
Contents

Preface	VII
1 : Introducing Spatial Data	1
1.1 Applied Spatial Data Analysis	1
1.2 Why Do We Use R	2
1.2.1 ... In General?	2
1.2.2 ... for Spatial Data Analysis?	3
1.3 R and GIS	4
1.3.1 What is GIS?	4
1.3.2 Service-Oriented Architectures	6
1.3.3 Further Reading on GIS	6
1.4 Types of Spatial Data	7
1.5 Storage and Display	10
1.6 Applied Spatial Data Analysis	11
1.7 R Spatial Resources	13
1.7.1 Online Resources	14
1.7.2 Layout of the Book	14

Part I Handling Spatial Data in

2 Classes for Spatial Data in	21
2.1 Introduction	21
2.2 Classes and Methods in R	23
2.3 <code>Spatial</code> Objects	28
2.4 <code>SpatialPoints</code>	30
2.4.1 Methods	31
2.4.2 Data Frames for Spatial Point Data	33
2.5 <code>SpatialLines</code>	38

2.6	SpatialPolygons	41
2.6.1	SpatialPolygonsDataFrame Objects	44
2.6.2	Holes and Ring Direction	46
2.7	SpatialGrid and SpatialPixel Objects	47
3	Visualising Spatial Data	57
3.1	The Traditional Plot System	58
3.1.1	Plotting Points, Lines, Polygons, and Grids	58
3.1.2	Axes and Layout Elements	60
3.1.3	Degrees in Axes Labels and Reference Grid	64
3.1.4	Plot Size, Plotting Area, Map Scale, and Multiple Plots	65
3.1.5	Plotting Attributes and Map Legends	66
3.2	Trellis/Lattice Plots with splot	68
3.2.1	A Straight Trellis Example	68
3.2.2	Plotting Points, Lines, Polygons, and Grids	70
3.2.3	Adding Reference and Layout Elements to Plots	72
3.2.4	Arranging Panel Layout	73
3.3	Interacting with Plots	74
3.3.1	Interacting with Base Graphics	74
3.3.2	Interacting with splot and Lattice Plots	76
3.4	Colour Palettes and Class Intervals	76
3.4.1	Colour Palettes	76
3.4.2	Class Intervals	77
4	Spatial Data Import and Export	81
4.1	Coordinate Reference Systems	82
4.1.1	Using the EPSG List	83
4.1.2	PROJ.4 CRS Specification	84
4.1.3	Projection and Transformation	85
4.1.4	Degrees, Minutes, and Seconds	87
4.2	Vector File Formats	88
4.2.1	Using OGR Drivers in rgdal	89
4.2.2	Other Import/Export Functions	93
4.3	Raster File Formats	93
4.3.1	Using GDAL Drivers in rgdal	94
4.3.2	Writing a Google Earth™ Image Overlay	97
4.3.3	Other Import/Export Functions	98
4.4	Grass	99
4.4.1	Broad Street Cholera Data	104
4.5	Other Import/Export Interfaces	106
4.5.1	Analysis and Visualisation Applications	108
4.5.2	TerraLib and aRT	108
4.5.3	Other GIS and Web Mapping Systems	110
4.6	Installing rgdal	111

5	Further Methods for Handling Spatial Data	113
5.1	Support	113
5.2	Overlay	116
5.3	Spatial Sampling	118
5.4	Checking Topologies	120
5.4.1	Dissolving Polygons	121
5.4.2	Checking Hole Status	122
5.5	Combining Spatial Data	123
5.5.1	Combining Positional Data	123
5.5.2	Combining Attribute Data	124
5.6	Auxiliary Functions	126
6	Customising Spatial Data Classes and Methods	127
6.1	Programming with Classes and Methods	127
6.1.1	S3-Style Classes and Methods	129
6.1.2	S4-Style Classes and Methods	130
6.2	Animal Track Data in Package Trip	130
6.2.1	Generic and Constructor Functions	131
6.2.2	Methods for Trip Objects	133
6.3	Multi-Point Data: <code>SpatialMultiPoints</code>	134
6.4	Hexagonal Grids	137
6.5	Spatio-Temporal Grids	140
6.6	Analysing Spatial Monte Carlo Simulations	144
6.7	Processing Massive Grids	146

Part II Analysing Spatial Data

7	Spatial Point Pattern Analysis	155
7.1	Introduction	155
7.2	Packages for the Analysis of Spatial Point Patterns	156
7.3	Preliminary Analysis of a Point Pattern	160
7.3.1	Complete Spatial Randomness	160
7.3.2	Function: Distance to the Nearest Event	161
7.3.3	Function: Distance from a Point to the Nearest Event	162
7.4	Statistical Analysis of Spatial Point Processes	163
7.4.1	Homogeneous Poisson Processes	164
7.4.2	Inhomogeneous Poisson Processes	165
7.4.3	Estimation of the Intensity	165
7.4.4	Likelihood of an Inhomogeneous Poisson Process	168
7.4.5	Second-Order Properties	171
7.5	Some Applications in Spatial Epidemiology	172
7.5.1	Case-Control Studies	173
7.5.2	Binary Regression Estimator	178

7.5.3	Binary Regression Using Generalised Additive Models	180
7.5.4	Point Source Pollution	182
7.5.5	Accounting for Confounding and Covariates	186
7.6	Further Methods for the Analysis of Point Patterns	190
8	Interpolation and Geostatistics	191
8.1	Introduction	191
8.2	Exploratory Data Analysis	192
8.3	Non-Geostatistical Interpolation Methods	193
8.3.1	Inverse Distance Weighted Interpolation	193
8.3.2	Linear Regression	194
8.4	Estimating Spatial Correlation: The Variogram	195
8.4.1	Exploratory Variogram Analysis	196
8.4.2	Cutoff, Lag Width, Direction Dependence	200
8.4.3	Variogram Modelling	201
8.4.4	Anisotropy	205
8.4.5	Multivariable Variogram Modelling	206
8.4.6	Residual Variogram Modelling	208
8.5	Spatial Prediction	209
8.5.1	Universal, Ordinary, and Simple Kriging	209
8.5.2	Multivariable Prediction: Cokriging	210
8.5.3	Collocated Cokriging	212
8.5.4	Cokriging Contrasts	213
8.5.5	Kriging in a Local Neighbourhood	213
8.5.6	Change of Support: Block Kriging	215
8.5.7	Stratifying the Domain	216
8.5.8	Trend Functions and their Coefficients	217
8.5.9	Non-Linear Transforms of the Response Variable	218
8.5.10	Singular Matrix Errors	220
8.6	Model Diagnostics	221
8.6.1	Cross Validation Residuals	222
8.6.2	Cross Validation z -Scores	223
8.6.3	Multivariable Cross Validation	225
8.6.4	Limitations to Cross Validation	225
8.7	Geostatistical Simulation	226
8.7.1	Sequential Simulation	227
8.7.2	Non-Linear Spatial Aggregation and Block Averages	229
8.7.3	Multivariable and Indicator Simulation	230
8.8	Model-Based Geostatistics and Bayesian Approaches	230
8.9	Monitoring Network Optimization	231
8.10	Other R Packages for Interpolation and Geostatistics	233
8.10.1	Non-Geostatistical Interpolation	233
8.10.2	spatial	233
8.10.3	RandomFields	234
8.10.4	geoR and geoRglm	235
8.10.5	fields	235

9	Areal Data and Spatial Autocorrelation	237
9.1	Introduction	237
9.2	Spatial Neighbours	239
9.2.1	Neighbour Objects	240
9.2.2	Creating Contiguity Neighbours	242
9.2.3	Creating Graph-Based Neighbours	244
9.2.4	Distance-Based Neighbours	246
9.2.5	Higher-Order Neighbours	249
9.2.6	Grid Neighbours	250
9.3	Spatial Weights	251
9.3.1	Spatial Weights Styles	251
9.3.2	General Spatial Weights	253
9.3.3	Importing, Converting, and Exporting Spatial Neighbours and Weights	255
9.3.4	Using Weights to Simulate Spatial Autocorrelation	257
9.3.5	Manipulating Spatial Weights	258
9.4	Spatial Autocorrelation: Tests	258
9.4.1	Global Tests	261
9.4.2	Local Tests	268
10	Modelling Areal Data	273
10.1	Introduction	273
10.2	Spatial Statistics Approaches	274
10.2.1	Simultaneous Autoregressive Models	277
10.2.2	Conditional Autoregressive Models	282
10.2.3	Fitting Spatial Regression Models	284
10.3	Mixed-Effects Models	287
10.4	Spatial Econometrics Approaches	289
10.5	Other Methods	296
10.5.1	GAM, GEE, GLMM	297
10.5.2	Moran Eigenvectors	302
10.5.3	Geographically Weighted Regression	305
11	Disease Mapping	311
11.1	Introduction	312
11.2	Statistical Models	314
11.2.1	Poisson-Gamma Model	315
11.2.2	Log-Normal Model	316
11.2.3	Marshall's Global EB Estimator	318
11.3	Spatially Structured Statistical Models	319
11.4	Bayesian Hierarchical Models	321
11.4.1	The Poisson-Gamma Model Revisited	322
11.4.2	Spatial Models	325
11.5	Detection of Clusters of Disease	332
11.5.1	Testing the Homogeneity of the Relative Risks	333
11.5.2	Moran's Test of Spatial Autocorrelation	335

XIV Contents

11.5.3 Tango's Test of General Clustering	335
11.5.4 Detection of the Location of a Cluster	337
11.5.5 Geographical Analysis Machine	337
11.5.6 Kulldorff's Statistic	338
11.5.7 Stone's Test for Localised Clusters	340
11.6 Other Topics in Disease Mapping	341
Afterword	343
R and Package Versions Used	344
Data Sets Used	344
References	347
Subject Index	361
Functions Index	371