Introduction to Relational Databases

Principles of Data Science with R

Dr. Uma Ravat

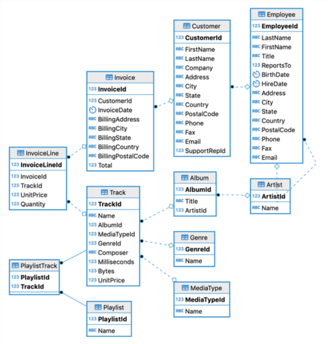
PSTAT 10

Next we will see. . .

- Intro to Databases
- Connecting to database from R
  - the R packages `RSQLite`, `DBI`
  - the database on disk/file `Chinook_Sqlite.sqlite`
- SQL (Structured Query Language)
- 3 parts of the relational data model

What is a (relational) database?

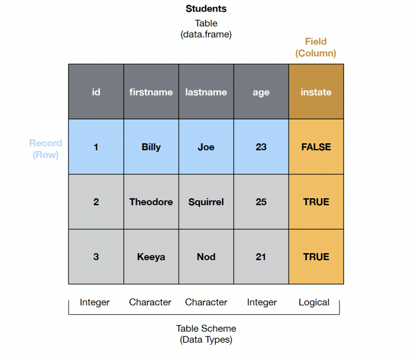
- A **database** is a **collection of tables** that are **related** to one another, together **with specification of these relations.**



- An **entity relationship diagram** (ER diagram) helps visualize the structure of the tables and their relation to one another in a database.

dataframes in R to Tables in databases

R jargon	Database jargon	definition
column	field/attribute	a variable/quantity of interest
row	record/tuple	collection of fields/attributes
dataframe	table/relation	a collection of records which all have the same fields/attribute (with different values)
types of the columns	table schema	datatype and other specifics about each field/attribute.



Why do we need database software?

- **Size**
  - R keeps its data frames in memory
  - Industrial databases are much bigger, need to store out of memory and bring into memory only required subsets
  - Must work with selected subsets
- **Speed**
  - Relational database model published in 70's by E. F. Codd at IBM labs in San Jose, CA.
  - Smart people have worked very hard making relational databases efficient
  - 2014 Turing award winner Michael Stonebraker
- **Concurrency**
  - Many users access the same database simultaneously
  - Potential for trouble (two users want to change the same record at once)
  - Database software takes care of this issue.

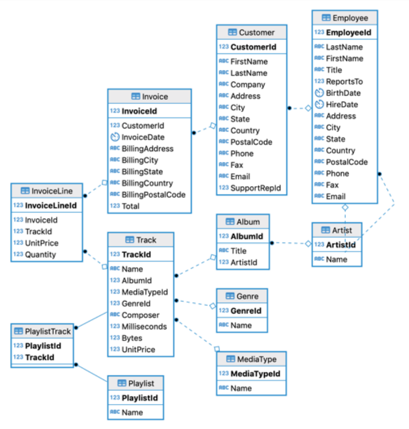
Database software.

A **Relational Database Management System (RDBMS)** is software that enables you to create and maintain databases and interact with the data stored in tables in the relational database.

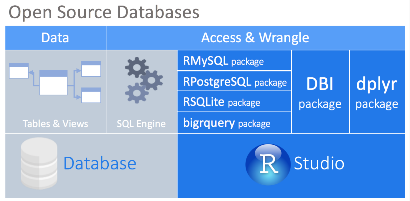
- **SQLite** is a popular light-weight, fast, full-featured RDBMS designed for simple applications (mobile apps)
  - is a simpler, file-based system that we will use via `RSQLite` package in `R`

Chinook DB

This DB represents a digital media store, including tables for artists, albums, media tracks, invoices, and customers.



Connecting R to SQLite



- First, we need to install the packages `DBI`, `RSQLite`,

```
install.packages("DBI")
install.packages("RSQLite")
```

- then we load them into our R session with `library()`

Also, we need a SQLite database file available at `Chinook_Sqlite.sqlite` for this lecture

Connecting to the database in R

```
library(DBI)
library(RSQLite)
drv = dbDriver("SQLite")
chinook_db = dbConnect(drv,
                       dbname="./data/Chinook_Sqlite.sqlite")
```

The object `chinook_db` is now a persistent connection to the `Chinook_Sqlite.sqlite` database on disk.

Listing what's available

The data in a relational database is stored in relations, aka **tables**:

```
# List tables in our database
dbListTables(chinook_db)
```

```
##  [1] "Album"         "Artist"        "Customer"      "Employee"
##  [5] "Genre"         "Invoice"       "InvoiceLine"   "MediaType"
##  [9] "Playlist"      "PlaylistTrack" "Track"
```

Each table has rows of tuples, aka **records**, and columns of attributes, aka **fields**.

```r
#List fields in Customer table
dbListFields(chinook_db, "Customer")
```

```
## [1] "CustomerId" "FirstName" "LastName" "Company" "Address"
## [6] "City" "State" "Country" "PostalCode" "Phone"
## [11] "Fax" "Email" "SupportRepId"
```

Importing a table as a data frame

```
customer = dbReadTable(chinook_db, "Customer")
class(customer)
```

```
## [1] "data.frame"
```

```
dim(customer)
```

```
## [1] 60 13
```

Now we could go on and perform R operations on `customer`, since it's a dataframe

Databases and SQL

- **SQL** (**structured query language**) is language/software to interact with data stored in databases
- **SQL** is the standard for database software
    - many different implementations of SQL, each with unique features.
- Most basic actions with databases are **SQL queries**, like row/column selections, inserts, updates and deletes

Main tool in the SQL language: **`SELECT`**, which allows you to perform queries on a particular table in a database. It has the form:

```
SELECT columns
  FROM table
  WHERE condition
  GROUP BY columns
  HAVING condition
  ORDER BY column [ASC | DESC]
  LIMIT offset, count;
```

`WHERE`, `GROUP BY`, `HAVING`, `ORDER BY`, `LIMIT` are all optional

Example

Pick out five columns from the table "Customer", and only look at the first 6 rows:

```
dbGetQuery(chinook_db,
          "select CustomerId, FirstName, LastName, City, Country
          from Customer
          limit 6" )
```

```
##   CustomerId FirstName    LastName                  City        Country
## 1          1      Luís   Gonçalves São José dos Campos         Brazil
## 2          2    Leonie      Köhler             Stuttgart        Germany
## 3          3  François    Tremblay              Montréal         Canada
## 4          4     Bjørn      Hansen                  Oslo         Norway
## 5          5 František Wichterlová                Prague Czech Republic
## 6          6    Helena        Holý                Prague Czech Republic
```

To replicate this simple command on the imported data frame:

```r
customer[1:6, c("CustomerId", "FirstName", "LastName","City", "Country")]
```

```
##   CustomerId FirstName    LastName                 City        Country
## 1          1      Luís   Gonçalves São José dos Campos          Brazil
## 2          2    Leonie      Köhler           Stuttgart        Germany
## 3          3  François    Tremblay            Montréal         Canada
## 4          4     Bjørn      Hansen                Oslo         Norway
## 5          5 František Wichterlová              Prague Czech Republic
## 6          6    Helena        Holý              Prague Czech Republic
```

ORDER BY

We can use the ORDER BY option in SELECT to specify an ordering for the rows

Default is ascending order; add DESC for descending

```
dbGetQuery(chinook_db,
           "select CustomerId, FirstName, LastName, City, Country
                   from Customer
                   ORDER BY FirstName DESC
                   limit 10")
```

```
##    CustomerId FirstName   LastName           City        Country
## 1          42     Wyatt     Girard       Bordeaux         France
## 2          25    Victor    Stevens        Madison            USA
## 3          19       Tim      Goyer      Cupertino            USA
## 4          44     Terhi Hämäläinen       Helsinki        Finland
## 5          54     Steve     Murray      Edinburgh  United Kingdom
## 6          49 Stanisław     Wójcik         Warsaw         Poland
## 7          12   Roberto    Almeida Rio de Janeiro         Brazil
## 8          29    Robert      Brown        Toronto         Canada
## 9          26   Richard Cunningham     Fort Worth            USA
## 10         59      Puja Srivastava      Bangalore          India
```

Close connection

We opened a connection as follows:

```
chinook_db <- dbConnect(SQLite(),
                        "Chinook_Sqlite.sqlite")
```

After the end of a session, it is good practice to explicitly close your connection.

```
dbDisconnect(chinook_db)
```

If indeed the connection is closed, reading some data should give an error

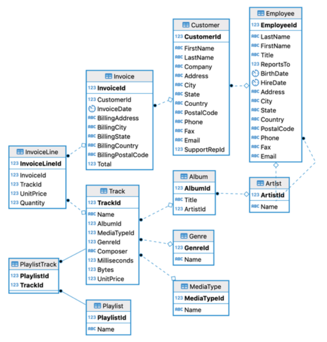
```
dbGetQuery(chinook_db, "select CustomerId, FirstName, LastName from Customer")
```

Error in h(simpleError(msg, call)) : error in evaluating the argument 'conn' in selecting a method for function 'dbGetQuery': object 'chinook_db' not found

Back to some theory: The relational model

In the **relational database**, the data is organized into **relations/tables.**

A relational model is used to represent data and the relationships between data items



The Relational Model consist of 3 parts

1. Manipulative part
   - Allows for data to be manipulated in the database.
   - SQL for create, update, delete tables, databases and user access
   - SQL for select, insert, update, delete data in tables
   - We saw some SQL queries for Select; more later
2. Structural part
   - Tables, relations between tables and rules/constraints for these
   - Visually as ER diagram: Table schema and relations between tables
   - Database Schema and rules/constraints, Primary Keys and Foreign Keys.
3. Integrity part
   - Rules to maintain integrity of data
   - Necessary to keep data complete, consistent and reliable.
     - Entity integrity: integrity of each relation
     - Referential integrity : integrity between relations

Structural part : Relations

Table/Relation

- Each relation must have a **unique name** in the database
- **No duplicate rows**, or tuples, are allowed in a table/relation
- **Each row** in a table/relation has **its own unique key**

Why Keys?

Students

id	firstname	lastname	age	instate
1	Bitly	Jones	19	FALSE
2	Tiny	Lark	25	TRUE
3	Hugh	Grand	22	TRUE

Grades

student_id	course_id	grade
1	1	A
2	2	A
1	2	B
3	4	A
3	1	B

Courses

course_id	Name	Department
1	PSTAT10	pstat
2	PSTAT120A	pstat
3	PSTAT120B	pstat
4	HIST101	hist
5	HIST201	hist

Exams

student_id	name	exam
1	PSTAT10	90.9
1	PSTAT120A	84.5
2	PTAT120A	90.7
3	HIST101	83
3	PSTAT10	96

Why Keys?

	Grades	
student_id	course	grade
1	PSTAT10	A
2	PSTAT120A	A
1	PSTAT120A	B
3	HIST101	A
3	PSTAT10	B

	Exams	
student_id	course	exam
1	PSTAT10	90.9
1	PSTAT120A	84.5
2	PTAT120A	90.7
3	HIST101	83
3	PSTAT10	96

Why Keys?

Grades

student_id	course	grade
1	PSTAT10	A
2	PSTAT120A	A
1	PSTAT120A	B
3	HIST101	A
3	PSTAT10	B

Exams

student_id	course	exam
1	PSTAT10	90.9
1	PSTAT120A	84.5
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3	HIST101	83
3	PSTAT10	96

student_id	course	exam	grade
1	PSTAT10	90.9	A
2	PSTAT120A	84.5	A
1	PSTAT120A	90.7	B
3	HIST101	83	A
3	PSTAT10	96	B

Structural part : Keys

A Key

- consists of one or more attributes
- places certain constraints on a databases
- Each row in a table/relation has its own unique key (primary key)
- used to establish and identify relationships between relations
  - a row in a relation can be linked with another row in other relations (foreign key)

4 types of keys

- Super key
- Candidate key
- Primary key
- Foreign key

Keys: Super Keys

A super key is a set of one or more attributes that uniquely identify a tuple in a relation.

APPOINTMENT	CustNmb	CustName	ApptDay
	5	Brian	Monday
	213	Grayson	Tuesday
	7	Jon	Monday
	88	Nitin	Wednesday
	7	Jon	Tuesday

Super Keys for the Appointment relation:

- {CustNmb, CustName, ApptDay},
- {CustNmb, ApptDay},
- {CustName, ApptDay}

What about {CustNmb, CustName}, {CustNmb},{CustName}, {ApptDay} ?

Keys: Candidate Keys

- Candidate key is a minimal set of attributes which can uniquely identify a tuple.
- Candidate keys are selected from the set of super keys.
- Candidate keys should not have any redundant attributes.
- There can be more than one candidate key in a relation
- The candidate key can be simple, having only one attribute, or it can be a composite of multiple attributes.
- A candidate key is a super key, but not the other way round

Keys: Candidate Keys

APPOINTMENT	CustNmb	CustName	ApptDay
	5	Brian	Monday
	213	Grayson	Tuesday
	7	Jon	Monday
	88	Nitin	Wednesday
	7	Jon	Tuesday

Candidate Keys for the Appointment relation

- {CustNmb, ApptDay},
- {CustName, ApptDay}

What about {CustNmb, CustName, ApptDay}, {CustNmb, CustName}, {CustNmb},{CustName}, {ApptDay} ?

Keys: Primary Keys

- A primary key is the minimal set of attributes which can uniquely identify a tuple.
- one of the candidate keys is chosen as the primary key.
- Candidate keys NOT selected for use as the primary key are called Alternate Keys.
- The same primary key cannot be used for different relations
- Primary key values cannot be null

Keys: Primary Keys

APPOINTMENT	CustNmb	CustName	ApptDay
	5	Brian	Monday
	213	Grayson	Tuesday
	7	Jon	Monday
	88	Nitin	Wednesday
	7	Jon	Tuesday

The primary key for our APPOINTMENT relation is

- {CustNmb, ApptDay}

What about {CustNmb, CustName, ApptDay}, {CustNmb, CustName}, {CustNmb},{CustName}, {ApptDay} ?

What about {CustName, ApptDay}?

Back to Chinook DB : Field metadata

Unlike a dataframe, there is extra information in a database table that expresses relational information between tables.

```
dbGetQuery(chinook_db, "pragma table_info(Customer)")
```

```
##    cid         name         type notnull dflt_value pk
## 1    0   CustomerId      INTEGER       1         NA  1
## 2    1    FirstName NVARCHAR(40)       1         NA  0
## 3    2     LastName NVARCHAR(20)       1         NA  0
## 4    3      Company NVARCHAR(80)       0         NA  0
## 5    4      Address NVARCHAR(70)       0         NA  0
## 6    5         City NVARCHAR(40)       0         NA  0
## 7    6        State NVARCHAR(40)       0         NA  0
## 8    7      Country NVARCHAR(40)       0         NA  0
## 9    8   PostalCode NVARCHAR(10)       0         NA  0
## 10   9        Phone NVARCHAR(24)       0         NA  0
## 11  10          Fax NVARCHAR(24)       0         NA  0
## 12  11        Email NVARCHAR(60)       1         NA  0
## 13  12 SupportRepId      INTEGER       0         NA  0
```

KEYS: Primary key

The **primary key** is a *unique identifier* of the rows in a table. Two rows cannot have the same primary key:

```
dbGetQuery(chinook_db,
    "select CustomerId, FirstName, LastName, City, Country
        from Customer
        limit 2")
```

```
##   CustomerId FirstName  LastName                City Country
## 1          1      Luís Gonçalves São José dos Campos  Brazil
## 2          2    Leonie    Köhler           Stuttgart Germany
```

```r
dbExecute(chinook_db,
    paste("insert into customer",
        "(CustomerId, FirstName, LastName, Email)",
        "values",
        "(1, 'Luis','Armstrong','LuisArmstrong@pstat.ucsb.edu')"))
```

```
## Error: UNIQUE constraint failed: Customer.CustomerId
```

CustomerId is the **primary key** and must be unique.

Multi-column primary key

Primary key's can consist of multiple columns if it takes multiple columns to identify a row in a table. But, two rows cannot have the same primary key.

```r
# Single column primary key
dbGetQuery(chinook_db, "pragma table_info(Customer)")
```

```
##    cid         name         type notnull dflt_value pk
## 1    0   CustomerId      INTEGER       1         NA  1
## 2    1    FirstName NVARCHAR(40)       1         NA  0
## 3    2     LastName NVARCHAR(20)       1         NA  0
## 4    3      Company NVARCHAR(80)       0         NA  0
## 5    4      Address NVARCHAR(70)       0         NA  0
## 6    5         City NVARCHAR(40)       0         NA  0
## 7    6        State NVARCHAR(40)       0         NA  0
## 8    7      Country NVARCHAR(40)       0         NA  0
## 9    8   PostalCode NVARCHAR(10)       0         NA  0
## 10   9        Phone NVARCHAR(24)       0         NA  0
## 11  10          Fax NVARCHAR(24)       0         NA  0
## 12  11        Email NVARCHAR(60)       1         NA  0
## 13  12 SupportRepId      INTEGER       0         NA  0
```

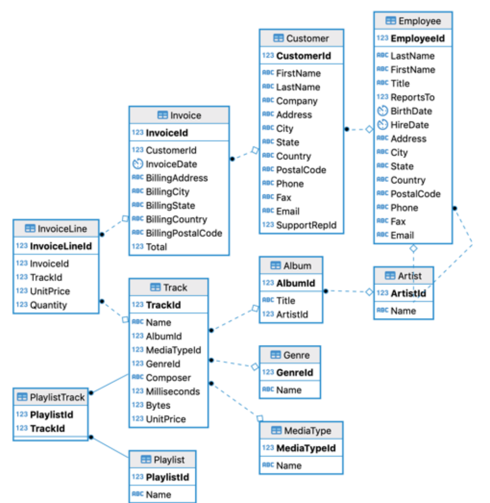
```r
# Multi column primary key
dbGetQuery(chinook_db, "pragma table_info(PlayListTrack)")
```

```
##   cid       name    type notnull dflt_value pk
## 1   0 PlaylistId INTEGER       1         NA  1
## 2   1    TrackId INTEGER       1         NA  2
```

KEYS: Primary key

Tables are not required to have a primary key, but most do. All the tables in Chinook have a primary key.

In ER diagram, Primary Key is denoted as **bold** or underlined field name.



The foreign key is a set of attributes that matches the primary key for another relation. A foreign key field *points to* the primary key of another table.

The foreign key links two relations and can be used to cross-reference the relations.

KEYS: Foreign Keys

The relationship between tables is expressed by primary keys and **foreign keys**.

Remember we are working with a relational database, following a relational data model.

```
dbGetQuery(chinook_db,
           "pragma foreign_key_list(customer)")
```

```
##   id seq    table         from         to on_update on_delete match
## 1  0   0 Employee SupportRepId EmployeeId NO ACTION NO ACTION  NONE
```

KEYS: Enforcing Foreign keys

Foreign keys must either point to an existing value or be NULL.

To enforce Foreign key constraints in SQLite RDBMS

```
# Required for foreign-key support otherwise foreign keys are not enforced
dbExecute(chinook_db, "pragma foreign_keys = on")
```

```
dbGetQuery(chinook_db,
           "SELECT max(EmployeeId) FROM Employee")
```

```
##   max(EmployeeId)
## 1               8
```

```
dbGetQuery(chinook_db,
           "SELECT max(CustomerId) FROM Customer")
```

```
##   max(CustomerId)
## 1             888
```

```r
dbExecute(chinook_db,
    "INSERT INTO Customer
    (CustomerId, FirstName, LastName, Email, SupportRepId)
    VALUES
    (59, 'Luis', 'Armstrong', 'luisArmstrong@pstat.ucsb.edu', 88)")
```

```
## Error: UNIQUE constraint failed: Customer.CustomerId
```

```r
dbExecute(chinook_db,
    "INSERT INTO Customer
    (CustomerId, FirstName, LastName, Email, SupportRepId)
    VALUES
    (60, 'Luis', 'Armstrong', 'luisArmstrong@pstat.ucsb.edu', 10)")
```

```
## Error: FOREIGN KEY constraint failed
```

Interpretation of foreign key

- Each customer in Customer table *can* be assigned a support representative
- The support rep is an employee at the store and therefore has a unique id, EmployeeId
- This unique id,EmployeeId , is the primary key of the employee table

Thus real-world relationship is encoded by the relational model using primary and foreign key relationships.

Keys: Why do we need keys?

- For identifying any row of data in a relation uniquely
- They ensure integrity of data is maintained.
- Keys establish relationships between relations and identify relationships between relations

The Relational Model consist of 3 parts

1. Manipulative part
   - Allows for data is manipulated in the database.
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3. Integrity part
   - Rules to maintain integrity of data
   - Necessary to keep data complete, consistent and reliable.
     - **Entity integrity:** integrity of each relation
     - **Referential integrity:** integrity between relations

Integrity Constraints

We have seen two examples of *integrity constraints*:

- **Entity integrity:** Primary keys must be unique (and not NULL)
  - This ensures there are no duplicate records
- **Referential integrity:** Foreign keys must reference existing primary keys or be NULL
  - ensures that cross-references to non-existing tuples cannot occur

These constraints enforce the *integrity* of a database; no bad data or corrupted relationships.

Keys help maintain the integrity of the data

Database Schema

The **schema** of a database describes its *structure*:

- Names of all the tables
- Names of all fields in each table
- Primary key/foreign key relationships between tables
- Other metadata (data types of each field in each table, ...)

Basically everything other than the actual data itself.

Represented via E-R diagrams (Entity relationship)

We have been looking at parts of the schema with the `pragma` keyword.

```
dbGetQuery(chinook_db, "pragma table_info(customer)")
```

```
##    cid         name         type notnull dflt_value pk
## 1    0   CustomerId      INTEGER       1         NA  1
## 2    1    FirstName NVARCHAR(40)       1         NA  0
## 3    2     LastName NVARCHAR(20)       1         NA  0
## 4    3      Company NVARCHAR(80)       0         NA  0
## 5    4      Address NVARCHAR(70)       0         NA  0
```

We saw…

- Databases are used to store massive amounts of data that cannot fit in memory.
- SQL is the language used to manipulate relational databases
- SQLite is the SQL implementation we will use, provided by the `RSQLite` package.