

Synchronous Online: Start 12pm, Wednesday 21st October

MAS2905: Probability and Bayesian Methods with R

Newcastle University
`lee.fawcett@ncl.ac.uk`

Semester 1, 2020/21

Chapter 1

General Housekeeping

1.1 Lecturer information

The module leader for MAS2905, and lecturer for both semesters, is Dr. Lee Fawcett

- Lee is based in room 2.07 on the second floor of the Herschel Building (in a non-Covid world)/in his Lego Room (at all other times)
- If you have any questions about the module he can be contacted via email: lee.fawcett@newcastle.ac.uk
- Feel free to post a query to the module Canvas page
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1.1 Lecturer information

There will be several other people assisting with this module in semester 1, primarily in the computer practical sessions.

They're all really friendly PhD students – Amy, Kieran and Nicola. Give them a “shout” in class if you're stuck with anything!



1.2 Classes

As you probably know, things will be very different in 2020/21...!

You will have a **blended learning** experience¹, meaning you will have some **Present-in-Person** activities on campus and some online activities.

Your online activities might be **synchronous** or **non-synchronous**.

¹Your modules might move entirely online at short notice, as has happened for the first two weeks of term

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For semester 1 of MAS2905, this is how we will use these activities:

- **Present-in-Person (PiP):**

- A series of 90 minute supervised computer practical sessions in the Herschel PC cluster/online
- These take place roughly every three weeks
- They will appear on your timetable and will be advertised on Canvas
- These sessions might be replaced with “nPiP” sessions...

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■ Non-synchronous online (NSO):

- **Online activities** posted to Canvas every week, covering what would have ordinarily been covered in standard lectures
- Directed reading (e.g. lecture notes), completing exercises/practice questions, summaries/discussions of learning objectives, assessment feedback, other 'fun' activities...
- These activities must be completed in your **own time**, whenever you can fit them in, but it is *vital* that they are completed by their completion dates

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■ Synchronous online (SO):

- Timetabled sessions, broadcast live online via **Zoom**
- **No new material will be presented** – instead, we will work through exercises based on the theory you have studied in the NSO activities
- Some SO sessions will be dedicated '**office hours**' held via Zoom
- You should make every effort to attend these SO sessions when they appear on your timetable

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Students can take part in other NSO activities, should they wish, including:

- Interacting with the **Canvas discussion board**
- Optional Zoom **drop-in sessions**
- One-to-one Zoom meetings, arranged via email

And of course, you will all be expected to prepare and complete homeworks in your own time and revise for tests!

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1.3 Schedule

Week	w/b	Activities	Date	Time	Deadline?
1	19 Oct	SO Lecture NSO activities	Wed 21 Oct	12:00-13:00 <i>After lecture, in your own time: Videos/exercises/reading</i>	— Completed by Mon 26 Oct
2	26 Oct	NPfP Practical NSO activities	Thurs 27 Oct	10:00-11:00 <i>After practical, in your own time: Videos/exercises/reading</i>	Completed by Mon 2 Nov
3	2 Nov	SO Lecture NSO activities	Wed 4 Nov	12:00-13:00 <i>Some pre-lecture reading; Start Test 1</i>	— Completed by Mon 9 Nov
4	9 Nov	Test 1 released SO Lecture NSO activities	Thu 5 Nov	16:00 Wed 11 Nov	16:00 Thu 12 Nov —
		Test 1 due	Thu 12 Nov	16:00	16:00 Thu 12 Nov
—	16 Nov	—Buffer week, no new work scheduled—			

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		Project released	Thurs 26 Nov	16:00	16:00 Thu 17 Dec
6	30 Nov	SO lecture NSO activities	2 Dec	12:00-13:00 Some pre-lecture reading/videos; After lecture, in your own time: Exercises/project work	Completed by 7 Dec
7	7 Dec	SO lecture NSO activities	9 Dec	12:00-13:00 Project drop-ins, times TBA Project work	—
8	14 Dec	PiP Practical NSO activities Project due	Tues 15 Dec	—90 minute intervals, check your timetable— Project work, practice test questions	16:00 Thu 17 Dec
—			—Christmas holidays—		
9	11 Jan	SO Lecture NSO activities Test 2 released Test 2 due	Wed 13 Jan Thu 14 Jan Thu 14 Jan	12:00-13:00 10:00 16:00	— 16:00 Thu 14 Jan 16:00 Thu 14 Jan

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1.4 Assessment

The full 20 credit MAS2905 module will be assessed via a formal written examination in summer 2021 and some in-course assessment (ICA).

The make-up is **50% summer exam, 50% ICA**

- Summer exam – 100 marks in total

- Semester 1: Section A (20 marks)
- Semester 2: Section B (80 marks)
- Answer *all* questions in *both* parts

- ICA – 100 marks in total

- Semester 1: Test 1 (Numbas, 20 marks), project (30 marks), test 2 (30 marks)
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- **Test 1** will be open for a 1-week period and will test your basic R skills, including:
 - Dataframe querying
 - For loops
 - Use of simple built-in functions to test your knowledge of probability calculations in R
- **Test 2** will cover later material from the course – it will require a mix of pencil-and-paper calculations and R work, and must be completed within a six hour window

Test-style questions, with solutions, will be made available in advance of both tests, to help you prepare.

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1.5 Late work policy

In this module, deadline extensions can be requested for the mini project submitted in week 8 (by means of submitting a PEC form), and work submitted within 7 days of the deadline without good reason will be marked for reduced credit.

This module also contains a test worth more than 10% for which rescheduling can be requested (by means of submitting a PEC form).

For details of the policy (including procedures in the event of illness etc.) please consult the Mathematics, Statistics & Physics Community pages on Canvas, under: Assessment Information, Late Work and Missed Assessments.

1.6 Course materials

All course materials will be posted to the **dedicated Canvas page** for MAS2905. Here, you will find:

- A full copy of the lecture notes you might be looking at now, with gaps
- A copy of the lecture notes with the gaps filled in, after the associated PiP/SO/NSO activities
- These slides used to support PiP/SO/NSO activities after these have taken place
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- Solutions to assessed exercises
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1.7 Books and other resources

At various points in the module you will be directed to additional reading, should you want extra examples or just another source of information relating to the material presented in the notes.

This will primarily be text books (many of which are available to view online), but perhaps other sources (e.g. journal publications, magazine articles etc.).

1.7 Books and other resources

Some useful books for semester 1 include:

- W.N. Venables and D.M. Smith: [An Introduction To R](#). Free to download at:
<https://cran.r-project.org/doc/manuals/R-intro.pdf>
- D. Braun and D.J. Murdoch: [A First Course In Statistical Programming With R](#)
- S. Ross: [A First Course in Probability](#)
- N.A. Weiss, P.T. Holmes and H. Michael: [A Course In Probability](#)

1.8 General background for Part 1 of MAS2905

In Part 1 of the module we will learn about computational tools for performing probability calculations and statistical analysis.

We will use the R programming language.

R is very widely used in universities, businesses and other organizations due to its many advantages over other similar software packages.

- It is available for **free**
- It is '**open source**' and can be used for a very wide range of statistical and scientific applications
- **Libraries** of R functions and data-structures have been created and are readily available on the web

1.8 General background for Part 1 of MAS2905

Learning to use R is important because:

- (i) It is the foremost tool in modern computational statistics
- (ii) It is a great way to learn general concepts in programming which can be used with other languages or in other contexts
- (iii) It can be used to illustrate ideas in probability and statistics

In MAS1802 last year we focused mainly on point (ii) above; in this module, we focus mainly on points (i) and (iii).

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1.8 General background for Part 1 of MAS2905

Strikes, COVID-19 and Joint Honours/Major-Minor students

- This course would normally rely on a full understanding of material in MAS1802
- Strike action, and then COVID, might have put pay to that!
- We also have quite a few JH/MM students joining this course
- Don't worry! 2 week R Refresher/Intro!

Rough structure of the course

- Weeks 1–2: R Refresher/Intro
- Weeks 3–5: Statistical Methods: Simulation/Transformations
- Weeks 6–8: Statistical Methods: Bivariate distributions
- Week 9: Simulation studies in R

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Rough structure of the course

- Weeks 1–2: R Refresher/Intro
- Weeks 3–5: Statistical Methods: Simulation/Transformations
- Weeks 6–8: Statistical Methods: Bivariate distributions
- Week 9: Simulation studies in R

1.8 General background for Part 1 of MAS2905

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Quiz #1



Do you think you would benefit from a detailed coverage of the material in *Chapter 2: R Refresher*?

1. Yes
2. No
3. Not bothered either way

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All materials for semester 1 of the module are in the main booklet:

- **Background theory** – some of which you will be expected to read yourself through NSO activities
- **Pencil-and-paper exercises** – some of which you will try out yourself in NSO activities, and some of which we will work through together in SO sessions
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- Please, if possible, attend your scheduled computer lab on Tuesdays – this is a great opportunity to ask us questions face-to-face, seek help from other students, and of course prepare for the two tests
- It is even more important that you follow instructions on Canvas and complete the other activities by the dates suggested – if you are told that some NSO activities should be completed before the next PiP computer practical, then make sure you do exactly that!
- **General message: Make every effort to engage with the activities set and keep to the schedule. And ask Lee if you're not sure about anything!**

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Chapter 2

R Refresher

2.1 Preliminaries

R is installed on all University machines.

In this module we will be using **RStudio**, which is an R *Integrated Development Environment*, or IDE.

This just makes R much easier to use and navigate, through the four windows that you see when you open RStudio (text editor, console window, file explorer and graphics display).

You might remember from MAS1802 that both R and RStudio are free, so you can install them on your own computer. See

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2.1 Preliminaries

The first two weeks of this module are designed to recap the basics from MAS1802.

Specifically, we will review:

- (i) Data types and vectors in R
- (ii) Dataframe manipulation
- (iii) Data summaries
- (iv) Functions and control statements

2.1 Preliminaries

You might recall the `movies` dataset from MAS1802.

This was obtained from the internet movie database (IMDB): <http://imdb.com/>, which is a website devoted to collecting movie data supplied by studios and fans.

More information can be found online:

http://imdb.com/help/show_leaf?about

This is a great dataset to use to demonstrate R's dataframe manipulation and querying capabilities – it is large, has many variables, and is interesting. Everyone loves movies!

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2.1 Preliminaries

Title	Year	Length	Budget	Voting statistics					Movie genre							
				Rating	Votes	r1	...	r10	mpaa	Action	Animation	Comedy	Drama	Documentary	Romance	Short
A.k.a. Cassius	1970	85	NA	5.7	43	4.5	...	14.5	PG	0	0	0	0	1	0	0
AKA	2002	123	NA	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	NA	5.0	46	14.5	...	24.5	R	0	0	0	0	0	0	0
Aberration	1997	93	NA	4.8	149	14.5	...	4.5	R	0	0	0	0	0	0	0
Abilene	1999	104	NA	4.9	42	0.0	...	24.5	PG	0	0	0	1	0	0	0
Ablaze	2001	97	NA	3.6	98	24.5	...	14.5	R	1	0	0	1	0	0	0
Abominable Dr	1971	94	NA	6.7	1547	4.5	...	14.5	PG-13	0	0	0	0	0	0	0
About Adam	2000	105	NA	6.4	1303	4.5	...	4.5	R	0	0	1	0	0	1	0

2.1 Preliminaries

We have written an add-on R package for the module which will allow easy access to many interesting datasets.

Installing the package is straightforward:

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

To load the package, type:

```
1 library(ncldata)
```

Then, to specifically load the movies dataset, type:

```
1 data(movies)
```

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```
1 data(movies)
```

2.2 Data types in R

R has a variety of data types. For example:

```
1 v = TRUE           # 'Logical' or 'boolean' - TRUE or FALSE
2 w = "fred"         # 'Character' or 'string'
3 x = 5.0             # 'Double' or 'numerical'
```

There are also some 'special' data types:

```
1 y = 5/0             # Returns Inf
2 z = y-y             # Returns NaN
```

2.2 Data types in R

Another important data type is NA, short for 'Not Available' and used for missing values.

A summary of the data types in R is given in the Table below.

Type	Example 1	Example 2	Example 3	Example 4
Doubles	2	3.1242	-45.6	4e-10
Logicals/Boolean	TRUE	FALSE		
Characters	"Fred"	"TRUE"	"Male"	"2"
Infinity	Inf	5/0		
Other	NaN	NA		

Quiz #2

In the code below, what is the value of x?

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



1. 5
2. 11
3. 16
4. 22

Quiz #2

In the code below, what is the value of x?

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



- 1. 5
- 2. **11**
- 3. 16
- 4. 22

Quiz #3

In the code below, what type of variable is x?

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



1. Character
2. Double
3. Logical
4. NA

Quiz #3

In the code below, what type of variable is x?

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



1. Character
2. **Double**
3. Logical
4. NA

Quiz #4

In the code below, what type of variable is y?

```
1 x = 0  
2 y = 2/0  
3 y = "Fred"
```



1. NaN
2. Double
3. NA
4. Character

Quiz #4

In the code below, what type of variable is y?

```
1 x = 0  
2 y = 2/0  
3 y = "Fred"
```



1. NaN
2. Double
3. NA
4. **Character**

2.3 Vectors

Vectors are the most basic of all data structures, but are used in almost all R code.

An R vector contains n values of the same type, where n can be zero.

For example:

```
1 c(0, 1, 2, 3, 4, 5)
2 [1] 0 1 2 3 4 5
3 (first_vec = c(0, 1, 2, 3, 4, 5))
4 [1] 0 1 2 3 4 5
5 second_vec = c("Male", "Female", "Male")
6 [1] "Male" "Female" "Male"
7 x = 5.2
8 y = "Fred"
```

2.3 Vectors

There are special functions in R that can be used to determine the variable type. For example:

```
1 is.double(x)
2 [1] TRUE
3 is.character(x)
4 [1] FALSE
5 is.character(y)
6 [1] TRUE
7 is.vector(first_vec)
8 [1] TRUE
```

2.3 Vectors

And of course, we can use the `length` command to determine the length of a vector:

```
1 length(first_vec)
2 [1] 6
3 length(second_vec)
4 [1] 3
```

And you can use the `seq` command to generate sequence vectors:

```
1 (x1 = seq(1, 6))
2 [1] 1 2 3 4 5 6
3 (x2 = seq(-4, 4, by=2))
4 [1] -4 -2 0 2 4
5 (x3 = seq(3, -2, by=-0.5))
6 [1] 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0 -1.5
7 [11] -2.0
```

2.3 Vectors

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7 [11] -2.0
```

2.3 Vectors

Other useful commands for vectors:

```
1 rev(x1) # Reverses the order of the vector
2 [1] 6 5 4 3 2 1
3 sort(x3) # Sorts the vector into ascending order
4 [1] -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5
5 3.0
6 sort(second_vec) # Can be applied to characters: alphabetical order
7 [1] "Female" "Male" "Male"
8 sum(x2); sum(x3); sum(second_vec)
9 [1] 0
10 [1] 5.5
11 Error in sum(second_vec) : invalid 'type' (character)
12 of argument
13 unique(second_vec) # Lists all unique elements of the vector
14 [1] "Male" "Female"
15 which(x2==2) # Gives index/indices of particular elements
16 [1] 4
```

2.3.1 Vector operations

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

```
1 (x = seq(-4, 4))
2 [1] -4 -3 -2 -1 0 1 2 3 4
3 x*x
4 [1] 16 9 4 2 1 0 1 2 4 9 16
5 x-5
6 [1] -9 -8 -7 -6 -5 -4 -3 -2 -1
7 x + x
8 [1] -8 -6 -4 -2 0 2 4 6 8
```

2.3.2 Extracting elements from vectors

R has a number of useful methods that we can use to extract subsets of our data.

For example, square brackets:

```
1 first_vec[2]
2 [1] 1
3 second_vec[2:3]
4 [1] "Female" "Male"
5 first_vec[4:2]
6 [1] 3 2 1
7 (z = 1:10)
8 [1] 1 2 3 4 5 6 7 8 9 10
9 z[z<3 | z>=7] # Values of z that are less than 3 or at least 7
10 [1] 1 2 7 8 9 10
```

We will look at extraction from two-dimensional R objects shortly.

2.3.2 Extracting elements from vectors

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For example, square brackets:

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```

We will look at extraction from two-dimensional R objects shortly.

2.3.2 Extracting elements from vectors

Another useful way of extracting elements from vectors is to use logical vectors.

Recall that the logical data type in R can take only the values TRUE and FALSE. Hence:

```
1 A = TRUE
2 B = FALSE
3 !A      # Read as "Not A"
4 [1] FALSE
5 !B
6 [1] TRUE
7 A & B   # Need "both A and B"
8 [1] FALSE
9 A | B   # Need "either A or B"
10 [1] TRUE
```

2.3.2 Extracting elements from vectors

Then we could declare a vector of such logicals to help us extract from another vector:

```
1 (logic1 = c(TRUE, FALSE, TRUE, FALSE))
2 [1] TRUE FALSE TRUE FALSE
3 (vec1 = seq(3, 6))
4 [1] 3 4 5 6
5 vec1[logic1]      # Will extract the elements in vec1 where logic1 is true
6 [1] 3 5
```

We can also sum a logical vector. For example:

```
1 sum(logic1)
2 [1] 2
3 sum(vec1[logic1])
4 [1] 8
```

2.3.2 Extracting elements from vectors

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```
1 sum(logic1)
2 [1] 2
3 sum(vec1[logic1])
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```

Example 2.1

If you've not already got RStudio installed on the machine you're using, **you must do so now** by following the advice on the Canvas Community or our student resources webpage:

<http://www.ncl.ac.uk/maths-physics/students/resources/>

From this link, click on the link for our “Computing page”, log-in using your University details, and then click on the link for “R”.

- Here you will find some basic resources aimed at students who have never used R before
- Scroll down, and you'll find information about how to install R on your home PC

Example 2.1



In RStudio, commit the following lines of code. Both lines read in files stored on a webpage. **Do not copy-and-paste this code – you must type it in carefully!**

```
1 x = scan("https://www.mas.ncl.ac.uk/~nlf8/teaching/mas2905/x.txt")
2 y = as.logical(scan("https://www.mas.ncl.ac.uk/~nlf8/teaching/mas2905/y.txt", what="logical"))
```

Questions about x

- (a) What type of data is in the vector x?
- (b) How many values are in the vector x?
- (c) What is the smallest value in the vector x?
- (d) What is the value of x in position 3500?
- (e) What is the 97th smallest value in x?
- (f) Find $\sum_{i=5612}^{8664} x_i$.

Questions about y

- (a) What type of data is in the vector y?
- (b) What is the first value of y?
- (c) What is the last value of y?
- (d) How many times does TRUE occur?
- (e) When is the 472nd occurrence of TRUE?
- (f) How many occurrences of TRUE are there between positions 504 and 593 (inclusive)?

- That's us done for today, thanks for coming along!
- Non-Synchronous activities to be completed by the end of **Monday 26th October**, in the following order:
 1. Use RStudio to find answers to the questions in **Example 2.1**
 2. Watch the short video “**Home Study 1**”, which will reveal answers to Example 2.1 before covering Section 2.4 of the course notes; work through **Examples 2.2 and 2.3**
 3. Watch the short video “**Home Study 2**”, which will reveal answers to Examples 2.2 and 2.3, before covering Section 2.5 of the course notes
- You **must** complete these activities by the date shown, to prepare you for forthcoming activities next week