Databases
The Relational Model

Kai Brünnler
CAS Applied Data Science
University of Bern

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Database Management System

- A DBMS consists of
  - A collection of interrelated data
  - A set of programs to access the data
  - An environment that is both *convenient* and *efficient* to use
- Classic Database Applications:
  - Banking, Airlines, Universities, Sales, Online retailers, Manufacturing, Human resources
- Our running Example: A University Database.
  - Example tasks: add new students, register students for courses, list course participants, assign grades, compute grade point averages, generate transcripts
- Today databases are everywhere!
  - What's the most widely deployed database software?

SQLite

- SQLite is a public domain embedded SQL database engine
- The most widely deployed database
- https://www.sqlite.org
- Less than 500KB
- "a replacement for fopen()"

- It is used in:
  - Android, iPhone
  - Windows 10, MacOS
  - Firefox, Chrome, Safari
  - Skype, Dropbox, Adobe Reader
  - etc.

Drawbacks of File Systems

In the early days, database applications were built directly on top of file systems. But that leads to:

- Data isolation
  - Multiple files, multiple file formats
- Data redundancy and inconsistency
  - Duplication of information in different files
  - Example: data of a student with double major is stored by both departments
- Difficulty in accessing data
  - Need to write a new program for a new task
  - Example: generate list of all students with certain grade
- Integrity problems
  - Integrity constraint example: no two students should have the same email address
  - Integrity constraints become “burried” in program code: hard to understand and hard to change

Drawbacks of File Systems

- Updates are not atomic
  - Failures may leave database in an inconsistent state
  - Example: Transfer of funds from one account to another should either complete or not happen at all
- Problems with concurrent access
  - Concurrent access can lead to inconsistencies
  - Example: Two people reading a balance (say 100) and updating it by withdrawing money (say 50 each) at the same time
- Security problems
  - Hard to provide user access to some, but not all, data
  - Example: A schedule planner needs to know department of an instructor but is not allowed to see salary

Database systems were developed to solve these problems.

Relational Model

- Example of tabular data in the relational model

Columns

Rows

ID	*name*	*dept_name*	*salary*
22222	Einstein	Physics	95000
12121	Wu	Finance	90000
32343	El Said	History	60000
45565	Katz	Comp. Sci.	75000
98345	Kim	Elec. Eng.	80000
76766	Crick	Biology	72000
10101	Srinivasan	Comp. Sci.	65000
58583	Califieri	History	62000
83821	Brandt	Comp. Sci.	92000
15151	Mozart	Music	40000
33456	Gold	Physics	87000
76543	Singh	Finance	80000

(a) The *instructor* table

A Sample Relational Database

ID	*name*	*dept_name*	*salary*
22222	Einstein	Physics	95000
12121	Wu	Finance	90000
32343	El Said	History	60000
45565	Katz	Comp. Sci.	75000
98345	Kim	Elec. Eng.	80000
76766	Crick	Biology	72000
10101	Srinivasan	Comp. Sci.	65000
58583	Califieri	History	62000
83821	Brandt	Comp. Sci.	92000
15151	Mozart	Music	40000
33456	Gold	Physics	87000
76543	Singh	Finance	80000

(a) The *instructor* table

dept_name	*building*	*budget*
Comp. Sci.	Taylor	100000
Biology	Watson	90000
Elec. Eng.	Taylor	85000
Music	Packard	80000
Finance	Painter	120000
History	Painter	50000
Physics	Watson	70000

(b) The *department* table

Schema and Instance

- They are similar to type and value of a variable in programming languages
- **Schema** – the logical structure of the database
  - Example:
    - instructor(ID, name, dept_name, salary)
    - department(dept_name, building, budget)
    - … and the meaning of all those terms
- **Instance** – the actual content of the database at a particular point in time
  - Example: the tables we have seen before
- We usually use **SQL** (Structured Query Language) to access a database
  - The schema is modified by the **Data Definition Language** (DDL)
  - The instance is modified by the **Data Manipulation Language** (DML)

SQL: Data Definition Language

- Defining the database schema and implementation details

  Example: **create table** *instructor* (
  ID **char**(5),
  name **varchar**(20)**,**
  dept_name **varchar**(20),
  salary **numeric**(8,2))

- DDL compiler generates metadata stored in the **data dictionary:**
  - Database schema
  - Integrity constraints
    - Primary key constraint
      - Example: An ID uniquely identifies an instructor
    - Foreign key constraint
      - Example: The *dept_name* of an *instructor* must exist in the *department* relation
  - Authorization

SQL: Data Manipulation Language

- Example: Find the name of the instructor with ID 22222

  select *name*
  from *instructor*
  where *ID* = '22222'

- Example: Find the building of the instructor "Einstein"

  select *building*
  from *instructor*, *department*
  where *instructor.dept_name* = *department.dept_name* **and**
  name = 'Einstein'

Database Schema Design

- Is there any problem with this schema?

ID	*name*	*salary*	*dept_name*	*building*	*budget*
22222	Einstein	95000	Physics	Watson	70000
12121	Wu	90000	Finance	Painter	120000
32343	El Said	60000	History	Painter	50000
45565	Katz	75000	Comp. Sci.	Taylor	100000
98345	Kim	80000	Elec. Eng.	Taylor	85000
76766	Crick	72000	Biology	Watson	90000
10101	Srinivasan	65000	Comp. Sci.	Taylor	100000
58583	Califieri	62000	History	Painter	50000
83821	Brandt	92000	Comp. Sci	Taylor	100000
15151	Mozart	40000	Music	Packard	80000
33456	Gold	87000	Physics	Watson	70000
76543	Singh	80000	Finance	Painter	120000

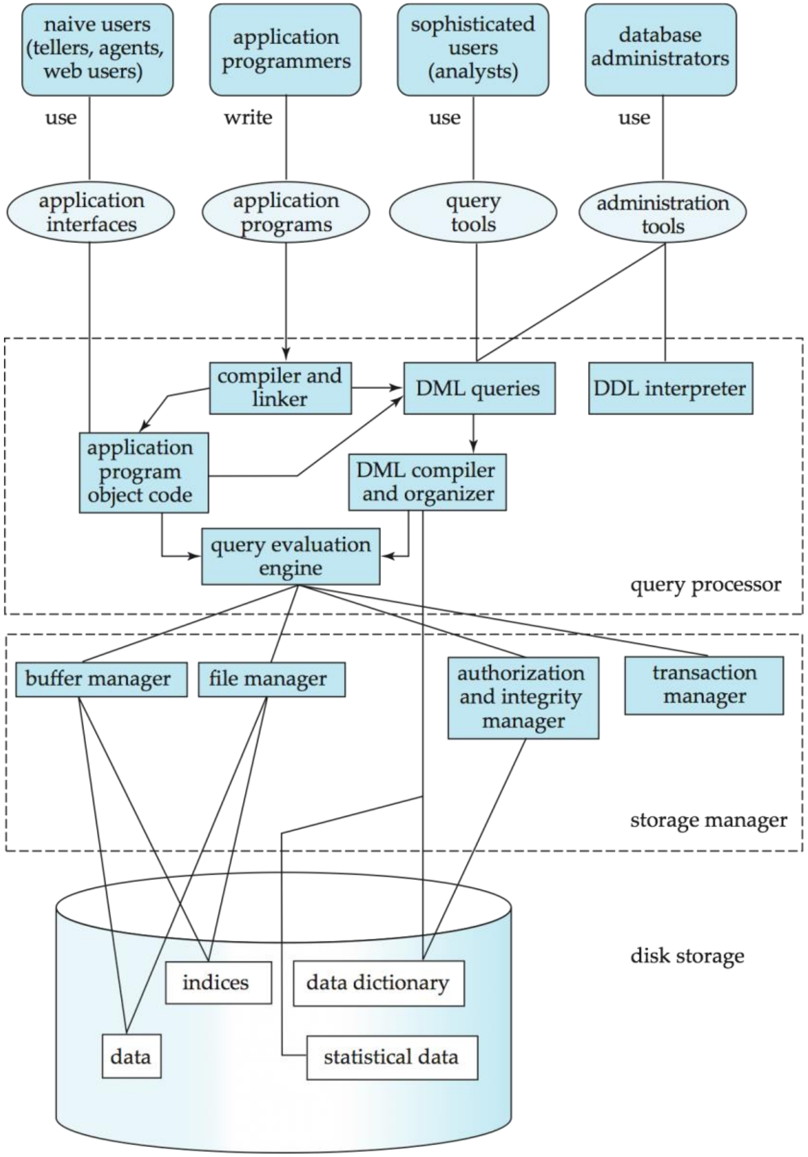
Database Schema Design

- The previous database schema is bad:
  - Repetition of information:
    - the budget of a certain department is stored redundantly for each instructors in the department
  - Difficulty of storing information:
    - how to store the budget of a department without instructors?

- Would it be better to split the data into two tables?

Structure of a DBMS

- A database system consists of two main components:
  - The **Query Processor** translates queries into an efficient sequence of operations at the physical level.
  - The **Storage manager** stores data and executes operations at the physical level.



The *course* Relation

course_id	*title*	*dept_name*	*credits*
BIO-101	Intro. to Biology	Biology	4
BIO-301	Genetics	Biology	4
BIO-399	Computational Biology	Biology	3
CS-101	Intro. to Computer Science	Comp. Sci.	4
CS-190	Game Design	Comp. Sci.	4
CS-315	Robotics	Comp. Sci.	3
CS-319	Image Processing	Comp. Sci.	3
CS-347	Database System Concepts	Comp. Sci.	3
EE-181	Intro. to Digital Systems	Elec. Eng.	3
FIN-201	Investment Banking	Finance	3
HIS-351	World History	History	3
MU-199	Music Video Production	Music	3
PHY-101	Physical Principles	Physics	4

The *section* Relation

course_id	*sec_id*	*semester*	*year*	*building*	*room_number*	*time_slot_id*
BIO-101	1	Summer	2009	Painter	514	B
BIO-301	1	Summer	2010	Painter	514	A
CS-101	1	Fall	2009	Packard	101	H
CS-101	1	Spring	2010	Packard	101	F
CS-190	1	Spring	2009	Taylor	3128	E
CS-190	2	Spring	2009	Taylor	3128	A
CS-315	1	Spring	2010	Watson	120	D
CS-319	1	Spring	2010	Watson	100	B
CS-319	2	Spring	2010	Taylor	3128	C
CS-347	1	Fall	2009	Taylor	3128	A
EE-181	1	Spring	2009	Taylor	3128	C
FIN-201	1	Spring	2010	Packard	101	B
HIS-351	1	Spring	2010	Painter	514	C
MU-199	1	Spring	2010	Packard	101	D
PHY-101	1	Fall	2009	Watson	100	A

The *teaches* Relation

ID	*course_id*	*sec_id*	*semester*	*year*
10101	CS-101	1	Fall	2009
10101	CS-315	1	Spring	2010
10101	CS-347	1	Fall	2009
12121	FIN-201	1	Spring	2010
15151	MU-199	1	Spring	2010
22222	PHY-101	1	Fall	2009
32343	HIS-351	1	Spring	2010
45565	CS-101	1	Spring	2010
45565	CS-319	1	Spring	2010
76766	BIO-101	1	Summer	2009
76766	BIO-301	1	Summer	2010
83821	CS-190	1	Spring	2009
83821	CS-190	2	Spring	2009
83821	CS-319	2	Spring	2010
98345	EE-181	1	Spring	2009

Superkeys

- Let *K* be a subset of the set of attributes of a schema *R.*

- *K* is a **superkey of** *R* if in each possible relation of schema *R,* the values for *K* are sufficient to identify a unique tuple of *r.*

  Example: Find all superkeys of the schema *instructor*

ID	*name*	*dept_name*	*salary*
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
32343	El Said	History	60000
33456	Gold	Physics	87000
45565	Katz	Comp. Sci.	75000
58583	Califieri	History	62000
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76766	Crick	Biology	72000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000

Candidate Keys

- A minimal superkey is a superkey such that, when one attribute is removed, it is no longer a superkey.

- A candidate key is a minimal superkey.
  - Example: {*ID*} is a candidate key for instructor, *but* {*ID, name*} is not

Primary Keys

- Database designer chooses a primary means of identifying a tuple: the **primary key**.

- The primary key is part of the schema – every schema needs a primary key.

  Notation:

  instructor (<u>ID</u>, name, dept_name, salary)

  teaches (<u>ID</u>, <u>course_id</u>, <u>sec_id</u>, <u>semester</u>, <u>year</u>)

- The **primary key constraint** means two tuples can not have the same values for the primary key attributes
  - The database will reject adding a new instructor with an existing ID

How to Choose the Primary Key

- Choose a set of attributes which is
  1. a candidate key, and has
  2. stable values
- If there is no candidate key with stable values, and only then, add an additional attribute with a unique value per tuple, called **surrogate key**
- Choosing the primary key is an important and difficult decision: it is used in other parts of the database, often exposed to partners, hard to change
  - e.g. imagine choosing {semester, year, timeslot_id, building, room} as the primary key of section and later encountering a situation that requires that two sections happen in the same room
- There are not many natural (non-surrogate) primary keys, most are surrogate keys from other databases (e.g. ISBN)

Foreign Keys

- A **foreign key** is a set of attributes in one relation which is the primary key of another relation
  - Example: the dept_name attribute in the instructor relation is the primary key of the department relation

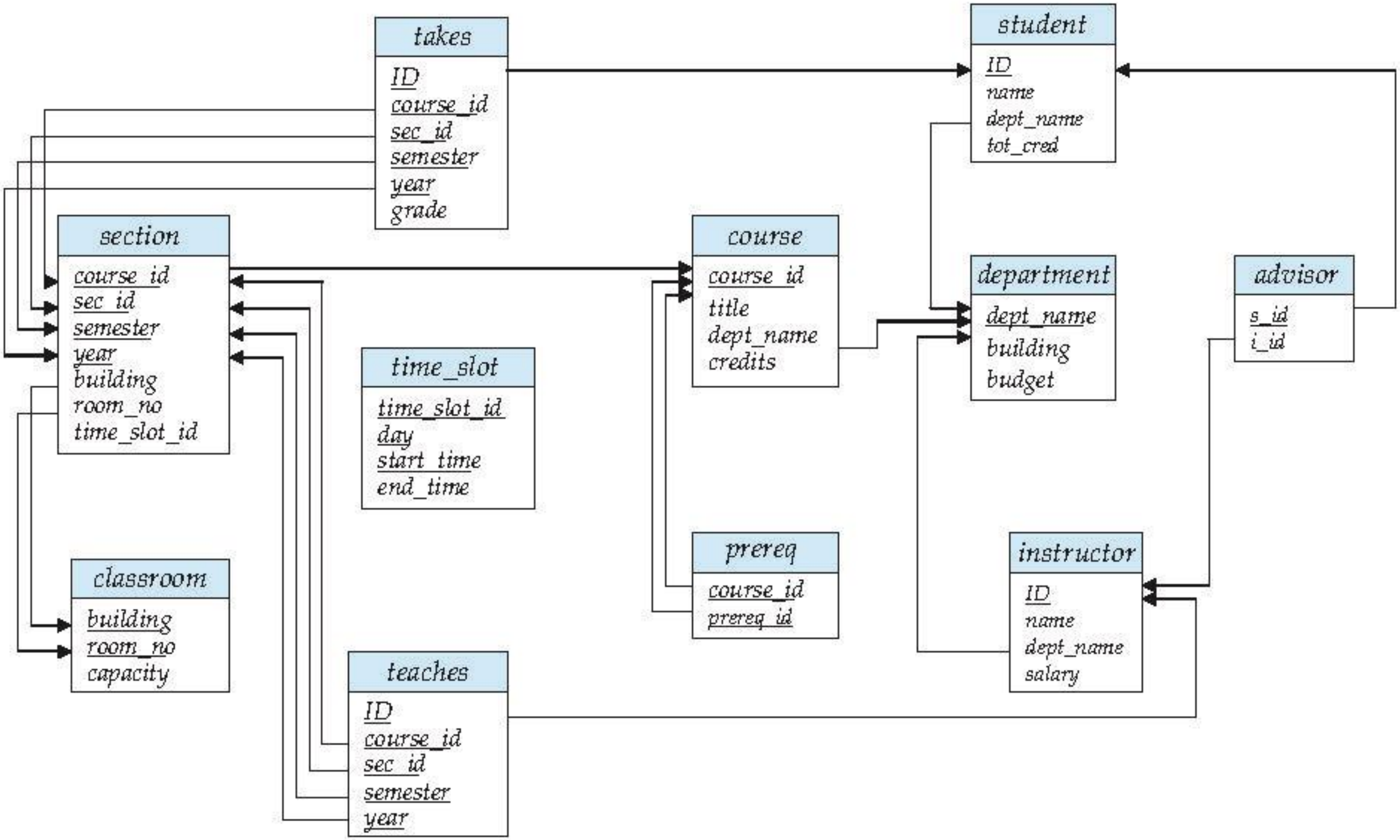
- Notation:

  instructor (<u>ID</u>, name, dept_name, salary)
  dept_name → department

  - instructor is called the referencing relation
  - department is called the referenced relation

- The **foreign key constraint** says that attribute values of the foreign key in the referencing relation have to occur in the referenced relation
  - The database will reject adding an instructor with a department which is not in the department relation

Schema Diagram for University Database



Other Data Models

- A **data model** says what data is.
- The Relational data model essentially says “data is a set of tables”
- The Object-oriented data model essentially says “data is a graph of objects”
- The Semistructured data model essentially says “data is a hierarchical, tree-like structure” (XML, JSON)