CS 133: Databases

Fall 2019
Lec 01 – 09/03
Introduction & Relational Model

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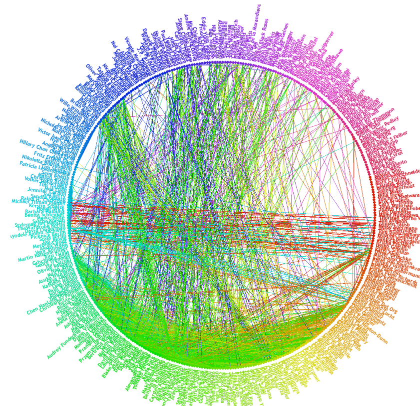
http://www.puntogeek.com/wp-content/uploads/2012/12/21168.strip_.gif

Data!

Need systems to manage the data

- Data is everywhere
  - Banking, airline reservations
  - Social media, clicking anything on the internet

http://www.bigdataanalyticstoday.com/category/infographics/



"facebook friend wheel", https://www.flickr.com/photos/antjeverena/

Goals for Today

- What is a database anyway?
- Important DBMS features
  - and challenges!
- Course logistics
- Relational data model
  - Why it's great
  - What it looks like (intro to SQL)

So, what is a database?

From the textbook:

- *Database*: a collection of data, typically describing the activities of one or more related organizations
- *Database system, DataBase Management System (DBMS)*: software designed to assist in maintaining and utilizing large collections of data

DBMS desiderata

- Ask questions (queries) about data
- Add and update data
- Persist the data (keep it around)

- E.g., banking application
  - *Query*: What is Alice's balance?
  - Update: Alice deposits $100
  - Persist: Alice hopes her money is still there after a power outage…

Sounds easy!

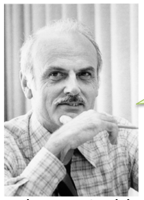
```
Account, Branch, Name, Balance
45, Claremont, Alice, 200
67, Claremont, Bob, 100000
78, Pasadena, Carl, 987654
.
.
.
```

- Store data in text files
  - Accounts separated by newlines
  - Fields separated by commas
- *Query: what is Alice's balance?*

Abstracting data management

- Can come up with tricks to optimize a particular query/application
  - End up redoing this work for new apps

Relational DBMS to the rescue



Edgar F. Codd
Turing award, 1981

[There should be] *a clear boundary* between the **logical and physical aspects** of database management[1]

[1]http://en.wikiquote.org/wiki/E._F._Codd

Physical Independence
- Applications need not know how data is physically structured and stored
- Instead, have logical ***data model***
- Leave the implementation details and optimization to DBMS

Relational DBMS to the rescue

- Relational data model: data is stored in relations
- Example: *Banking* info

account	branch	name	balance
45	Claremont	Alice	200
67	Claremont	Bob	100000
78	Pasadena	Carl	987654

- A declarative query language
  - Specify what answers a query should return, but not how the query is executed
  - E.g., SQL, Datalog (subset of Prolog)

Query: what is Alice's balance?

```
SELECT balance
FROM Banking
WHERE name = "Alice";
```

DBA designs these!

Relational Model: Levels of Abstraction

- Conceptual/Logical schema
  Students (***sid***: string, *name:* string, *login:* string, *gpa:* real)
  Courses (***cid***: string, *cname:* string, *credits:* integer)
  Enrolled (***sid***: string, ***cid***: string, *grade:* string)

Describes data in terms of data model

Entities and relationships!

- Physical schema
  - Store the relations as unsorted files
  - Create *indexes* on Students.sid and Courses.cid

Specifies storage details

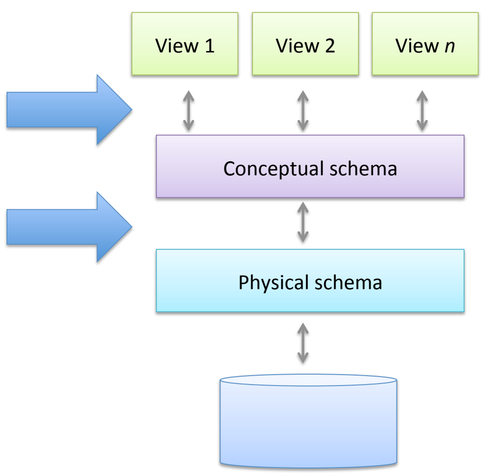
- External schema ("views")
  - view each course's enrollment
    CourseInfo(***cid***: string, *enrollmnt:* integer)

```
CREATE VIEW CourseInfo AS
    SELECT cid, COUNT (*) as enrollmnt
    FROM Enrolled
    GROUP BY cid;
```

Allow customized data access

Data Independence

- Logical data independence
  - Protected from changes in conceptual schema
- Physical data independence
  - Protected from changes in physical schema



Modern DBMS Features

- Logical data model
  - We focus on relational in this course
    - May touch on others, e.g., XML, Document
  - Data independence!
- Declarative language
  - Queries
  - Updates
- Persistence

But wait, there's more…

Concurrent Access

- **Banking example: ATM withdrawal pseudocode**
  get *balance*;
  if *balance* > *amount*
   withdraw *amount;*
   newBalance = balance - amount;
   write *balance = newBalance;*

- Alice and Bob share an account.
  - Alice goes to one ATM, withdraws $100
  - Bob goes to another ATM, withdraws $50

- Initial balance = $400
- Final balance?

Example from Jun Yang

Concurrent Access

Alice withdraws $100
get *balance*; $400

Bob withdraws $50
get *balance*; $400
if *balance* > *amount*
 withdraw *amount;*
 newBalance = balance - amount;
 write *balance = newBalance;* $350

Alice:
if *balance* > *amount*
 withdraw *amount;*
 newBalance = balance - amount;
 write *balance = newBalance;* $300

What can we do?

Final balance = $300!!

Example from Jun Yang

System Failures

- **Banking example: balance transfer**
  decrement account X by $100
  increment account Y by $100

- What if power goes out after first instruction?

- DBMS buffers and updates some data in memory before writing to disk
  - what if power goes out before write to disk?

- *Keep a log of updates, undo/redo upon recovery*

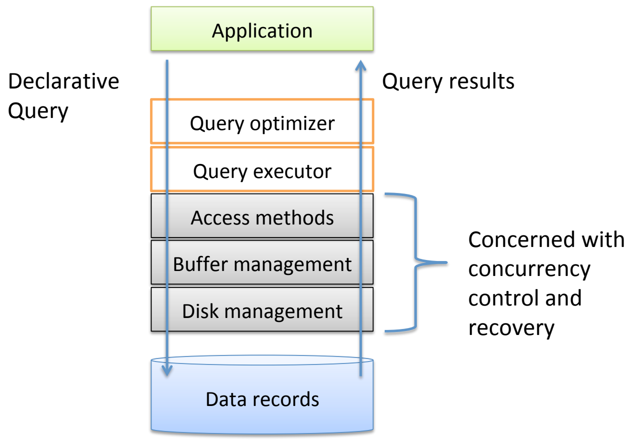
Example from Jun Yang

Modern DBMS Features (cntd)

- Logical data model
- Declarative language
- Persistence

- Concurrent access
- Fault tolerance
- Performance!
  - Lots of queries
  - Lots of data

Simplified RDBMS Architecture



Course Overview

- Design principles behind DBMS!
- "Bottom-up" order of topics to show role of **abstraction** and **algorithms for efficiency/ optimization**
  - Physical data organization
  - Relational algebra and SQL
  - Query evaluation and optimization
  - Transactions, concurrency control, recovery
  - Database design

Course Objectives

- Provide a solid background in database management **system design principles**
- Promote understanding of these principles through hands-on exercises **implementing the internals** of a relational database management system
- Further develop students' ability to reason about algorithm and software design, optimization, and **tradeoffs generally applicable in computer science**

Labs: SimpleDB

- Labs 1-4: Implement key features of a (simplified) DBMS in Java
  - Files, Storage
  - Relational Operators
  - Query Optimizer
  - Locking with Transactions
- Lab 5: database design

Lab 1: Getting started "due" next Wednesday

Grade Components (see syllabus)

• Weekly problem sets	14%	70 pts
• (5) Labs	40%	200 pts
• Midterm	20%	100 pts
• Final	20%	100 pts
• Participation	6%	30 pts

Administrivia

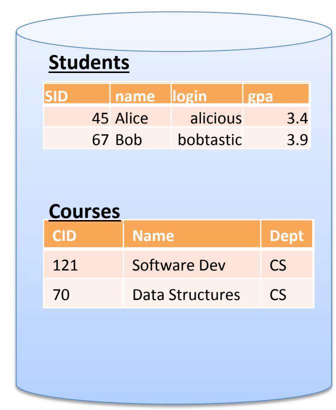
- Course website: https://www.cs.hmc.edu/~beth/courses/cs133/current
  - Syllabus, calendar, lab descriptions
- Textbook: ***Database Management Systems 3rd Edition***, by Ramakrishnan and Gehrke
- Piazza for questions about labs, problem sets, etc.: piazza.com/hmc/fall2019/cs133/home
- Assignment submission
  - Problem sets → Sakai
  - Lab assignments → Gradescope
- Grutors
  - Ivy Liu

The Relational Model

- Many RDBMS vendors, including open-source
  - Oracle
  - MySQL
  - PostgreSQL
  - SQLite
  - DB2
  - SQL Server
  - …
- We'll touch on other data models as well

Key Concepts: Relational Model

- *Database*: collection of relations
- *Relation:* list of attributes
- Relations have sets of *tuples*
- Schema (metadata)
  - Specification of how data is to be structured logically
  - Contains attribute *types*
  - Defined at set-up



Relational Model: Synonyms

More formal	....	Less formal
Relation	Table	
Tuple	Row	Record
Attribute	Column	Field
Domain	Type	

Structured Query Language (SQL)

- Data definition language (DDL)
  - Define the schema (create, change, delete relations)
  - Specify constraints, user permissions
- Data modification language (DML)
  - Find data that matches criteria
  - Add, remove, update data
  - ***The DBMS is responsible for efficient evaluation!***
- Co-invented by
  Don Chamberlin (HMC '66)!

Photo: http://researcher.watson.ibm.com/researcher/view.php?person=us-dchamber

A Relation Instance

- An ***instance*** of a relation is its contents at a given time
  - *cardinality: # tuples*
  - *arity: # attributes*

Students

SID	Name	Login	SSN	GPA
45	Alice	alicious	000-00-0000	3.4
67	Bob	bobtastic	000-00-0001	3.9
78	Carl	carl	000-00-0010	2.5

SQL: Creating Relations

- Create **Students** relation:

```
CREATE TABLE
Students (
   sid CHAR(20),
   name CHAR(20),
   login CHAR(100),
   SSN CHAR(12),
   gpa FLOAT);
```

Create **Enrolled** relation:

```
CREATE TABLE Enrolled (
    sid CHAR(20),
    cid CHAR(20),
    grade CHAR(2));
```

- Domain info is type of Integrity constraint (IC)
  - IC: a condition on the database schema, restricts data that can be stored

Adding and Removing Tuples

- Insert a single tuple

```
INSERT INTO Students (sid, name, login, SSN, gpa)
VALUES (45, 'Alice', 'alicious', '000-00-0000,
3.4);
```

- Delete tuples that satisfy condition (*predicate)*

```
DELETE FROM Students S
WHERE S.name = 'Alice';
```

Integrity Constraints: Keys

- *Superkey* is a set of field(s) that
  - Uniquely identifies a tuple
  - *Candidate key*: does so *minimally*
  - *Primary key:* a chosen candidate key

Students

SID	Name	Login	SSN	GPA
45	Alice	alicious	000-00-0000	3.4
67	Bob	bobtastic	000-00-0001	3.9
78	Carl	carl	000-00-0010	2.5

Primary key

Integrity Constraints: Foreign Keys

- Referential integrity, logical "pointer"
  - Set of fields in one relation refer to primary key of another

Students

SID	Name	Login	SSN	GPA
45	Alice	alicious	000-00-0000	3.4
67	Bob	bobtastic	000-00-0001	3.9
78	Carl	carl	000-00-0010	2.5

Primary key

Enrolled

SID	CID	Grade
45	CS133	A
45	CS121	B
78	CS5	A

Foreign key

```
INSERT INTO
Enrolled(sid,cid,grade)
VALUES (43,CS133,D); ?
```

Defining Key Constraints

- Specified in schema definition

```
CREATE TABLE Students (
  sid CHAR(20),
    name CHAR(20),
    login CHAR(10),
    SSN CHAR(20),
    gpa FLOAT,
    PRIMARY KEY(sid),
    UNIQUE (SSN)
  );
```

```
CREATE TABLE Enrolled (
   sid CHAR(20),
   cid CHAR(20),
   grade CHAR(2),
   PRIMARY KEY (sid,cid),
   FOREIGN KEY (sid)
      REFERENCES Students
);
```

Primary and Candidate Keys in SQL

- Possibly many *candidate keys* (specified using UNIQUE), one of which is chosen as the *primary key*.
- Keys must be used carefully!
- Example:
  "For a given student and course, there is a single grade."

```
CREATE TABLE Enrolled
  (sid CHAR(20)
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY (sid,cid))
```

VS.

```
CREATE TABLE Enrolled
  (sid CHAR(20)
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY  (sid),
   UNIQUE (cid, grade))
```

"Students can take only one course, and no two students in a course receive the same grade."

SQL: Single Relation Queries

Students

SID	name	login	gpa
45	Alice	alicious	3.4
67	Bob	bobtastic	3.9
78	Carl	carl	2.5

```
SELECT name
FROM Students
WHERE gpa > 3.7;
```

name
Bob

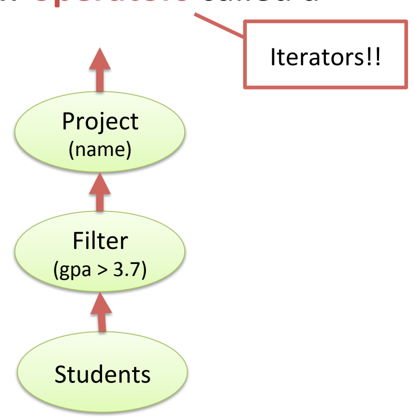
```
SELECT *
FROM Students S
WHERE S.gpa > 3.7;
```

sid	name	login	gpa
67	Bob	bobtastic	3.9

Query Execution: Teaser

Query optimizer transforms a declarative query into a pipeline of dataflow **operators** called a ***query execution plan***

```
SELECT name
FROM Students
WHERE gpa > 3.7;
```



SQLite Demo

```
19:05 [beth@knuth:
8 % sqlite3 college.db
SQLite version 3.8.6 2014-08-15 11:46:33
Enter ".help" for usage hints.
sqlite> CREATE TABLE Students (
   ...> sid INT,
   ...> name VARCHAR(255),
   ...> login VARCHAR(20),
   ...> gpa FLOAT,
   ...> PRIMARY KEY (sid)
   ...> );
sqlite> .tables
Students
sqlite> INSERT INTO Students(sid,name,login,gpa) VALUES(45,"Alice","alicious",3.4);
sqlite> SELECT * FROM Students;
45|Alice|alicious|3.4
sqlite> .mode column
sqlite> .header on
sqlite> SELECT * FROM Students;
sid         name        login       gpa
----------  ----------  ----------  ----------
45          Alice       alicious    3.4
sqlite> .quit
```

The database is in the file you specify. The file is created if it doesn't exist.

SQL statements end with a semicolon. Capitalization looks nice, but not required.

These two settings for mode and header make query results easier to read.

Also see: "Resources" on course website and www.sqlite.org