CS 6400 A

Database Systems Concepts and Design

Lecture 1

08/18/25

Agenda

1. Course logistics and overview

2. Why study relational databases?

3. Relational data model

The essentials

Instructor: Kexin Rong

TAs:

- Jie Jeff Xu
- Hongbin Zhong
- Wen-Hsin Tai

How to reach us: cs6400-staff@groups.gatech.edu

- The above email reaches all of the course staff. You are strongly encouraged to use this, instead of emailing individual course staff.

The essentials

Course website: https://kexinrong.github.io/fa25-cs6400

schedule, assignments, and course material

Canvas/Gradescope: submitting assignments

Piazza: discussing course contents and finding teammates

- https://piazza.com/class/me527in87oo2ny

Email: special requests; mention CS6400 in the email title

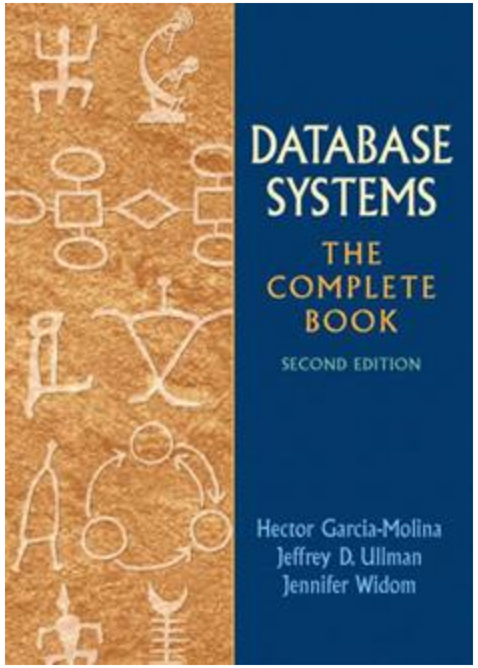
OH: Starting next week. Time will be announced.

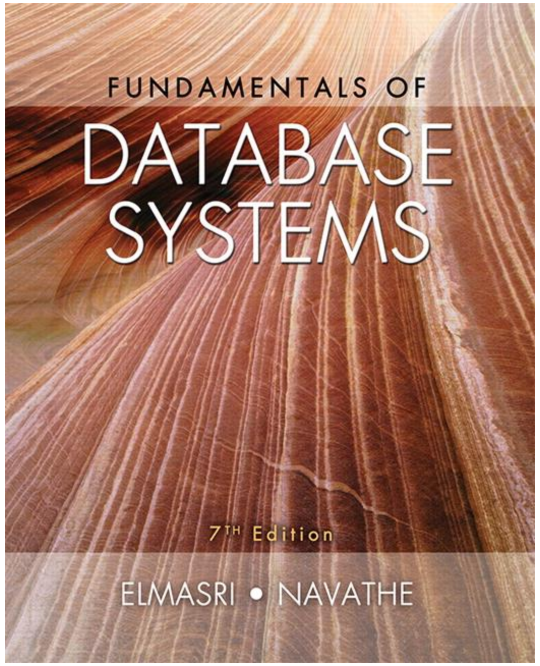
Course materials

Textbooks:

- Database Systems: The Complete Book (2nd edition)
- Fundamentals of Database Systems
- Can use interchangeably

* Both books have international versions and have PDFs searchable online





Grading

Assignments – 35%

- Individual

Course Project – 25%

- Team-based

Exams – 40%

- Midterm– 20%
- Final– 20%

Details: https://kexinrong.github.io/fa25-cs6400/grading/

Assignment 0: Questionnaire

Will be released by EOD today on canvas

Due next Monday (Aug 25) @ 11:59PM

Tell us about your database background

* Assignment not graded

Assignments

Assignment 1: JSON to SQLite (15%)

- Schema design, bulk loading and querying with SQL
- Programming language: Python and SQL

Assignment 2: In-memory Data Layout (15%)

- Storage and access methods
- Programming language: Java

Assignment 3: Foundations of Data-Intensive Systems (5%)

- Short answers based on assigned readings

Exams

Written tests based on material covered in lectures, assignments and readings

Midterm (20%):

- in-class (Sep 22)

Final (20%):

- take-home, during final's week
- Final will cover the entire course, but focus on the second half

Course Project

Teams of 3-4 people

Timeline:

- W7: Proposal (5%)
- W12: Milestone (5%)
- W16: Final report and code (15%)

Project options:

- Option 1: Hybrid vector search
- Option 2: Replicate research

Details: https://kexinrong.github.io/fa25-cs6400/project/proposal/

Attendance

No mandatory attendance.

But in the past we noticed…

- People who did not attend did worse ☹
- People who did not attend used more course resources ☹
- People who did not attend were less happy with the course ☹

So come join us if you can.

Course Policy - IMPORTANT

Follow the Georgia Tech Honor Code!

Late policy: One automatic late day without penalty. Otherwise 10% deduction per 24 hours. Does not apply to projects and exams.

Makeup exam policy: No makeup exam for midterm.

Generative AI policy: Clearly attribute AI-generated contents (e.g., direct quotes, different color text). Do not use generative AI tools to write code for you.

Details: https://kexinrong.github.io/fa25-cs6400/policy/

Why study relational databases?

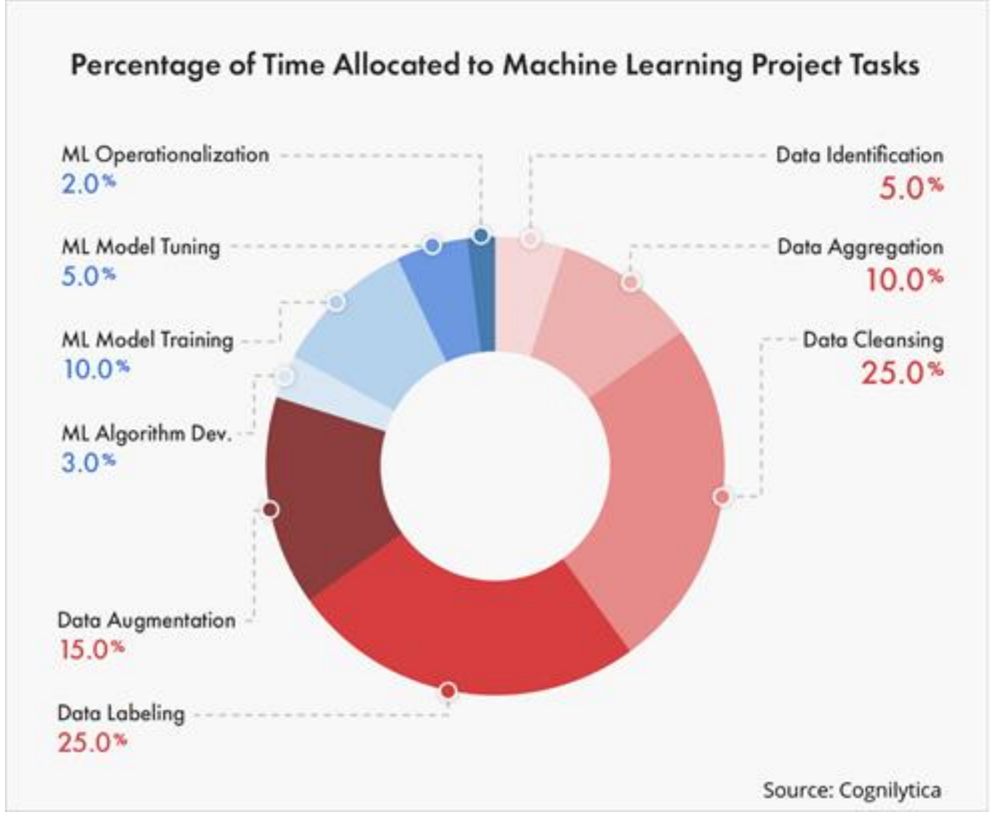
Why study relational databases?

Most important computer applications must manage, update and query datasets

- Bank, store, search app…

Data quality, quantity & timeliness becoming even more important with AI

- Machine learning = algorithms that generalize from data



Adapted from Stanford CS245 from Matei Zaharia

Relational databases => data-intensive systems

Relational databases are the most popular type of data-intensive system (MySQL, Oracle, etc)

Many other systems facing similar concerns: key-value stores, streaming systems, ML frameworks, your custom app?

Goal:

- Learn how to use and design relational databases
- Get a taste of the main issues and principles that span all data-intensive systems

Adapted from Stanford CS245 from Matei Zaharia

Typical System Challenges

Reliability in the face of hardware crashes, bugs, bad user input, etc

Concurrency: access by multiple users

Performance: throughput, latency, etc

Access interface from many, changing apps

Security and data privacy (not covered in this course)

Adapted from Stanford CS245 from Matei Zaharia

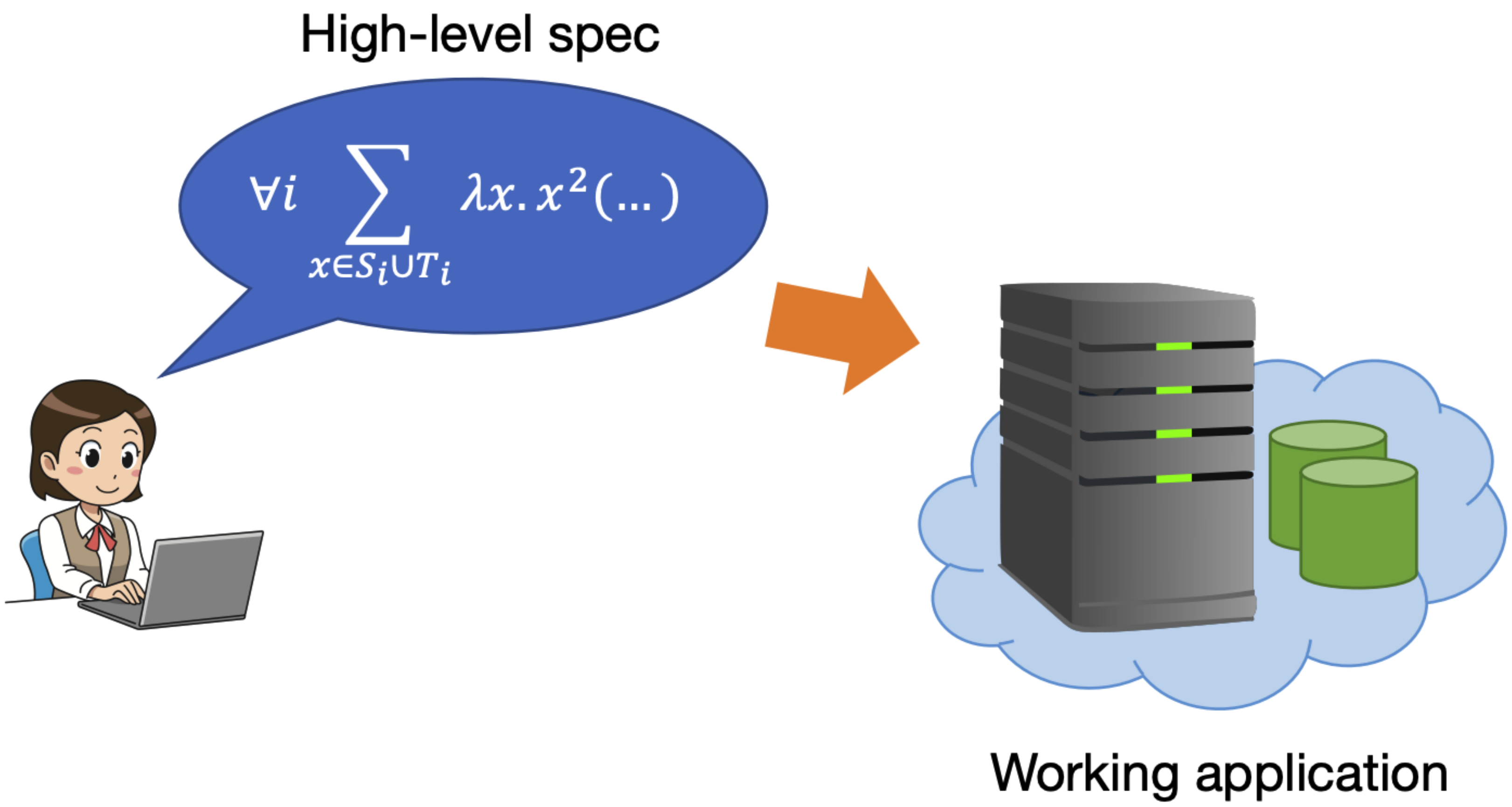
Scientific Interest

Interesting algorithmic and design ideas

In many ways, data systems are the highest-level successful programming abstractions

Adapted from Stanford CS245 from Matei Zaharia

Programming: The Dream



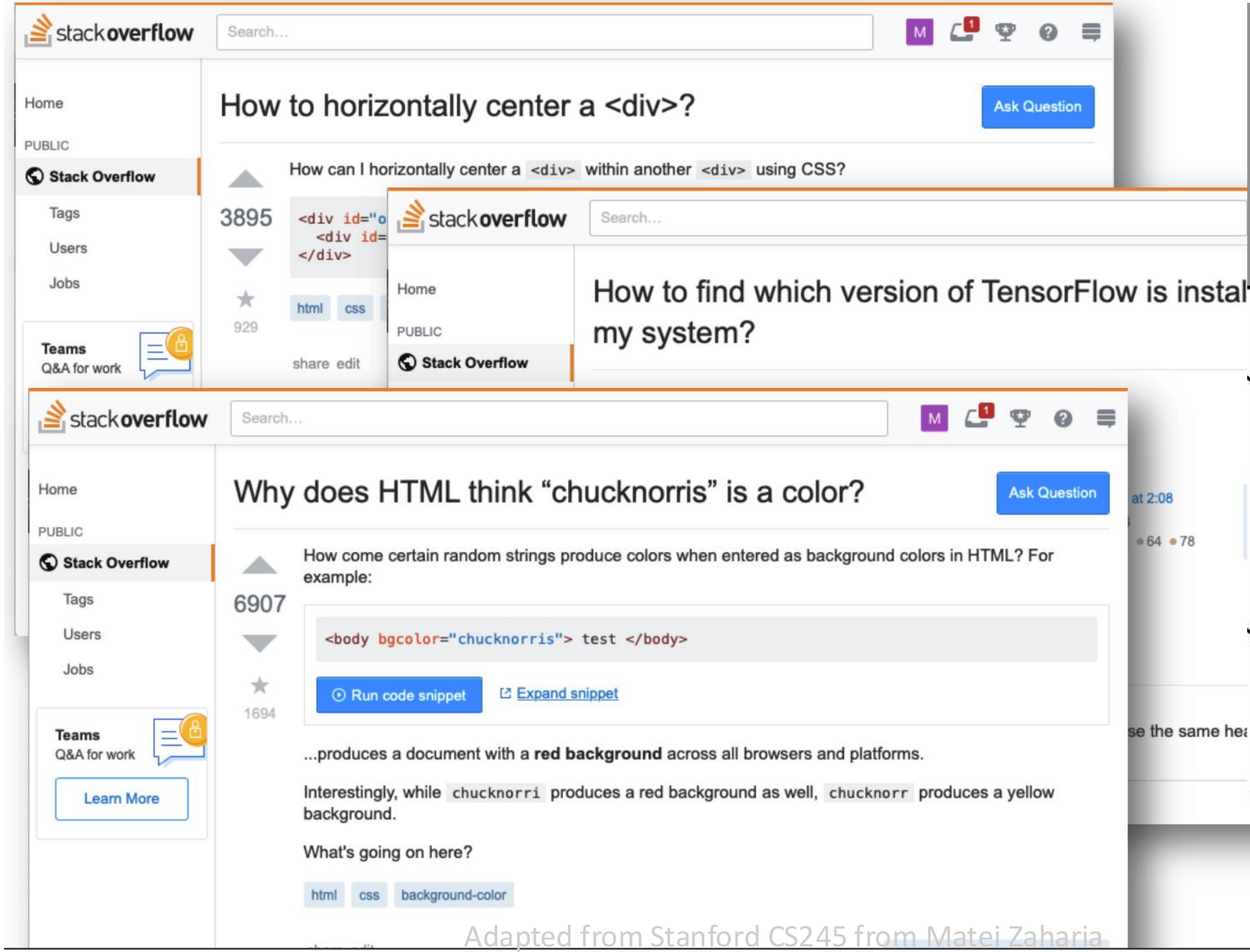
High-level spec

$$\forall i \sum_{x \in S_i \cup T_i} \lambda x. x^2(\ldots)$$

Working application

Adapted from Stanford CS245 from Matei Zaharia

Programming: The Reality



How to horizontally center a <div>?

3895

How can I horizontally center a `<div>` within another `<div>` using CSS?

```
<div id="o
  <div id=
</div>
```

929

html css

How to find which version of TensorFlow is instal
my system?

at 2:08

64 78

se the same hea

Why does HTML think “chucknorris” is a color?

6907

How come certain random strings produce colors when entered as background colors in HTML? For example:

```
<body bgcolor="chucknorris"> test </body>
```

1694

...produces a document with a **red background** across all browsers and platforms.

Interestingly, while `chucknorri` produces a red background as well, `chucknorr` produces a yellow background.

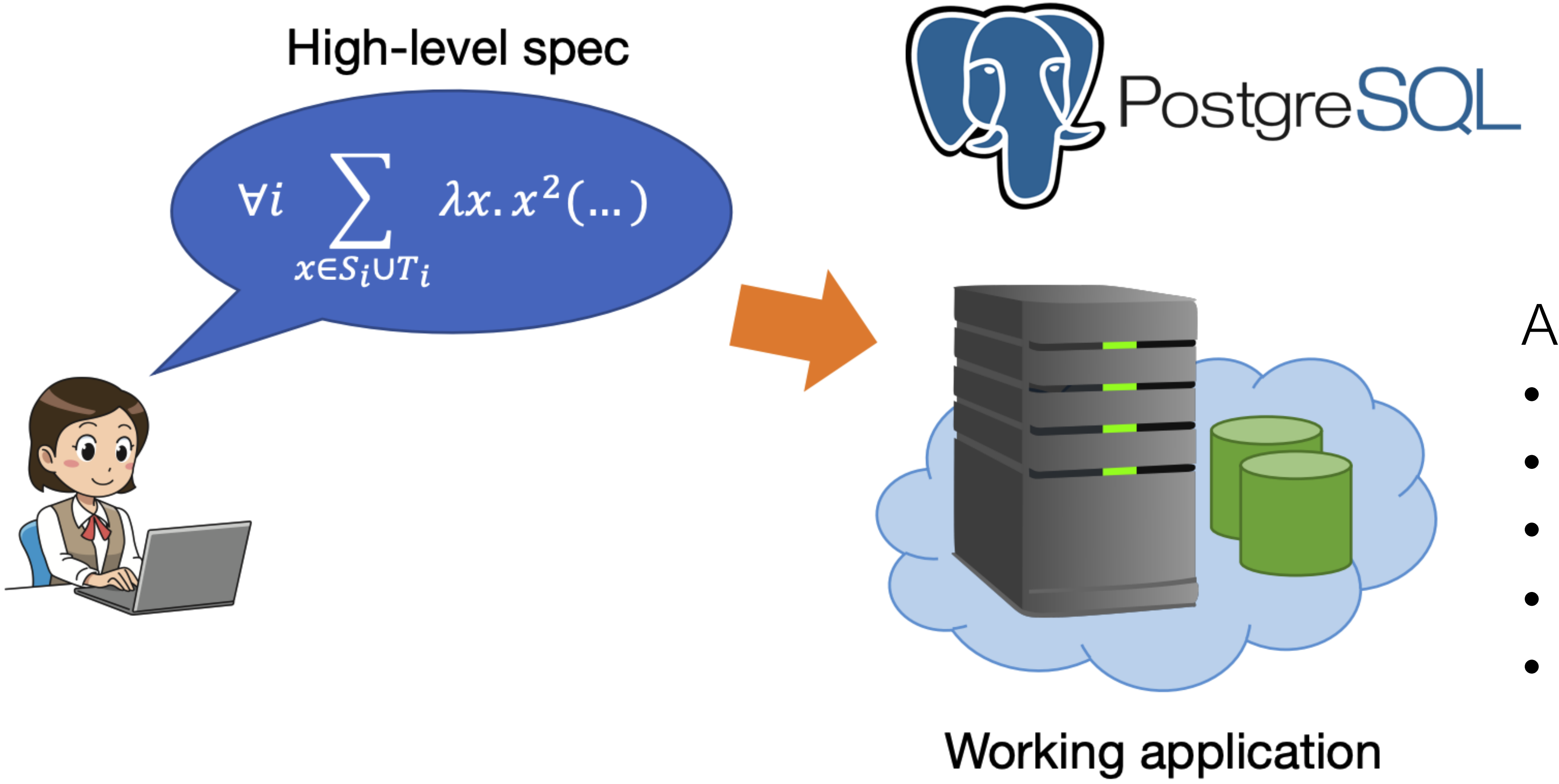
What's going on here?

html css background-color

11

Adapted from Stanford CS245 from Matei Zaharia

Programming with databases



High-level spec

$$\forall i \sum_{x \in S_i \cup T_i} \lambda x. x^2(\dots)$$

Working application

Actually manages:
- Durability
- Concurrency
- Query optimization
- Security
- …

Adapted from Stanford CS245 from Matei Zaharia

Case study: building a book-selling website

- E.g., your own version of mini-Amazon
- Large data! (think about all books in the world or even in English)

Where do we get started?

Adapted from Duke CompSci 316 from Sudeepa Roy

Q1: Who are the key people?

- At least two types:
  - Database admin (assuming they own all copies of all the books)
  - Customers who purchase books
  - Let’s proceed with these two only

- Other people:
  - Sellers
  - Who deal with the warehouse of the books
  - …

Adapted from Duke CompSci 316 from Sudeepa Roy

Q2: What should the user be able to do?

- i.e., what does the interface look like? (think about Amazon)

1. Search for books
   - According to author, title, price range, …
2. Purchase books
3. Add to wishlist
4. …

Adapted from Duke CompSci 316 from Sudeepa Roy

Q3: What should the platform do?

1. Update no. of copies as books are sold
2. Returns books as searched by the authors
3. Check that the payment method is valid
4. Add new books as they are published
5. …

Q4: What are the desired and necessary properties of the platform?

- Should be able to handle a large amount of data
- Should be efficient and easy to use (e.g., search with authors as well as title)
- If there is a crash or loss of power, information should not be lost or inconsistent
  - Imagine a user was in the middle of a transaction when a crash happened, paid the money, but the book has not been purchased
- No surprises with multiple users logged in at the same time
  - Imagine one last copy of a book that two users are trying to purchase at the same time
- Easy to update and program
  - For the admin

That was the design phase (a basic one though)

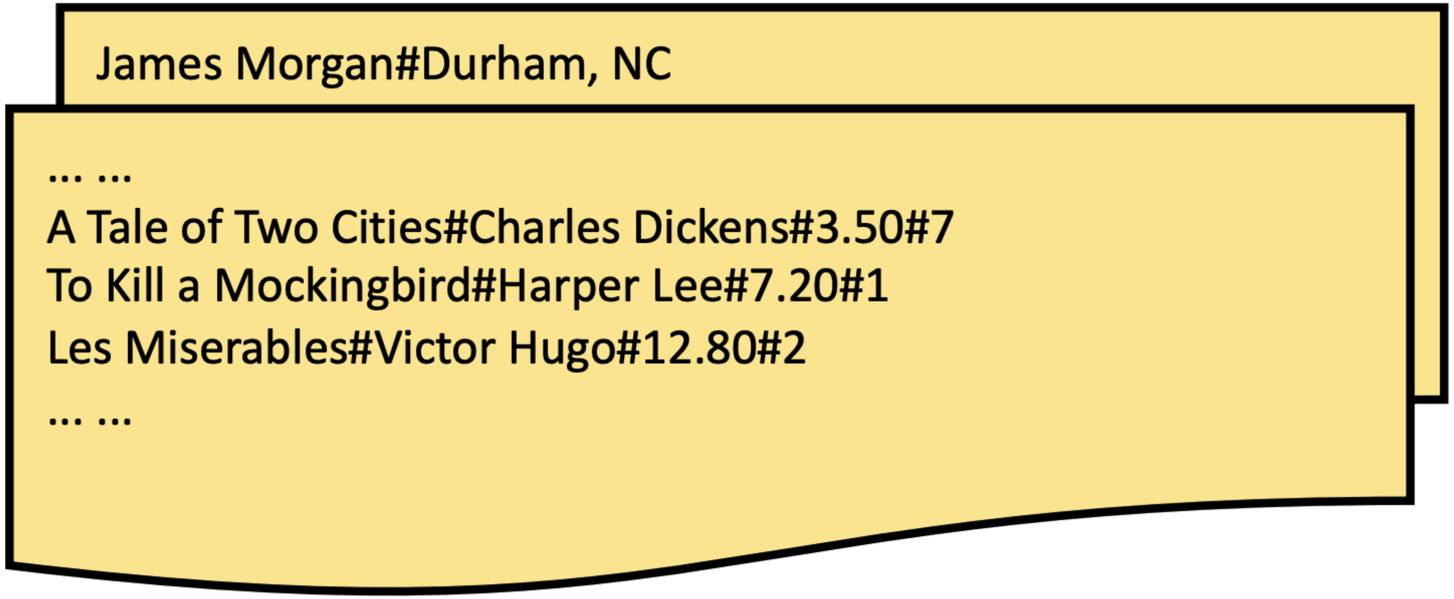
Image source: https://www.flaticon.com/free-icon/girl_5986069

Let's implement this!

How about:

- Your favorite programming language
- On data stored in large files

Sounds simple!



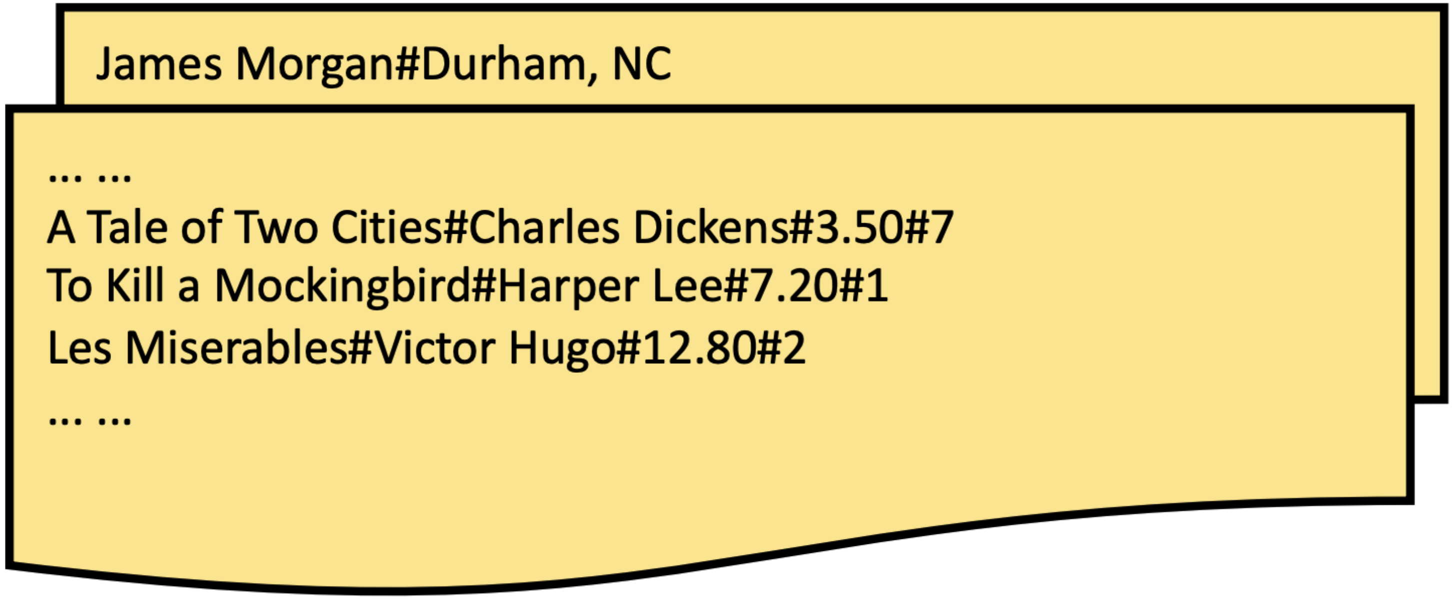
```
James Morgan#Durham, NC
```

```
… …
A Tale of Two Cities#Charles Dickens#3.50#7
To Kill a Mockingbird#Harper Lee#7.20#1
Les Miserables#Victor Hugo#12.80#2
… …
```

- Text files – for books, customers, ..
- Books listed with title, author, price and no. of copies
- Fields separated by #'s

Adapted from Duke CompSci 316 from Sudeepa Roy

Query by programming



```
James Morgan#Durham, NC
```

```
… …
A Tale of Two Cities#Charles Dickens#3.50#7
To Kill a Mockingbird#Harper Lee#7.20#1
Les Miserables#Victor Hugo#12.80#2
… …
```

- James Morgan wants to buy "To Kill a Mockingbird"
- A simple script
  - Scan through the book files
  - Look for the line containing "To Kill a Mockingbird"
  - Check if there are more than 1 copy left
  - Charge James $7.20 and reduce the number of copies by 1

Better idea than scanning?

Binary search (with file sorted on titles)

What if he changes the "query" and wants to buy a book by Victor Hugo?

Adapted from Duke CompSci 316 from Sudeepa Roy

Revisit: What are the desired and necessary properties of the platform?

- Should be able to handle a large amount of data

Try to open a 10-100 GB file

- Should be efficient and easy to use (e.g., search with authors as well as title)

Try to search both on a large flat file

- If there is a crash or loss of power, information should not be lost or inconsistent
  - Imagine a user was in the middle of a transaction when a crash happened, paid the money, but the book has not been purchased

Imagine programmer's task

- No surprises with multiple users logged in at the same time
  - Imagine one last copy of a book that two users are trying to purchase at the same time
- Easy to update and program
  - For the admin

Imagine adding a new book or updating copies (+ allow search) on a 10-100 GB text file

Adapted from Duke CompSci 316 from Sudeepa Roy

Solution?

DBMS = Database Management System

PostgreSQL
IBM
DB2
cassandra
ORACLE®
DATABASE
MySQL™
mongoDB

Adapted from Duke CompSci 316 from Sudeepa Roy

What is a DBMS?

A large, integrated collection of data

Models a real-world *enterprise*

- *Entities* (e.g., Customers, Books)
- *Relationships* (e.g., James purchases a tale of two cities)

A Database Management System (DBMS) is a piece of software designed to store and manage databases

A DBMS takes care of all of the following (and more): In an easy-to-use, efficient, and robust way

- Sh e to handle a large amount of data
- Should be efficient and easy to use (e arch with authors as wel as title)
- If ther ash or loss of power, information should not be lost or inconsistent
- No surprises with multiple users logged in at t time
- Easy to update and program

Optimization

Index

Recovery

Concurrency Control

Declarative

** We will learn these in this course!*

This course gives an (advanced) intro to DBMS

1. How to use a DBMS (programmer’s/designer’s perspective)

- Run queries, update data (SQL, Relational Algebra)
- Design a good database (ER diagram, design theory)

2. How does a DBMS work (system’s perspective, also for programmers for writing better queries)

- Storage and index
- Query processing and optimization
- Transactions: recovery and concurrency control

3. Glimpse of advanced topics and other DBMS

- Map Reduce, Spark, NoSQL
- Parallel and distributed DBMS

Should I take this class?

The class does NOT assume prior background in databases.

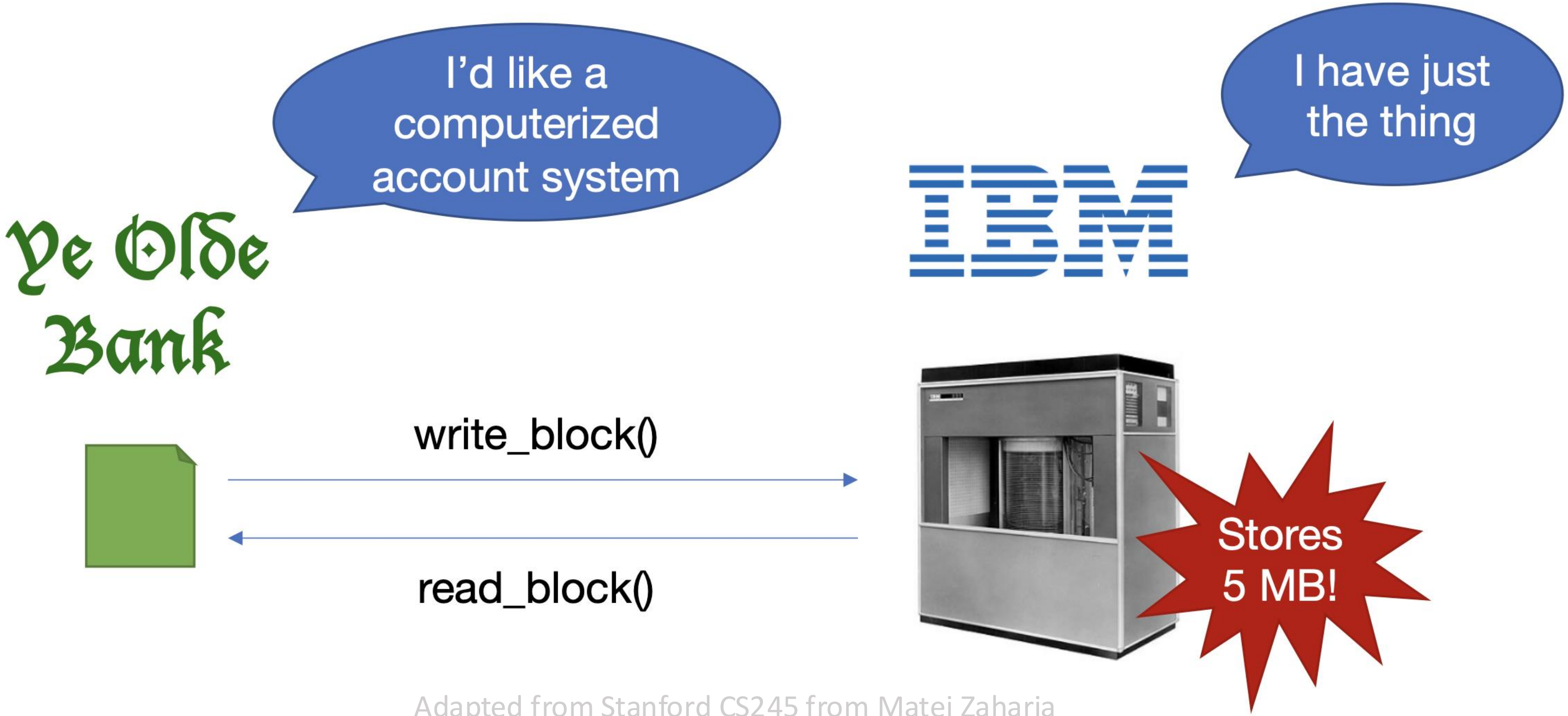
You are expected to be comfortable programming in languages such as Python and Java, but not in SQL.

Check out our syllabus - if you have sufficient undergraduate database coursework, consider taking *CS6422: Database System Implemnt* instead

Relational Data Model

Early Data Management

At first, each application did its own data management directly against storage (e.g., our book-selling website example)



Adapted from Stanford CS245 from Matei Zaharia

Problems with App Storage Management

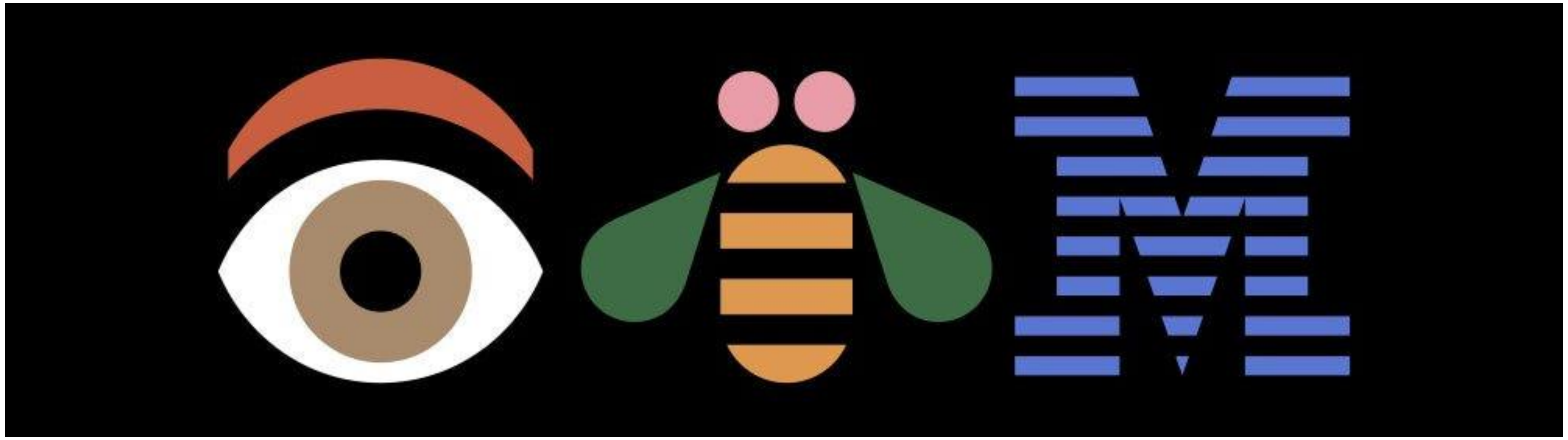
- How should we lay out and navigate data?
- How do we keep the application reliable?
- What if we want to share data across apps?

Every app is solving the *same* problems!

Adapted from Stanford CS245 from Matei Zaharia

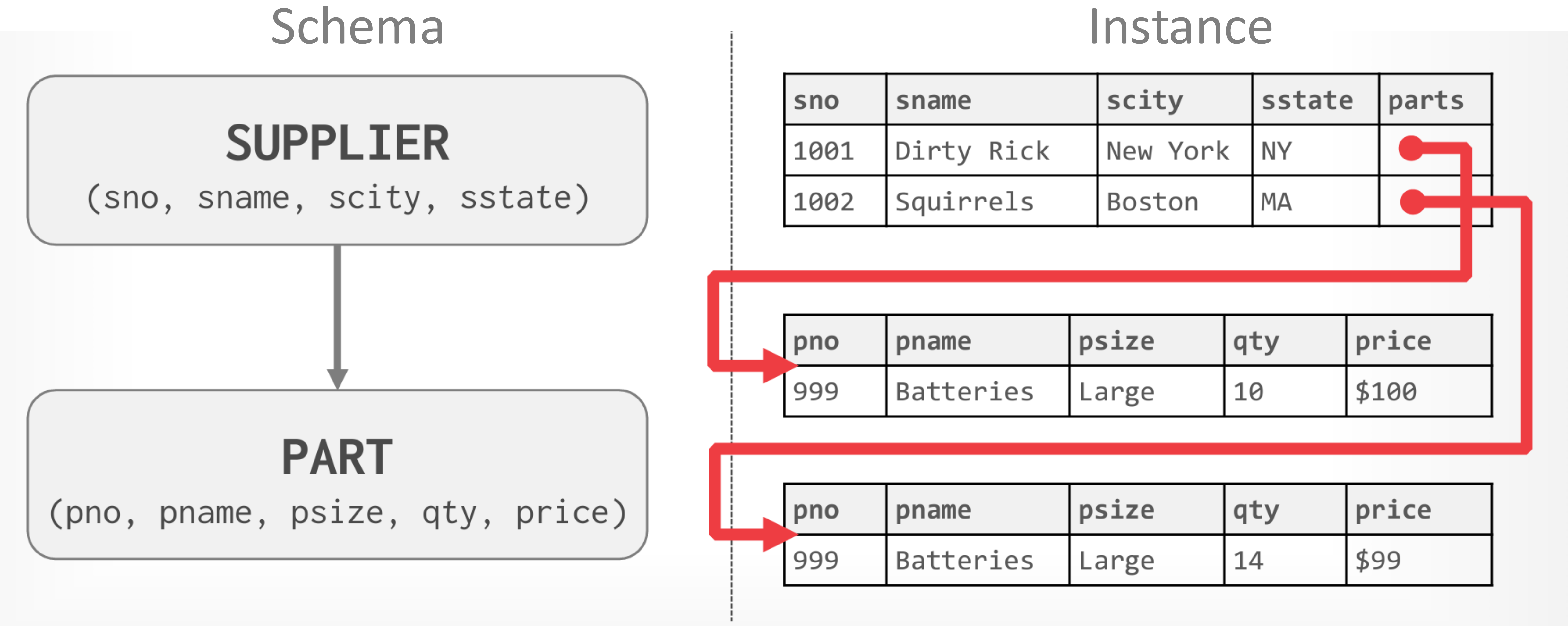
1960s – IBM IMS

- Information Management System
- Early database system developed to keep track of purchase orders for Apollo moon mission.
  - Hierarchical data model.
  - Programmer-defined physical storage format.
  - Tuple-at-a-time queries.



Acknowledgement: Prof. Andy Pavlo, CMU

Hierarchical Data Model



Schema

SUPPLIER

(sno, sname, scity, sstate)

PART

(pno, pname, psize, qty, price)

Instance

sno	sname	scity	sstate	parts
1001	Dirty Rick	New York	NY	●
1002	Squirrels	Boston	MA	●

pno	pname	psize	qty	price
999	Batteries	Large	10	$100

pno	pname	psize	qty	price
999	Batteries	Large	14	$99

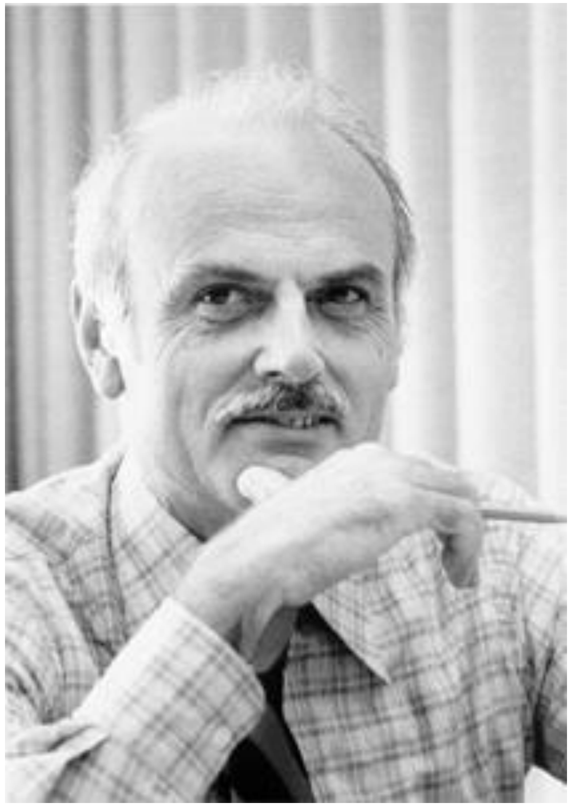
Acknowledgement: Prof. Andy Pavlo, CMU

1970s - Relational data model

- Ted Codd was a mathematician working at IBM Research. He saw developers spending their time rewriting IMS programs every time the database's schema or layout changed.

- Database abstraction to avoid this maintenance:
  - Store database in simple data structures.
  - Access data through set-at-a-time high-level language.
  - Physical storage left up to implementation.

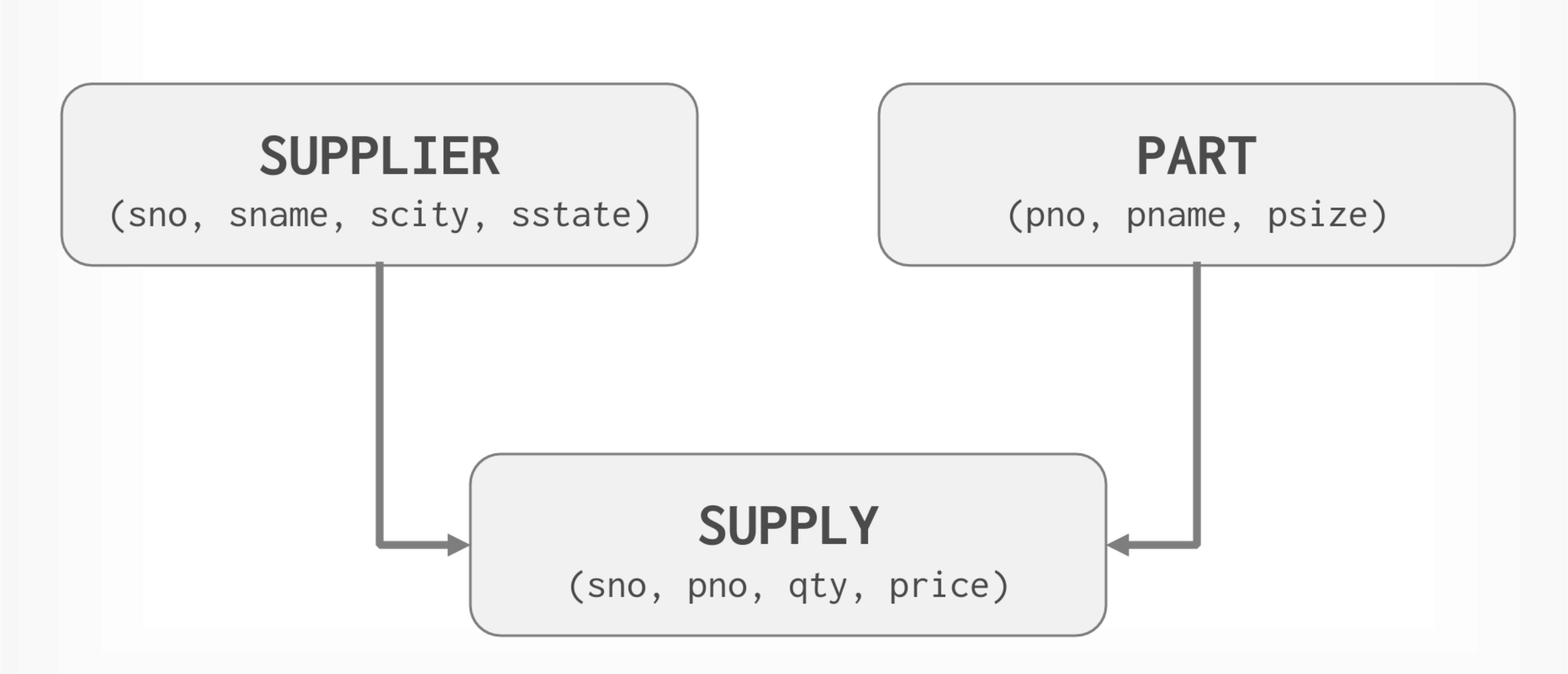
Turing Award 1981



Codd

Acknowledgement: Prof. Andy Pavlo, CMU

Relational Data Model - *schema*



SUPPLIER

(sno, sname, scity, sstate)

PART

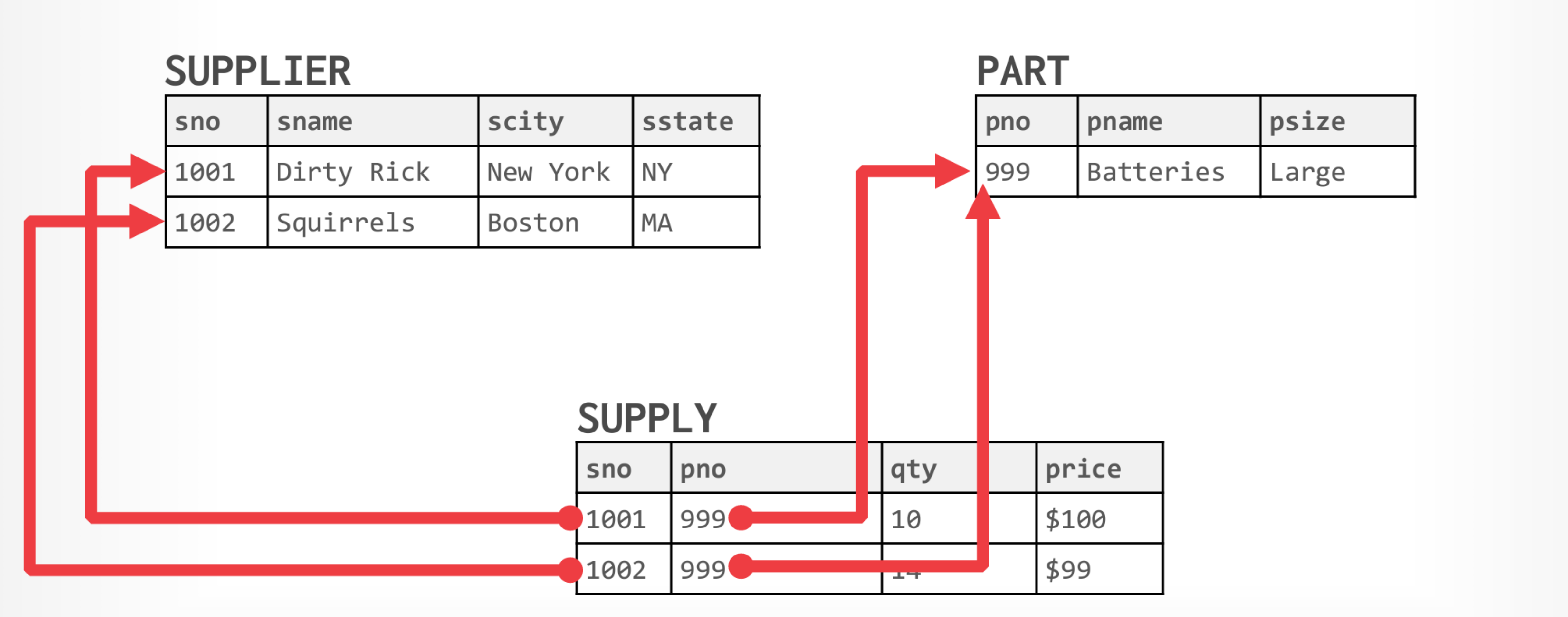
(pno, pname, psize)

SUPPLY

(sno, pno, qty, price)

Acknowledgement: Prof. Andy Pavlo, CMU

Relational Data Model - *instance*



SUPPLIER

sno	sname	scity	sstate
1001	Dirty Rick	New York	NY
1002	Squirrels	Boston	MA

PART

pno	pname	psize
999	Batteries	Large

SUPPLY

sno	pno	qty	price
1001	999	10	$100
1002	999	14	$99

Acknowledgement: Prof. Andy Pavlo, CMU

Data independence

Concept: Applications do not need to worry about *how the data is structured and stored*

Logical data independence: protection from changes in the *logical structure of the data*

i.e. should not need to ask: can we add a new table, or remove a field in a table without rewriting the application?

Physical data independence: protection from *physical layout changes*

i.e. should not need to ask: which disks are the data stored on? Is the data indexed?

One of the most important reasons to use a DBMS

Data model

A notation for describing data or information

Consists of:

- Structure of the data
- Operations on the data
- Constraints on the data

Adapted from KAIST EE477 from Steven Whang

Structure of the data

- Referred to as a “conceptual model” of the data
- Higher level than “physical models” or data structures like arrays and lists
- Example: a relation consists of a schema, attributes, and tuples

title	*year*	*length*	*genre*
Oldboy	2003	120	mystery
Ponyo	2008	103	anime
Frozen	2013	102	anime

Adapted from KAIST EE477 from Steven Whang

Operations on the data

Usually a limited set of operations that can be performed

- Queries (operations that retrieve information)
- Modifications (operations that change the database)
- Relation algebra

This is a strength, not a weakness

- Programmers can describe operations at a very high level
- The DBMS implements them efficiently
- Not easy to do when coding in C

```
SELECT *
FROM Movies
WHERE studioName = ‘Disney’
AND year = 2013;
```

Adapted from KAIST EE477 from Steven Whang

Constraints on the data

Usually have limitations on the data; helpful for data quality

Examples

- Day of a week is an integer between 1 and 7
- Age is larger than 0
- Student IDs are unique

Data models

- **Relational** → Most DBMS's

- Key/Value
- Graph
- Document (Semi-structured)
- Column-family

NoSQL

- Array/Matrix → Machine Learning

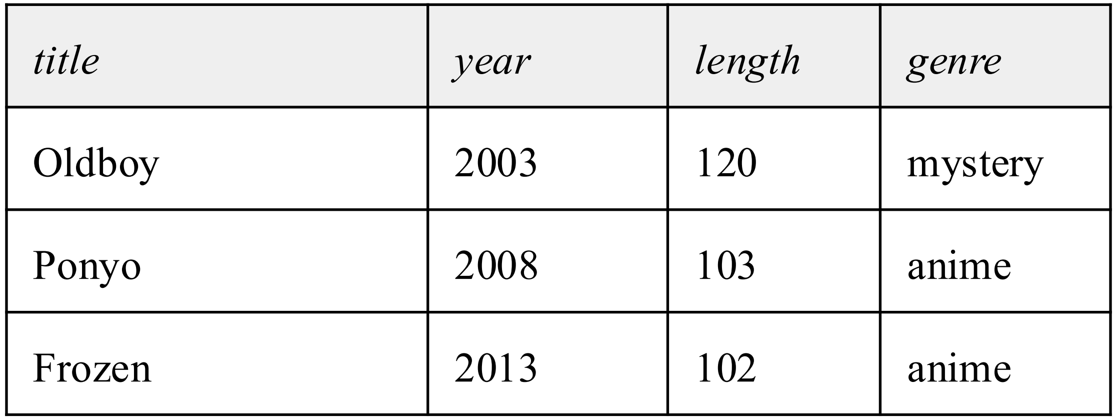
- Hierarchical
- Network

Obsolete

Adapted from KAIST EE477 from Steven Whang

The relational model

- Structure
  - Based on tables (relations)
  - Looks like an array of structs in C, but this is just one possible implementation
  - In database systems, tables are not stored as main-memory structures and must take into account the need to access relations on disk

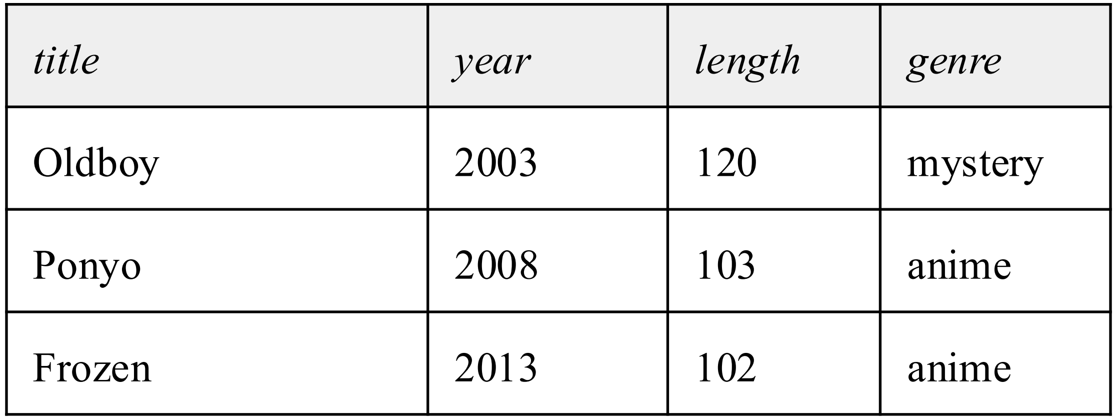


title	*year*	*length*	*genre*
Oldboy	2003	120	mystery
Ponyo	2008	103	anime
Frozen	2013	102	anime

Adapted from KAIST EE477 from Steven Whang

The relational model

- Operations
  - ○ Relational algebra
  - ○ E.g., all the rows where genre is “anime”
- Constraints
  - ○ E.g., Genre must be one of a fixed list of values, no two movies can have the same title



title	*year*	*length*	*genre*
Oldboy	2003	120	mystery
Ponyo	2008	103	anime
Frozen	2013	102	anime

The semi-structured model

Structure

- Resembles trees or graphs, rather than tables or arrays
- Represent data by hierarchically nested tagged elements

Operations

- Involve following path from element to subelements

Constraints

- Involve types of values associated with tags
- E.g., <Length> tag values are integers,
  each <Movie> element must have a <Length>

```
<Movies>
  <Movie title=”Oldboy”>
    <Year>2003</Year>
    <Length>120</Length>
    <Genre>mystery</Genre>
  </Movie>
  <Movie title=”Ponyo”>
    <Year>2008</Year>
    …
</Movies>
```

Adapted from KAIST EE477 from Steven Whang

The key-value model

- Structure
  - (key, value) pairs
  - Key is a string or integer
  - Value can be any blob of data
- Operations
  - get (key), put(key, value)
  - Operations on values not supported
- Constraints
  - E.g., key is unique, value is not NULL

key	*value*
1000	(oldboy, 2003)
1001	(ponyo, 2008)
1002	(frozen, 2013)

Adapted from KAIST EE477 from Steven Whang

Comparison of modeling approaches

- Relational model
  - Simple and limited, but reasonably versatile
  - Limited, but useful operations
  - Efficient access to large data
  - A few lines of SQL can do the work of 1000’s of lines of C code
  - Preferred in DBMS’s
- Semi-structured model
  - More flexible, but slower to query
- Key-value model
  - Even more flexible, but cannot query