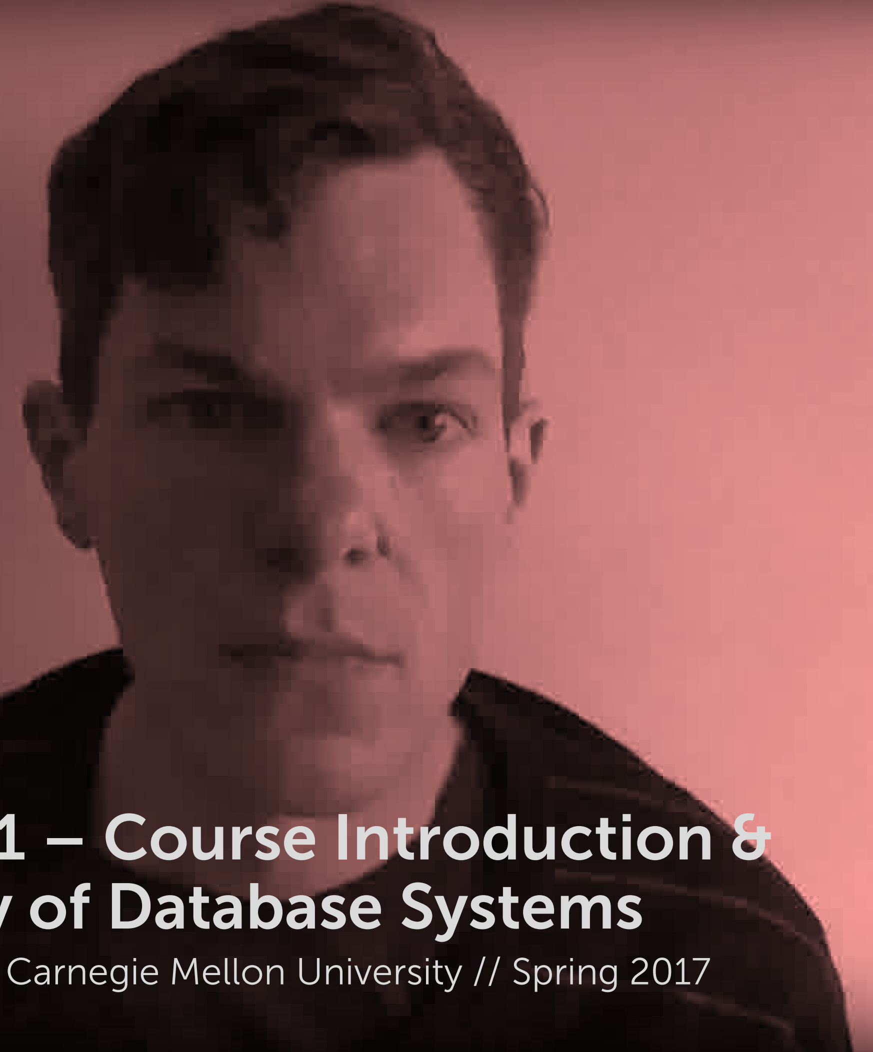
15-721 ADVANCED DATABASE SYSTEMS



Lecture #01 – Course Introduction & History of Database Systems

@Andy_Pavlo // Carnegie Mellon University // Spring 2017

Who are the richest people in the world?

	#1	Bill Gates	$75 B	61	Microsoft	United States
	#2	Amancio Ortega	$67 B	80	Zara	Spain
	#3	Warren Buffett	$60.8 B	86	Berkshire Hathaway	United States
	#4	Carlos Slim Helu	$50 B	76	telecom	Mexico
	#5	Jeff Bezos	$45.2 B	53	Amazon.com	United States
	#6	Mark Zuckerberg	$44.6 B	32	Facebook	United States
	#7	Larry Ellison	$43.6 B	72	Oracle	United States

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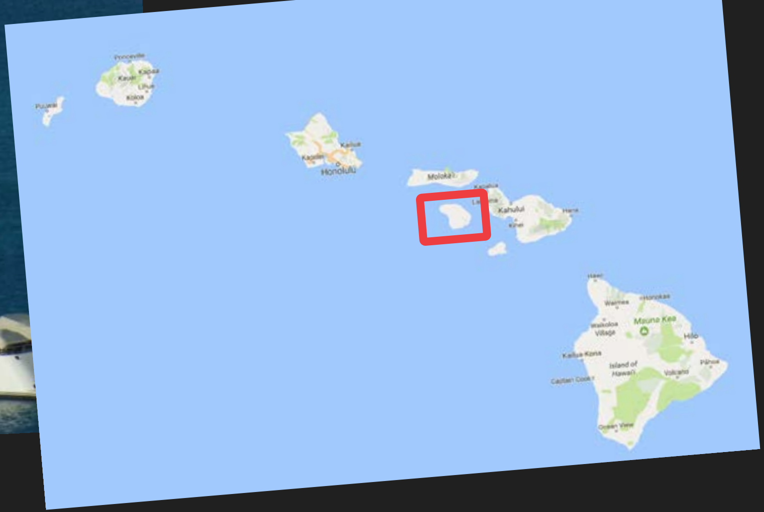

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WHY YOU SHOULD TAKE THIS COURSE

DBMS developers are in demand and there are many challenging unsolved problems in data management and processing.

If you are good enough to write code for a DBMS, then you can write code on almost anything else.

TODAY'S AGENDA

Wait List
Course Outline
History of Database Systems

WAIT LIST

There are 53 people on the waiting list.

Max capacity is 40.

There are currently three free slots.

I will pull people off of the waiting list in the order that you complete Project #1.

COURSE OBJECTIVES

Learn about modern practices in database internals and systems programming.

Students will become proficient in:
→ Writing correct + performant code
→ Proper documentation + testing
→ Code reviews
→ Working on a large code base

COURSE TOPICS

The internals of single node systems for in-memory databases. We will ignore distributed deployment problems.

We will cover state-of-the-art topics.
This is **not** a course on classical DBMSs.

COURSE TOPICS

Concurrency Control

Indexing

Storage Models, Compression

Parallel Join Algorithms

Logging & Recovery Methods

Query Optimization, Execution, Compilation

New Storage Hardware

BACKGROUND

I assume that you have already taken an intro course on databases (e.g., 15-415/615).

We will discuss modern variations of classical algorithms that are designed for today's hardware.

Things that we will **not** cover:
SQL, Serializability Theory, Relational Algebra, Basic Algorithms + Data Structures.

BACKGROUND

All projects will be written in C++11.

Be prepared to debug, profile, and test a multi-threaded program.

COURSE LOGISTICS

Course Policies + Schedule:

→ Refer to course web page.

Academic Honesty:

→ Refer to CMU policy page.
→ If you're not sure, ask me.
→ I'm serious. Don't plagiarize or I will wreck you.

OFFICE HOURS

Immediately after class in my office:
→ Tue/Thu: 1:30 – 2:30
→ Gates-Hillman Center 9019

Things that we can talk about:
→ Issues on implementing projects
→ Paper clarifications/discussion
→ Relationship advice

TEACHING ASSISTANTS

Head TA: Dana Van Aken

→ 3rd Year PhD Student (CSD)

→ 2016 MSR Internship

→ 2016 NSF Fellowship Winner

COURSE RUBRIC

Reading Assignments
Programming Projects
Final Exam
Extra Credit

READING ASSIGNMENTS

One mandatory reading per class (★). You can skip **four** readings during the semester.

You must submit a synopsis **before** class:

→ Overview of the main idea (three sentences).
→ System used and how it was modified (one sentence).
→ Workloads evaluated (one sentence).

Submission Form:
http://cmudb.io/15721-s17-submit

☠ PLAGIARISM WARNING ☠

Each review must be your own writing.

You may **not** copy text from the papers or other sources that you find on the web.

Plagiarism will **not** be tolerated.
See CMU's Policy on Academic Integrity for additional information.

PROGRAMMING PROJECTS

Projects will be implemented in CMU's new DBMS **Peloton**.

→ In-memory, hybrid DBMS
→ Modern code base (C++11, Multi-threaded)
→ Open-source / Apache v2.0 License
→ Postgres-wire protocol compatible

We will provide more details about how to get started with the first project next class.

PROGRAMMING PROJECTS

Do all development on your local machine.
→ Peloton only builds on Linux.
→ We will provide a Vagrant configuration.

Do all benchmarking using DB Lab cluster.
→ We will provide login details later in semester.

Hardware donation from **MemSQL** + **Micron**.

PROJECTS #1 AND #2

We will provide you with test cases and scripts for the first two programming projects.

Project #1 will be completed individually.

Project #2 will be done in a group of **three**.
→ 40 people in the class
→ ~13 groups of 3 people

☠ PLAGIARISM WARNING ☠

These projects must be all of your own code.

You may **not** copy source code from other groups or the web.

Plagiarism will **not** be tolerated.
See CMU's Policy on Academic Integrity for additional information.

PROJECT #3

Each group will choose a project that is:

→ Relevant to the materials discussed in class.
→ Requires a significant programming effort from all team members.
→ Unique (i.e., two groups can't pick same idea).
→ Approved by me.

You don't have to pick a topic until after you come back from Spring Break.
We will provide sample project topics.

PROJECT #3

Project deliverables:
- → Proposal
- → Project Update
- → Code Reviews
- → Final Presentation
- → Code Drop

PROJECT #3 – PROPOSAL

Five minute presentation to the class that discusses the high-level topic.

Each proposal must discuss:

→ What files you will need to modify.

→ How you will test whether your implementation is correct.

→ What workloads you will use for your project.

PROJECT #3 – STATUS UPDATE

Five minute presentation to update the class about the current status of your project.

Each presentation should include:
→ Current development status.
→ Whether anything in your plan has changed.
→ Any thing that surprised you.

PROJECT #3 – CODE REVIEWS

Each group will be paired with another group and provide feedback on their code at least two times during the semester.

Grading will be based on participation.

PROJECT #3 – FINAL PRESENTATION

10 minute presentation on the final status of your project during the scheduled final exam.

You'll want to include any performance measurements or benchmarking numbers for your implementation.

Demos are always hot too…

PROJECT #3 – CODE DROP

A project is **not** considered complete until:

→ The code can merge into the master branch without any conflicts.
→ All comments from code review are addressed.
→ The project includes test cases that correctly verify that implementation is correct.
→ The group provides documentation in both the source code and in separate Markdown files.

FINAL EXAM

Written long-form examination on the mandatory readings and topics discussed in class. Closed notes.

Will be held on the last class (Thursday May 2nd) in this room.

EXTRA CREDIT

We are writing an encyclopedia of DBMSs. Each student can earn extra credit if they write an entry about one DBMS.

→ Must provide citations and attributions.

Additional details will be provided later.

This is optional.

☠ PLAGIARISM WARNING ☠

The extra credit article must be your own writing. You may **not** copy text/images from papers or other sources that you find on the web.

Plagiarism will **not** be tolerated.
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GRADE BREAKDOWN

Reading Reviews (10%)
Project #1 (10%)
Project #2 (25%)
Project #3 (40%)
Final Exam (15%)
Extra Credit (+10%)

COURSE MAILING LIST

On-line Discussion through Piazza:
http://piazza.com/cmu/spring2017/15721

If you have a technical question about the projects, please use Piazza.
→ Don't email me or TAs directly.

All non-project questions should be sent to me.

ANDY'S ABRIDGED

HISTORY OF DATABASES

WHAT GOES AROUND COMES AROUND
Readings in DB Systems, 4th Edition, 2006.

WHAT'S REALLY NEW WITH NEWSQL?
SIGMOD Record, vol. 45, iss. 2, 2016

HISTORY REPEATS ITSELF

Old database issues are still relevant today.

The "SQL vs. NoSQL" debate is reminiscent of "Relational vs. CODASYL" debate.

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

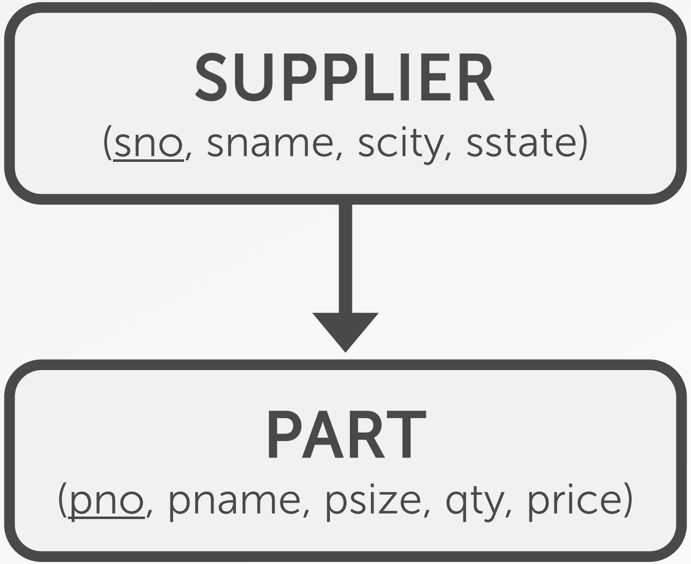
1960S – IBM IMS

First 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.

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

HIERARCHICAL DATA MODEL

Duplicate Data

No Independence

(sno, sname, scity, sstate)

				parts
1002	Squirrels	Boston	MA	

	price
	$100

PART

(pno, pname, psize, qty, price)

pno	pname	psize	qty	price
999	Batteries	Large	14	$99

1970s – CODASYL

COBOL people got together and proposed a standard for how programs will access a database. Lead by Charles Bachman.

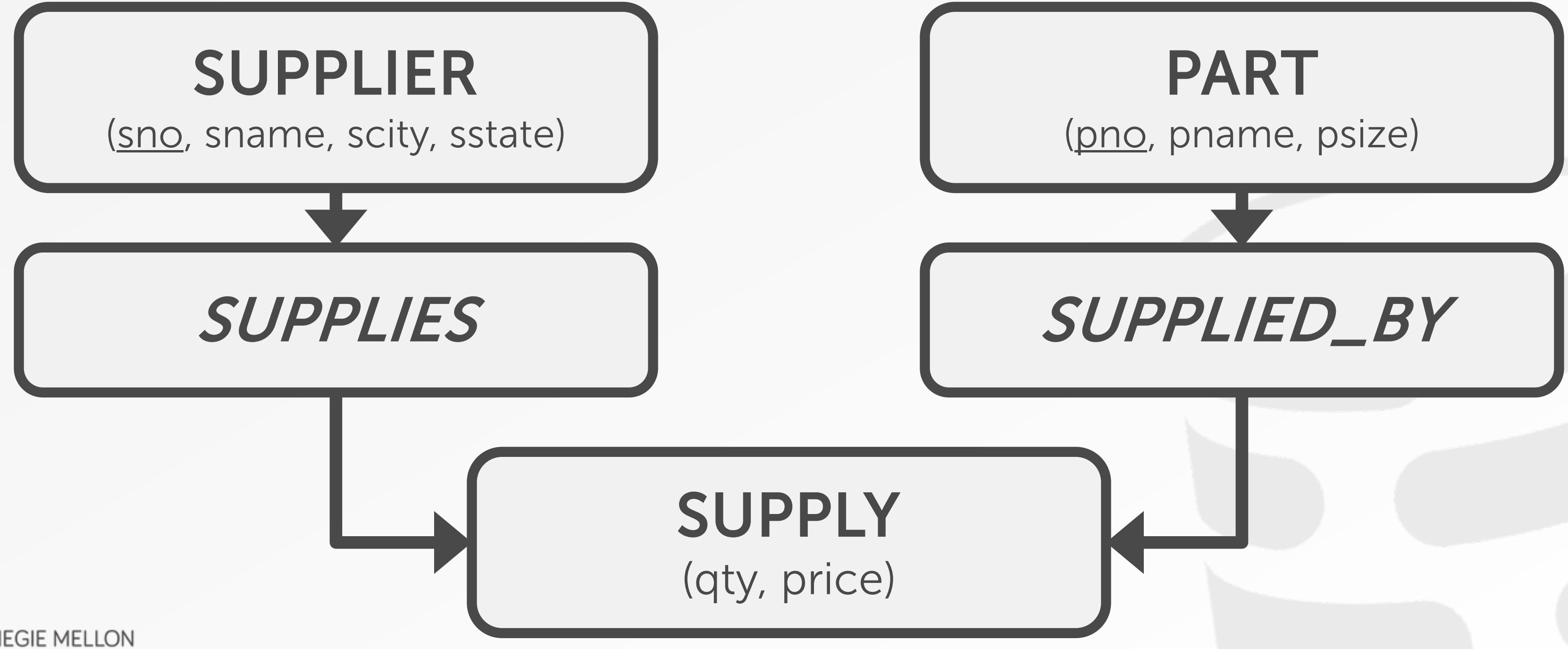
→ Network data model.

→ Tuple-at-a-time queries.

Bachman

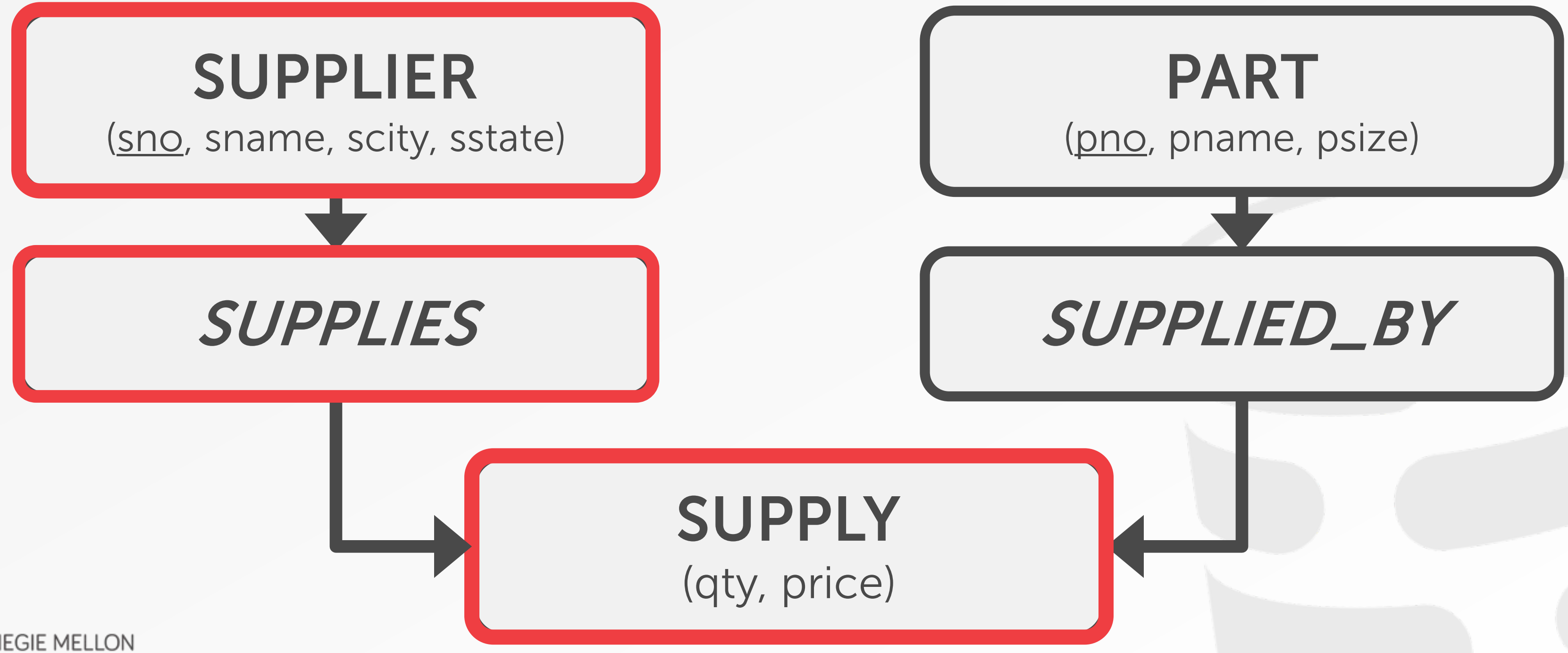
NETWORK DATA MODEL

Schema



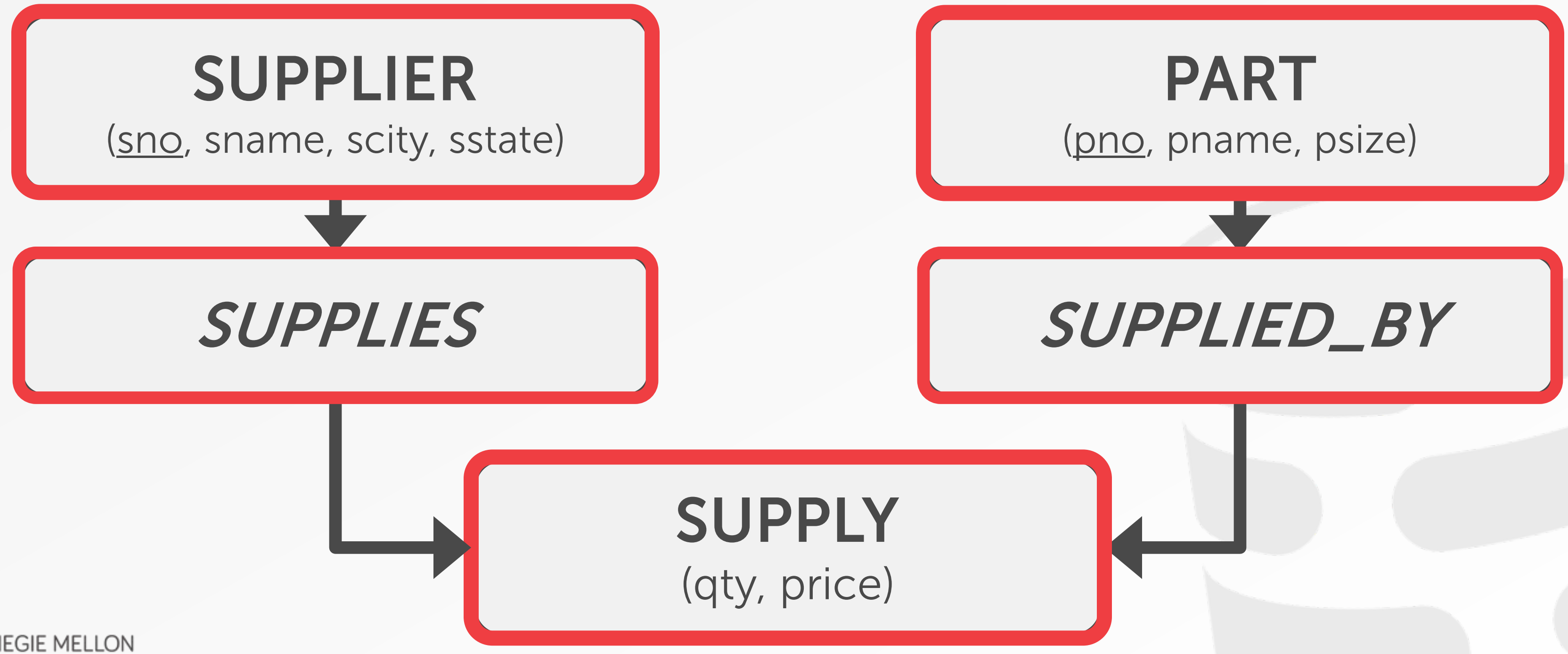
NETWORK DATA MODEL

Schema



NETWORK DATA MODEL

Schema



NETWORK DATA MODEL

(sno, sname, scity, sstate)

(pno, pname, psize)

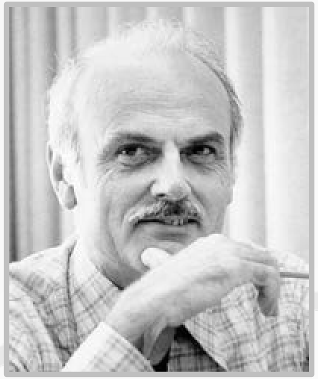
Complex Queries

Easily Corrupted

SUPPLY
(qty, price)

1970s – RELATIONAL 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.

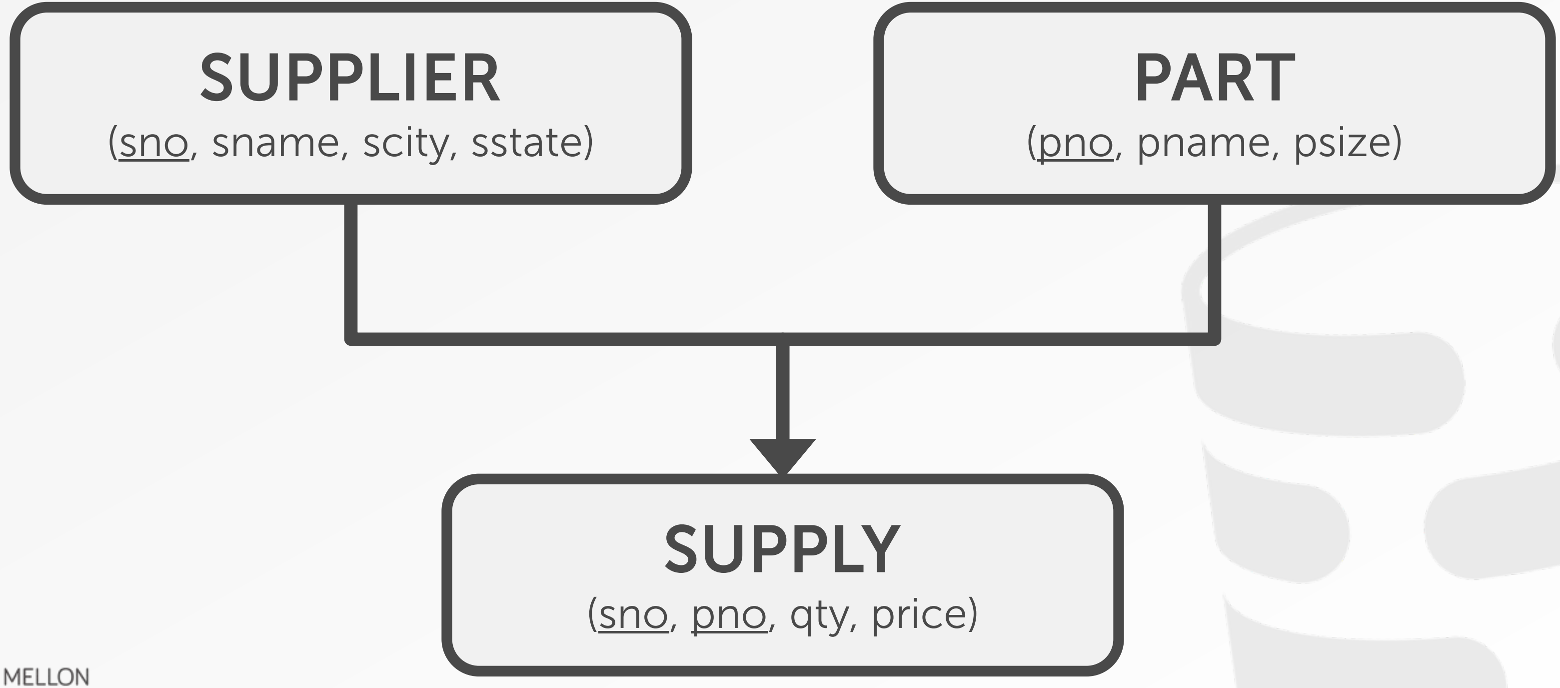

Codd

Database abstraction to avoid this maintenance:

→ Store database in simple data structures.
→ Access data through high-level language.
→ Physical storage left up to implementation.

RELATIONAL DATA MODEL

Schema



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 noninferential 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.

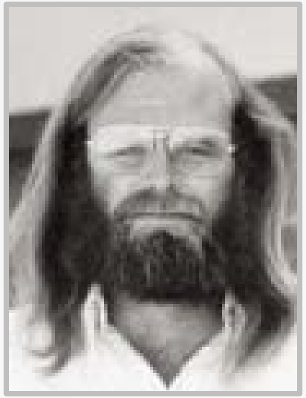
1.2. Data Dependencies in Present Systems

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

1970s – RELATIONAL MODEL

Early implementations of relational DBMS:
→ **System R** – IBM Research
→ **INGRES** – U.C. Berkeley
→ **Oracle** – Larry Ellison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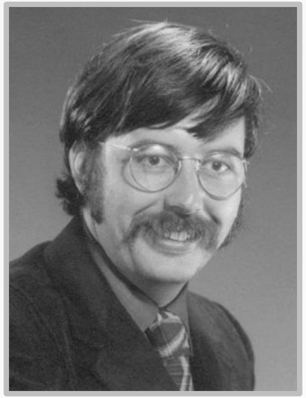

Stonebraker


Ellison

1980s – RELATIONAL MODEL

The relational model wins.
→ IBM comes out with DB2 in 1983.
→ "SEQUEL" becomes the standard (SQL).

Many new "enterprise" DBMSs but Oracle wins marketplace.

Stonebraker creates Postgres.

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)

OBJECT-ORIENTED MODEL

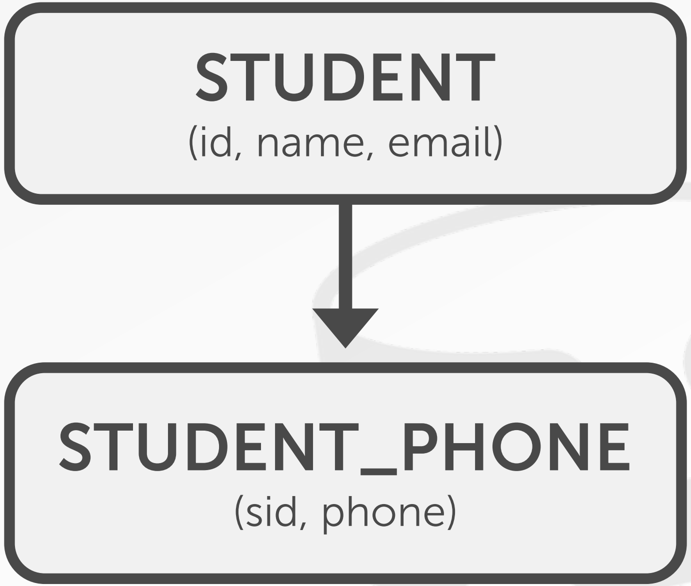
Application Code

```
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



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"
   ]
}
```

OBJECT-ORIENTED MODEL

Complex Queries

```
c…
    String email;
    String phone[];
}
```

```
  "email": "ante@up.com",
  "phone": [
      "444-444-4444",
      "555-555-5555"
   ]
}
```

OBJECT-ORIENTED MODEL

```
c
    String email;
    String phone[];
}
```

```
"email": "ante@up.com",
```

Complex Queries

No Standard API

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.

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.

2000s – DATA WAREHOUSES

Rise of the special purpose OLAP DBMSs.
→ Distributed / Shared-Nothing
→ Relational / SQL
→ Usually closed-source.

Significant performance benefits from using Decomposition Storage Model (i.e., columnar)

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

2010s – NewSQL

Provide same performance for OLTP workloads as NoSQL DBMSs without giving up ACID:

→ Relational / SQL
→ Distributed
→ Usually closed-source

2010s – HYBRID SYSTEMS

Hybrid **T**ransactional-**A**nalytical **P**rocessing.

Execute fast OLTP like a NewSQL system while also executing complex OLAP queries like a data warehouse system.

→ Distributed / Shared-Nothing
→ Relational / SQL
→ Mixed open/closed-source.

MEMSQL HyPer SNAPPY SAP HANA
JustOne DB splice MACHINE Peloton

PARTING THOUGHTS

There are many innovations that come from both industry and academia:

→ Lots of ideas start in academia but few build complete DBMSs to verify them.
→ IBM was the vanguard during 1970-1980s but now Google is current trendsetter.
→ Oracle borrows ideas from anybody.

The relational model has won for operational databases.

NEXT CLASS

Disk vs. In-Memory DBMSs

Project #1 Discussion

Reminder: First reading review is due at 12:00pm on Thursday January 19th.