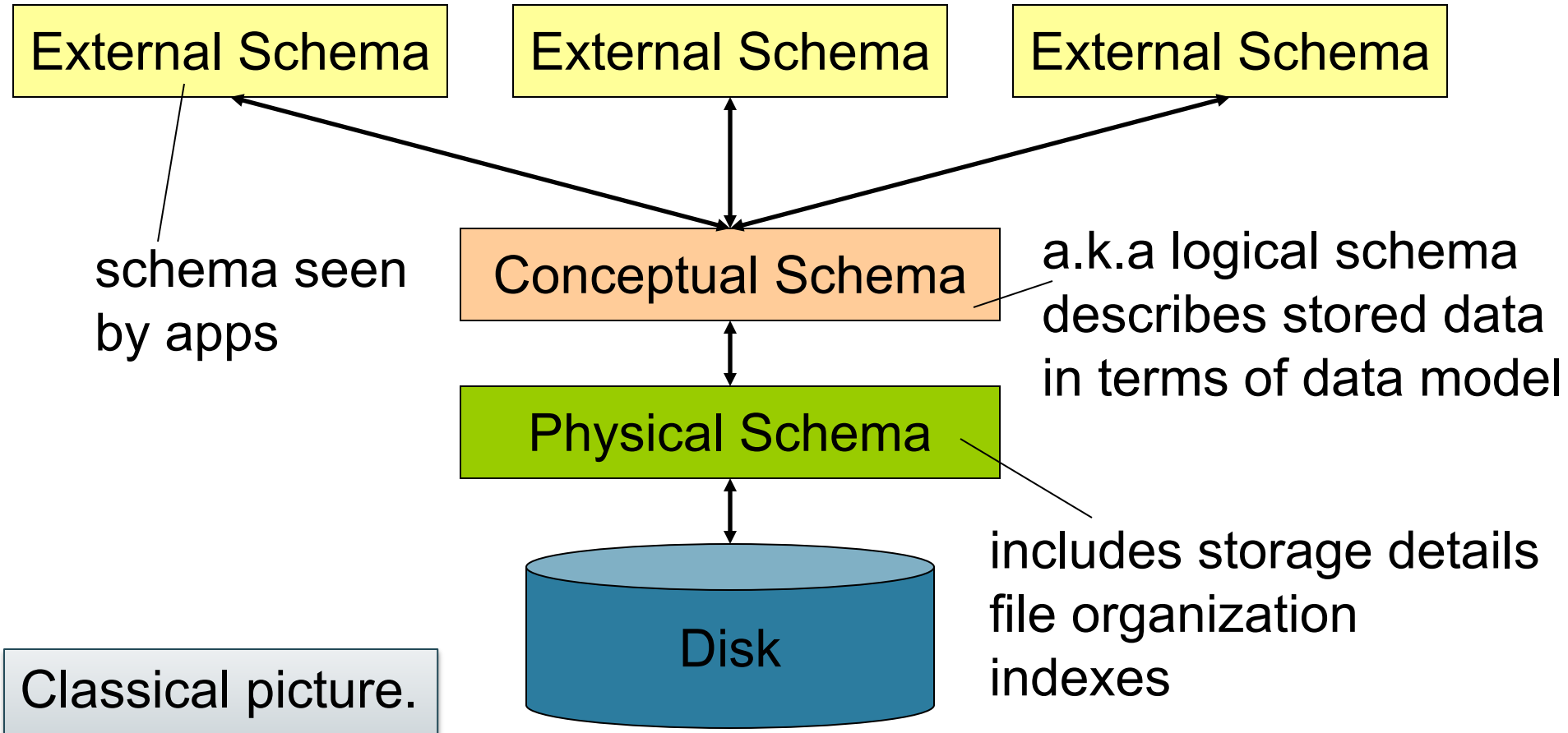
References

- M. Stonebraker and J. Hellerstein. What Goes Around Comes Around. In "Readings in Database Systems" (aka the Red Book). 4th ed.

Data Model Motivation

- Applications need to model real-world data
- User somehow needs to define data to be stored in DBMS
- Data model enables a user to define the data using high-level constructs without worrying about many low-level details of how data will be stored on disk

Levels of Abstraction



Classical picture.
Remember it !

Different Types of Data

- **Structured data**
  - All data conforms to a schema. Ex: business data
- **Semistructured data**
  - Some structure in the data but implicit and irregular
- **Unstructured data**
  - No structure in data. Ex: text, sound, video, images
- Our focus: structured data & relational DBMSs

Outline

- Early data models
  - IMS
  - CODASYL

- Physical and logical independence in the relational model

- Data models that followed the relational model

Early Proposal 1: IMS

- What is it?

Early Proposal 1: IMS

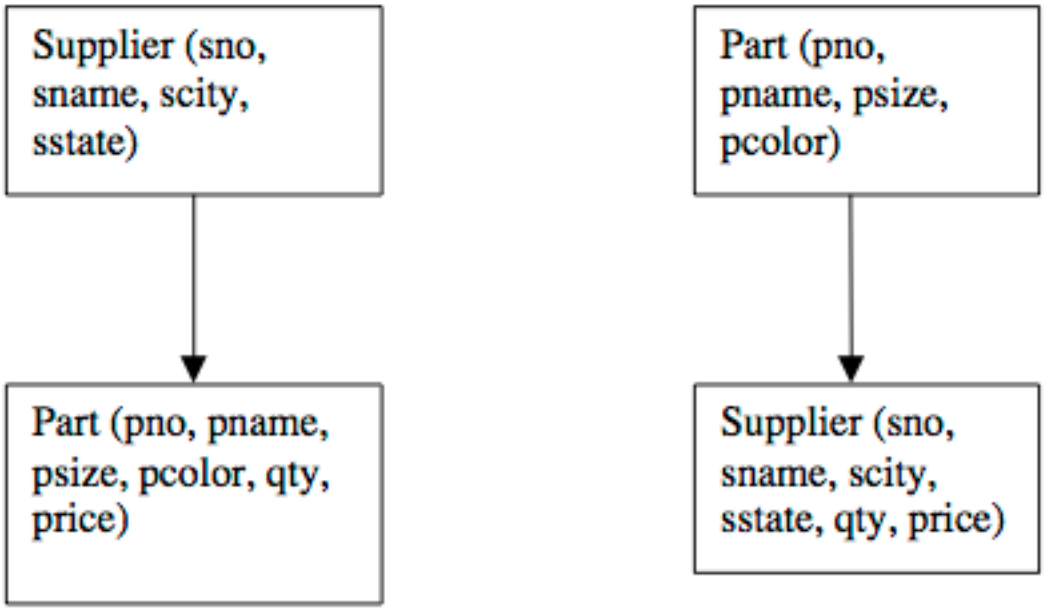
- **Hierarchical data model**

- **Record**
  - **Type**: collection of named fields with data types
  - **Instance**: must match type definition
  - Each instance has a **key**
  - Record types arranged in a **tree**

- **IMS database** is collection of instances of record types organized in a tree

IMS Example

- Figure 2 from “What goes around comes around”



Data Manipulation Language: DL/1

How does a programmer retrieve data in IMS?

Data Manipulation Language: DL/1

How does a programmer retrieve data in IMS?

- Each record has a hierarchical sequence key (HSK)
- HSK defines semantics of commands:
  - get_next; get_next_within_parent
- **DL/1 is a record-at-a-time language**
  - Programmers construct algorithm, worry about optimization

Data storage

How is data physically stored in IMS?

Data storage

How is data physically stored in IMS?

- Root records
  - Stored sequentially (sorted on key)
  - Indexed in a B-tree using the key of the record
  - Hashed using the key of the record
- Dependent records
  - Physically sequential
  - Various forms of pointers
- Selected organizations restrict DL/1 commands
  - No updates allowed due to sequential organization
  - No “get-next” for hashed organization

Data Independence

What is it?

Data Independence

What is it?

- **Physical data independence**: Applications are insulated from changes in **physical storage details**

- **Logical data independence**: Applications are insulated from changes to **logical structure of the data**

IMS Limitations

- **Tree-structured data model**
  - Redundant data; existence depends on parent
- **Record-at-a-time** user interface
  - User must specify algorithm to access data
- **Very limited physical independence**
  - Phys. organization limits possible operations
  - Application programs break if organization changes
- **Some logical independence but limited**

Early Proposal 2: CODASYL

What is it?

Early Proposal 2: CODASYL

What is it?

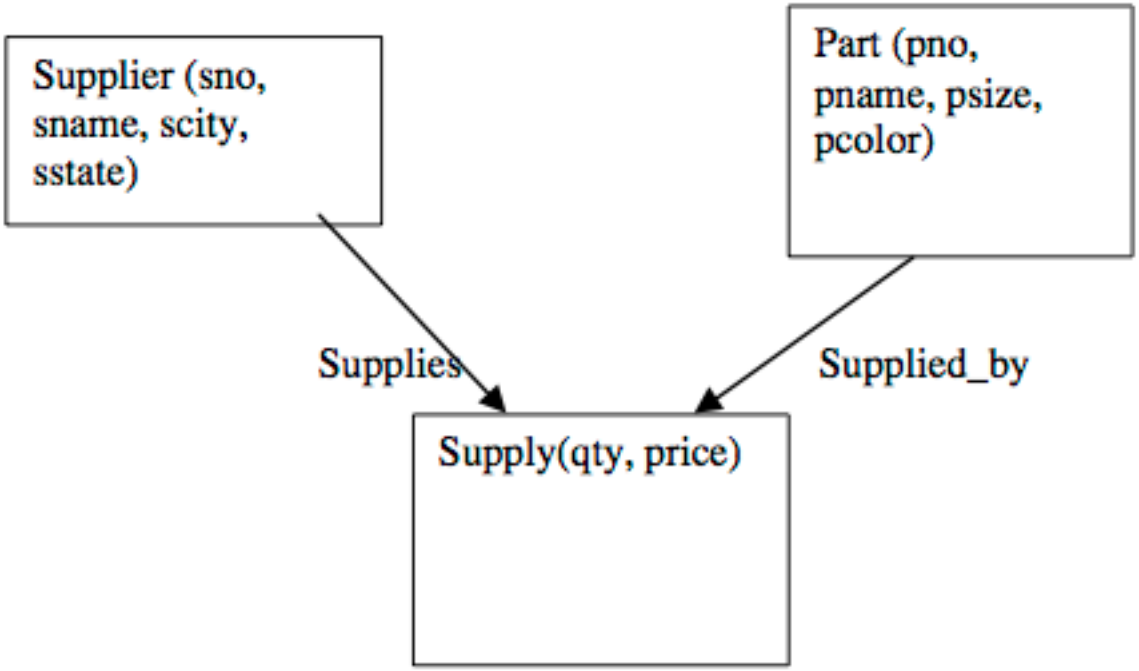
- **Networked data model**

- Primitives are also **record types** with **keys**
- Record types are organized into **network**
  - Multiple parents; arcs = “sets”; at least one entry point
- More flexible than hierarchy

- **Record-at-a-time** data manipulation language

CODASYL Example

- Figure 5 from “What goes around comes around”



CODASYL Limitations

- **No physical data independence**
  - Application programs break if organization changes
- **No logical data independence**
  - Application programs break if organization changes
- Very complex
- Programs must “navigate the hyperspace”
- Load and recover as one gigantic object

The Programmer as Navigator

by Charles W. Bachman

Outline

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  - CODASYL
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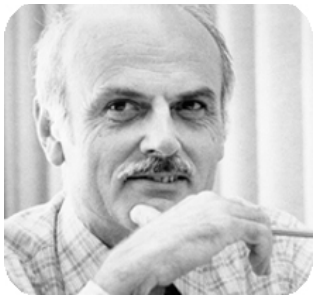
Relational Model Overview

- Proposed by Ted Codd in 1970
- Motivation: logical and physical data independence
- Overview
  - Store data in a **simple data structure** (table)
  - Access data through **set-at-a-time** language
  - **No need for physical storage proposal**

Relational Database: A Practical Foundation for Productivity



Great Debate

- Pro relational
  - What were the arguments?
- Against relational
  - What were the arguments?
- How was it settled?

Great Debate

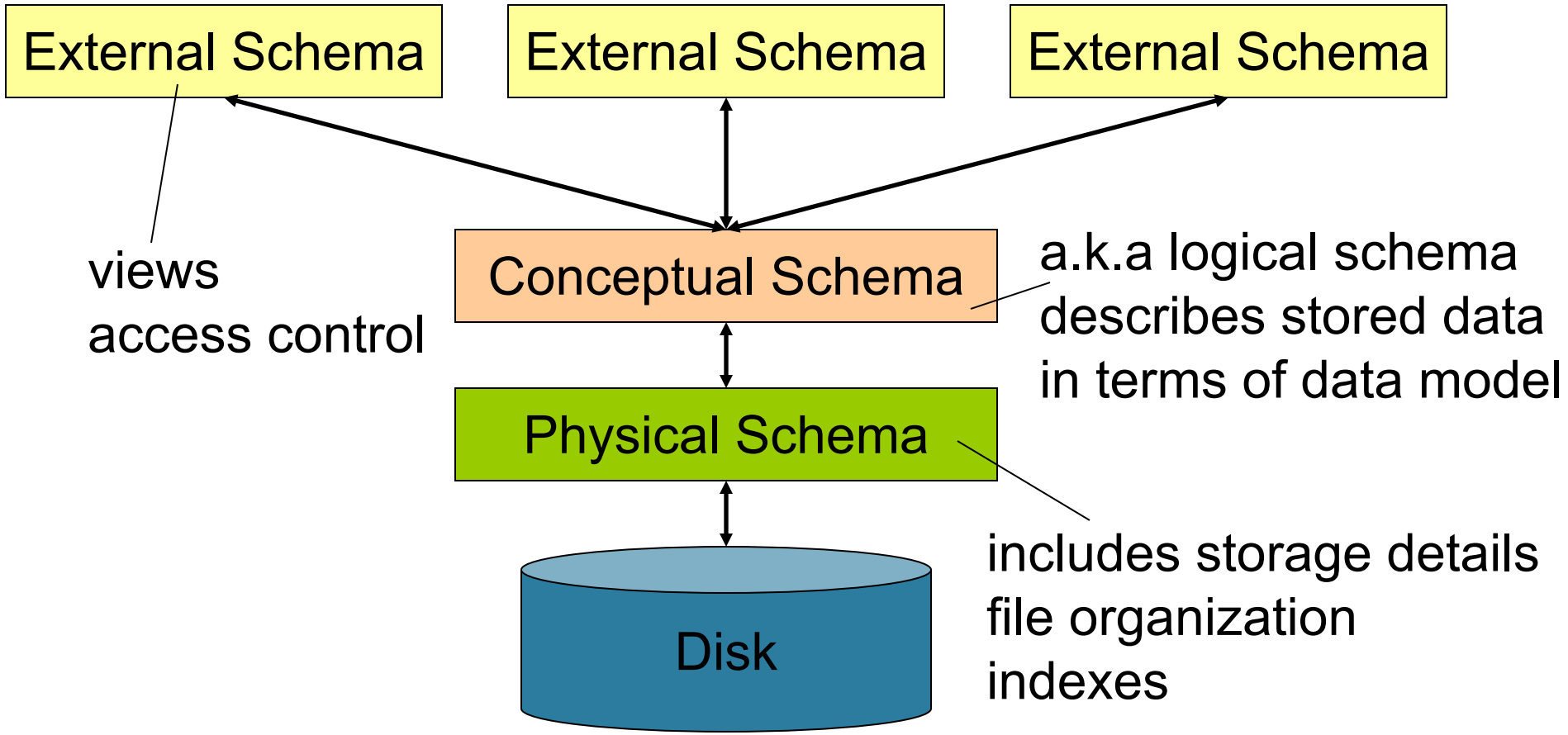
- Pro relational
  - CODASYL is too complex
  - CODASYL does not provide sufficient data independence
  - Record-at-a-time languages are too hard to optimize
  - Trees/networks not flexible enough to represent common cases
- Against relational
  - COBOL programmers cannot understand relational languages
  - Impossible to represent the relational model efficiently
- Ultimately settled by the market place

Data Independence

How is data independence is achieved in RDBMS today:

- Physical independence:
  - SQL to Query Plan
- Logical independence
  - SQL Views

Levels of Abstraction



Query Optimizer

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

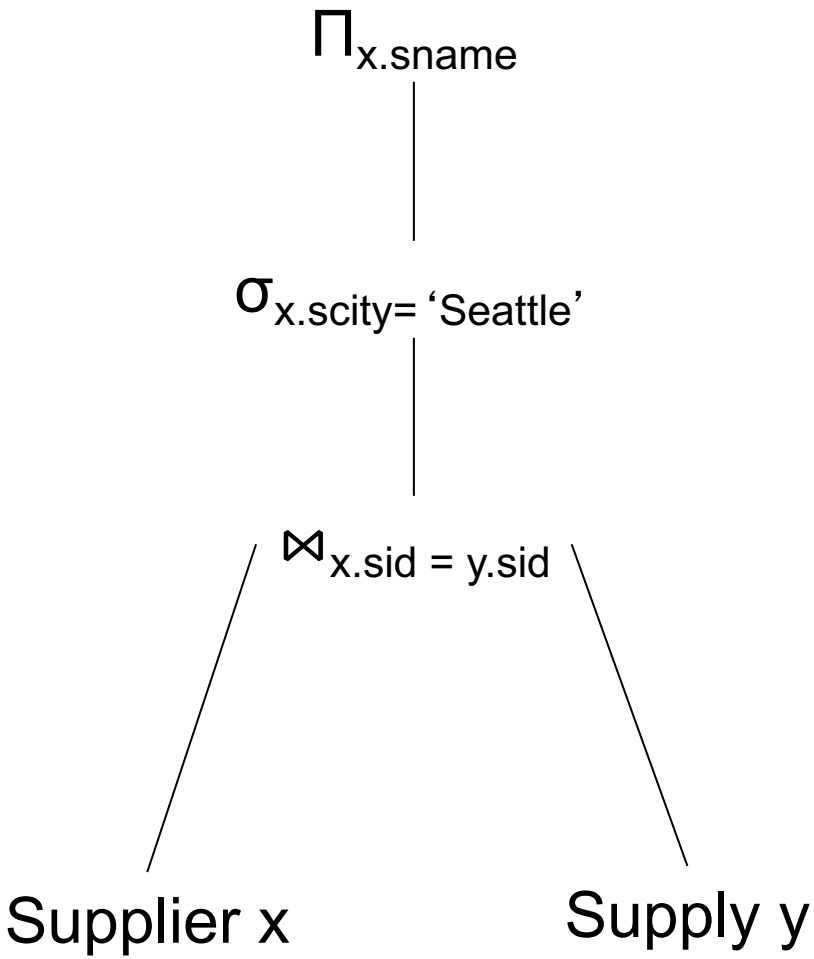
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

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

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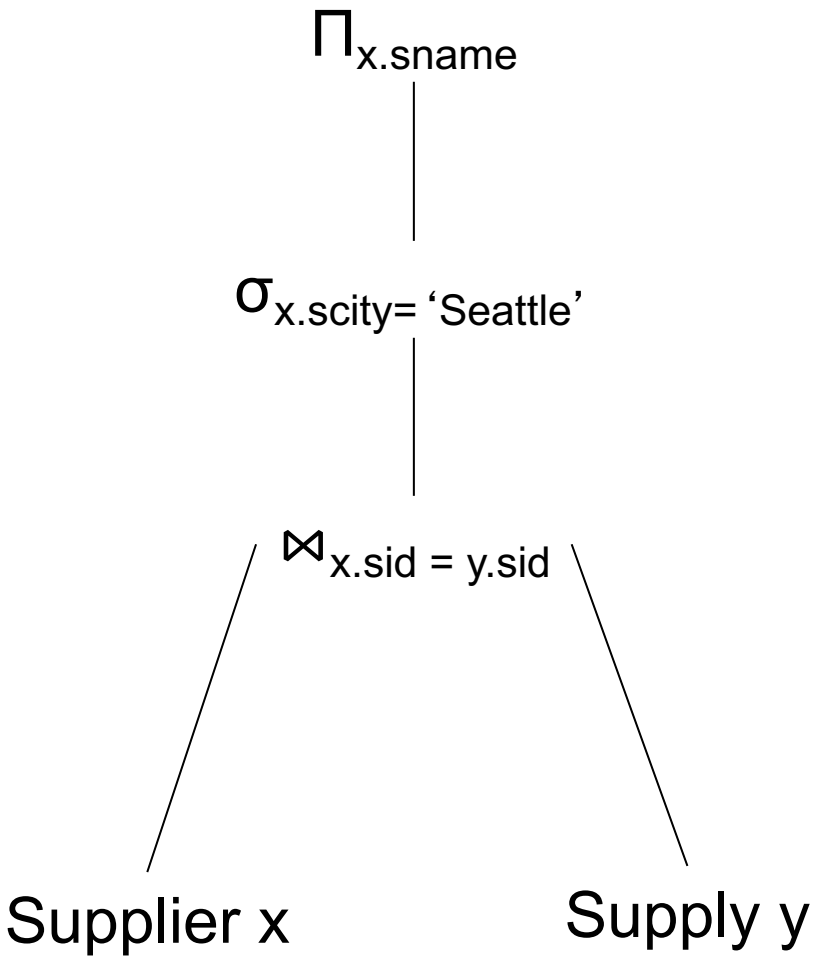
Push Selections Down



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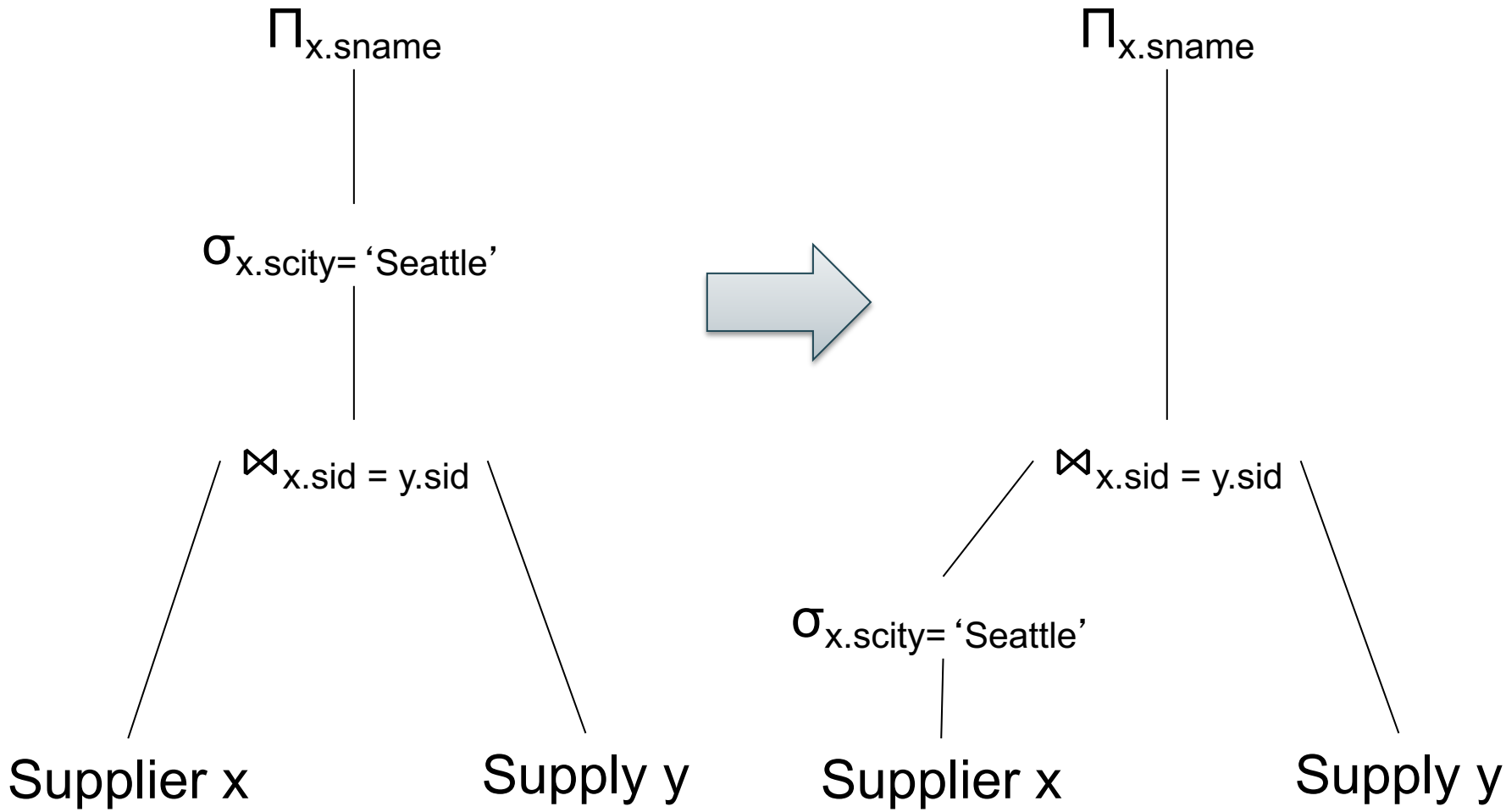

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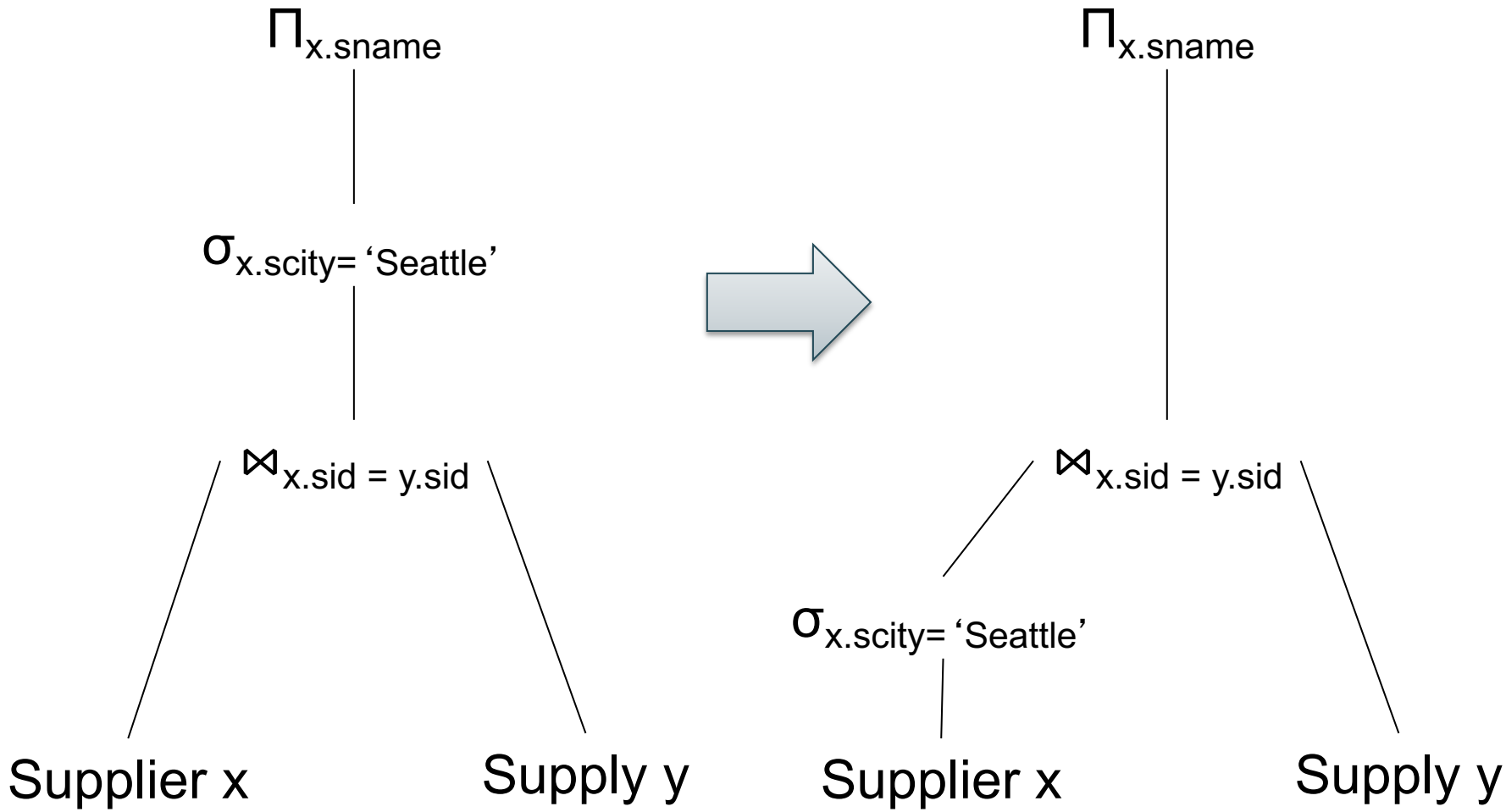
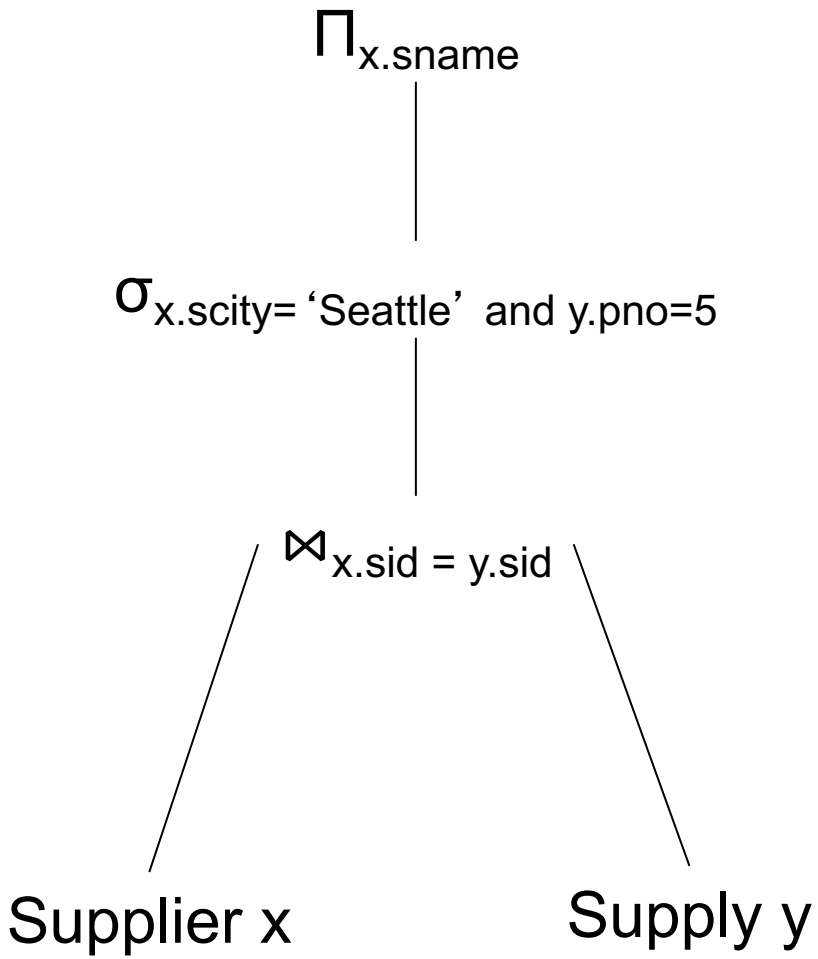


$\sigma_C(R \bowtie S) = \sigma_C(R) \bowtie S$ when C refers only to R

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

Push Selections Down



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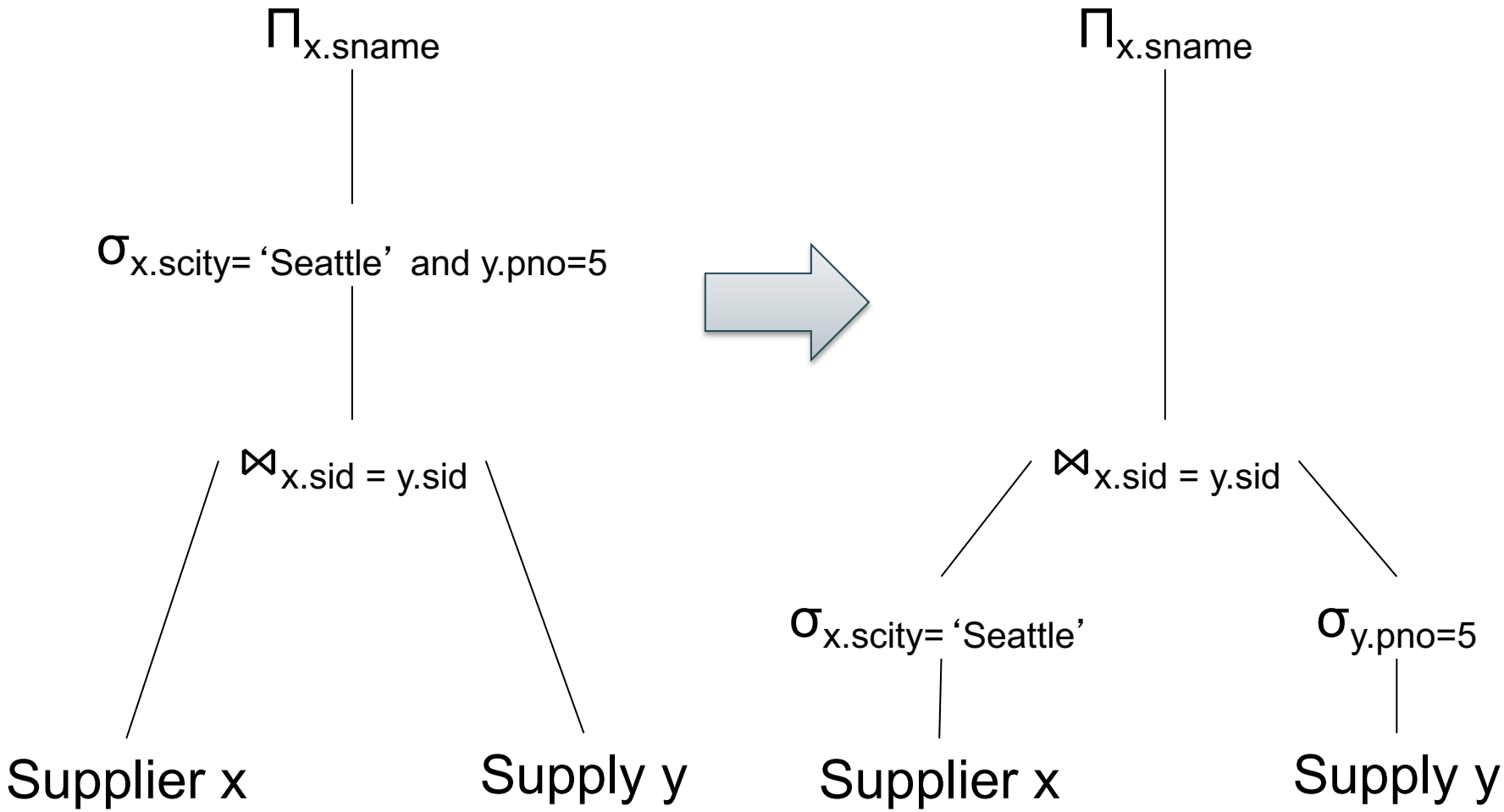

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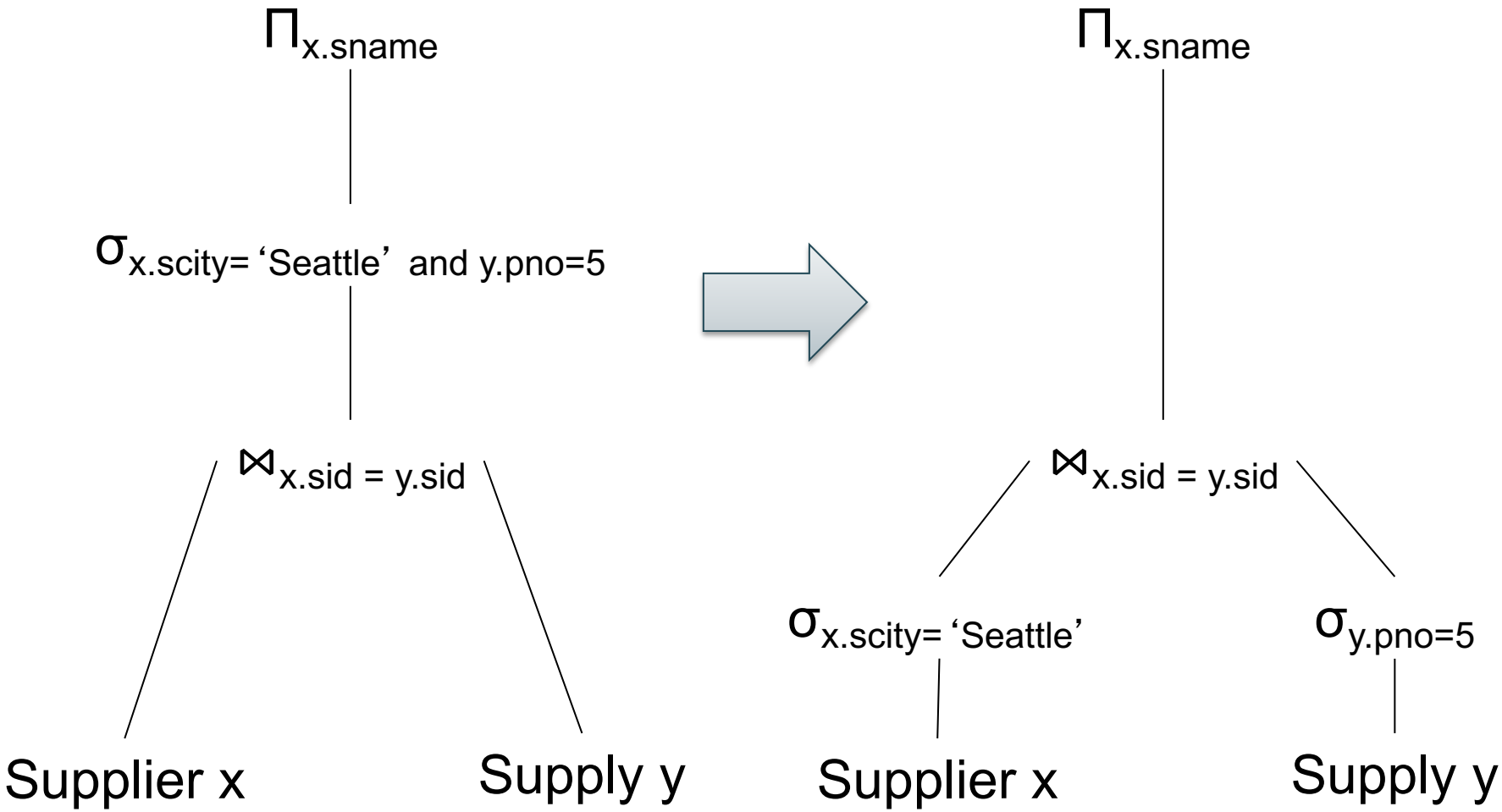
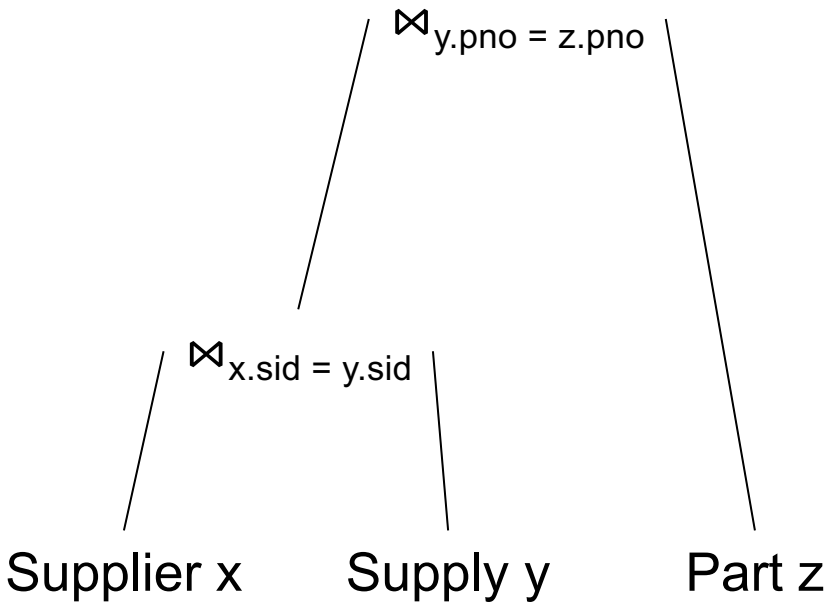


$$\sigma_{C1 \text{ and } C2}(R \bowtie S) = \sigma_{C1}(\sigma_{C2}(R \bowtie S)) = \sigma_{C1}(R \bowtie \sigma_{C2}(S)) = \sigma_{C1}(R) \bowtie \sigma_{C2}(S)$$

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

Join Reorder



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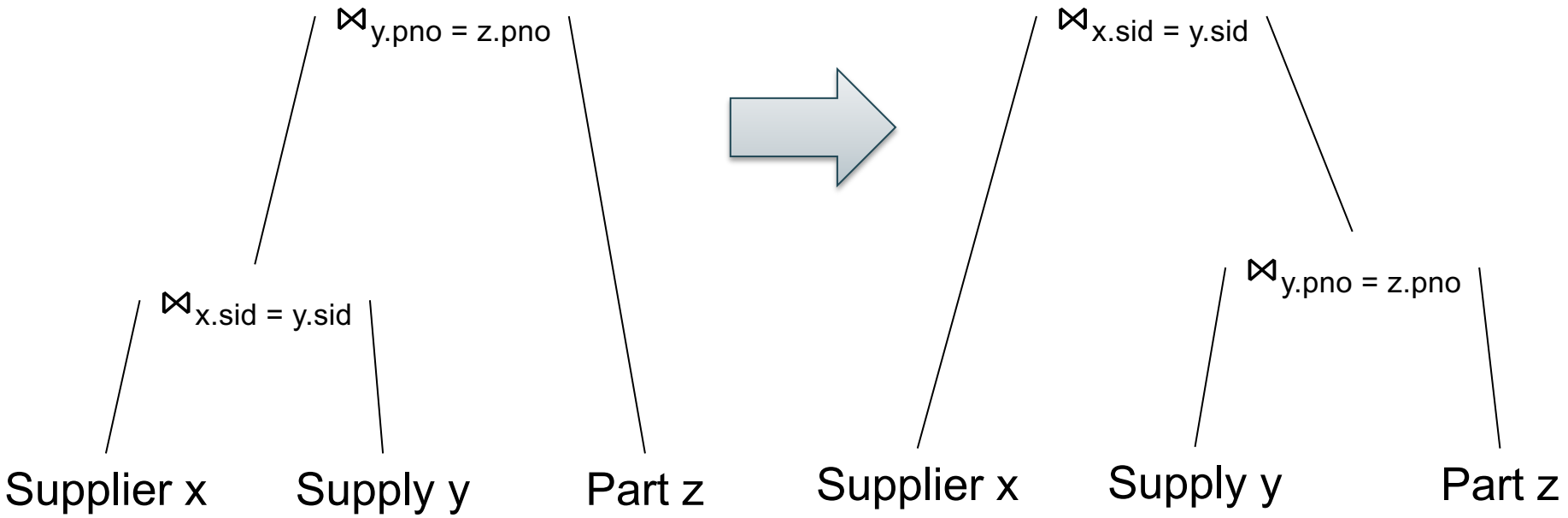

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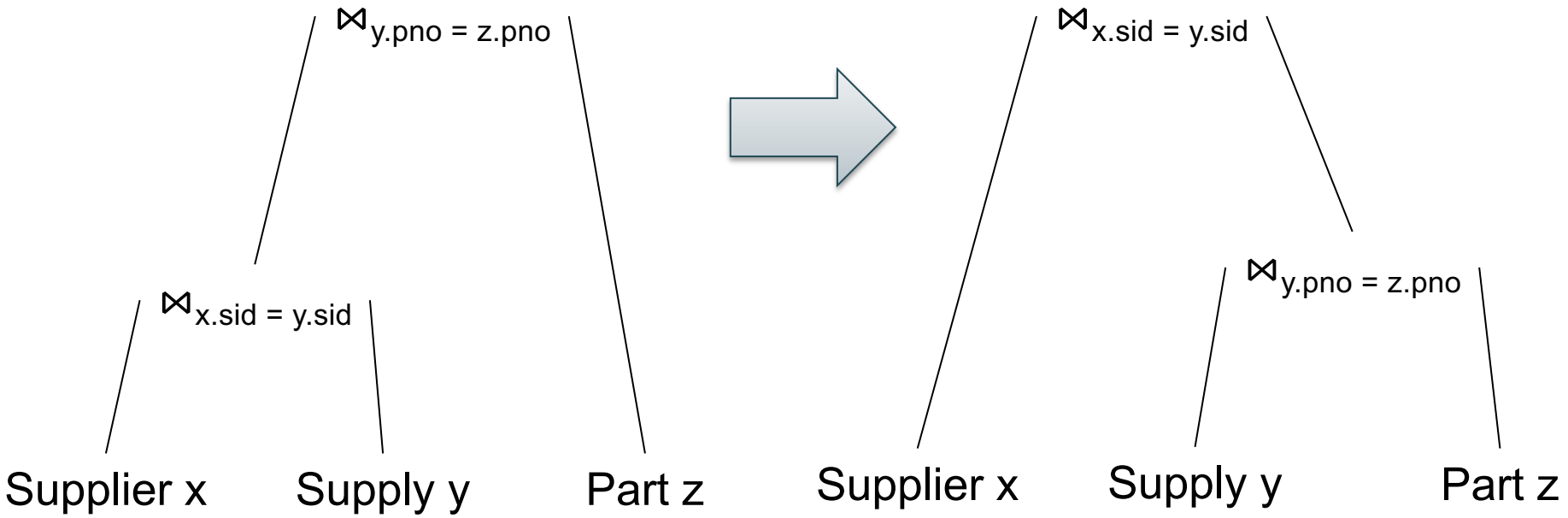

$$(R \bowtie S) \bowtie T = R \bowtie (S \bowtie T)$$

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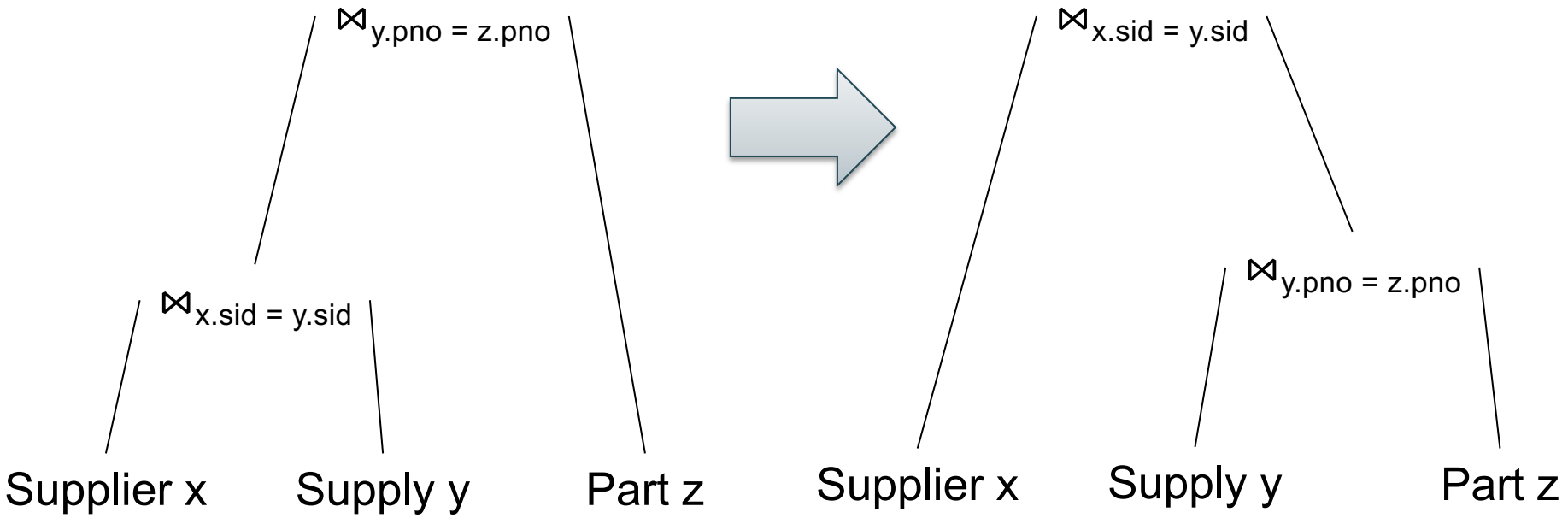


$$(R \bowtie S) \bowtie T = R \bowtie (S \bowtie T)$$

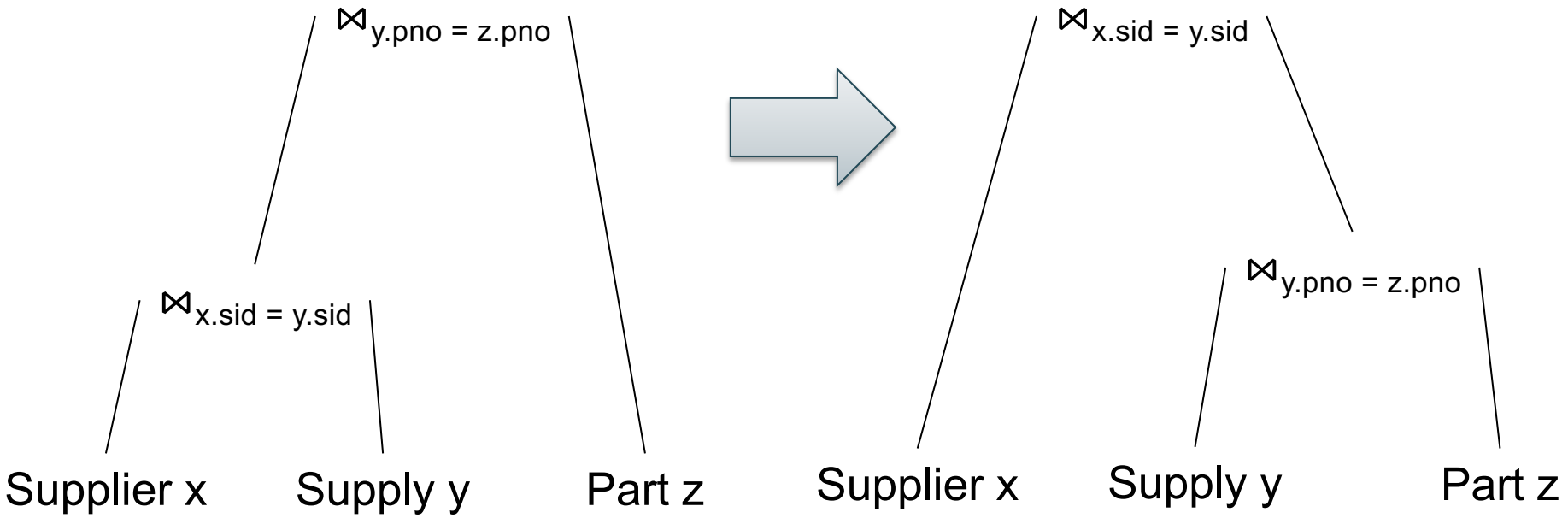
Also:

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

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

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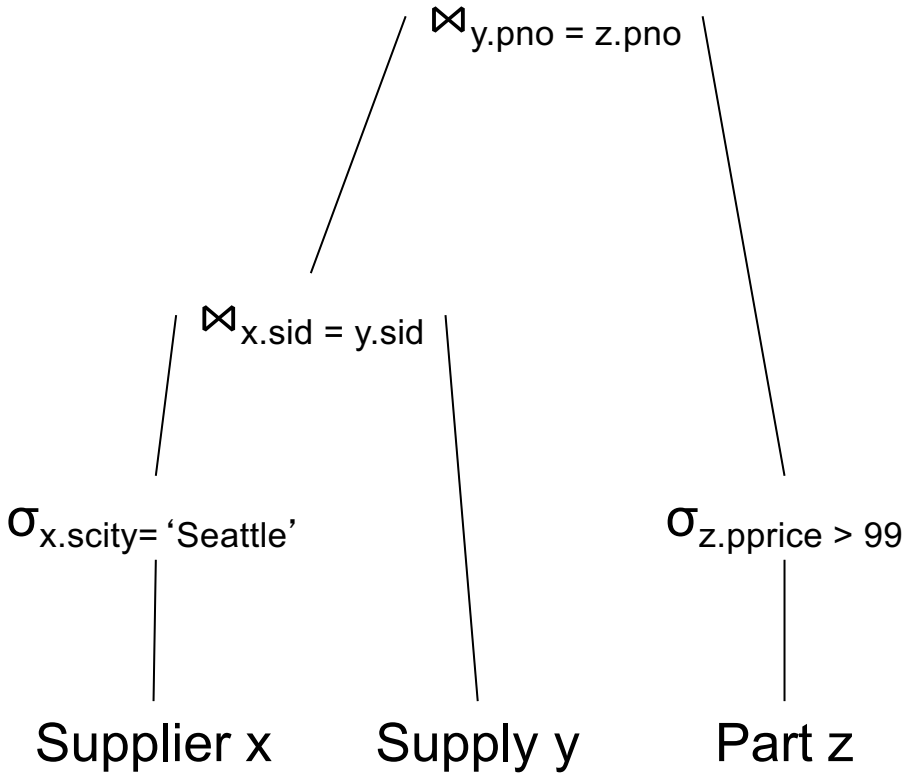

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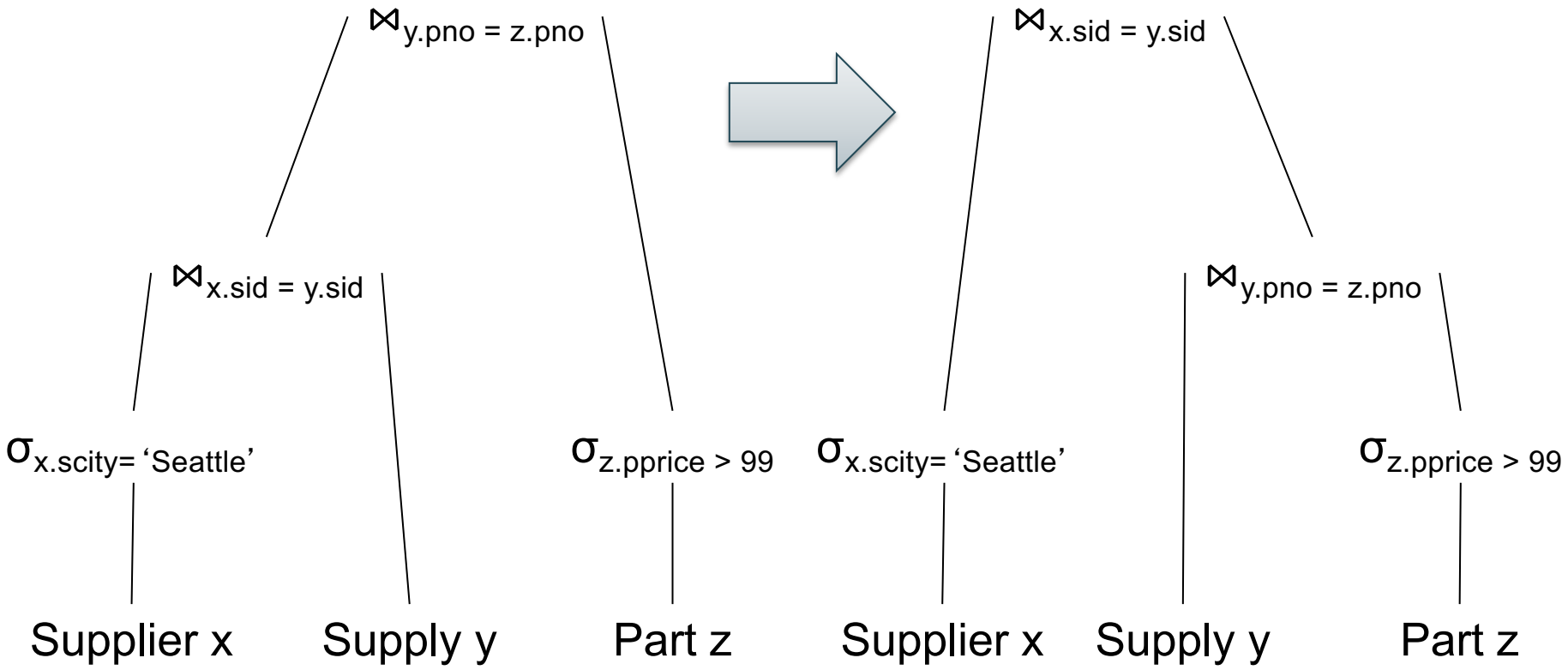

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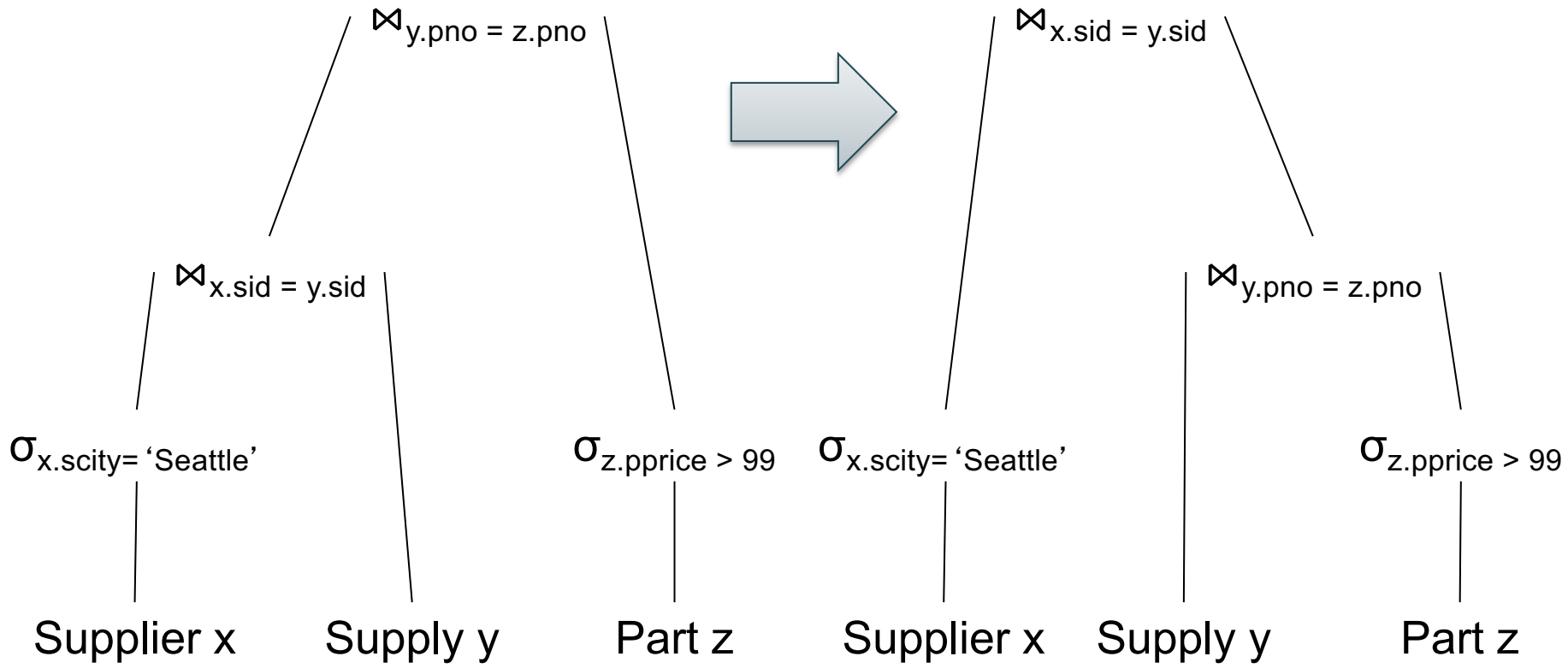

Lesson: need sizes of $\sigma_{x.scity= \text{'Seattle'}}$(Supplier), $\sigma_{z.pprice > 99}$(Part)

Summary of Phys. Data Indep

Physical data independence based on:

- SQL to Query Plan
- Query Plan is optimized
- Optimized Query Plan to Physical Plan

Will discuss this later in this course

Logical Independence

- Applications are insulated from changes to logical structure of the data

- Relational model
  - Logical independence through views

Logical Data Independence

In SQL: based on views

A View is a relation

- Virtual views:
  - Computed on demand, at query time
  - Default in SQL, and what Stonebraker means in the paper
- Materialized views:
  - Computed and stored persistently
- Pros and cons?

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

View Example

View definition:

```
CREATE VIEW Big_Parts AS
        SELECT * FROM Part
        WHERE psize > 10;
```

Supplier(sno,sname,scity,sstate)
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View Example

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Virtual table: Big_Parts(pno,pname,psize,pcolor)

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View Example

View definition:

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CREATE VIEW Big_Parts AS
        SELECT * FROM Part
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```

Virtual table: Big_Parts(pno,pname,psize,pcolor)

Querying the view:

```
SELECT *
FROM Big_Parts
WHERE pcolor='blue';
```

Updating Through Views

- **Updatable views** (SQL-92)
  - Defined on single base relation
  - No aggregation in definition
  - Inserts have NULL values for missing fields
  - Better if view definition includes primary key
- Non-Updatable views (SQL-99)
  - May be defined on multiple tables
- **Messy issue in general**

Summary of Logical Data Indep

- SQL views

- Beyond Logical data indep
  - An index is a view (why?)
  - Any query result can be stored, and considered a view
  - New problem: given views V1, V2, … find optimal way to compute a query Q

Outline

- Early data models
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Other Data Models

- Entity-Relationship: 1970's
  - Successful in logical database design (last lecture)
- Extended Relational: 1980's
- Semantic: late 1970's and 1980's
- Object-oriented: late 1980's and early 1990's
  - Address impedance mismatch: relational dbs ←→ OO languages
  - Interesting but ultimately failed (several reasons, see references)
- Object-relational: late 1980's and early 1990's
  - User-defined types, ops, functions, and access methods
- Semi-structured: late 1990's to the present

Semistructured vs Relational

- Relational data model
  - “Schema first”
- Semistructured data model: XML, Json, Protobuf
  - ”Schema last”
  - Hierarchical (trees)

XML Syntax

```
<article mdate="2011-01-11" key="journals/acta/GoodmanS83">
    <author>Nathan Goodman</author>
    <author>Oded Shmueli</author>
    <title>NP-complete Problems Simplified on Tree Schemas.</title>
    <pages>171-178</pages>
    <year>1983</year>
    <volume>20</volume>
    <journal>Acta Inf.</journal>
    <url>db/journals/acta/acta20.html#GoodmanS83</url>
    <ee>http://dx.doi.org/10.1007/BF00289414</ee>
</article>
```

Semistructured, self-describing schema

JSon

Example from: http://www.jsonexample.com/

```
myObject = {
   "first": "John",
   "last": "Doe",
   "salary": 70000,
   "registered": true,
   "interests": [ "Reading", “Biking”, "Hacking" ]
}
```

Semistructured, self-describing schema

Discussion

- Stonebraker (circa 1998)
  - "schema last" is a niche market
- Today (circa 2020)
  - Major vendors scramble to offer efficient schema discovery while ingesting Json
- Why? What changed?

Discussion

- Stonebraker (circa 1998)
  - "schema last" is a niche market
- Today (circa 2020)
  - Major vendors scramble to offer efficient schema discovery while ingesting Json
- Why? What changed?
  - Today datasets are available in text format, often in Json; ingest first, process later

NoSQL Data Model(s)

- Web boom in the 2000's created a scalability crises
  - Startup X grows from 10 customers to 10M customers overnight, how does the MySQL database grow?
- NoSQL answer:
  - "Shard" data, i.e. distribute AWS
  - Simple data mode: key/value pairs

Key-Value Pair Data Model

- **Data model**: (key,value) pairs
  - Key = string/integer, unique for the entire data
  - Value = can be anything (very complex object)

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  - `get(key)`, `put(key,value)`
  - Operations on value not supported

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  - Key = string/integer, unique for the entire data
  - Value = can be anything (very complex object)
- **Operations**
  - `get(key)`, `put(key,value)`
  - Operations on value not supported
- **Distribution / Partitioning** – w/ hash function
  - No replication: key k is stored at server h(k)
  - 3-way replication: key k stored at h1(k),h2(k),h3(k)

Flights(fid, date, carrier, origin, dest, ...)
Carriers(cid, name)

Example

- How would you represent the Flights data as key, value pairs?

How does query processing work?

Flights(fid, date, carrier, origin, dest, ...)
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Example

- How would you represent the Flights data as key, value pairs?

- Option 1: key=fid, value=entire flight record

How does query processing work?

Flights(fid, date, carrier, origin, dest, ...)
Carriers(cid, name)

Example

- How would you represent the Flights data as key, value pairs?
- Option 1: key=fid, value=entire flight record
- Option 2: key=date, value=all flights that day

How does query processing work?

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Example

- How would you represent the Flights data as key, value pairs?
- Option 1: key=fid, value=entire flight record
- Option 2: key=date, value=all flights that day
- Option 3: key=(origin,dest), value=all flights between

How does query processing work?

No physical data independence!

Conclusion

- Data independence is desirable
  - Both physical and logical
  - People keep reinventing data models with predefined physical schema
  - Relational model is the only one that provides independence
- Query optimizer:
  - Is the critical piece that ensures performance with physical independence