Databases – Introduction

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Course Goals & Structure

Course Goals

Overall Goal

Thorough understanding of database concepts

- from a user perspective
  (not how databases work internally)

Learning Goals

- Developing data models
- Reasoning about good/bad design
  (functional depencencies)
- Understanding and writing non-trivial SQL statements
- Basic knowledge of database programming

Motivation

Storing data is important everywhere in industry!

Course Structure

- **Introduction & Overview**
- **Relational Model**
- **Data Modelling**
  - entity relationship diagrams (ER)
  - unified modelling language (UML)
- **From Conceptual to Relational Model**
- **Advanced SQL**
  - writing nested queries with joins
- **Functional Dependencies**
  - reasoning about good/bad design
  - normalising a database schema
- **Transactions**
  - analysing transaction schedules
- **Database APIs**

Database Management Systems

Databases

A **database (DB)** is a collection of data with

- a certain logical structure
- a specific semantics
- a specific group of users

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A **database management system (DBMS)** allows to

- **create**, **modify** and manipulate a database
- **query** (retrieve) the data using a query language
- support **persistent** storage of **large amounts of data**
- enable **durability** and **recovery** from failure
- **control access** to the data by many users in **parallel**
  - without unexpected interactions among users (**isolation**)
  - actions on the data should never be partial (**atomicity**)

Motivation for Database Management Systems

Why not just store data in files?

- **no query language**
- **weak logical structure** (limited to directories)
- **no efficient access**
  - searching through a large file can take hours
- no or **limited protection** from data loss
- **no access control** for parallel manipulation of data

So we need database management systems…

ANSI SPARC Architecture

Motivation for Database Management Systems

Motivation for database management systems

- **data independence**
  - logical view on the data independent of physical storage
  - user interacts with a simple view on the data
  - behind the scenes (invisible for the user) are complex storage structures that allow rapid access and manipulation
- **avoidance of duplication**
  - different views on the same database
    - for different users or different applications
    - hiding parts of the data for privacy or security

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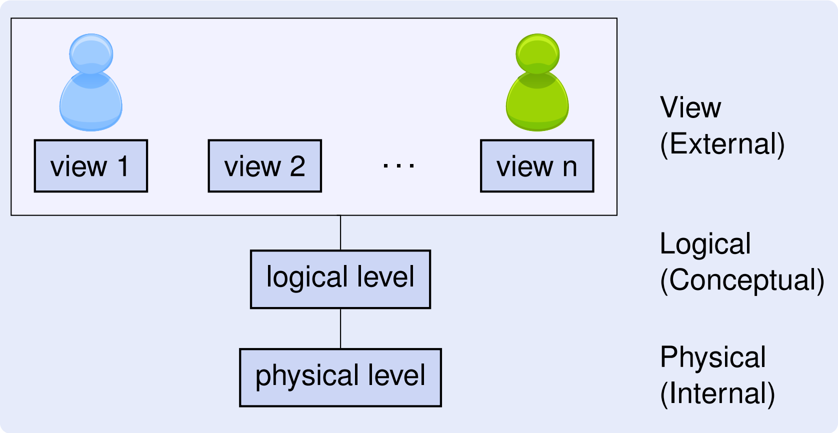
This is achieved by the ANSI SPARC Architecture ...

ANSI SPARC Architecture: 3 levels



- Different applications might use different views
- Data stored once at physical level (good for consistency)

ANSI SPARC Architecture: 3 levels

ANSI SPARC Architecture

- **View level:**
  - application programs hide details of data types
  - hide information (e.g. exam grade) for privacy or security
- **Logical level:** also called ‘conceptual schema’
  - describes data stored in the database, and
  - relations among the data
- **Physical level:**
  - how the data is stored
  - disk pages, index structures, byte layout, record order

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  - how the data is stored
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This ensures logical and physical data independence...

Data Independence

Logical data independence

Logical data independence is the ability to modify the logical schema without breaking existing applications

- applications access the views, not the logical database

Physical data independence

Physical data independence is the ability to modify the physical schema without changing the logical schema

- e.g. a change in workload might cause the need for
  - different indexing structures
  - different database engine
  - distributing the database on multiple machines
  - ...

Relational Model

Relational Model

In this course, we work with **relational databases.**
View and logical level represent data as **relations/tables.**

Example relational database instance

Customers			
id	name	street	city
191	George	1 Main	London
302	Elvis	12 East	Amsterdam
239	Lisa	5 North	New York

Accounts	
depositor	accountnr
191	101
302	217
239	205

- **row = tuple record**: (302, Elvis, 12 East, Amsterdam)

In the **pure relational model**, a table is a **set** of tuples:

- has no duplicate tuples (rows)
- no order on the tuples

Relational Model: Schema

Database schema

= structure of the database, that is, relations + constraints

Example schema

- Customers(<u>id</u>, name, street, city)
- Accounts(depositor $\rightarrow$ Customers(id), <u>accountnr</u>)

Database instance

= actual content (‘state’) of the database at some moment

Example instance

Customers			
<u>id</u>	name	street	city
191	George	1 Main	London
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depositor	<u>accountnr</u>
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Structured Query Language

Motivation for Database Management Systems

Motivation for database management systems

- high-level **declarative query languages**
  - query tells what you want, independent of storage structure
  - efficient data access (automatic query optimisation)

Declarative query languages:

- describe **what** information is sought
- **not** prescribe **how** to retrieve the desired information

Imperative vs. Declarative Languages

Algorithm = Logic + Control (Kowalski)

Imperative languages:

- explicit control
- implicit logic

Declarative languages:

- implicit control
- explicit logic

Examples of declarative languages

- logic programming (e.g. Prolog),
- functional programming (e.g. Haskell),
- markup languages (e.g. HTML), ...

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Relational databases usually use SQL as query language ...

SQL = Structured Query Language

SQL is a declarative data manipulation language. The user describes conditions the requested data is required to fulfil.

SQL Query

```
select id
from   Customers
where  name = 'Elvis' and city = 'Amsterdam'
```

SQL = Structured Query Language

SQL is a declarative data manipulation language. The user describes conditions the requested data is required to fulfil.

SQL Query

```
select id
from   Customers
where  name = 'Elvis' and city = 'Amsterdam'
```

More concise than imperative languages:

- less expensive program development
- easier maintenance

Database system will optimise the query:

- decides how to execute the query as fast as possible
- users (usually) do not need to think about efficiency

Data Models & Integrity Constraints

Motivation for Database Management Systems

Motivation for database management systems

- well-defined **data models** & **data integrity constraints**
  - relational model
  - meta language for describing
    - data
    - data relationships
    - data constraints

SQL can be used for table and constraint definitions . . .

Integrity Constraints

Example schema with key constraints

- Customers(<u>id</u>, name, street, city)
  Primary key constraint on <u>id</u>
- Accounts(depositor $\rightarrow$ Customers(id), <u>accountnr</u>)
  Foreign key constraint on depositor

Various types of constraints:

- **data types**, constrained data types (domains)
  (e.g. `numeric(2,0)`, `varchar(40)`, ...)
- **columns constraints**
  (e.g. unique, nullability, counter, ...)
- **check constraints**: logical expression for domain integrity
  (e.g. `age >= 18 and age <= 150`)

SQL DDL (Data Definition Language)

Creating a table with constraints

```
create table Solved (
  id       int          auto_increment,
  name     varchar(40)  not null,
  homework numeric(2,0) not null,
  points   numeric(2,0) not null check (points <= 10),
  primary key (id)
);
```

Note the data types and constraints!

Solved			
id	name	homework	points

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Solved			
<u>id</u>	name	homework	points

Creating a view

```
create view SolvedHomework as
    select id, name, homework
    from   Solved;
```

Concurrent Access & Transactions

Concurrent Access & Transactions

Motivation for database management systems

- multiple users, **concurrent access**
  - transactions with ACID properties

A **transaction** is a sequence of operations that performs a single logical function in a database application.

Database management system ensures **ACID properties**

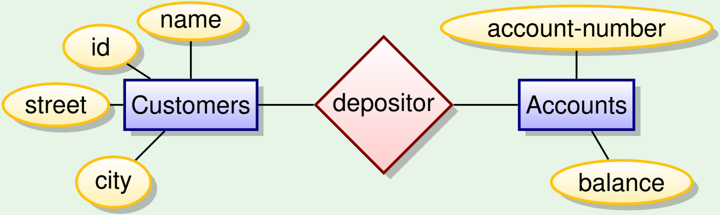
- **Atomicity:** transaction executes fully (commit) or not at all (abort)
- **Consistency:** database remains in a consistent state where all integrity constraints hold
- **Isolation:** multiple users can modify the database at the same time but will not see each others partial actions
- **Durability:** once a transaction is committed successfully, the modified data is persistent, regardless of disk crashes

Designing Database Schemes

Entity Relationship (ER) Model

Entity relationship (ER) model

- entities = objects
  - e.g. customers, accounts, bank branches
- relationship between entities
  - e.g. account 217 is held by customer Elvis
  - **relationship set descriptor** links customers with accounts

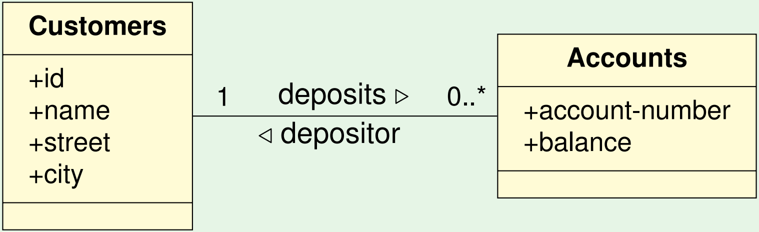


UML Class Diagram

UML class diagrams

- similar to ER diagrams:
  entities/relationships $\Longrightarrow$ **classes/associations**

Example schema as UML class diagram



Conceptual design is usually converted to the relational model.

Summary

Summary

Why Database Management Systems?

- **data independence**
  - logical view on the data independent of physical storage
- **avoidance of duplication**
  - different views on the same database
- high-level **declarative query languages** (what, not how)
  - efficient data access, automatic query optimisation
- **data models** & **data integrity (consistency)**
- multiple users, **concurrent access**
  - transactions with ACID properties
- **persistent storage**, **safety** and **high availability**
  - safety against failure (backup/restore)
- **scalability** (data could by much larger than main memory)
  - indexing, scalable algorithms
- **security** (user permission management)