Lecture 1: Course Introduction & History of Database Systems

Welcome!

- This course focuses on the design and implementation of database management systems (DBMSs).
- We will study the internals of modern database management systems.
- We will cover the core concepts and fundamentals of the components that are used in high-performance transaction processing systems (OLTP) and large-scale analytical systems (OLAP).

Today's Agenda

Course Outline & Logistics

Why you should take this course?

- You want to learn how to make database systems **scalable**, for example, to support web or mobile applications with millions of users.
- You want to make applications that are highly **available** (*i.e.*, minimizing downtime) and operationally robust.
- You have a natural curiosity for the way things work and want to know what goes on inside major websites and online services.
- You are looking for ways of making systems easier to maintain in the long run,even as they grow and as requirements and technologies change.
- If you are good enough to write code for a database system, then you can write code on almost anything else.

Course Objectives

- Learn about modern practices in database internals and systems programming.
- Students will become proficient in:
  - Writing correct + performant code
  - Proper documentation + testing
  - Working on a systems programming project

Course Topics

- Logging & Recovery Methods
- Concurrency Control
- Query Optimization
- New Hardware (NVM, GPU)

Background

- I will assume that you have already taken an intro course on database systems (*e.g.*,, GT 4400).
- We will discuss modern variations of classical algorithms that are designed for today's hardware.
- Things that we will **not** cover: SQL, Relational Algebra, Basics of Operating Systems, Computer Architecture, Algorithms + Data Structures.

Background

- All programming assignments will be written in C++11.
- You will learn how to debug and profile multi-threaded programs.
- Assignment 0 will help get you caught up with C++.

Course Logistics

- Course Web Page
  - Schedule: https://www.cc.gatech.edu/ jarulraj/courses/8803-s22/
- Discussion Tool: Piazza
  - For all technical questions, please use Piazza. Don't email me directly.
  - All non-technical questions should be sent to me
- Grading Tool: Gradescope
  - You will get immediate feedback on your assignment.
  - You can iteratively improve your score over time.
- Office Hours
  - Both in-person and remote participation allowed
  - Sign-up sheet posted on Piazza.

Course Logistics

- Course Policies
  - Programming assignments (not the zeroth one) will be done in groups of two people.
  - Exercise sheets must be your own work. They are **not** group assignments.
  - You may **not** copy source code from other people or the web.
  - Plagiarism will **not** be tolerated.
- Academic Honesty
  - Refer to Georgia Tech Academic Honor Code.
  - If you are not sure, ask me.

Late Policy

- You are allowed **<u>four</u>** slip days for either programming assignments or exercise sheets.
- You lose 25% of an assignment's points for every 24 hrs it is late.
- Mark on your submission (1) how many days you are late and (2) how many late days you have left.

Teaching Assistants

- Gaurav Tarlok Kakkar
  - M.S. (Computer Science)
  - Worked at Adobe (2 years).
  - Research Topic: Video analytics using deep learning.
- If you are acing through the assignments, you might want to hack on the video analytics system (codenamed EVA) that we are building.
- Drop me a note if you are interested!

Course Rubric

- Programming Assignments (5% + 3 $\times$ 10%)
- Exercise Sheets (3 $\times$ 5%)
- Mid-term Exam (15%)
- Final Exam (15%)
- Class Participation (10%)

Programming Assignments

- Four assignments based on the BuzzDB academic DBMS.
- Goal is to familiarize you with the internals of database management systems.
- We will use Gradescope for giving you immediate feedback on programming assignments and Piazza for providing clarifications.
- We will provide you with test cases and scripts for the programming assignments.
- If you have not yet received an invite from Gradescope, you can use the entry code that has been shared on Canvas.

Machine Setup

- Operating System (OS): Ubuntu 18.04
- **Build System**: cmake
- Testing Library: Google Testing Library (gtest)
- **Continuous Integration (CI)** System: Gradescope
- Memory Error Detector: valgrind memcheck

C++ Topics

- STL map
- File I/O
- Threading (later assignments)
- Smart Pointers (later assignments)

Assignment 0

- **Goal:** Help brush up your C++ programming skills
- Knowledge of basic data structures and algorithm design

Final Assignment - Project Option

- An optional component of this course will be an exploratory research project.
- Students will organize into a group and choose to implement a project that is:
  - Relevant to any topic discussed in class.
  - Requires programming effort from all team members.
  - Goal is to get your creative juices flowing!

Final Assignment - Project Option

- Optional component of the course (not needed for getting an A grade)
- You don't have to pick a topic until midway through the course.
- We will provide sample project topics.
- This project can be a conversation starter in job interviews.

Project Option – Deliverables

- Proposal: 1-page report
- Final Presentation: 2-page report + presentation

Project Option – Proposal

- Each proposal must discuss:
  - What is the problem being addressed by the project?
  - Why is this problem important?
  - How will the team solve this problem?

Project Option – Final Presentation

- Five minute presentation on the final status of your project.
- You'll want to include any performance measurements or benchmarking numbers for your implementation.
- Demos are always hot too.
- Prizes for top two groups picked by the class.

Exercise Sheets

- Four pencil-and-paper tasks.
- You will need to upload the sheets to Gradescope.
- We will share the grading rubric for exercise sheets via Gradescope.

Exercise Sheet #0

- Hand in one page with the following information:
  - Digital picture (ideally 2x2 inches of face)
  - Name, interests, More details on Gradescope
- The purpose of this sheet is to help me:
  - know more about your background for tailoring the course, and
  - recognize you in class

History of Database Systems

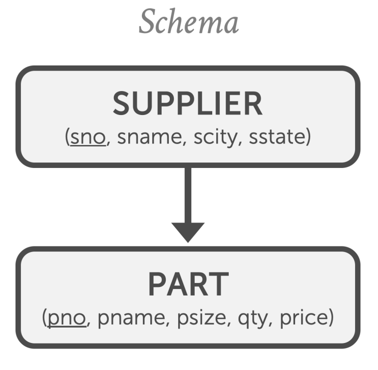
History Repeats Itself

- Reference
- Design decisions in early database systems are still relevant today.
- The “SQL vs. NoSQL” debate is reminiscent of “Relational vs. CODASYL” debate.
- Old adage: he who does not understand history is condemned to repeat it.
- Goal: ensure that future researchers avoid replaying history.

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.

Hierarchical Data Model



Hierarchical Data Model

students

sno	sname	scity	sstate	parts
1001	Electrical Parts	New York	NY	part-1
1002	Auto Parts	Boston	MA	part-2

part-1

pno	pname	psize	qty	price
999	Fridge	Large	10	100

part-2

pno	pname	psize	qty	price
888	Batteries	Small	14	99

Hierarchical Data Model

- Advantages
  - No need to reinvent the wheel for every application
  - **Logical data independence**: New record types may be added as the logical requirements of an application may change over time.

Hierarchical Data Model

- Limitations
  - Information is repeated.
  - **Tree** structured data model is very restrictive: Existence depends on parent tuples.
  - No **Physical data independence**: Cannot freely change storage organization to tune a database application because there is no guarantee that the applications will continue to run
  - Optimization: A tuple-at-a-time user interface forces the programmer to do manual query optimization, and this is often hard.

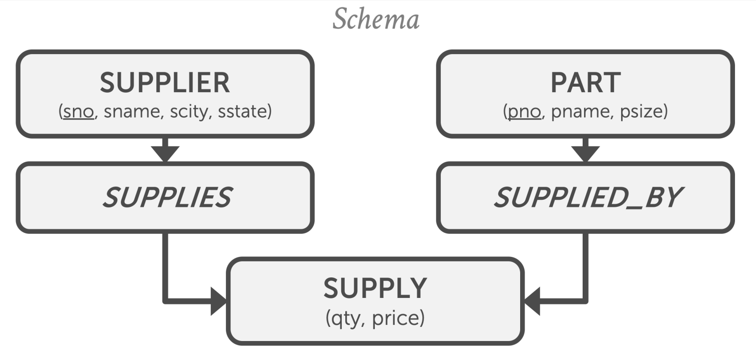
1960s – IDS

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

1960s – CODASYL

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

Network Data Model

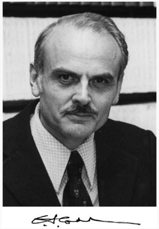


Network Data Model

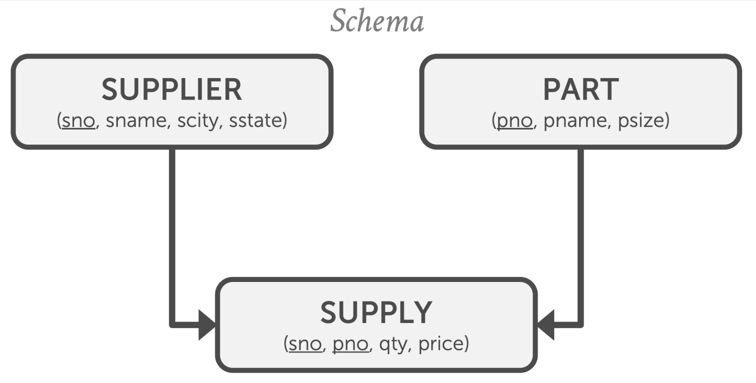
- Advantages
  - **Graph** structured data models are less restrictive
- Limitations
  - Poorer physical and logical data independence: Cannot freely change storage organizations or change application schema
  - **Slow loading and recovery:** Data is typically stored in one large network. This much larger object had to be bulk-loaded all at once, leading to very long load times.

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 high-level declarative language.
  - Physical storage left up to implementation.



1970s – Relational Data Model

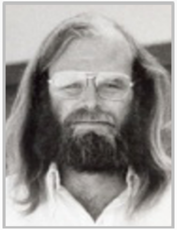


Relational Data Model

- Advantages
  - Set-a-time languages are good, regardless of the data model, since they offer physical data independence
  - Logical data independence is easier with a simple data model than with a complex one.
  - Query optimizers can beat all but the best tuple-at-a-time DBMS application programmers.

1970s – Relational Data Model

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



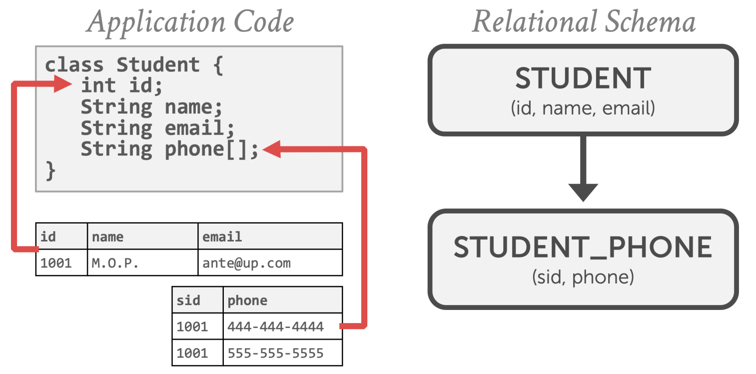
1980s – Relational Data Model

- The relational model wins.
  - IBM comes out with DB2 in 1983.
  - "SEQUEL" becomes the standard (SQL).
- Many new "enterprise" DBMSs, but Oracle wins marketplace.
- **Examples:** Teradata, Informix, Tandem, *e.t.c.*

1980s – Object-Oriented Data Model

- Avoid **relational-object impedance mismatch** by tightly coupling objects and database.
- Analogy: Gluing an apple onto a pancake
- Objects are treated as a first class citizen.
- Objects may have many-to-many relationships and are accessed using pointers.
- Few of these original DBMSs from the 1980s still exist today but many of the technologies exist in other forms (*e.g.*, JSON, XML)
- **Examples:** Object Store, Mark Logic, *e.t.c.*

1980s – Object-Oriented Data Model



1980s – Object-Oriented Data 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.

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 storage)

2000s – NoSQL Systems

- Focus on high-availability & high-scalability:
  - Schema-less (*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 Transactional-Analytical Processing.
- 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.

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 – Specialized Systems

- Shared-disk DBMSs
- Embedded DBMSs
- Times Series DBMS
- Multi-Model DBMSs
- Blockchain DBMSs

2010s – Specialized Systems

Conclusion

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 there is no single trendsetter.
  - The era of cloud systems has begun.
- The relational model has won for operational databases.

Next Class

- Recap of topics covered in the CS 4420/6422
  - Storage Management
  - Access Methods
  - Query Execution
- Submit exercise sheet #0 via Gradescope.