MAS1802: Problem Solving II (Statistical Computing with R)

Dr Lee Fawcett

School of Mathematics, Statistics & Physics

Semester 2, 2018/2019

1.1 Housekeeping

MAS1802 – A tale of two halves:

- Weeks 1–5: Pencil-and-paper problem solving with Evgenios Kakariadis
- Weeks 6–11: Statistical computing with Lee Fawcett
- Week 12: Revision for the exam with Evgenios

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Computing – General course structure:

Type of session	Day	Time	Place
Lecture	Tuesday	4–5	Herschel LT1
Practical	Friday	11–1	Herschel PC / ~~Barbara Strang 2.40~~
Drop-in	Monday	10–11	Herschel PC
Office hours	Monday	12-1	My office (2.07)
	Wednesday	12-1	My office (2.07)
Deadline:	*Friday*	*11.00am*	*General office/online*

- This week: No Monday drop-in, extra lecture (Thursday 11, Bedson LT1)!
- Next week: Monday drop-in $\longrightarrow$ work due in on Friday

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1.1.1 Lecturer information: who am I?

- The module leader, and lecturer for the computing part of this module, is Dr. Lee Fawcett
- If you have any questions, comments or feedback on this course I can be contacted via email
- More complicated questions about the course are best dealt with face-to-face

1.1.2 Lectures

- Fewer lectures for this course than for other modules (nature of the course)
- The calendar at the front of this handout contains a full schedule for the computing part of this course
- A summarised version of the notes will be used as slides - interspersed with quizes and other really fun things. Pay attention!
- Notes, slides and practical sheets will be posted to BlackBoard, and a dedicated webpage, soon after the lecture/practical session
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  - You have attended the lecture: In practicals, I will assume you have been to the lecture on Monday; this is reflected in what is expected of you in the practicals
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- Assessment of course-work worth **60%** of your overall mark:
  - 'Weekly' computing exercises (10%: 3@ 3.33% each)
  - Group computing project (30%)
  - Problem-solving exercises (20%)

The weekly computer exercises will be due on the following dates, all of which are Fridays at 11am:

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- These quiz questions are written within the usual computer-based assessment (CBA) framework – if you're interested, go to:

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- **R** is a computer package that is widely used
- For example Google, IBM, Shell and spread betting companies use **R** for statistical software development and data analysis
- See the NY times article at http://tinyurl.com/9m5qyh.
- **R** uses a command line interface, though several graphical user interfaces are available
- Why use a command line interface as opposed to Excel, say?

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1.2 What is **R**?

- **R** is highly extensible through the use of user-submitted libraries for specific functions or specific areas of study
- A particular strength of **R** is it's graphical facilities, which produce quality graphs (better than MatLab!) that can include mathematical symbols
- **R**'s syntax is similar to that used in MatLab
- **R** has loads of built-in functions for statistical analysis, but can also do lots of basic mathematical operations too
- **R** is completely free (unlike MatLab), as is the Rstudio software which we will use in this course
- Named after Ross Ihaka and Robert Gentleman (Auckland University, NZ) who developed the software
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1.2.1 Accessing **R**

- R is installed on all University machines
- In this class we will be using Rstudio, which is an R IDE
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- Since you will be using R throughout your degree, then it may be worthwhile buying a good R textbook...
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1.3 Movies dataset

- The internet movie database (IMDB) is a website devoted to collecting movie data supplied by studios and fans.
- It claims to be the biggest movie database on the web and is run by amazon. More information about imdb.com can be found online.
- Movies were selected for inclusion if they:
  - had a known length;
  - had been rated by at least one IMDB user;
  - had an MPAA rating.

1.3 Movie dataset

- **Title**. Title of the movie
- **Year**. Year of release
- **Budget**. Total budget in US dollars. If the budget isn't known, then it is stored as '-1'
- **Length**. Length in minutes
- **Rating**. Average IMDB user rating
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- **mpaa**. MPAA rating
- **Action**, **Animation**,.... Binary variables representing if movie was classified as belonging to that genre. A movie can belong to more one genre. See for example the film *Ablaze* in Table 1.1
- There are a total of 24 variables and 4988 films
- This is **only a subset** of the data, the actual data set contains information on over 50,000 movies

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				Voting statistics					Movie genre							
Title	Year	Length	Budget	Rating	Votes	r1	...	r10	mpaa	Action	Animation	Comedy	Drama	Documentary	Romance	Short
A.k.a. Cassius	1970	85	-1	5.7	43	4.5	...	14.5	PG	0	0	0	0	1	0	0
AKA	2002	123	-1	6.0	335	24.5	...	1.5	R	0	0	0	1	0	0	0
Alien Vs. Pred	2004	102	45000000	5.4	14651	4.5	...	4.5	PG-13	1	0	0	0	0	0	0
Abandon	2002	99	25000000	4.7	2364	4.5	...	4.5	PG-13	0	0	0	1	0	0	0
Abendland	1999	146	-1	5.0	46	14.5	...	24.5	R	0	0	0	0	0	0	0
Aberration	1997	93	-1	4.8	149	14.5	...	4.5	R	0	0	0	0	0	0	0
Abilene	1999	104	-1	4.9	42	0.0	...	24.5	PG	0	0	0	1	0	0	0
Ablaze	2001	97	-1	3.6	98	24.5	...	14.5	R	1	0	0	1	0	0	0
Abominable Dr	1971	94	-1	6.7	1547	4.5	...	14.5	PG-13	0	0	0	0	0	0	0
About Adam	2000	105	-1	6.4	1303	4.5	...	4.5	R	0	0	1	0	0	1	0

1.4 Useful R package

This module has an associated R package for quick access to datasets (e.g. the movies dataset). Installing this package is straightforward:

```
> install.packages("ncldata",
+          repos="http://R-Forge.R-project.org",
+          type="source")
```

To load the package, use:

```
> library(ncldata)
```

Then:

```
> data(movies)
```

Part II

Introduction to R

2.1 A simple R session

At its most basic, R can be used as a calculator – for example, for multiplication and division...

```
> 5*5
[1] 25
> 10.2/6
[1] 1.7
```

...and more ‘advanced’ operations:

```
> 2^3
[1] 8
```

```
> exp(1.5)
[1] 4.481689
```

```
> log(10)
[1] 2.302585
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```
> 4 %% 3
[1] 1
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2.1.1 Assignment operations

- In the computer practicals we will use assignment, i.e. `x = 5`.
- However, computer assignment is different from typical mathematical assignment.
- For example,

```
> x = 5
> x = x + 1
> x
[1] 6
```

- Notice that when we type `x = 5`, R doesn't display or print any output to the screen.
- If we want to see what value has been assigned to the variable, we type `x`.
- An alternative is to surround the expression with brackets.
- For example

```
> (x = 2*x)
[1] 12
```

- You can also use the `<-` operator for assignment. This is, for almost all situations, identical to the = operator.

Question 1

What is the value of x?

```
> x = 5
> x = 2*x + 1
> x
```

1. 5
2. 11
3. 12

Question 1

What is the value of x?

```
> x = 5
> x = 2*x + 1
> x
[1] 11
```

1. 5
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Question 2

What is the value of x?

```
> x = 5
> y = 6
> x = x + 2*y
> x + 5
> x
```

1. 5
2. 10
3. 17
4. 22

Question 2

What is the value of x?

```
> x = 5
> y= 6
> x = x + 2*y
> x + 5
[1] 22
> x
[1] 17
```

1. 5
2. 10
3. 17
4. 22

Question 3

What is the value of x?

```
> x = 5
> y = 6
> x + 5
> x
```

1. 5
2. 10
3. 17
4. 22

Question 3

What is the value of x?

```
> x = 5
> y = 6
> x + 5
[1] 10
> x
[1] 5
```

1. 5
2. 10
3. 17
4. 22

2.1.2 Data types

R has a variety of data types:

```
> (v = TRUE)
[1] TRUE
```

```
> (w = "fred")
[1] "fred"
```

```
> (x = 5.0)
[1] 5
```

2.1.2 Data types

R has a variety of data types:

```
> (v = TRUE)
[1] TRUE
```

```
> (w = "fred")
[1] "fred"
```

```
> (x = 5.0)
[1] 5
```

2.1.2 Data types

R has a variety of data types:

```
> (v = TRUE)
[1] TRUE
```

```
> (w = "fred")
[1] "fred"
```

```
> (x = 5.0)
[1] 5
```

And some “special" data types:

```
> (y = 5/0)
[1] Inf
> (z = y-y)
[1] NaN
```

Type	Example 1	Example 2	Example 3	Example 4
Doubles	2	3.1242	-45.6	4e-10
Logicals/Boolean	TRUE	FALSE		
Characters	“FRED”	“x”	“Male”	“TRUE”
Infinity	Inf	5/0		

Table: Summary of data types in R.

Another important data type in R is `NA`. This is used to represent missing values. A list of data tables is given in Table 1.1.

Question 4

What type of variable is x?

```
> x = "1"
```

1. Character
2. Double
3. Logical

Question 4

What type of variable is x?

```
> x = "1"
```

1. Character
2. Double
3. Logical

2.2 The R workspace

Once you create a variable, R stores that variable in memory for reuse. You can view available variables with the `ls()` command:

```
> ls()
[1] "movies"
```

To delete a variable in R, we use the `rm` function. For example,

```
> x = 0
> y = 1
> z = 2
> ls()
[1] "movies" "x"      "y"      "z"
```

```
> rm(x)
```

```
> ls()
[1] "movies" "y"      "z"
```

To delete a variable in R, we use the `rm` function. For example,

```
> x = 0
> y = 1
> z = 2
> ls()
[1] "movies" "x"      "y"      "z"
```

```
> rm(x)
```

```
> ls()
[1] "movies" "y"      "z"
```

To delete a variable in R, we use the `rm` function. For example,

```
> x = 0
> y = 1
> z = 2
> ls()
[1] "movies" "x"      "y"      "z"
```

```
> rm(x)
```

```
> ls()
[1] "movies" "y"      "z"
```

The nuclear option

We can remove everything in the workspace using:

```
> rm(list=ls())
```

2.3 Vectors

- Vectors are the most basic of all data structures, but are used in almost all R code.
- A R vector contains *n* values of the same type, where *n* can be zero.
- For example

```
> c(0, 1, 2, 3, 4, 5)
[1] 0 1 2 3 4 5
> (my_first_vec = c(0, 1, 2, 3, 4, 5))
[1] 0 1 2 3 4 5
> (my_second_vec = c("Male", "Female", "Male"))
[1] "Male"   "Female" "Male"
```

In R, when we type:

```
> x = 5
> y = "Fred"
```

We have actually created a vector of doubles and characters (of length one).

There are special functions in R to determine type of a variable:

```
> x = 5
```

```
> is.double(x)
[1] TRUE
```

```
> is.character(x)
[1] FALSE
```

```
> is.vector(x)
[1] TRUE
```

There are special functions in R to determine type of a variable:

```
> x = 5
```

```
> is.double(x)
[1] TRUE
```

```
> is.character(x)
[1] FALSE
```

```
> is.vector(x)
[1] TRUE
```

There are special functions in R to determine type of a variable:

```
> x = 5
```

```
> is.double(x)
[1] TRUE
```

```
> is.character(x)
[1] FALSE
```

```
> is.vector(x)
[1] TRUE
```

There are special functions in R to determine type of a variable:

```
> x = 5
```

```
> is.double(x)
[1] TRUE
```

```
> is.character(x)
[1] FALSE
```

```
> is.vector(x)
[1] TRUE
```

To determine the length of a vector in R, we use the `length` function:

```
> length(my_first_vec)
[1] 6
> length(my_second_vec)
[1] 3
```

To create sequences of numbers we use the `seq` command. For example,

```
> (x1 = seq(1, 6))
[1] 1 2 3 4 5 6
```

```
> (x2 = seq(-4, 4, by=2))
[1] -4 -2  0  2  4
```

To create sequences of numbers we use the `seq` command. For example,

```
> (x1 = seq(1, 6))
[1] 1 2 3 4 5 6
```

```
> (x2 = seq(-4, 4, by=2))
[1] -4 -2  0  2  4
```

Command description	Example	Result
Length	`length(x)`	4
Reverse order	`rev(x)`	3,5,5,1
Sort	`sort(x)`	1,3,5,5
Sum	`sum(x)`	14
Extract unique elements	`unique(x)`	1,5,3
Indices of particular elements	`which(x==5)`	2,3

Table: Useful vector functions. In the above examples, `x = c(1,5,5,3)`. Check the associated R help for further information.

Question 5

What is the value of x?

```
> x = seq(2, 6)
```

1. 2,3,4,5,6
2. 2,6
3. 6,4,2

Question 5

What is the value of x?

```
> x = seq(2, 6)
> x
[1] 2 3 4 5 6
```

1. 2,3,4,5,6
2. 2,6
3. 6,4,2

Question 6

What is the value of `blob`?

```
> blob = seq(2, -2, by=-2)
```

- -2 -1 0 1 2
- -2 0 2
- 2 0 -2
- 2 1 0 -1 -2

Question 6

What is the value of `blob`?

```
> (blob = seq(2, -2, by=-2))
[1]  2  0 -2
```

- -2 -1 0 1 2
- -2 0 2
- 2 0 -2
- 2 1 0 -1 -2

2.3.1 Vector operations

- When our data is in a vector structure, we can apply standard operations to the entire vector.
- For example,

```
> (x = seq(-4, 4))
[1] -4 -3 -2 -1  0  1  2  3  4
```

```
> x*x
[1] 16  9  4  1  0  1  4  9 16
```

2.3.1 Vector operations

- When our data is in a vector structure, we can apply standard operations to the entire vector.
- For example,

```
> (x = seq(-4, 4))
[1] -4 -3 -2 -1  0  1  2  3  4
```

```
> x*x
[1] 16  9  4  1  0  1  4  9 16
```

```
> x - 5
[1] -9 -8 -7 -6 -5 -4 -3 -2 -1
```

```
> x + x
[1] -8 -6 -4 -2  0  2  4  6  8
```

```
> x - 5
[1] -9 -8 -7 -6 -5 -4 -3 -2 -1
```

```
> x + x
[1] -8 -6 -4 -2  0  2  4  6  8
```

Question 7

What is the value of z?

```
> x = c(1,10,100,1000)
> y = c(1, 5, 10, 100)
> z = x/y
```

1. 1, 10, 100, 1000
2. 1, 5, 10, 1000
3. 1, 1, 1, 1
4. 1, 2, 10, 10

Question 7

What is the value of z?

```
> x = c(1,10,100,1000)
> y = c(1, 5, 10, 100)
> (z = x/y)
[1]  1  2 10 10
```

1. 1, 10, 100, 1000
2. 1, 5, 10, 1000
3. 1, 1, 1, 1
4. 1, 2, 10, 10

Question 8

What is the value of y?

```
> x = seq(1, 5)
> y = length(x + 1)
```

1. 1
2. 5
3. 10
4. 12

Question 8

What is the value of y?

```
> x = seq(1, 5)
> (y = length(x + 1))
[1] 5
```

1. 1
2. 5
3. 10
4. 12

2.3.2 Extracting elements from vectors

- R has a number of useful of methods that we use to extract subsets of our data.
- For example to pick out particular elements:

```
> my_first_vec[2]
[1] 1
> my_second_vec[2:3]
[1] "Female" "Male"
> my_first_vec[4:2]
[1] 3 2 1
```

- We can also use other arguments.
- For example to remove the last entry in the vector, we use the `length` function:

```
> l = length(my_first_vec)
> my_first_vec[1:(l-1)]
[1] 0 1 2 3 4
```

- We determine the length of the vector using the `length` function and select particular elements using the `[·]` operator.

Question 9

What is the value of x?

```
> y = seq(2, 6)
> x = y[3:length(y)]
```

1. 2,3,4,5,6
2. 3,4,5,6
3. 4,5,6
4. 3

Question 9

What is the value of x?

```
> y = seq(2, 6)
> (x = y[3:length(y)])
[1] 4 5 6
```

1. 2,3,4,5,6
2. 3,4,5,6
3. 4,5,6
4. 3

2.4 Logical vectors

Boolean	A	B	$\bar{A}$	$\bar{B}$	$A \cap B$	$A \cup B$
R	A	B	!A	!B	A & B	A | B
	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE
	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE
	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE

Table: Truth table for Boolean operation

2.4 Logical vectors

Boolean	A	B	$\bar{A}$	$\bar{B}$	$A \cap B$	$A \cup B$
R	A	B	!A	!B	A & B	A | B
	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE
	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE
	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE

Table: Truth table for Boolean operation

2.4 Logical vectors

Boolean	A	B	$\bar{A}$	$\bar{B}$	$A \cap B$	$A \cup B$
R	A	B	!A	!B	A & B	A | B
	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE
	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE
	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE

Table: Truth table for Boolean operation

2.4 Logical vectors

Boolean	A	B	$\bar{A}$	$\bar{B}$	$A \cap B$	$A \cup B$
R	A	B	!A	!B	A & B	A | B
	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE
	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE
	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE

Table: Truth table for Boolean operation

2.4 Logical vectors

Boolean	A	B	$\bar{A}$	$\bar{B}$	$A \cap B$	$A \cup B$
R	A	B	!A	!B	A & B	A | B
	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE
	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE
	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE

Table: Truth table for Boolean operation

2.4 Logical vectors

Boolean	A	B	$\bar{A}$	$\bar{B}$	$A \cap B$	$A \cup B$
R	A	B	!A	!B	A & B	A | B
	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE
	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE
	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE

Table: Truth table for Boolean operation

2.4 Logical vectors

Boolean	A	B	$\bar{A}$	$\bar{B}$	$A \cap B$	$A \cup B$
R	A	B	!A	!B	A & B	A | B
	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE
	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE
	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE

Table: Truth table for Boolean operation

2.4 Logical vectors

Boolean	A	B	$\bar{A}$	$\bar{B}$	$A \cap B$	$A \cup B$
R	A	B	!A	!B	A & B	A | B
	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE
	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE
	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE

Table: Truth table for Boolean operation

2.4 Logical vectors

Boolean	A	B	$\bar{A}$	$\bar{B}$	$A \cap B$	$A \cup B$
R	A	B	!A	!B	A & B	A | B
	TRUE	TRUE	FALSE	FALSE	TRUE	TRUE
	TRUE	FALSE	FALSE	TRUE	FALSE	TRUE
	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE

Table: Truth table for Boolean operation

Question 10

What is the value of z?

```
> x = TRUE
> y = FALSE
> z = x & !y
```

1. TRUE
2. FALSE

Question 10

What is the value of z?

```
> x = TRUE
> y = FALSE
> (z = x & !y)
[1] TRUE
```

1. TRUE
2. FALSE

Question 11

What is the value of z?

```
> x = TRUE
> y = FALSE
> z = 5
> x = (y | !y)  & x
> (z = x)
[1] TRUE
```

1. TRUE
2. FALSE

Question 11

What is the value of z?

```
> x = TRUE
> y = FALSE
> z = 5
> x = (y | !y)  & x
> z = x
```

1. TRUE
2. FALSE

2.4.1 Using logicals for sub-setting vectors

We can construct vectors of logical operators and use them to take subsets of vectors. For example:

```
> (logic1 = c(TRUE, FALSE, TRUE, FALSE))
[1]  TRUE FALSE  TRUE FALSE
> (vec1 = seq(1, 4))
[1] 1 2 3 4
> vec1[logic1]
[1] 1 3
```

2.4.2 Relational operators

When programming it is often necessary to test relations for equality and inequality. To do this in R we use the relation operators. First let's define some variables:

```
> x = 5
> y = 7
```

To test for equality we use ==:

```
> x == 5
[1] TRUE
> x == y
[1] FALSE
```

Similarly, to test for inequality we use !=:

```
> x != 5
[1] FALSE
> y != x
[1] TRUE
```

There are also commands for greater/less than:

```
> y > 6
[1] TRUE
> x >= 5
[1] TRUE
> x <= y
[1] TRUE
```

We can also apply these techniques to vectors. For example:

```
> (vec2 = seq(0, 10, by=2.5))
[1]  0.0  2.5  5.0  7.5 10.0
> vec2 > 3
[1] FALSE FALSE  TRUE  TRUE  TRUE
> vec2 < 9
[1]  TRUE  TRUE  TRUE  TRUE FALSE
> (vec2 > 3) & (vec2 < 9)
[1] FALSE FALSE  TRUE  TRUE FALSE
```

2.4.2 Relational operators

Operator	Tests for	Example	Result
$==$	Equality	`x == 5`	TRUE
$!=$	Inequality	`x != 5`	FALSE
$<$	Less than	`x < 5`	FALSE
$<=$	Less or equal	`x <= 5`	TRUE
$>$	Greater	`x > 5`	FALSE
$>=$	Greater or equal	`x >= 5`	TRUE

Table: Summary of R relational operators. The example is for `x = 5`.

Using relational operators allows us to extract subsets of data very easily. Consider the movie budgets:

```
> length(Budget)
[1] 4988
```

To select movies where the budget is known, we use the following command...

```
> non_zero_b = Budget[!is.na(Budget)]
> length(non_zero_b)
[1] 3990
```

Using relational operators allows us to extract subsets of data very easily. Consider the movie budgets:

```
> length(Budget)
[1] 4988
```

To select movies where the budget is known, we use the following command...

```
> non_zero_b = Budget[!is.na(Budget)]
> length(non_zero_b)
[1] 3990
```

... and to select movies where the movie length is greater than 60 mins but shorter than 90 mins

```
> m_l = Length[Length > 60 & Length < 90]
```

Question 12

What is the value of z?

```
> x = seq(-2, 10)
> z = x[(x >= 7) ]
```

- TRUE
- 7,8,9,10
- -2, -1, 7,8,9,10
- 0,1,2,3,4,5,6

Question 12

What is the value of z?

```
> x = seq(-2, 10)
> (z = x[(x >= 7) ])
[1]  7  8  9 10
```

- TRUE
- 7,8,9,10
- -2, -1, 7,8,9,10
- 0,1,2,3,4,5,6

Question 13

What is the value of z?

```
> x = seq(-2, 10)
> z = x[(x >= 7) | x <0]
```

- TRUE
- 7,8,9,10
- -2, -1, 7,8,9,10
- 0,1,2,3,4,5,6

Question 13

What is the value of z?

```
> x = seq(-2, 10)
> (z = x[(x >= 7) | x <0])
[1] -2 -1  7  8  9 10
```

- TRUE
- 7,8,9,10
- -2, -1, 7,8,9,10
- 0,1,2,3,4,5,6

2.5 Data frames

- A data frame is a special kind of object.
- We use data frames for storing and managing data sets that have a rectangular structure.
- Typically the rows correspond to *cases* and the columns to *variables*.
- The crucial difference between a data frame and a `matrix` is that all values in a matrix must be of the same type.
- The next code segment constructs a simple data frame.

2.5 Data frames

First, we construct three vectors:

```
> age = c(24, 26, 25, 21)
> sex = c("Male", "Female", "Male", "Female")
> respond = c(TRUE, FALSE, FALSE, FALSE)
```

Then we combine them using the `data.frame` function:

```
> (df1 = data.frame(age=age, gender=sex,
+    respond=respond))
  age gender respond
1  24   Male    TRUE
2  26 Female   FALSE
3  25   Male   FALSE
4  21 Female   FALSE
```

2.5 Data frames

First, we construct three vectors:

```
> age = c(24, 26, 25, 21)
> sex = c("Male", "Female", "Male", "Female")
> respond = c(TRUE, FALSE, FALSE, FALSE)
```

Then we combine them using the `data.frame` function:

```
> (df1 = data.frame(age=age, gender=sex,
+    respond=respond))
  age gender respond
1  24   Male    TRUE
2  26 Female   FALSE
3  25   Male   FALSE
4  21 Female   FALSE
```

2.5 Data frames

- The data frame `df1` has three columns and four rows.
- Once we put our data into a data frame, then data manipulation is easier.
- To calculate the dimensions of a data frame we use `dim`:

```
> dim(df1)
[1] 4 3
```

2.5 Data frames

To extract the first column we use square brackets:

```
> df1[ ,1]
[1] 24 26 25 21
```

Similarly, we can get the first row

```
> df1[1, ]
  age gender respond
1  24   Male    TRUE
```

2.5 Data frames

To extract the first column we use square brackets:

```
> df1[ ,1]
[1] 24 26 25 21
```

Similarly, we can get the first row

```
> df1[1, ]
  age gender respond
1  24   Male    TRUE
```

2.5 Data frames

The column names are also easily manipulated

```
> colnames(df1)
[1] "age"     "gender"  "respond"
```

```
> (colnames(df1) = c("Age", "Sex", "Respond"))
[1] "Age"     "Sex"     "Respond"
```

2.5 Data frames

The column names are also easily manipulated

```
> colnames(df1)
[1] "age"     "gender"  "respond"
```

```
> (colnames(df1) = c("Age", "Sex", "Respond"))
[1] "Age"     "Sex"     "Respond"
```

When we download the `movies` data set, we automatically create a data frame:

```
> dim(movies)
[1] 4988   23
> colnames(movies)[1:4]
[1] "Title"  "Year"   "Rating" "Votes"
> movies[3363, 1:4]
                                          Title Year
Rating  Votes
3363 Star Wars: Episode I - The Phantom Menace 1999
6.5 607932
```

2.5.1 Subsets of data frames

We can also retrieve subsets from the data frame. For example, if we wanted only female responses, then...

```
> (female_only = df1$Sex=="Female")
[1] FALSE  TRUE FALSE  TRUE
> (df2 = df1[female_only, ])
  Age    Sex Respond
2  26 Female   FALSE
4  21 Female   FALSE
```

2.5.1 Subsets of data frames

... or people 25 and over:

```
> over_25 = df1$Age>=25
> (df3 = df1[over_25, ])
  Age    Sex Respond
2  26 Female   FALSE
3  25   Male   FALSE
```

2.5.2 Example: movie data

We can select movies where the budget is greater than $100,000

```
> m1 = movies[movies$Budget > 100000,]
> dim(m1)
[1] 4881   23
```

Or movies that cost more than $100,000 but are not R rated:

```
> m2 = movies[movies$Budget > 100000 & movies$mpaa !=
"R",]
> dim(m2)
[1] 3174  23
```

2.5.2 Example: movie data

We can select movies where the budget is greater than $100,000

```
> m1 = movies[movies$Budget > 100000,]
> dim(m1)
[1] 4881   23
```

Or movies that cost more than $100,000 but are not R rated:

```
> m2 = movies[movies$Budget > 100000 & movies$mpaa !=
"R",]
> dim(m2)
[1] 3174  23
```

Or movies that are either PG or PG-13:

```
> m3 = movies[
+   movies$mpaa == "PG" | movies$mpaa == "PG-13",]
> dim(m3)
[1] 3229   23
```

Question 14

What type of variable is `m1`?

```
> m1 = movies[movies$Budget > 10000,]
```

- A vector of doubles
- A vector of String
- A vector of Logical
- A Data frame

Question 14

What type of variable is `m1`?

```
> m1 = movies[movies$Budget > 10000,]
> is.data.frame(m1)
[1] TRUE
```

- A vector of doubles
- A vector of String
- A vector of Logicals
- A Data frame

Question 15

What type of variable is `m2`?

```
> m2 = movies$Budget > 10000
```

- A vector of doubles
- A vector of Strings
- A vector of Logicals
- A Data frame

Question 15

What type of variable is m2?

```
> m2 = movies$Budget > 10000
> is.vector(m2)
[1] TRUE
> is.logical(m2)
[1] TRUE
```

- A vector of doubles
- A vector of String
- A vector of Logicals
- A Data frame