Information Systems
(Informationssysteme)

Jens Teubner, TU Dortmund
jens.teubner@cs.tu-dortmund.de

Summer 2017
Part II

Overview of Database Systems
Why not simply use OS files to keep the data?

Suppose you own a cocktail bar. You want to keep inventory of your cocktail ingredients:

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Alcohol</th>
<th>InStock</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange Juice</td>
<td>0.0</td>
<td>12</td>
<td>2.99</td>
</tr>
<tr>
<td>Campari</td>
<td>25.0</td>
<td>5</td>
<td>12.95</td>
</tr>
<tr>
<td>Bacardi</td>
<td>37.5</td>
<td>3</td>
<td>16.98</td>
</tr>
</tbody>
</table>

One way of storing these data could be:

Orange Juice:0.0:12:2.99
Campari:25.0:5:12.95
Bacardi:37.5:3:16.98
What do you think of this approach?
(Think of problems that might occur. Judge the effort to solve them.)
Databases provide **abstractions** to avoid many of these problems:

\[\text{User 1} \quad \text{User 2} \quad \text{User 3} \]

\[
\text{Database Management System}
\]

\[
\text{storage}^2
\]

---

\(^2\)Some databases work on top of operating system files, others access raw disk partitions or network-attached storage directly.
Abstraction 1: Data Model

- Rather than exposing bits and bytes of the underlying storage, databases present a high-level **data model** to the outside.
- By far the most popular data model today is the **relational model**:

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Name</th>
<th>Alcohol</th>
<th>InStock</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Orange Juice</td>
<td>0.0</td>
<td>12</td>
<td>2.99</td>
</tr>
<tr>
<td></td>
<td>Campari</td>
<td>25.0</td>
<td>5</td>
<td>12.95</td>
</tr>
<tr>
<td></td>
<td>Bacardi</td>
<td>37.5</td>
<td>3</td>
<td>16.98</td>
</tr>
</tbody>
</table>

- Other data models: hierarchical model, object-oriented model, object-relational model, XML.
Schema ↔ Instance

Database Schema:
- Formal definition of the **structure** of the database contents.
- **Defined once** (when database is created).
- Restricts the possible contents that can be put into the database.

\[\sim\]
In a programming language, this corresponds to the **declaration** of a variable:

```c
unsigned int i;
```

Database State (Instance of the Schema):
- Contains the **actual data**, structured according to the schema.
- **Changes often**

\[\sim\]
**Current value** of a variable in a programming language:

```c
i = i + 42;
```
What we just saw is only the **user’s understanding** of the data representation, the **conceptual schema** (also: logical schema).

The **physical representation** is at the DBMS’s discretion.

The physical schema may use different **file organizations** or **access mechanisms** (indexes) to improve performance.
The **external schema** provides **views** on top of the conceptual schema.

- Tailored to different users or applications
- Alternative data models (e.g., XML over relational data)

```
user 1    user 2    user 3    user 4
  ┌───────────┐  ┌───────────┐  ┌───────────┐  ┌───────────┐
  │ ext. schema 1 │ ext. schema 2 │ ext. schema 3 │
  └───────────┘  └───────────┘  └───────────┘
      ┌───────────┐                          ┌───────────┐
      │          │                          │          │
      │ conceptual schema │              │ conceptual schema │
      └───────────┘                          └───────────┘
            ┌───────────┐                          ┌───────────┐
            │          │                          │          │
            │ physical schema │                    │ physical schema │
            └───────────┘                          └───────────┘
                ┌───────────┐                          ┌───────────┐
                │          │                          │          │
                │ storage │                    │ storage │
                └───────────┘                          └───────────┘
                      ┌───────────┐
                      │          │
                      │ DBMS    │
                      └───────────┘
```
The separation of views on the same data allows for **data independence**.

**Physical data independence:**
- Change physical storage layout or create **indexes**.
  - Changes invisible to conceptual schema (and external schema)—only performance might have improved.

**Logical data independence:**
- Change the logical representation of the data, but leave external schema intact.
  - Existing applications still work as before.
Example: Logical Data Independence

As a bar owner, you want to better track where your cocktail ingredients are, so you create a table `Availabilities`:

<table>
<thead>
<tr>
<th>Name</th>
<th>InStock</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange Juice</td>
<td>3</td>
<td>refrigerator</td>
</tr>
<tr>
<td>Orange Juice</td>
<td>9</td>
<td>warehouse</td>
</tr>
<tr>
<td>Campari</td>
<td>2</td>
<td>refrigerator</td>
</tr>
</tbody>
</table>

The `InStock` field can now be removed from the `Ingredients` table and computed on-demand instead. Applications will not notice the change.

```
ALTER TABLE IngredientsConceptual DROP COLUMN InStock;
CREATE VIEW IngredientsExternal AS
    SELECT i.Name, i.Alcohol, SUM(a.InStock) AS InStock, i.Price
    FROM IngredientsConceptual AS i, Availabilities AS a
    WHERE i.Name = a.Name
    GROUP BY i.Name, i.Alcohol, i.Price
```
Abstraction 2: Query Language

Databases offer declarative query languages.

- Specify **which data** should be retrieved, rather than **how** they should be retrieved.

**Example:** Names and prices of non-alcoholic drinks, ordered by Name, expressed in **SQL (Structured Query Language):**

```
SELECT Name, Price
FROM Ingredients
WHERE Alcohol = 0
ORDER BY Name
```

→ Compare this to a **program** that you’d have to write if you used OS files for storage.

→ Physical data independence would not allow use of indexes anyway.
Declarative languages need powerful optimizers.
Declarative languages allow powerful optimizers.

Today’s query optimizers are really powerful.
This releases you from worrying how you write your query “most efficiently,” but focus on the application problem instead.

Additional benefit:
Once written, your query/application will automatically benefit from improvements in the physical schema, the database software, or the underlying hardware.
Databases help to keep the **integrity** of stored data.

- Sophisticated **access control** mechanisms support very fine-granular restrictions to read or modify data.

- **Integrity constraints** can be defined along with the conceptual schema and ensure plausibility of the stored data.

  ```sql
  ALTER TABLE Availabilities
  ADD FOREIGN KEY (Name)
  REFERENCES Ingredients (Name)
  ```

- **Consistency**: The database system will check integrity constraints and ensures that every user sees a consistent database state.
Abstraction 4: Multi-User Support

Databases shield the programmer from many **multi-user issues**.

- Give each user the illusion that he/she is the only user at any time.
- Perform **locking**, and **conflict detection** automatically.

At the same time, the database helps handling **problems** or **conflicts**.

- **Atomicity**: a database transaction (i.e., a sequence of SQL commands) is executed **atomically** ("all or nothing" principle).
- **Isolation**: transactions cannot see the effects of co-running transactions; every user has the impression he/she is alone on the system.
Abstraction 5: Tolerance to Failures

Databases ensure **durability** of data modifications.

- A successful transaction will **never** get lost, whatever **failure** the system might encounter, including
  - **software crashes** on client or server side (also: OS crash);
  - **hardware failures** (hard disk crash);
  - **catastrophic failures** (fire, water, etc.).

- The database will apply necessary measures to guarantee durability:
  - **redundant storage** (write-ahead logging),
  - **backup/recovery** mechanisms.

- **Durability:** The effect of a successful transaction remain persistent and may not be undone for system reasons.
Search engines are related, but serve a different purpose.

<table>
<thead>
<tr>
<th>database</th>
<th>search engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>structured data (e.g., relational)</td>
<td>unstructured data (&quot;documents&quot;)</td>
</tr>
<tr>
<td>tailor-made query language</td>
<td>natural language interface</td>
</tr>
<tr>
<td>expressive query language</td>
<td>limited expressiveness</td>
</tr>
<tr>
<td>exact-match queries</td>
<td>ranking-based queries (top-n)</td>
</tr>
<tr>
<td>deterministic result</td>
<td>probabilistic result</td>
</tr>
</tbody>
</table>

Application demands increasingly fall between those two extremes.
- Content-aware search (e.g., email search)
- Full-text indexes in databases
- Semi-structured data (e.g., XML)
Key-value stores are not databases in the sense discussed here.

- E.g., Cassandra, Dynamo, Memcached
- Designed for **massive scalability** in **cloud environments**
  - **CAP Theorem**: Cannot have such scalability and strong transaction guarantees.
- **Much** simpler data/query model: key/value lookups only
  - Think of them as a back-end on top of which database functionality could be built.
Databases are typically used in a **three-tier architecture**.

A database system forms the heart of virtually any business application!