# Data frames and tibbles: tables in R

## Introduction to R - Day 1

Instructor: Selina Baldauf

Freie Universität Berlin - Theoretical Ecology

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# Data frames

The built-in data structure for tables in R is a `data frame`.

- vectors in R can't represent a table with data that is connected via rows

> Data frames are one of the **biggest and most important ideas** in R, and one of the things that make R different from other programming languages.
>
> (Wickham, Advanced R)

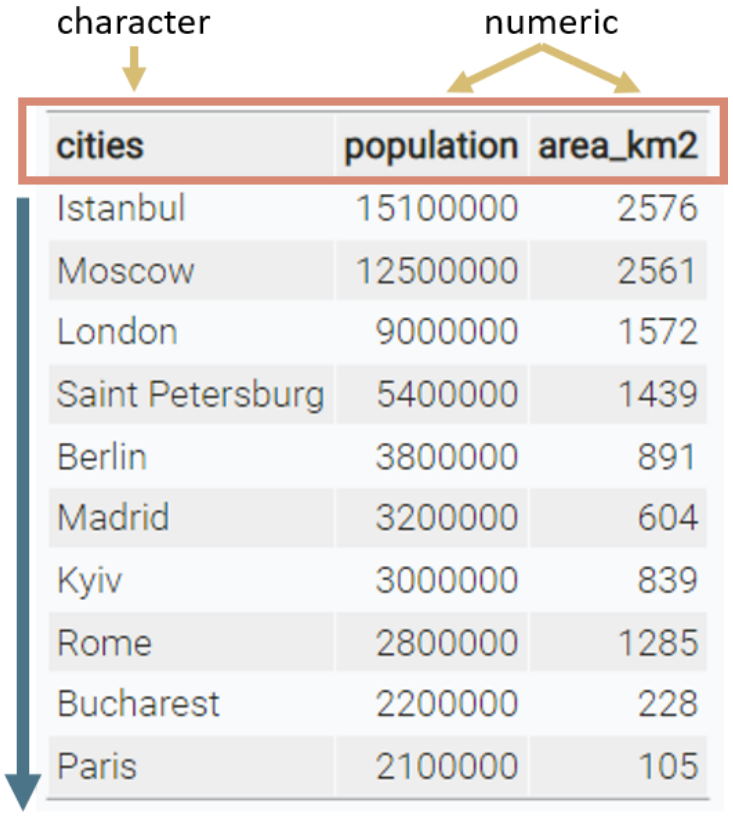
| cities | population | area_km2 |
|---|---|---|
| Istanbul | 15100000 | 2576 |
| Moscow | 12500000 | 2561 |
| London | 9000000 | 1572 |
| Saint Petersburg | 5400000 | 1439 |
| Berlin | 3800000 | 891 |
| Madrid | 3200000 | 604 |
| Kyiv | 3000000 | 839 |
| Rome | 2800000 | 1285 |
| Bucharest | 2200000 | 228 |
| Paris | 2100000 | 105 |

# Data frames

A data frame is a **named list of vectors** of the same length.

## Basic properties of a data frame

- every column is a vector
- columns have a header
  - this is the name of the vector in the list
- within one column, all values are of the same data type
- every column has the same length




| cities | population | area_km2 |
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| Bucharest | 2200000 | 228 |
| Paris | 2100000 | 105 |

# Data frames

Data frames are created with the function `data.frame()`:

```
cities <- c(
  "Istanbul", "Moscow", "London",
  "Saint Petersburg", "Berlin","Madrid",
  "Kyiv", "Rome", "Bucharest","Paris")

population <- c(
  15.1e6, 12.5e6, 9e6, 5.4e6, 3.8e6,
  3.2e6, 3e6, 2.8e6, 2.2e6, 2.1e6)

area_km2 <- c(2576, 2561, 1572, 1439,
  891, 604, 839, 1285, 228, 105)
```

```
data.frame(
  cities = cities,
  population = population,
  area_km2 = area_km2
  )
```

```
##                cities population area_km2
## 1            Istanbul   15100000     2576
## 2              Moscow   12500000     2561
## 3              London    9000000     1572
## 4  Saint Petersburg     5400000     1439
## 5              Berlin    3800000      891
## 6              Madrid    3200000      604
## 7                Kyiv    3000000      839
## 8                Rome    2800000     1285
## 9           Bucharest    2200000      228
## 10              Paris    2100000      105
```

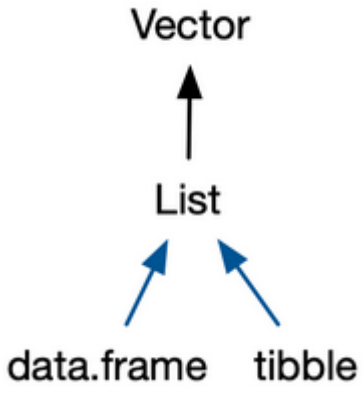
# Tibbles

Tibbles are

> a **modern reimagining of the data frame**. Tibbles are designed to be (as much as possible) **drop-in replacements** for data frames.
>
> (Wickham, Advanced R)

Have a look at this book chapter for a full list of the differences between data frames and tibbles and the advantages of using tibbles.

- tibbles have the same basic properties as data frames (named list of vectors)
- everything that you can do with data frames, you can do with tibbles



# Tibbles

Tibbles are a available from the `tibble` package.

Before we use tibbles, we need to install the package once using the function `install.packages`:

```
# This has do be once
install.packages("tibble")
```

Then, we need to load and attach the package to our current R session using `library`:

```
# This has to be done every time R restarts
# Put it at the beginning of a script
library(tibble)
```

# Tibbles

Create a tibble using the `tibble()` function:

```
library(tibble)

tibble(
  cities = cities,
  population = population,
  area_km2 = area_km2
)
```

```
## # A tibble: 10 x 3
##    cities           population area_km2
##    <chr>                 <dbl>    <dbl>
##  1 Istanbul           15100000     2576
##  2 Moscow             12500000     2561
##  3 London              9000000     1572
##  4 Saint Petersburg    5400000     1439
##  5 Berlin              3800000      891
##  6 Madrid              3200000      604
##  7 Kyiv                3000000      839
##  8 Rome                2800000     1285
##  9 Bucharest           2200000      228
## 10 Paris               2100000      105
```

Note: If you want to use a function from a package you can attach it using `library(package)` or you can use `package::function` to tell R where a function is from (e.g. `tibble::tibble()`). I will sometimes do this to clearly distinguish between base R and package functions.

# Exploring tibbles

Look at the structure of an object using `str()`:

```
str(cities_tbl)
```

```
## tibble [10 x 3] (S3: tbl_df/tbl/data.frame)
##  $ cities    : chr [1:10] "Istanbul" "Moscow" "London" "Saint Petersburg" ...
##  $ population: num [1:10] 15100000 12500000 9000000 5400000 3800000 3200000 3000000 2800000
2200000 2100000
##  $ area_km2  : num [1:10] 2576 2561 1572 1439 891 ...
```

- This function shows you:
  - data type of object (`tbl_df/tbl/data.frame`)
  - extent of the data (10 rows times 3 columns)
  - column names and data types
- This function works for every R object and is very useful if code doesn't work and you don't know why

# Exploring tibbles

How many rows?

```
nrow(cities_tbl)
```

```
## [1] 10
```

How many columns?

```
ncol(cities_tbl)
```

```
## [1] 3
```

What are the column headers?

```
names(cities_tbl)
```

```
## [1] "cities"     "population" "area_km2"
```

# Exploring tibbles

Look at the entire table in a separate window with `view()`:

```
tibble::view(cities_tbl)
```

Get a quick summary of all columns:

```
summary(cities_tbl)
```

```
##     cities             population          area_km2
##  Length:10          Min.   : 2100000   Min.   : 105.0
##  Class :character   1st Qu.: 2850000   1st Qu.: 662.8
##  Mode  :character   Median : 3500000   Median :1088.0
##                     Mean   : 5910000   Mean   :1210.0
##                     3rd Qu.: 8100000   3rd Qu.:1538.8
##                     Max.   :15100000   Max.   :2576.0
```

# Indexing tibbles

Indexing tibbles works similar to indexing vectors but with two dimensions instead of 1:

tibble [ row_index, col_index or col_name ]

- Missing row_index or col_index means *all rows* or *all columns* respectively.
- Indexing a tibble using `[]` always returns another tibble.

# Indexing tibbles

```
# First row and first column
cities_tbl[1, 1]
```

```
## # A tibble: 1 x 1
##   cities
##   <chr>
## 1 Istanbul
```

This is the same as

```
cities_tbl[1, "cities"]
```

# Indexing tibbles: rows

```
# rows 1 & 5, all columns:
cities_tbl[c(1, 5), ]
```

# Indexing tibbles: columns

```
# All rows, first 2 columns
cities_tbl[ ,1:2]
# same as
cities_tbl[ ,c("cities", "population")]
```

```
## # A tibble: 10 x 2
##   cities   population
##   <chr>         <dbl>
## 1 Istanbul   15100000
## 2 Moscow     12500000
## 3 London      9000000
## # ... with 7 more rows
```

# Indexing tibbles: columns

Indexing columns by name is usually preferred to indexing by position

```
cities_tbl[ ,1:2] # okay
cities_tbl[ ,c("cities", "population")] # better
```

## Why?

- code is much easier to read
- code is more robust against
    - changes in column order
    - mistakes in the code (e.g. typos)

```
cities_tbl[ ,c(1,3)] # 3 instead of 2 -> wrong but no error
cities_tbl[ ,c("cities", "popluation")] # typo -> wrong and error
```

General rule: Good code produces errors when something unintended or wrong happens

# Tibbles: Select columns with `$`

Select an entire column from a tibble using `$` (this returns a vector instead of a tibble):

```
cities_tbl$cities
```

```
##  [1] "Istanbul"          "Moscow"            "London"            "Saint Petersburg" "Berlin"
##  [6] "Madrid"            "Kyiv"              "Rome"              "Bucharest"        "Paris"
```

# Adding new columns

New columns can be added as vectors using the `$` operator. The vectors need to have the same length as the tibble has rows.

```
# add a country column
cities_tbl$country <- c(
  "Turkey", "Russia", "UK", "Russia", "Germany", "Spain",
  "Ukraine", "Italy", "Romania", "France"
)
```

```
## # A tibble: 10 x 4
##    cities           population area_km2 country
##    <chr>                 <dbl>    <dbl> <chr>
##  1 Istanbul           15100000     2576 Turkey
##  2 Moscow             12500000     2561 Russia
##  3 London              9000000     1572 UK
##  4 Saint Petersburg    5400000     1439 Russia
##  5 Berlin              3800000      891 Germany
##  6 Madrid              3200000      604 Spain
##  7 Kyiv                3000000      839 Ukraine
##  8 Rome                2800000     1285 Italy
##  9 Bucharest           2200000      228 Romania
## 10 Paris               2100000      105 France
```

# Adding new columns

Adding a new column **based on other columns**:

```
cities_tbl$density <- cities_tbl$population / cities_tbl$area_km2
```

```
## # A tibble: 10 x 5
##    cities           population area_km2 country density
##    <chr>                 <dbl>    <dbl> <chr>     <dbl>
##  1 Istanbul           15100000     2576 Turkey    5862.
##  2 Moscow             12500000     2561 Russia    4881.
##  3 London              9000000     1572 UK        5725.
##  4 Saint Petersburg    5400000     1439 Russia    3753.
##  5 Berlin              3800000      891 Germany   4265.
##  6 Madrid              3200000      604 Spain     5298.
##  7 Kyiv                3000000      839 Ukraine   3576.
##  8 Rome                2800000     1285 Italy     2179.
##  9 Bucharest           2200000      228 Romania   9649.
## 10 Paris               2100000      105 France   20000
```

# Adding new columns

Adding new columns **based on a condition**:

```
cities_tbl$category <- ifelse(cities_tbl$population > 5e6, # test
                              "very large", # yes
                              "large") # no
```

```
## # A tibble: 10 x 6
##    cities           population area_km2 country density category
##    <chr>                 <dbl>    <dbl> <chr>     <dbl> <chr>
##  1 Istanbul           15100000     2576 Turkey    5862. very large
##  2 Moscow             12500000     2561 Russia    4881. very large
##  3 London              9000000     1572 UK        5725. very large
##  4 Saint Petersburg    5400000     1439 Russia    3753. very large
##  5 Berlin              3800000      891 Germany   4265. large
##  6 Madrid              3200000      604 Spain     5298. large
##  7 Kyiv                3000000      839 Ukraine   3576. large
##  8 Rome                2800000     1285 Italy     2179. large
##  9 Bucharest           2200000      228 Romania   9649. large
## 10 Paris               2100000      105 France   20000  large
```

# Logical indexing

As with vectors, we can use us logical tests to **select rows** from a tibble. The basic structure is:

tibble [ logical indexing vector of length nrow(tibble), cols to select ]

Only rows that match `TRUE` in the indexing vector get selected.

```
# select all rows for which the population exceeds 15 M
cities_tbl[ cities_tbl$population > 15e6, ]
```

```
## # A tibble: 1 x 6
##   cities   population area_km2 country density category
##   <chr>         <dbl>    <dbl> <chr>     <dbl> <chr>
## 1 Istanbul   15100000     2576 Turkey    5862. very large
```

# Logical indexing

What is happening in detail?

```
cities_tbl[cities_tbl$population > 15e6, ]
```

```
cities_tbl$population # vector with population
```

```
##  [1] 15100000 12500000  9000000  5400000  3800000  3200000  3000000  2800000  2200000  2100000
```

```
cities_tbl$population > 15e6 # logical vector after relational test
```

```
##  [1]  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
```

So we actually subset the tibble like this:

```
cities_tbl[c(TRUE, FALSE, FALSE, FALSE, FALSE,
             FALSE, FALSE, FALSE, FALSE, FALSE), ]
```

# Logical indexing

Some more examples:

```
cities_tbl[cities_tbl$cities != "Istanbul" & cities_tbl$area_km2 > 1000, ]
```

```
## # A tibble: 4 x 6
##   cities           population area_km2 country density category
##   <chr>                 <dbl>    <dbl> <chr>     <dbl> <chr>
## 1 Moscow              12500000     2561 Russia    4881. very large
## 2 London               9000000     1572 UK        5725. very large
## 3 Saint Petersburg     5400000     1439 Russia    3753. very large
## 4 Rome                 2800000     1285 Italy     2179. large
```

# Logical indexing

Some more examples:

```
cities_tbl[cities_tbl$cities != "Istanbul" & cities_tbl$area_km2 > 1000, ]
cities_tbl[cities_tbl$cities %in% c("Istanbul", "Madrid", "Paris"), ]
```

```
## # A tibble: 3 x 6
##   cities   population area_km2 country density category
##   <chr>         <dbl>    <dbl> <chr>     <dbl> <chr>
## 1 Istanbul   15100000     2576 Turkey    5862. very large
## 2 Madrid      3200000      604 Spain     5298. large
## 3 Paris       2100000      105 France   20000  large
```

# Changing values in tibbles

As with vectors, we can use indexing to change specific values in the tibble.

Idea:

1. Index row and column or the values you want to change
2. Overwrite them using the assignment operator `<-`

For example, the population of Madrid changed but we don't know the new population.

We can replace the population value from Madrid with NA:

```
cities_tbl[cities_tbl$cities == "Madrid", "population"] <- NA
```

```
cities_tbl[6, ] # row 6 is Madrid
```

```
## # A tibble: 1 x 6
##   cities population area_km2 country density category
##   <chr>       <dbl>    <dbl> <chr>     <dbl> <chr>
## 1 Madrid         NA      604 Spain     5298. large
```

# Summary I

## data frames and tibbles

- can be used to represent tables in R
- are pretty similar, however tibbles are slightly conventient and modern
- are **named lists of vectors of the same length**
  - every column is a vector
  - columns have a header which is the name of the vector in the list
  - within one column, values are of same data type
  - every column has the same length

## tibbles

- to use tibbles, install the package once with `install.packages("tibble")`
- put `library(tibble)` at the beginning of your script to load package

# Summary II

## Creating tibbles and data frames

```
# data frame
data.frame(
  a = 1:3,
  b = c("a", "b", "c"),
  c = c(TRUE, FALSE, FALSE)
)
# tibble
tibble(
  a = 1:3,
  b = c("a", "b", "c"),
  c = c(TRUE, FALSE, FALSE)
)
# convert data frame to tibble
as_tibble(df)
```

# Summary III

## Looking at tibble structure

```
# structure of tibble and data types of columns
str(tbl)
# number of rows
nrow(tbl)
# number of columns
ncol(tbl)
# column headers
names(tbl)
# look at the data in a new window
tibble::view(tbl)
# summary of values from each column
summary(tbl)
```

# Summary IV

## Indexing tibbles and selecting columns

Return result as tibble:

```
# rows and columns by position
tbl[1:3, c(1, 3)]
tbl[1:3, ] # all columns
tbl[, 3] # column 3, all rows
tbl[3] # same as above

# columns by name
tbl[, c("colA", "colB")]
tbl[c("colA", "colB")]
```

Return result as vector:

```
tbl$colA # select colA
```

# Summary V

## Logical indexing to select rows

- Index tibbles with a vector of the same length
- Use
  - logical and relational operators
  - `%in%`

```
tbl[tbl$colA == 5, ] # only rows where colA is 5 (all columns)
tbl[tbl$colA >= 10, ]
tbl[tbl$colB %in% c("hello", "cat", "apple"), ] # only rows where colB is "hello", "cat" or
"apple"
tbl[tbl$colB == "hello" | tbl$colB == "cat" | tbl$colB == "apple", ] # same as above
```

## Logical indexing to select columns

```
select_cols <- c("colA", "colB", "colC")
tbl[names(tbl) %in% select_cols]
tbl[c("colA", "colB", "colC")] # same as above
```

# Summary VI

## Add and remove columns

```
tbl$new_col <- c(1, 2, 3)
tbl$new_col <- tbl$colA / tbl$colB # new column based on other columns
tbl$new_col <- NULL # remove new_col
```

# Now you

## Task 3: Tibbles

Find the task description here