CS 4440 A

Emerging Database Technologies

Lecture 1

01/08/24

Agenda

Course logistics and overview

A brief history of databases

- 1960s – 2020s

The essentials

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The essentials

Course website: https://kexinrong.github.io/sp24-cs4440/
schedule, assignments, and course material

Canvas: submitting assignments

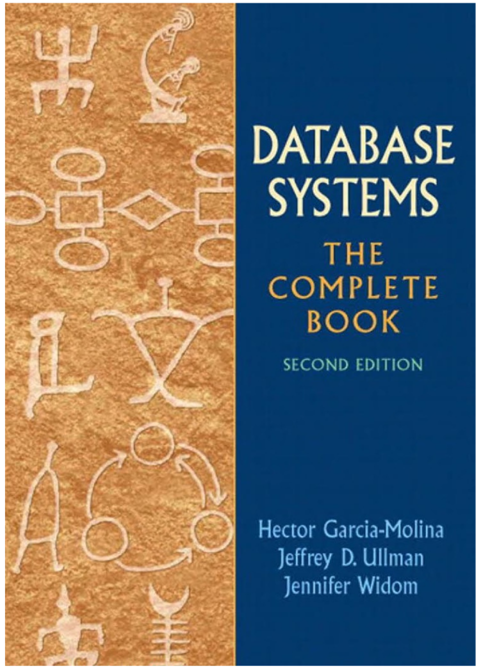
Piazza: discussing course contents and finding teammates
- https://piazza.com/gatech/spring2024/cs4440a

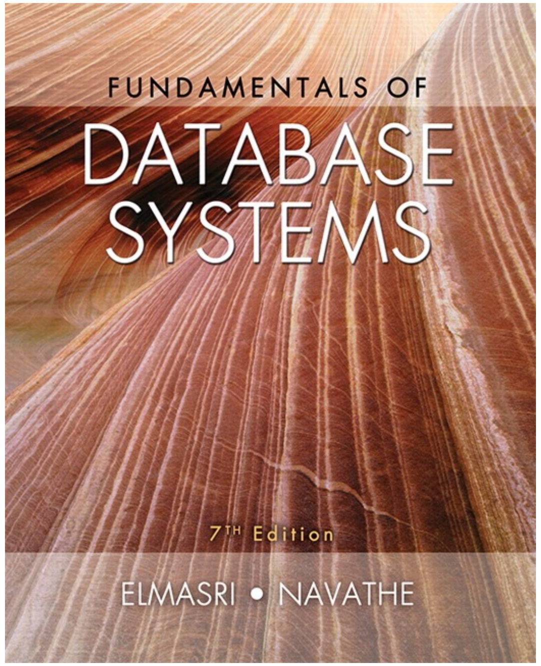
Email: special requests; mention CS4440 in the email title

OH: time TBD

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





Course Learning Objectives

Learn about advanced and emerging database technologies beyond what is covered in CS4400 and get hands on experience with building database applications.

Four ways to learn:

- Through lectures on database fundamentals
- Through surveying technologies in the wild
- Through reading research papers
- Through an implementation-oriented course project

Grading

Assignments – 40%

- Combination of individual and group assignments

Course Project – 30%

Exams and Quizzes – 25%

- Take-home Midterm – 20%
- Quiz – 5%

Attendance and Participation - 5%

Details: https://kexinrong.github.io/sp24-cs4440/grading/

Assignments Overview

Technology review and presentation

- Assignment 1 (Technology Review) due Jan 24

Research paper review and presentation

- After midterm

Course Project

- Assignment 2 (Proposal Draft) due Feb 7
- Final project demo

Course Project

- Groups of 4
- Implementation-oriented
- Need to use some database systems
- Examples of past projects can be found on Canvas
  - Files -> Sample Projects

Course Policy - IMPORTANT

Follow the Georgia Tech Honor Code!

Late policy: One automatic late day without penalty. Otherwise 10% deduction per 24 hours.

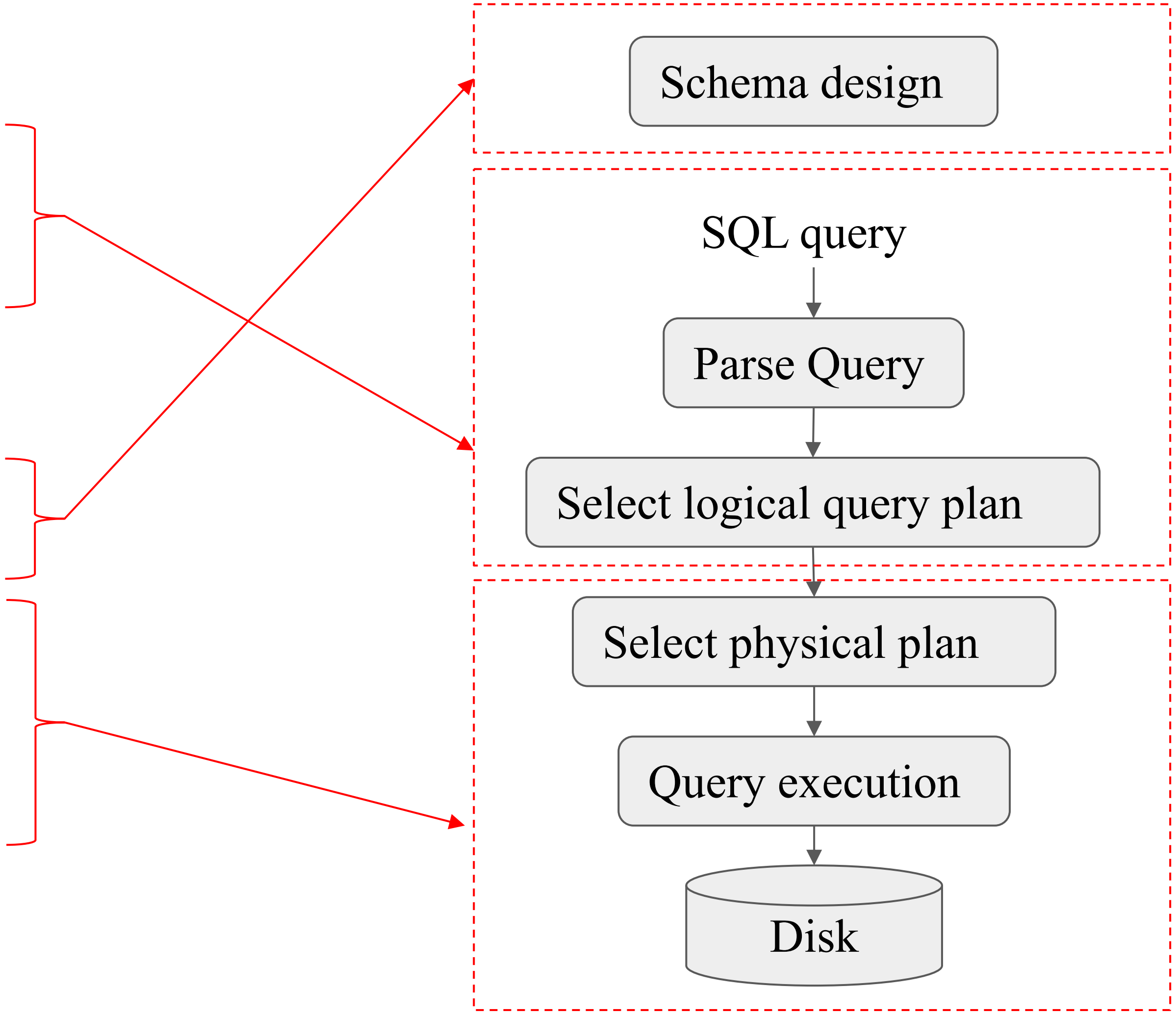
Generative AI policy: Clearly attribute AI-generated contents (e.g., direct quotes, different color text). No more than 10% AI-generated contents in submissions.

Details: https://kexinrong.github.io/sp24-cs4440/policy/

Course outline (tentative)

What we are not covering:
- Relational model
- SQL
- Relational algebra

What we will discuss:
- ER model
- Design theory
- Secondary storage
- Indexing
- Query optimization
- Transactions (concurrency, recovery)
- MapReduce, NewSQL
- Selected emerging technologies



A brief history of databases

What Goes Around Comes Around.
Readings in DB Systems. 2006.

Acknowledgement: Slides taken from Prof. Andy Pavlo, CMU

Main takeaway: history repeats itself

Old database issues are still relevant today.

- Many of the ideas in today’s database systems are not new.

Someone invents a ”SQL replacement” every decade. It then fails and/or SQL absorbs the key ideas into standards.

- The SQL vs. NoSQL debate is reminiscent of Relational vs. CODASYL debate from the 1970s.
- Spoiler: The relational model almost always wins.

Acknowledgement: Prof. Andy Pavlo, CMU

1960s - IDS

- Integrated Data Store
- Developed internally at GE in the early 1960s.
- GE sold their computing division to Honeywell in 1969.
- One of the first DBMSs:
  - Network data model.
  - Tuple-at-a-time queries.

Honeywell

Acknowledgement: Prof. Andy Pavlo, CMU

1960s - CODASYL

Turing Award 1973

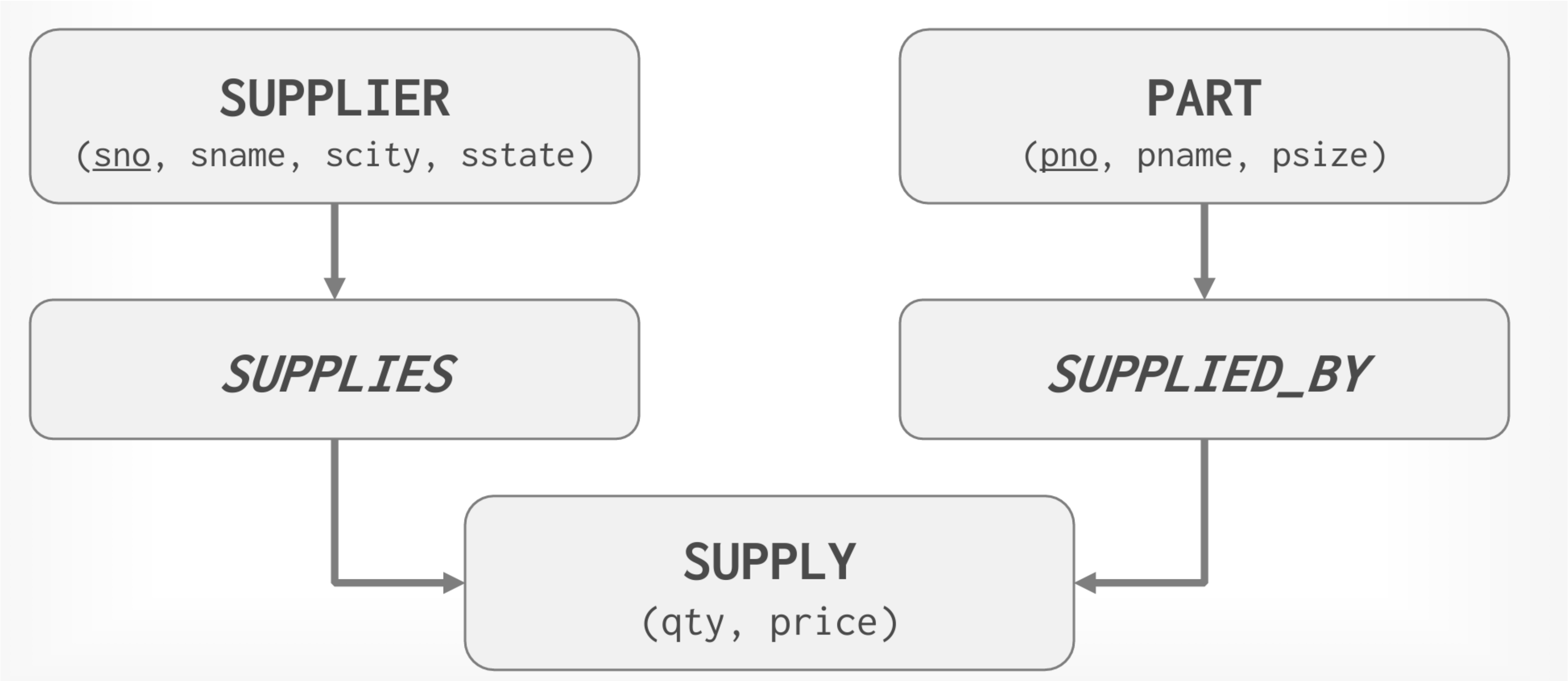
- COBOL people got together and proposed a standard for how programs will access a database. Lead by Charles Bachman.
  - Network data model.
  - Tuple-at-a-time queries.

- Bachman also worked at Culliane Database Systems in the 1970s to help build **IDMS**.

Bachman

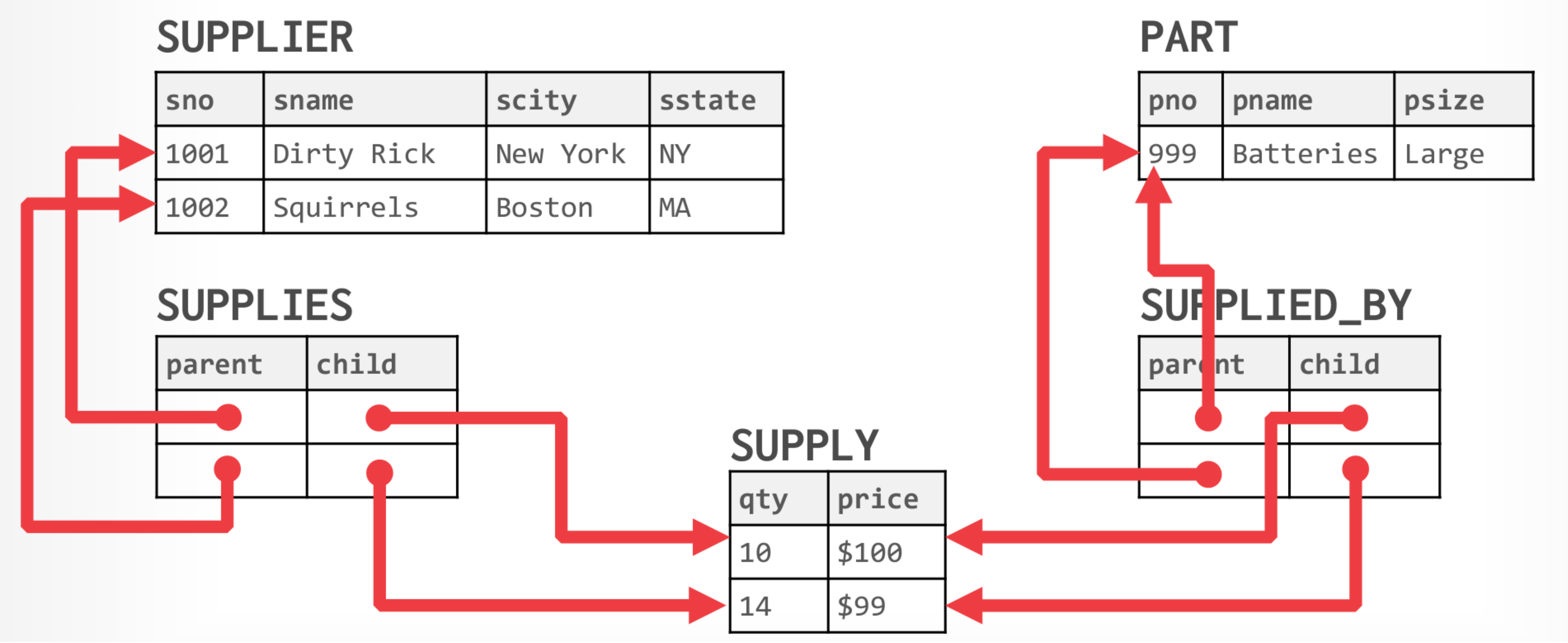
Acknowledgement: Prof. Andy Pavlo, CMU

Network data model - *schema*



Acknowledgement: Prof. Andy Pavlo, CMU

Network 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

SUPPLIES

parent	child

SUPPLIED_BY

parent	child

SUPPLY

qty	price
10	$100
14	$99

Acknowledgement: Prof. Andy Pavlo, CMU

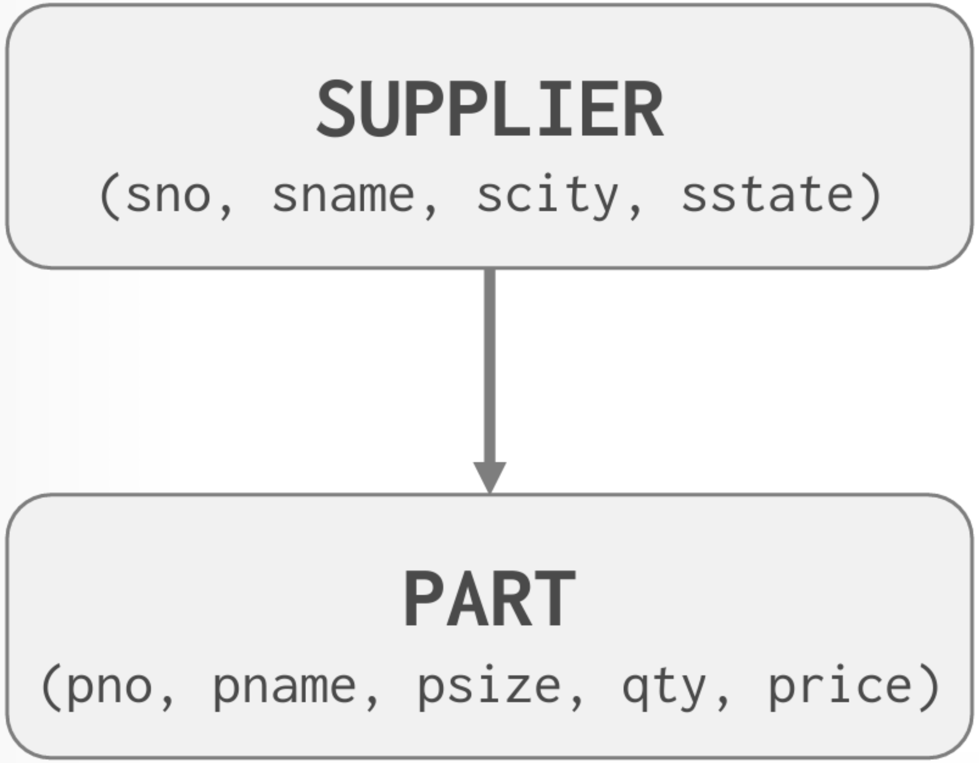
1960s – IBM IMS

- 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



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

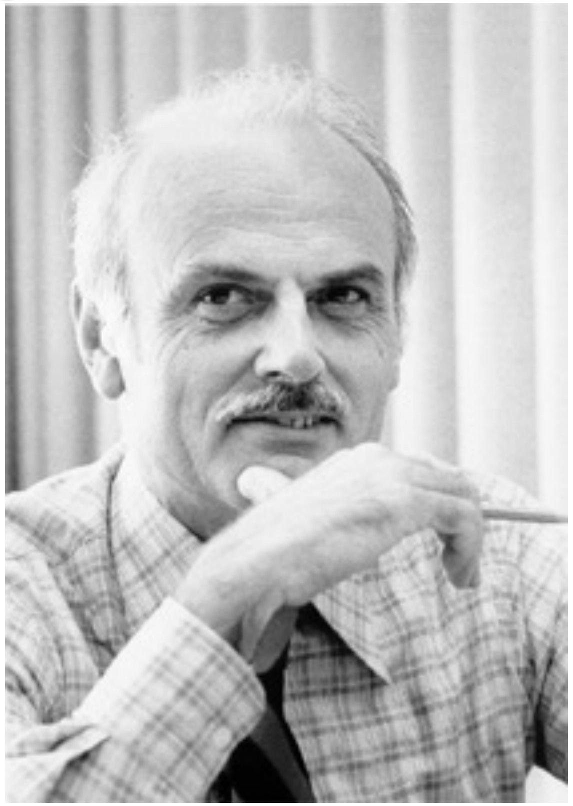
Acknowledgement: Prof. Andy Pavlo, CMU

1970s - Relational data model

- Ted Codd was a mathematician working at IBM Research. He saw developers spending their time rewriting IMS and CODASYL 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

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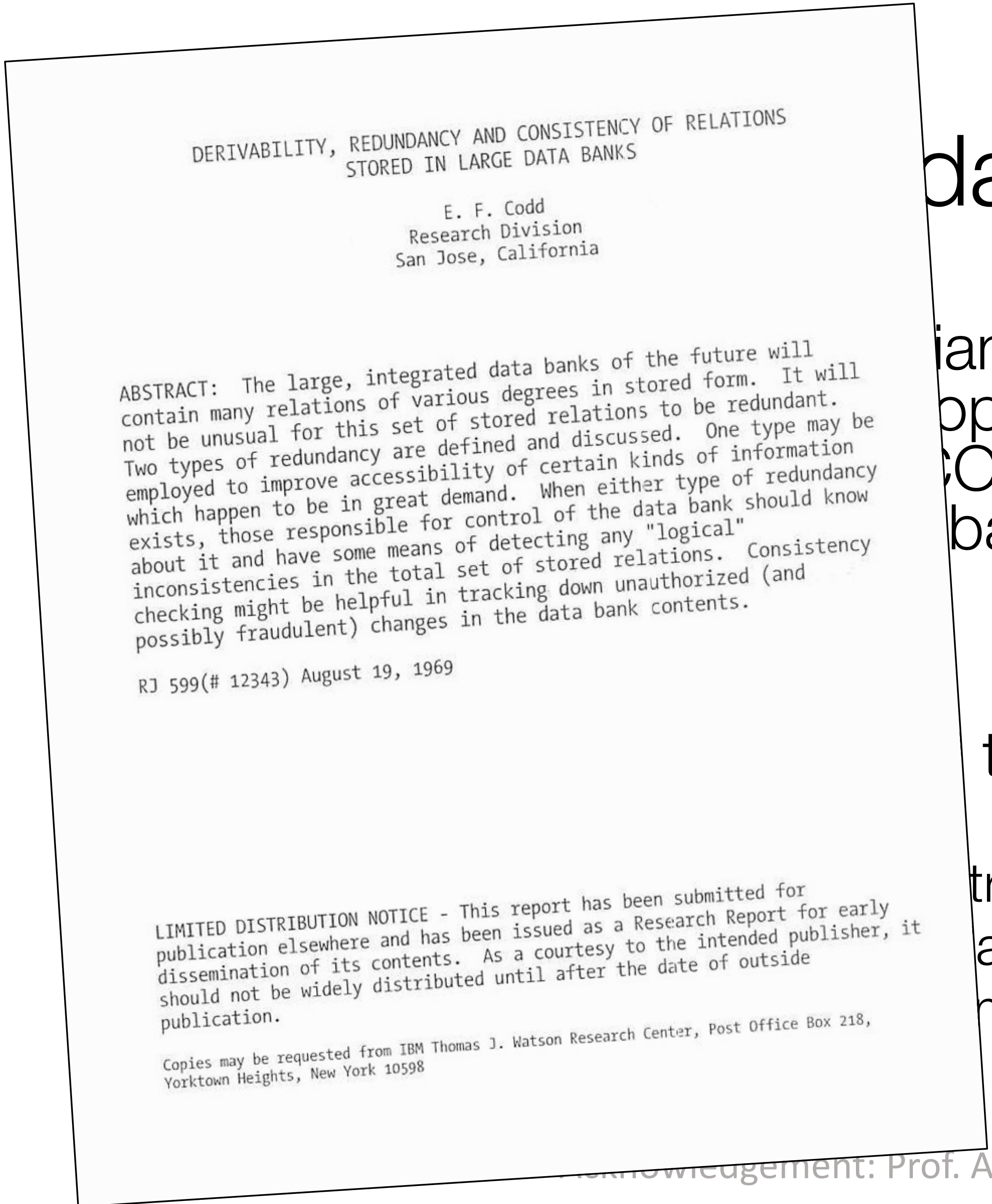
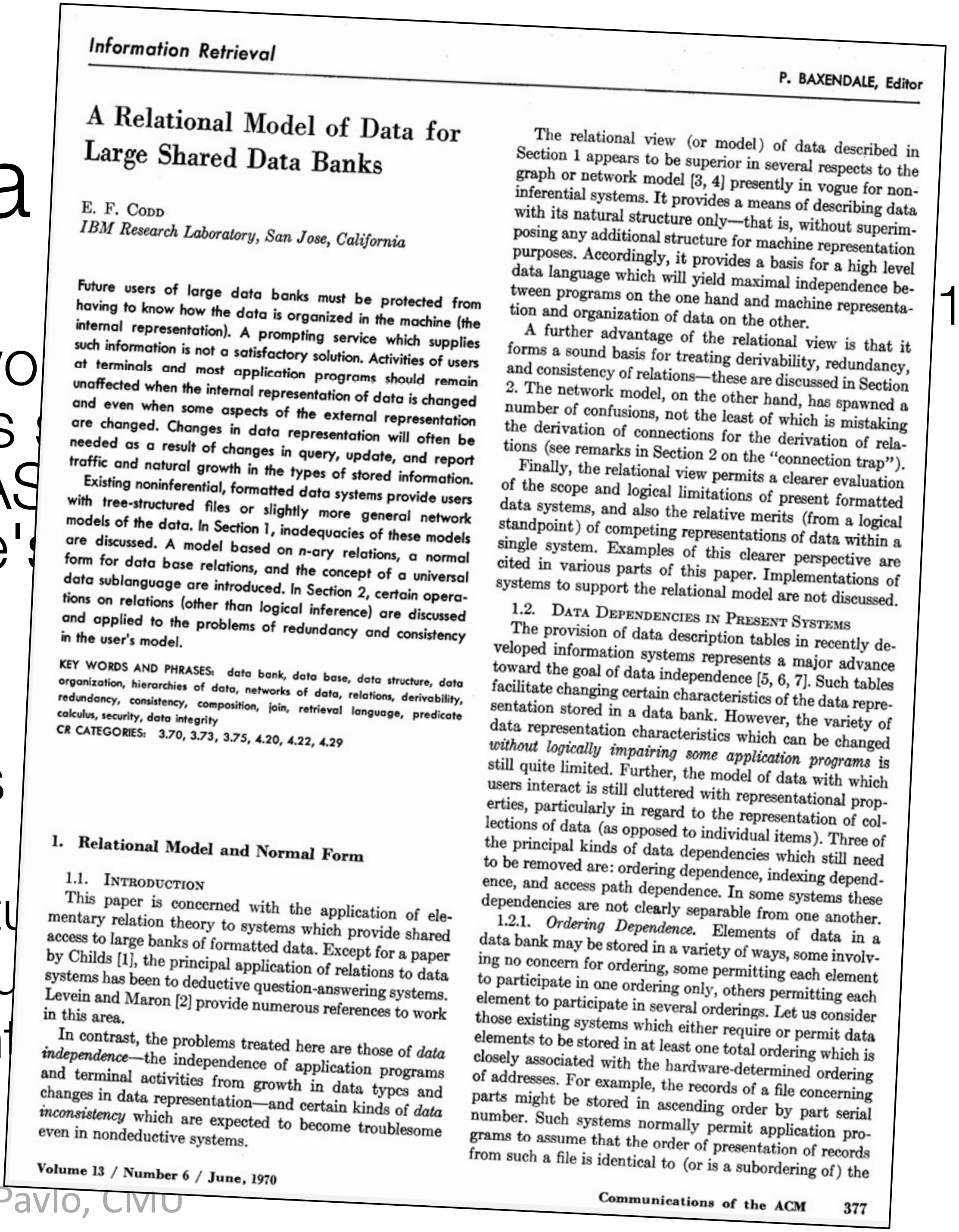


DERIVABILITY, REDUNDANCY AND CONSISTENCY OF RELATIONS
STORED IN LARGE DATA BANKS

E. F. Codd
Research Division
San Jose, California

ABSTRACT: The large, integrated data banks of the future will contain many relations of various degrees in stored form. It will not be unusual for this set of stored relations to be redundant. Two types of redundancy are defined and discussed. One type may be employed to improve accessibility of certain kinds of information which happen to be in great demand. When either type of redundancy exists, those responsible for control of the data bank should know about it and have some means of detecting any "logical" inconsistencies in the total set of stored relations. Consistency checking might be helpful in tracking down unauthorized (and possibly fraudulent) changes in the data bank contents.

RJ 599(# 12343) August 19, 1969



A Relational Model of Data for Large Shared Data Banks

E. F. Codd
IBM Research Laboratory, San Jose, California

Future users of large data banks must be protected from having to know how the data is organized in the machine (the internal representation). A prompting service which supplies such information is not a satisfactory solution. Activities of users at terminals and most application programs should remain unaffected when the internal representation of data is changed and even when some aspects of the external representation are changed. Changes in data representation will often be needed as a result of changes in query, update, and report traffic and natural growth in the types of stored information.

Existing noninferential, formatted data systems provide users with tree-structured files or slightly more general network models of the data. In Section 1, inadequacies of these models are discussed. A model based on *n*-ary relations, a normal form for data base relations, and the concept of a universal data sublanguage are introduced. In Section 2, certain operations on relations (other than logical inference) are discussed and applied to the problems of redundancy and consistency in the user's model.

KEY WORDS AND PHRASES: data bank, data base, data structure, data organization, hierarchies of data, networks of data, relations, derivability, redundancy, consistency, composition, join, retrieval language, predicate calculus, security, data integrity
CR CATEGORIES: 3.70, 3.73, 3.75, 4.20, 4.22, 4.29

1. Relational Model and Normal Form

1.1. Introduction

This paper is concerned with the application of elementary relation theory to systems which provide shared access to large banks of formatted data. Except for a paper by Childs [1], the principal application of relations to data systems has been to deductive question-answering systems. Levein and Maron [2] provide numerous references to work in this area.

In contrast, the problems treated here are those of *data independence*—the independence of application programs and terminal activities from growth in data types and changes in data representation—and certain kinds of *data inconsistency* which are expected to become troublesome even in nondeductive systems.

The relational view (or model) of data described in Section 1 appears to be superior in several respects to the graph or network model [3, 4] presently in vogue for non-inferential systems. It provides a means of describing data with its natural structure only—that is, without superimposing any additional structure for machine representation purposes. Accordingly, it provides a basis for a high level data language which will yield maximal independence between programs on the one hand and machine representation and organization of data on the other.

A further advantage of the relational view is that it forms a sound basis for treating derivability, redundancy, and consistency of relations—these are discussed in Section 2. The network model, on the other hand, has spawned a number of confusions, not the least of which is mistaking the derivation of connections for the derivation of relations (see remarks in Section 2 on the "connection trap").

Finally, the relational view permits a clearer evaluation of the scope and logical limitations of present formatted data systems, and also the relative merits (from a logical standpoint) of competing representations of data within a single system. Examples of this clearer perspective are cited in various parts of this paper. Implementations of systems to support the relational model are not discussed.

1.2. Data Dependencies in Present Systems

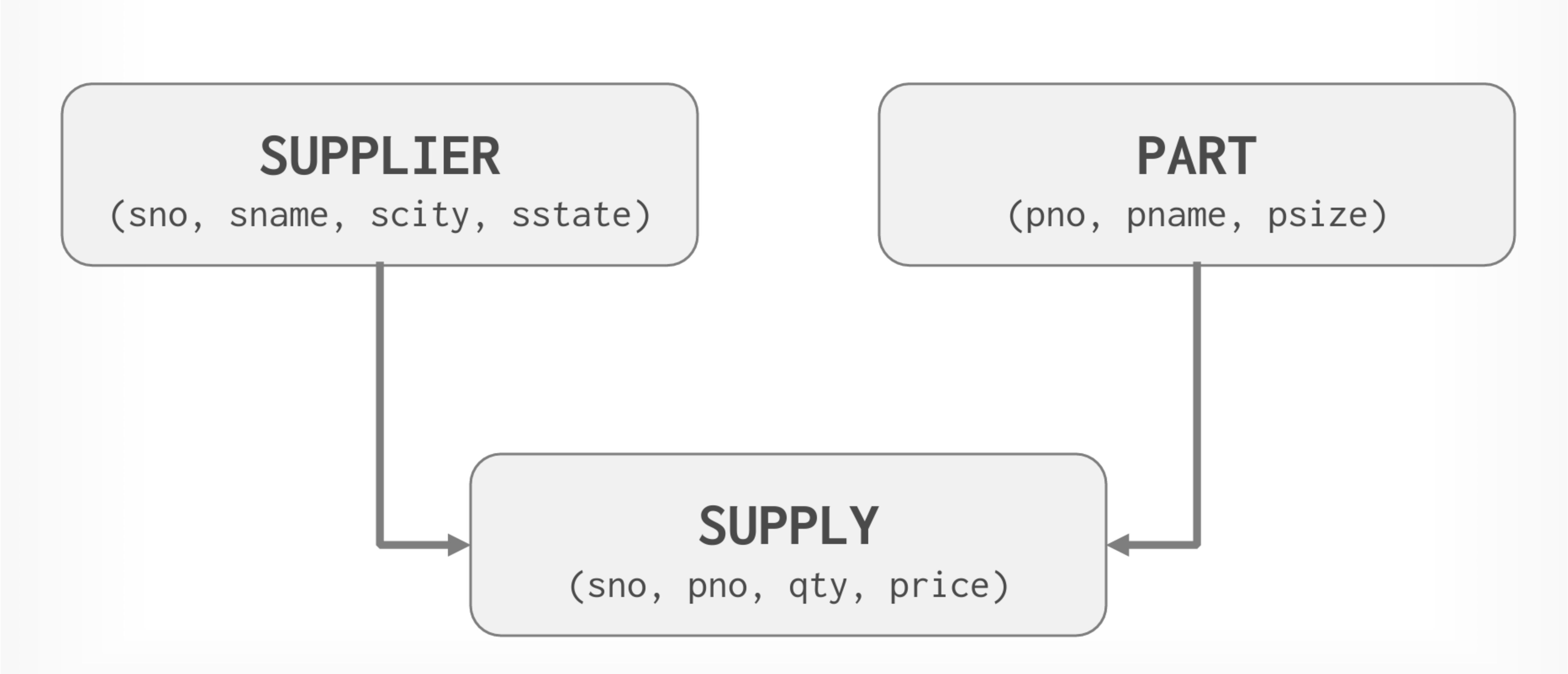
The provision of data description tables in recently developed information systems represents a major advance toward the goal of data independence [5, 6, 7]. Such tables facilitate changing certain characteristics of the data representation stored in a data bank. However, the variety of data representation characteristics which can be changed *without logically impairing some application programs* is still quite limited. Further, the model of data with which users interact is still cluttered with representational properties, particularly in regard to the representation of collections of data (as opposed to individual items). Three of the principal kinds of data dependencies which still need to be removed are: ordering dependence, indexing dependence, and access path dependence. In some systems these dependencies are not clearly separable from one another.

1.2.1. *Ordering Dependence.* Elements of data in a data bank may be stored in a variety of ways, some involving no concern for ordering, some permitting each element to participate in one ordering only, others permitting each element to participate in several orderings. Let us consider those existing systems which either require or permit data elements to be stored in at least one total ordering which is closely associated with the hardware-determined ordering of addresses. For example, the records of a file concerning parts might be stored in ascending order by part serial number. Such systems normally permit application programs to assume that the order of presentation of records from such a file is identical to (or is a subordering of) the

1

Acknowledgement: Prof. Andy Pavlo, CMU

Relational Data Model - *schema*



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

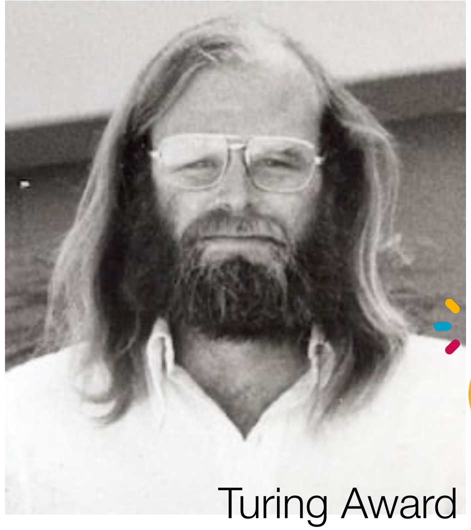
SUPPLY

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

Acknowledgement: Prof. Andy Pavlo, CMU

1970s – Relational Model

- Early implementations of relational DBMS:
  - Peterlee Relational Test Vehicle – IBM Research (UK)
  - System R–IBM Research
  - INGRES–U.C. Berkeley
  - Oracle–Larry Ellison



Turing Award 1998

Gray

Turing Award 2015

Stonebraker

Ellison

Acknowledgement: Prof. Andy Pavlo, CMU

1980s - Relational model

- The relational model wins.
  - IBM first releases SQL/DS in 1981.
  - IBM then turns out DB2 in 1983.
  - “SEQUEL” becomes the standard (SQL).

- Many new “enterprise” DBMSs but Oracle wins marketplace.

- Stonebraker creates Postgres as an “object-relational” DBMS

Acknowledgement: Prof. Andy Pavlo, CMU

1980s - Object-oriented databases

- Avoid “relational-object impedance mismatch” by tightly coupling objects and database.

- Few of these original DBMSs from the 1980s still exist today but many of the technologies exist in other forms (JSON, XML)

VERSANT ObjectStore MarkLogic

Acknowledgement: Prof. Andy Pavlo, CMU

Object-oriented Model

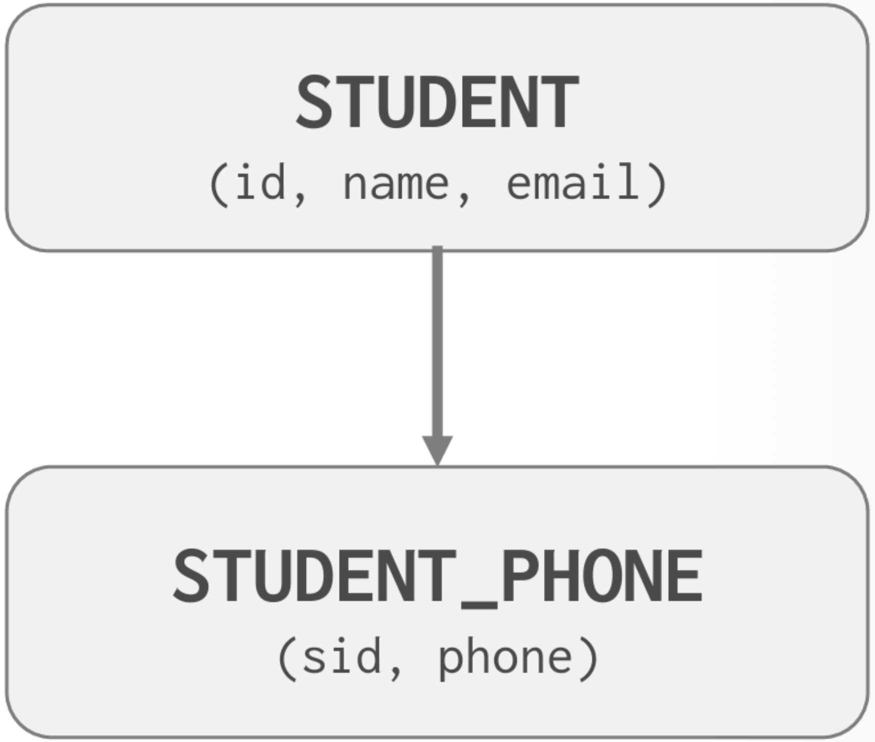
Application Code

```
class Student {
    int id;
    String name;
    String email;
    String phone[];
}
```

id	name	email
1001	M.O.P.	ante@up.com

sid	phone
1001	444-444-4444
1001	555-555-5555

Relational Schema



Acknowledgement: Prof. Andy Pavlo, CMU

Object-oriented Model

Application Code

```
class Student {
    int id;
    String name;
    String email;
    String phone[];
}
```

Student

```
{
  "id": 1001,
  "name": "M.O.P.",
  "email": "ante@up.com",
  "phone": [
      “444-444-4444”,
      “555-555-5555”
   ]
}
```

Acknowledgement: Prof. Andy Pavlo, CMU

1990s - Boring days

- No major advancements in database systems or application workloads.
  - Microsoft forks Sybase and creates SQL Server.
  - MySQL is written as a replacement for mSQL.
  - Postgres gets SQL support.
  - SQLite started in early 2000.
- Some DBMSs introduced pre-computed data cubes for faster analytics.

Acknowledgement: Prof. Andy Pavlo, CMU

2000s - Internet boom

- All the big players were heavyweight and expensive. Open-source databases were missing important features.

- Many companies wrote their own custom middleware to scale out database across single-node DBMS instances.

Acknowledgement: Prof. Andy Pavlo, CMU

2000s - Data warehouses

- Rise of the special purpose OLAP DBMSs.
  - Distributed / Shared-Nothing
  - Relational / SQL
  - Usually closed-source.
- Significant performance benefits from using columnar data storage model.

Acknowledgement: Prof. Andy Pavlo, CMU

2000s – MapReduce Systems

- Distributed programming and execution model for analyzing large data sets.
  - First proposed by Google (MapReduce).
  - Yahoo! created an open-source version (Hadoop).
  - Data model decided by user-written functions.
- People (eventually) realized this was a bad idea and grafted SQL on top of MR. That was a bad idea too.

Acknowledgement: Prof. Andy Pavlo, CMU

2000s - NoSQL Systems

- Focus on high-availability & high-scalability:
  - Schemaless (i.e., “Schema Last”)
  - Non-relational data models (document, key/value, etc)
  - No ACID transactions
  - Custom APIs instead of SQL
  - Usually open-source

Acknowledgement: Prof. Andy Pavlo, CMU

2010s - NewSQL

- Provide same performance for OLTP workloads as NoSQL DBMSs without giving up ACID:
  - Relational / SQL
  - Distributed
- Almost all the first group of systems failed
- Second wave of “distributed SQL” systems are (potentially) doing better

Acknowledgement: Prof. Andy Pavlo, CMU

2010s - Cloud systems

- First database-as-a-service (DBaaS) offerings were "containerized" versions of existing DBMSs.

- There are new DBMSs that are designed from scratch explicitly for running in a cloud environment.

Acknowledgement: Prof. Andy Pavlo, CMU

2010s - Shared-disk engines

- Instead of writing a custom storage manager, the DBMS leverages distributed storage.
  - Scale execution layer independently of storage.
  - Favors log-structured approaches.
- This is what most people think of when they talk about a <u>data lake</u>.

Acknowledgement: Prof. Andy Pavlo, CMU

2010s - Graph systems

- Systems for storing and querying graph data.
- Their main advantage over other data models is to provide a graph centric query API
  - Recent research (2023) demonstrated that is unclear whether there is any benefit to using a graph-centric execution engine and storage manager.

Acknowledgement: Prof. Andy Pavlo, CMU

2010s - Timeseries systems

- Specialized systems that are designed to store timeseries / event data.
- The design of these systems make deep assumptions about the distribution of data and workload query patterns.

Acknowledgement: Prof. Andy Pavlo, CMU

2020s – Specialized Systems

- Embedded DBMSs
- Multi-Model DBMSs
- Hardware Acceleration
- Array / Matrix / Vector DBMSs

2010s – SPECIALIZED SYSTEMS

- Embedded DBMSs
- Multi-Model DBMSs
- Blockchain DBMSs
- Hardware Acceleration

Final Thoughts

- The demarcation lines of DBMS categories will continue to blur over time as specialized systems expand the scope of their domains.
  - Every NoSQL DBMS (except for Redis) now supports SQL

- The relational model and declarative query languages promote better data engineering.

Acknowledgement: Prof. Andy Pavlo, CMU