

# Contents

<b>Preface</b>	xxv
<b>Acknowledgments</b>	xxvii
<b>Introduction</b>	xxix
<b>1 Getting started with R and RStudio</b>	<b>1</b>
1.1 Why R?	1
1.2 The R console	1
1.3 Scripts	2
1.4 RStudio	3
1.4.1 The panes	3
1.4.2 Key bindings	5
1.4.3 Running commands while editing scripts	6
1.4.4 Changing global options	8
1.5 Installing R packages	8
<b>I R</b>	<b>11</b>
<b>2 R basics</b>	<b>13</b>
2.1 Case study: US Gun Murders	13
2.2 The very basics	15
2.2.1 Objects	15
2.2.2 The workspace	15
2.2.3 Functions	16
2.2.4 Other prebuilt objects	18
2.2.5 Variable names	18
2.2.6 Saving your workspace	19
2.2.7 Motivating scripts	19
2.2.8 Commenting your code	20
2.3 Exercises	20



2.4	Data types . . . . .	21
2.4.1	Data frames . . . . .	21
2.4.2	Examining an object . . . . .	21
2.4.3	The accessor: <code>\$</code> . . . . .	22
2.4.4	Vectors: numerics, characters, and logical . . . . .	23
2.4.5	Factors . . . . .	24
2.4.6	Lists . . . . .	24
2.4.7	Matrices . . . . .	26
2.5	Exercises . . . . .	27
2.6	Vectors . . . . .	28
2.6.1	Creating vectors . . . . .	28
2.6.2	Names . . . . .	29
2.6.3	Sequences . . . . .	29
2.6.4	Subsetting . . . . .	30
2.7	Coercion . . . . .	31
2.7.1	Not availables (NA) . . . . .	32
2.8	Exercises . . . . .	32
2.9	Sorting . . . . .	33
2.9.1	<code>sort</code> . . . . .	33
2.9.2	<code>order</code> . . . . .	33
2.9.3	<code>max</code> and <code>which.max</code> . . . . .	34
2.9.4	<code>rank</code> . . . . .	34
2.9.5	Beware of recycling . . . . .	35
2.10	Exercises . . . . .	35
2.11	Vector arithmetics . . . . .	36
2.11.1	Rescaling a vector . . . . .	37
2.11.2	Two vectors . . . . .	37
2.12	Exercises . . . . .	38
2.13	Indexing . . . . .	38
2.13.1	Subsetting with logicals . . . . .	38
2.13.2	Logical operators . . . . .	39
2.13.3	<code>which</code> . . . . .	39
2.13.4	<code>match</code> . . . . .	40
2.13.5	<code>%in%</code> . . . . .	40



2.14	Exercises	40
2.15	Basic plots	41
2.15.1	plot	41
2.15.2	hist	42
2.15.3	boxplot	43
2.15.4	image	43
2.16	Exercises	44
<b>3</b>	<b>Programming basics</b>	<b>45</b>
3.1	Conditional expressions	45
3.2	Defining functions	47
3.3	Namespaces	48
3.4	For-loops	49
3.5	Vectorization and functionals	50
3.6	Exercises	51
<b>4</b>	<b>The tidyverse</b>	<b>53</b>
4.1	Tidy data	53
4.2	Exercises	54
4.3	Manipulating data frames	55
4.3.1	Adding a column with <code>mutate</code>	55
4.3.2	Subsetting with <code>filter</code>	56
4.3.3	Selecting columns with <code>select</code>	56
4.4	Exercises	57
4.5	The pipe: <code>%&gt;%</code>	58
4.6	Exercises	59
4.7	Summarizing data	60
4.7.1	<code>summarize</code>	60
4.7.2	<code>pull</code>	62
4.7.3	Group then summarize with <code>group_by</code>	63
4.8	Sorting data frames	64
4.8.1	Nested sorting	64
4.8.2	The top $n$	65
4.9	Exercises	65
4.10	Tibbles	66



4.10.1	Tibbles display better . . . . .	67
4.10.2	Subsets of tibbles are tibbles . . . . .	67
4.10.3	Tibbles can have complex entries . . . . .	68
4.10.4	Tibbles can be grouped . . . . .	68
4.10.5	Create a tibble using <code>tibble</code> instead of <code>data.frame</code> . . . . .	68
4.11	The dot operator . . . . .	69
4.12	<code>do</code> . . . . .	70
4.13	The <code>purrr</code> package . . . . .	71
4.14	Tidyverse conditionals . . . . .	73
4.14.1	<code>case_when</code> . . . . .	73
4.14.2	<code>between</code> . . . . .	73
4.15	Exercises . . . . .	74
<b>5</b>	<b>Importing data</b> . . . . .	<b>75</b>
5.1	Paths and the working directory . . . . .	76
5.1.1	The filesystem . . . . .	76
5.1.2	Relative and full paths . . . . .	77
5.1.3	The working directory . . . . .	77
5.1.4	Generating path names . . . . .	78
5.1.5	Copying files using paths . . . . .	78
5.2	The <code>readr</code> and <code>readxl</code> packages . . . . .	79
5.2.1	<code>readr</code> . . . . .	79
5.2.2	<code>readxl</code> . . . . .	80
5.3	Exercises . . . . .	80
5.4	Downloading files . . . . .	81
5.5	R-base importing functions . . . . .	82
5.5.1	<code>scan</code> . . . . .	82
5.6	Text versus binary files . . . . .	83
5.7	Unicode versus ASCII . . . . .	83
5.8	Organizing data with spreadsheets . . . . .	84
5.9	Exercises . . . . .	84



<b>II</b>	<b>Data Visualization</b>	<b>85</b>
<b>6</b>	<b>Introduction to data visualization</b>	<b>87</b>
<b>7</b>	<b>ggplot2</b>	<b>91</b>
7.1	The components of a graph	92
7.2	ggplot objects	93
7.3	Geometries	94
7.4	Aesthetic mappings	95
7.5	Layers	96
7.5.1	Tinkering with arguments	97
7.6	Global versus local aesthetic mappings	98
7.7	Scales	99
7.8	Labels and titles	100
7.9	Categories as colors	101
7.10	Annotation, shapes, and adjustments	102
7.11	Add-on packages	103
7.12	Putting it all together	104
7.13	Quick plots with <code>qplot</code>	105
7.14	Grids of plots	106
7.15	Exercises	106
<b>8</b>	<b>Visualizing data distributions</b>	<b>109</b>
8.1	Variable types	109
8.2	Case study: describing student heights	110
8.3	Distribution function	110
8.4	Cumulative distribution functions	111
8.5	Histograms	112
8.6	Smoothed density	113
8.6.1	Interpreting the y-axis	117
8.6.2	Densities permit stratification	118
8.7	Exercises	118
8.8	The normal distribution	122
8.9	Standard units	124
8.10	Quantile-quantile plots	125
8.11	Percentiles	127



8.12	Boxplots	127
8.13	Stratification	129
8.14	Case study: describing student heights (continued)	129
8.15	Exercises	131
8.16	ggplot2 geometries	132
8.16.1	Barplots	133
8.16.2	Histograms	134
8.16.3	Density plots	135
8.16.4	Boxplots	136
8.16.5	QQ-plots	136
8.16.6	Images	137
8.16.7	Quick plots	138
8.17	Exercises	140
<b>9</b>	<b>Data visualization in practice</b>	<b>141</b>
9.1	Case study: new insights on poverty	141
9.1.1	Hans Rosling's quiz	142
9.2	Scatterplots	143
9.3	Faceting	144
9.3.1	<code>facet_wrap</code>	146
9.3.2	Fixed scales for better comparisons	147
9.4	Time series plots	147
9.4.1	Labels instead of legends	150
9.5	Data transformations	151
9.5.1	Log transformation	151
9.5.2	Which base?	153
9.5.3	Transform the values or the scale?	154
9.6	Visualizing multimodal distributions	155
9.7	Comparing multiple distributions with boxplots and ridge plots	155
9.7.1	Boxplots	156
9.7.2	Ridge plots	157
9.7.3	Example: 1970 versus 2010 income distributions	159
9.7.4	Accessing computed variables	164
9.7.5	Weighted densities	167
9.8	The ecological fallacy and importance of showing the data	167



9.8.1	Logistic transformation . . . . .	168
9.8.2	Show the data . . . . .	168
<b>10</b>	<b>Data visualization principles</b>	<b>171</b>
10.1	Encoding data using visual cues . . . . .	171
10.2	Know when to include 0 . . . . .	174
10.3	Do not distort quantities . . . . .	177
10.4	Order categories by a meaningful value . . . . .	179
10.5	Show the data . . . . .	180
10.6	Ease comparisons . . . . .	183
10.6.1	Use common axes . . . . .	183
10.6.2	Align plots vertically to see horizontal changes and horizontally to see vertical changes . . . . .	184
10.6.3	Consider transformations . . . . .	185
10.6.4	Visual cues to be compared should be adjacent . . . . .	187
10.6.5	Use color . . . . .	188
10.7	Think of the color blind . . . . .	188
10.8	Plots for two variables . . . . .	189
10.8.1	Slope charts . . . . .	189
10.8.2	Bland-Altman plot . . . . .	191
10.9	Encoding a third variable . . . . .	191
10.10	Avoid pseudo-three-dimensional plots . . . . .	193
10.11	Avoid too many significant digits . . . . .	195
10.12	Know your audience . . . . .	196
10.13	Exercises . . . . .	196
10.14	Case study: vaccines and infectious diseases . . . . .	201
10.15	Exercises . . . . .	204
<b>11</b>	<b>Robust summaries</b>	<b>205</b>
11.1	Outliers . . . . .	205
11.2	Median . . . . .	206
11.3	The inter quartile range (IQR) . . . . .	206
11.4	Tukey's definition of an outlier . . . . .	207
11.5	Median absolute deviation . . . . .	208
11.6	Exercises . . . . .	208
11.7	Case study: self-reported student heights . . . . .	209



<b>III Statistics with R</b>	<b>213</b>
<b>12 Introduction to statistics with R</b>	<b>215</b>
<b>13 Probability</b>	<b>217</b>
13.1 Discrete probability	217
13.1.1 Relative frequency	217
13.1.2 Notation	218
13.1.3 Probability distributions	218
13.2 Monte Carlo simulations for categorical data	218
13.2.1 Setting the random seed	220
13.2.2 With and without replacement	220
13.3 Independence	221
13.4 Conditional probabilities	221
13.5 Addition and multiplication rules	222
13.5.1 Multiplication rule	222
13.5.2 Multiplication rule under independence	222
13.5.3 Addition rule	223
13.6 Combinations and permutations	223
13.6.1 Monte Carlo example	227
13.7 Examples	227
13.7.1 Monty Hall problem	228
13.7.2 Birthday problem	229
13.8 Infinity in practice	231
13.9 Exercises	232
13.10 Continuous probability	234
13.11 Theoretical continuous distributions	235
13.11.1 Theoretical distributions as approximations	235
13.11.2 The probability density	237
13.12 Monte Carlo simulations for continuous variables	238
13.13 Continuous distributions	239
13.14 Exercises	239
<b>14 Random variables</b>	<b>241</b>
14.1 Random variables	241
14.2 Sampling models	242



14.3	The probability distribution of a random variable . . . . .	243
14.4	Distributions versus probability distributions . . . . .	245
14.5	Notation for random variables . . . . .	245
14.6	The expected value and standard error . . . . .	246
14.6.1	Population SD versus the sample SD . . . . .	248
14.7	Central Limit Theorem . . . . .	249
14.7.1	How large is large in the Central Limit Theorem? . . . . .	250
14.8	Statistical properties of averages . . . . .	250
14.9	Law of large numbers . . . . .	252
14.9.1	Misinterpreting law of averages . . . . .	252
14.10	Exercises . . . . .	252
14.11	Case study: The Big Short . . . . .	254
14.11.1	Interest rates explained with chance model . . . . .	254
14.11.2	The Big Short . . . . .	257
14.12	Exercises . . . . .	260
<b>15</b>	<b>Statistical inference . . . . .</b>	<b>261</b>
15.1	Polls . . . . .	261
15.1.1	The sampling model for polls . . . . .	262
15.2	Populations, samples, parameters, and estimates . . . . .	264
15.2.1	The sample average . . . . .	264
15.2.2	Parameters . . . . .	265
15.2.3	Polling versus forecasting . . . . .	265
15.2.4	Properties of our estimate: expected value and standard error . . . . .	266
15.3	Exercises . . . . .	267
15.4	Central Limit Theorem in practice . . . . .	268
15.4.1	A Monte Carlo simulation . . . . .	269
15.4.2	The spread . . . . .	271
15.4.3	Bias: why not run a very large poll? . . . . .	271
15.5	Exercises . . . . .	272
15.6	Confidence intervals . . . . .	274
15.6.1	A Monte Carlo simulation . . . . .	276
15.6.2	The correct language . . . . .	277
15.7	Exercises . . . . .	277
15.8	Power . . . . .	278



15.9	p-values	279
15.10	Association tests	280
15.10.1	Lady Tasting Tea	281
15.10.2	Two-by-two tables	282
15.10.3	Chi-square Test	282
15.10.4	The odds ratio	283
15.10.5	Confidence intervals for the odds ratio	284
15.10.6	Small count correction	285
15.10.7	Large samples, small p-values	285
15.11	Exercises	286
<b>16</b>	<b>Statistical models</b>	<b>287</b>
16.1	Poll aggregators	288
16.1.1	Poll data	290
16.1.2	Pollster bias	292
16.2	Data-driven models	293
16.3	Exercises	295
16.4	Bayesian statistics	298
16.4.1	Bayes theorem	298
16.5	Bayes theorem simulation	299
16.5.1	Bayes in practice	300
16.6	Hierarchical models	301
16.7	Exercises	303
16.8	Case study: election forecasting	305
16.8.1	Bayesian approach	306
16.8.2	The general bias	307
16.8.3	Mathematical representations of models	307
16.8.4	Predicting the electoral college	310
16.8.5	Forecasting	314
16.9	Exercises	317
16.10	The t-distribution	318
<b>17</b>	<b>Regression</b>	<b>321</b>
17.1	Case study: is height hereditary?	321
17.2	The correlation coefficient	322



17.2.1	Sample correlation is a random variable . . . . .	324
17.2.2	Correlation is not always a useful summary . . . . .	326
17.3	Conditional expectations . . . . .	326
17.4	The regression line . . . . .	329
17.4.1	Regression improves precision . . . . .	330
17.4.2	Bivariate normal distribution (advanced) . . . . .	331
17.4.3	Variance explained . . . . .	333
17.4.4	Warning: there are two regression lines . . . . .	333
17.5	Exercises . . . . .	334
<b>18</b>	<b>Linear models</b> . . . . .	<b>335</b>
18.1	Case study: Moneyball . . . . .	335
18.1.1	Sabermetrics . . . . .	336
18.1.2	Baseball basics . . . . .	337
18.1.3	No awards for BB . . . . .	338
18.1.4	Base on balls or stolen bases? . . . . .	339
18.1.5	Regression applied to baseball statistics . . . . .	341
18.2	Confounding . . . . .	344
18.2.1	Understanding confounding through stratification . . . . .	345
18.2.2	Multivariate regression . . . . .	348
18.3	Least squares estimates . . . . .	348
18.3.1	Interpreting linear models . . . . .	349
18.3.2	Least Squares Estimates (LSE) . . . . .	349
18.3.3	The <code>lm</code> function . . . . .	351
18.3.4	LSE are random variables . . . . .	352
18.3.5	Predicted values are random variables . . . . .	353
18.4	Exercises . . . . .	354
18.5	Linear regression in the tidyverse . . . . .	355
18.5.1	The broom package . . . . .	358
18.6	Exercises . . . . .	359
18.7	Case study: Moneyball (continued) . . . . .	360
18.7.1	Adding salary and position information . . . . .	364
18.7.2	Picking nine players . . . . .	365
18.8	The regression fallacy . . . . .	367
18.9	Measurement error models . . . . .	369



18.10 Exercises	371
<b>19 Association is not causation</b>	<b>373</b>
19.1 Spurious correlation	373
19.2 Outliers	376
19.3 Reversing cause and effect	378
19.4 Confounders	379
19.4.1 Example: UC Berkeley admissions	379
19.4.2 Confounding explained graphically	380
19.4.3 Average after stratifying	381
19.5 Simpson's paradox	382
19.6 Exercises	383
<b>IV Data Wrangling</b>	<b>385</b>
<b>20 Introduction to data wrangling</b>	<b>387</b>
<b>21 Reshaping data</b>	<b>389</b>
21.1 gather	389
21.2 spread	391
21.3 separate	391
21.4 unite	394
21.5 Exercises	395
<b>22 Joining tables</b>	<b>397</b>
22.1 Joins	398
22.1.1 Left join	399
22.1.2 Right join	400
22.1.3 Inner join	400
22.1.4 Full join	400
22.1.5 Semi join	401
22.1.6 Anti join	401
22.2 Binding	402
22.2.1 Binding columns	402
22.2.2 Binding by rows	402
22.3 Set operators	403
22.3.1 Intersect	403



22.3.2	Union . . . . .	404
22.3.3	setdiff . . . . .	404
22.3.4	setequal . . . . .	404
22.4	Exercises . . . . .	405
<b>23</b>	<b>Web scraping</b> . . . . .	<b>407</b>
23.1	HTML . . . . .	408
23.2	The rvest package . . . . .	409
23.3	CSS selectors . . . . .	411
23.4	JSON . . . . .	412
23.5	Exercises . . . . .	413
<b>24</b>	<b>String processing</b> . . . . .	<b>415</b>
24.1	The stringr package . . . . .	415
24.2	Case study 1: US murders data . . . . .	417
24.3	Case study 2: self-reported heights . . . . .	419
24.4	How to <i>escape</i> when defining strings . . . . .	421
24.5	Regular expressions . . . . .	423
24.5.1	Strings are a regexp . . . . .	423
24.5.2	Special characters . . . . .	423
24.5.3	Character classes . . . . .	425
24.5.4	Anchors . . . . .	426
24.5.5	Quantifiers . . . . .	426
24.5.6	White space <code>\s</code> . . . . .	427
24.5.7	Quantifiers: <code>*</code> , <code>?</code> , <code>+</code> . . . . .	428
24.5.8	Not . . . . .	428
24.5.9	Groups . . . . .	429
24.6	Search and replace with regex . . . . .	430
24.6.1	Search and replace using groups . . . . .	432
24.7	Testing and improving . . . . .	433
24.8	Trimming . . . . .	435
24.9	Changing lettercase . . . . .	436
24.10	Case study 2: self-reported heights (continued) . . . . .	436
24.10.1	The <code>extract</code> function . . . . .	437
24.10.2	Putting it all together . . . . .	438



24.11	String splitting	439
24.12	Case study 3: extracting tables from a PDF	442
24.13	Recoding	445
24.14	Exercises	446
<b>25</b>	<b>Parsing dates and times</b>	<b>449</b>
25.1	The date data type	449
25.2	The lubridate package	450
25.3	Exercises	453
<b>26</b>	<b>Text mining</b>	<b>455</b>
26.1	Case study: Trump tweets	455
26.2	Text as data	457
26.3	Sentiment analysis	462
26.4	Exercises	467
<b>V</b>	<b>Machine Learning</b>	<b>469</b>
<b>27</b>	<b>Introduction to machine learning</b>	<b>471</b>
27.1	Notation	471
27.2	An example	472
27.3	Exercises	474
27.4	Evaluation metrics	474
27.4.1	Training and test sets	475
27.4.2	Overall accuracy	476
27.4.3	The confusion matrix	478
27.4.4	Sensitivity and specificity	479
27.4.5	Balanced accuracy and $F_1$ score	481
27.4.6	Prevalence matters in practice	482
27.4.7	ROC and precision-recall curves	483
27.4.8	The loss function	484
27.5	Exercises	486
27.6	Conditional probabilities and expectations	486
27.6.1	Conditional probabilities	487
27.6.2	Conditional expectations	488
27.6.3	Conditional expectation minimizes squared loss function	488
27.7	Exercises	489



27.8	Case study: is it a 2 or a 7? . . . . .	489
<b>28</b>	<b>Smoothing</b> . . . . .	<b>493</b>
28.1	Bin smoothing . . . . .	495
28.2	Kernels . . . . .	497
28.3	Local weighted regression (loess) . . . . .	498
28.3.1	Fitting parabolas . . . . .	502
28.3.2	Beware of default smoothing parameters . . . . .	503
28.4	Connecting smoothing to machine learning . . . . .	504
28.5	Exercises . . . . .	504
<b>29</b>	<b>Cross validation</b> . . . . .	<b>507</b>
29.1	Motivation with k-nearest neighbors . . . . .	507
29.1.1	Over-training . . . . .	509
29.1.2	Over-smoothing . . . . .	510
29.1.3	Picking the $k$ in kNN . . . . .	511
29.2	Mathematical description of cross validation . . . . .	513
29.3	K-fold cross validation . . . . .	514
29.4	Exercises . . . . .	517
29.5	Bootstrap . . . . .	518
29.6	Exercises . . . . .	521
<b>30</b>	<b>The caret package</b> . . . . .	<b>523</b>
30.1	The caret <code>train</code> function . . . . .	523
30.2	Cross validation . . . . .	524
30.3	Example: fitting with loess . . . . .	526
<b>31</b>	<b>Examples of algorithms</b> . . . . .	<b>529</b>
31.1	Linear regression . . . . .	529
31.1.1	The <code>predict</code> function . . . . .	530
31.2	Exercises . . . . .	531
31.3	Logistic regression . . . . .	533
31.3.1	Generalized linear models . . . . .	534
31.3.2	Logistic regression with more than one predictor . . . . .	538
31.4	Exercises . . . . .	539
31.5	k-nearest neighbors . . . . .	540
31.6	Exercises . . . . .	541



31.7	Generative models	541
31.7.1	Naive Bayes	542
31.7.2	Controlling prevalence	543
31.7.3	Quadratic discriminant analysis	545
31.7.4	Linear discriminant analysis	547
31.7.5	Connection to distance	549
31.8	Case study: more than three classes	549
31.9	Exercises	553
31.10	Classification and regression trees (CART)	554
31.10.1	The curse of dimensionality	554
31.10.2	CART motivation	555
31.10.3	Regression trees	558
31.10.4	Classification (decision) trees	564
31.11	Random forests	566
31.12	Exercises	571
<b>32</b>	<b>Machine learning in practice</b>	<b>573</b>
32.1	Preprocessing	574
32.2	k-nearest neighbor and random forest	575
32.3	Variable importance	578
32.4	Visual assessments	579
32.5	Ensembles	579
32.6	Exercises	580
<b>33</b>	<b>Large datasets</b>	<b>581</b>
33.1	Matrix algebra	581
33.1.1	Notation	582
33.1.2	Converting a vector to a matrix	584
33.1.3	Row and column summaries	585
33.1.4	apply	586
33.1.5	Filtering columns based on summaries	586
33.1.6	Indexing with matrices	588
33.1.7	Binarizing the data	590
33.1.8	Vectorization for matrices	590
33.1.9	Matrix algebra operations	591



33.2	Exercises	591
33.3	Distance	591
33.3.1	Euclidean distance	592
33.3.2	Distance in higher dimensions	592
33.3.3	Euclidean distance example	593
33.3.4	Predictor space	595
33.3.5	Distance between predictors	595
33.4	Exercises	595
33.5	Dimension reduction	596
33.5.1	Preserving distance	596
33.5.2	Linear transformations (advanced)	599
33.5.3	Orthogonal transformations (advanced)	600
33.5.4	Principal component analysis	602
33.5.5	Iris example	604
33.5.6	MNIST example	607
33.6	Exercises	609
33.7	Recommendation systems	610
33.7.1	Movielens data	610
33.7.2	Recommendation systems as a machine learning challenge	612
33.7.3	Loss function	612
33.7.4	A first model	613
33.7.5	Modeling movie effects	614
33.7.6	User effects	615
33.8	Exercises	616
33.9	Regularization	617
33.9.1	Motivation	617
33.9.2	Penalized least squares	619
33.9.3	Choosing the penalty terms	622
33.10	Exercises	624
33.11	Matrix factorization	625
33.11.1	Factors analysis	628
33.11.2	Connection to SVD and PCA	630
33.12	Exercises	633



<b>34 Clustering</b>	<b>639</b>
34.1 Hierarchical clustering	640
34.2 k-means	642
34.3 Heatmaps	642
34.4 Filtering features	643
34.5 Exercises	644
<b>VI Productivity Tools</b>	<b>645</b>
<b>35 Introduction to productivity tools</b>	<b>647</b>
<b>36 Organizing with Unix</b>	<b>649</b>
36.1 Naming convention	649
36.2 The terminal	650
36.3 The filesystem	650
36.3.1 Directories and subdirectories	651
36.3.2 The home directory	651
36.3.3 Working directory	652
36.3.4 Paths	653
36.4 Unix commands	653
36.4.1 <code>ls</code> : Listing directory content	654
36.4.2 <code>mkdir</code> and <code>rmdir</code> : make and remove a directory	654
36.4.3 <code>cd</code> : navigating the filesystem by changing directories	655
36.5 Some examples	657
36.6 More Unix commands	658
36.6.1 <code>mv</code> : moving files	658
36.6.2 <code>cp</code> : copying files	659
36.6.3 <code>rm</code> : removing files	659
36.6.4 <code>less</code> : looking at a file	659
36.7 Preparing for a data science project	660
36.8 Advanced Unix	661
36.8.1 Arguments	661
36.8.2 Getting help	662
36.8.3 Pipes	662
36.8.4 Wild cards	663
36.8.5 Environment variables	663



36.8.6 Shells . . . . . 664

36.8.7 Executables . . . . . 664

36.8.8 Permissions and file types . . . . . 665

36.8.9 Commands you should learn . . . . . 665

36.8.10 File manipulation in R . . . . . 665

**37 Git and GitHub 667**

37.1 Why use Git and GitHub? . . . . . 667

37.2 GitHub accounts . . . . . 667

37.3 GitHub repositories . . . . . 670

37.4 Overview of Git . . . . . 671

37.4.1 Clone . . . . . 672

37.5 Initializing a Git directory . . . . . 676

37.6 Using Git and GitHub in RStudio . . . . . 678

**38 Reproducible projects with RStudio and R markdown 683**

38.1 RStudio projects . . . . . 683

38.2 R markdown . . . . . 686

38.2.1 The header . . . . . 688

38.2.2 R code chunks . . . . . 688

38.2.3 Global options . . . . . 689

38.2.4 knitR . . . . . 689

38.2.5 More on R markdown . . . . . 690

38.3 Organizing a data science project . . . . . 690

38.3.1 Create directories in Unix . . . . . 690

38.3.2 Create an RStudio project . . . . . 691

38.3.3 Edit some R scripts . . . . . 692

38.3.4 Create some more directories using Unix . . . . . 693

38.3.5 Add a README file . . . . . 693

38.3.6 Initializing a Git directory . . . . . 693

38.3.7 Add, commit, and push files using RStudio . . . . . 694

**Index 695**

<https://www.coursera.org/professional-certificates/harvardx-data-science>  
<https://github.com/rafalab/dsbook>  
<https://creativecommons.org/licenses/by-nc-sa/4.0/>  
<https://twitter.com/rafalab>