

CONTENTS IN DETAIL

ACKNOWLEDGMENTS

xvii

INTRODUCTION

xix

Why Use R for Your Statistical Work?	xix
Object-Oriented Programming	xvii
Functional Programming	xvii
Whom Is This Book For?	xviii
My Own Background	xix

1

GETTING STARTED

1

1.1 How to Run R	1
1.1.1 Interactive Mode	2
1.1.2 Batch Mode	3
1.2 A First R Session	4
1.3 Introduction to Functions	7
1.3.1 Variable Scope	9
1.3.2 Default Arguments	9
1.4 Preview of Some Important R Data Structures	10
1.4.1 Vectors, the R Workhorse	10
1.4.2 Character Strings	11
1.4.3 Matrices	11
1.4.4 Lists	12
1.4.5 Data Frames	14
1.4.6 Classes	15
1.5 Extended Example: Regression Analysis of Exam Grades	16
1.6 Startup and Shutdown	19
1.7 Getting Help	20
1.7.1 The help() Function	20
1.7.2 The example() Function	21
1.7.3 If You Don't Know Quite What You're Looking For	22
1.7.4 Help for Other Topics	23
1.7.5 Help for Batch Mode	24
1.7.6 Help on the Internet	24

2		25
VECTORS		
2.1	Scalars, Vectors, Arrays, and Matrices	26
2.1.1	Adding and Deleting Vector Elements	26
2.1.2	Obtaining the Length of a Vector	27
2.1.3	Matrices and Arrays as Vectors	28
2.2	Declarations	28
2.3	Recycling	29
2.4	Common Vector Operations	30
2.4.1	Vector Arithmetic and Logical Operations	30
2.4.2	Vector Indexing	31
2.4.3	Generating Useful Vectors with the : Operator	32
2.4.4	Generating Vector Sequences with seq()	33
2.4.5	Repeating Vector Constants with rep()	34
2.5	Using all() and any()	35
2.5.1	Extended Example: Finding Runs of Consecutive Ones	35
2.5.2	Extended Example: Predicting Discrete-Valued Time Series	37
2.6	Vectorized Operations	39
2.6.1	Vector In, Vector Out	40
2.6.2	Vector In, Matrix Out	42
2.7	NA and NULL Values	43
2.7.1	Using NA	43
2.7.2	Using NULL	44
2.8	Filtering	45
2.8.1	Generating Filtering Indices	45
2.8.2	Filtering with the subset() Function	47
2.8.3	The Selection Function which()	47
2.9	A Vectorized if-then-else: The ifelse() Function	48
2.9.1	Extended Example: A Measure of Association	49
2.9.2	Extended Example: Recoding an Abalone Data Set	51
2.10	Testing Vector Equality	54
2.11	Vector Element Names	56
2.12	More on c()	56

3 **MATRICES AND ARRAYS** **59**

3.1	Creating Matrices	59
3.2	General Matrix Operations	61
3.2.1	Performing Linear Algebra Operations on Matrices	61
3.2.2	Matrix Indexing	62
3.2.3	Extended Example: Image Manipulation	63
3.2.4	Filtering on Matrices	66
3.2.5	Extended Example: Generating a Covariance Matrix	69

3.3	Applying Functions to Matrix Rows and Columns	70
3.3.1	Using the <code>apply()</code> Function	70
3.3.2	Extended Example: Finding Outliers	72
3.4	Adding and Deleting Matrix Rows and Columns	73
3.4.1	Changing the Size of a Matrix	73
3.4.2	Extended Example: Finding the Closest Pair of Vertices in a Graph	75
3.5	More on the Vector/Matrix Distinction	78
3.6	Avoiding Unintended Dimension Reduction	80
3.7	Naming Matrix Rows and Columns	81
3.8	Higher-Dimensional Arrays	82

4

LISTS

85

4.1	Creating Lists	85
4.2	General List Operations	87
4.2.1	List Indexing	87
4.2.2	Adding and Deleting List Elements	88
4.2.3	Getting the Size of a List	90
4.2.4	Extended Example: Text Concordance	90
4.3	Accessing List Components and Values	93
4.4	Applying Functions to Lists	95
4.4.1	Using the <code>lapply()</code> and <code>sapply()</code> Functions	95
4.4.2	Extended Example: Text Concordance, Continued	95
4.4.3	Extended Example: Back to the Abalone Data	99
4.5	Recursive Lists	99

5

DATA FRAMES

101

5.1	Creating Data Frames	102
5.1.1	Accessing Data Frames	102
5.1.2	Extended Example: Regression Analysis of Exam Grades Continued	103
5.2	Other Matrix-Like Operations	104
5.2.1	Extracting Subdata Frames	104
5.2.2	More on Treatment of NA Values	105
5.2.3	Using the <code>rbind()</code> and <code>cbind()</code> Functions and Alternatives	106
5.2.4	Applying <code>apply()</code>	107
5.2.5	Extended Example: A Salary Study	108
5.3	Merging Data Frames	109
5.3.1	Extended Example: An Employee Database	111
5.4	Applying Functions to Data Frames	112
5.4.1	Using <code>lapply()</code> and <code>sapply()</code> on Data Frames	112
5.4.2	Extended Example: Applying Logistic Regression Models	113
5.4.3	Extended Example: Aids for Learning Chinese Dialects	115

6**FACTORS AND TABLES****121**

6.1	Factors and Levels	121
6.2	Common Functions Used with Factors	123
6.2.1	The tapply() Function	123
6.2.2	The split() Function	124
6.2.3	The by() Function	126
6.3	Working with Tables	127
6.3.1	Matrix/Array-Like Operations on Tables	130
6.3.2	Extended Example: Extracting a Subtable	131
6.3.3	Extended Example: Finding the Largest Cells in a Table	134
6.4	Other Factor- and Table-Related Functions	136
6.4.1	The aggregate() Function	136
6.4.2	The cut() Function	136

7**R PROGRAMMING STRUCTURES****139**

7.1	Control Statements	139
7.1.1	Loops	140
7.1.2	Looping Over Nonvector Sets	142
7.1.3	if-else	143
7.2	Arithmetic and Boolean Operators and Values	145
7.3	Default Values for Arguments	146
7.4	Return Values	147
7.4.1	Deciding Whether to Explicitly Call return()	148
7.4.2	Returning Complex Objects	148
7.5	Functions Are Objects	149
7.6	Environment and Scope Issues	151
7.6.1	The Top-Level Environment	152
7.6.2	The Scope Hierarchy	152
7.6.3	More on ls()	155
7.6.4	Functions Have (Almost) No Side Effects	156
7.6.5	Extended Example: A Function to Display the Contents of a Call Frame	157
7.7	No Pointers in R	159
7.8	Writing Upstairs	161
7.8.1	Writing to Nonlocals with the Superassignment Operator	161
7.8.2	Writing to Nonlocals with assign()	163
7.8.3	Extended Example: Discrete-Event Simulation in R	164
7.8.4	When Should You Use Global Variables?	171
7.8.5	Closures	174
7.9	Recursion	176
7.9.1	A Quicksort Implementation	176
7.9.2	Extended Example: A Binary Search Tree	177

7.10	Replacement Functions	182
7.10.1	What's Considered a Replacement Function?	183
7.10.2	Extended Example: A Self-Bookkeeping Vector Class	184
7.11	Tools for Composing Function Code	186
7.11.1	Text Editors and Integrated Development Environments	186
7.11.2	The edit() Function	186
7.12	Writing Your Own Binary Operations	187
7.13	Anonymous Functions	187

8

DOING MATH AND SIMULATIONS IN R 189

8.1	Math Functions	189
8.1.1	Extended Example: Calculating a Probability	190
8.1.2	Cumulative Sums and Products	191
8.1.3	Minima and Maxima	191
8.1.4	Calculus	192
8.2	Functions for Statistical Distributions	193
8.3	Sorting	194
8.4	Linear Algebra Operations on Vectors and Matrices	196
8.4.1	Extended Example: Vector Cross Product	198
8.4.2	Extended Example: Finding Stationary Distributions of Markov Chains	199
8.5	Set Operations	202
8.6	Simulation Programming in R	204
8.6.1	Built-In Random Variate Generators	204
8.6.2	Obtaining the Same Random Stream in Repeated Runs	205
8.6.3	Extended Example: A Combinatorial Simulation	205

9

OBJECT-ORIENTED PROGRAMMING 207

9.1	S3 Classes	208
9.1.1	S3 Generic Functions	208
9.1.2	Example: OOP in the lm() Linear Model Function	208
9.1.3	Finding the Implementations of Generic Methods	210
9.1.4	Writing S3 Classes	212
9.1.5	Using Inheritance	214
9.1.6	Extended Example: A Class for Storing Upper-Triangular Matrices	214
9.1.7	Extended Example: A Procedure for Polynomial Regression	219
9.2	S4 Classes	222
9.2.1	Writing S4 Classes	223
9.2.2	Implementing a Generic Function on an S4 Class	225
9.3	S3 Versus S4	226

9.4	Managing Your Objects	226
9.4.1	Listing Your Objects with the ls() Function	226
9.4.2	Removing Specific Objects with the rm() Function	227
9.4.3	Saving a Collection of Objects with the save() Function	228
9.4.4	"What Is This?"	228
9.4.5	The exists() Function	230

10 INPUT/OUTPUT 231

10.1	Accessing the Keyboard and Monitor	232
10.1.1	Using the scan() Function	232
10.1.2	Using the readline() Function	234
10.1.3	Printing to the Screen	234
10.2	Reading and Writing Files	235
10.2.1	Reading a Data Frame or Matrix from a File	236
10.2.2	Reading Text Files	237
10.2.3	Introduction to Connections	237
10.2.4	Extended Example: Reading PUMS Census Files	239
10.2.5	Accessing Files on Remote Machines via URLs	243
10.2.6	Writing to a File	243
10.2.7	Getting File and Directory Information	245
10.2.8	Extended Example: Sum the Contents of Many Files	245
10.3	Accessing the Internet	246
10.3.1	Overview of TCP/IP	247
10.3.2	Sockets in R	247
10.3.3	Extended Example: Implementing Parallel R	248

11 STRING MANIPULATION 251

11.1	An Overview of String-Manipulation Functions	251
11.1.1	grep()	252
11.1.2	nchar()	252
11.1.3	paste()	252
11.1.4	sprintf()	253
11.1.5	substr()	253
11.1.6	strsplit()	253
11.1.7	regexpr()	253
11.1.8	gregexpr()	254
11.2	Regular Expressions	254
11.2.1	Extended Example: Testing a Filename for a Given Suffix	255
11.2.2	Extended Example: Forming Filenames	256
11.3	Use of String Utilities in the edtdbg Debugging Tool	257

12 GRAPHICS

261

12.1	Creating Graphs	261
12.1.1	The Workhorse of R Base Graphics: The <code>plot()</code> Function	262
12.1.2	Adding Lines: The <code>abline()</code> Function	263
12.1.3	Starting a New Graph While Keeping the Old Ones	264
12.1.4	Extended Example: Two Density Estimates on the Same Graph	264
12.1.5	Extended Example: More on the Polynomial Regression Example	266
12.1.6	Adding Points: The <code>points()</code> Function	269
12.1.7	Adding a Legend: The <code>legend()</code> Function	270
12.1.8	Adding Text: The <code>text()</code> Function	270
12.1.9	Pinpointing Locations: The <code>locator()</code> Function	271
12.1.10	Restoring a Plot	272
12.2	Customizing Graphs	272
12.2.1	Changing Character Sizes: The <code>cex</code> Option	272
12.2.2	Changing the Range of Axes: The <code>xlim</code> and <code>ylim</code> Options	273
12.2.3	Adding a Polygon: The <code>polygon()</code> Function	275
12.2.4	Smoothing Points: The <code>lowess()</code> and <code>loess()</code> Functions	276
12.2.5	Graphing Explicit Functions	276
12.2.6	Extended Example: Magnifying a Portion of a Curve	277
12.3	Saving Graphs to Files	280
12.3.1	R Graphics Devices	280
12.3.2	Saving the Displayed Graph	281
12.3.3	Closing an R Graphics Device	281
12.4	Creating Three-Dimensional Plots	282

13 DEBUGGING

285

13.1	Fundamental Principles of Debugging	285
13.1.1	The Essence of Debugging: The Principle of Confirmation	285
13.1.2	Start Small	286
13.1.3	Debug in a Modular, Top-Down Manner	286
13.1.4	Antibugging	287
13.2	Why Use a Debugging Tool?	287
13.3	Using R Debugging Facilities	288
13.3.1	Single-Stepping with the <code>debug()</code> and <code>browser()</code> Functions	288
13.3.2	Using Browser Commands	289
13.3.3	Setting Breakpoints	289
13.3.4	Tracking with the <code>trace()</code> Function	291
13.3.5	Performing Checks After a Crash with the <code>traceback()</code> and <code>debugger()</code> Function	291
13.3.6	Extended Example: Two Full Debugging Sessions	292
13.4	Moving Up in the World: More Convenient Debugging Tools	300

13.5	Ensuring Consistency in Debugging Simulation Code.....	302
13.6	Syntax and Runtime Errors.....	303
13.7	Running GDB on R Itself.....	303

14

PERFORMANCE ENHANCEMENT: SPEED AND MEMORY 305

14.1	Writing Fast R Code.....	306
14.2	The Dreaded for Loop.....	306
14.2.1	Vectorization for Speedup.....	306
14.2.2	Extended Example: Achieving Better Speed in a Monte Carlo Simulation.....	308
14.2.3	Extended Example: Generating a Powers Matrix.....	312
14.3	Functional Programming and Memory Issues.....	314
14.3.1	Vector Assignment Issues.....	314
14.3.2	Copy-on-Change Issues.....	314
14.3.3	Extended Example: Avoiding Memory Copy.....	315
14.4	Using Rprof() to Find Slow Spots in Your Code.....	316
14.4.1	Monitoring with Rprof().....	316
14.4.2	How Rprof() Works.....	318
14.5	Byte Code Compilation.....	320
14.6	Oh No, the Data Doesn't Fit into Memory!.....	320
14.6.1	Chunking.....	320
14.6.2	Using R Packages for Memory Management.....	321

15

INTERFACING R TO OTHER LANGUAGES 323

15.1	Writing C/C++ Functions to Be Called from R.....	323
15.1.1	Some R-to-C/C++ Preliminaries.....	324
15.1.2	Example: Extracting Subdiagonals from a Square Matrix.....	324
15.1.3	Compiling and Running Code.....	325
15.1.4	Debugging R/C Code.....	326
15.1.5	Extended Example: Prediction of Discrete-Valued Time Series.....	327
15.2	Using R from Python.....	330
15.2.1	Installing RPy.....	330
15.2.2	RPy Syntax.....	330

16

PARALLEL R 333

16.1	The Mutual Outlinks Problem.....	333
16.2	Introducing the snow Package.....	334
16.2.1	Running snow Code.....	335
16.2.2	Analyzing the snow Code.....	336
16.2.3	How Much Speedup Can Be Attained?.....	337
16.2.4	Extended Example: K-Means Clustering.....	338

16.3	Resorting to C	340
16.3.1	Using Multicore Machines	340
16.3.2	Extended Example: Mutual Outlinks Problem in OpenMP	341
16.3.3	Running the OpenMP Code	342
16.3.4	OpenMP Code Analysis	343
16.3.5	Other OpenMP Pragmas	344
16.3.6	GPU Programming	345
16.4	General Performance Considerations	345
16.4.1	Sources of Overhead	346
16.4.2	Embarrassingly Parallel Applications and Those That Aren't	347
16.4.3	Static Versus Dynamic Task Assignment	348
16.4.4	Software Alchemy: Turning General Problems into Embarrassingly Parallel Ones	350
16.5	Debugging Parallel R Code	351

A

INSTALLING R 353

A.1	Downloading R from CRAN	353
A.2	Installing from a Linux Package Manager	353
A.3	Installing from Source	354

B

INSTALLING AND USING PACKAGES 355

B.1	Package Basics	355
B.2	Loading a Package from Your Hard Drive	356
B.3	Downloading a Package from the Web	356
	B.3.1 Installing Packages Automatically	356
	B.3.2 Installing Packages Manually	357
B.4	Listing the Functions in a Package	358