T01: A brief introduction to R

MATH 2411 Applied Statistics

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What is it and why should I be using it?

What is R?

R is ‘GNU S’, a **freely available** language and environment for **statistical computing and graphics** which provides a wide variety of **statistical and graphical techniques** [1] :

- Linear and nonlinear modelling
- Statistical tests
- Time series analysis
- Classification
- Clustering
- ……

R is used among data miners, bioinformaticians and statisticians for **data analysis** and **developing statistical software.** [2]

[1] From CRAN

[2] From Wikipedia

Now let's become a useR!

Download and install R

The Comprehensive R Archive Network (CRAN)

Built in RGui: not recommended

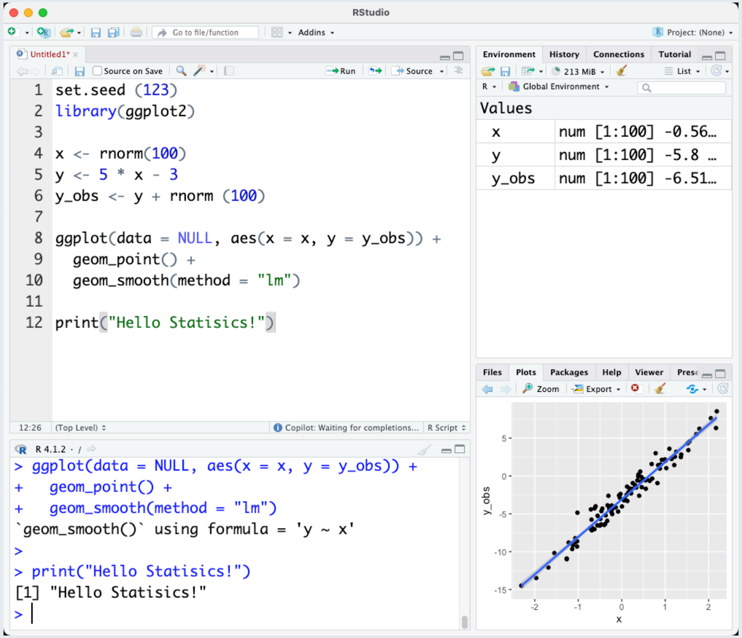
Download and install RStudio

RStudio is an integrated development environment (IDE) for R and Python. It includes a console, syntax-highlighting editor that supports direct code execution, and tools for plotting, history, debugging, and workspace management. RStudio is available in open source and commercial editions and runs on the desktop (Windows, Mac, and Linux). [*]

[*] From RStudio

RStudio has 4 main windows (‘panes’)

- **Source pane** create a file that you can save and run later
- **Console pane** type or paste in commands to get output from R
- **Workspace/History pane** see a list of variables or previous commands
- **Files/Plots/Packages/Help pane** see plots, help pages, and other items in this window



```
set.seed (123)
library(ggplot2)

x <- rnorm(100)
y <- 5 * x - 3
y_obs <- y + rnorm (100)

ggplot(data = NULL, aes(x = x, y = y_obs)) +
  geom_point() +
  geom_smooth(method = "lm")

print("Hello Statisics!")
```

Values

x	num [1:100] -0.56…
y	num [1:100] -5.8 …
y_obs	num [1:100] -6.51…

```
> ggplot(data = NULL, aes(x = x, y = y_obs)) +
+   geom_point() +
+   geom_smooth(method = "lm")
`geom_smooth()` using formula = 'y ~ x'
>
> print("Hello Statisics!")
[1] "Hello Statisics!"
> 
```

Now let's have a try!

- Create a new **R Script** (.R) file from the menu `File -> New File -> R Script`

- Type `print("Hello Statistics!")`

- Type `print("Hello R!")`

- Click the `Run` option in the top right of the **Source** window

```
print("Hello Statistics!")
```

```
[1] "Hello Statistics!"
```

```
print("Hello R!")
```

```
[1] "Hello R!"
```

- Save your **R Script** file as `hello.R`

R Markdown

Why use R Markdown?

- R Markdown allows the user to integrate **R code** into a **report**
- When data changes or code changes, so does the report
- No more need to copy-and-paste graphics, tables, or numbers
- Creates **reproducible** reports

  Anyone who has your R Markdown (.Rmd) file and input data can re-run your analysis and get the exact same results (tables, figures, summaries)

- Can output report in HTML (default), Microsoft Word, or PDF

In-class exercise: create your first R Markdown file!

- Create a new **R Markdown** file from the menu `File -> New File -> R Markdown` …
- Edit **metadata**

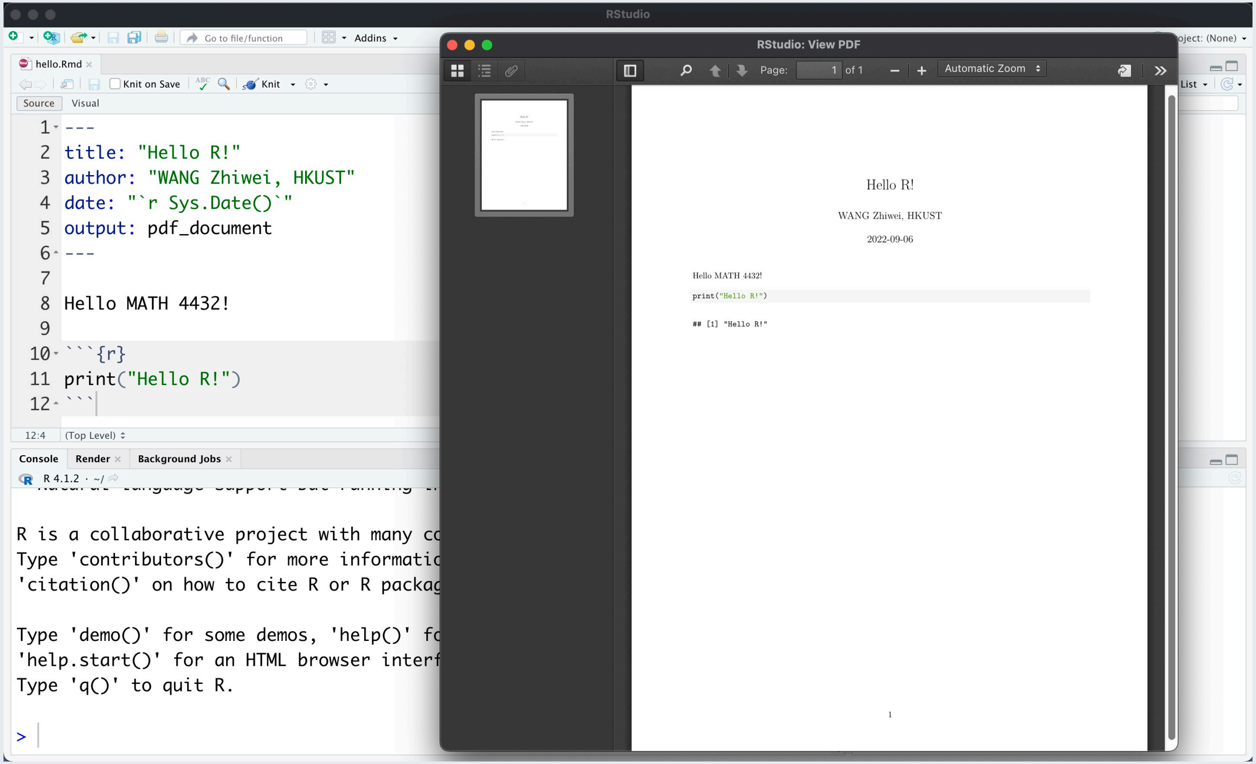
```
---
title: "Hello R!"
author: "WANG Zhiwei"
date: "2024-09-17"
output: pdf_document
---
```

- **Text** `Hello Statistics!`
- **R code**

  ~~~
  ```{r}
  print("Hello R!")
  ```
  ~~~

Output the report

- Click the `Knit` option to produce a PDF file



~~~
---
title: "Hello R!"
author: "WANG Zhiwei, HKUST"
date: "`r Sys.Date()`"
output: pdf_document
---

Hello MATH 4432!

```{r}
print("Hello R!")
```
~~~

```
R is a collaborative project with many co
Type 'contributors()' for more informatio
'citation()' on how to cite R or R packag

Type 'demo()' for some demos, 'help()' fo
'help.start()' for an HTML browser interf
Type 'q()' to quit R.

>
```

Hello R!

WANG Zhiwei, HKUST

2022-09-06

Hello MATH 4432!

```
print("Hello R!")
```

```
## [1] "Hello R!"
```

1

- Save your Rmd file as `hello.Rmd`

Data types

All data is represented in binary format, by bits (TRUE/FALSE, YES/NO, 1/0)

Booleans

Direct binary values: `TRUE` or `FALSE` in R

```
TRUE
```

```
[1] TRUE
```

```
FALSE
```

```
[1] FALSE
```

```
T
```

```
[1] TRUE
```

```
F
```

```
[1] FALSE
```

Integers

The number zero (`0`), a positive natural number (`1, 2, 3, etc.`) or a negative integer with a minus sign (`-1, -2, -3, etc.`), represented by a fixed-length block of bits

```
0L
```

```
[1] 0
```

```
1L
```

```
[1] 1
```

```
as.integer(-100)
```

```
[1] -100
```

Floating point numbers

Positive or negative whole number with a decimal point

```
1
```

```
[1] 1
```

```
1.23
```

```
[1] 1.23
```

```
5e-8
```

```
[1] 5e-08
```

Characters

Fixed-length blocks of bits, with special coding

Strings = sequences of characters

```r
"Hello Statistics!"
```

```
[1] "Hello Statistics!"
```

```r
"Hello R!"
```

```
[1] "Hello R!"
```

```r
'HKUST'
```

```
[1] "HKUST"
```

Special values

Missing or **ill-defined values** and others

```r
NA
```

```
[1] NA
```

```r
NaN
```

```
[1] NaN
```

```r
0 / 0
```

```
[1] NaN
```

```r
1 / 0
```

```
[1] Inf
```

Some useful functions about data types

typeof()

Returns the type of the input

```
typeof(TRUE)
```

```
[1] "logical"
```

```
typeof(3L)
```

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

```
typeof(3)
```

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

```
typeof("HKUST")
```

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

`is.foo()`

Return Booleans for whether the argument is of type `foo`

```
is.character(3)
```

```
[1] FALSE
```

```
is.character("3")
```

```
[1] TRUE
```

```
is.nan(0 / 0)
```

```
[1] TRUE
```

```
is.na(3 / 0)
```

```
[1] FALSE
```

`as.foo()`

Tries to “cast” its argument to type `foo` — to translate it sensibly into a `foo`-type value

```r
as.character(1 / 3)
```

```
[1] "0.3333333333333333"
```

```r
as.numeric(as.character(1 / 3))
```

```
[1] 0.3333333
```

```r
3 * as.numeric(as.character(1 / 3))
```

```
[1] 1
```

Operators

Arithmetic operators

Binary usual arithmetic operators, take two numbers and give a number

- Addition
- Subtraction
- Multiplication
- Division
- Exponentiation
- ……

```
5 + 3
```

```
[1] 8
```

```
5 - 3
```

```
[1] 2
```

```
5 * 3
```

```
[1] 15
```

```
5 / 3
```

```
[1] 1.666667
```

```
5 ^ 3
```

```
[1] 125
```

Comparison operators

Binary operators

Take two objects, like numbers, and give a Boolean

```
5 > 3
```

```
[1] TRUE
```

```
5 < 3
```

```
[1] FALSE
```

```
5 >= 5
```

```
[1] TRUE
```

```
5 == 3
```

```
[1] FALSE
```

```
5 != 3
```

```
[1] TRUE
```

Think about why!

```r
0.3 - 0.7 + 0.4 == 0
```

```
[1] FALSE
```

```r
sqrt(2)^2 == 2
```

```
[1] FALSE
```

- Keywords: **floating point precision**, **finite precision**

```r
0.3 - 0.7 + 0.4
```

```
[1] 5.551115e-17
```

```r
sqrt(2)^2 - 2
```

```
[1] 4.440892e-16
```

- Try to use `all.equal()` function

```r
all.equal(0.3 - 0.7 + 0.4, 0)
```

```
[1] TRUE
```

```r
all.equal(sqrt(2)^2, 2)
```

```
[1] TRUE
```

Boolean operators

! **NOT**, **unary** for arithmetic **negation**

```
! TRUE
```

```
[1] FALSE
```

```
! F
```

```
[1] TRUE
```

& **AND** (**conjunction**), **binary**

```
TRUE & TRUE
```

```
[1] TRUE
```

```
TRUE & FALSE
```

```
[1] FALSE
```

| **OR** (**disjunction**), **binary**

```
FALSE | TRUE
```

```
[1] TRUE
```

```
FALSE | FALSE
```

```
[1] FALSE
```

More complicated cases

- TRUE **AND** TRUE

```
(3 < 5) & (3 * 5 == 15)
```

[1] TRUE

- FALSE **AND** TRUE

```
(3 > 5) & (3 * 5 == 15)
```

[1] FALSE

- FALSE **OR** TRUE

```
(3 > 5) | (3 * 5 == 15)
```

[1] TRUE

Data can have names!

Variables

We can give names to data objects; these give us **variables**

Some built-in variables

```
pi
```

```
[1] 3.141593
```

```
cos(pi)
```

```
[1] -1
```

```
letters
```

```
[1] "a" "b" "c" "d" "e" "f" "g" "h" "i" "j" "k" "l" "m" "n" "o" "p" "q" "r" "s" [20] "t" "u" "v"
"w" "x" "y" "z"
```

Assignment operator

Most variables are created with the **assignment operator**, `<-` or `=`

```
a <- 1L
a
```

[1] 1

```
is.integer(a)
```

[1] TRUE

```
b = 5
a * b
```

[1] 5

Use descriptive variable names!

- Good: `quota_class <- 40`
- Bad: `qc <- 40`

Data structure

Vectors

A **vector** is a sequence of values, all of the **same type**, including `logical`, `integer`, `numeric`, `character`, etc.

`c()` function returns a vector containing all its arguments **in order**

```
students <- c("Jerry", "Tara", "Tom")
id <- c(1:3)
midterm <- c(80, 96, 75)
```

Type the variable name to display its value

```
students
```

```
[1] "Jerry" "Tara" "Tom"
```

```
id
```

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

Adding Elements

The function `c()` (for combine) can also be used to add elements to a vector

```
students
```

```
[1] "Jerry" "Tara" "Tom"
```

```
students <- c(students, "Zhiwei")
id <- c(id, 4)
midterm <- c(midterm, 59)
```

```
students
```

```
[1] "Jerry" "Tara" "Tom" "Zhiwei"
```

```
midterm
```

```
[1] 80 96 75 59
```

Indexing

- `vec[1]` is the 1st element, `vec[3]` is the 3rd

```
students[1]
```

```
[1] "Jerry"
```

```
students[3]
```

```
[1] "Tom"
```

```
students[c(2, 4)]
```

```
[1] "Tara" "Zhiwei"
```

- `vec[-3]` is a vector containing all but the 3rd element

```
students[-3]
```

```
[1] "Jerry" "Tara" "Zhiwei"
```

Named components

You can give **names** to elements or components of vectors

```
students
```

```
[1] "Jerry" "Tara" "Tom" "Zhiwei"
```

```
names(midterm) <- students # Assign students' names to the score
```

```
midterm
```

```
Jerry Tara Tom Zhiwei 80 96 75 59
```

```
midterm["Zhiwei"] # Get score for Zhiwei
```

```
Zhiwei 59
```

```
midterm[c("Tara", "Zhiwei")] # Get scores for 2 students
```

```
Tara Zhiwei 96 59
```

Vector arithmetic

Operators apply to vectors **pairwise** or **elementwise**

```
final <- c(84, 90, 78, 61) # Final exam scores
final
```

```
[1] 84 90 78 61
```

```
midterm # Midterm exam scores
```

```
Jerry Tara Tom Zhiwei 80 96 75 59
```

```
average <- (midterm + final) / 2 # Average exam score
average
```

```
Jerry Tara Tom Zhiwei 82.0 93.0 76.5 60.0
```

```
bonus <- 5
average + bonus
```

```
Jerry Tara Tom Zhiwei 87.0 98.0 81.5 65.0
```

Pairwise comparisons

Is the final score higher than the midterm score?

```
midterm
```

```
Jerry Tara Tom Zhiwei 80 96 75 59
```

```
final
```

```
[1] 84 90 78 61
```

```
final > midterm
```

```
Jerry Tara Tom Zhiwei TRUE FALSE TRUE TRUE
```

Boolean operators can be applied pairwise

```
(final > midterm) & (midterm < 80)
```

```
Jerry Tara Tom Zhiwei FALSE FALSE TRUE TRUE
```

Functions on vectors

```
sum(vec)     # sum of vec
mean(vec)       # mean of vec
median(vec)     # median of vec
min(vec)     # the smallest element of vec
max(vec)     # the largest element of vec
sd(vec)      # the standard deviation of vec
var(vec)     # the variance of vec
length(vec)     # the number of elements in vec
sort(vec)       # returns the vec in sorted order
order(vec)     # returns the index that sorts the vector vec
unique(vec)     # lists the unique elements of vec
summary(vec) # gives a five-number summary
```

Matrix

As with atomic vectors, the elements of a matrix must be of the **same data type**

```
mat_1 <- matrix(c(1:6), nrow = 3, ncol = 2)
mat_1
```

```
 [,1] [,2]
```

```
[1,] 1 4 [2,] 2 5 [3,] 3 6
```

Dimension of the matrix

```
dim(mat_1)
```

```
[1] 3 2
```

Elements of a matrix can be referenced by specifying the index

```
mat_1[2, 1]
```

```
[1] 2
```

Matrix operations

```
mat_2 <- matrix(c(1:6), nrow = 3, ncol = 2)
mat_2
```

```
 [,1] [,2]
```

```
[1,] 1 4 [2,] 2 5 [3,] 3 6
```

```
mat_1 + mat_2 # Addition
```

```
 [,1] [,2]
```

```
[1,] 2 8 [2,] 4 10 [3,] 6 12
```

```
mat_1 - mat_2 # Substraction
```

```
 [,1] [,2]
```

```
[1,] 0 0 [2,] 0 0 [3,] 0 0
```

Matrix operations

Elementwise multiplication

```
mat_1 * mat_2
```

```
 [,1] [,2]
```

[1,] 1 16 [2,] 4 25 [3,] 9 36

Multiplication

```
mat_3 <- matrix(c(5:10), nrow = 2, ncol = 3)
mat_4 <- mat_1 %*% mat_3
mat_4
```

```
 [,1] [,2] [,3]
```

[1,] 29 39 49 [2,] 40 54 68 [3,] 51 69 87

Matrix operations

Transpose

```
t(mat_4)
```

```
 [,1] [,2] [,3]
```

[1,] 29 40 51 [2,] 39 54 69 [3,] 49 68 87

`diag()` function returns a vector containing the elements of the principal diagonal

```
diag(mat_4)
```

[1] 29 54 87

```
diag(t(mat_4))
```

[1] 29 54 87

Data Frame

`data.frame` is a very important data type in R

Creating `data.frame` by hand

```
grade <- data.frame(id = id,
                    midterm = midterm,
                    final = final,
                    average = average)
rownames(grade) <- students
grade
```

```
  id midterm final average
```

Jerry 1 80 84 82.0 Tara 2 96 90 93.0 Tom 3 75 78 76.5 Zhiwei 4 59 61 60.0

Elements of `data.frame` can also be referenced by specifying the row and the column index

```
grade[2, 3]
```

[1] 90

Data Frame

Refer to columns

```
grade[, 4]
```

```
[1] 82.0 93.0 76.5 60.0
```

```
grade[, "average"]
```

```
[1] 82.0 93.0 76.5 60.0
```

```
grade[["average"]]
```

```
[1] 82.0 93.0 76.5 60.0
```

```
grade$average
```

```
[1] 82.0 93.0 76.5 60.0
```

Data Frame

Add a new row

```
# new row
Can <- data.frame(id = 5,
                  midterm = 99,
                  final = 99,
                  average = 99)
rownames(Can) <- "Can"

grade <- rbind(grade, Can)
grade
```

```
   id midterm final average
```

Jerry 1 80 84 82.0 Tara 2 96 90 93.0 Tom 3 75 78 76.5 Zhiwei 4 59 61 60.0 Can 5 99 99 99.0

Data Frame

Add a new column

```
grade <- cbind(grade,
               gender = c("male", "female", "male", "male", "male"))
grade
```

```
   id midterm final average gender
```

Jerry 1 80 84 82.0 male Tara 2 96 90 93.0 female Tom 3 75 78 76.5 male Zhiwei 4 59 61 60.0 male Can 5 99 99 99.0 male

Transfer `gender` to `factor` mode

```
grade[, "gender"] <- factor(grade[, "gender"], levels = c("female", "ma
grade
```

```
   id midterm final average gender
```

Jerry 1 80 84 82.0 male Tara 2 96 90 93.0 female Tom 3 75 78 76.5 male Zhiwei 4 59 61 60.0 male Can 5 99 99 99.0 male

Data Frame

Actually we usually `data.frame` by `read.csv()` and `read.table()`, i.e. when importing the data into R

```
df <- read.csv("<filename>")
df <- read.table("<filename>")
```

When meeting big data, `fread()` function from `data.table` package will be helpful!

```
dt <- fread("<filename>")
```

Packages

Install and library packages

Many useful R functions come in packages, free libraries of code written by R's active user community.

To install an R package, open an R session and type at the command line

```
install.packages("<package name>")
```

R will download the package from CRAN

Once you have a package installed, you can make its contents available to use in your current R session by running

```
library(<package name>)
```

Recommended packages

`tidyverse`, `stringr`, `ggplot2`, `data.table`, `devtools`, etc.

ggplot2

Base-R Code Plot ggplot2 Code Figure

We first use `plot()` function in Base-R

ggplot2

Base-R | **Code** | Plot | ggplot2 | Code | Figure

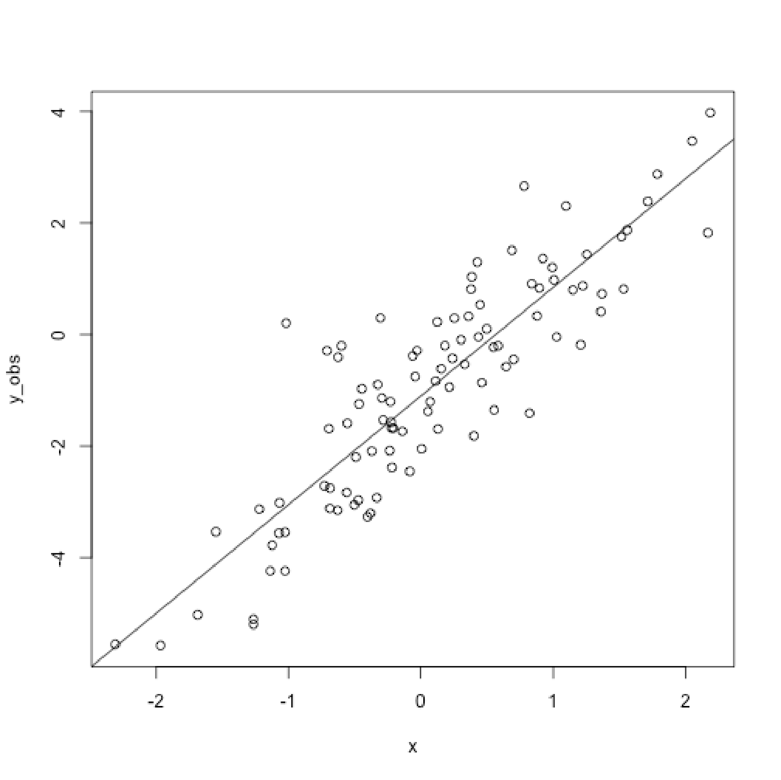
```r
set.seed(123)

# Generate data
x <- rnorm(100) # 100 samples
y <- 2 * x - 1 # Linear function
y_obs <- y + rnorm(100) # Add noise

# Plot
plot(x = x, y = y_obs)
abline(lm(y_obs ~ x))
```

ggplot2

Base-R Code Plot ggplot2 Code Figure



ggplot2

Base-R Code Plot ggplot2 Code Figure

ggplot2 a famous package for making beautiful graphics

ggplot2

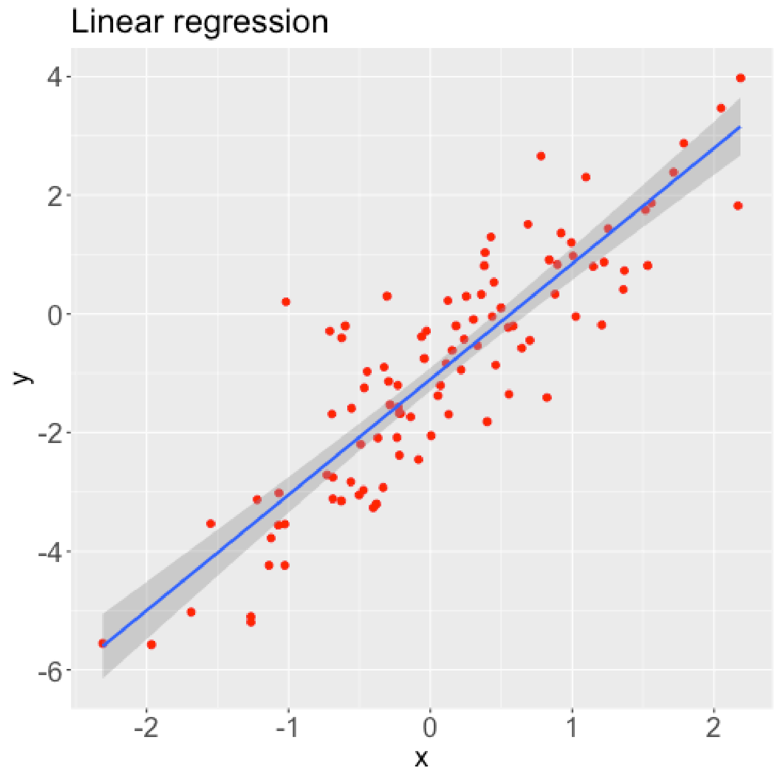
Base-R Code Plot ggplot2 **Code** Figure

```r
# install.packages("ggplot2")
library(ggplot2)
ggplot(data = NULL, aes(x = x, y = y_obs)) +
  geom_point(color = "red", size = 2) +
  geom_smooth(method = "lm") +
  ggtitle("Linear regression") +
  ylab("y") +
  theme(
    text = element_text(size = 18),
    axis.title = element_text(size = 18),
    axis.text.y = element_text(size = 18),
    axis.text.x = element_text(size = 18)
    )
```

ggplot2

Base-R Code Plot ggplot2 Code **Figure**

```
#> `geom_smooth()` using formula = 'y ~ x'
```

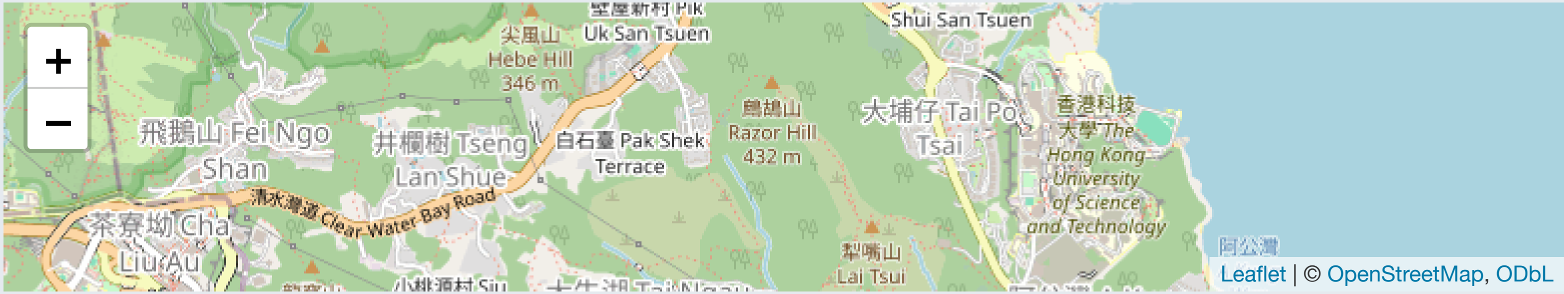


leaflet

Leaflet is one of the most popular open-source `JavaScript` libraries for interactive maps.

This R package makes it easy to integrate and control Leaflet maps in R.

```r
# install.packages("leaflet")
library(leaflet)
leaflet() %>%
  addTiles() %>%
  setView(lng = 114.2654614760902,
          lat = 22.33639483440875,
          zoom = 14)
```



Helpful resources

References

- 94-842: Programming in R for Analytics, Instructor: Prof. Alexandra Chouldechova, Carnegie Mellon University
- R语言忍者秘笈 (Written in Chinese), 谢益辉, 肖楠
- Programming with R, Software Carpentry

Other resources

- Advanced R, Hadley Wickham (Chief Scientist at RStudio, PBC)
- Yihui Xie's homepage, Yihui Xie (Software Engineer at RStudio, PBC)
- 统计之都 (Capital of Statistics), an online community on statistics in China

Thank you!

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