05 - The R language: Vectors, Classes, Functions, Iteration

Data Science with R · Summer 2021

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https://brain.cs.uni-magdeburg.de/kmd/DataSciR/

Photo courtesy of Ulrich Arendt

Outline

Vectors

Basic vector operations

Suppose we have the following vector:

```
(v <- c(5, 2, 9, 1, 6, 2, 4, 5, 5, 1))
```

```
##  [1] 5 2 9 1 6 2 4 5 5 1
```

Sort the elements of a vector with `sort()`:

```
sort(v) #  order() returns the order of the values as vector indices
```

```
##  [1] 1 1 2 2 4 5 5 5 6 9
```

Get the unique values of a vector by the order in which they appear with `unique()`:

```
unique(v)
```

```
## [1] 5 2 9 1 6 4
```

Create a contingency table for a vector with `table()`:

```
table(v)
```

```
## v
## 1 2 4 5 6 9
## 2 2 1 3 1 1
```

Vectors types

- In `R`, there are two vector types: **atomic vectors** and **lists**.
- An atomic vector is a sequence of elements of the **same data type**.
- Lists are **recursive vectors**, i.e., lists can contain other lists.

The most important atomic data types are:

- `logical`: `FALSE` or `TRUE`
- `integer`: whole number, e.g. `5L`
- `double`: floating-point number, e.g. `3.4`
- `character`: character string, e.g. `"DataSciR"`

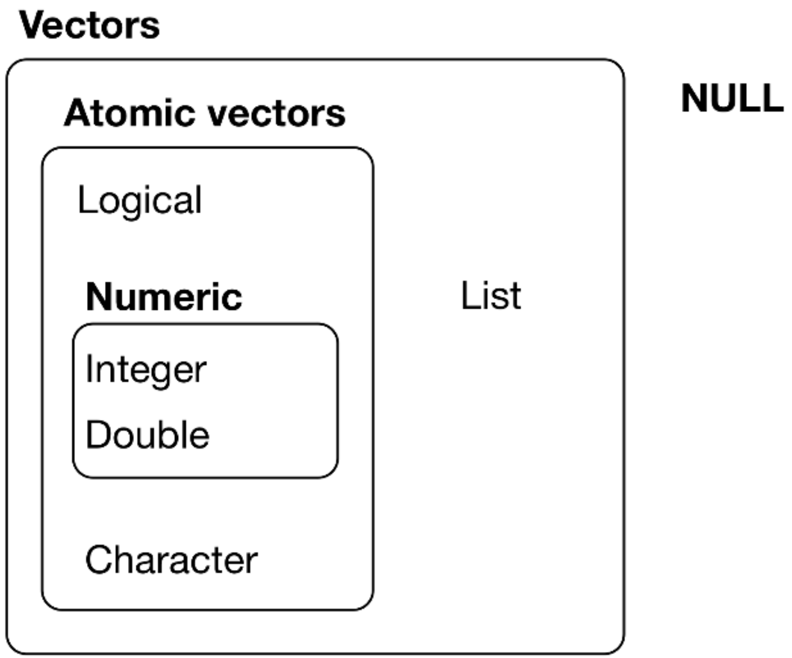


Figure source: Hadley Wickham and Garrett Grolemund. *R for Data Science*. O'Reilly, 2017.

Vector properties

Vectors have two major properties: **type** and **length**.

```
x <- 1:5
typeof(x)
```

```
## [1] "integer"
```

```
length(x)
```

```
## [1] 5
```

Naming vector elements

Naming and renaming of vector elements:

```
names(x) <- letters[1:5] # same as x <- c(a = 1, b = 2, c = 3, d = 4, e = 5)
x
```

```
## a b c d e
## 1 2 3 4 5
```

```
typeof(x)
```

```
## [1] "integer"
```

Accessing vector elements

```r
x[2] # the second element
```

```
## b
## 2
```

```r
x["b"] # the element named "b"
```

```
## b
## 2
```

```r
x[-2] # all elements but the second
```

```
## a c d e
## 1 3 4 5
```

```r
x[-(3:5)] # all elements but the third to fifth
```

```
## a b
## 1 2
```

Vector coercion

An atomic vector must be homogeneous with respect to the type of its elements. If you create a vector with elements of mixed types, `R` tries to convert the elements into the **most flexible** type of its elements. This process is called **vector coercion**. As a result, creating a vector with elements of mixed types does not yield an error.

Order of types, from *least flexible* to *most flexible*:

1. `logical` (`FALSE`, `TRUE`)
2. `integer` (`1L`, `2L`)
3. `double` (`0.51`, `3.19`)
4. `character` (`"abc"`, `"xz"`)

```
x <- c(1, 4, 1, 3, 2)
typeof(x) # why not integer?
```

```
## [1] "double"
```

```
x <- c(1, 4, 1, 3, 2, "4")
x
```

```
## [1] "1" "4" "1" "3" "2" "4"
```

```
typeof(x)
```

```
## [1] "character"
```

Implicit coercion

Functions that require a specific vector type use implicit coercion:

```
# Create a random boolean vector with 10 elements.
lgl_vec <- sample(c(FALSE, TRUE), size = 10, replace = TRUE)
lgl_vec
```

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

```
sum(lgl_vec) # sum() requires numeric type ---> FALSE -> 0, TRUE -> 1
```

```
## [1] 5
```

```
mean(lgl_vec) # mean() requires numeric type --->  FALSE -> 0, TRUE -> 1
```

```
## [1] 0.5
```

```
paste("this", "is", "a", "test") # concatenate strings
```

```
## [1] "this is a test"
```

```
paste(c("this", "is", "a", "test"), collapse = " ")
```

```
## [1] "this is a test"
```

```
paste(lgl_vec, collapse = " ")
```

🤔 *What is the result?*

```
## [1] "TRUE FALSE TRUE TRUE FALSE FALSE FALSE F
```

Explicit coercion

```
x <- c(1, 4, 1, 3, 2, "4.0")
x
```

```
## [1] "1"   "4"   "1"   "3"   "2"   "4.0"
```

Convert a `character` vector into a `double` vector (explicit coercion):

```
as.numeric(x)
```

```
## [1] 1 4 1 3 2 4
```

Explicit coercion can also be realized with `as.logical()`, `as.integer()`, `as.double()` and `as.character()`.

Creating vectors

Vectors can be created with `c()`, `:`, `seq()` or `rep()`.

```r
# "C"ombine elements to a vector
c(1,2,3)
```

```
## [1] 1 2 3
```

```r
# integer sequence
1:3
```

```
## [1] 1 2 3
```

```r
# sequence with an increment of 0.5
seq(1, 3, by = 0.5)
```

```
## [1] 1.0 1.5 2.0 2.5 3.0
```

```r
# repeat the whole vector
rep(1:3, times = 2)
```

```
## [1] 1 2 3 1 2 3
```

```r
# repeat each element of the vector
rep(1:3, each = 2)
```

```
## [1] 1 1 2 2 3 3
```

There is no separate data structure for **scalars** in `R`. Scalars are simply vectors of length 1.

Special values

Missing values or **unknown values** are represented as `NA` (*not applicable*).

These special values can be identified with `is.na()`.

```
is.na(c(1, NA, 5))
```

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

Further special values besides `NA` include:

- `NaN` (not a number): e.g. `sqrt(-2)` → `is.nan()`
- `Inf`: e.g. `1/0` → `is.infinite()`
- `NULL`: absence of a whole vector → `is.null()`

Vector recycling

When combining two vectors, `R` tries to match their lengths.

Vector recycling involves replicating elements of the shorter of two vectors so that the two vectors' lengths are equal.

```
1:6 + 1:3
```

```
## [1] 2 4 6 5 7 9
```

```
1:5 + 1:3
```

🤔 *What is the result?*

```
1:5 + 1:3
```

```
## Warning in 1:5 + 1:3: longer object length is
## not a multiple of shorter object length
```

```
## [1] 2 4 6 5 7
```

Equivalent with:

```
1:5 + c(1:3, 1, 2)
```

```
## [1] 2 4 6 5 7
```

Lists

A **list** is a **recursive vector**, because it can contain other vectors.

Create a list with `list()`:

```
x <- list(1:5)
x
```

```
## [[1]]
## [1] 1 2 3 4 5
```

```
y <- list(1, 2, 3, 4, 5)
y
```

```
## [[1]]
## [1] 1
##
## [[2]]
## [1] 2
##
## [[3]]
## [1] 3
##
## [[4]]
## [1] 4
##
## [[5]]
## [1] 5
```

Inspect the **str**ucture of a list with `str()`:

```
str(y)
```

```
## List of 5
##  $ : num 1
##  $ : num 2
##  $ : num 3
##  $ : num 4
##  $ : num 5
```

Lists

A list is a vector that can contain **elements of different types**:

```
x <- list(TRUE, 1L, 1.23, "u")
str(x)
```

```
## List of 4
##  $ : logi TRUE
##  $ : int 1
##  $ : num 1.23
##  $ : chr "u"
```

Lists can contain other lists:

```
x <- list(list(TRUE, 1L), list(1.23, "u"))
str(x)
```

```
## List of 2
##  $ :List of 2
##   ..$ : logi TRUE
##   ..$ : int 1
##  $ :List of 2
##   ..$ : num 1.23
##   ..$ : chr "u"
```

List subsetting

There are 3 ways to access list elements:

- `[]` extracts a **sublist**. The results is **always** a list,
- `[[]]` extracts a **single element** and removes one level of hierarchy,
- `$` extracts a **named element**.

```
x <- list(
  list(TRUE, 1L),
  list(1.23, "u")
)
str(x)
```

```
## List of 2
##  $ :List of 2
##   ..$ : logi TRUE
##   ..$ : int 1
##  $ :List of 2
##   ..$ : num 1.23
##   ..$ : chr "u"
```

```
str(x[1])
```

```
## List of 1
##  $ :List of 2
##   ..$ : logi TRUE
##   ..$ : int 1
```

```
str(x[[1]])
```

```
## List of 2
##  $ : logi TRUE
##  $ : int 1
```

```
str(x[[1]][[1]])
```

```
##  logi TRUE
```

List subsetting

Compare list subsetting to this unusual pepper shaker:

Figure adapted from: Hadley Wickham and Garrett Grolemund. ["R for Data Science"](). O'Reilly, 2017.

Classes

Classes

- Classes are used to create more complex data structures
- The class attribute of a vector determines its behavior
- The class attribute mostly refers to the S3 class
  - Examples: data frames, factors, and dates

Data frames

Data frames are built on top of regular lists. Thus, element indexing works similar. An important difference between data frames and lists is that a data frame requires its vectors (variables) to have the same length while a list does not.

Example: the `mtcars` dataset

> *The data was extracted from the 1974 Motor Trend US magazine, and comprises fuel consumption and 10 aspects of automobile design and performance for 32 automobiles (1973–74 models).* — `?mtcars`

```
mtcars
```

```
##                    mpg cyl disp  hp drat    wt  qsec vs am gear carb
## Mazda RX4         21.0   6  160 110 3.90 2.620 16.46  0  1    4    4
## Mazda RX4 Wag     21.0   6  160 110 3.90 2.875 17.02  0  1    4    4
## Datsun 710        22.8   4  108  93 3.85 2.320 18.61  1  1    4    1
## Hornet 4 Drive    21.4   6  258 110 3.08 3.215 19.44  1  0    3    1
## Hornet Sportabout 18.7   8  360 175 3.15 3.440 17.02  0  0    3    2
## Valiant           18.1   6  225 105 2.76 3.460 20.22  1  0    3    1
```

`class(mtcars)` → data.frame `typeof(mtcars)` → list

Extracting data frame elements

You can extract a single element (such as a variable of a data frame) with `[[]]`, `$`, and `dplyr::pull()`:

```
mtcars[[1]] # [[]] using the column index
```

```
##  [1] 21.0 21.0 22.8 21.4 18.7 18.1 14.3 24.4 22.8 19.2 17.8 16.4 17.3 15.2 10.4 10.4 14.7
## [18] 32.4 30.4 33.9 21.5 15.5 15.2 13.3 19.2 27.3 26.0 30.4 15.8 19.7 15.0 21.4
```

```
mtcars[["mpg"]] # [[]] using a character string
```

```
##  [1] 21.0 21.0 22.8 21.4 18.7 18.1 14.3 24.4 22.8 19.2 17.8 16.4 17.3 15.2 10.4 10.4 14.7
## [18] 32.4 30.4 33.9 21.5 15.5 15.2 13.3 19.2 27.3 26.0 30.4 15.8 19.7 15.0 21.4
```

```
mtcars$mpg # $ (without quotation marks!)
```

```
##  [1] 21.0 21.0 22.8 21.4 18.7 18.1 14.3 24.4 22.8 19.2 17.8 16.4 17.3 15.2 10.4 10.4 14.7
## [18] 32.4 30.4 33.9 21.5 15.5 15.2 13.3 19.2 27.3 26.0 30.4 15.8 19.7 15.0 21.4
```

```
mtcars %>% pull(mpg)# pull is a dplyr function
```

```
##  [1] 21.0 21.0 22.8 21.4 18.7 18.1 14.3 24.4 22.8 19.2 17.8 16.4 17.3 15.2 10.4 10.4 14.7
## [18] 32.4 30.4 33.9 21.5 15.5 15.2 13.3 19.2 27.3 26.0 30.4 15.8 19.7 15.0 21.4
```

To access one or more elements, you can use `[]`:

```
mtcars[c("mpg", "disp")]
```

```
##                      mpg  disp
## Mazda RX4           21.0 160.0
## Mazda RX4 Wag       21.0 160.0
## Datsun 710          22.8 108.0
## Hornet 4 Drive      21.4 258.0
## Hornet Sportabout   18.7 360.0
## Valiant             18.1 225.0
## Duster 360          14.3 360.0
## Merc 240D           24.4 146.7
## Merc 230            22.8 140.8
## Merc 280            19.2 167.6
## Merc 280C           17.8 167.6
## Merc 450SE          16.4 275.8
## Merc 450SL          17.3 275.8
## Merc 450SLC         15.2 275.8
## Cadillac Fleetwood  10.4 472.0
## Lincoln Continental 10.4 460.0
## Chrysler Imperial   14.7 440.0
## Fiat 128            32.4  78.7
## Honda Civic         30.4  75.7
## Toyota Corolla      33.9  71.1
## Toyota Corona       21.5 120.1
## Dodge Challenger    15.5 318.0
## AMC Javelin         15.2 304.0
## Camaro Z28          13.3 350.0
## Pontiac Firebird    19.2 400.0
## Fiat X1-9           27.3  79.0
## Porsche 914-2       26.0 120.3
```

You can filter rows and subset variables at the same time:

```
mtcars[1:3, c("mpg", "disp")]
```

```
##                mpg disp
## Mazda RX4     21.0  160
## Mazda RX4 Wag 21.0  160
## Datsun 710    22.8  108
```

Alternatively, if the rows are named:

```
mtcars[c("Mazda RX4", "Mazda RX4 Wag",
         "Datsun 710"),
       c("mpg", "disp")]
```

```
##                mpg disp
## Mazda RX4     21.0  160
## Mazda RX4 Wag 21.0  160
## Datsun 710    22.8  108
```

Factors

- A **factor** is a vector class built on top of an **integer** vector.
- A factor vector contains predefined categorical values, the so-called **levels**.

```
(gender <- factor(c("m", "f", "f", "m", "m"), levels = c("f", "m", "d")))
```

```
## [1] m f f m m
## Levels: f m d
```

```
class(gender)
```

```
## [1] "factor"
```

```
typeof(gender)
```

```
## [1] "integer"
```

```
levels(gender)
```

```
## [1] "f" "m" "d"
```

Factors

A values that is not an element of the set of levels must not be used:

```r
gender[2] <- "male" # only "f", "m", and "d" allowed
```

```
## Warning in `[<-.factor`(`*tmp*`, 2, value = "male"): invalid factor level, NA generated
```

```r
gender
```

```
## [1] m    <NA> f    m    m
## Levels: f m d
```

Factors

Factors are also useful if all possible values are known in advance but some of them are not observed initially.

```
table(gender)
```

```
## gender
## f m d
## 1 3 0
```

Compare with:

```
x <- as.character(gender)
table(x)
```

```
## x
## f m
## 1 3
```

The `forcats` package

The core Tidyverse package `forcats` provides functions to modify categorical variables.

Function	Description
fct_reorder()	Change the levels order by the values of another variable
fct_inorder()	Change the levels order by the order in which they first appear
fct_rev()	Reverse the levels order
fct_relevel()	Change the order of one or more levels manually
fct_reorder2()	Change the levels order by the values of a second variable. Which value of the second variable is considered is dependent on the highest value of a third variable.
fct_collapse()	Merge two or more levels
fct_recode()	Rename levels
fct_lump()	Merge levels based on their occurence
…	

The data: descriptors of socio-economic status in the US

Wealth and income in the USA over time | Employed Status

```
income <- read_rds(here::here("data/income.rds"))
glimpse(income)
```

```
## Rows: 1,854
## Columns: 5
## $ year            <dbl> 2019, 2019, 2019, 2019, 2019, 2019, 2018, 2018, 2018, 2018, 2018~
## $ race            <chr> "All Races", "All Races", "All Races", "All Races", "All Races",~
## $ number          <dbl> 128451000, 128451000, 128451000, 128451000, 128451000, 128451000~
## $ income_quintile <chr> "Lowest", "Second", "Third", "Fourth", "Highest", "Top 5%", "Low~
## $ income_share    <dbl> 3.1, 8.3, 14.1, 22.7, 51.9, 23.0, 3.1, 8.3, 14.1, 22.6, 52.0, 23~
```

"The US Census provides Historical Income Tables, of which we have joined several to compare wealth and income over time by race."

Source: TidyTuesday

The data: descriptors of socio-economic status in the US

Wealth and income in the USA over time | **Employed Status**

Employed persons by industry, sex, race, and occupation in the US between 2015 and 2020

```
employed <- read_rds(here::here("data/employed.rds"))
glimpse(employed)
```

```
## Rows: 8,184
## Columns: 7
## $ industry         <chr> "Agriculture and related", "Agriculture and related", "Agricult~
## $ major_occupation <chr> "Management, professional, and related occupations", "Managemen~
## $ minor_occupation <chr> "Management, business, and financial operations occupations", "~
## $ race_gender      <chr> "TOTAL", "TOTAL", "TOTAL", "TOTAL", "TOTAL", "TOTAL", "TOTAL", ~
## $ industry_total   <dbl> 2349000, 2349000, 2349000, 2349000, 2349000, 2349000, 2349000, ~
## $ employ_n         <dbl> 961000, 58000, 13000, 94000, 12000, 96000, 931000, 10000, 33000~
## $ year             <dbl> 2020, 2020, 2020, 2020, 2020, 2020, 2020, 2020, 2020, 2020, 202~
```

Source: [TidyTuesday]

`fct_reorder()`

Default: alphabetic order | Industries ordered by number of employed persons | Code

`fct_reorder()`

Default: alphabetic order | Industries ordered by number of employed persons | Code

`fct_reorder()`

Default: alphabetic order | Industries ordered by number of employed persons | Code

Syntax: `fct_reorder(<factor_column>, <numeric_column_to_order_by>)`

```
employed %>%
  drop_na() %>%
  filter(year == 2020, race_gender == "TOTAL") %>%
  distinct(industry, industry_total) %>%
  mutate(industry = fct_reorder(industry, industry_total)) %>%
  ggplot(aes(x = industry_total / 1000000, y = industry)) +
  geom_col() +
  labs(
    x = "Employed persons (x 1,000,000)", y = NULL,
    title = "Employed persons per industry in the USA in 2020"
    )
```

`fct_inorder()`

Start | fct_inorder(): order by first appearance | fct_infreq() + fct_rev() | Code

```
employed$race_gender %>% unique() # order in the data
```

```
## [1] "TOTAL"                     "Men"                       "Women"
## [4] "White"                     "Black or African American" "Asian"
```

`fct_inorder()`

Start | fct_inorder(): order by first appearance | fct_infreq() + fct_rev() | Code

`fct_inorder()`

Start | fct_inorder(): order by first appearance | fct_infreq() + fct_rev() | Code

`fct_inorder()`

Start | fct_inorder(): order by first appearance | fct_infreq() + fct_rev() | Code

Syntax: `fct_inorder(<factor_column>)`

```
employed %>%
  mutate(race_gender = fct_inorder(race_gender)) %>%
  filter(year == 2020, industry == "Education and health services") %>%
  drop_na() %>%
  distinct(industry, race_gender, industry_total) %>%
  ggplot(aes(x = industry_total / 1000000, y = fct_rev(race_gender))) +
  geom_col() +
  labs(
    x = "Employed persons (x 1,000,000)", y = NULL,
    title = "Employed persons per race/gender in education and health\nservices in the USA in 2020"
    )
```

`fct_relevel()`

Category names have an inherent order | fct_relevel() | Code

`fct_relevel()`

Category names have an inherent order | fct_relevel() | Code

`fct_relevel()`

Category names have an inherent order | fct_relevel() | **Code**

Syntax: `fct_relevel(<factor_column>, <level_to_bring_to_first_pos>, <level_to_bring_to_second_pos>, ...)`

```
income %>%
  filter(year == 2019, race == "All Races", income_quintile != "Top 5%") %>%
  mutate(income_quintile = fct_relevel(income_quintile,
    "Highest", "Second", "Third", "Fourth", "Lowest"
  )) %>%
  ggplot(aes(x = race, y = income_share, fill = income_quintile)) +
  geom_col() +
  scale_fill_brewer(palette = "PiYG", direction = -1) +
  labs(x = NULL, y = "Income share (%)", fill = "Income\nquintile",
       title = "Income share by income quantile\nin the USA in 2019")
```

`fct_reorder2()`

Hard to read | fct_reorder2() | Code

Goal: Order `race` by `income_share` in 1986 (last year)

`fct_reorder2()`

Hard to read | fct_reorder2() | Code

`fct_reorder2()`

Hard to read | fct_reorder2() | **Code**

Syntax: `fct_reorder2(<factor_column>, <numeric_column>, <numeric_column>)`

```
income %>%
  filter(income_quintile == "Top 5%", year <= 1986) %>%
  filter(race %in% c("All Races", "Black Alone", "Hispanic", "White Alone")) %>%
  mutate(race = fct_reorder2(race, year, income_share)) %>%
  ggplot(aes(x = year, y = income_share, color = race)) +
  geom_line(size = 0.7) +
  scale_color_brewer(palette = "Set1") +
  labs(
    x = "Year", y = "Income share (%)", color = "Race",
    title = "Income share of the top 5% incomes by race in the USA over time"
    )
```

`fct_collapse()`

We want to display "Highest" vs. others combined | fct_collapse() | fct_collapse() + fct_rev() | Code

`fct_collapse()`

We want to display "Highest" vs. others combined | **fct_collapse()** | fct_collapse() + fct_rev() | Code

`fct_collapse()`

We want to display "Highest" vs. others combined | fct_collapse() | fct_collapse() + fct_rev() | Code

`fct_collapse()`

We want to display "Highest" vs. others combined | fct_collapse() | fct_collapse() + fct_rev() | **Code**

Syntax: `fct_collapse(<factor_column>, <new_level>, c(<old_level1>, <old_level2>, ...))`

```
income %>%
  filter(year == 2019, race == "All Races", income_quintile != "Top 5%") %>%
  mutate(income_category = fct_collapse(
    income_quintile,
    "Other" = c("Second", "Third", "Fourth", "Lowest")
  )) %>%
  ggplot(aes(x = race, y = income_share, fill = fct_rev(income_category))) +
  geom_col() +
  scale_fill_manual(values = c("gray70", "green4"))
```

Dates and times

The Tidyverse package `lubridate` provides functions to work with dates and times. Since `lubridate` is not a core Tidyverse packages, we have to load it separately.

```
library(lubridate)
today() # date
```

```
## [1] "2021-03-28"
```

```
today() %>% class()
```

```
## [1] "Date"
```

```
now() # date-time
```

```
## [1] "2021-03-28 15:05:13 CEST"
```

```
now() %>% class()
```

```
## [1] "POSIXct" "POSIXt"
```

```
today() %>% typeof()
```

```
## [1] "double"
```

```
now() %>% typeof()
```

```
## [1] "double"
```

Creating dates from character strings

```
tibble(x = c("2021-01-31", "2021-02-05", "2021-03-31")) %>%
  mutate(dte = ymd(x))
```

```
## # A tibble: 3 x 2
##   x          dte
##   <chr>      <date>
## 1 2021-01-31 2021-01-31
## 2 2021-02-05 2021-02-05
## 3 2021-03-31 2021-03-31
```

```
tibble(x = c("31.01.21", "05.02.21", "31.03.21")) %>%
  mutate(dte = dmy(x))
```

```
## # A tibble: 3 x 2
##   x        dte
##   <chr>    <date>
## 1 31.01.21 2021-01-31
## 2 05.02.21 2021-02-05
## 3 31.03.21 2021-03-31
```

```
tibble(x = c("January 31 21", "Feb 05 21", "Mar 31 21")) %>%
  mutate(dte = mdy(x))
```

```
## # A tibble: 3 x 2
##   x             dte
##   <chr>         <date>
## 1 January 31 21 2021-01-31
## 2 Feb 05 21     2021-02-05
## 3 Mar 31 21     2021-03-31
```

Extracting date/time components

```
tibble(x = c("2021-01-31 11:59:59", "2021-02-05 02:11:20", "2021-03-31 00:00:00")) %>%
  transmute(dte_tme = ymd_hms(x)) %>%
  mutate(
    year = year(dte_tme),
    month = month(dte_tme),
    day = day(dte_tme),
    hour = hour(dte_tme),
    minute = minute(dte_tme),
    second = second(dte_tme),
  )
```

```
## # A tibble: 3 x 7
##   dte_tme              year month   day  hour minute second
##   <dttm>              <dbl> <dbl> <int> <int>  <int>  <dbl>
## 1 2021-01-31 11:59:59  2021     1    31    11     59     59
## 2 2021-02-05 02:11:20  2021     2     5     2     11     20
## 3 2021-03-31 00:00:00  2021     3    31     0      0      0
```

Arithmetic operations on dates

Differences between two dates/times are of class `difftime`:

```
dft <- ymd(20210301) - ymd(20210201)
dft
```

```
## Time difference of 28 days
```

```
as.double(dft, units = "weeks")
```

```
## [1] 4
```

```
class(dft)
```

```
## [1] "difftime"
```

`lubridate` implements three classes to perform arithmetic operations on **time spans**, i.e. addition, subtraction, and division:

- `Duration`: exact number of seconds
- `Period`: human units like weeks and months
- `Interval`: represent a starting and ending point

Durations

```r
ymd("2021-03-27") + ddays(1)
```

```
## [1] "2021-03-28"
```

```r
ymd("2021-03-27") + dyears(1)
```

```
## [1] "2022-03-27 06:00:00 UTC"
```

Why `06:00:00`?

```r
dyears(1) / ddays(1)
```

```
## [1] 365.25
```

Periods

```r
ymd("2021-03-27") + years(1)
```

```
## [1] "2022-03-27"
```

```r
ymd("2021-02-01") + dmonths(1) # duration
```

```
## [1] "2021-03-03 10:30:00 UTC"
```

```r
ymd("2021-02-01") + months(1) # period
```

```
## [1] "2021-03-01"
```

```r
dmonths(1) / ddays(1)
```

```
## [1] 30.4375
```

```r
months(1) / days(1)
```

```
## [1] 30.4375
```

Why are `dmonths(1)` and `months(1)` seemingly equal?

Intervals

```
first_of_march <- ymd("2021-02-01") + months(1)
first_of_march
```

```
## [1] "2021-03-01"
```

```
(ymd("2021-02-01") %--% first_of_march) / dmonths(1)
```

```
## [1] 0.9199179
```

```
(ymd("2021-02-01") %--% first_of_march) / months(1)
```

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

Functions

COVID-19 data for Germany

How did the proportion of different age groups to the number of infected persons in German states change over the period of the pandemic?

COVID-19 data | Data description | Plot | Code

```
covid <- read_rds(here::here("data/RKI_COVID19.rds"))
glimpse(covid)
```

```
## Rows: 1,509,819
## Columns: 10
## $ row_id        <int> 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19,~
## $ ref_date      <date> 2021-01-27, 2021-01-28, 2021-02-05, 2021-02-16, 2021-02-21, 2021-~
## $ federal_state <fct> Schleswig-Holstein, Schleswig-Holstein, Schleswig-Holstein, Schles~
## $ district      <chr> "SK Flensburg", "SK Flensburg", "SK Flensburg", "SK Flensburg", "S~
## $ age_group     <chr> "A35-A59", "A35-A59", "A35-A59", "A35-A59", "A35-A59", "A35-A59", ~
## $ sex           <fct> unknown, unknown, unknown, unknown, unknown, unknown, f, f, f, f, ~
## $ cases         <int> 2, 5, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 1, 1, 1, 1, 1, 1, 1, ~
## $ deaths        <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, ~
## $ convalescents <int> 2, 5, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 1, 1, 1, 1, 1, 1, 1, ~
## $ data_date     <date> 2021-03-28, 2021-03-28, 2021-03-28, 2021-03-28, 2021-03-28, 2021-~
```

Source: Robert Koch Institute

COVID-19 data for Germany

How did the proportion of different age groups to the number of infected persons in German states change over the period of the pandemic?

COVID-19 data | **Data description** | Plot | Code

Column	Description
row_id	Row number
ref_date	Date of infection or, if this is not known, the date of notification.
federal_state	Federal state (German: Bundesland)
district	Administrative district (German: Landkreis)
age_group	Age group
sex	Sex
cases	Number of active cases
deaths	Number of new deaths
convalescents	Number of new recovered
data_date	Date of dataset (German: Datenstand)

Source: [Dataset description (in German)]

COVID-19 data for Germany

How did the proportion of different age groups to the number of infected persons in German states change over the period of the pandemic?

COVID-19 data | Data description | **Plot** | Code

COVID-19 data for Germany

How did the proportion of different age groups to the number of infected persons in German states change over the period of the pandemic?

COVID-19 data | Data description | Plot | **Code**

```
covid %>%
  filter(federal_state == "Saxony-Anhalt") %>%
  complete(ref_date, age_group, fill = list(cases = 0)) %>%
  group_by(ref_date, age_group) %>%
  summarize(n_cases = sum(cases)) %>% # average over districts and sexes
  group_by(age_group) %>%
  arrange(ref_date) %>%
  mutate(rolling_mean = RcppRoll::roll_mean(n_cases, n = 14, fill = NA)) %>%
  ungroup() %>% drop_na() %>%
  ggplot(aes(x = ref_date, y = rolling_mean, fill = age_group)) +
  geom_area(position = "fill") +
  scale_fill_manual(values = c(RColorBrewer::brewer.pal(6, "Blues"), "gray30")) +
  labs(
    x = NULL, y = NULL, fill = "Age group",
    title = "Active COVID-19 cases by age group in Saxony-Anhalt",
    caption = paste0("Source: Robert Koch Institute (", format(covid$data_date[1], "%d.%m.%y"), ")")
  ) +
  coord_cartesian(expand = FALSE) +
  scale_y_continuous(labels = scales::percent) +
  theme(plot.title = element_text(size = rel(1.05)))
```

We want to create this plot also for the other 15 states. Is there an a better way than copy-and-pasting?

Why functions?

From R4DS:

- A function with an expressive name makes your code easier to understand.
- If you want to make changes to the code, you only need to update in one place instead of many.
- You eliminate the chance of making inadvertently mistakes because of copy and paste.

In the long run, it is advisable to make your code available in functions (*within packages*) so that future you and others can use your code.

Writing functions

Function scaffolding:

```
plot_covid_cases_by_age_groups <- function(state) {
  # code from an earlier slide goes here
}
```

- `plot_covid_cases_by_age_groups` is the function **name**
  - Try to find informative, expressive names, preferably a verb
- Since a function is an object, we use the `<-` operator
- `state` is the only **argument** of the function
  - If we had more than one argument, we would write `function(state, arg2, arg3)`
  - We can specify default values, e.g. `function(state = "Berlin")`. If an argument does not have a default value, its value must be given in the function call.
- The actual code is placed in the **body** of the function enclosed by `{}`. The opening curly brackets `{` must follow immediately after `function()`.
- Use `return(some_object)` to return the object `some_object` (early). If `return()` is not used, the result of the function's last command will be returned.

plot_covid_cases_by_age_groups()

```r
plot_covid_cases_by_age_groups <- function(state) {
  covid %>%
  filter(federal_state == state) %>%
  complete(ref_date, age_group, fill = list(cases = 0)) %>%
  group_by(ref_date, age_group) %>%
  summarize(n_cases = sum(cases)) %>% # average over districts and sexes
  group_by(age_group) %>%
  arrange(ref_date) %>%
  mutate(rolling_mean = RcppRoll::roll_mean(n_cases, n = 14, fill = NA)) %>%
  ungroup() %>% drop_na() %>%
  ggplot(aes(x = ref_date, y = rolling_mean, fill = age_group)) +
  geom_area(position = "fill") +
  scale_fill_manual(values = c(RColorBrewer::brewer.pal(6, "Blues"), "gray30")) +
  labs(
    x = NULL, y = NULL, fill = "Age group",
    title = paste("Active COVID-19 cases by age group in", state),
    caption = paste0("Source: Robert Koch Institute (", format(covid$data_date[1], "%d.%m.%y"), ")")
  ) +
  coord_cartesian(expand = FALSE) +
  scale_y_continuous(labels = scales::percent) +
  theme(plot.title = element_text(size = rel(1.05)))
}
```

Calling the function

```
plot_covid_cases_by_age_groups("Saxony-Anhalt")
```

```
plot_covid_cases_by_age_groups("Bavaria")
```

More function arguments

Let's improve the function by adding the moving average window length as the second function argument.

Code | w = 14 (default) | w = 7 | w = 50

```
plot_covid_cases_by_age_groups <- function(state, w = 14) {
  covid %>%
    filter(federal_state == state) %>%
    complete(ref_date, age_group, fill = list(cases = 0)) %>%
    group_by(ref_date, age_group) %>%
    summarize(n_cases = sum(cases)) %>% # average over districts and sexes
    group_by(age_group) %>%
    arrange(ref_date) %>%
    mutate(rolling_mean = RcppRoll::roll_mean(n_cases, n = w, fill = NA)) %>%
    ungroup() %>% drop_na() %>%
    ggplot(aes(x = ref_date, y = rolling_mean, fill = age_group)) +
    geom_area(position = "fill") +
    scale_fill_manual(values = c(RColorBrewer::brewer.pal(6, "Blues"), "gray30")) +
    labs(
      x = NULL, y = NULL, fill = "Age group",
      title = paste("Active COVID-19 cases by age group in", state),
      caption = paste0("Source: Robert Koch Institute (", format(covid$data_date[1], "%d.%m.%y"), ")"),
      subtitle = paste("Moving average window length =", w, "days")
    ) +
    coord_cartesian(expand = FALSE) +
    scale_y_continuous(labels = scales::percent) +
    theme(plot.title = element_text(size = rel(1.05)))
}
```

More function arguments

Let's improve the function by adding the moving average window length as the second function argument.

Code | w = 14 (default) | w = 7 | w = 50

```
plot_covid_cases_by_age_groups("Saxony-Anhalt")
```

More function arguments

Let's improve the function by adding the moving average window length as the second function argument.

Code | w = 14 (default) | w = 7 | w = 50

```
plot_covid_cases_by_age_groups("Saxony-Anhalt", w = 7)
```

More function arguments

Let's improve the function by adding the moving average window length as the second function argument.

Code | w = 14 (default) | w = 7 | **w = 50**

```
plot_covid_cases_by_age_groups("Saxony-Anhalt", w = 50)
```

Return value

Recall that by default, the result of the function's last evaluated command will be returned. We can use `return(some_object)` to return the object `some_object` early.

Example without return() | Example with return()

```
convert_cm_to_inch <- function(cm) {
  0.393701 * cm
  42
}
```

```
convert_cm_to_inch(10)
```

```
## [1] 42
```

```
convert_cm_to_inch(100)
```

```
## [1] 42
```

Return value

Recall that by default, the result of the function's last evaluated command will be returned. We can use `return(some_object)` to return the object `some_object` early.

Example without return() | Example with return()

```
convert_cm_to_inch <- function(cm) {
  return(0.393701 * cm)
  42
}
```

```
convert_cm_to_inch(10)
```

```
## [1] 3.93701
```

```
convert_cm_to_inch(100)
```

```
## [1] 39.3701
```

Naming things

In `R`, **functions are objects**. Objects must have **syntactically valid** names:

- Names can only consist of letters, digits, `_` and `.`
- Names must begin with a letter or with `.` *not* followed by a digit
  - Example: `.7up` is not valid, but `.sevenup` is
- Names must not be one of the reserved words, e.g. `if`, `else`, `for`, `TRUE`, `NULL`...

For names consisting of multiple words, it is recommended to use **snake_case** 🐍 opposed to **camelCase** 🐪. You are free to use `.`, but please mind consistency.

```
# good
crawl_corona_data
crawl_covid19_data

# bad
crawl_data_on_sars_cov_2 # a bit too long
ccd # too short and uninformative
CrawlCoronaData # rather start with lowercase letter
crawlcoronadata # rather separated words
data # don't overwrite existing popular/base functions
```

Documentation:

- `?make.names` describes all requirements for syntactically valid names
- `?reserved` lists all reserved words in `R`'s parser.

Further reading: The tidyverse style guide

Lexical scoping

Scoping describes in which order `R` searches for objects.

```
a <- 3
f <- function() {
  a <- 5
  b <- 2
  a^b
}
```

🤔 *"What is the result of running `f()`?"*

```
f()
```

```
## [1] 25
```

🤔 *"Why is the result not 9?"*

First, `R` searches for object names in the environment of the called function.

If the names does not exist in this environment, `R` searches in the next higher environment level.

Lexical scoping

```r
a <- 3
f <- function() {
  a <- 5
  b <- 2
  a^b
}
f()
```

```
## [1] 25
```

```r
a <- 3
g <- function() {
  b <- 2
  a^b
}
g()
```

```
## [1] 9
```

Lexical scoping

Each function call starts with a new environment:

```r
h <- function() {
  if(!exists("x")) {
    x <- 1
  } else {
    x <- x + 1
  }
  x
}
```

```r
h()
```

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

```r
h()
```

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

```r
x
```

```
## Error in eval(expr, envir, enclos): object 'x' not found
```

```r
x <- 5
h()
```

```
## [1] 6
```

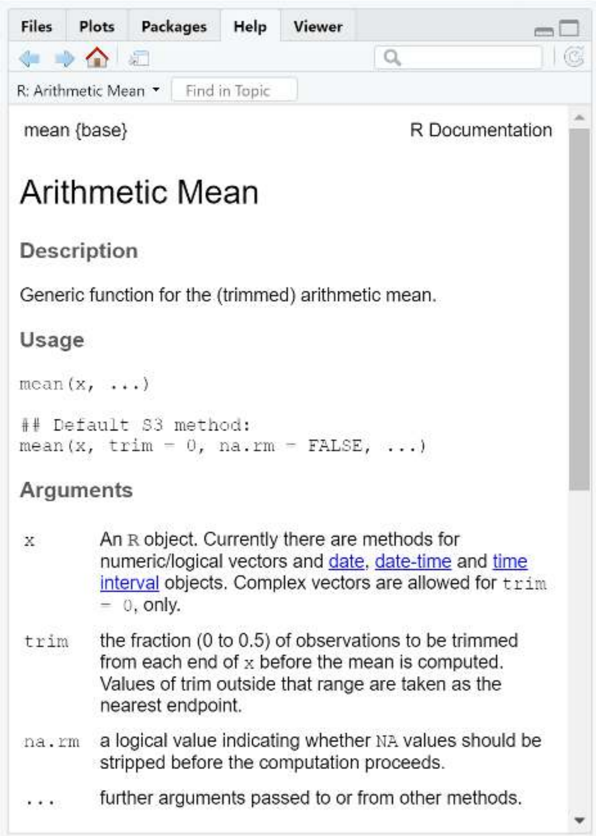
```r
h()
```

```
## [1] 6
```

Calling functions

Basic function call scheme:

```
some_function(arg_1 = val_1,
              arg_2 = val_2,
              ...)
```



Example: the `mean()` function:

- `x` is the only mandatory argument
- arguments `trim` and `na.rm` have default values

```
x <- 1:10
mean(x) # trim = 0 and na.rm = FALSE
```

```
## [1] 5.5
```

```
x <- c(1:10, NA)
mean(x)
```

```
## [1] NA
```

```
mean(x, na.rm = TRUE) # NA's will be ignored
```

```
## [1] 5.5
```

```
mean(x, TRUE) # match unnamed args to their position
```

```
## Error in mean.default(x, TRUE): 'trim' must be numeric of length one
```

Iteration

Define the task

Goal: Create and save a stacked area chart on Covid-19 cases by age groups for each of the 16 German states.

So far, we can do this:

```
plot_covid_cases_by_age_groups("Baden-Wuerttemberg")
plot_covid_cases_by_age_groups("Bavaria")
plot_covid_cases_by_age_groups("Berlin")
plot_covid_cases_by_age_groups("Brandenburg")
# ...
```

Iteration

How can we apply our `plot_covid_cases_by_age_groups()` function to each federal state?

1. Option: using a `for` loop

```
states <- sort(unique(covid$federal_states))
plots <- vector("list", length = length(states))
for(i in seq_along(states)) {
  plots[[i]] <- plot_covid_cases_by_age_groups(states[i])
}
```

2. Option: using **functionals** (recommended)

Functionals

Suppose we have the ratings of four persons for three TV series stored in a data frame:

```
ratings <- tibble(
  breaking_bad = c(1, 9, 4, 8),
  the_crown = c(4, 2, 0, 5),
  vikings = c(9, 9, 4, 1)
)
```

We can calculate the average rating for each TV series with `map()`:

```
map(ratings, mean)
```

```
## $breaking_bad
## [1] 5.5
##
## $the_crown
## [1] 2.75
##
## $vikings
## [1] 5.75
```

Return the result as double vector:

```
map_dbl(ratings, mean)
```

```
## breaking_bad    the_crown      vikings
##         5.50         2.75         5.75
```

Return the result as character vector:

```
map_chr(ratings, mean)
```

```
## breaking_bad    the_crown      vikings
##   "5.500000"   "2.750000"   "5.750000"
```

The `purrr` package

The `purrr` package is part of the core Tidyverse and provides the `map` function family. A `map` function applies a given function to each element of a vector.

`map*()` takes as arguments

1. a vector and
2. a function.

It return a new vector of the **same length** as the input. The **type** of the vector is specified by the **suffix** of the `map*()` function.

- `map()` returns a list
- `map_lgl()` returns a logical vector
- `map_int()` returns an integer vector
- `map_dbl()` returns a double vector
- `map_chr()` returns a character vector
- `map_dfr()` returns a data frame by row binding
- `map_dfc()` returns a data frame by column binding
- ...

Create a plot for each federal state

Map the function `plot_covid_cases_by_age_groups` to each federal state and return a list of plots.

```
states <- sort(unique(covid$federal_state))
plots <- map(states, plot_covid_cases_by_age_groups)
plots[[7]]
```

List columns in data frames

`map()` helps to work with list columns in dplyr pipelines.

For example, a ggplot2 plot is a list object.

Suppose we want to store the plots in a data frame where each row contains the name of the federal state and the area plot.

```
tibble(state = sort(unique(covid$federal_state))) %>%
  mutate(plot_covid_cases_by_age_groups(state))
```

```
## Warning in `==.default`(federal_state, state): longer object length is not a multiple of
## shorter object length

## Warning in is.na(e1) | is.na(e2): longer object length is not a multiple of shorter object
## length

## Error: Problem with `mutate()` input `..1`.
## x Input `..1` must be a vector, not a `gg/ggplot` object.
## i Input `..1` is `plot_covid_cases_by_age_groups(state)`.
```

The code yields an error because `dplyr` functions generally expect the output of functions to be of atomic vector type, i.e., logical, integer, double or character.

We can leverage `map` functions to get it work.

```
covid_plots <- tibble(state = sort(unique(covid$federal_state))) %>%
  mutate(plot = map(state, plot_covid_cases_by_age_groups))
covid_plots
```

```
## # A tibble: 16 x 2
##    state                          plot
##    <fct>                          <list>
##  1 Baden-Wuerttemberg             <gg>
##  2 Bavaria                        <gg>
##  3 Berlin                         <gg>
##  4 Brandenburg                    <gg>
##  5 Bremen                         <gg>
##  6 Hamburg                        <gg>
##  7 Hesse                          <gg>
##  8 Mecklenburg-Western Pomerania <gg>
##  9 Lower Saxony                   <gg>
## 10 North Rhine-Westphalia         <gg>
## 11 Rhineland-Palatinate           <gg>
## 12 Saarland                       <gg>
## 13 Saxony                         <gg>
## 14 Saxony-Anhalt                  <gg>
## 15 Schleswig-Holstein             <gg>
## 16 Thuringia                      <gg>
```

Other useful `purrr` functions

pluck() | One-sided formulas | map2() | walk*()

Use `pluck()` to index into data structures. The function is particularly useful within a pipeline.

Suppose we want to extract the plot for Hamburg:

```
covid_plots %>%
  filter(state == "Hamburg") %>%
  pluck("plot", 1)
```

Other useful `purrr` functions

pluck() | **One-sided formulas** | map2() | walk*()

To save some typing, use **one-sided formulas** for small (anonymous) functions you want to use in `map()`:

```
covid_plots %>%
  mutate(plot = map(plot, ~ .x + theme(text = element_text(color = "red")))) %>%
  pluck("plot", 10)
```

```
# ...which is equivalent to:
covid_plots %>%
  mutate(plot = map(plot, function(x) {x + theme(text = element_text(color = "red"))})) %>%
  pluck("plot", 10)
```

Other useful `purrr` functions

pluck() | One-sided formulas | **map2()** | walk*()

Use `map2()` if you want to map over **two** vectors.

Suppose we want to save our plots as png files, using the federal state's name as file name.

```
save_plot <- function(gg, name) {
  ggsave(
    filename = paste0(name, ".png"), plot = gg,
    width = 28, height = 12, units = "cm", dpi = 300
  )
}
covid_plots %>% mutate(save_plot = map2(plot, state, save_plot))
```

```
## # A tibble: 16 x 3
##    state                         plot   save_plot
##    <fct>                         <list> <list>
##  1 Baden-Wuerttemberg            <gg>   <NULL>
##  2 Bavaria                       <gg>   <NULL>
##  3 Berlin                        <gg>   <NULL>
##  4 Brandenburg                   <gg>   <NULL>
##  5 Bremen                        <gg>   <NULL>
##  6 Hamburg                       <gg>   <NULL>
##  7 Hesse                         <gg>   <NULL>
##  8 Mecklenburg-Western Pomerania <gg>   <NULL>
##  9 Lower Saxony                  <gg>   <NULL>
## 10 North Rhine-Westphalia        <gg>   <NULL>
```

Other useful `purrr` functions

pluck() | One-sided formulas | map2() | **walk*()**

Use `walk()` to apply a function for its **side-effect** to each element of a vector.

For each map function, there is an equivalent walk function, e.g. `map2()` → `walk2()`

```
walk2(covid_plots$plot, covid_plots$state, save_plot)
```

Session info

```
##  setting  value
##  version  R version 4.0.4 (2021-02-15)
##  os       Windows 10 x64
##  system   x86_64, mingw32
##  ui       RTerm
##  language (EN)
##  collate  English_United States.1252
##  ctype    English_United States.1252
##  tz       Europe/Berlin
##  date     2021-03-28
```

package	version	date	source
dplyr	1.0.5	2021-03-05	CRAN (R 4.0.4)
forcats	0.5.1	2021-01-27	CRAN (R 4.0.3)
ggplot2	3.3.3	2020-12-30	CRAN (R 4.0.3)
kableExtra	1.3.4	2021-02-20	CRAN (R 4.0.3)
knitr	1.31	2021-01-27	CRAN (R 4.0.3)
lubridate	1.7.10	2021-02-26	CRAN (R 4.0.4)

package	version	date	source
purrr	0.3.4	2020-04-17	CRAN (R 4.0.2)
readr	1.4.0	2020-10-05	CRAN (R 4.0.3)
stringr	1.4.0	2019-02-10	CRAN (R 4.0.2)
tibble	3.1.0	2021-02-25	CRAN (R 4.0.3)
tidyr	1.1.3	2021-03-03	CRAN (R 4.0.4)
tidyverse	1.3.0	2019-11-21	CRAN (R 4.0.2)

Thank you! Questions?

📷 Photo courtesy of Stefan Berger