Lecture 1 - Relational Algebra

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Problems with Flat File System

- Data Integrity and Redundancy
  - Differing preferences formats
  - Languages among sysadmins lead to possible data inconsistencies
  - Duplicate Data
- Sysadmin is the Bottleneck: all system changes, course changes restrictions must be encoded in a custom application.
- Lack of Atomicity: system failures in the middle of a multi-step process can result in lost data. (i.e. bank transfer, exchanging classes). we should do it perfectly.
- Concurrent Access: It's possible for data to get out of sync when multiple people read/write concurrently
- Security: Without proper filesystem controls, flat files can be read by anybody with access to the filesystem.

Better Approach: Databases

- A database abstracts away how the data is stored, maintained and processed.
- Users don't necessarily care how the data is laid out on disk.
- Big Data and distributed systems, such as Spark, have reintroduced the importance of understanding how data is laid out on disks/nodes
- Database Purposes
  - Provides a way to view, add, update and delete data without worrying about files and breaking data integrity.
  - Provides ONE single location for all data in the database

Examples of Databases that You Wouldn't Expect

- Blockchain
  - Blockchain is similar to a distributed database, with one major difference.
  - With blockchain, each participant maintains their own data and updates to the database. All nodes in the system cooperate to make sure the database comes to the same conclusion – a form of security.
  - Coindesk: >"Blockchains allow different parties that do not trust each other to share information without requiring a central administrator. Transactions are processed by a network of users acting as a consensus mechanism so that everyone is creating the same shared system of record simultaneously."
- Git
  - Git can be used to track any kind of content, and it can be used to create a NoSQL database.
  - Git is basically a key-value store.

Levels of Abstraction 1. Physical. How the data are stored. * MySQL has 9 storage engines, most importantly, MyISAMa and InnoDBb (speed, reads) and InnoDB (foreign keys and transactions). * PostgreSQL only has one. 2. Logical. * Describes what data there are and the relationships among the data. 3. View. * What the user sees. It is typically just a part of the database, such as used to generate a report. In the flat file case, the user relied on the sysadmin to "see" the data.

A database (more precisely a table or schema, which we will discuss in a bit) is a way of abstracting a structured type, like you'd see in C++.

```
struct Section
{
    int srs; // Unique ID number for this section
    int cap; // Max number of students allowed
    int instructor_uid; // Instructor's ID
```

```
    int parent_srs; // link to lecture
};
```

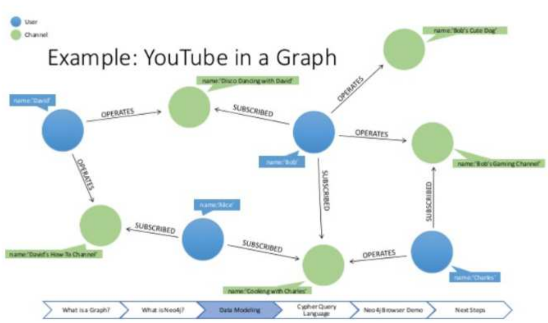
Instances and Schema

- The information stored in a database at a particular point in time is called an instance. This terminology has been resurrected by its use with Amazon Web Services.
- The overall design of a database is called a schema.
  - The term schema is used interchangeably to describe the logical structure of a database or a relation (table).
- A subschema refers to the design of a particular part of the database, (often still called schema) if it refers to a DB or a table.

Data Model

The data model contains "conceptual" tools for describing data, their relationships, semantics and consistency constraints. Contains 5 major types:

1. **Relational**: Uses a collection of tables to represent data and their relationships. Each table has columns with unique names and a data type. Each column represents an attribute, and each row represents a record.
2. **Entity-Relationship (ER)**. Uses a collection of basic objects called entities and relationships among them. Typically used to visualize a database design. 3.**Object-Oriented**: Draws a strong analogy to object-oriented programming with encapsulation, methods and object identity.
   - Data are essentially treated as instances of classes rather than tables.
3. **Document**: Individual data objects may have different sets of attributes.
   - Each data record mimics a flexible struct with no, or few, fixed fields.
   - Very different from the relational model, but many common semi-structured data types can be converted into the relational model.
   - JSON and XML are two examples of data types that are natural for the semi-structured model (Document Database).
4. **Network/Hierarchical/Graph**:
   - Actually pre-dates the relational model.
   - Defines data records as nodes, and relationships between records as edges.
   - Was considered unwieldy as they tied data very closely to database implementation details. This is still the case.
   - One notable NoSQL example is neo4j.



Database Languages

1. Data Definition Language (DDL)
   - A query is a written expression to retrieve or manipulate data.
   - A query language is simply the language it is written in. (Ex: SQL)
     - A SQL query takes takes one or a pair of relations and outputs a single relation as a result.
   - Note that JavaScript can be a query language!
   - **SQL**

  - Is not a procedural language.
  - There are computations that cannot be done in SQL, for example, sequential or iterative computations typically used in mathematical fields. Or algorithms that require the user to specify how to perform a computation.
  - In the case that SQL isn't enough, extract the data into your favorite language and then use that language to transform the data however you like, then insert back

2. Data Manipulation Language (DML)
   - Specifies a schema, a collection of attribute names and data types. It may also specify storage structure and access methods.
   - Constraints that can be specified
     1. **Domain Constraints**: restrict the values of a particular column to a particular type, or a particular set of values.
     2. **Referential Integrity**: There are many situations where a value in one relation must appear in some other relation for the data to be considered complete and valid. (Ex: Foriegn Keys)
     3. **Assertions**: Both a and b are types of assertions, but there are several other constraints we can impose. In the student records case, we can impose some example constraints that are checked by the DBMS on each attempted data manipulation:
     4. **Authorization**: Can restrict access to databases and schemas as well as particular operations on these databases and schemas. We can apply these rules to users, groups, etc.

Data Storage and Querying

- Databases have a storage manager that abstracts how the data is laid out on disk.
- Most of the data cannot fit in RAM, and must be read in from disk. This must be done eficiently because reading from the disk is very slow.
- The Storage Manager has the following duties
  1. **Authorization and data integrity checks** to prevent unauthorized access and enforce integrity constraints.
  2. **Transaction management** ensures the database remains in a consistent state despite a system failure, and that concurrent accesses are handled appropriately. A transaction is a series of operations that must be executed as a logical unit, in a particular order.
  3. **File manager** allocates and manages disk space.
  4. **Buffer manager** deals with swapping data from disk to RAM and back.
- The storage manager uses a few of its own data structures
  1. Data files which store the... well... data.
  2. Data dictionary containing metadata about the structure and schema of the database.
  3. Indices that enable optimized and eficient lookup of data.
- Another element is a query manager.
  - When a query is executed the DML (i.e. SQL) statements are organized into a query plan that consists of low-level instructions that the query evaluation engine understands

Note on Duplicate Data: Duplicate data should of course try to be avoided, this can be done through the process of deduplicating, called normalization

Distributed Architecture

- In a distributed architecture, there are several database servers. They may all contain identical data (replicated) or different parts of the data (sharded) that depend on geography or some other circumstance.

- Replicated or Sharded?

  1. You are developing a new social network to replace Facebook. It will allow people to create profiles and share content on a newsfeed across the entire (connected) world.
  2. You are the system administrator for UCLA and are responsible not only for student records, but also healthcare records at a variety of hospitals and medical centers in Southern California.
  3. You are creating a new blogging system that protects user privacy by relying on the user's own

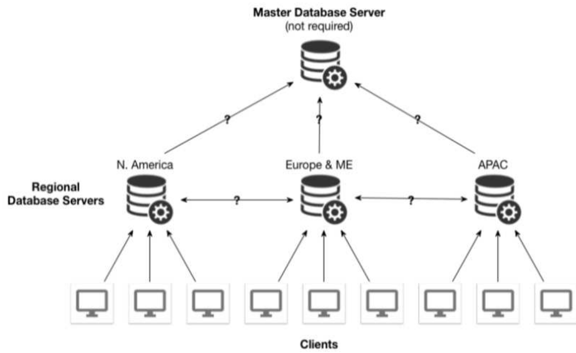


Figure 1: Distributed Architecture

system to host their content.

Relational Model

- A relational database consists of a collection of relations (often called tables).
- Each relation consists of records and attributes:
- Each row is a record, with a set of attributes that are related to that record.
- Each column represents a particular attribute, has a unique name, and a particular data type. (Columns are also referred to as n-tuples)
- Each attribute has a domain, a set of legal values. This domain can be discrete or continuous.
- An attribute can have a null value meaning it is unknown or does not exist.

SuperKey

A **superkey** is a set of one or more attributes that uniquely identifies a tuple and distinguishes it from all other tuples.

Illustration: Suppose we use the sequential comment id version of the youtube comment relation where the superkey K is video id and comment id.

1. I can also include other attributes and it is a valid superkey, but it contains redundant information because video id and comment id are the only attributes we need to uniquely identify a tuple.
2. Suppose we drop video id from K. comment id is a proper subset of K, but it is not a superkey because each video with at least one comment will have a duplicated comment id.

Thus, you can prove that comment id and video id are a composite superkey.

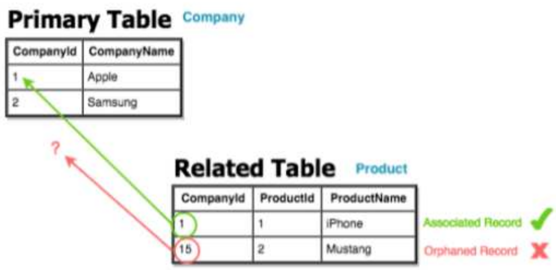
Primary Key

- Since a superkey uniquely identifies a tuple in a relation, no two tuples may same the same values for all of the attributes in K. A superkey that is minimal is also called a candidate key.
- A candidate key chosen by the database designer is more commonly called a primary key.
- A primary key MUST be unique, and MUST be `NOT NULL`. For composite primary keys, all components of the primary key must be `NOT NULL`.

Foriegn Key

- For a particular relation R, a foreign key is an attribute of R that is the primary key of some other relation R'
- A foreign key is an attribute that can be used to tie together the tuples of two relations together into one. A foreign key in R does not uniquely identify a tuple in R, but does in the referred relation R'.
- Foreign keys are often used to satisfy referential integrity constraints.
  - Suppose we have two relations: company that contains an ID and the name of a company, and product which maps products to the company that created it.

– It does not make sense for a product to not be associated with a company in this schema. This design violates referential integrity



Relational Algebra

All relational databases provide a set of operations that can be performed on a single relation, or on a pair of relations. We will introduce most of them today, and see the rest next time. We can work with multiple relations, by chaining operations on pairs of relations. This is how we will do it in SQL, unsurprisingly.

$$y = 40 - 40^x \tag{1}$$