Information Systems (Informationssysteme)

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Part II

Overview of Database Systems

Why a Database System?

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:

Ingredients			
Name	Alcohol	InStock	Price
Orange Juice	0.0	12	2.99
Campari	25.0	5	12.95
Bacardi	37.5	3	16.98

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
```

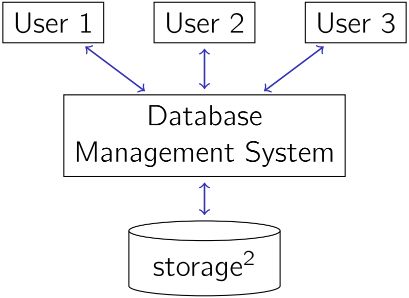
Why a Database System?

✎ **What do you think of this approach?**

(Think of problems that might occur. Judge the effort to solve them.)

Databases Provide Abstractions

Databases provide **abstractions** to avoid many of these problems:



[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**:

Ingredients			
Name	Alcohol	InStock	Price
Orange Juice	0.0	12	2.99
Campari	25.0	5	12.95
Bacardi	37.5	3	16.98

relation or table (the whole table); schema (title and header rows); record, row, or tuple (a data row); field, column, or attribute (the Name column)

- 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.

⇝ In a programming language, this corresponds to the **declaration** of a variable:

```
unsigned int i;
```

Database State (Instance of the Schema):

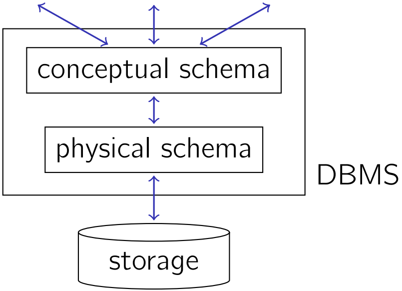
- Contains the **actual data**, structured according to the schema.
- **Changes often**

⇝ **Current value** of a variable in a programming language:

```
i = i + 42;
```

Physical vs. Conceptual Schema

- 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.

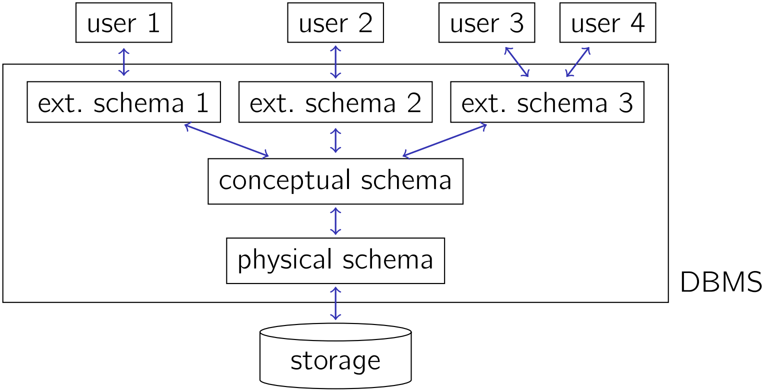


- The physical schema may use different **file organizations** or **access mechanisms** (indexes) to improve performance.

External Schemata

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)



Data Independence

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`:

Availabilities		
Name	InStock	Location
Orange Juice	3	refrigerator
Orange Juice	9	warehouse
Campari	2	refrigerator

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.

Query Optimization

- 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.

Abstraction 3: Access Control, Data Integrity

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.

```
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.

Related: Information Retrieval (Search)

> I always use Google to find the information I need.

Search engines are related, but serve a different purpose.

database	**search engine**
structured data (*e.g.*, relational)	unstructured data ("documents")
tailor-made query language	natural language interface
expressive query language	limited expressiveness
exact-match queries	ranking-based queries (top-n)
deterministic result	probabilistic result

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)

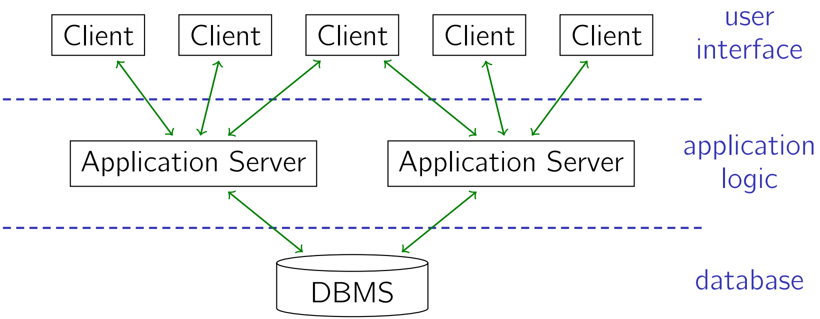
Related: Key-Value Stores

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.

DBMS in the Software Stack

Databases are typically used in a **three-tier architecture**.



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