Databases

Contents

Definitions

An **entity** is a category of object, person, event, or thing about which data needs to be recorded.

A simple (flat file) database is a single file containing information on a single entity.

An entity maps to a table. A table contains many records, each holding information about a particular instance of an entity. For example, a `tblCustomer` table will contain many records, each representing a single customer.

Each record of an entity table needs an identifier to uniquely identify it. The identifier is known as the **primary key**.

A composite primary key is a combination of keys in a record, where the *combination* uniquely identifies the record rather than having a separate ID key.

Most databases automatically index the primary key field so that any particular record can be found quickly.

If another key field also needs to be searched for, then it can be called a **secondary key**, and this field will be indexed.

Entities can be linked by one-to-one, one-to-many, or many-to-many relationships. See the diagrams.

To create a relationship between entities, the 'many' side must have a **foreign key**, which matches the primary key in another table. Say a customer can have many subscriptions. Each record must have a fixed number of fields, so they can't have an arbitrary number of foreign keys to link to subscriptions. Therefore, each subscription record should have a foreign key to point to a customer.

Referential integrity means that every foreign key must reference a existent record in a related table that actually exists. Dangling foreign keys are forbidden.

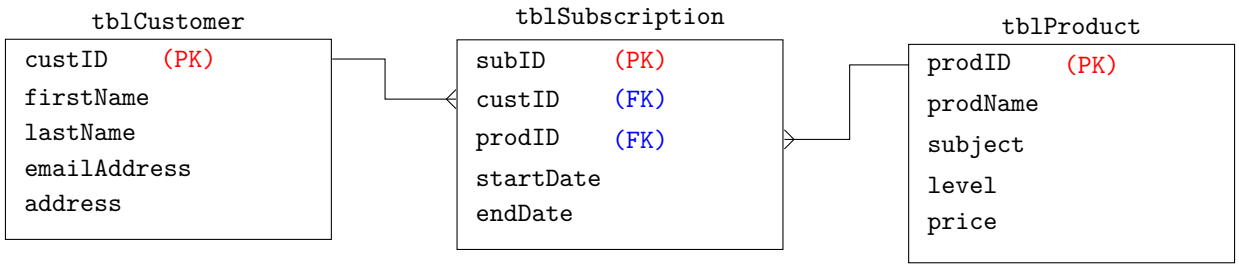
As a canonical example, a customer can have many orders; an order can have many orderLines (an order is like a shopping cart, and an orderLine is like a single order with product, quantity, price); a product can appear in many orderLines.

Many-to-many relationships cause problems with unknowable column numbers. This can be fixed with a **linking table**. Consider a fitness center - members can take many classes, and classes can have many members. Instead, have an enrolment table in the middle. A member can have many enrolments, and a class can be part of many enrolments. Each enrolment record is a single link between a member and a class.

Entity-Relationship Diagrams

Boxes contain entities, or the fields of a record in that table. Relationship lines have a single line connection to the box for a *one* connection, and a crow's foot connection for *many*.

In this example, there is an online revision service which provides textbooks. A customer can subscribe to different tiers. A customer has personal details; a product is a book with a name, subject, level, and price; and a subscription links these two together with foreign keys for each, as well as a start and end date.



The `tblCustomer` table has personal details and a unique ID, which is its primary key. The `tblProduct` table has details about the product and its own unique ID primary key. The `tblSubscription` table has a unique ID primary key, a start and end date, and two foreign keys. Each subscription references the customer that subscribes to it and the product they subscribe to, in the form of two primary keys.

Normalisation

Normalisation is a process used to come up with the best possible design for a database. Tables should be organised so that data is not duplicated in the same table or different tables. The structure should allow complex queries to be made.

A normalised database is much easier to maintain and change; there is no unnecessary duplication of data; integrity is maintained and updates are small; having smaller tables with fewer fields makes searching faster and saves storage.

There are 3 main stages of normalisation:

First Normal Form (1NF)

A table is 1NF normalised if it contains no repeating attributes or groups of attributes. **All attributes must be atomic (separate first and last names etc.)**. A field cannot be a composite data type. It must instead by a foreign key referencing another table which contains the desired data.

Second Normal Form (2NF)

A table is 2NF if it's 1NF and **contains no partial dependencies**.

Identify a table's purpose. Each column must describe the singular thing that the primary key identifies. If it doesn't, then it should belong in a different table. For example, in a `tblEmployee`, all columns should describe an attribute of the particular employee identified by the primary key.

If a table has a composite primary key, then it is only in 2NF if each column directly relates to *both* parts of the primary key. The table must refer entirely to a singular entity.

Third Normal Form (3NF)

A table is 3NF if it's 2NF and **contains no non-key dependencies**. All attributes are dependent entirely on the primary key and nothing else. This means that the primary key determines all other attributes in its record.

SQL

SQL is a declarative language used for querying and updating tables in a relational database.

The `SELECT` statement is used to extract fields from one or more tables. The syntax is the following:
`SELECT (fields) FROM (tables) [WHERE (criteria)] [SELECTORS].. [ORDER BY (field) [ASC | DESC]];`

An example would be:
`SELECT (prodID, name, subject, price) FROM tblProduct WHERE level = 4 AND price BETWEEN 500 AND 1500 ORDER BY name;`

Every SQL statement **MUST** end in a semicolon. A logical statement can span multiple physical lines, so the semicolon is needed to end the statement.

`WHERE` clauses

Wild cards can be used, and act like they do in glob patterns. `*` matches anything. `LIKE` can be used in a `WHERE` clause to find fields by matching a pattern.

`WHERE` clauses can also accept ranges with `BETWEEN` or `IN`. The `BETWEEN` selector finds values in an inclusive numerical range. `IN` finds values where they match one of several possibilities.

All standard mathematical comparison operators can be used, as well as `AND`, `OR`, as well as `NOT`.

Using multiple tables

Multiple tables can be selected from using a `SELECT` statement. This is most often useful for a `WHERE` clause. Consider this expression:

```
SELECT tblCustomer.firstName, tblCustomer.lastName, tblProduct.name
  FROM tblCustomer, tblProduct, tblSubscription
  WHERE tblSubscription.custID = tblCustomer.custID
  AND tblSubscription.prodID = tblProduct.prodID;
```

This will select the customer name and product name for every subscription. There will be one row for each subscription and each row will contain the appropriate customer and product. This query can be made simpler by using the `JOIN` clause.

`JOIN`-ing tables

Data can be extracted using the join clause. You can select from multiple tables and join them together by their foreign key relationships. This then treats the results as one table, which you can then use something like a `WHERE` clause with.

Here is a `SELECT` statement equivalent to the previous one, but using `JOIN` clauses instead:

```
SELECT tblCustomer.firstName, tblCustomer.lastName, tblProduct.name
  FROM tblSubscription
  JOIN tblCustomer ON tblCustomer.custID = tblSubscription.custID
  JOIN tblProduct ON tblProduct.prodID = tblSubscription.prodID;
```

The `JOIN` clause is used to match foreign keys between tables to search them together.

Defining and updating tables with SQL

Creating tables

The `CREATE TABLE` command expects a table name and a comma-separated list of fields. Each field has a name, a type, and some extra information about the field, such as `NOT NULL` or `PRIMARY KEY`. For example:

```
CREATE TABLE tblProduct (
    productID   CHAR(4) NOT NULL UNIQUE PRIMARY KEY,
    description VARCHAR(20) NOT NULL,
    price       CURRENCY
);
```

Data types

`CHAR(`n`)`	String of fixed length n
`VARCHAR(`n`)`	Variable length string of max length n
`BOOLEAN`	True or false
`INTEGER` or `INT`	Integer
`FLOAT`	Floating point decimal number
`DATE`	Date in local format
`TIME`	Time in local format
`CURRENCY`	Currency in local format

Defining links between tables

When defining a new table with foreign keys, we want to ensure that foreign keys always reference valid keys in other tables. We also want to be able to specify composite primary keys. These things can both be done by adding extra lines to the initial table definition.

For example, to link products and components with a many-to-many relationship, you can use a linking table in the middle like so:

```
CREATE TABLE productComponent (
    productID   CHAR(4) NOT NULL,
    componentID CHAR(6) NOT NULL,
    quantity    INTEGER,
    FOREIGN KEY productID REFERENCES tblProduct(productID),
    FOREIGN KEY componentID REFERENCES tblComponent(componentID),
    PRIMARY KEY (productID, componentID)
);
```

Altering a table

The `ALTER TABLE` command is used to alter tables by adding, deleting, or modifying the columns of the table. Some examples:

```
ALTER TABLE tblProduct ADD qtyInStock INTEGER;
ALTER TABLE tblCustomer DROP COLUMN postcode;
ALTER TABLE tblProduct MODIFY COLUMN productName NOT NULL;
```

Inserting, updating, and deleting data

The `INSERT INTO` command is used to insert a new record into a table. For example:

```
INSERT INTO tblCustomer (customerID, firstName, lastName, dateOfBirth, email)
  VALUES ("JS3592", "John", "Smith", DATE "1982-04-16", "johnnyboysmith@gmail.com");
```

The `UPDATE` command can update a set of records (possibly a set of size 1, meaning a single record) and change fields of the selected records. For example:

```
UPDATE tblCustomer
  SET email = "johnsmith1982@gmail.com"
  WHERE customerID = "JS3592";
```

The `DROP` command is used to delete a whole table or a column of it, but `DELETE` is used to delete individual records from a table. For exmaple:

```
DELETE FROM tblCustomer
  WHERE customerID = "JS3592";
```

Transaction processing

Capturing data

There are various ways of collecting data, including smart card readers, barcode readers, scanners, optical character recognition, optical mark recognition (like UKMT answer sheets), magnetic ink character recognition (like on banking cheques), and sensors.

Once data has been collected, it needs to be transferred to a database. This is often done using **Electronic Data Interchange (EDI)**, which is used to transfer data between computer systems.

EDI

EDI is the computer-to-computer exchange of documents such as purchase orders, invoices and shipping documents between companies or business partners. It replaces post, email, or fax. All documents must be in a standard format so that the computers can understand them. EDI translation software may be used to translate the EDI format so the data can be input directly to a company database.

Transactions

In the context of databases, a single logical operation is defined as a transaction. It may consist of several operations; for example, a customer order may consist of several order lines:

- All of the order lines must be processed
- The quantity of each product must be adjusted on the stock file
- Credit card details must be checked
- Payments must be accepted or rejected

What happens if the stock file has been updated and the system crashes before payment is processed?

ACID

Atomicity, **C**onsistency, **I**solation, **D**urability: this is a set of properties to ensure that the integrity of the database is maintained under all circumstances. It guarantees that transactions are processed reliably.

Atomicity requires that a transaction is processed entirely or not at all. In any situation, including power cuts or hard disk crashed, it is not possible to process only part of a transaction.

Consistency ensures that no transaction can violate any of the defined validation rules. Referential integrity will always be upheld.

Isolation ensures that concurrent execution of transactions leads to the same result as if transactions were processed one after the other. This is crucial in a multi-user database.

Durability ensures that once a transaction has been committed, it will remain so, even in the event of a power cut. As each part of a transaction is completed, it is held in a buffer on disk until all elements of the transaction are completed. Only then will the changes to the tables actually be made.

Record locking and multi-user databases

Allowing multiple suers to simultaneously access a databases could potentially cause one of the updates to be lost.

For example, when an item is to be updated, the entire block in which the record is located is read into the user's local memory, then when the record is saved, the block is rewritten to the file server. This can easily result in overwriting.

Record locking prevents simultaneous access to objects in a database in order to prevent updates being lost or inconsistencies in the data arising. A record is locked when a user retrieves it for editing or updating. Anyone else attempting to retrieve it is denied access until the transaction is completed or cancelled. A bit like a mutex.

If Alice is trying to make a transfer from A to B and Bob is trying to make a transfer from B to A, then we get a deadlock. Neither can write their transaction because the target record is held by another user. This is a deadlock.

Serialisation

Serialisation ensures that transactions do not overlap in time and therefore cannot interfere with each other or lead to updates being lost. Serialisation techniques include *timestamp ordering* and *commitment ordering*.

In **timestamp ordering**, every object has a *read timestamp* and a *write timestamp*. These are updated whenever an object is read or written. When a user tries to save an update, if the write timestamp of the record in the DB is newer than the read timestamp of the transaction, then the DBMS knows another used has written to the same object since, so the update will fail.

Commitment ordering ensures that no transactions are lost at all, even if two clients are simultaneously trying to update the same record. Transactions are ordered in terms of their *dependencies* on each other as well as the time they were initiated. It can be used to prevent deadlock by blocking one request until another is completed.

Redundancy

Many organisations cannot afford to have their computer systems go down for even a short time. Air traffic control, for example, normally has a full redundant system on standby if the system crashes. This is, however, very expensive. Duplicate hardware, located in a different location, mirrors every transaction that takes place on the main system. If the main system fails, then the company switches to the backup on-the-fly and the customer won't even notice.