

# Contents

<b>Preface</b>	<b>v</b>
<b>Typographical Conventions</b>	<b>xi</b>
<b>1 Introduction</b>	<b>1</b>
1.1 A Quick Overview of S . . . . .	3
1.2 Using S . . . . .	5
1.3 An Introductory Session . . . . .	6
1.4 What Next? . . . . .	12
<b>2 Data Manipulation</b>	<b>13</b>
2.1 Objects . . . . .	13
2.2 Connections . . . . .	20
2.3 Data Manipulation . . . . .	27
2.4 Tables and Cross-Classification . . . . .	37
<b>3 The S Language</b>	<b>41</b>
3.1 Language Layout . . . . .	41
3.2 More on S Objects . . . . .	44
3.3 Arithmetical Expressions . . . . .	47
3.4 Character Vector Operations . . . . .	51
3.5 Formatting and Printing . . . . .	54
3.6 Calling Conventions for Functions . . . . .	55
3.7 Model Formulae . . . . .	56
3.8 Control Structures . . . . .	58
3.9 Array and Matrix Operations . . . . .	60
3.10 Introduction to Classes and Methods . . . . .	66
<b>4 Graphics</b>	<b>69</b>
4.1 Graphics Devices . . . . .	71
4.2 Basic Plotting Functions . . . . .	72

4.3	Enhancing Plots . . . . .	77
4.4	Fine Control of Graphics . . . . .	82
4.5	Trellis Graphics . . . . .	89
<b>5</b>	<b>Univariate Statistics</b>	<b>107</b>
5.1	Probability Distributions . . . . .	107
5.2	Generating Random Data . . . . .	110
5.3	Data Summaries . . . . .	111
5.4	Classical Univariate Statistics . . . . .	115
5.5	Robust Summaries . . . . .	119
5.6	Density Estimation . . . . .	126
5.7	Bootstrap and Permutation Methods . . . . .	133
<b>6</b>	<b>Linear Statistical Models</b>	<b>139</b>
6.1	An Analysis of Covariance Example . . . . .	139
6.2	Model Formulae and Model Matrices . . . . .	144
6.3	Regression Diagnostics . . . . .	151
6.4	Safe Prediction . . . . .	155
6.5	Robust and Resistant Regression . . . . .	156
6.6	Bootstrapping Linear Models . . . . .	163
6.7	Factorial Designs and Designed Experiments . . . . .	165
6.8	An Unbalanced Four-Way Layout . . . . .	169
6.9	Predicting Computer Performance . . . . .	177
6.10	Multiple Comparisons . . . . .	178
<b>7</b>	<b>Generalized Linear Models</b>	<b>183</b>
7.1	Functions for Generalized Linear Modelling . . . . .	187
7.2	Binomial Data . . . . .	190
7.3	Poisson and Multinomial Models . . . . .	199
7.4	A Negative Binomial Family . . . . .	206
7.5	Over-Dispersion in Binomial and Poisson GLMs . . . . .	208
<b>8</b>	<b>Non-Linear and Smooth Regression</b>	<b>211</b>
8.1	An Introductory Example . . . . .	211
8.2	Fitting Non-Linear Regression Models . . . . .	212
8.3	Non-Linear Fitted Model Objects and Method Functions . . . . .	217
8.4	Confidence Intervals for Parameters . . . . .	220
8.5	Profiles . . . . .	226

8.6	Constrained Non-Linear Regression . . . . .	227
8.7	One-Dimensional Curve-Fitting . . . . .	228
8.8	Additive Models . . . . .	232
8.9	Projection-Pursuit Regression . . . . .	238
8.10	Neural Networks . . . . .	243
8.11	Conclusions . . . . .	249
<b>9</b>	<b>Tree-Based Methods</b>	<b>251</b>
9.1	Partitioning Methods . . . . .	253
9.2	Implementation in <code>rpart</code> . . . . .	258
9.3	Implementation in <code>tree</code> . . . . .	266
<b>10</b>	<b>Random and Mixed Effects</b>	<b>271</b>
10.1	Linear Models . . . . .	272
10.2	Classic Nested Designs . . . . .	279
10.3	Non-Linear Mixed Effects Models . . . . .	286
10.4	Generalized Linear Mixed Models . . . . .	292
10.5	GEE Models . . . . .	299
<b>11</b>	<b>Exploratory Multivariate Analysis</b>	<b>301</b>
11.1	Visualization Methods . . . . .	302
11.2	Cluster Analysis . . . . .	315
11.3	Factor Analysis . . . . .	321
11.4	Discrete Multivariate Analysis . . . . .	325
<b>12</b>	<b>Classification</b>	<b>331</b>
12.1	Discriminant Analysis . . . . .	331
12.2	Classification Theory . . . . .	338
12.3	Non-Parametric Rules . . . . .	341
12.4	Neural Networks . . . . .	342
12.5	Support Vector Machines . . . . .	344
12.6	Forensic Glass Example . . . . .	346
12.7	Calibration Plots . . . . .	349
<b>13</b>	<b>Survival Analysis</b>	<b>353</b>
13.1	Estimators of Survivor Curves . . . . .	355
13.2	Parametric Models . . . . .	359
13.3	Cox Proportional Hazards Model . . . . .	365

13.4	Further Examples . . . . .	371
<b>14</b>	<b>Time Series Analysis</b>	<b>387</b>
14.1	Second-Order Summaries . . . . .	389
14.2	ARIMA Models . . . . .	397
14.3	Seasonality . . . . .	403
14.4	Nottingham Temperature Data . . . . .	406
14.5	Regression with Autocorrelated Errors . . . . .	411
14.6	Models for Financial Series . . . . .	414
<b>15</b>	<b>Spatial Statistics</b>	<b>419</b>
15.1	Spatial Interpolation and Smoothing . . . . .	419
15.2	Kriging . . . . .	425
15.3	Point Process Analysis . . . . .	430
<b>16</b>	<b>Optimization</b>	<b>435</b>
16.1	Univariate Functions . . . . .	435
16.2	Special-Purpose Optimization Functions . . . . .	436
16.3	General Optimization . . . . .	436
<b>Appendices</b>		
<b>A</b>	<b>Implementation-Specific Details</b>	<b>447</b>
A.1	Using S-PLUS under Unix / Linux . . . . .	447
A.2	Using S-PLUS under Windows . . . . .	450
A.3	Using R under Unix / Linux . . . . .	453
A.4	Using R under Windows . . . . .	454
A.5	For Emacs Users . . . . .	455
<b>B</b>	<b>The S-PLUS GUI</b>	<b>457</b>
<b>C</b>	<b>Datasets, Software and Libraries</b>	<b>461</b>
C.1	Our Software . . . . .	461
C.2	Using Libraries . . . . .	462
<b>References</b>		<b>465</b>
<b>Index</b>		<b>481</b>