GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

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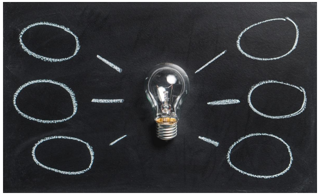
Databases and Data Warehouses



Learning Objectives

- Define Database, DBMS, and Data Warehouse
- Create a relational model for a given problem
- Draw an ER diagram for a given relational model (and vice versa)
- Normalize a small relational model into a redundant-free model
- List the result of an inner join of two tables to resolve relationships
- Formulate SQL queries for a relational model
- Create a Star-Schema from a relational model (and formulate queries)
- Sketch the operations for an OLAP cube
- Appraise the pro/cons of OLAP vs. traditional relational model
- Describe DBMS optimizations: index, bulk loading, garbage cleaning

Outline

Relational Model [10]

- Database model based on first-order predicate logic
  - Theoretic foundations: relational algebra and calculus
- Data is represented as tuples
- Relation/Table: groups similar tuples
  - Table consists of rows and named columns (attributes)
  - No duplicates of complete rows allowed
- In a pure form, no support for collections in tuples
- Schema: specify structure of tables
  - Datatypes (domain of attributes)
  - Organization and optimizations
  - Consistency via constraints

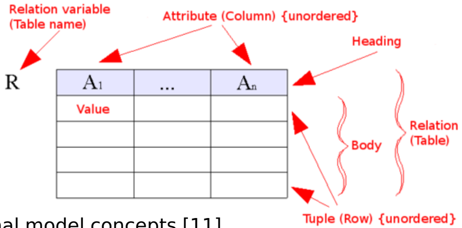


Figure: Source: Relational model concepts [11]

Example Schema for our Students Data

Description

Database for information about students and lectures

Relational model

Matrikel	Name	Birthday
242	Hans	22.04.1955
245	Fritz	24.05.1995

Table: Student table

ID	Name
1	HPDA
2	Hochleistungsrechnen

Table: Lecture table

Matrikel	LectureID
242	1
242	2
245	2

Table: Attends table representing a relation

Relationships

- Model relationships between data entities
- Cardinality defines how many entities are related
  - One-to-many: One entity of type A with many entities of type B
  - Many-to-many: One-to-many in both directions
  - One-to-one: One entity of type A with at most one entity of type B
- Relationships can be expressed with additional columns (this is not optimal!)
  - Packing data of entities together in the table
  - Alternatively: provide a “reference” to other tables

Matrikel	Name	Birthday	Lecture ID	Lecture Name
242	Hans	22.04.1955	1	HPDA
242	Hans	22.04.1955	2	Hochleistungsrechnen
245	Fritz	24.05.1995	2	Hochleistungsrechnen

Table: Student table with attended lecture information embedded

Entity Relationship Diagrams

- Illustrate the relational model and partly the database schema
- Elements: Entity, relation, attribute
  - Additional information about them, e.g., cardinality, data types

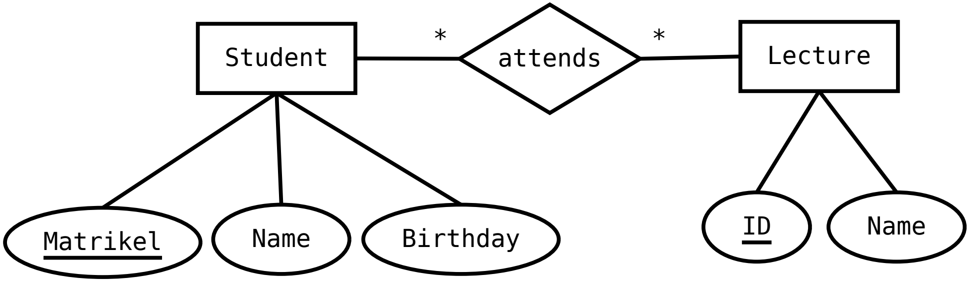


Figure: A student/lecture example in modified Chen notation
* is the cardinality and means any number is fine

Keys [16, 17, 18]

- A Superkey[16] allows addressing specific tuples in a table
- Superkey: Set of attributes that identify/address each tuple in a table
  - There can be **at most one tuple for each possible key value**
  - A superkey does not have to be minimal
    - e.g., all columns together are a Superkey of any table
    - After removing an attribute, it can still be a key
  - Simple key: key is only one attribute
  - Compound key: consists of at least two attributes
- Candidate key: a minimal key, i.e., no attribute can be removed
- **Primary key**: the selected candidate key for a table
- Foreign key: inherited key of another table
- Natural key: key that naturally is unique, e.g., matrikel
- Surrogate key: artificial key, e.g., numeric ID for a row

16 Often it is just called key

Example Keys

Table: Student table

Matrikel	Name	Birthday	...
242	Hans	22.04.1955	
245	Fritz	24.05.1995	

Table: Lecture table

ID	Name	Semester
1	HPDA	SS15
2	Hochleistungsrechnen	WS1516

Table: Attends table representing a relation

Matrikel	LectureID
242	1
242	2
245	2

- Student table
  - Candidate keys: Matrikel, (name, birthday, city), social insurance ID
  - Primary key: Matrikel (also a natural key)
- Lecture table
  - Candidate keys: ID, (Name, Semester)
  - Primary key: ID (also a Surrogate Key)
- Attends table
  - Candidate key: (Matrikel, Lecture ID)
  - Primary key: (Matrikel, Lecture ID)

Normalization [10]: My Simplified Perspective

- Normalization: process of organizing tables to minimize redundancy[19]
  - Reduces dependencies within and across tables
  - Prevents inconsistency across replicated information
  - Normally, **reduces required storage space** and **speeds up updates**
- There are different normal forms with increasing requirements
  - 1NF: It follows our notion of a table.
    - No collections in the table. A primary key exists.
  - 2NF: No redundancy of data
    - i.e., entities of many-to-many relations are stored in separate tables
    - Every column must depend on each candidate key and not a subset
  - 3NF: Columns are not functional dependent to sth. else than a candidate key
  - 4NF: Do not store multiple relationships in one table
- 4NF is a good choice[17] for transactional data processing but not big data

[17] It has been shown that 4NF can always be achieved for relational data

Example for Unnormalized Data

Matrikel	**Name**	Birthday	**Name**
242	Hans	22.04.1955	**[HPDA, Hochleistungsrechnen]**
245	Fritz	24.05.1995	Hochleistungsrechnen

Table: Not normalized Student and lecture table/relation, contains identical column names and collections. Problematic if we want to update the name of an lecture.

Matrikel	Name	Birthday	Lecture Name
242	Hans	22.04.1955	HPDA
242	Hans	22.04.1955	**Hochleistungsrechnen**
245	Fritz	24.05.1995	**Hochleistungsrechnen**

Table: Student and lecture table/relation in 1NF, it contains a many-to-many relation. Changing lecture name requires still to touch multiple rows.

Example for Unnormalized Data

Matrikel	Name	Birthday	**Age**
242	Hans	22.04.1955	40
245	Fritz	24.05.1995	20

Table: In 2NF but not 3NF: Age is functional depending on birthday

Matrikel	Attended lecture	Attended seminar
242	BDA	SIW
242	HR	SIW
242	BDA	NTH
242	HR	NTH

Table: In 3NF but not 4NF: Candidate key depends on all three columns

Outline

Databases [29]

- **Database**: an organized collection of data
  - Includes layout (schemes), queries, views
  - Database models: Relational, graph, document, ...
- **Database management system (DBMS)**: *software application that* ***interacts*** *with the user, other applications and the database itself* ***to capture and analyze data*** [29]
  - Functionality: Definition, creation, update, querying and administration of databases

DBMS functions for managing databases

- Data definition: Creation, modification of definitions for data organization
- Update: Insertion, modification and deletion of data
- Query/Retrieval: Retrieve stored and computing derived data
- Administration of users, security, monitoring, data integrity, recovery

Structured Query Language (SQL) [20]

- Declarative language: specify **what** to achieve and **not how**
- Evolving standard with growing feature set

Language elements

- Statement: instructions to perform, terminate by ;
  - Query: alternative name; usually only retrieves/computes data
- Clause: components of statements
- Predicates: conditions limiting the affected rows/columns
- Expressions: produce scalar values or tables
- Operators: compare values, change column names
- Functions: transform/compute values

PostgreSQL [10]

A popular database implementation

- Semantics: ACID support for transactions
  - A transaction is a batch of operations that either fails or succeeds
- Implements majority of SQL:2011 standard
  - Syntax may differ from SQL standard and extensions are provided
- Interactive shell via `psql`

Excerpt of features

- Materialized views (create physical tables from virtual table)
- Fulltext search
- Regular expression
- Statistics and histograms
- User defined objects (functions, operators)
- Triggers: events upon insert or update statements; may invoke functions
- New versions support semi-structed data in arrays, XML, JSON[18]

[18] See `http://www.postgresql.org/docs/14/arrays.html` and `.../functions-json.html`

Schemas (in Postgres)

Creation of a database and table

```
CREATE ROLE "bigdata" NOSUPERUSER LOGIN PASSWORD 'mybigdata';
CREATE DATABASE bigdata OWNER "bigdata";
```

To connect to a database we can use `psql -W -U` $< USERNAME > < DBNAME >$

Create our tables

```
CREATE TABLE students (matrikel INT, name VARCHAR, birthday DATE, PRIMARY KEY(matrikel));
CREATE TABLE lectures (id SERIAL, name VARCHAR, PRIMARY KEY(id));
CREATE TABLE attends  (matrikel INT, lid INT,
  FOREIGN KEY (matrikel) REFERENCES students(matrikel),
  FOREIGN KEY (lid) REFERENCES lectures(id));
--\d <TABLE>  prints the schema
```

Constraints (keeps data clean ⇒ data governance)

```
-- minimum length of the name shall be 5
ALTER TABLE students ADD CONSTRAINT length CHECK (char_length(name) > 3);
-- to remove the constraint later: ALTER TABLE students DROP CONSTRAINT length ;
-- minimum age of students should be 10 years
ALTER TABLE students ADD CONSTRAINT age CHECK (extract('year' from age(birthday)) > 10);
-- disallow NULL values in students
ALTER TABLE students ALTER COLUMN birthday SET NOT NULL; -- during CREATE with "birthday DATE NOT NULL"
ALTER TABLE students ALTER COLUMN name SET NOT NULL;
```

Populating the Tables

```sql
-- Explicit specification of columns, not defined values are NULL
INSERT INTO students (matrikel, name, birthday)
  VALUES (242, 'Hans', '22.04.1955');
-- Insertation of the same name twice could be prevented using a constraint
INSERT INTO students (matrikel, name) VALUES (246, 'Hans');
-- Order is expected to match the columns in the table
INSERT INTO students VALUES (245, 'Fritz', '24.05.1995');
INSERT INTO lectures VALUES (1, 'HPDA');
INSERT INTO lectures VALUES (2, 'Hochleistungsrechnen');

-- Populate relation
INSERT into attends VALUES(242, 1);
INSERT into attends VALUES(242, 2);
INSERT into attends VALUES(245, 2);

-- Insertations that will fail due to table constraints:
INSERT INTO students (matrikel, name) VALUES (250, 'Hans');
-- ERROR:  null value in column "birthday" violates not-null constraint
INSERT INTO students VALUES (250, 'Hans', '22.04.2009');
-- ERROR:  new row for relation "students" violates check constraint "age"
INSERT INTO students VALUES (245, 'Fritz', '24.05.1995');
-- ERROR:  duplicate key value violates unique constraint "students_pkey"
-- DETAIL:  Key (matrikel)=(245) already exists.
```

Queries [20]

- A query retrieves/computes a (sub)table from tables
  - It does **not change/mutate** any content of existing tables
- Statement: SELECT $< column1 >, < column2 >, ...$
- Subqueries: nesting of queries is possible to create temporary tables

Supported clauses

- FROM: specify the table(s) to retrieve data
- WHERE: filter rows returned
- GROUP BY: group rows together that match conditions
- HAVING: filters grouped rows
- ORDER BY: sort the rows

```sql
SELECT Matrikel, Name FROM students WHERE Birthday='22.04.1955';
-- Returns a table with one row:
--  matrikel | name
-- ----------+------
--       242 | Hans
```

More Queries

Ordering of results

```sql
-- Example comment, alternatively /* */
select * from students
  where (name != 'fritz' and name != 'nena') -- two constraints
  order by name desc; -- descending sorting order
```

Aggregation functions

```sql
-- There are several aggregate functions such as max, min, sum, avg
select max(birthday) from students;
-- 1995-05-24

-- It is not valid to combine reductions with non-reduced columns e.g.
select matrikel, max(birthday) from students; -- Erroneous...
```

Counting the number of students

```sql
-- Number of students in the table and rename the column to number
SELECT count(*) AS number FROM students;
-- number
--     2
```

Subqueries

A subquery creates a new (virtual) named table to be accessed

Identify the average age

```
-- Identify the min, max, avg age; we create a new table and convert the date
select min(age), avg(age), max(age) from
    -- Here we create the virtual table with the name ageTbl
    (SELECT age(birthday) as age from students) as ageTbl;
--            min             |                avg                |          max
-- 20 years 3 mons 30 days | 40 years 4 mons 15 days 12:00:00 | 60 years ...
```

Identify students which are not attending any course

```
-- We use a subquery and comparison with the set
select matrikel from students
where matrikel not in  -- compare a value with entries in a column
  (select matrikel from attends);
```

Subquery expressions: exists, in, some, all, (operators, e.g., $<$) [19]

[19] See http://www.postgresql.org/docs/14/functions-subquery.html

Grouping of Data

Data can be grouped by one or multiple (virtual) columns

It leads to errors when including non-grouped / non-reduced values

Identify students with the same name and birthday, count them

```
select name, birthday, count(*) from students group by name, birthday;
-- name  |    max     | count
---------+------------+-------
-- Fritz | 1995-05-24 |     1
-- Hans  | 1955-04-22 |     1
```

Figure out the number of people starting with the same letter

```
select upper(substr(name,1,1)) as firstletter, count(*) from students
   group by firstletter;
-- firstletter | count
---------------+-----------
-- F           | 1
-- H           | 1
```

Filtering Groups of Data

- With the HAVING clause, groups can be filtered
- ORDER BY is the last clause and can be applied to aggregates

Identify students with the same name and birthday, and return the total number of non-“duplicates”

```
select sum(mcount) from
  (select count(*) as mcount from students
   group by name, birthday having count(*) = 1 order by count(*)) as groupCount;
-- sum
-- 2

-- Alternatively in a subquery you can use:
select sum(count) from
  (select count(*) as count from students
   group by name, birthday) as groupCount
   where count = 1;
```

Joins [10]

A join combines records from multiple tables

- Used to resolve relations of entities in normalized schemes
- Usually filtering tuples according to a condition during this process

Types of joins

- CROSS JOIN: Cartesian product of two tables (all combination of rows)
- NATURAL JOIN: All combinations that are equal on their common attributes (i.e, both tables contain the matrikel column)
- INNER JOIN: Return all rows that have matching records based on a condition
- OUTER JOIN: Return all rows of both tables even if they are not matching the condition
  - LEFT OUTER JOIN: Return all combinations and all tuples from the left table
  - RIGHT OUTER JOIN: ... from the right table
  - FULL OUTER JOIN: Return all combinations

Example Joins

```
select * from students as s1 CROSS JOIN students as s2;
-- matrikel | name  |  birthday  | matrikel | name  |  birthday
------------+-------+------------+----------+-------+------------
--      242 | Hans  | 1955-04-22 |      242 | Hans  | 1955-04-22
--      242 | Hans  | 1955-04-22 |      245 | Fritz | 1995-05-24
--      245 | Fritz | 1995-05-24 |      242 | Hans  | 1955-04-22
--      245 | Fritz | 1995-05-24 |      245 | Fritz | 1995-05-24

select * from students  NATURAL JOIN attends;
-- matrikel | name  |  birthday  | lid
-- ----------+-------+------------+-----
--      242 | Hans  | 1955-04-22 |   1
--      242 | Hans  | 1955-04-22 |   2
--      245 | Fritz | 1995-05-24 |   2

select * from students INNER JOIN attends ON students.matrikel = attends.matrikel;
-- matrikel | name  |  birthday  | matrikel | lid
------------+-------+------------+----------+-----
--      242 | Hans  | 1955-04-22 |      242 |   1
--      242 | Hans  | 1955-04-22 |      242 |   2
--      245 | Fritz | 1995-05-24 |      245 |   2
```

Example Joins

```
-- This join returns NULL values for Fritz as he has not the selected matrikel
select * from students LEFT OUTER JOIN attends ON students.matrikel = 242;
-- matrikel | name  |  birthday  | matrikel | lid
----------+-------+------------+----------+-----
--      242 | Hans  | 1955-04-22 |      242 |   1
--      242 | Hans  | 1955-04-22 |      242 |   2
--      242 | Hans  | 1955-04-22 |      245 |   2
--      245 | Fritz | 1995-05-24 |          |
select * from students as s FULL OUTER JOIN attends as a ON s.matrikel = a.lid;
-- matrikel | name  |  birthday  | matrikel | lid
------------+-------+------------+----------+-----
--          |       |            |      242 |   1
--          |       |            |      242 |   2
--          |       |            |      245 |   2
--      242 | Hans  | 1955-04-22 |          |
--      245 | Fritz | 1995-05-24 |          |
-- Now identify all lectures attended by Hans
select s.name, l.name from students as s INNER JOIN attends as a ON s.matrikel
     ↪ = a.matrikel INNER JOIN lectures as l ON a.lid=l.id;
-- name  |        name
---------+---------------------
-- Hans  | HPDA
-- Hans  | Hochleistungsrechnen
-- Fritz | Hochleistungsrechnen
```

Mutating Tables

- UPDATE statement changes values of columns
- DELETE statement removes rows
- Each operation yields the ACID semantics[20]
- Transactions allow to batch operations together

```sql
-- Change the name of Fritz
UPDATE students SET name='Fritzchen' WHERE matrikel=245;

-- Remove Fritzchens attendance in Hochleistungsrechnen
DELETE FROM attends WHERE matrikel=242 and lid=2;

-- Subqueries can be used to select rows that are updated/deleted
-- Remove Fritzchen attendence with the name
DELETE from attends WHERE matrikel=242 and lid = (SELECT id from lectures where name =
     ↪ 'Hochleistungsrechnen');
```

[20] In fact, when AUTOCOMMIT is enabled, every statement is wrapped in a transaction. To change this behavior on the shell, invoke: SET AUTOCOMMIT [OFF|ON]

Transactions

- Transaction: A sequence of operations executed with ACID semantics
  - It either succeeds and becomes visible and durable; or it fails
  - Note: Complex data dependencies of concurrent operations may create a unresolvable state that requires restart of the transaction
- Isolation: queries access data in the version when the transaction started
  - The isolation level can be relaxed, e.g., to see uncommited changes
- Internally, complex locking schemes ensure conflict detection

Example: Atomic money transfer between bank accounts

```sql
START TRANSACTION;
UPDATE account SET balance=balance-1000.40 WHERE account=4711;
UPDATE account SET balance=balance+1000.40 WHERE account=5522;

-- if anything failed, revert to the original state
IF ERRORS=0 COMMIT; -- make the changes durable
IF ERRORS!=0 ROLLBACK; -- revert
```

Group Work

- Discuss the creation of a relational schema for organizing music (albums)
  - Describe a schema (there is really wrong answer)
  - List 1-2 operations and their implementation using SQL
- Time: 10 min
- Organization: breakout groups - please use your mic or chat

Performance Aspects

Problem: When searching for a variable with a condition, e.g., x=y, the table data needs to be read completely (full scan)

Indexes

- Index allows lookup of rows for which a condition (likely) holds
- Postgres supports B-tree, hash, GiST, SP-GiST and GIN indexes[21]

```
CREATE INDEX ON students (name);
```

Optimizing the execution of operations (query plan)

- Postgres uses several methods to optimize the query plan
  - The query planer utilizes statistics about access costs
  - Knowing how values are distributed helps optimizing access
- ANALYZE statement triggers collection of statistics
- Alternatively: automatically collect statistics
- EXPLAIN statement: describes the query plan (for debugging)

[21] See http://www.postgresql.org/docs/14/sql-createindex.html

Performance Aspects (2) [22]

Bulk Loads/Restores

- Combine several INSERTS into one transaction
- Perform periodic commits
- Create indexes/foreign key/constraints after data was inserted

Garbage cleaning / vacuuming: Cleaning empty space

- When changing or inserting rows, additional space is needed
- It is expensive to identify deleted / empty rows and compact them
  - ⇒ Just append new data
  - Mark data, e.g., in a bitmap as outdated
- Periodically space is reclaimed and data structures are cleaned
- VACCUUM statement also triggers cleanup
- ANALYZE also estimates the amount of garbage to optimize queries

Outline

Views

- View: virtual table based on a query
  - Can be used to re-compute complex dependencies/apply joins
  - The query is evaluated at runtime, which may be costly
- Materialized view: copies data when it is created/updated[22]
  - Better performance for complex queries
  - Suitable for data analytics of data analysts
  - Export views with permissions and reduce knowledge of schema

```
CREATE  VIEW studentsView AS
  SELECT s.matrikel, s.name as studentName, l.name as lectureName, age(birthday) as age from students as s
       ↪ INNER JOIN attends as a ON s.matrikel = a.matrikel INNER JOIN lectures as l ON a.lid=l.id;

select * from studentsView;
-- matrikel | studentname |     lecturename      |           age
------------+-------------+----------------------+------------------------
--      242 | Hans        | HPDA    | 60 years 5 mons 1 day
--      242 | Hans        | Hochleistungsrechnen | 60 years 5 mons 1 day
--      245 | Fritz       | Hochleistungsrechnen | 20 years 3 mons 30 days
-- To replace the data with new data
REFRESH MATERIALIZED VIEW studentsView;
```

22 www.postgresql.org/docs/14/sql-creatematerializedview.html

Regular Expressions

- PostgreSQL supports several styles of regular expressions[23]
- We will look at POSIX regular expressions (regex)
- Operator: $\sim$ for matching and $\sim$* for not matching
- `regexp_matches(string, pattern)` returns text array with all matches

Examples

```sql
-- Any lecture which name contains Data
select name from lectures where name~*'data';
-- HPDA

-- Lectures starting with HP
select name from lectures where name~'^HP.*$';
-- HPDA

-- Students whose name contain at least two vocals
select name from students where name~'(i|a|o|u).*(a|i|o|u)';

-- Students whose name contain at least one vacal and at most three
select name from students where name~'^([^auiu]*(i|a|o|u)[^aiou]*){1,3}$';

-- Retrieve all lower case letters in the names
select regexp_matches(name, '[a-z]', 'g') as letter from students;
-- {a}, {n} ...
```

[23] See http://www.postgresql.org/docs/14/functions-matching.html

Array Operations

- Operations allow manipulation of multidimensional arrays[24]
- Useful operators: `unnest`, `array_agg`, `array_length`
- JSON support in new PostgreSQL version (not discussed here)

```sql
-- Alternative schema for our student/lecture example using an array for the attends relationship
CREATE TABLE studentsA (matrikel INT, name VARCHAR, birthday DATE, attends INT[], PRIMARY KEY(matrikel));
CREATE TABLE lectures (id SERIAL, name VARCHAR, PRIMARY KEY(id));

INSERT INTO studentsA VALUES (242, 'Hans', '22.04.1955', '{1,2}' );
INSERT INTO studentsA VALUES (245, 'Fritz', '24.05.1995', '{2}');

-- Addressing array elements: first lecture attended by each student
SELECT attends[1] from studentsA;
-- Slicing is supported: First three lectures
SELECT attends[1:3] from studentsA;

-- Retrieve the lecture name attended for each student
SELECT s.name, l.name from studentsA AS s INNER JOIN lectures AS l ON l.id = ANY(s.attends);
-- Hans  | HPDA
-- Hans  | Hochleistungsrechnen
-- Fritz | Hochleistungsrechnen

-- Now retrieve the lectures in an array per person
SELECT s.name, array_agg(l.name) from studentsA AS s INNER JOIN lectures AS l ON l.id = ANY(s.attends)  GROUP by s.matrikel;
-- Hans  | {"HPDA",Hochleistungsrechnen}
-- Fritz | {Hochleistungsrechnen}
```

24 See `http://www.postgresql.org/docs/14/arrays.html`

Processing Geospatial Data with PostGIS [30, 31]

- PostGIS is a PostgreSQL extension providing datatapes and functions for
  - Topology: Faces, Edges and Nodes
    - Defines constraints on data, e.g., sharing of edges in maps
  - Geometry/Geography: coordinates according to SRID
    - Spatial Reference System Identifier (SRID) defines coordinate system
    - Lon/Lat coordinates on a sphere with the unit degrees
    - Points, lines, poligones
  - Raster data: like pixels, square-based split of a 2D plane
    - Example: Import / export of images
- QGIS viewer[25] can visualize geometry and raster data

25 http://qgis.org/

PostGIS: Example [31]

```
-- Creating a database with geography data (SRID 4326 => WGS 84 => for GPS => lon/lat)
CREATE TABLE cities(gid serial PRIMARY KEY, n TEXT, loc geography(POINT,4326) );
CREATE INDEX cities_idx ON cities USING GIST ( loc );

-- Insert three cities with Lon/Lat coordinates
INSERT INTO cities (n, loc) VALUES('Hamburg',ST_GeographyFromText('POINT(9.99 53.5)'));
INSERT INTO cities (n, loc) VALUES('Tokio',ST_GeographyFromText('POINT(139.8 35.65)'));
INSERT INTO cities (n, loc) VALUES('Aleppo',ST_GeographyFromText('POINT(37 36)'));

-- Compute distance between Hamburg and Tokio
SELECT ST_Distance( (Select loc from cities where n = 'Hamburg'),
                    (Select loc from cities where n = 'Tokio'));
-- 9012369.89691784 == 9012 km

-- How far is Allepo from a plane flying from Hamburg to Tokio, here as text
SELECT ST_Distance('LINESTRING(9.99 53.5, 139.8 35.65)'::geography,
      'POINT(37 36)':: geography);
-- 2833 km
```

Outline

Data Warehouse

"A data warehouse (DW or DWH), also known as an enterprise data warehouse (EDW), is a system used for reporting and data analysis." [27]

- Central repository for structured data
- Integrates data from multiple inhomogeneous sources
- Data analysts use a simplified data model: a multidimensional data cube
- Provides tools for the data analyst to support descriptive analysis
- May provide some tools for predictive analysis
- Many queries are executed periodically and used in reports
- Often used for business data

Databases vs. Data Warehouses for Structured Data

Database management systems (DBMS)

- Standardized systems and methods to process structured data
- Use the relational model for data representation
- Use SQL for processing

Online Transaction Processing (OLTP)

- Real-time processing
- Offer ACID qualities
- Relies on normalized schemes (avoid redundant information)

Online Analytical Processing (OLAP)

- Systems and methods to analyze large quantities of data
- Utilizes data warehouses with non-normalized schemes
- Extract, Transform and Load (ETL): import data from OLTP

OLAP

- Online analytical process with large quantities of business data
- Utilizes denormalized dimensional model to avoid costly joins
- Technology alternatives:
  - **MOLAP** (Multidimensional OLAP): problem-specific solution
  - **ROLAP**: use relational databases to represent cube
    - Star schema
    - Snowflake schema
- **Dimensional modeling**: design techniques and concepts [26]
  1. Choose the business process, e.g., sales situation
  2. Declare the grain: what does the model focus on, e.g., item purchased
  3. Identify the dimensions
  4. Identify the facts

The OLAP Cube: Typical Operations [27]

- Slice: Fix one value to reduce the dimension by one
- Dice: Pick specific values of multiple dimensions
- Roll-up: Summarize data along a dimension
  - Formulas can be applied, e.g., profit = income - expense
- Pivot: Rotate the cube to see the faces

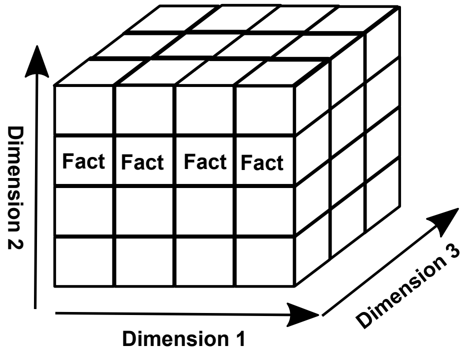


Figure: Example 3D cube

The OLAP Cube: Slice [27]

- Slice: Fix one value to reduce the dimension by one
- Example: Sales (in Euro) for worlwide stores

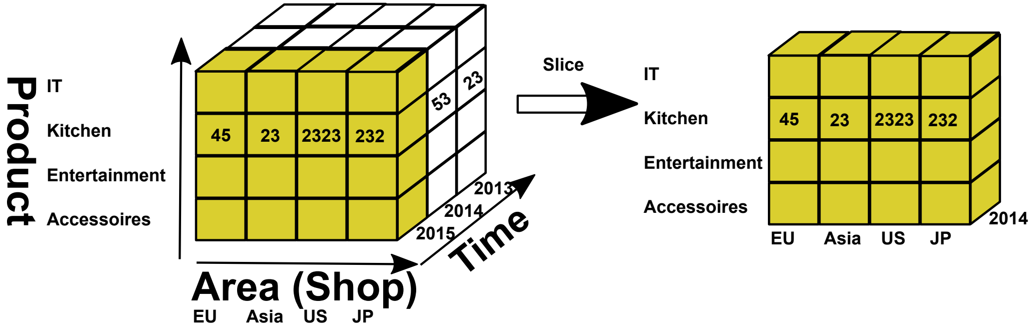


Figure: Example cube for sales in stores

The OLAP Cube: Dice [27]

- Dice: Pick specific values of multiple dimensions

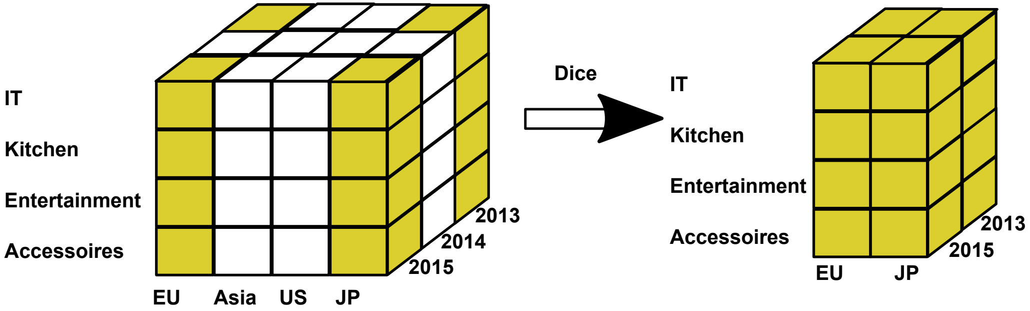


Figure: Example cube for sales in stores

The OLAP Cube: Drill Down/Up [27]

- Drill Down/Up: Navigate the aggregation level
  - Drill down increases the detail level
  - Drill up decreases the detail level

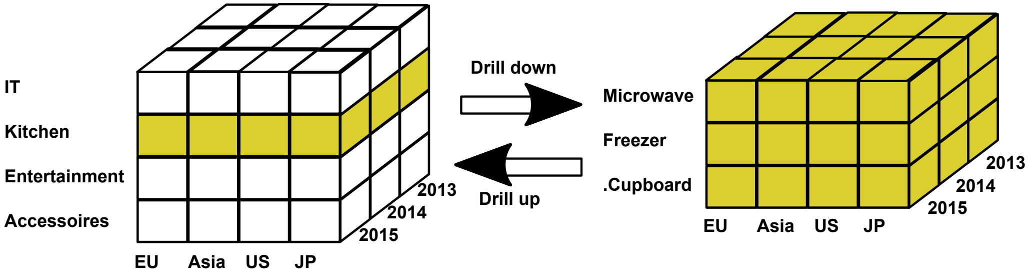


Figure: Example cube for sales in stores

Star (and Snowflake) Schemas [23]

Implement the OLAP cube in relational databases

Data model

- Fact table: records measurements/metrics for a specific event
  - Center of the star
  - Transaction table: records a specific event, e.g., sale
  - Snapshot table: record facts at a given point in time, e.g., account balance at the end of the month
  - Accumulating table: aggregate facts for a timespan, e.g., month-to-date sales for a product

  ⇒ A fact table retains information at a low granularity and can be huge
- Dimension tables: describe the facts in one dimension
  - Contains, e.g., time, geography, product (hierarchy), employee, range
  - The fact table contains a FOREIGN KEY to all dimension tables

  ⇒ Comparably small tables

Snowflake schema normalizes dimensions to reduce storage costs

Star Schema Example Model

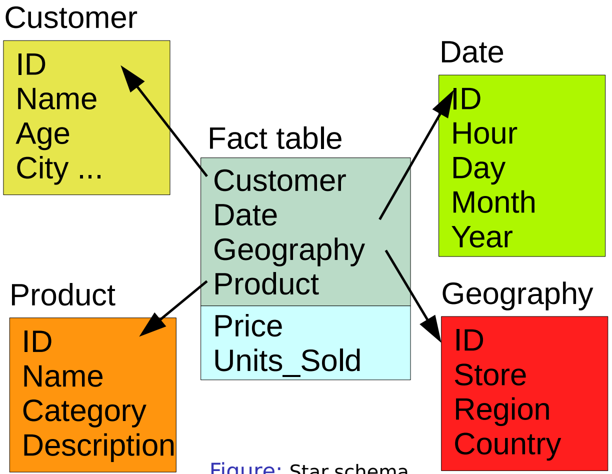


Figure: Star schema

Star Schema: Example Query

Analyze the sales of TVs per country and brand [23]

```
SELECT  P.Brand, S.Country AS Countries, SUM(F.Units_Sold)
FROM Fact_Sales F
INNER JOIN Date    D ON (F.Date_Id = D.Id)
INNER JOIN Store   S ON (F.Store_Id = S.Id)
INNER JOIN Product P ON (F.Product_Id = P.Id)

WHERE D.Year = 1997 AND  P.Product_Category = 'tv'

GROUP BY
  P.Brand,
  S.Country
```

Star Schema [23]

Advantages

- Simplification of queries and performance gains
- Emulates OLAP cubes

Disadvantages

- Data integrity is not guaranteed
- No natural support for many-to-many relations

Snowflake Schema Example Model

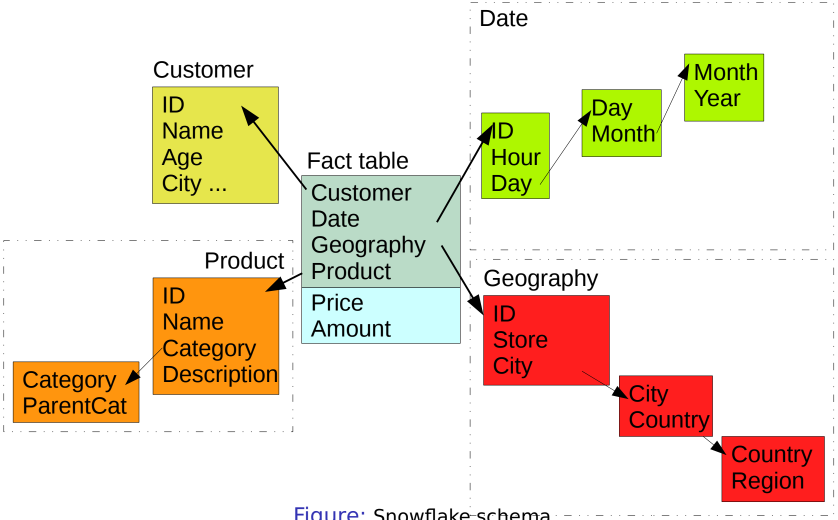


Figure: Snowflake schema

Summary

- ER-diagrams visualize the relational data model
- Keys allow addressing of tuples (rows)
- Normalization reduces dependencies
  - Avoids redundancy, prevents inconsistency
- SQL combines data retrieval/modification and computation
  - Insert, Select, Update, Delete
  - Joins combine records
- Transactions executes a sequence of operations with ACID semantics
- A database optimizes the execution of the queries (query planer)
- Semi-structured data analysis is possible within JSON and XML
- OLAP (Cube) deals with multidimensional business data
- Data warehouses store facts along their dimensions
- Star-schema implements OLAP in a relational schema

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