Lecture #01

Carnegie Mellon University

ADVANCED DATABASE SYSTEMS

History of Databases

Andy Pavlo // 15-721 // Spring 2023

amazon

TODAY'S AGENDA

Course Logistics Overview
History of Databases

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.

And people will pay you lots of money to do it…


salesforce


snowflake


amazon


LinkedIn


salesforce


snowflake


OTTERTUNE


salesforce


HyPer


salesforce


OTTERTUNE


impira


facebook


Google


amazon


databricks


ROCKSET


yugabyteDB


ORACLE


OTTERTUNE


databricks


Materialize


sisu


yugabyteDB


databricks

COURSE OBJECTIVES

Learn about modern practices in database internals and systems programming for analytical workloads.

Students will become proficient in:

→ Writing correct + performant code
→ Proper documentation + testing
→ Code reviews
→ Working on a large code base

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

COURSE TOPICS

Storage Models, Compression

Indexing

Vectorized Execution + Compilation

Parallel Join Algorithms

Networking Protocols

Query Optimization

Modern System Analysis

BACKGROUND

I assume that you have already taken an intro course on databases (e.g., 15-445/645).

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.

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

Before class in my office:
→ Mon/Wed: 1:00 – 2:00
→ Gates-Hillman Center 9019

Things that we can talk about:
→ Issues on implementing projects
→ Paper clarifications/discussion
→ How to get a database dev job.
→ How to handle the police

TEACHING ASSISTANTS

Head TA: Wan Shen Lim

→ 3rd Year PhD Student (CSD)
→ Former Paralegal
→ Certified Chicken Farmer
→ Capybara Enthusiast
→ #1 Ranked Database Ph.D. Student at Carnegie Mellon University.

COURSE RUBRIC

Reading Assignments

Projects

Final Exam

READING ASSIGNMENTS

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

You must submit a synopsis **before** class:
- → Overview of the main idea (three sentences).
- → Main finding/takeaway of paper (one sentence).
- → System used and how it was modified (one sentence).
- → Workloads evaluated (one sentence).

Submission Form:
https://cmudb.io/15721-s23-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.

PROJECT #1

Build a SQL/MED extension (foreign data wrapper) for PostgreSQL for processing columnar data.

This will expose you to developing for PostgreSQL and building a vectorized execution engine.

We will provide more details in a week.

PROJECT #2

We are writing an encyclopedia of DBMSs. Each student will pick one DBMS and write an entry about it.

→ Must provide citations and attributions.
→ Avoid unscientific (i..e, marketing) language and claims.

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

PROJECT #3

Each group (3 people) 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 cannot pick same idea).
- → Approved by me.

You don't have to pick a topic until Spring Break.
We will provide sample project topics.
- → There are some topics that I would like to turn into a (short) paper.

☠ PLAGIARISM WARNING ☠

These projects must be all of your own code and writing.

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.

FINAL EXAM

Written long-form take-home examination on the readings and topics discussed in class.

Will be given out in class on April 26th.

As of January 2023, ChatGPT is not able to answer these questions.

GRADE BREAKDOWN

Reading Reviews (15%)
Project #1 (20%)
Project #2 (10%)
Project #3 (45%)
Final Exam (15%)

COURSE MAILING LIST

On-line Discussion through Piazza:
https://piazza.com/cmu/spring2023/15721

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

HISTORY OF DATABASES

WHAT GOES AROUND COMES AROUND
READINGS IN DB SYSTEMS, 4TH EDITION, 2006.

WHAT GOES AROUND COMES AROUND... AND AROUND
UNDER SUBMISSION 2023

HISTORY REPEATS ITSELF

Old database issues are still relevant today.

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

Somebody invents a "SQL Replacement" every decade. It then fails and/or SQL absorbs the key ideas into the standard.

1960s – IDS

Integrated Data Store

Developed internally at GE in the early 1960s.

GE sold their computing division to Honeywell in 1969.

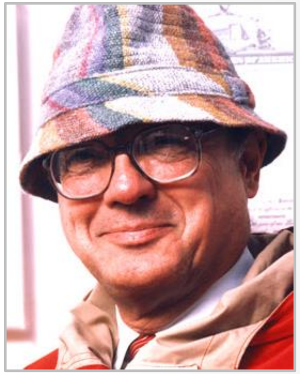
One of the first DBMSs:
→ Network data model.
→ Tuple-at-a-time queries.

1960s – 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.

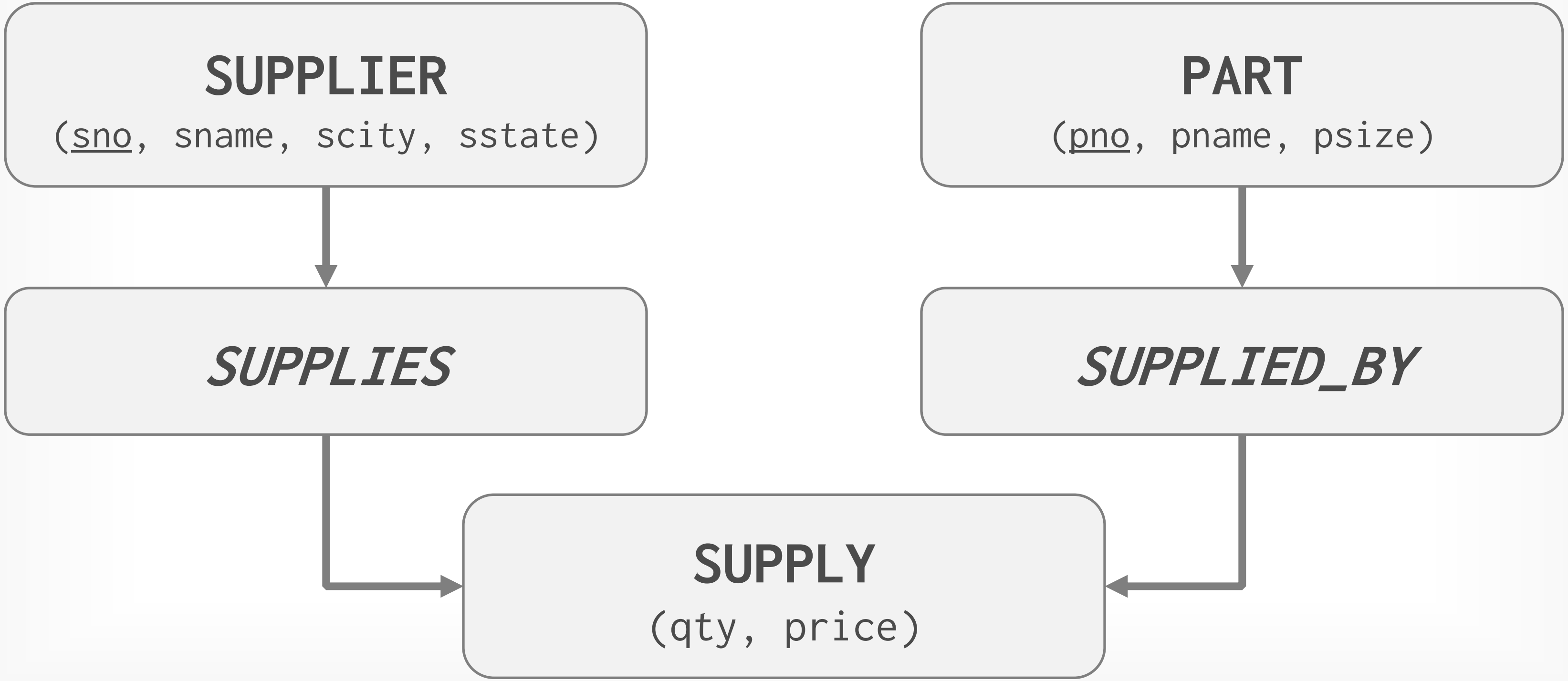


Bachman

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

NETWORK DATA MODEL

Schema



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

1960S – IBM IMS

Information **M**anagement **S**ystem

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.

HIERARCHICAL DATA MODEL

Schema

SUPPLIER

(sno, sname, scity, sstate)

↓

PART

(pno, pname, psize, qty, price)

Instance

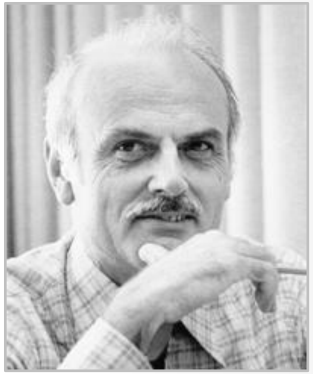
sno	sname	scity	sstate	parts
1001	Dirty Rick	New York	NY	•
1002	Squirrels	Boston	MA	•

pno	pname	psize	qty	price
999	Batteries	Large	10	$100

pno	pname	psize	qty	price
999	Batteries	Large	14	$99

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.

LATIO

matician
w devel
riting I
time th
out cha
avoid t
data stru
-level la
implem

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

Information Retrieval

P. BAXENDALE, Editor

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.

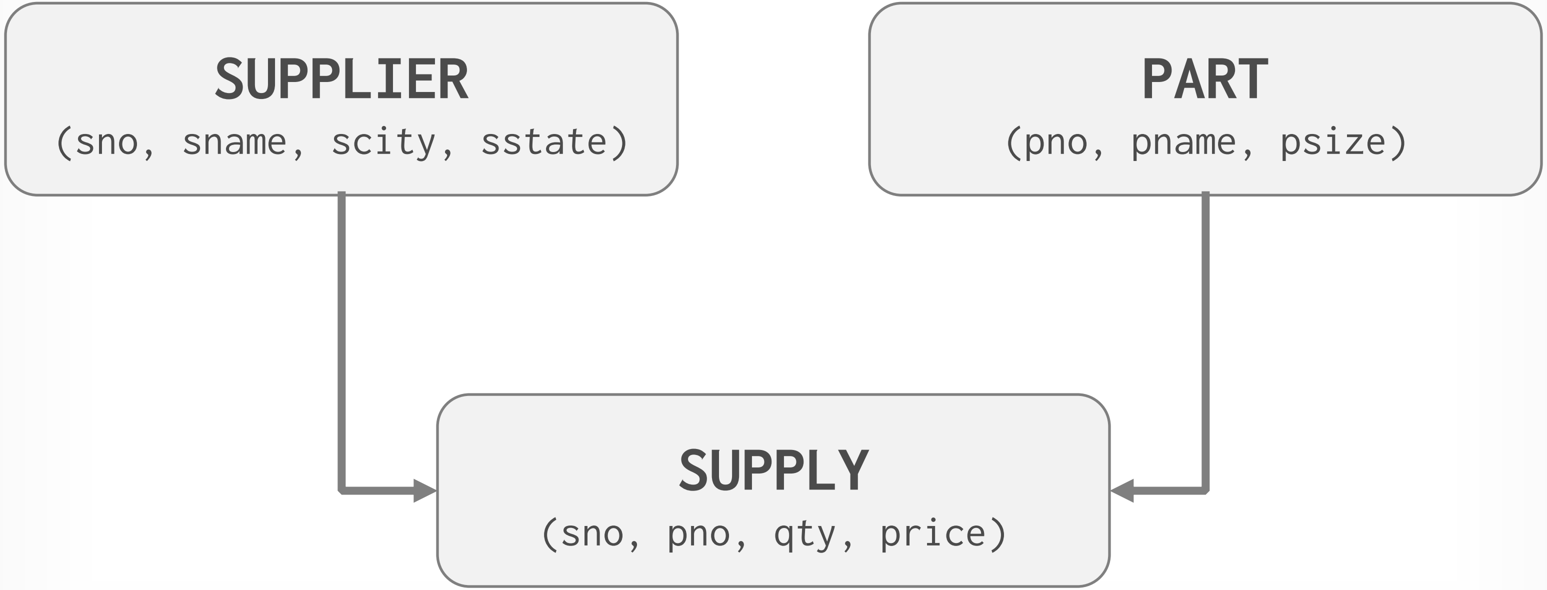
1.2. Data Dependencies in Present Systems

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

RELATIONAL DATA MODEL

Schema



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

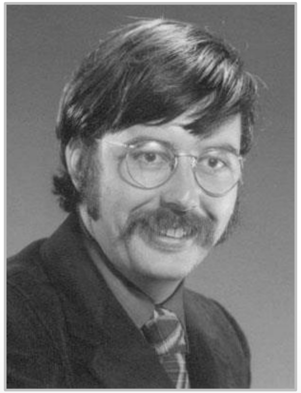
SUPPLY

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

1970s – RELATIONAL MODEL

Early implementations of relational DBMS:
→ **Peterlee Relational Test Vehicle** – IBM Research (UK)
→ **System R** – IBM Research (San Jose)
→ **INGRES** – U.C. Berkeley
→ **Oracle** – Larry Ellison
→ **Mimer** – Uppsala University


Gray


Stonebraker


Ellison

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) after supposedly Stonebraker refused to talk to the ANSI standards committee.

Many new "enterprise" DBMSs but Oracle wins marketplace.

Stonebraker creates Postgres as an "object-relational" DBMS.

1980s – RELATIONAL MODEL

The relational model wins.

→ IBM first releases SQL/DS ir

→ IBM then turns out DB2 in 1

→ "SEQUEL" becomes the stan after supposedly Stonebraker talk to the ANSI standards c

Many new "enterprise" DE but Oracle wins marketplace.

Stonebraker creates Postgres as an "object-relational" DBMS.

But Ingres did not show up at the committee meetings because founder Mike Stonebraker detested the idea of having technology standards. Stonebraker was vocal about it. He thought they inhibited innovation and artificially restricted what got to the marketplace. Maybe so, but his hard-line position probably did not help his company. Don Deutsch, who served as chairman of the database committee, summed things up this way: "I tell you, QUEL was a much nicer language than SQL. No rational person would have chosen SQL instead of QUEL. . . . Ingres was stupid."

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™

OBJECT-ORIENTED MODEL

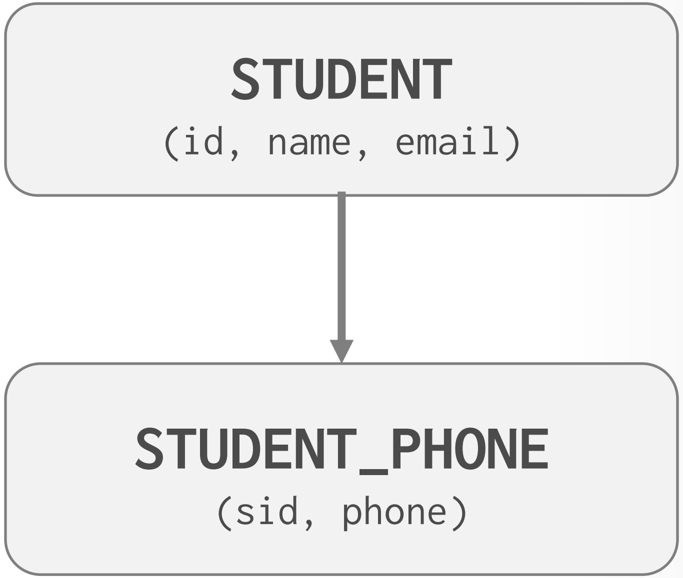
Application Code

```
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”
    ]
}
```

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.

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 **columnar data storage** model.

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.

2000s – NoSQL SYSTEMS

Focus on high-availability & high-scalability:

→ Schemaless (i.e., "Schema Last")
→ Non-relational data models (document, key/value, column-family)
→ No ACID transactions
→ Custom APIs instead of SQL
→ Usually open-source

2010s – NewSQL SYSTEMS

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.

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.

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 **data lake**.

2010s – GRAPH SYSTEMS

Systems for storing and querying graph data.
→ Similar to the network data model (CODASYL)

Their (supposed) advantage over other data models is to provide a graph-centric query API
→ SQL:2023 is adding graph query syntax (SQL/PCG)

Latest research (2023) shows that a relational DBMS outperforms state-of the-art graph DBMSs.

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.

2020s – BLOCKCHAIN DATABASES

Decentralized distributed log with incremental checksums (Merkle Trees).

→ Uses Byzantine Fault Tolerant (BFT) protocol to determine next entry to append to log.

Andy is not aware of a blockchain usecase that could not also be solved with a "traditional" OLTP DBMS and/or external policies (e.g., authentication).

fluree BIGCHAINDB Condensation CovenantSQL

2010s – SPECIALIZED SYSTEMS

Embedded DBMSs

Multi-Model DBMSs

Hardware Acceleration

Array / Matrix / Vector DBMSs

SPECIALIZED SYSTEMS

Embedded DBMSs

Multi-Model DBMSs

Hardware Acceleration

Array / Matrix / Vector DBMSs

PARTING 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.

NEXT CLASS

Modern Analytical Database Systems

Make sure that you submit the first reading review

https://cmudb.io/15721-s23-submit