Lecture 2: Communicating and Programming in R

CME/STATS 195

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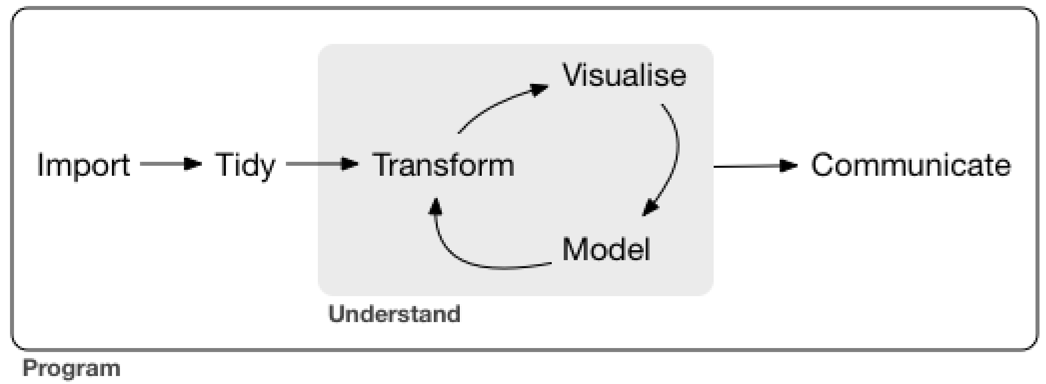
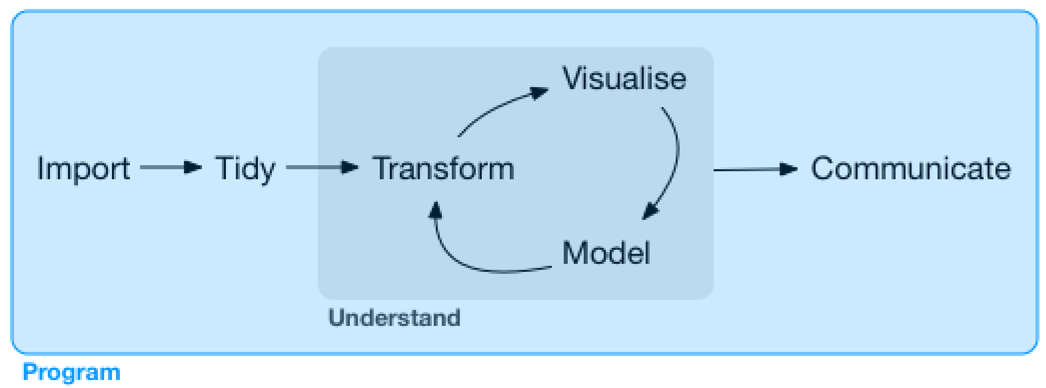


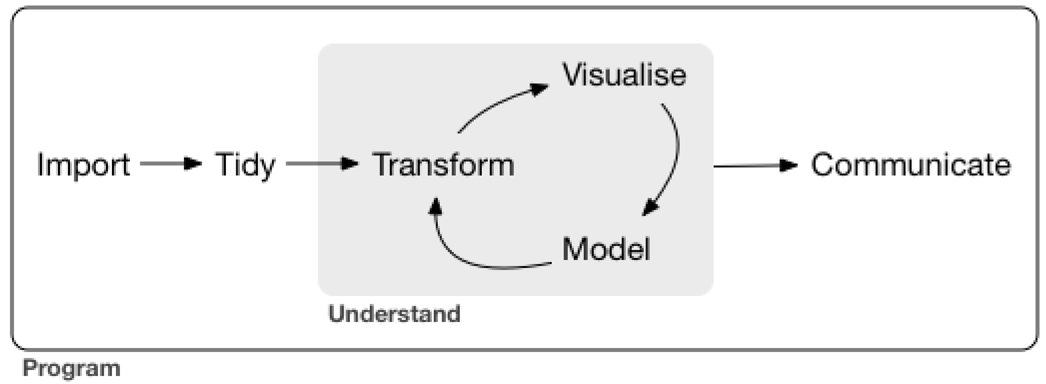


Data Science

Data Science Workflow

> *Data science is an exciting discipline that allows you to turn raw data into understanding, insight, and knowledge.* [1]

1. Import
2. Wrangle (tidy & transform)
3. Visualize
4. Model
5. Communicate



tidyverse

> *The `tidyverse` is an opinionated collection of R packages designed for data science. All packages share an underlying design philosophy, grammar, and data structures.* [2]

`tidyverse` includes packages for **importing, wrangling, exploring and modeling data**.

The system is intended to make data scientists more productive. To use `tidyverse` do the following:

```r
# Install the package
install.packages("tidyverse")
# Load it into memory
library("tidyverse")
```

The `tibble` package

The `tibble` package is part of the core `tidyverse`.

> *Tibbles are a modern take on data frames. They keep the features that have stood the test of time, and drop the features that used to be convenient but are now frustrating.*

`tibbles` are data frames, tweaked to make life a little easier. Unlike regular `data.frames` they:

- never change the type of the inputs (e.g. do not convert strings to factors!)
- never changes the names of variables
- never creates row.names()
- only recycles inputs of length 1

Using `tibbles`

To use functions from `tibble` and other `tidyverse` packages:

```
# load it into memory
library(tidyverse)
```

Printing `tibble` is much nicer, and always fits into your window:

```
# e.g. a built-in dataset 'diamonds' is a tibble:
class(diamonds)
```

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

```
diamonds
```

```
## # A tibble: 53,940 x 10
##    carat cut       color clarity depth table price     x     y     z
##    <dbl> <ord>     <ord> <ord>   <dbl> <dbl> <int> <dbl> <dbl> <dbl>
##  1 0.23  Ideal     E     SI2      61.5    55   326  3.95  3.98  2.43
##  2 0.21  Premium   E     SI1      59.8    61   326  3.89  3.84  2.31
##  3 0.23  Good      E     VS1      56.9    65   327  4.05  4.07  2.31
##  4 0.290 Premium   I     VS2      62.4    58   334  4.2   4.23  2.63
##  5 0.31  Good      J     SI2      63.3    58   335  4.34  4.35  2.75
##  6 0.24  Very Good J     VVS2     62.8    57   336  3.94  3.96  2.48
##  7 0.24  Very Good I     VVS1     62.3    57   336  3.95  3.98  2.47
##  8 0.26  Very Good H     SI1      61.9    55   337  4.07  4.11  2.53
##  9 0.22  Fair      E     VS2      65.1    61   337  3.87  3.78  2.49
## 10 0.23  Very Good H     VS1      59.4    61   338  4     4.05  2.39
## # … with 53,930 more rows
```

Using `tibbles`

Creating `tibbles` is similar to `data.frames`, but no strict rules on column names:

```
(tb <- tibble(x = 1:5, y = 1,z = x ^ 2 + y, `:)` =  "smile"))
```

```
## # A tibble: 5 x 4
##       x     y     z `:)`
##   <int> <dbl> <dbl> <chr>
## 1     1     1     2 smile
## 2     2     1     5 smile
## 3     3     1    10 smile
## 4     4     1    17 smile
## 5     5     1    26 smile
```

Subsetting `tibbles` is stricter than subsetting `data.frames`, and ALWAYS returns objects with expected class: a single `[` returns a `tibble`, a double `[[` returns a vector.

```
class(diamonds$carat)
```

```
## [1] "numeric"
```

```
class(diamonds[["carat"]])
```

```
## [1] "numeric"
```

```
class(diamonds[, "carat"])
```

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

More on `tibbles`

You can read more about other `tibble` features by calling on your R console:

```r
vignette("tibble")
```

Communicating with R Markdown

R Markdown

R Markdown provides an unified authoring framework for data science, combining your code, its results, and your prose commentary.

R Markdown was designed to be used:

- for communicating your conclusions with people who do not want to focus on the code behind the analysis.
- for collaborating with other data scientists, interested in both conclusions, and the code.
- as a modern day lab notebook for data science, where you can capture both your work and your thought process.

R Markdown sourse files

R Markdown files are a plain text files with “.Rmd” extension.

````
---
title: "Title of my first document"
date: "2018-09-27"
output: html_document
---

# Section title

```{r chunk-name, include = FALSE}
library(tidyverse)
summary(cars)
```

## Subsection title

```{r pressure, echo=FALSE}
plot(pressure)
```

Note that the `echo = FALSE` parameter was added to the code chunk to
prevent printing of the R code that generated the plot.
````

The documents must contain **YAML header** marked with dashes. You can ass both **code chunks** and **plain text**. Sections and subsections are marked with hashtags.

Compiling R Markdown files

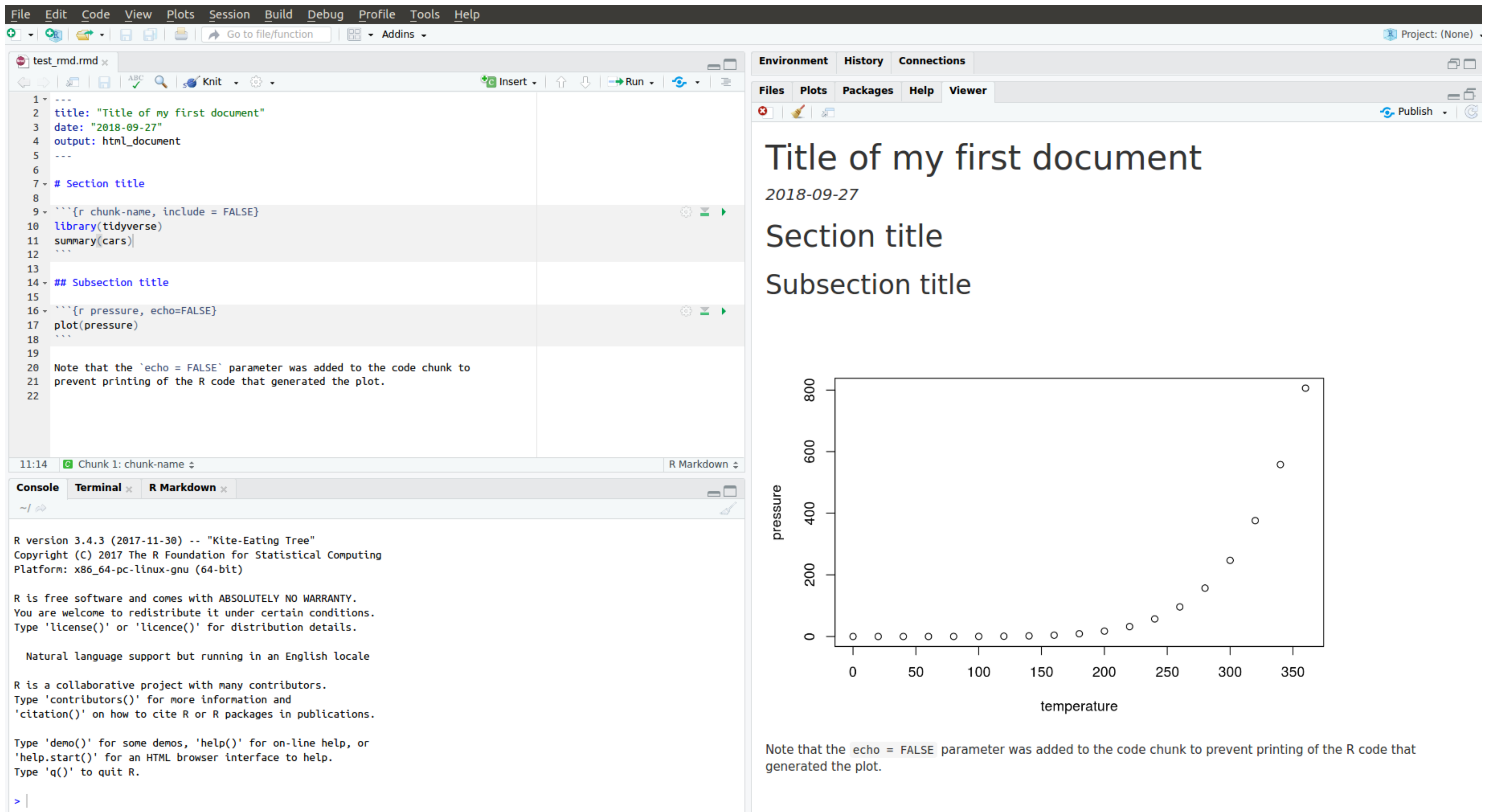
To produce a complete report containing all text, code, and results:

- In RStudio, click on "Knit" or press `Cmd/Ctrl` + `Shift + K`.
- From the R command line, type rmarkdown::render("filename.Rmd")

This will display the report in the viewer pane, and create a self-contained HTML file that you can share with others.

After compiling the R Markdown document from the previous slide, you get this html.

Viewing the report in RStudio



YAML header

A YAML header is a set of `key: value` pairs at the start of your file. Begin and end the header with a line of three dashes (---), e.g.

```
---
title: "Untitled"
author: "Anonymous"
output: html_document
---
```

You can tell R Markdown what type of document you want to render: `html_document` (default), `pdf_document`, `word_document`, `beamer_presentation` etc.

You can print a table of contents (toc) with the following:

```
---
title: "Untitled"
author: "Anonymous"
output:
  html_document:
    toc: true
---
```

Text in R Markdown

In ".Rmd" files, prose is written in Markdown, a lightweight markup language with plain text files formating syntax.

Section headers/titles:

```
# 1st Level Header

## 2nd Level Header

### 3rd Level Header
```

Text formatting:

```
*italic* or _italic_
**bold** __bold__

`code`
superscript^2^ and subscript~2~
```

Text in R Markdown

Lists:

```
* unordered list
* item 2
    + sub-item 1
    + sub-item 2

1. ordered list
1. item 2. The numbers are incremented automatically in the output.
```

Links and images:

```
<http://example.com>

[linked phrase](http://example.com)

![optional caption text](path/to/img.png)
```

Text in R Markdown

Tables:

```
Table Header | Second Header
-------------| -------------
Cell 1       | Cell 2
Cell 3       | Cell 4
```

Math formulae

```
$\alpha$ is the first letter of the Greek alphabet.

Using $$ prints a centered equation in the new line.

$$\sqrt{\alpha^2 + \beta^2} = \frac{\gamma}{2}$$
```

Code chunks

In R Markdown R code must go inside code chunks, e.g.:

````
```{r chunk-name}
    x <- runif(10)
    y <- 10 * x + 4
    plot(x, y)
```
````

Keyboard shortcuts:

- Insert a new code chunk: **`Ctrl/Cmd + Alt + I`**
- Run current chunk: **`Ctrl/Cmd + Shift + Enter`**
- Run current line (where the cursor is): **`Ctrl/Cmd + Enter`**

Chunk Options:

Chunk output can be customized with options supplied to chunk header. Some non-default options are:

- `eval = FALSE` : prevents code from being evaluated
- `include = FALSE` : runs the code, but hides code and its output in the final document
- `echo = FALSE` : hides the code, but not the results, in the final document
- `message = FALSE` : hides messages
- `warning = FALSE` : hides warnings
- `results = ‘hide’` : hides printed output
- `fig.show = ‘hide’` : hides plots
- `error = TRUE` : does not stop rendering if error occurs

Inline code

You can evealuate R code in a middle of your text:

```
There are 26 in the alphabet, and 12 months in each year.
Today, there are `as.Date("2019-08-23") - Sys.Date()` days left till my next birthday.
```

There are 26 in the alphabet, and 12 months in a year. Today, there are 330 days left till my next birthday.

More on R Markdown

R Markdown is relatively young, and growing rapidly.

Official R Markdown website: (http://rmarkdown.rstudio.com)

Further reading and references:

- https://bookdown.org/yihui/rmarkdown/
- http://www.stat.cmu.edu/~cshalizi/rmarkdown
- https://www.rstudio.com/resources/cheatsheets/

Some R Markdown advice

- See your future self as a collaborator.
- Ensure each notebook has a descriptive title and name.
- Use the header date to record start time
- Keep track of failed attempts
- If you discover an error in a data file, write code to fix it.
- Regularly knit the notebook
- Use random seeds before sampling.
- Keep track the versions of the packages you use, e.g. by including `sessionInfo()` command at the end of your document.

All the above will help you increase the reproduciblity of your work.

Programming: style guide

Naming conventions

The first step of programming is naming things.

In the "Hadley Wickam" R style convention:

File names are meaningful. Script files end with ".R", and R Markdown with ".Rmd"

```
# Good
fit-models.R
utility-functions.R
```

```
# Bad (works but does not follow style conventio
foo.r
stuff.r
```

Variable and function names are lowercase.

```
# Good
day_one
day_1
```

```
# Bad (works but does not follow style conventio
first_day_of_the_month
DayOne
```

Spacing

Spacing around all infix operators (=, +, -, <-, etc.):

```
average <- mean(feet / 12 + inches, na.rm = TRUE)     # Good
average<-mean(feet/12+inches,na.rm=TRUE)              # Bad
```

Spacing before left parentheses, except in a function call

```
# Good
if (debug) do(x)
plot(x, y)

# Bad
if(debug)do(x)
plot (x, y)
```

```
# Good
x <- 1 + 2
```

Assignment use ‘<-’ not ‘=’:

```
# Bad (works but does not follow style conventic
x = 1 + 2
```

Curly braces

- An opening curly brace "{" should not go on its own line and be followed by a new line.
- A closing curly "}" brace can go on its own line.
- Indent the code inside curly braces.
- It's ok to leave very short statements on the same line

```
# Good
if (y < 0 && debug) {
  message("Y is negative")
}
if (y == 0) {
  log(x)
} else {
  y ^ x
}

# Bad
if (y < 0 && debug)
message("Y is negative")

if (y == 0) {
  log(x)
}
else {
  y ^ x
}
```

```
if (y < 0 && debug) message("Y is negative")
```

Comments and documentation

Comment your code!

```r
# 'get_answer' returns the answer to life, the universe and everything else.
get_answer <- function(){ return(42)}    # This is a comment
```

Comments are not subtitles, i.e. don't repeat the code in the comments.

```r
# Bad comments:
# Loop through all bananas in the bunch
for(banana in bunch) {
  # make the monkey eat one banana
  MonkeyEat(b)
}
```

Use dashes to separate blocks of code:

```r
# Generate Data ---------------------------
x <- rnorm(100)
y <- 12 * x + 5

# Plot Data -------------------------------
plot(x, y)
```

Programming: control flow

Booleans/logicals

Booleans are logical data types (TRUE/FALSE) associated with conditional statements, which allow different actions and change control flow.

```
# equal "==""
5 == 5
```

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

```
# not equal: "!=""
5 != 5
```

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

```
# greater than: ">""
5 > 4
```

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

```
# greater than or equal: ">="" (# similarly < ar
5 >= 5
```

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

```
# You can combine multiple boolean expressions
TRUE & TRUE
```

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

```
TRUE & FALSE
```

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

```
TRUE | FALSE
```

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

```
!(TRUE)
```

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

Booleans/logicals

In R if you combine 2 vectors of booleans, by each element then use &. Rember the **recycling property** for vectors.

```
c(TRUE, TRUE) & c(FALSE, TRUE)
```

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

```
c(5 < 4, 7 == 0, 1< 2) | c(5==5, 6> 2, !FALSE)
```

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

```
c(TRUE, TRUE) & c(TRUE, FALSE, TRUE, FALSE)  # recycling
```

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

Booleans/logicals

If we use double operators && or | | is used only the first elements are compared:

```
c(TRUE, TRUE) && c(FALSE, TRUE)
```

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

```
c(5 < 4, 7 == 0, 1< 2) || c(5==5, 6> 2, !FALSE)
```

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

```
c(TRUE, TRUE) && c(TRUE, FALSE, TRUE, FALSE)
```

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

Booleans/logicals

- Another possibility to combine booleans is to use `all()` or `any()` functions:

```
all(c(TRUE, FALSE, TRUE))
```

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

```
any(c(TRUE, FALSE, TRUE))
```

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

```
all(c(5 > -1, 3 >= 1, 1 < 1))
```

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

```
any(c(5 > -1, 3 >= 1, 1 < 1))
```

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

Control statements

- **Control flow** is the order in which individual statements, instructions or function calls of a program are evaluated.
- Control statements allow you to do more complicated tasks.
- Their execution results in a choice between which of two or more paths should be followed.
  - `If/else`
  - `For`
  - `While`

If statements

- Decide on whether a block of code should be executed based on the associated boolean expression.
- **Syntax**. The if statements are followed by a boolean expression wrapped in parenthesis. The conditional block of code is inside curly braces `{}`.

```
if (traffic_light == "green") {
  print("Go.")
}
```

- 'if-else' statements let you introduce more options

```
if (traffic_light == "green") {
   print("Go.")
} else {
   print("Stay.")
}
```

- You can also use `else if()`

```
if (traffic_light == "green") {
  print("Go.")
} else if (traffic_light == "yellow") {
  print("Get ready.")
} else {
  print("Stay.")
}
```

Switch statements

For very long sequence of if statements, use the `switch()` function

```r
operator <- function(x, y, op) {
  switch(as.character(op),
    '+' = x + y,
    '-' = x - y,
    '*' = x * y,
    '/' = x / y,
  stop("Unknown op!")
  )
}
```

```r
operator(2, 7, '+')
```

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

```r
operator(2, 7, '-')
```

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

```r
operator(2, 7, '/')
```

```
## [1] 0.2857143
```

```r
operator(2, 7, "a")
```

```
## Error in operator(2, 7, "a"): Unknown op!
```

For loops

- A for loop is a statement which **repeats the execution a block of code** a given number of iterations.

```
for (i in 1:5){
  print(i^2)
}
```

```
## [1] 1
## [1] 4
## [1] 9
## [1] 16
## [1] 25
```

While loops

- Similar to for loops, but repeat the execution as long **as the boolean condition supplied is TRUE**.

```
i = 1
while(i <= 5) {
  cat("i =", i, "\n")
  i = i + 1
}
```

```
## i = 1
## i = 2
## i = 3
## i = 4
## i = 5
```

Next

- `next` halts the processing of the current iteration and advances the looping index.

```
for (i in 1:10) {
  if (i <= 5) {
    print("skip")
    next
  }
  cat(i, "is greater than 5.\n")
}
```

```
## [1] "skip"
## [1] "skip"
## [1] "skip"
## [1] "skip"
## [1] "skip"
## 6 is greater than 5.
## 7 is greater than 5.
## 8 is greater than 5.
## 9 is greater than 5.
## 10 is greater than 5.
```

- `next` applies only to the innermost of nested loops.

```
for (i in 1:3) {
  cat("Outer-loop i: ", i, ".\n")
  for (j in 1:4) {
    if(j > i) {
      print("skip")
      next
    }
    cat("Inner-loop j:", j, ".\n")
  }
}
```

```
## Outer-loop i:  1 .
## Inner-loop j: 1 .
## [1] "skip"
## [1] "skip"
## [1] "skip"
## Outer-loop i:  2 .
## Inner-loop j: 1 .
## Inner-loop j: 2 .
## [1] "skip"
## [1] "skip"
## Outer-loop i:  3 .
## Inner-loop j: 1 .
## Inner-loop j: 2 .
## Inner-loop j: 3 .
## [1] "skip"
```

Break

- The `break` statement allows us to break out out of a for, while loop (of the smallest enclosing).
- The control is transferred to the first statement outside the inner-most loop.

```
for (i in 1:10)  {
  if (i == 6)  {
    print(paste("Coming out from for loop Where i = ", i))
    break
  }
  print(paste("i is now: ", i))
}
```

```
## [1] "i is now:  1"
## [1] "i is now:  2"
## [1] "i is now:  3"
## [1] "i is now:  4"
## [1] "i is now:  5"
## [1] "Coming out from for loop Where i =  6"
```

Exercise 1

- Go to “Lec2_Exercises.Rmd” in RStudio.
- Do Exercise 1.

Programming: functions

What is a function in R?

- A **function** is a procedure/routine that performs a specific task.
- Functions are used to **abstract** components of larger program.
- Similarly to mathematical functions, they **take some input and then do something to find the result**.
- Functions allow you to **automate common tasks** in a more powerful and general way than copy-and-pasting.
- **If you’ve copied and pasted a block of code more than twice, you should use a function instead**.

Why should you use functions?

Functions become very useful as soon as your code becomes long enough.

- Functions will make your **code easier to understand**.
- Errors are less likely to occure and easier to fix.
- For repeated taskes, **changes can be made once** by editing a function and not many distant chunks of code. Example:

```r
set.seed(1)
a <- rnorm(10); b <- rnorm(10); c <- rnorm(10); d <- rnorm(10)
# Bad
a <- (a - min(a, na.rm = TRUE)) /
  (max(a, na.rm = TRUE) - min(a, na.rm = TRUE))
b <- (b - min(b, na.rm = TRUE)) /
  (max(b, na.rm = TRUE) - min(b, na.rm = TRUE))
c <- (c - min(c, na.rm = TRUE)) /
  (max(b, na.rm = TRUE) - min(c, na.rm = TRUE))
d <- (d - min(d, na.rm = TRUE)) /
  (max(d, na.rm = TRUE) - min(d, na.rm = TRUE))
```

```r
# Good
rescale_data <- function(x) {
  rng <- range(x, na.rm = TRUE)
  return((x - rng[1]) / (rng[2] - rng[1]))
}
a <- rescale_data(a)
b <- rescale_data(b)
c <- rescale_data(c)
d <- rescale_data(d)
```

Function Definition

- To define a function you assign a variable name to a `function` object.
- Functions take **arguments, mandatory and optional**.
- Provide the brief **description of your function in comments** before the function definition.

```
# Computes mean and standard deviation of a vector,
# and optionally prints the results.
summarize_data <- function(x, print=FALSE) {
  center <- mean(x)
  spread <- sd(x)
  if (print) {
    cat("Mean =", center, "\n",
        "SD   =", spread, "\n")
  }
  list(mean=center, sd=spread)
}
```

Calling functions

```r
# without printing
x <- rnorm(n = 500, mean = 4, sd = 1)
y <- summarize_data(x)
```

```r
# with printing
y <- summarize_data(x, print = TRUE)
```

```
## Mean = 4.009679
##  SD   = 1.01561
```

```r
# Results are stored in list "y"
y$mean
```

```
## [1] 4.009679
```

```r
y$sd
```

```
## [1] 1.01561
```

```r
# The order of arguments does not matter if the names are specified
y <- summarize_data(print=FALSE, x = x)
```

Explicit return statements

The value returned by the function is usually the last statement it evaluates. You can choose to return early by using `return()`; this makes you code easier to read.

```
# Complicated function simplified by the use of early return statements
complicated_function <- function(x, y, z) {
  # Check some condition
  if (length(x) == 0 || length(y) == 0) {
    return(0)
  }
  # Complicated code here
}
```

Returning invisible objects can be done with `invisible()`

```
show_missings <- function(df) {
  cat("Missing values:", sum(is.na(df)), "\n")
  invisible(df)       # this result doesn't get printed out
}
```

```
show_missings(mtcars)
```

```
## Missing values: 0
```

```
dim(show_missings(mtcars))
```

```
## Missing values: 0
```

```
## [1] 32 11
```

Environment

The environment of a function controls how R finds an object associated with a name.

```
f <- function(x) {
  x + y
}
```

R uses rules called lexical scoping to find the value associated with a name. Here, R will look for `y` in the environment where the function was defined

```
y <- 100
f(10)
```

```
## [1] 110
```

This behaviour attracts bugs. You should try to **avoid using global variables**.

apply, lapply, sapply functions

- The `apply` family functions, are **functions which manipulate slices of data** stored as matrices, arrays, lists and data-frames **in a repetitive way**.
- These functions **avoid the explicit use of loops**, and might be **more computationally efficient**, depending on how big a dataset is. For more details on runtimes see this link.
- `apply` allow you to perform operations with **very few lines of code.**
- The family comprises: **apply, lapply , sapply, vapply, mapply, rapply, and tapply**. The difference lies in the structure of input data and the desired format of the output).

apply function

`apply` operates on arrays/matrices.

In the example below we obtain column sums of matrix X.

```
(X <- matrix(sample(30), nrow = 5, ncol = 6))
```

```
##      [,1] [,2] [,3] [,4] [,5] [,6]
## [1,]   11   21   10   16    7   15
## [2,]   30   13   14   27   23    2
## [3,]   18    3    5    8    4   28
## [4,]    1   20    6   24   26   25
## [5,]   19    9   12   29   22   17
```

```
apply(X, MARGIN = 2 , FUN = sum)
```

```
## [1]  79  66  47 104  82  87
```

Note: that in a matrix `MARGIN = 1` indicates rows and `MARGIN = 2` indicates columns.

apply function

- `apply` can be used with **user-defined functions**:

```
# number entries < 15
apply(X, 2, function(x) 10*x + 2)
```

```
##      [,1] [,2] [,3] [,4] [,5] [,6]
## [1,]  112  212  102  162   72  152
## [2,]  302  132  142  272  232   22
## [3,]  182   32   52   82   42  282
## [4,]   12  202   62  242  262  252
## [5,]  192   92  122  292  222  172
```

- a function can be defined outside `apply()`,

```
logColMeans <- function(x, eps = NULL) {
  if (!is.null(eps)) x <- x + eps
  return(mean(x))
}
apply(X, 2, logColMeans)
```

```
## [1] 15.8 13.2  9.4 20.8 16.4 17.4
```

```
apply(X, 2, logColMeans, eps = 0.1)
```

```
## [1] 15.9 13.3  9.5 20.9 16.5 17.5
```

lapply/sapply functions

- `lapply()` is used to **repeatedly apply a function to elements of a sequential object** such as a vector, list, or data-frame (applies to columns).
- The **output is a list** with the same number of elements as the input object.

```
# lapply returns a list
lapply(1:3, function(x) x^2)
```

```
## [[1]]
## [1] 1
##
## [[2]]
## [1] 4
##
## [[3]]
## [1] 9
```

- `sapply` is the same as `lapply` but **returns a "simplified" output**.

```
sapply(1:3, function(x) x^2)
```

```
## [1] 1 4 9
```

- like with `apply()`, user-defined functions can be used with `sapply/lapply`.

Functional Programming

> *The idea of **passing a function to another function** is extremely powerful idea, and it's one of the behaviours that makes R **a functional programming** (FP) language.*

The **apply family** of functions in base R are basically tools to extract out this duplicated code, so each common for loop pattern gets its own function.

The package `purrr` in `tidyverse` framework solves similar problems, more in line with the 'tidyverse-philosophy'. We will learn in in following lectures.

Exercise 2 and 3

- Go back to “Lec2_Exercises.Rmd” in RStudio.
- Do Exercise 2 and 3.

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1. R for Data Science↩
2. Tidyverse website↩