AUA CS108, Statistics, Fall 2020

Lecture 00, Intro to R

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Installing R

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Here is a link to a reference book for **R**: An Introduction to R

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The output will be dispayed on the next line, and start with a number in a parenthesis, say,

```r
2+3
```

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

Running a command in the Console

Here '##' sign is for the slides, **R** will not show that sign. It is to emphasize the **R** output line. Also note that the **R** code in my slides will be written in a color (and will not start by the ">" sign) [1].

[1] I am using the **R Markdown**, which gives a possibility to integrate *R* code with **LaTeX**.

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The symbol **[1]** after the **##** sign in the output shows the position in the output of the first element in the row. Let me explain by examples:

```
x <- c(12,3,43,24); x
```

```
## [1] 12  3 43 24
```

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The symbol **[1]** after the **##** sign in the output shows the position in the output of the first element in the row. Let me explain by examples:

```
x <- c(12,3,43,24); x
```

```
## [1] 12  3 43 24
```

Here the first element in the output row, 12, is the first element in the output, so this line starts by [1].

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Running a command in the Console

Now, let us run the following:

```
seq(7, 120, 2)
```

```
##  [1]   7   9  11  13  15  17  19  21  23  25  27  29  31
## [20]  45  47  49  51  53  55  57  59  61  63  65  67  69
## [39]  83  85  87  89  91  93  95  97  99 101 103 105 107
```

Running a command in the Console

Now, let us run the following:

```r
seq(7, 120, 2)
```

```
##  [1]   7   9  11  13  15  17  19  21  23  25  27  29  31
## [20]  45  47  49  51  53  55  57  59  61  63  65  67  69
## [39]  83  85  87  89  91  93  95  97  99 101 103 105 107
```

Here, in the output, the command prints all odd numbers from 7 to 120.

[2] This is in my slides, which I am prepared using **RMarkdown**. If you will run the code in **R** console, you can have just 3 lines (btw, not all elements are shown in the slide, the output is wide for the slides)

Running a command in the Console

Now, let us run the following:

```
seq(7, 120, 2)
```

```
##  [1]   7   9  11  13  15  17  19  21  23  25  27  29  31
## [20]  45  47  49  51  53  55  57  59  61  63  65  67  69
## [39]  83  85  87  89  91  93  95  97  99 101 103 105 107
```

Here, in the output, the command prints all odd numbers from 7 to 120. As you can see, the output is given in 4 lines[2]. [1] in the first line shows that the first element in that row, 7, is the no. 1 element in the output. [18] at the beginning of the second line means that the first element in that row, 41, is the 18-th element in the output, and hence, 43 is the 19-th one. So 109 is the 52-nd element in the output, 111 is the 53-rd one, and you can calculate that we have 57 elements in the output in total.

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Running a command in the Console

Working in the Console is not too hard. Say, *pi* is the π, and "^" means "to the power":

```r
pi^2
```

```
## [1] 9.869604
```

Hitting the up/down arrows in Console will run over the Commands History.

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This is because, for instanse, you can write at most one command in the Console (unless you put ";" sign between 2 commands), and also the code written in the Console will not be saved (well, will be saved in the History, in fact).

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This is because, for instanse, you can write at most one command in the Console (unless you put ";" sign between 2 commands), and also the code written in the Console will not be saved (well, will be saved in the History, in fact).

So we will write our code in **.r** files, so we can run, update, change our code when we wish to.

And please send your **R** homework as **.r** files $\ddot\smile$

Creating/Opening an R Script file

To create a New **R** Script:

- use *File* $\rightarrow$ *New File* $\rightarrow$ *R Script*

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To load your saved script from R:

- use *File* $\rightarrow$ *Open File...*

Running a line/part of a code

To run the command on some line of your R Script

- just put the cursor at that line and press *Ctrl* + *Enter*

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- just put the cursor at that line and press *Ctrl* + *Enter*
- or hit the Run button when the cursor is on that line

To run a block of commands of your R Script

- select that block and press *Ctrl* + *Enter*
- Say, *Ctrl* + *A*, *Ctrl* + *Enter* will execute the whole script. The same can be done by *Ctrl* + *Alt* + *R*

Commenting and Clearing the Console

- Use the symbol # to write a comment

  Example:

```r
# 1+2+3
4+5+6
```

```
## [1] 15
```

Commenting and Clearing the Console

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  Example:

```
# 1+2+3
4+5+6
```

```
## [1] 15
```

- when you are in the console, use *Ctrl* + *L* to clear the console (without deleting the variables and data you have)

R Basic Operations and Commands

Here are some simple calculation examples. Try to run the following lines in the **R** Console:

```r
pi*sqrt(10)+exp(4)
```

```
## [1] 64.53274
```

```r
2^10
```

```
## [1] 1024
```

```r
sin(2*pi)
```

```
## [1] -2.449213e-16
```

Defining Variables

Usually, we are giving some names to quantities we calculate, to use them later. In **R** this can be done in two ways:

```r
x = 10+20
```

or

```r
x <- 10+20
```

[3] You can read more about the difference between these assignment operators here or here

Defining Variables

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```
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or

```
x <- 10+20
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R community is usually using the last way to assign a value to a variable, and we will follow the community ⌣̈ [3]

You can also do in this way:

```
10 -> y
z <- x + y
```

[3] You can read more about the difference between these assignment operators here or here

Defining Variables

You can see that in both cases, x is assigned the value (say, you can see this in the *Environment* tab of **R Studio**), but the result is not printed on the screen.

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You can see that in both cases, x is assigned the value (say, you can see this in the *Environment* tab of **R Studio**), but the result is not printed on the screen.

If you want to see the result of the assignment, just type X after the assignment:

```
x
```

```
## [1] 30
```

or use

```
print(x)
```

```
## [1] 30
```

Defining Variables

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```
x
```

```
## [1] 30
```

or use

```
print(x)
```

```
## [1] 30
```

The other way is to run

```
(x <- 10 + 20)
```

```
## [1] 30
```

Example

Here is a piece of code, just some calculations:

```
x <- 20
y <- 2*(x-pi)
z <- sin(y)
z
```

```
## [1] 0.7451132
```

Example

Here is a piece of code, just some calculations:

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x <- 20
y <- 2*(x-pi)
z <- sin(y)
z
```

```
## [1] 0.7451132
```

You can write several commands in a line, by separating them by ";":

```
x <- 10; y <- exp(2); z <- sin(1); print(x+y+z)
```

```
## [1] 18.23053
```

Example

Here is a piece of code, just some calculations:

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x <- 20
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z <- sin(y)
z
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You can write several commands in a line, by separating them by ";":

```
x <- 10; y <- exp(2); z <- sin(1); print(x+y+z)
```

```
## [1] 18.23053
```

To remove the variable x from the memory (to "forget" the variable x), just run

```
rm(x)
```

Working with Vectors

The following assignment

```
x <- c(1,3,5, -3, 2.3)
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assigns x to be the vector $x = (1, 3, 5, -3, 2.3)$.

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x
```

```
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```r
x
```

```
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```

```r
x[2]
```

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

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```
x
```

```
## [1]  1.0  3.0  5.0 -3.0  2.3
```

```
x[2]
```

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

```
x[-1]
```

```
## [1]  3.0  5.0 -3.0  2.3
```

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x <- c()
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Using c, you can add an element to a vector:

```
x <- c(x, 2)
x
```

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

x was an empty vector, not we have added an element, and now x=(2)=2.

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Using `c`, you can add an element to a vector:

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x <- c(x, 2)
x
```

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

`x` was an empty vector, not we have added an element, and now `x=(2)=2`.

We can concatenate also several vectors:

```
x <- c(1,2,3); y <- c(4,5,6); z <- c(x,y)
z
```

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

Basic Methods to make Vectors

Besides the above method, by specifying all elements of the vector, we can make some standard vectors using appropriate commands:

```
(x <- 1:10)
```

```
##  [1]  1  2  3  4  5  6  7  8  9 10
```

```
a <- seq(from=1, to=10, by=2); a
```

```
## [1] 1 3 5 7 9
```

```
b <- seq(from=1, to=10, length.out = 7); b
```

```
## [1]  1.0  2.5  4.0  5.5  7.0  8.5 10.0
```

Basic Methods to make Vectors

```
y <- rep(1, 5); y
```

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

```
z <- rep(1:3, 4); z
```

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

```
t <- rep(1:3, each = 4); print(t)
```

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

```
w <- rep(c(1,3), 2); w
```

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

Basic Methods to make Vectors

Another useful method to generate vectors is to choose random samples:

```
# Uniform Sample of size 10 from [0,3]
x <- runif(10, min = 0, max = 3)
x
```

```
##  [1] 1.8438019 1.0636570 0.8362773 1.8863407 1.8961920 2
##  [8] 0.8500620 2.4509963 2.9031644
```

```
# Normal Sample of size 15 with Mean 0 and Standard Deviat
x <- rnorm(15, mean = 0, sd = 2)
x
```

```
##  [1] -5.2290711 -1.0571118  2.8299235 -0.7741859 -1.4392
##  [7]  1.6455064 -1.6083296 -0.5446899 -0.4510518  0.7016
## [13] -3.6048588  0.9346354  1.0930198
```

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```
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x <- rnorm(15, mean = 0, sd = 2)
x
```

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##  [1] -5.2290711 -1.0571118  2.8299235 -0.7741859 -1.439
##  [7]  1.6455064 -1.6083296 -0.5446899 -0.4510518  0.701
## [13] -3.6048588  0.9346354  1.0930198
```

Later we will talk about distributions in **R** and random samples.

Some operations on Vectors

For a vector

```
x <- c(-1, 2.3, 10, 5)
```

we can calculate

```
length(x) #The Lenght of a vector
```

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

```
sum(x) # The sum of elements
```

```
## [1] 16.3
```

```
cumsum(x) # The cumulative sum, x_1, x_1+x_2,...
```

```
## [1] -1.0  1.3 11.3 16.3
```

```
prod(x)
```

```
## [1] -115
```

Some operations on Vectors

```
cumprod(x)
```

```
## [1]   -1.0   -2.3  -23.0 -115.0
```

```
mean(x) # The mean of the elements
```

```
## [1] 4.075
```

```
max(x); min(x)
```

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

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

```
sin(x)
```

```
## [1] -0.8414710  0.7457052 -0.5440211 -0.9589243
```

```
x^2
```

```
## [1]   1.00   5.29 100.00  25.00
```

Some operations on Vectors

Sorting a vector is easy:

```
sort(x)
```

```
## [1] -1.0  2.3  5.0 10.0
```

Some operations on Vectors

Sorting a vector is easy:

```r
sort(x)
```

```
## [1] -1.0  2.3  5.0 10.0
```

Sorting in the decreasing order is easy too:

```r
sort(x, decreasing = TRUE)
```

```
## [1] 10.0  5.0  2.3 -1.0
```

Choosing a subvector

Let

```r
x <- c(3, -1, 4, 3, 2, 5)
```

Choosing a subvector

Let

```
x <- c(3, -1, 4, 3, 2, 5)
```

Then we can use

```
x[2] #The second element
```

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

```
x[2:4] #x[2], x[3] and x[4]
```

```
## [1] -1  4  3
```

```
x[c(2,4)] #x[2] and x[4]
```

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

```
x[-3] #everything without x[3]
```

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

Choosing a subvector

A little bit complicated example is

```r
x[x>0] #all positive elements
```

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

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```

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

You can use `x>0` to see what this command is doing:

```
x>0
```

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

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```
x[x>0] #all positive elements
```

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

You can use `x>0` to see what this command is doing:

```
x>0
```

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

Another example:

```
x[x%%2 == 0] #only the even elements of x
```

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

Making a DataFrame

DataFrame is one of the important objects in Data Analysis. It is a rectangular data set, similar to the MS Excel Table/Spreadsheet, if you know what it is $\ddot\smile$

Let us make a DataFrame in **R**:

```
x <- c(22,43,16,38)
y <- c(76, 81, 55, 66)
df <- data.frame(age=x, weight=y)
```

And here is our DataFrame:

```
df
```

```
##   age weight
## 1  22     76
## 2  43     81
## 3  16     55
## 4  38     66
```

Viewing/Editing DataFrames

Well, besides just typing the name of the DataFrame, or calling `print(df)`, one can use the following command to view the DataFrame:

```
View(df)
```

or to edit the DataFreame:

```
edit(df)
```

Accessing the columns/rows of a DataFrame

You can access the column "weight" by

```
df[,2]
```

```
## [1] 76 81 55 66
```

or by

```
df[,'weight']  # also df[,"weight"]
```

```
## [1] 76 81 55 66
```

or by

```
df$weight
```

```
## [1] 76 81 55 66
```

Some Examples

```r
mean(df$age)  # mean age
```

```
## [1] 29.75
```

```r
sum(df$weight) # sum of weights, total weight
```

```
## [1] 278
```

```r
length(df$weight) # the number of elements in df$weights
```

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

```r
sum(df$weight)/length(df$weight) # same as the mean(df$wei
```

```
## [1] 69.5
```

```r
sort(df$weight) # weights in the increasing order
```

```
## [1] 55 66 76 81
```

```r
sort(df$age, decreasing = T) # ages in the decreasing orde
```

R Built-In Datasets

The Basic **R** includes many Datasets to analyse. You can see the datasets supplied by the `datasets` package by running

```
data()
```

Or, if you will run

```
data(package="MASS")
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it will show the avalable datasets in the **R** package `MASS`.

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Or, if you will run

```r
data(package="MASS")
```

it will show the avalable datasets in the **R** package `MASS`.

For example, `cars` is one of the standard datasets in **R**. To see the content, just run

```r
cars
```

```
##    speed dist
## 1      4    2
## 2      4   10
## 3      7    4
## 4      7   22
## 5      8   16
```

R Built-In Datasets

In our previous example, the dataset was too large to fit into the slide (try to run it in **R** console by yourself). To see the first/last few rows of the dataset, use

```
head(cars) #first six rows
```

```
##   speed dist
## 1     4    2
## 2     4   10
## 3     7    4
## 4     7   22
## 5     8   16
## 6     9   10
```

or

```
tail(cars, 1) #last 1 row
```

```
##    speed dist
## 50    25   85
```

Installing a Package

There are a lot of supplementary packages designed for extra tasks, giving us different functions and datasets. To install a package, run `install.packages("name_of_the_package")`. For example, to install the `ggplot2` package (for nice graphics, **gg=grammar of graphics**, not a taxi service), you need to run

```
install.packages("ggplot2")
```

Using a function from a Package

If you want to use a function or a dataset from a package, you need to load that package first, then use the function/dataset. Say, we want to use the `rmvnorm` function from the package `mvtnorm` to generate a random sample of size 100 from the multivariate Normal Distribution. First, install `mvtnorm` by using

```
install.packages("mvtnorm")
```

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```
install.packages("mvtnorm")
```

Then run:

```
library(mvtnorm)
mu <- c(1,2) #The Mean of our Bivariate Normal Distributio
sigma <- matrix(c(4,2,2,3), ncol = 2) # The Covariance Mat
x <- rmvnorm(n = 100, mean = mu, sigma = sigma)
```

Here the command `library(mvtnorm)` is similar to `include` of C++ or `import` of `Python`, and the above code will give an error without this line.

Using a function from a Package

Another way, without importing the package by the `library` command, is to use

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x <- mvtnorm::rmvnorm(n = 100, mean = mu, sigma = sigma)
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Anothe example:

```
MASS::SP500
```

will print the SP500 dataset of the `MASS` package (returns of the S&P500 index in 1990's).

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To see the list of loaded base/attached packages, you can use

```
sessionInfo()
```

Using Help

To open the **R**'s help page for some command, say, for the `sum` command, you can use on of the following options:

```
?sum
```

or

```
help(sum)
```

or, in **R Studio**, just put the cursor at some place on the word `sum` and hit *F1*. Anothe method is just to use the Google $\ddot\smile$

Making Plots

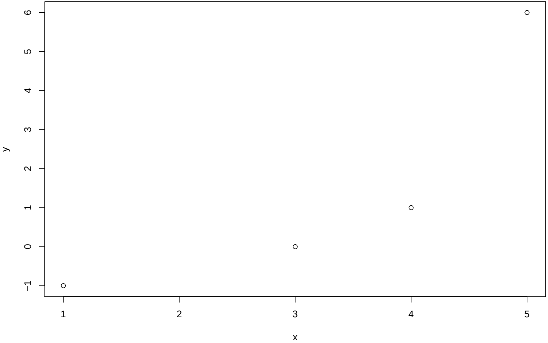
Here we will use the default package for plots[4].

[4] More you can get using the `ggplot2` package

Making Plots

Here we will use the default package for plots[4]. First, let us plot some points (x_i, y_i), $i = 1, ..., n$:

```
x <- c(1,3,5,4); y <- c(-1, 0 ,6, 1)
plot(x,y)
```

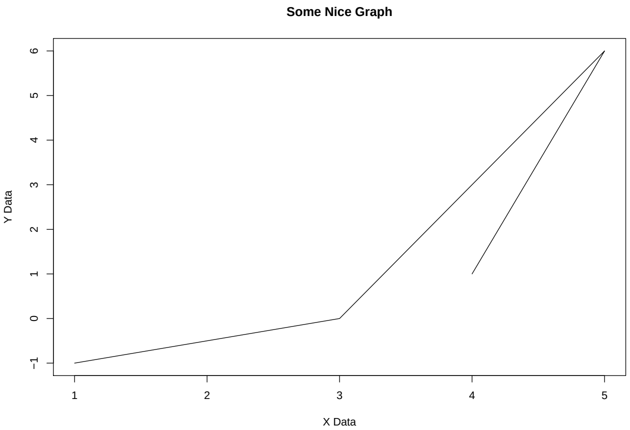


[4]More you can get using the `ggplot2` package

Making Plots

Now, we join the points with line segments, add a title and axis labels to our graph:

```
plot(x,y, type = "l", main = "Some Nice Graph",
     xlab = "X Data", ylab = "Y Data")
```



Making Plots

Comments:

- `type` is the type of the plot. `type="l"` means that the type is set to lines. Try without the type parameter, or by `type = "h"`, `type = "s"`
- `main` is the title of the graph
- `xlab` and `ylab` are the axis labels (names)

Making Plots

In **R**, we have low-level and high-level graphical commands. The `plot` command is a low-level plot. If you will use 2 `plot` commands one after another, the last command will draw on a new canvas. So if you want to draw two graphs one over anoher, you cannot just use two `plot` commands consecutively.

[5] In fact, in **R Studio**, under the **Plots** tab, you can navigate through the plots

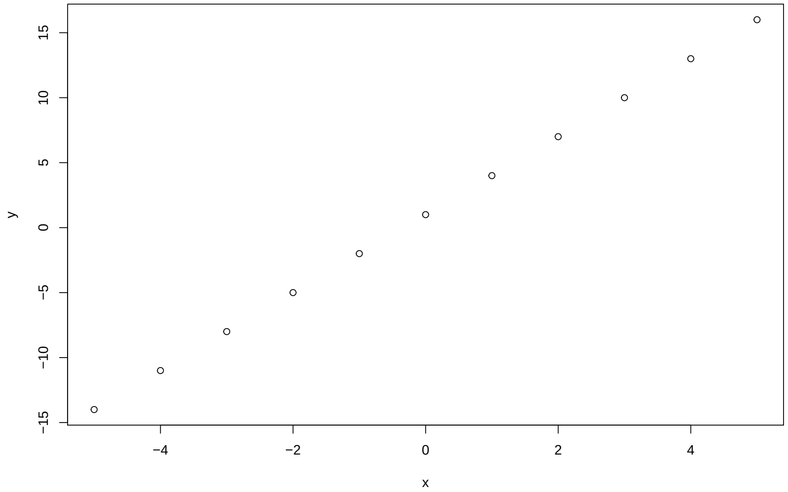
Making Plots

In **R**, we have low-level and high-level graphical commands. The `plot` command is a low-level plot. If you will use 2 `plot` commands one after another, the last command will draw on a new canvas. So if you want to draw two graphs one over anoher, you cannot just use two `plot` commands consecutively. In general, when using 2 low-level graphical commands, the last one will "overwrite" the previous plot [5]. But, when using high-level plotting commands after the low-level one, you will have the high-level plot added to the low-level one. High-level plot examples are `points` and `lines`.

[5] In fact, in **R Studio**, under the **Plots** tab, you can navigate through the plots

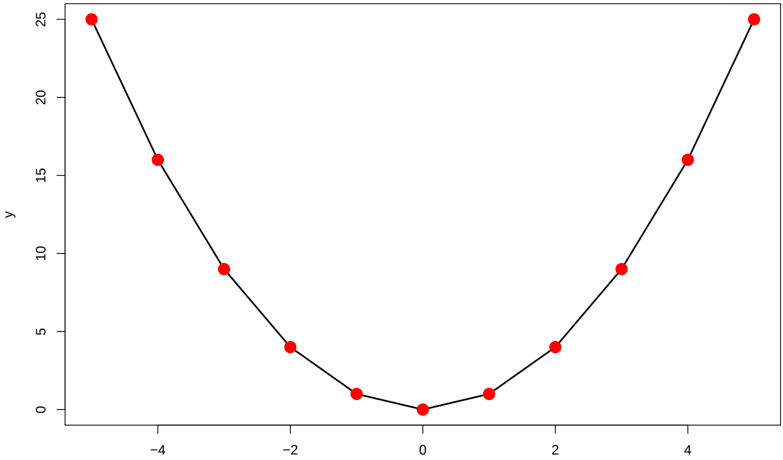
Making Plots, Example

```
x <- -5:5; y <- 3*x+1
plot(x,y)
```



Making Plots

```
x <- -5:5; y <- x^2
plot(x,y, type = "l", lwd = 2)
points(x,y, pch = 16, col = "red", cex = 2)
```



Making Plots

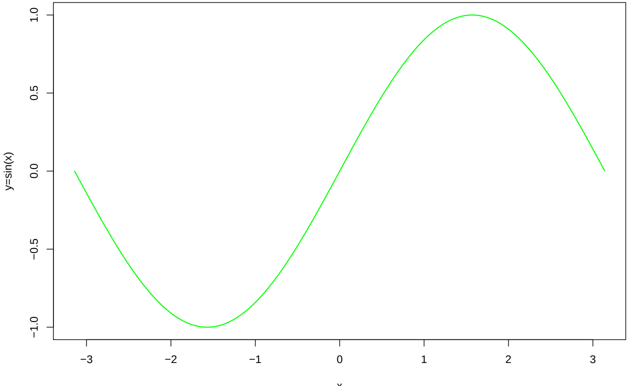
Comments:

- `lwd` is the *line width*
- `pch` is the *point character*, try to change 16 to other integers
- `col` is the *color*
- `cex` is the *character size*, *point size*

Making Plots

Let us plot the graph of $y = \sin(x)$, $x \in [-\pi, \pi]$:

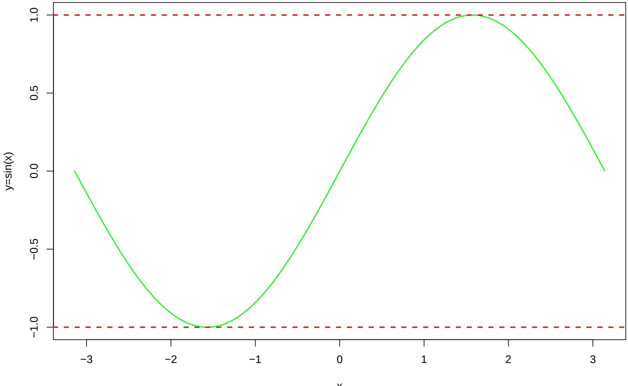
```
x <- seq(from = -pi, to = pi, by = 0.01)
y <- sin(x)
plot(x,y, type = "l", lwd =1.5, col = 'green',
     xlab = "x", ylab = "y=sin(x)")
```



Making Plots

Now, let us add horizontal lines $y = \pm 1$ to previous plot:

```
plot(x,y, type = "l", lwd =1.5, col = 'green',
     xlab = "x", ylab = "y=sin(x)")
abline(h = 1, lty = 2, lwd = 2, col = "red")
abline(h = -1, lty = 2, lwd = 2, col = "red")
```



Making Plots

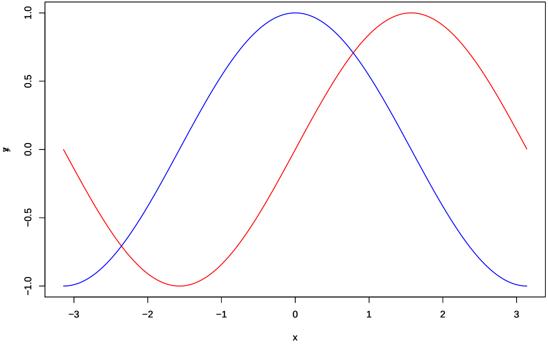
Comments:

- `abline` is to draw a line $y = a + b \cdot x$, you can give parameters $h = h_0$ for a horizontal line $y = h_0$ or $v = v_0$ for a vertical line $x = v_0$. `abline` is a high-level graphical command
- `lty` is the *line type*, try changing the values to see the difference (here we have a *dotted line*)

Making Plots

Now, let us draw two plots one over another:

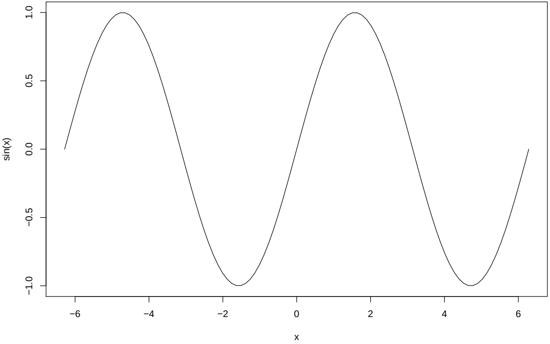
```
x <- seq(from = -pi, to = pi, by = 0.01)
y <- sin(x); z <- cos(x)
plot(x,y, type = "l", lwd =1.5, col = 'red')
par(new = TRUE) #setting a parameter to keep the previous p
plot(x,z, type = "l", lwd =1.5, col = 'blue')
```



Making Plots

Another method to draw graphs is to use the `curve` command:

```
curve(sin, from = -2*pi, to = 2*pi)
```



Try also[6]

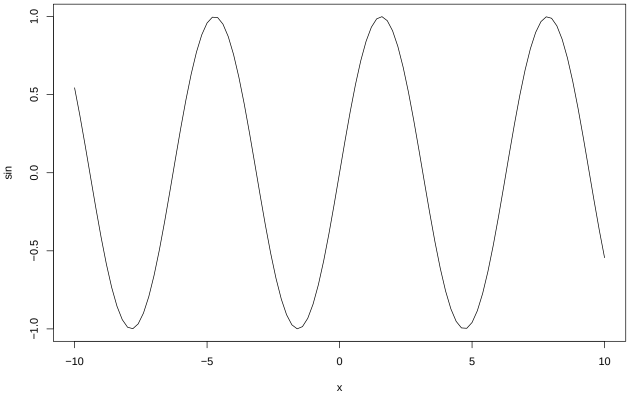
```
curve(sin(x), from = -2*pi, to = 2*pi)
```

[6] If the variable x is not defined!

Making Plots

Yet another method to draw graphs is to use the `plot` command with function name:

```
plot(sin, -10, 10)
```



Defining Functions

It is easy to define a function in **R**. You just need to use the following template:

For example, let us define the function $z = x^2 + 2 * \arctan \frac{x}{x+\sin(x)}$:

```
my.nicefunction <- function (x){
  z = x^2 +2* atan(x/(x+sin(x)))
  return(z)
}
```

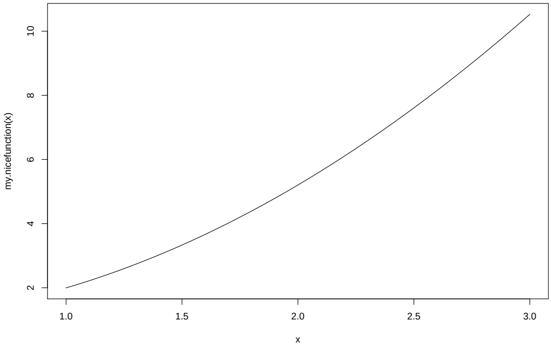
Defining Functions

Now, we can calculate our function's value at, say, the point 3, and plot its graph:

```
my.nicefunction(3)
```

```
## [1] 10.52485
```

```
curve(my.nicefunction, 1, 3) #or plot(my.nicefunction, 1, 3
```



Defining Functions

Now, let us define a function of 2 variables:

```
my_fun1 <- function (x, y){
  return(x+y^2)
}
```

In this case, to calculate the value at $(1, 2)$, you just write

```
my_fun1(1,2)
```

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

Defining Functions

You can define also functions with default values:

```
my_fun2 <- function (x, y = 0){
  return(x+y^2)
}
```

Now, `my_fun(2)` will give `my_fun(2,0)`, and `my_fun(2, 4)` will calculate `my_fun(2,4)`:

```
my_fun2(2)
```

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

```
my_fun2(2,4)
```

```
## [1] 18
```

Defining Functions

By the way, if you will give default values to each variable, like here:

```
my_fun3 <- function (x = 0, y = 0){
  return(x+y^2)
}
```

Then you can use the followings to calculate `my_fun3(2,1)`:

```
my_fun3(2,1)
```

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

```
my_fun3(x = 2, y = 1)
```

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

```
my_fun3(y = 1, x = 2)
```

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

Defining Functions

Actually, most of the built-in **R** functions have named variables with default values. Say, use

You will see the help page, containing the usage of the function `rnorm`, in the form:

```
rnorm(n, mean = 0, sd = 1)
```

This means, that if you will use `rnorm(10)`, it will assume `mean = 0` and `sd = 1`. And you can mix the order of the *named* variables, say, run `rnorm(10, sd = 3, mean = -1)`. But please note that you cannot skip the first variable, the value of `n`, since it has no default value !