

Introduction to R

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Timetable and material

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Day	hour
Thursday	16:00-19:00 hours
Friday	10:00-13:00 hours
Saturday	11:00-14:00 hours

There will a 30-minute break during each session.

The material of this workshop is [here](#)

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- You should have defined a **project** (working directory) somewhere in your computer (e.g., Desktop).
- R is the actual programming language
- RStudio is an IDE (Integrated Development Environment) for R.
- R is **case sensitive**; e. g., **Mean** \neq **mean**
- R(Studio) may not work very well when files (or directory containing working files) have accented characters. If the locale language of your filesystem is not in English, then some errors may occur in those cases.

Basic calculations

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- R can be used as a calculator
- Mathematical constants:
 - $\pi = 3.142$
 - $\exp(1) = 2.718$
- Logarithms:
 - $\log(e) = 1$
 - $\log_{10}(100) = 2$
 - $\log(16, \text{base} = 4) = 2$

Display Information

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- Getting help: in the console, put a question mark before the function name; RStudio will display the documentation:

```
?cos
```

- Set the display of decimal digits to 3, for a better output:

```
options(digits = 3)
```

Installing packages

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One of the strengths of R is the increasing number of available packages (more than 14,000 of them): [CRAN Packages](#)

To install and use a package we have

- firstly to **install** it;
- then, to **load** it in the current session.

To install a package (e.g., `tseries`), we can use the `install.packages("tseries")` function.

To load it in the current session, use `library(tseries)`

To install a package, we can also use the **Tools** option in the RStudio window and follow **Install Packages...**

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The data types used by R are

- numeric (double precision): 2.718, 1.4, ...
- integer: 1, -13, ...
- complex: $2 - 3i$, ...
- logical: TRUE, FALSE. Also NA is considered logical
- character: "one plus two", "Hello world!"

Data Structure

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- Vector: basic data structure in R. Its components have the same data type.
- Matrix: think of linear algebra.
 - A matrix as a collection of vectors.
- Dataframe: similar to a matrix, except that it is not necessarily homogeneous.
 - A collection of vectors (of possible different types) with the same length.
- List: generic data structure containing other **objects** (vectors, other lists), **not necessarily of the same length.**

Assignment operator

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- In R, we assign a value, **value**, to an object **x** by means of
<-: `x <- value`
- To type it, you can use the shortcut ALT+"-" (ALT key and minus sign); it works with Windows, MacOS.
- It is also possible to use **=**, but the equal sign has lower priority than **<-**.
 - Check the discussion at [StackExchange](#).

Vectors

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The easiest way to create a vector in R is to use the `c()` (concatenate) function:

```
v <- c(1, 3, 5, 7, 9)
```

```
v
```

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

Vectors: coercion

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If we define a vector with components of different data types, the result will be coerced to the same data type

```
w <- c(1.56, "Hello World", 4, TRUE)
```

```
typeof(w)
```

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

Notice that

```
u <- c(1.56, 4, TRUE)
```

```
typeof(u)
```

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

Vectors by sequences

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- Create a vector with the first 30 integer numbers:

```
(x <- 1:30)
```

```
## [1] 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15  
## [26] 26 27 28 29 30
```

- In reverse order:

```
(x <- 30:1)
```

```
## [1] 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16  
## [26] 5 4 3 2 1
```

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- Create a sequence of the first odd numbers, up to 11:

```
(y <- seq(1, 11, 2))
```

```
## [1] 1 3 5 7 9 11
```

- Repeat the character "Hello" 5 times:

```
(z <- rep("Hello", 5))
```

```
## [1] "Hello" "Hello" "Hello" "Hello" "Hello"
```

- Repeat the vector y, defined above, 2 times:

```
(rep(y,2))
```

```
## [1] 1 3 5 7 9 11 1 3 5 7 9 11
```

Length of a vector

The length of a vector (number of its components) is obtained with the function `length()`

```
x <- 1:30  
length(x)
```

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

```
y <- seq(1, 11, 2)  
length(y)
```

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

```
z <- rep("Hello", 5)  
length(z)
```

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

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Let `y <- seq(1,11,2)`: 1, 3, 5, 7, 9, 11.

- Select the third component: `y[3]` = 5
- Exclude the fourth component: `y[-4]`: 1, 3, 5, 9, 11.
- Select the first four components: `y[c(1:4)]`: 1, 3, 5, 7
- Select the first, fifth and last element:

```
y[c(1, 5, length(y))]
```

```
## [1] 1 9 11
```

or

```
y[c(1, length(y) - 1, length(y))]
```

```
## [1] 1 9 11
```

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- Remove the first four components: `y[-c(1:4)]`: 9, 11.
- Select the second, fifth and sixth components: `y[c(2, 5, 6)]`: 3, 9, 11.
- Select components by using a vector of logic type:

```
s <- c(TRUE, TRUE, FALSE, FALSE, TRUE, FALSE)
y[c(s)]
```

```
## [1] 1 3 9
```

Vectorization

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Consider the vector

```
x <- 1:100
```

Then,

- $x + 4 = 5, 6, 7, 8, 9, 10 \dots$
- $x^2 = 1, 4, 9, 16, 25, 36 \dots$
- $2*x+3 = 5, 7, 9, 11, 13, 15 \dots$
- $\text{sqrt}(x) = 1, 1.414, 1.732, 2, 2.236, 2.449 \dots$
- $\log(x) = 0, 0.693, 1.099, 1.386, 1.609, 1.792 \dots$

Vectorization

We can add up two vectors even when they have different lengths, provided that the length of one is an integer multiple of the other:

```
x <- seq(1,11,2)
y <- 1:12
x + y
```

```
## [1] 2 5 8 11 14 17 8 11 14 17 20 23
```

Check for identity

```
all(x + y == rep(x,2) + y)
```

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

```
identical(x + y, rep(x,2) + y)
```

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

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Logical operators

Each of the following operators returns either **TRUE** or **FALSE**.

- **==** (equality)
- **!=** (not equal to)
- **>** (greater than)
- **<** (less than)
- **>=** (greater than or equal to)
- **<=** (less than or equal to)
- **!x** (not **x**)
- **x | y** (**x** OR **y**)
- **x & y** (**x** AND **y**)

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Examples

Let `x <- c(1,2,3,4,5,6)`

- `x > 4`: FALSE, FALSE, FALSE, FALSE, TRUE, TRUE
- `x == 4`: FALSE, FALSE, FALSE, TRUE, FALSE, FALSE
- `x != 3`: TRUE, TRUE, FALSE, TRUE, TRUE, TRUE
- `x == 4 | x != 3`: TRUE, TRUE, FALSE, TRUE, TRUE, TRUE
- `x == 4 & x != 3`: FALSE, FALSE, FALSE, TRUE, FALSE, FALSE
- `as.numeric(x == 4 | x != 3)`: 1, 1, 0, 1, 1, 1
- Arithmetically, **TRUE** is considered 1 and **FALSE** 0:
`sum(x == 4 | x != 3)`: 5

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Logical operators and subsetting

Subsetting will extract the values of the components that satisfy the given logical condition.

Let `x <- c(1,2,3,4,5,6)`

- `x[x > 3]`: 4, 5, 6
- `x[x != 3]`: 1, 2, 4, 5, 6
- `x[x <= 0]`: numeric(0) (empty set)
- `x[x <= 0 | x > 3]`: 4, 5, 6
- `x[x <= 0 & x > 3]`: numeric(0) (empty set)
- `sum(x[x <= 0 & x>3])`: 0

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Selection

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

- `which(y <= 4)`: 1, 2, 3, 6, 7
selects which **entries** satisfy the condition. Indexing of vectors starts from 1.
- `y[which(y <= 4)]`: 1, -2, 4, 2, 1
returns the **values** of the entries satisfying the condition.
- `which(y == max(y))`: 5
entry of the vector with the maximum value
- `y[which(y == max(y))]`: 9
maximum value of the vector

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A matrix A is specified by the number of its rows and columns, $m \times n$.

The **order** of rows and columns is **important**.

Matrix can be created by means of the `matrix()` function:

```
x <- 1:8  
A <- matrix(x, nrow = 4, ncol = 2)  
B <- matrix(x, nrow = 2, ncol = 4)  
dim(A) # rows = 4; columns = 2
```

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

```
dim(B) # rows = 2; columns = 4
```

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

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A

##		[,1]	[,2]
##	[1,]	1	5
##	[2,]	2	6
##	[3,]	3	7
##	[4,]	4	8

B

##		[,1]	[,2]	[,3]	[,4]
##	[1,]	1	3	5	7
##	[2,]	2	4	6	8

Matrices: Subsetting

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- Select the entry of the matrix A in the first row, second column:

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

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

- Select the third column of the matrix B

```
B[,3]
```

```
## [1] 5 6
```

- Select the third row of the matrix A

```
A[3,]
```

```
## [1] 3 7
```

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- Select the first and fourth column of the matrix B

```
B[, c(1,4)]
```

```
##      [,1] [,2]  
## [1,]    1    7  
## [2,]    2    8
```

Binding vectors: by columns

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```
u <- 1:4
v = rev(u)
w <- rep(1,4)
C <- cbind(u,v,w)
rownames(C) <- c("1st", "2nd", "3rd", "4th")
C
```

```
##      u v w
## 1st  1 4 1
## 2nd  2 3 1
## 3rd  3 2 1
## 4th  4 1 1
```

Binding vectors: by rows

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```
u <- 1:4
v = rev(u)
w <- rep(1,4)
D <- rbind(u,v,w)
colnames(D) <- c("1st", "2nd", "3rd", "4th")
D
```

##		1st	2nd	3rd	4th
##	u	1	2	3	4
##	v	4	3	2	1
##	w	1	1	1	1

Matrix operations

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- The sum of two compatible matrices is $A + B$
- The subtraction of two compatible matrices is $A - B$
- The product of two compatible matrices is $A \%*\% B$
- The transpose of a matrix A is $t(A)$
- The inverse of a square matrix, A , if it exists, is $solve(A)$

Inverse matrix

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```
x <- c(1,2,3,5, 4, 1, 2,2,1)
A <- matrix(x, nrow = 3, ncol = 3)
A1 <- solve(A)
A1 %*% A
```

```
##           [,1] [,2]      [,3]
## [1,] 1.00e+00  0 2.22e-16
## [2,] 8.88e-16  1 1.11e-15
## [3,] 0.00e+00  0 1.00e+00
```

The result is the identity matrix, up to round-off errors.

More matrices

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- We can use the function `all.equal()` to compare the results of `solve(A)` and `A1 %*% A` with the identity matrix:

```
all.equal(A1 %*% A, diag(3))
```

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

- The function `diag()` can also be used to extract the diagonal elements of a matrix

```
diag(A)
```

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

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```
diag((1:5)^(.5))
```

##		[,1]	[,2]	[,3]	[,4]	[,5]
##	[1,]	1	0.00	0.00	0	0.00
##	[2,]	0	1.41	0.00	0	0.00
##	[3,]	0	0.00	1.73	0	0.00
##	[4,]	0	0.00	0.00	2	0.00
##	[5,]	0	0.00	0.00	0	2.24

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```
diag(log(1):log(5))
```

```
##           [,1] [,2]  
## [1,]         0  0  
## [2,]         0  1
```

```
diag(log(1:5))
```

```
##           [,1] [,2] [,3] [,4] [,5]  
## [1,]         0 0.000  0.0  0.00 0.00  
## [2,]         0 0.693  0.0  0.00 0.00  
## [3,]         0 0.000  1.1  0.00 0.00  
## [4,]         0 0.000  0.0  1.39 0.00  
## [5,]         0 0.000  0.0  0.00 1.61
```

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R has some built-in functions to deal with matrices. Consider

A

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

- `rowSums(A)` = 8, 8, 5
- `colSums(A)` = 6, 10, 5
- `rowMeans(A)` = 2.667, 2.667, 1.667
- `colMeans(A)` = 2, 3.333, 1.667

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The operator %*%

The operator %*% works differently on vectors and matrices.

- On vectors it computes the **dot product**
- On matrices, the matrix multiplication (matrix multiplication is a form of ordered, vectorized dot product)

```
a <- c(1,2,3)
```

```
b <- c(4,5,6)
```

```
a %*% b
```

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

```
## [1,] 32
```

- The dot product can also be implemented as

```
sum(a*b)
```

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

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Vector can be coerced to work as matrices; in this case, columns matrices:

```
as.matrix(a)
```

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

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

```
## [2,]      2
```

```
## [3,]      3
```

```
t(as.matrix(b)) %*% as.matrix(a) # dot product
```

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

```
## [1,]    32
```

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```
as.matrix(a) %*% t(as.matrix(b))
```

##		[,1]	[,2]	[,3]
##	[1,]	4	5	6
##	[2,]	8	10	12
##	[3,]	12	15	18

Dataframes

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- Statistical analysis is done using datasets. A dataset contains a certain number of variables and observations.
- It is a good practice to have each variable set as a column vector and each observation as a row vector.
- A dataframe, in R, is the data structure of an observed dataset.
- A dataframe can be thought of as a matrix in which different columns may have different data types.

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When loading a dataset for analysis, there are some aspects to consider.

- 1 Understand the data: what the dataset is about; what are its variables; how many observation the dataset contains.
- 2 Determine whether there are missing observations; some functions will not work properly otherwise.
- 3 Visualize some of its variables.

Import the dataset with RStudio

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Information about the dataset

- The dataset is taken from the [UCI, Machine Learning Repository](#) website.
- The dataset can be found [here](#).
 - Download the file, change its name to **cleve.csv** and move it to the project (working directory).
 - The names of the variables will be assigned later.
- The dataset will be called **cleve** hereinafter in the presentation.
- The dataset format is **csv** (comma separated variables).

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- 1 Open an **R script** and save it in the project.
- 2 Write in the script

```
cleve <- read.csv("cleve.csv", header = FALSE)
```

and hit **CTRL + Enter** (Windows); **CMD + Enter** (Mac OSX) to execute.
 - a. If you get an error in the console, you may be not in the project (working directory)
- 3 Type

```
head(cleve)
```

 in the script and execute the instruction. It will show in the console the first **six** observations.

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- Set the names of the variables. Copy the instructions and paste it in the script:

```
cleve.names <- c("age", "sex", "cp", "trestbps",  
                 "chol", "fbs", "restcg", "thalac",  
                 "exang", "oldpeak", "slope", "ca",  
                 "thal", "diagnostic")  
  
names(cleve) <- cleve.names
```

- The documentation of the dataset is found [here](#)
- The gender variable **sex**: 0 for females, 1 for males.

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- To work with only one variable from the dataset, e.g., *age*, we can **extract** it by means of **\$**.

```
age <- cleve$age
```

- On the other hand, if we work with several variables in a dataset, it is better to use **attach(*namedataset*)** at the beginning; once done, use **detach(*namedataset*)**.

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The dataset is a dataframe

```
class(cleve)
```

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

with

```
dim(cleve)
```

```
## [1] 303 14
```

$\text{nrow}(\text{cleve}) = 303$ observations and $\text{ncol}(\text{cleve}) = 14$ variables.

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The names of the variables can also be obtained by `colnames(cleve)`.

The first six observations can be displayed by

```
head(cleve)
```

(Output omitted because it does not fit the slide.)

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Display the first 3 observations of the first, third and seventh through ninth variables:

```
cleve[1:3,c(1,3,7:9)]
```

##		age	cp	restcg	thalac	exang	
##	1	63	1		2	150	0
##	2	67	4		2	108	1
##	3	67	4		2	129	1

or with (omitted for space)

```
cleve[1:2, c("age", "cp", "restcg",  
             "thalac", "exang")]
```

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Examples

- 1 Compute the number of individuals whose age is greater than, or equal to, 50 years:

```
length(cleve$age[cleve$age >= 50])
```

```
## [1] 216
```

- 2 Compute the number of individuals without a diagnosis of heart disease:

```
length(cleve$sex[cleve$diagnostic == 0])
```

```
## [1] 164
```

Remark The variable `diagnostic` is strictly positive if there is indication of a heart condition.

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Examples

- ③ Compute the number of individuals with a diagnosis of heart disease **and** with fasting blood sugar > 120 mg/dl

```
length(cleve$sex[cleve$diagnostic > 0 &  
               cleve$fbs == 1])
```

```
## [1] 22
```

- ④ Compute the number of individuals with a diagnosis of heart disease **or** with fasting blood sugar > 120 mg/dl

```
length(cleve$sex[cleve$diagnostic > 0 |  
               cleve$fbs == 1])
```

```
## [1] 162
```

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Consider, e.g., the variable *age*. Compute:

- 1 the mean (average)

```
mean(cleve$age)
```

```
## [1] 54.4
```

- 2 the median

```
median(cleve$age)
```

```
## [1] 56
```

- 3 the interquartile range

```
IQR(cleve$age) # Q3 - Q1
```

```
## [1] 13
```

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- ④ the summary of the principal statistics

```
summary(cleve$age)
```

##	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
##	29.0	48.0	56.0	54.4	61.0	77.0

Remark The function `summary()` does not return neither the variance nor the standard deviation.

- ⑤ Quantile distribution

```
quantile(cleve$age, c(.1, .25, .40, .60, .80))
```

##	10%	25%	40%	60%	80%
##	42	48	53	58	62

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It is possible to apply the `summary()` function to a full dataset, or to several variables of it

```
summary(cleve[,c(1,5,8)])
```

##	age	chol	thalac
##	Min. :29.0	Min. :126	Min. : 71
##	1st Qu.:48.0	1st Qu.:211	1st Qu.:134
##	Median :56.0	Median :241	Median :153
##	Mean :54.4	Mean :247	Mean :150
##	3rd Qu.:61.0	3rd Qu.:275	3rd Qu.:166
##	Max. :77.0	Max. :564	Max. :202

(Only three variables are selected for space.)

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Variance and standard deviation

- The variance (resp., standard deviation) is computed by `var()` (resp., `sd()`).
- If the variable has `NA` (missing values), then `var()`, `sd()` return `NA`:

```
var(cleve$thal)
```

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

```
sd(cleve$thal)
```

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


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Variance

We can apply the function `var()` to a single variable or several of them; in the latter case, we obtain the variance-covariance matrix of the selected variables:

```
var(cleve[, c(1, 3, 5, 6)])
```

##		age	cp	chol	fbs
##	age	81.697	0.9037	97.787	0.3816
##	cp	0.904	0.9218	3.595	-0.0137
##	chol	97.787	3.5951	2680.849	0.1815
##	fbs	0.382	-0.0137	0.181	0.1269

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Standard deviation

The standard deviation `sd()`, on the other hand, can only be applied to a single variable:

```
sd(cleve$age)
```

```
## [1] 9.04
```

```
sd(cleve$chol)
```

```
## [1] 51.8
```

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Standard deviation of a set of variables

We have to vectorize the function `sd()` by means of `apply()`:

```
apply(cleve[,11:13], 2, sd)
```

- The value `2` in the second parameter of the function `apply()` computes the standard deviation, `sd`, of each variable (column).
- The value `1` would compute the standard deviation of each row (observation).

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Standard deviation of a set of variables

```
apply(cleve[,11:13], 2, sd)
```

```
## slope      ca    thal
```

```
## 0.616      NA     NA
```

There are missing values in the dataset.

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Count and remove NA's

Let's count them:

```
sum(is.na(cleve))
```

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

We can eliminate them (less than 2% of the observed values)

```
cleve <- na.omit(cleve)
```

```
sum(is.na(cleve))
```

```
## [1] 0
```

Remark

R works in memory (RAM), so only the dataset **cleve** loaded in memory is changed. The file **cleve.csv** with the original observations is not changed (reproducibility in research).

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Standard deviation of a set of variables

```
apply(cleve[,11:13], 2, sd)
```

```
## slope      ca    thal
```

```
## 0.618 0.939 1.939
```

The variable **slope** has a slightly larger standard deviation now.

Contingency Tables

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Write a contingency table of gender and diagnosis of heart disease:

```
table(cleve$sex, cleve$diagnostic)
```

```
##  
##      0  1  2  3  4  
##  0 71  9  7  7  2  
##  1 89 45 28 28 11
```

Using the `with()` function:

```
with(cleve, table(age, diagnostic))
```

(Same result; output omitted for space.)

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Alternative to `table`

Using the `xtabs()` function:

```
with(cleve, xtabs(~ sex + diagnostic))
```

```
##      diagnostic
## sex  0  1  2  3  4
##    0 71  9  7  7  2
##    1 89 45 28 28 11
```


Estimated Frequencies

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Redefine the variable **diagnostic** as dummy, with value 1 if some heart problem is observed:

```
cleve$diagnostic[cleve$diagnostic >0] <- 1
```

Table of estimated frequencies:

```
with(cleve, xtabs(~ sex + diagnostic)/nrow(cleve))
```

##		diagnostic	
##	sex	0	1
##	0	0.2391	0.0842
##	1	0.2997	0.3771

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```
barplot(table(cleve$diagnostic),  
         main = "Diagnostic (observed)")
```

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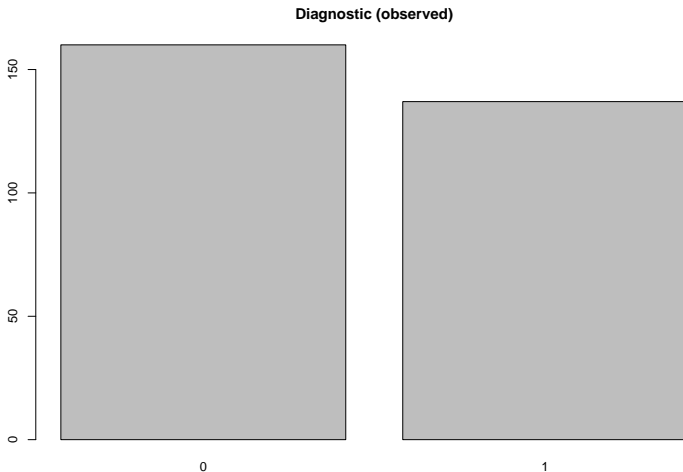
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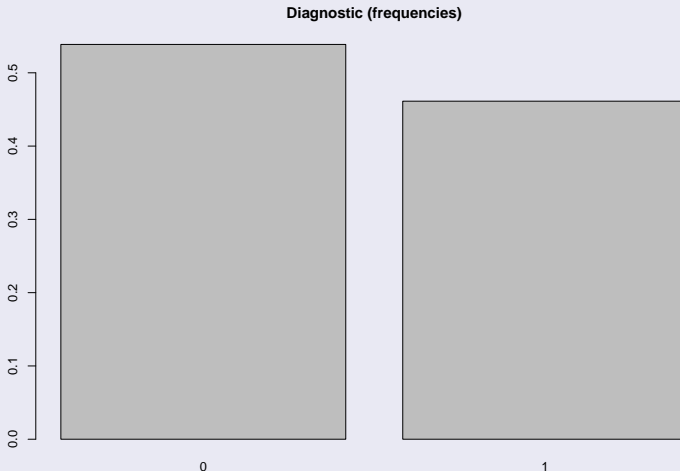
Time series

Barplot with observed frequencies

```
barplot(table(cleve$diagnostic)/nrow(cleve),  
        main = "Diagnostic (frequencies)")
```

Visualization: Barplot

Barplot with observed frequencies



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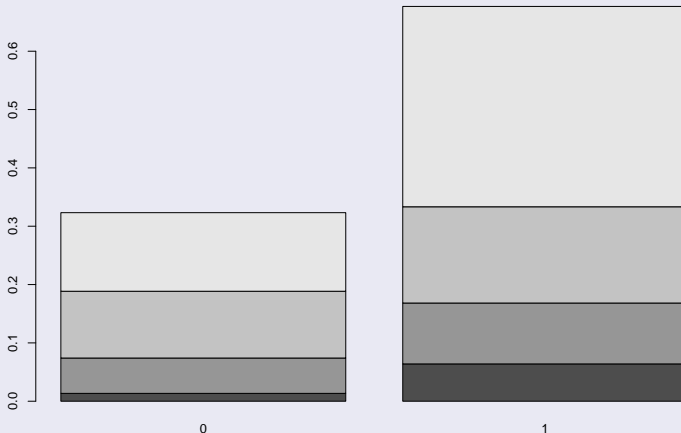
Barplot with a contingency table

```
barplot(table(cleve$cp,  
              cleve$sex)/nrow(cleve),  
        main = "Chest pain by gender")
```

Visualization: Barplot

Barplot with a contingency table

Chest pain by gender



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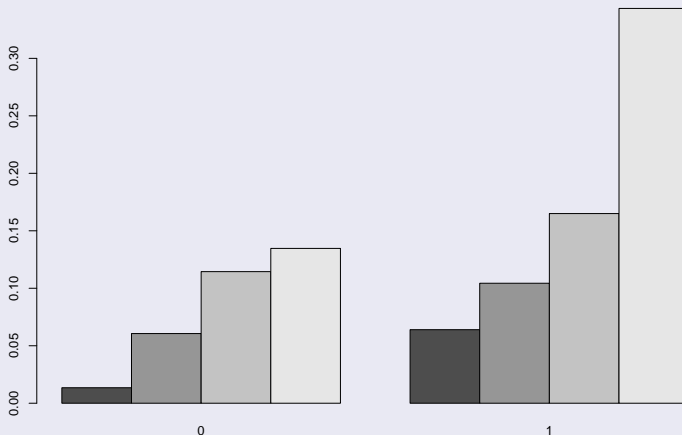
Grouped barplots

```
barplot(table(cleve$cp,  
              cleve$sex)/nrow(cleve),  
        main = "Diagnostic (frequencies)",  
        beside = TRUE)
```


Visualization: Barplot

Grouped barplots

Chest pain by gender



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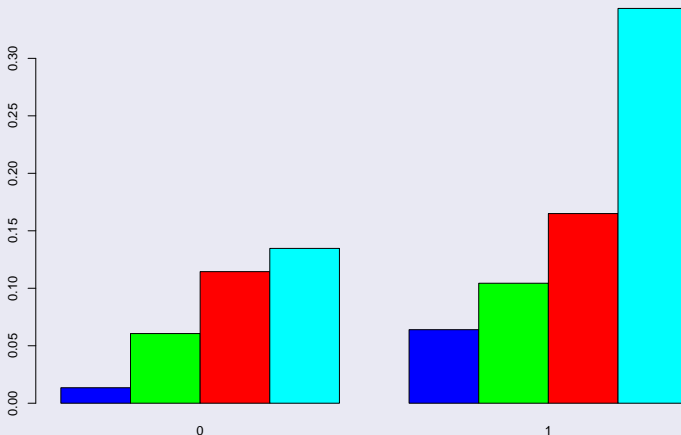
Grouped barplots with colors

```
barplot(table(cleve$cp,  
              cleve$sex)/nrow(cleve),  
        main = "Chest pain by gender",  
        beside = TRUE,  
        col = c("blue", "green", "red", "cyan"))
```

Visualization: Barplot

Grouped barplots with colors

Chest pain by gender



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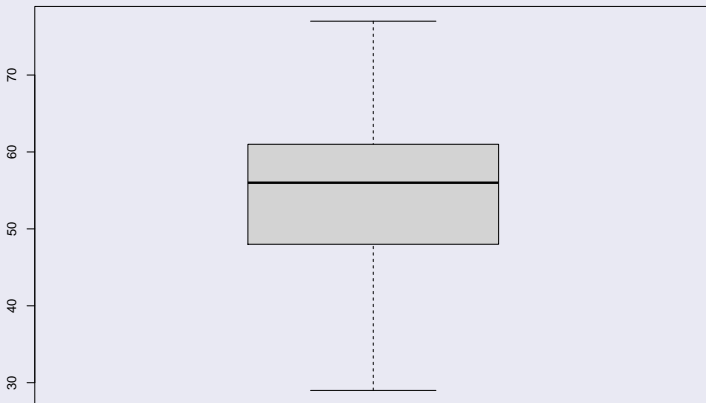
Time series

Variable “age”

```
boxplot(cleve$age)
```

Visualization: Boxplot

Variable “age”



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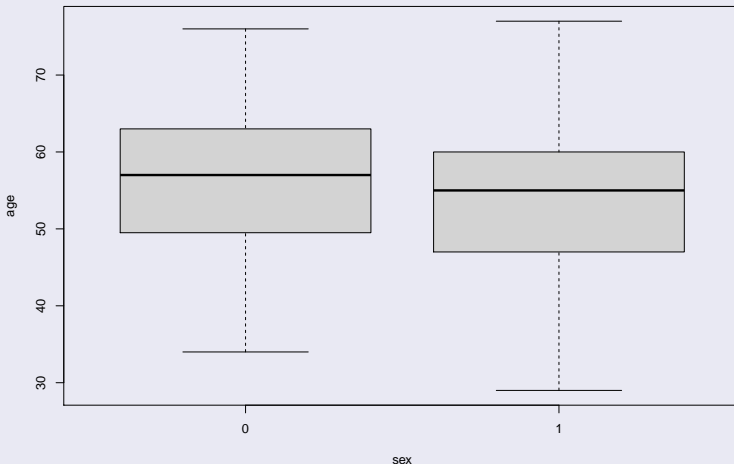
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Age as a function of gender

```
boxplot(age ~ sex, data = cleve)
```

Visualization: Boxplot

Age as a function of gender



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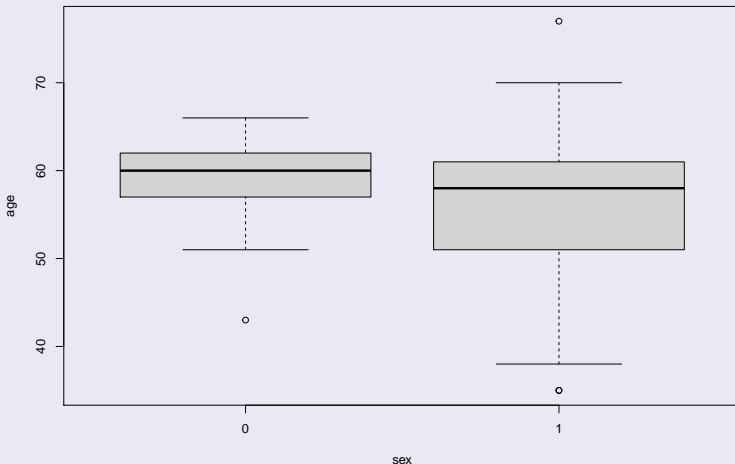
Time series

Age as a function of gender, with positive diagnosis

```
boxplot(age ~ sex, data = cleve,  
        subset = diagnostic == 1)
```


Visualization: Boxplot

Age as a function of gender, with positive diagnosis



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Age as a function of gender

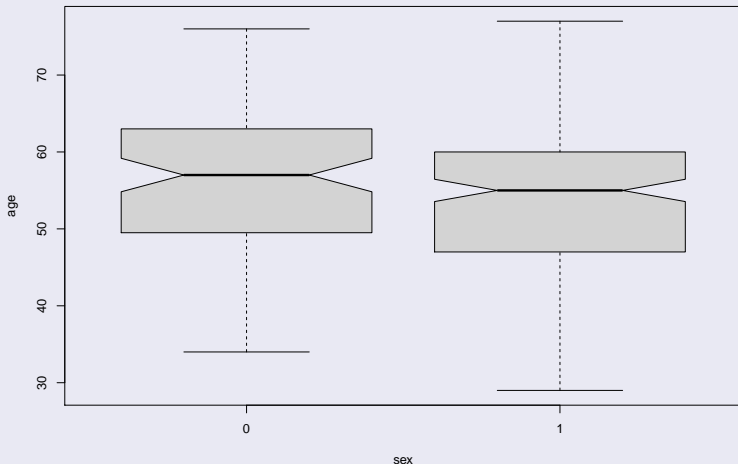
```
boxplot(age ~ sex, data = cleve,  
        notch = TRUE)
```

Justification

See, e.g., John M. Chalmers, William S. Cleveland, Beat Kleiner, Paul A. Tukey, "Graphical Methods for Data Analysis", Wadsworth International Group, Duxbury Press, 1983, pp. 60-63.

Visualization: Boxplot with notch

Age as a function of gender



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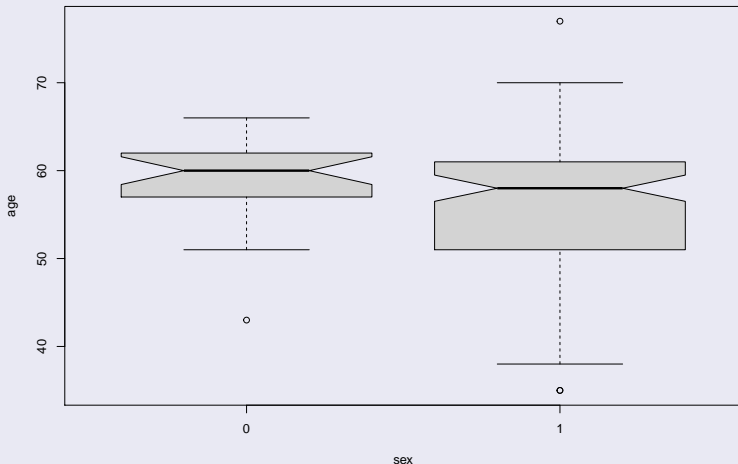
Time series

Age as a function of gender with positive diagnosis

```
boxplot(age ~ sex, data = cleve,  
        notch = TRUE,  
        subset = diagnostic == 1)
```

Visualization: Boxplot with notch

Age as a function of gender with positive diagnosis



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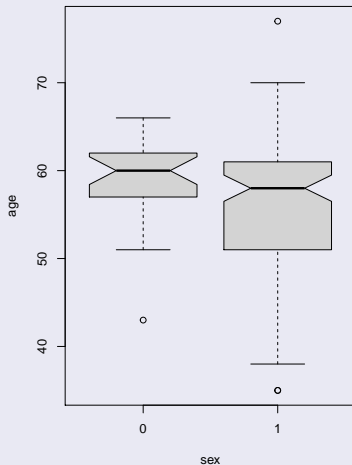
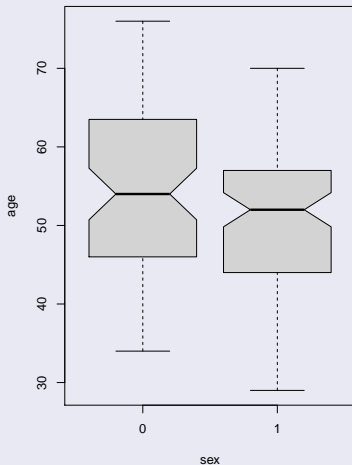
Time series

Two graphs side by side

```
par(mfrow=c(1,2))  
boxplot(age ~ sex, data = cleve,  
        notch = TRUE,  
        subset = diagnostic == 0)  
boxplot(age ~ sex, data = cleve,  
        notch = TRUE,  
        subset = diagnostic == 1)  
par(mfrow = c(1,1))
```

Visualization: Boxplot

Two graphs side by side



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```
mosaicplot(cleve$sex ~ cleve$diagnostic,  
            shade=F, color=T,  
            main = "Diagnosis by gender", xlab="Gender",  
            ylab = "Diagnostic")
```


Visualization: Mosaicplot

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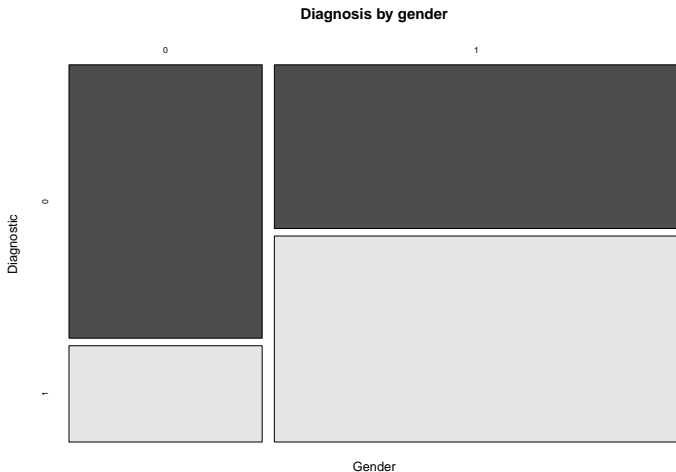
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```
mosaicplot(cleve$cp ~ cleve$diagnostic,  
            shade=F, color=T,  
            xlab = "Chest pain", ylab = "Diagnostic",  
            main = "Diagnostic by Chest Pain")
```

The variable **cp** has four levels.

Visualization: Mosaicplot

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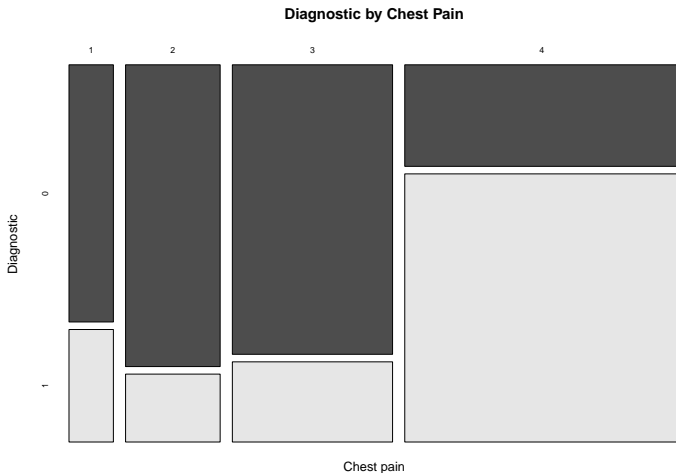
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```
mosaicplot(cleve$exang ~ cleve$diagnostic,  
            shade=F, color=T,  
            xlab = "Exercise-induced angina",  
            ylab = "Diagnostic",  
            main = "Diagnostic by Angina")
```

The variable **exang** (exercise induced angina): 1 = yes; 0 = no

Visualization: Mosaicplot

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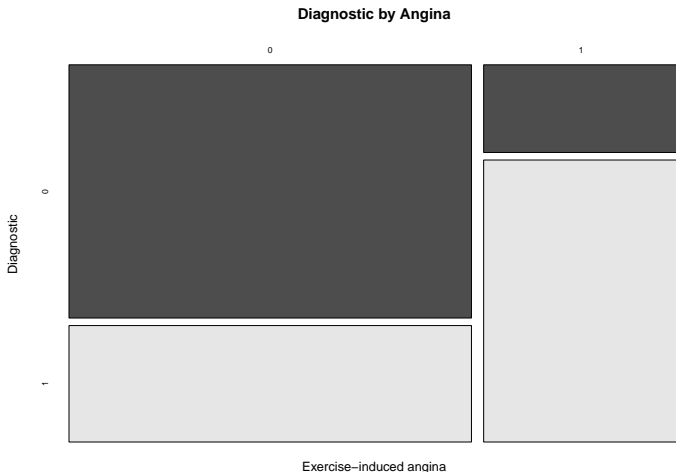
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Consider the variable *age*.

```
plot(cleve$age)
```

gives the scatterplot of the variable.

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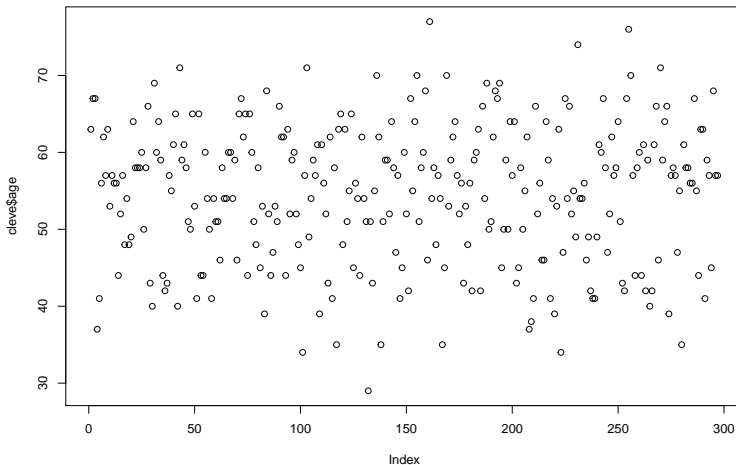
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```
plot(cleve$age, cleve$chol)
```


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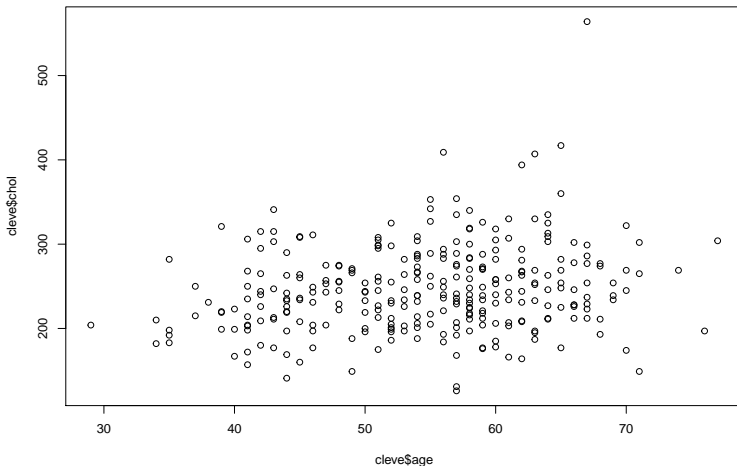
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With regression line:

```
plot(cleve$age, cleve$chol)
abline(lm(chol ~ age, data = cleve), col = "red")
```

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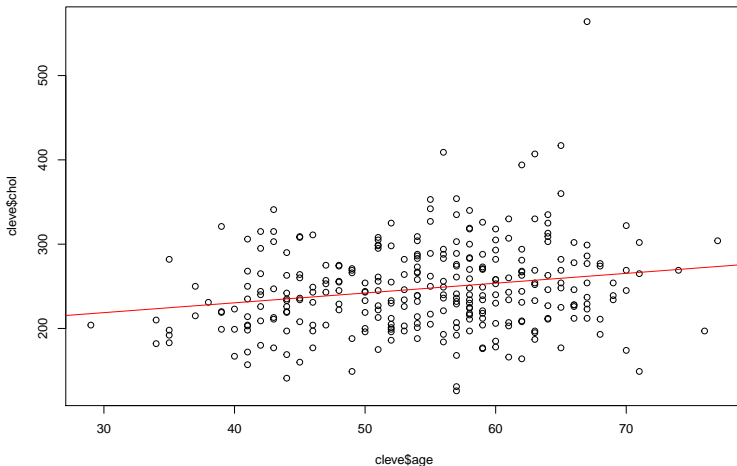
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Classification by K-means clustering

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See the script `classification.R`

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We want to determine whether there is a difference in age between individuals with no heart condition and those with an indication of a heart condition¹.

```
age.pos <- cleve$age[cleve$diagnostic == 1]  
age.neg <- cleve$age[cleve$diagnostic == 0]
```

Formally

$$H_0 : \text{age.pos} = \text{age.neg}$$

$$H_1 : \text{age.pos} \neq \text{age.neg}$$

(significance level: $\alpha = .05$)

¹We set 'diagnostic=1' if some heart problem are present, using 'cleve\$diagnostic[cleve\$diagnostic > 0] <- 1' in slide 65.

Hypothesis testing

95% Confidence interval

```
t.test(age.pos, age.neg, mu = 0)
```

```
##
```

```
## Welch Two Sample t-test
```

```
##
```

```
## data: age.pos and age.neg
```

```
## t = 4, df = 295, p-value = 6e-05
```

```
## alternative hypothesis: true difference in means is not equal to 0
```

```
## 95 percent confidence interval:
```

```
## 2.12 6.11
```

```
## sample estimates:
```

```
## mean of x mean of y
```

```
## 56.8 52.6
```

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99% Confidence interval

```
t.test(age.pos, age.neg, mu = 0, conf.level = .99)

##
##  Welch Two Sample t-test
##
## data:  age.pos and age.neg
## t = 4, df = 295, p-value = 6e-05
## alternative hypothesis: true difference in means is not equal to 0
## 99 percent confidence interval:
##  1.49 6.74
## sample estimates:
## mean of x mean of y
##      56.8      52.6
```


Hypothesis testing

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- The function `t.test()` uses by default the Welch *t*.test, with Welch-Satterthwaite correction for degrees of freedom.
- When the variances are equal, we can use

```
t.test(age.pos, age.neg, mu = 0,  
       var.equal = TRUE)
```

- The test for equal variances is

```
var.test(age.pos, age.neg, mu = 0, ratio = 1)
```

Hypothesis testing

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Power calculation

Having rejected the null hypothesis, we compute the power of the test under the alternative

$$H_1 : \text{age.pos} - \text{age.neg} = 2.5$$

A power calculation needs four parameters, α , sd , n (sample size), δ (true difference in mean). It must also specify whether the test is one sided or two sided.

Hypothesis testing

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Power calculation

```
power.t.test(n = nrow(cleve), sd =  
  sqrt(var(age.pos)+var(age.neg)),  
  sig.level = .05, delta = 2.5,  
  alternative = "two.sided"  
)
```

Hypothesis testing

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Power calculation

```
##  
##      Two-sample t test power calculation  
##  
##              n = 297  
##            delta = 2.5  
##             sd = 12.4  
##    sig.level = 0.05  
##         power = 0.689  
## alternative = two.sided  
##  
## NOTE: n is number in *each* group
```

Hypothesis testing

Power calculation

Compute the sample size needed so that the power of the test is .90, when $\delta = 2.5$; $sd = 12.395$, with $\alpha = .05$ in a two sided alternative:

```
##  
##           Two-sample t test power calculation  
##  
##               n = 518  
##             delta = 2.5  
##             sd = 12.4  
##       sig.level = 0.05  
##             power = 0.9  
##       alternative = two.sided  
##  
## NOTE: n is number in *each* group
```

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Power curve

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```
curve(power.t.test(n=50,delta = x,  
  sd = sqrt(var(age.pos)+var(age.neg)),  
  type="two.sample",  
  alternative="two.sided")$power,  
  from=.1, to=10, xlab="delta",  
  ylab="power")
```

Power curve

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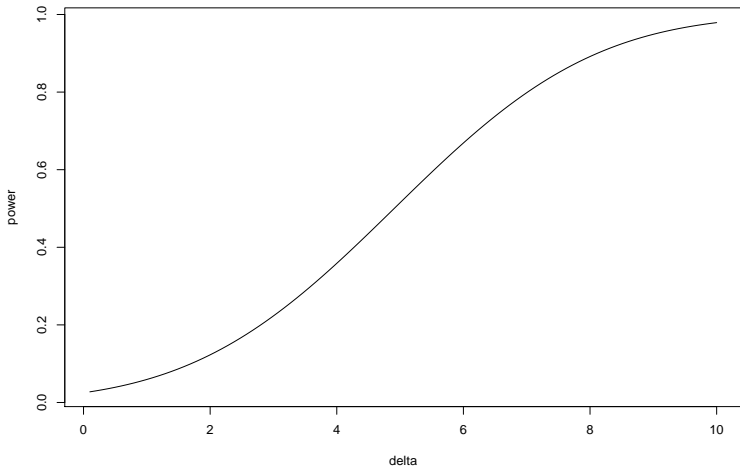
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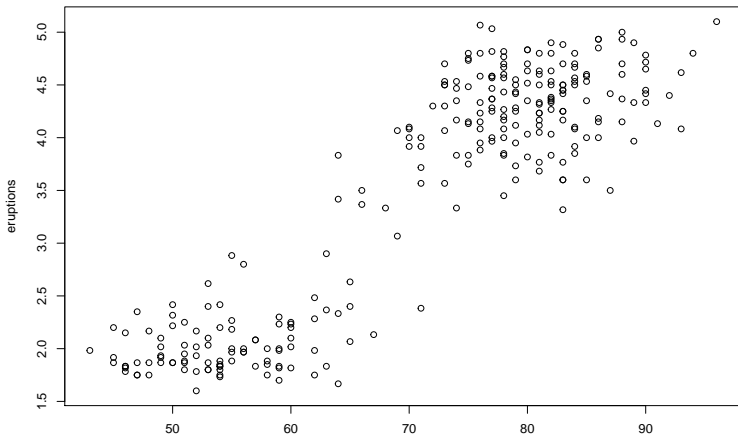
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Linear regression models

Simple linear regression model

```
attach(faithful)
plot(waiting, eruptions)
```



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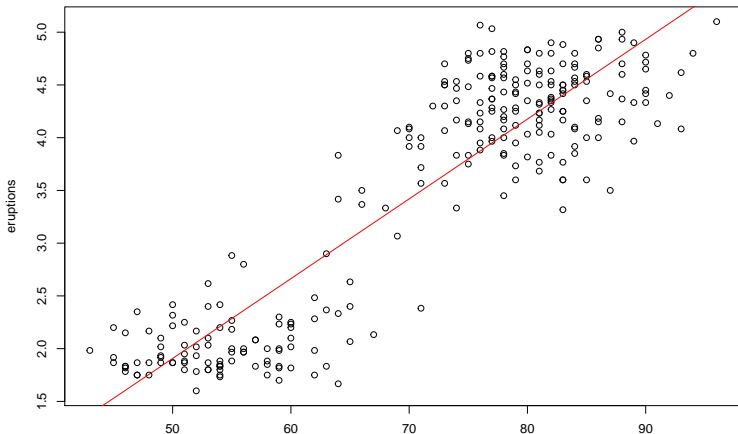
**Linear
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Simple linear regression model

```
plot(waiting, eruptions)
abline(lm(eruptions ~ waiting), col = "red")
```



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Let us consider the model

$$eruptions = \beta_0 + \beta_1 waiting + u$$

```
slrm <- lm(eruptions ~ waiting)
```

Simple linear regression model

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```
slrm.summary <- summary(slrn)  
slrm.summary$coefficients
```

##	Estimate	Std. Error	t value	Pr(> t)
## (Intercept)	-1.8740	0.16014	-11.7	7.36e-26
## waiting	0.0756	0.00222	34.1	8.13e-100

Simple linear regression model

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Estimation

Estimate *eruptions*, when *waiting* = 90.

- Using the function `coefficients` to extract the coefficients from the estimated model:

```
eruptions.fit.coef <- coefficients(slm)  
c <- c(1,90)  
eruptions.fit.coef %*% c
```

```
##      [,1]  
## [1,] 4.93
```

- Using the function `predict`:

```
predict(slm, data.frame(waiting = 90))  
##      1  
## 4.93
```

Simple linear regression model

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Confidence interval

Find a 99% confidence interval for *eruptions*, when *waiting* = 90.

```
predict.lm(slrn, data.frame(waiting = 90),  
           interval = "confidence",  
           level = .99)
```

```
##      fit lwr  upr  
## 1 4.93 4.8 5.07
```

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Prediction interval

Find a 99% confidence interval for a prediction of *eruptions*, when *waiting* = 90.

```
predict.lm(slm, data.frame(waiting = 90),  
           interval = "prediction",  
           level = .99)
```

```
##      fit  lwr  upr  
## 1 4.93 3.64 6.23
```

Remark

After using a dataset, detach it:

```
detach(faithful)
```

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Download and then load the library **openintro**

```
install.packages("openintro") # download the library  
library(openintro)  
# load the library in the current session
```

Load the dataset **hsb2**:

```
data(hsb2)  
attach(hsb2)
```

The description of the variables is obtained typing

```
?hsb2
```

or can be found [here](#).

Multiple linear regression

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Example 1

Estimate the standardized math score by race:

$$math = \beta_0 + \beta_1 race + u.$$

The variable *race* is **categorical** and has four levels:

```
levels(factor(race))
```

```
## [1] "african american" "asian" "hispani
```

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Example 1

Model estimation

```
attach(hsb2)
m1 <- lm(math ~ factor(race))
summary.m1 <- summary(m1)
```

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Example 1

Model estimation: Extraction of the estimated coefficients

```
summary.m1$coefficients
```

##	Estimate	Std. Error	t value	P
## (Intercept)	46.750	2.00	23.417	1
## factor(race)asian	10.523	3.35	3.140	1
## factor(race)hispanic	0.667	2.70	0.247	8
## factor(race)white	7.222	2.13	3.391	8

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Example 1

Use of vectorization

```
summary.m1$coefficients[2,]
```

##	Estimate	Std. Error	t value	Pr(> t)
##	10.52273	3.35145	3.13975	0.00195

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Example 2

Factor interaction

Estimate the standardized math score by gender, race.

R code

```
m2 <- lm(math ~ factor(gender)*factor(race))  
summary.m2 <- summary(m2)
```

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Example 2

Estimated model

```
summary(m2)$coefficients
```

##	Estimate	S
## (Intercept)	47.54	
## factor(gender)male	-2.25	
## factor(race)asian	9.21	
## factor(race)hispanic	-2.27	
## factor(race)white	6.24	
## factor(gender)male:factor(race)asian	4.17	
## factor(gender)male:factor(race)hispanic	6.21	
## factor(gender)male:factor(race)white	2.66	

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Example 3

Estimate the effect of the scores of reading skills, *read*; social studies, *socst*, y science, *science* on the score of mathematics, *math*.

Model

$$math = \beta_0 + \beta_1 read + \beta_2 socst + \beta_3 science + u.$$

R code

```
m3 <- lm(math ~ read + socst + science)
m3.estim <- summary(m3)
m3.estim$coefficients
```

Multiple linear regression

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Example 3

Estimated model

##	Estimate	Std. Error	t value	Pr(> t)
## (Intercept)	11.887	2.7937	4.25	3.24e-05
## read	0.313	0.0654	4.79	3.24e-06
## socst	0.154	0.0548	2.82	5.37e-03
## science	0.315	0.0599	5.25	3.96e-07

The model is significant, as the F -statistic of the model is equal to 74.576, with associated p -value $= 3.201 \times 10^{-32}$.

The model fit $R^2 = 0.533$.

Multiple linear regression

Remark

If we need to estimate models with interactions, or quadratic terms (continuous variables), we need to use $I(x1*x2)$ in the model definition.

For example, to estimate either model

$$math = \beta_0 + \beta_1 read + \beta_2 socst + \beta_3 socst^2 + u$$

$$math = \beta_0 + \beta_1 read + \beta_2 socst + \beta_3 socst \cdot read + u$$

we have to define the model as either

```
m.quad <- lm(math ~ read + socst + I(socst^2))
```

or

```
m.inter <- lm(math ~ read + socst  
               + I(socst* read))
```

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We randomly split the data and use one set to estimate the model and the rest to estimate the goodness of fit. To ensure reproducibility, we set the RNG seed to `set.seed(13)`.

To show the necessary coding, we shall use the third model, `m3`.

To validate other models, we only need to suitably change the object `linmodel.Train`.

In-sample and out-of-sample validation

Example 3

```
set.seed(13)
TrainRows <- sample(1:nrow(hsb2),
                    .8*nrow(hsb2), replace = FALSE)
Train <- hsb2[TrainRows,]
Valid <- hsb2[-TrainRows, ]
linmodel.Train <-
  lm(math ~ read + socst + science, data = Train)
mathPredic <-
  predict(linmodel.Train, Valid)
actual.predic <-
  data.frame(cbind(actual = Valid$math,
                    predicted = mathPredic))
```

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Example 3

Correlation matrix

```
corr.accuracy <- cor(actual.predic)
corr.accuracy
```

##	actual	predicted
## actual	1.000	0.829
## predicted	0.829	1.000

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Accuracy: Min-Max

The Min-Max method compute the mean of the minimum over the mean of the maximum.

Values very close to 1 (Min-Max > .90) denotes excellent accuracy.

R code

```
min.max.accuracy <-  
  mean(apply(actual.predic,  
              1, min)/apply(actual.predic, 1, max))  
min.max.accuracy  
## [1] 0.915
```

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Accuracy: Mean Absolute Error (MAE)

If A_i are the actual (observed) values of the response and F_i are the forecast ones, then

$$MAE = \frac{1}{T} \sum_{i=1}^T |A_i - F_i|;$$

T is the sample size.

R code

```
mae <- mean(abs((actual.predic$predicted -  
                actual.predic$actual)))  
  
mae  
  
## [1] 4.63
```

In-sample and out-of-sample validation

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Accuracy: Mean Absolute Percentage Error (MAPE)

The mean absolute percentage error (MAPE) is defined as

$$MAPE = \frac{1}{T} \sum_{i=1}^T \left| \frac{A_i - F_i}{A_i} \right|.$$

- MAPE can be interpreted as the average percentage error.
- Sometimes, MAPE can be very large, even though the forecast is reasonably good. If, e.g., $A_i \approx 10^{-3}$ and $|F_i - A_i| \approx 10^{-1}$, entonces

$$\left| \frac{A_i - F_i}{A_i} \right| \approx 10^2$$

- If the forecast is exact, then $MAPE = 0$.

In-sample and out-of-sample validation

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MAPE: R code

```
mape <- mean(  
  abs((actual.predic$predicted -  
        actual.predic$actual))/actual.predic$actual)  
mape
```

```
## [1] 0.0924
```

On the average, the error is 9.2%.

In-sample and out-of-sample validation

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RMSE

$$RMSE = \sqrt{\frac{1}{T} \sum_{i=1}^T (y_i - \hat{y}_i)^2}$$

- RMSE is the square root of the variance of the residuals.
- It can be interpreted as the standard deviation of the unexplained variance of the model.
- It has the same units as the response variable.

In-sample and out-of-sample validation

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RMSE: R code

```
rmse <- sqrt(  
  mean(((actual.predic$predicted -  
          actual.predic$actual))^2)  
)  
rmse  
## [1] 5.66
```

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The library `lmtest` permits to run tests to determine

- normality of errors;
- heteroskedasticity;
- serial autocorrelation, and
- correct specification of the model (RESET)

The library `sandwich` permits to estimate HC, HAC² standard errors.

We shall run the diagnostics on the model `m3` (Example 3).

²HC: Heteroskedastic Consistent standard errors; HAC: Heteroskedastic and Autocorrelation Consistent errors.

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Normality

There are several normality test available.

- The Shapiro-Wilk test is available in the **base** library (loaded by default), but it cannot be applied to vectors with more than 5,000 observations. For this reason, we also present the Jarque-Bera test.
- The normality of errors is less of a concern when the sample size is sufficiently large.

Hypothesis test

H_0 : errors are normal

H_1 : errors are not normal

$(\alpha = .05)$

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Normality: Shapiro-Wilk test

```
shapiro.test(m3$residuals)
```

```
##
```

```
##  Shapiro-Wilk normality test
```

```
##
```

```
## data:  m3$residuals
```

```
## W = 1, p-value = 0.5
```

Conclusion

There is no evidence of non-normality of errors.

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Jarque-Bera test

The Jarque-Bera test is available in the library **tseries**:

```
library(tseries)
jarque.bera.test(m3$residuals)
```

```
##
## Jarque Bera Test
##
## data:  m3$residuals
## X-squared = 3, df = 2, p-value = 0.2
```

Conclusion

There is no evidence of non-normality of errors.

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QQ plot

The QQ plot compares the observed quantiles of the errors to the theoretical quantiles of the standard normal distribution.

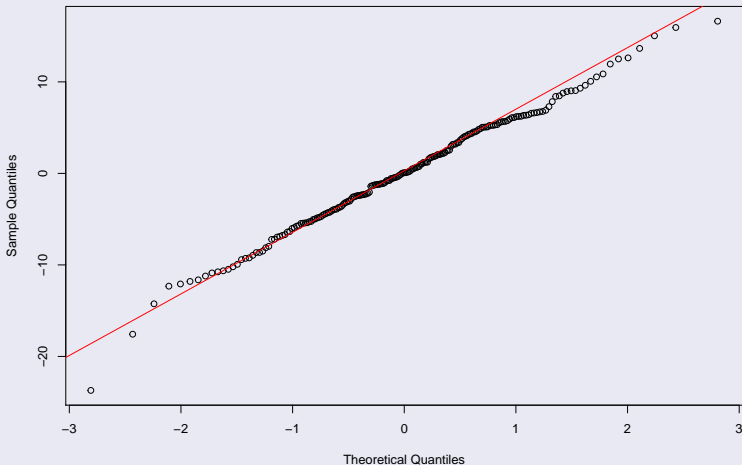
```
qqnorm(m3$residuals)  
qqline(m3$residuals, col = "red")
```

We can see that the distribution of the errors follows pretty closely the standard normal distribution.

Diagnostics

QQ plot

Normal Q-Q Plot



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Heteroskedasticity

The underlying hypothesis test is

H_0 : the model is homoskedastic

H_1 : the model is heteroskedastic

Function `bptest()`

Apply the function `bptest()` to the fitted model.

```
library(lmtest)
```

```
bptest(m3)
```

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Heteroskedasticity

```
bptest(m3)
```

```
##  
## studentized Breusch-Pagan test  
##  
## data: m3  
## BP = 9, df = 3, p-value = 0.03
```

Conclusion

- There is evidence of heteroskedasticity.
- If there is evidence of autocorrelation of errors, then neither OLS nor HC standard errors are correct.

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Serial autocorrelation

The purpose of the test is to determine whether there is any linear dependence among terms of the innovations.

We can apply the Durbin-Watson test, `dwtest()`, and the Breusch-Godfrey test, `bgtest()`.

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Serial autocorrelation

```
dwtest(m3, alternative = "two.sided")  
  
##  
## Durbin-Watson test  
##  
## data: m3  
## DW = 2, p-value = 0.3  
## alternative hypothesis: true autocorrelation is not 0
```

Result

There is no evidence that $\text{corr}(u_t, u_{t-1}) \neq 0$.

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Serial autocorrelation

```
bgtest(m3, order = 10)
```

```
##
```

```
## Breusch-Godfrey test for serial correlation of order
```

```
##
```

```
## data: m3
```

```
## LM test = 12, df = 10, p-value = 0.3
```

Result

There is no evidence of linear dependence among the first 10 terms of the errors.

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Heteroskedasticity

We have detected heteroskedasticity, but not autocorrelation of the errors, so HC standard errors are appropriate.

HC standard errors are obtained using the function `coeftest()` passing the parameter `vcov. = vcovHCa`

```
library(sandwich)  
coeftest(m3, vcov. = vcovHC)
```

All controls are still significant.

^aThere are several variants of HC standard errors.

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Heteroskedasticity

```
##
```

```
## t test of coefficients:
```

```
##
```

```
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   11.8865      2.4585    4.83  2.7e-06 *
## read           0.3134      0.0600    5.22  4.5e-07 *
## socst          0.1542      0.0572    2.70  0.0076 *
## science        0.3145      0.0567    5.54  9.5e-08 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.'
```

Remark The estimated slopes are not affected by heteroskedasticity.

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RESET: Hypothesis test

H_0 : the model does not need nonlinear combination of controls

H_1 : the model needs nonlinear combination of controls

- Typically, quadratic and cubic powers are considered.
- The test statistics may need heteroskedastic (HC; HAC) corrections.

R code

```
resettest(m3, power = 2:3, vcov = vcovHC)
```


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RESET

```
##  
## RESET test  
##  
## data: m3  
## RESET = 1, df1 = 2, df2 = 196, p-value = 0.3
```

Conclusion

There is no need of nonlinear combinations of regressors.

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Plots

We can also apply `plot()` to a `lm()` object to obtain these tests.

It is an interactive plot and it is convenient to do it in the console.

```
plot(m3)
```

Plots: documentation

It can be found [here](#) (check “Details”).

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Plots: Leverage and influential observations

The concepts of leverage and influential observations can be used as a proxy for finding whether a given observation is an outlier.

- Leverage is a measure of how far the independent variables of an observation are from those of other observations.
- An influential observation is one whose deletion will affect greatly the estimate.

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Plots: Leverage and influential observations

- The leverage in a linear regression can be computed using the projection matrix (F. Hayashi, 2000, *Econometrics*, Princeton University Press, pp. 21-23).
- The Cook's distance defined in the next slide can be often used as a measure of observations with high leverage; Cook's distance can also be used to detect highly influential observations.
- In R, the **residual-leverage** plot draws a red, dashed line identifying observations with Cook's distance greater than .5.
- In R, observations with leverage greater than 1 are omitted with a warning; check Residual-Leverage plot in "Details" [here](#),

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Cook's distance

The Cook's distance is a tool that is used to check whether a single observation has a large influence on the estimate of the linear regression:

$$D_i = \frac{\sum_{j=1}^T (\hat{y}_j - \hat{y}_{j(i)})^2}{(k+1)TSS}$$

where $\hat{y}_{j(i)}$ is the fitted response value when excluding i ; TSS is the total sum of square (mean square error):

$$TSS = (1/T) \sum_{i=1}^T (y_i - \hat{y}_i)^2.$$

```
detach(hsb2)
```

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Estimate the probability of a positive diagnosis of heart disease, controlling for cholesterol levels and age:

$$\text{logit}(\textit{diagnostic}) = \beta_0 + \beta_1 \textit{chol} + \beta_2 \textit{age},$$

where

$$\text{logit}(\textit{diagnostic}) = \log \left(\frac{\textit{diagnostic}}{1 - \textit{diagnostic}} \right)$$

is the **log-odds** of a positive diagnosis.

Thus, e.g., β_1 is the change of the log-odds of a positive diagnosis with respect to a unit increase of *chol*.

Logit model

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Estimation

```
modelo.logit <- glm(diagnostic ~ chol + age,  
                    data = cleve,  
                    family = "binomial")  
summary(modelo.logit)
```


Logit model

Estimation

```
##
## Call:
## glm(formula = diagnostic ~ chol + age, family = "b
##
## Deviance Residuals:
##      Min       1Q   Median       3Q      Max
## -1.593  -1.085  -0.815   1.158   1.729
##
## Coefficients:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept) -3.32713    0.89145  -3.73  0.00019 *
## chol         0.00147    0.00237   0.62  0.53411
## age          0.05129    0.01405   3.65  0.00026 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.'
```

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Goodness of fit

A measure of goodness of fit is a comparison of the estimated logit model to the null model

$$\text{logit}(\textit{diagnostic}) = \beta_0$$

The comparison is done by the hypothesis test

H_0 : The null model fits better the data

H_1 : The logit model fits better the data

($\alpha = .05.$)

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Goodness of fit

The test statistics is the **difference of deviations**, which has χ^2 distribution, with `df.null - df.residual` degrees of freedom:

```
with(modelo.logit,  
      pchisq(null.deviance - deviance,  
              df.null - df.residual,  
              lower.tail = FALSE))  
## [1] 0.000322
```

Conclusion

The logit model better fit the data.

Logit model

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Diagnosis of heart disease ($diagnostic = 1$), if the estimated value of $diagnostic$ in the logit model is greater than $mean(diagnostic)$.

Validation

```
probs.predicted <- predict(modelo.logit,  
                           type = "response")  
mu <- mean(cleve$diagnostic)  
probs.predicted2 <-  
  ifelse(probs.predicted > mu, 1, 0)  
table(cleve$diagnostic,  
      probs.predicted2)/nrow(cleve)
```

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Off-diagonal terms are false positives and false negatives.

Validation

```
##      probs.predicted2
##           0           1
##  0 0.323 0.215
##  1 0.148 0.313
```

There is a 21.5% of false positives and a 14.8% of false negatives.

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Diagnosis of heart disease ($diagnostic = 1$), if the estimated value of *diagnostic* in the logit model is greater than .5.

Validation

```
probs.predicted3 <-  
  ifelse(probs.predicted > .5, 1, 0)  
table(cleve$diagnostic,  
      probs.predicted3)/nrow(cleve)
```

```
##      probs.predicted3  
##           0         1  
##  0 0.374 0.165  
##  1 0.226 0.236
```

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Needed libraries are `forecast`, `tseries`.

Download them,

```
install.packages("forecast", "tseries")
```

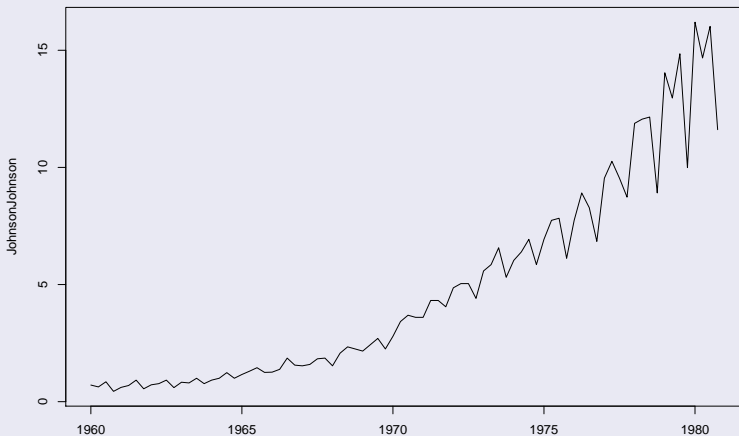
and then load them in your session

```
library(forecast)  
library(tseries)
```


Time series

Plots (Multiplicative model)

```
plot.ts(JohnsonJohnson)
```



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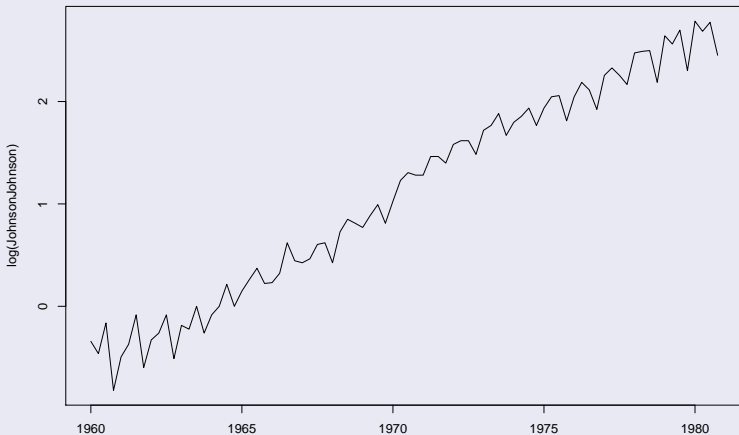
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Plots (Additive model)

```
plot.ts(log(JohnsonJohnson))
```



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Let y_t be a stochastic process.

The idea of exponential smoothing is to compute the *one-step ahead forecast*, $\hat{y}_{T+1|T}$, as a weighted mean of the previous observed terms:

$$\begin{aligned}\hat{y}_{T+1|T} &= \alpha y_T + \alpha(1 - \alpha)y_{T-1} + \cdots \\ &= \alpha y_T + (1 - \alpha)\hat{y}_{T|T-1}, \quad 0 \leq \alpha < 1;\end{aligned}$$

rearranging terms,

$$\hat{y}_{t+1|t} = \alpha y_t + (1 - \alpha)\hat{y}_{t|t-1},$$

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which gives

$$\begin{aligned}\hat{y}_{t+1|t} &= \alpha y_t + (1 - \alpha)\hat{y}_{t|t-1} = \hat{y}_{t|t-1} + \alpha(y_t - \hat{y}_{t|t-1}) \\ &= \hat{y}_{t|t-1} + \alpha e_t,\end{aligned}$$

where $e_t = y_t - \hat{y}_{t|t-1}$ is the forecast error.

The value α is estimated optimizing the errors squared.

The work by Holt & Winters allowed the inclusion of seasonal, s_t , and trending, b_t , terms, beside the level term, ℓ_t .

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Holt-Winters Modeling (Additive model)

$$y_{t+h|t} = \ell_t + hb_t + s_{t-m+h_m^+}$$

$$\ell_t = \alpha(y_t - s_{t-m}) + (1 - \alpha)(\ell_{t-1} - b_{t-1})$$

$$b_t = \beta^*(\ell_t - \ell_{t-1}) + (1 - \beta^*)b_{t-1}$$

$$s_t = \gamma(y_t - \ell_{t-1} - b_{t-1}) + (1 - \gamma)s_{t-m}$$

where m denotes the seasonality period (per year)

The symbol

$$h_m^+ = \lfloor (h - 1) \bmod(m) \rfloor + 1$$

makes sure that the estimation of the seasonality is the last year of the sample.

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Estimation

```
logJJ.forecast <- HoltWinters(  
  log(JohnsonJohnson), beta = TRUE, gamma = TRUE)  
logJJ.forecast
```

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Estimation

```
logJJ.forecast$coefficients[1]
```

```
##      a
```

```
## 2.61
```

```
logJJ.forecast$SSE # measure of estimate error
```

```
## [1] 0.661
```

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Plots

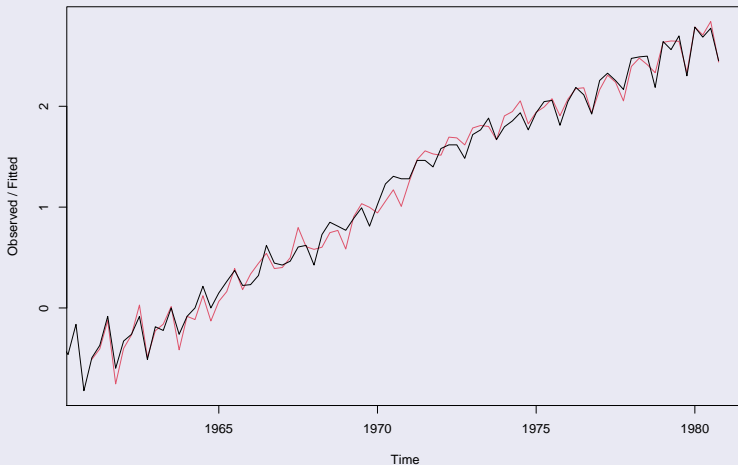
```
plot(logJJ.forecast)
```

The original series is plotted in black and the forecast is in red.

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Plots

Holt-Winters filtering



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Estimate with an initial value

```
logJJ.forecast2 <- HoltWinters(  
  log(JohnsonJohnson), beta = TRUE, gamma =  
    TRUE, l.start = .91) # arbitrary initial value  
logJJ.forecast2
```

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Estimate with an initial value

```
logJJ.forecast2$coefficients[1]
```

```
##      a
```

```
## 2.68
```

```
logJJ.forecast$coefficients[1]
```

```
##      a
```

```
## 2.61
```

```
logJJ.forecast$SSE # measure of estimate error
```

```
## [1] 0.661
```

```
logJJ.forecast2$SSE
```

```
## [1] 6.01
```

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Comparing plots

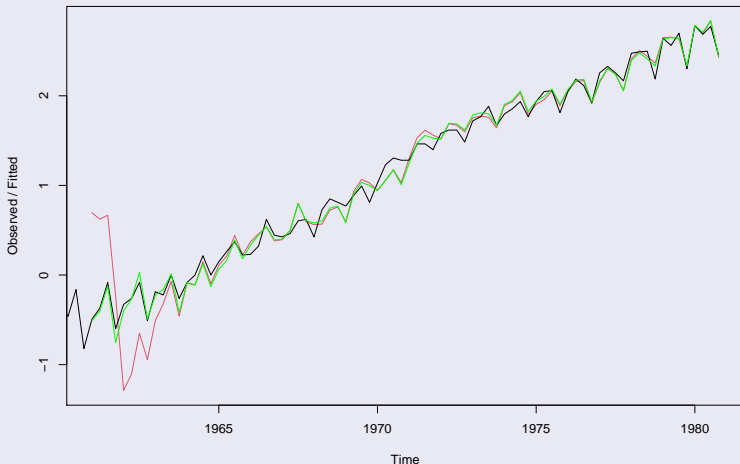
```
plot(logJJ.forecast2)  
lines(logJJ.forecast$fitted[,1], col = "green")
```

The object is a matrix whose columns are, respectively, the fitted time series; its level part; its trend part and the seasonality. We select above the fitted part.

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Comparing plots

Holt-Winters filtering



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Forecast

Forecast can be performed using the library **forecast**

```
library(forecast)
```

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Forecast

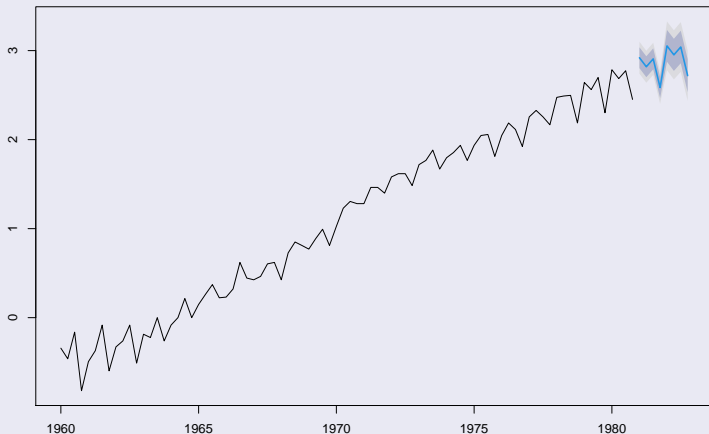
```
logJJ.forecast8095 <-  
  forecast(logJJ.forecast, h=8)
```

- We use the first estimate, `logJJ.forecast`, as it is proven to be the better.
- The parameter `h=8` will forecast the estimate **eight** periods in the future (two years).
- The forecast also plots a confidence interval (80%; 95% is the default).

Exponential smoothing

Forecast: Plot

Forecasts from HoltWinters



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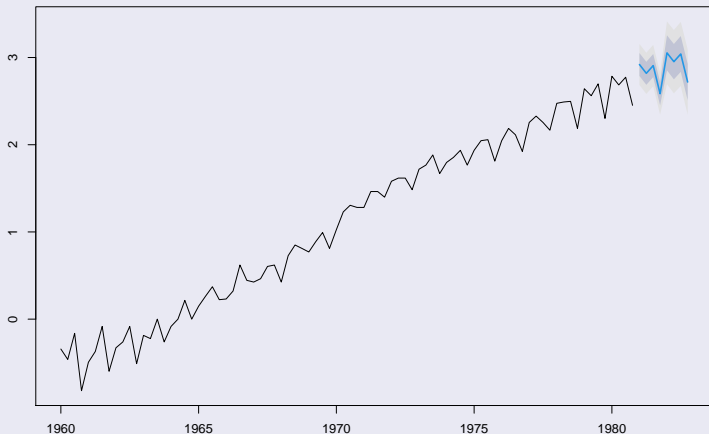
Forecast: Plot

```
logJJ.forecast8599 <- forecast(  
  logJJ.forecast, h=8, level = c(85,99))  
plot(logJJ.forecast8599)
```

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Forecast: Plot

Forecasts from HoltWinters



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Diagnostics

```
library(tseries)
ts8095.fitted <- as.ts(logJJ.forecast8095$fitted)
ts8095.fitted <- na.omit(ts8095.fitted)
ts8095.residuals <-
  as.ts(logJJ.forecast8095$residuals)
ts8095.residuals <-
  na.omit(as.ts(logJJ.forecast8095$residuals))
```

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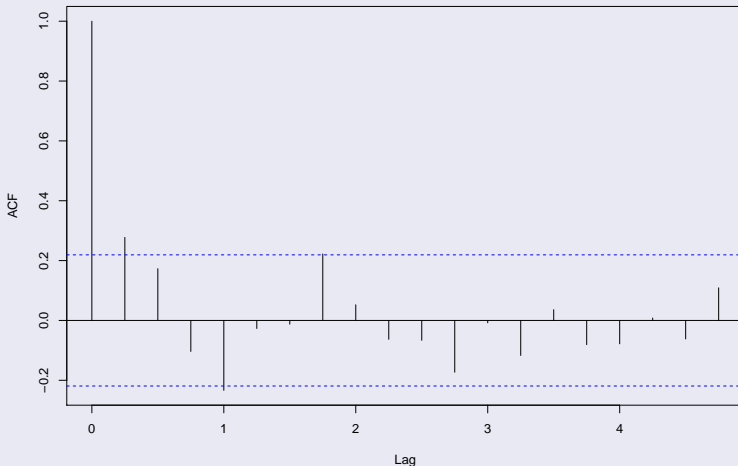
Diagnostics: ACF

```
acf(ts8095.residuals)
```

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Diagnostics: ACF

Series ts8095.residuals



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Diagnostics: Ljung-Box Test

```
Box.test(ts8095.residuals, lag = 20)
```

```
##
```

```
## Box-Pierce test
```

```
##
```

```
## data: ts8095.residuals
```

```
## X-squared = 25, df = 20, p-value = 0.2
```

Conclusion

We do not reject the null hypothesis of no autocorrelation (for the first 20 lags).

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Diagnostics: Augmented Dickey-Fuller Test

```
adf.test(ts8095.fitted)

##
##   Augmented Dickey-Fuller Test
##
## data:   ts8095.fitted
## Dickey-Fuller = -1, Lag order = 4, p-value = 0.8
## alternative hypothesis: stationary
```

Conclusion

There is evidence that the errors are not white noise.

Box-Jenkins approach

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See the script `BoxJenkins.R`