CSE544
Data Management

Lecture 3: Data Models

Announcements

- Today: office hour ends at 12:10
- Friday: Homework 1 is due
- Next Monday: MLK day, no lecture
- Start thinking 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

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?

* IBM Information Management System

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**

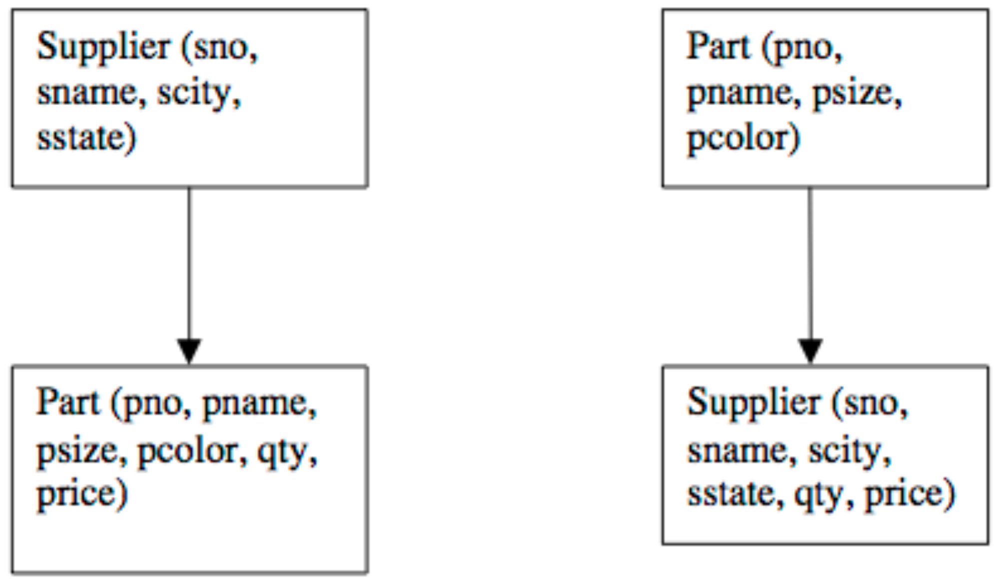
- **IMS database** is collection of instances of record types organized in a tree

* IBM Information Management System

IMS Example

- Figure 2 from “What goes around comes around”

What does this mean?



IMS Example

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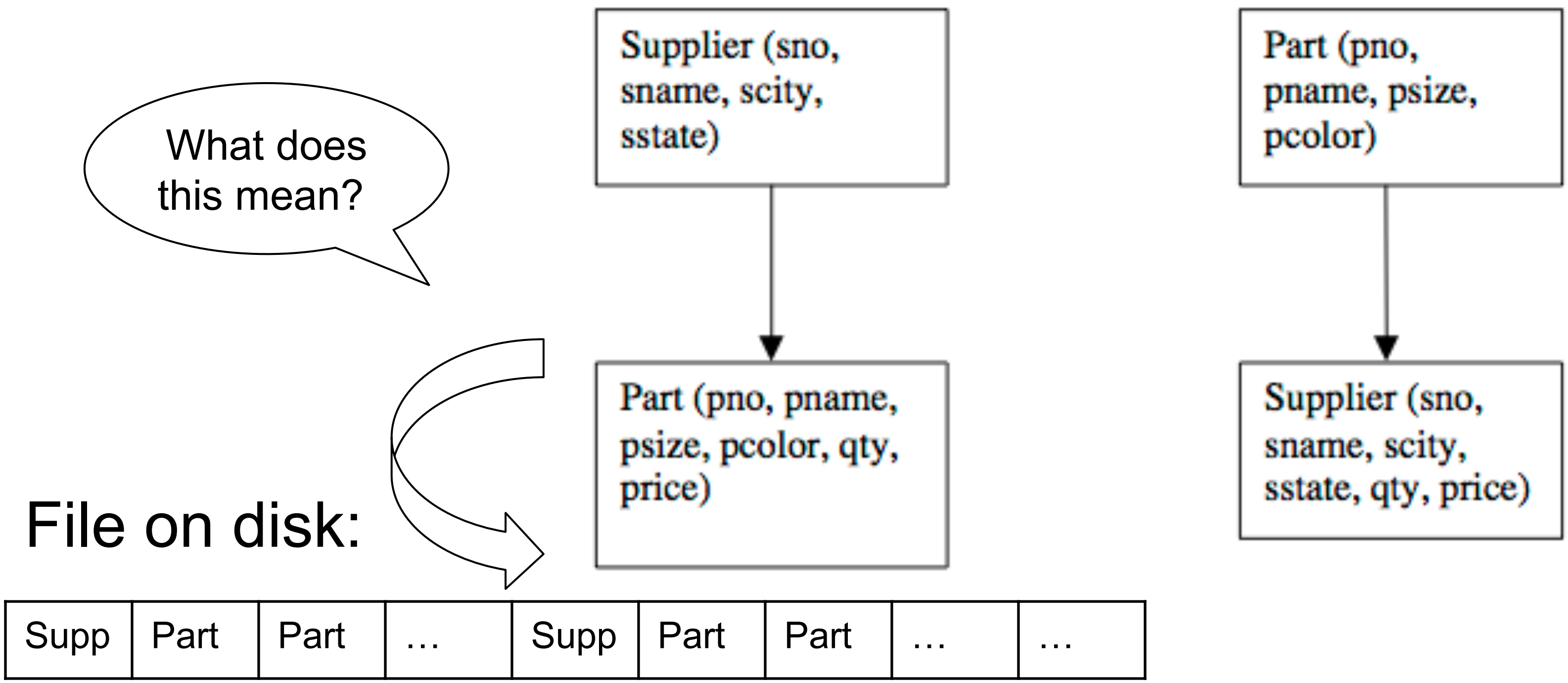

IMS Example

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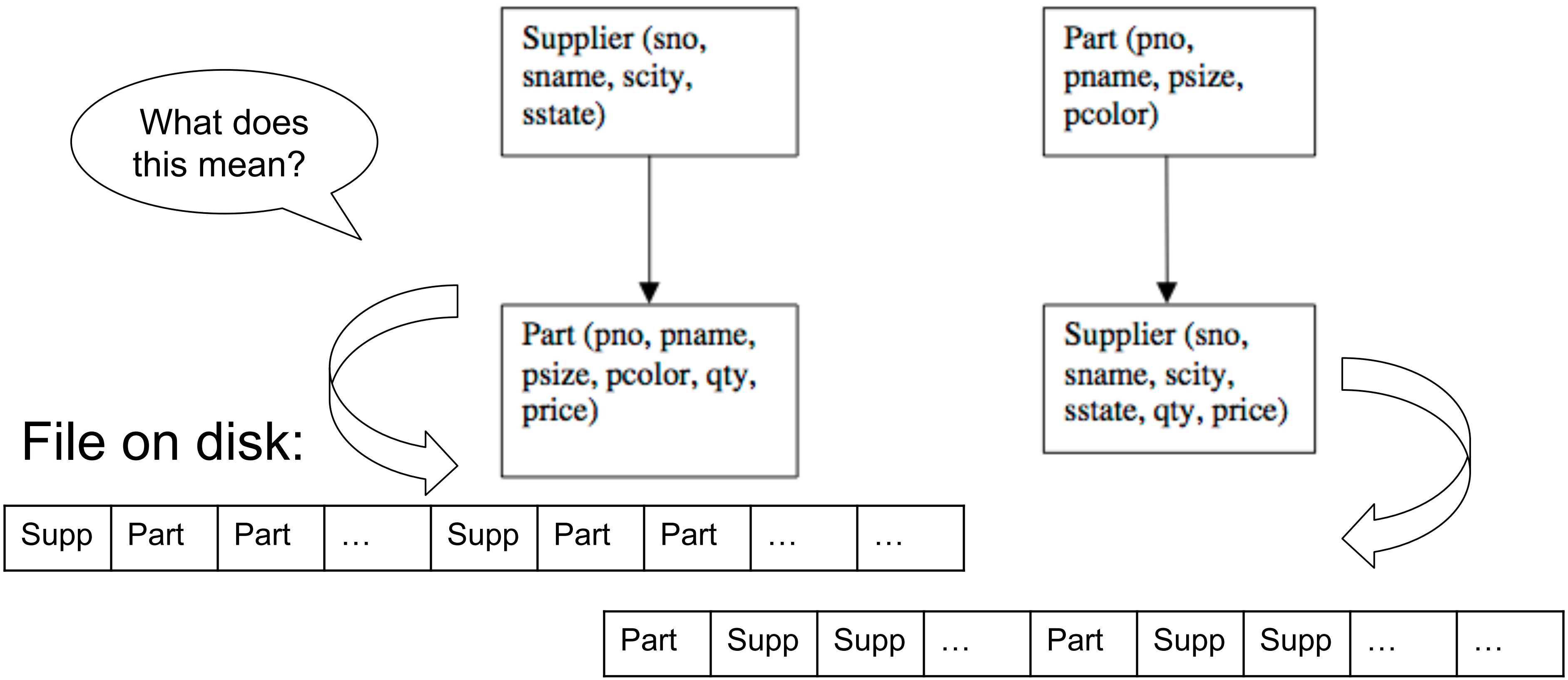

IMS Limitations

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- **Tree-structured data model**
  - Redundant data; existence depends on parent

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  - User must specify algorithm to access 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**

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**

Lessons from IMS

- Physical/logical data independence needed
- Tree structure model is restrictive
- Record-at-a-time programming forces user to do optimization

Early Proposal 2: CODASYL

What is it?

Early Proposal 2: CODASYL

What is it?

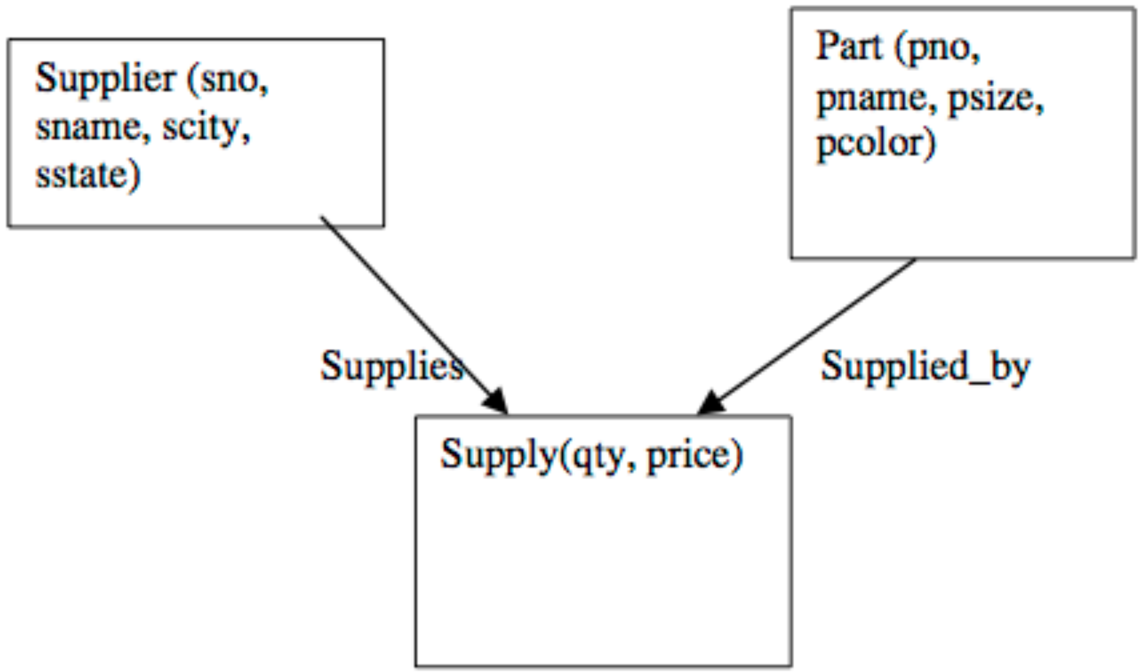
- **Networked data model**

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

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

CODASYL Example

- Figure 5 from “What goes around comes around”



CODASYL Limitations

- No data independence: application programs break if organization changes
- Record-at-a-time: “navigate the hyperspace”

The Programmer as Navigator

by Charles W. Bachman

Outline

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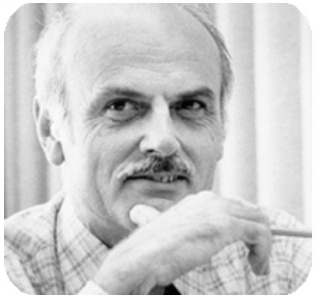
Relational Model Overview

Ted Codd 1970

- What was the motivation? What is the model?



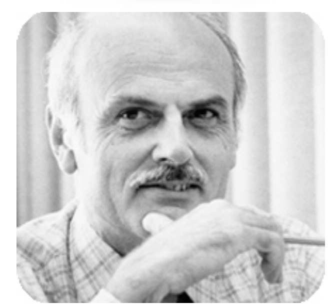
Relational Model Overview

Ted Codd 1970

- Motivation: logical and physical data independence

- 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
  - No data independence
  - Record-at-a-time hard to optimize
  - Trees/networks not flexible enough
- Against relational
  - COBOL programmers cannot understand relational languages
  - Impossible to implement efficiently
- Ultimately settled by the market place

Data Independence

How it is achieved today:

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

Physical Data Independence

- In SQL we express ***What*** data we want to retrieve

- The optimizers figures out ***How*** to retrieve it

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

Query Plan

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

We say *What* we want

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

Logical Query Plan

```
SELECT DISTINCT x.name, z.name
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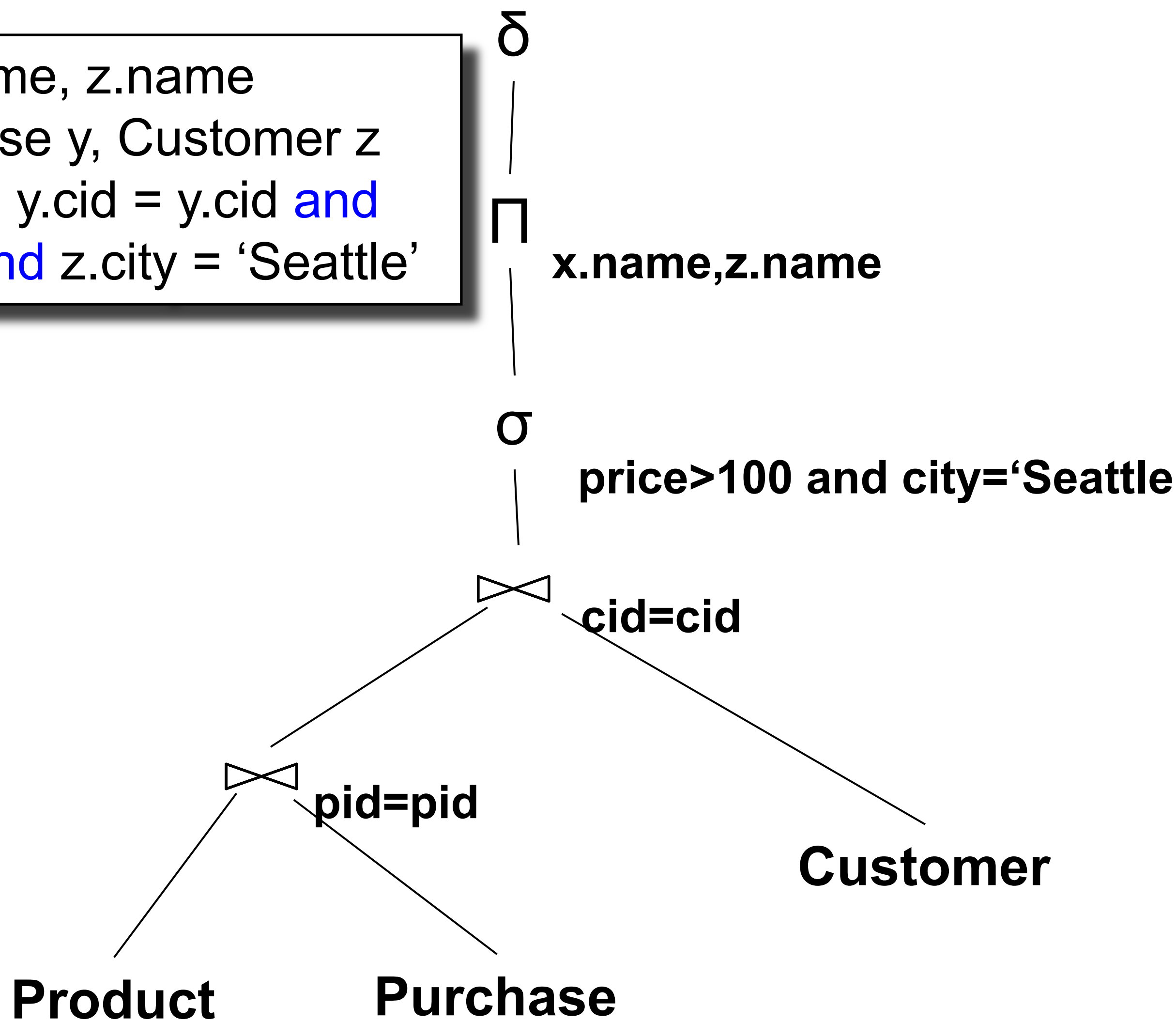

Product(pid, name, price)
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Physical Query Plan

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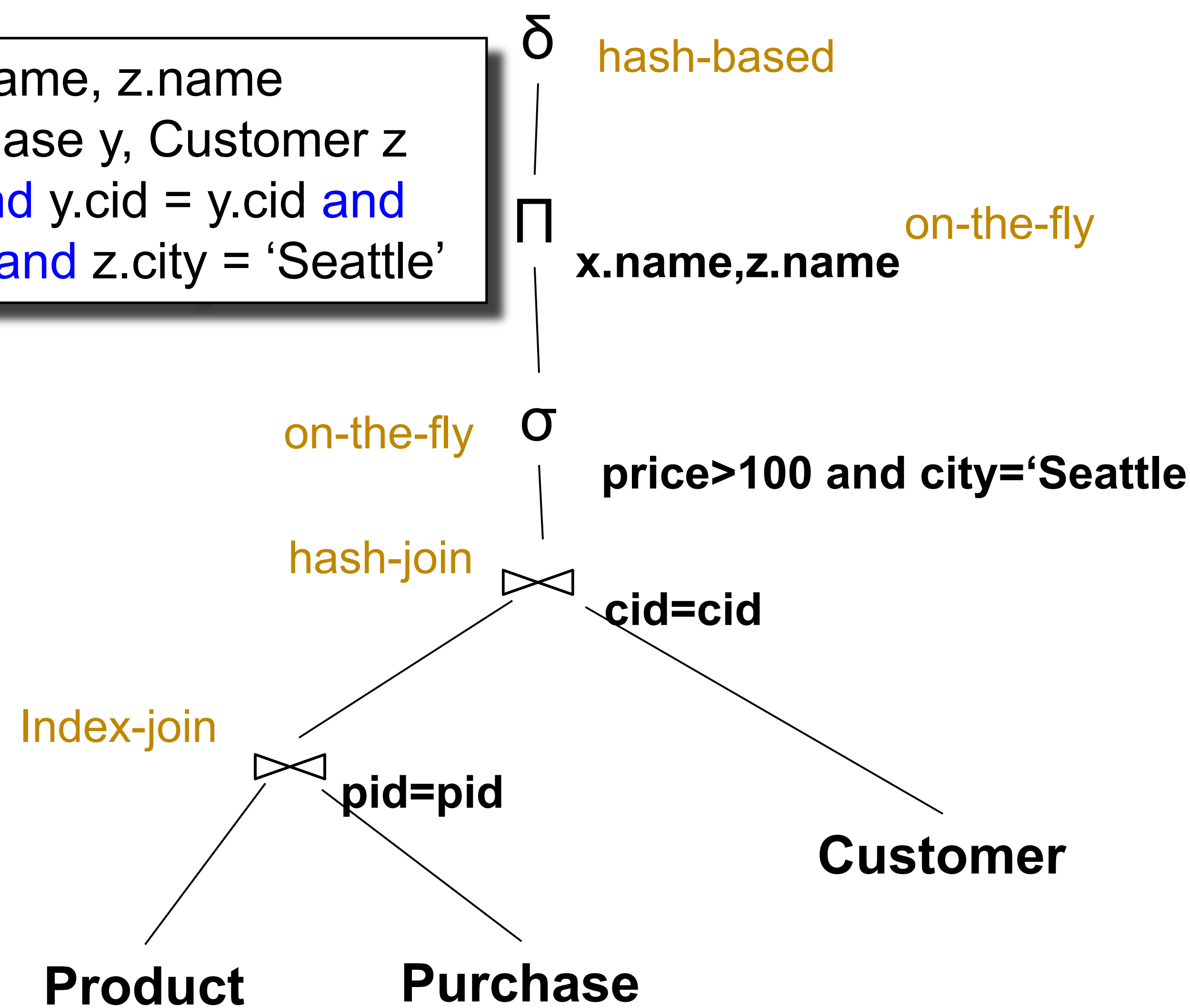
We say *What* we want

Says *How* to get it



Query Optimizer

- Rewrite one relational algebra expression to a better one
- Very brief review now, more details next lectures

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

Optimization

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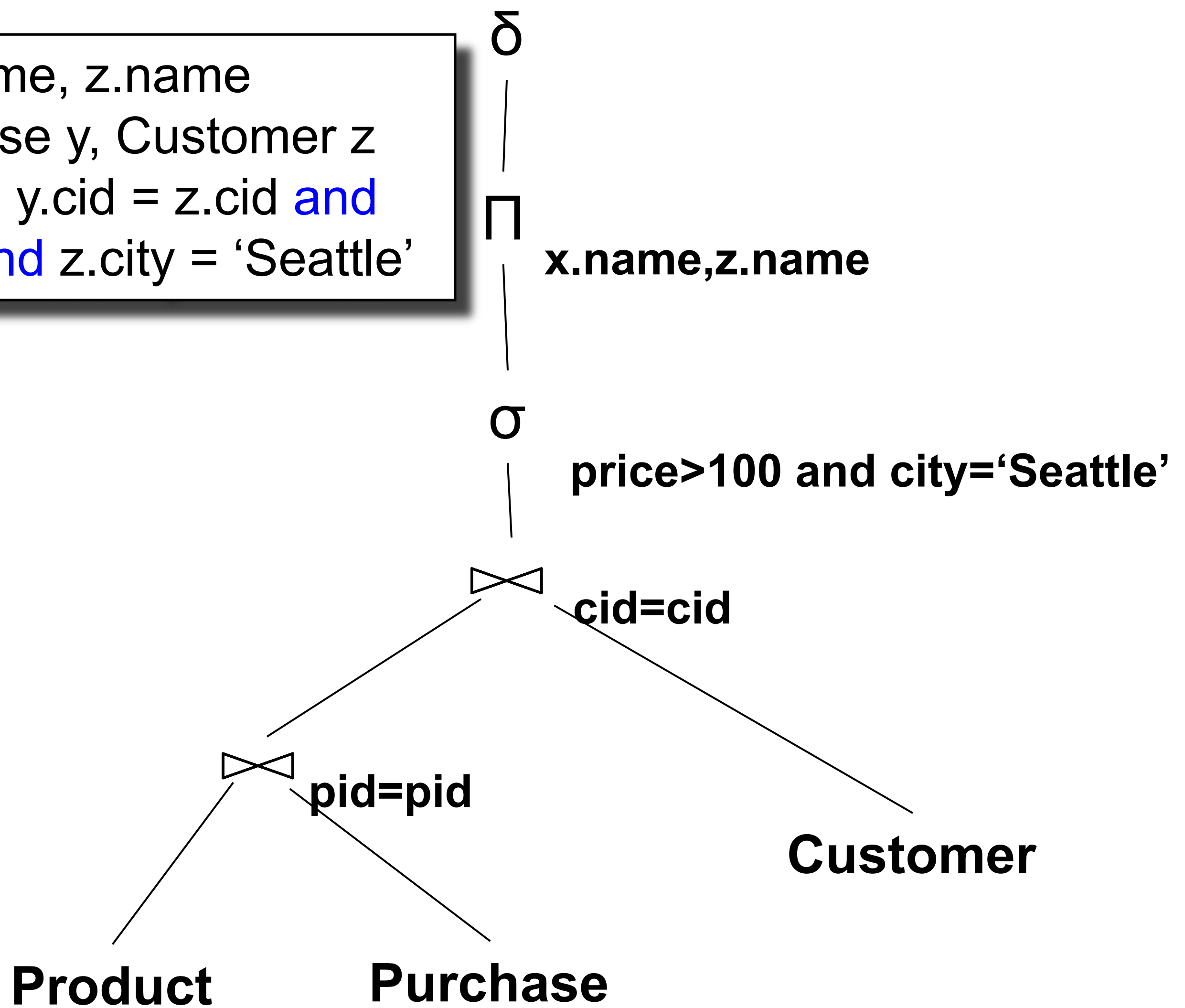

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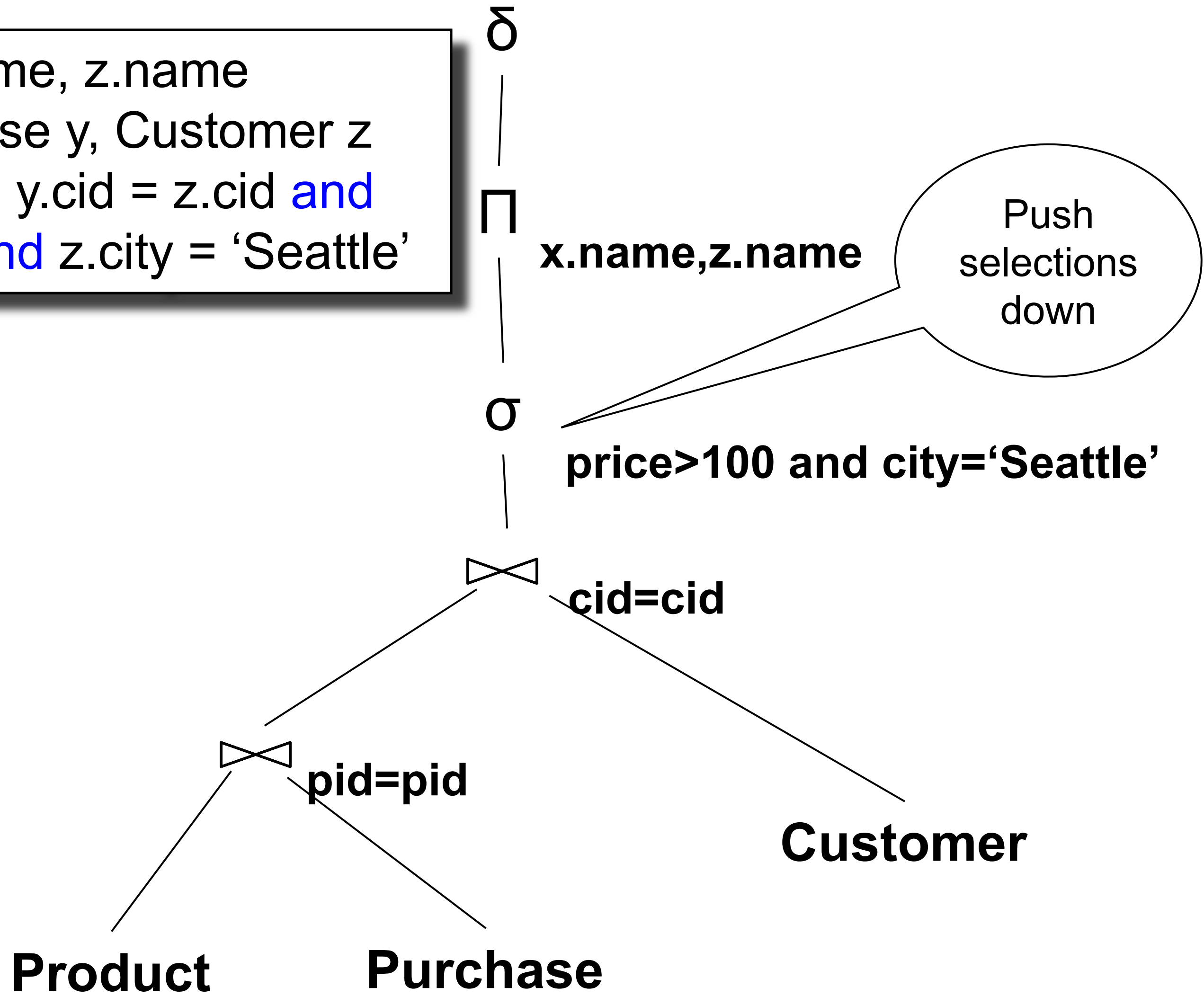

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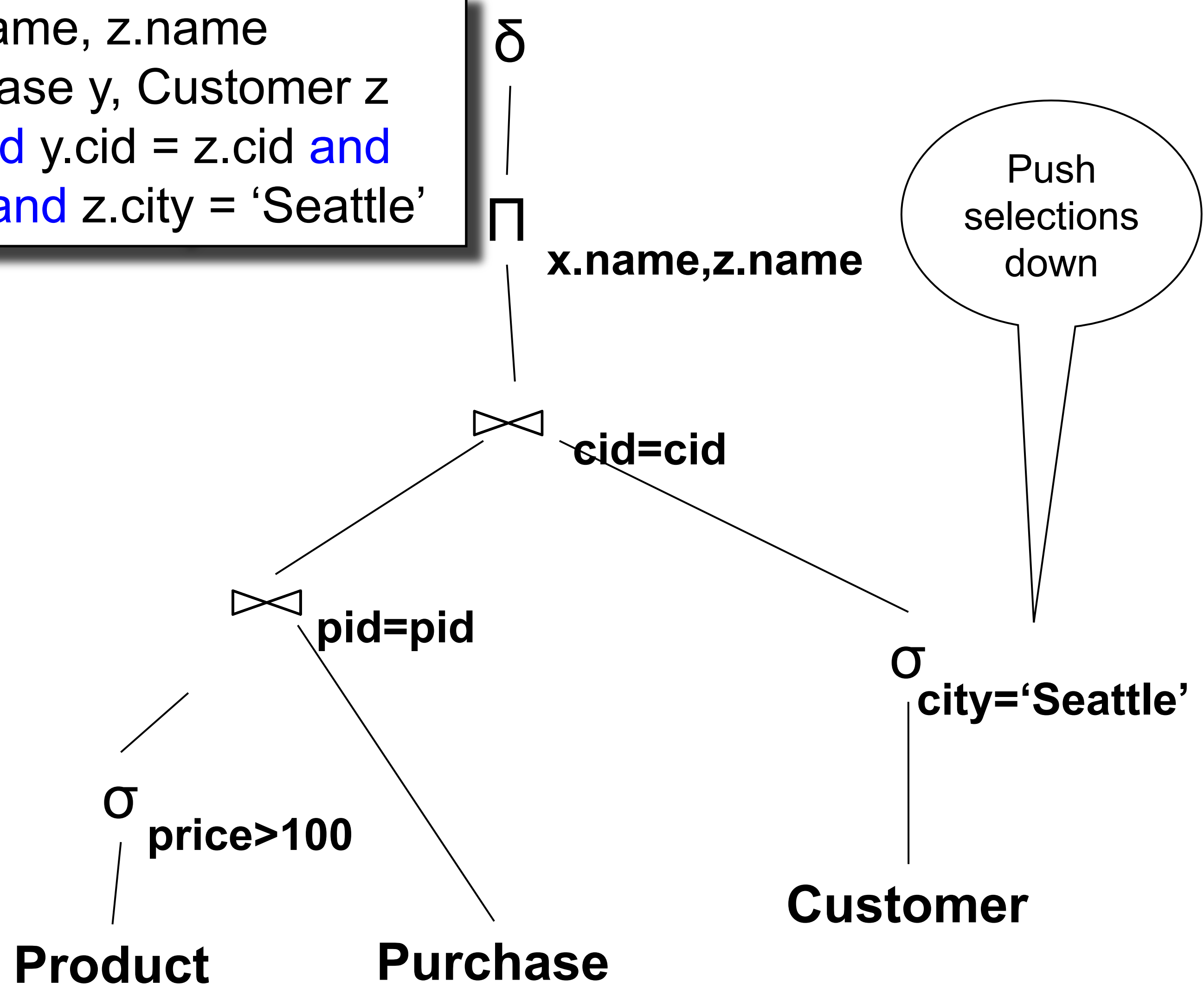

More about this next lectures

Logical Data Independence

A View is a Relation defined by a SQL query

It can be used in any SQL query as a normal relation

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;
```

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

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View Example

View definition:

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

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

Querying the view:

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

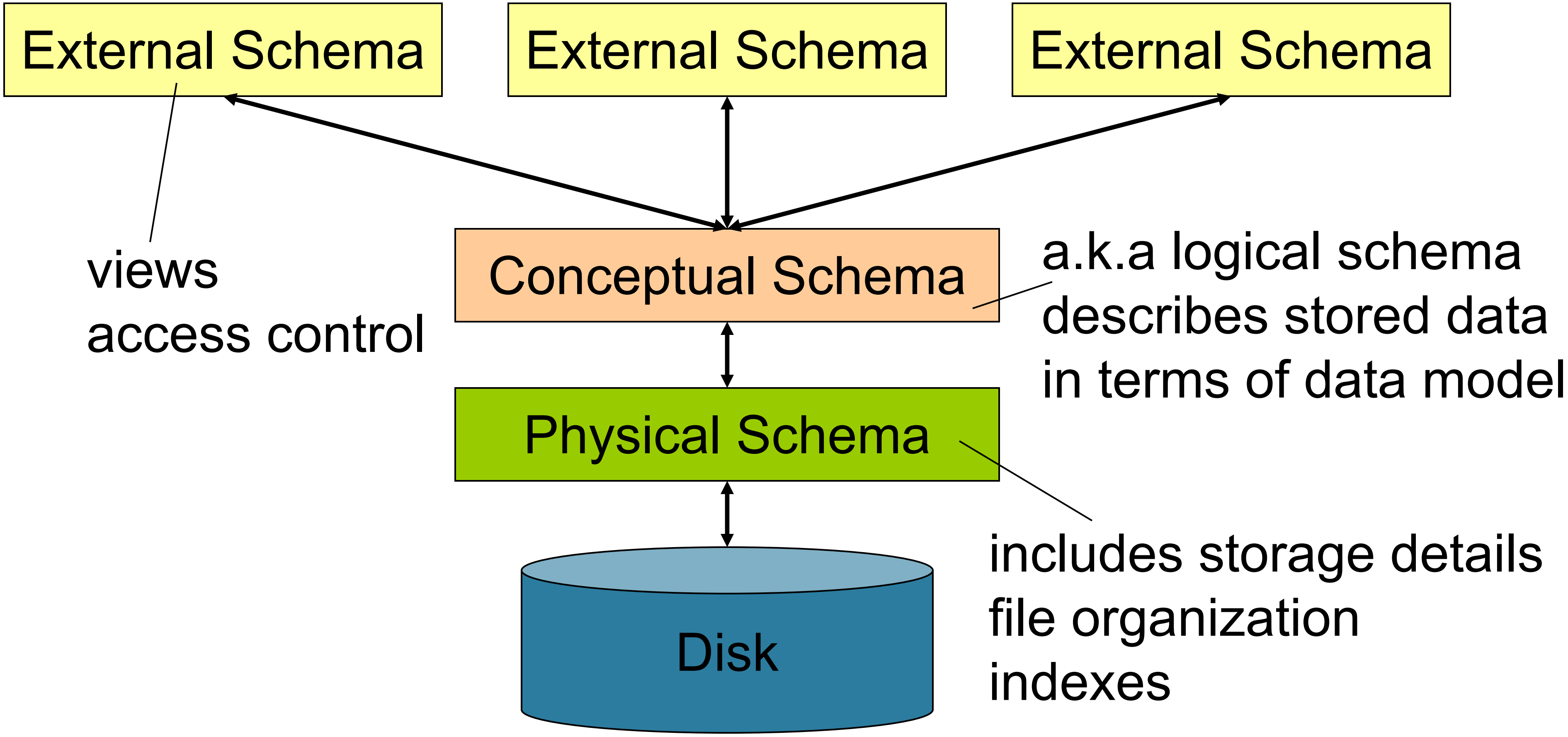
Two Types of Views

- Virtual views:
  - Default in SQL, and what Stonebraker means in the paper
  - CREATE VIEW xyz AS …
  - Computed at query time

- Materialized views:
  - Some SQL engines support them
  - CREATE MATERIALIZED VIEW xyz AS
  - Computed at definition time

- Pros and cons?

Levels of Abstraction



Recap

- Physical data independence:
  - Updates to the physical representation do not affect the SQL query
  - Achieved using RA and query optimization
- Logical data independence
  - Updates to the logical schema do not affect SQL query
  - Achieved using views

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Other Data Models

- Entity-Relationship: 1970's
  - Successful in logical database design
- 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?

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- 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
  - DBMS are single server and don’t scale; e.g. MySQL
- NoSQL answer:
  - “Shard” data, i.e. distribute on 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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- **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, ...)
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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

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

- Option 3: key=(origin,dest), value=all flights between

How does query processing work?

No physical data independence!

Conclusion

- Data model: a formalism to describe/query the data
- Relational data model: tables+relational language; no description of physical store
- Data independence: efficiency needs to be realized separately, by the query optimizer
- Many competing “more efficient” data models have been proposed, and will be proposed, but fail because of lack of data independence