

# Contents

<i>Preface</i>	page xiii
<b>1 Think Spatially: Basic Concepts of Spatial Analysis and Space</b>	
<b>Conceptualization</b>	1
Learning Objectives	1
1.1 Introduction: Spatial Analysis	2
1.2 Basic Definitions	6
1.3 Spatial Data: What Makes Them Special?	10
1.4 Conceptualization of Spatial Relationships	15
1.5 Distance Measure	17
1.5.1 Fixed Distance Band (Sphere of Influence)	18
1.5.2 Distance Decay	20
1.6 Contiguity: Adjacency Matrix	23
1.6.1 Polygons Contiguity	23
1.6.2 Adjacency Matrix	25
1.7 Interaction	26
1.8 Neighborhood and Neighbors	27
1.8.1 $k$ -Nearest Neighbors ( $k$ -NN)	27
1.8.2 Space–Time Window	29
1.8.3 Proximity Polygons	30
1.8.4 Delaunay Triangulation and Triangular Irregular Networks (TIN)	31
1.9 Spatial Weights and Row Standardization	31
1.10 Chapter Concluding Remarks	33
Questions and Answers	34
Lab 1 The Project: Spatial Analysis for Real Estate Market Investments	39
Overall Progress	39
Scope of Analysis	39
Dataset Structure	44
Guidelines	45

Section A	ArcGIS	45
Exercise 1.1	Getting to Know the Data and Study Region	45
Section B	GeoDa	52
Exercise 1.1	Getting to Know the Data and Study Region	52
<b>2</b>	<b>Exploratory Spatial Data Analysis Tools and Statistics</b>	<b>59</b>
	Learning Objectives	59
2.1	Introduction in Exploratory Spatial Data Analysis, Descriptive Statistics, Inferential Statistics and Spatial Statistics	60
2.2	Simple ESDA Tools and Descriptive Statistics for Visualizing Spatial Data (Univariate Data)	63
2.2.1	Choropleth Maps	63
2.2.2	Frequency Distribution and Histograms	65
2.2.3	Measures of Center	69
2.2.4	Measures of Shape	71
2.2.5	Measures of Spread/Variability – Variation	72
2.2.6	Percentiles, Quartiles and Quantiles	75
2.2.7	Outliers	76
2.2.8	Boxplot	78
2.2.9	Normal QQ Plot	81
2.3	ESDA Tools and Descriptive Statistics for Analyzing Two or More Variables (Bivariate Analysis)	82
2.3.1	Scatter Plot	82
2.3.2	Scatter Plot Matrix	84
2.3.3	Covariance and Variance–Covariance Matrix	85
2.3.4	Correlation Coefficient	87
2.3.5	Pairwise Correlation	90
2.3.6	General QQ Plot	91
2.4	Rescaling Data	91
2.5	Inferential Statistics and Their Importance in Spatial Statistics	95
2.5.1	Parametric Methods	96
2.5.2	Nonparametric Methods	100
2.5.3	Confidence Interval	101
2.5.4	Standard Error, Standard Error of the Mean, Standard Error of Proportion and Sampling Distribution	102
2.5.5	Significance Tests, Hypothesis, p-Value and z-Score	104
2.6	Normal Distribution Use in Geographical Analysis	109
2.7	Chapter Concluding Remarks	111
	Questions and Answers	112
Lab 2	Exploratory Spatial Data Analysis (ESDA): Analyzing and Mapping Data	117



Overall Progress	117
Scope of the Analysis: Income and Expenses	117
Section A ArcGIS	118
Exercise 2.1 ESDA Tools: Mapping and Analyzing the Distribution of Income	118
Exercise 2.2 Bivariate Analysis: Analyzing Expenditures by Educational Attainment	131
Section B GeoDa	136
Exercise 2.1 ESDA Tools: Mapping and Analyzing the Distribution of Income	136
Exercise 2.2 Bivariate Analysis: Analyzing Expenditures by Educational Attainment	142
<b>3 Analyzing Geographic Distributions and Point Patterns</b>	<b>147</b>
Learning Objectives	147
3.1 Analyzing Geographic Distributions: Centrography	148
3.1.1 Mean Center	148
3.1.2 Median Center	151
3.1.3 Central Feature	152
3.1.4 Standard Distance	154
3.1.5 Standard Deviation Ellipse	156
3.1.6 Locational Outliers and Spatial Outliers	158
3.2 Analyzing Spatial Patterns: Point Pattern Analysis	163
3.2.1 Definitions: Spatial Process, Complete Spatial Randomness, First- and Second-Order Effects	165
3.2.2 Spatial Process	167
3.3 Point Pattern Analysis Methods	169
3.3.1 Nearest Neighbor Analysis	170
3.3.2 Ripley's $K$ Function and the $L$ Function Transformation	172
3.3.3 Kernel Density Function	176
3.4 Chapter Concluding Remarks	179
Questions and Answers	180
Lab 3 Spatial Statistics: Measuring Geographic Distributions	183
Overall Progress	183
Scope of the Analysis: Crime Analysis	184
Exercise 3.1 Measuring Geographic Distributions	184
Exercise 3.2 Point Pattern Analysis	191
Exercise 3.3 Kernel Density Estimation	197
Exercise 3.4 Locational Outliers	203

<b>4</b>	<b>Spatial Autocorrelation</b>	207
	Learning Objectives	207
	4.1 Spatial Autocorrelation	208
	4.2 Global Spatial Autocorrelation	211
	4.2.1 Moran's $I$ Index and Scatter Plot	211
	4.2.2 Geary's $C$ Index	216
	4.2.3 General $G$ -Statistic	217
	4.3 Incremental Spatial Autocorrelation	219
	4.4 Local Spatial Autocorrelation	222
	4.4.1 Local Moran's $I$ (Cluster and Outlier Analysis)	222
	4.4.2 Optimized Outlier Analysis	226
	4.4.3 Getis-Ord $G_i$ and $G_i^*$ (Hot Spot Analysis)	227
	4.4.4 Optimized Hot Spot Analysis	229
	4.5 Space–Time Correlation Analysis	230
	4.5.1 Bivariate Moran's $I$ for Space–Time Correlation	230
	4.5.2 Differential Moran's $I$	232
	4.5.3 Emerging Hot Spot Analysis	233
	4.6 Multiple Comparisons Problem and Spatial Dependence	234
	4.7 Chapter Concluding Remarks	237
	Questions and Answers	238
	Lab 4 Spatial Autocorrelation	241
	Overall Progress	241
	Scope of the Analysis	241
	Section A ArcGIS	242
	Exercise 4.1 Global Spatial Autocorrelation	242
	Exercise 4.2 Incremental Spatial Autocorrelation and Spatial Weights Matrix	246
	Exercise 4.3 Cluster and Outlier Analysis (Anselin Local Moran's $I$ )	252
	Exercise 4.4 Hot Spot Analysis (Getis-Ord $G_i^*$ ) and Optimized Hot Spot Analysis	255
	Exercise 4.5 Optimized Hot Spot Analysis for Crime Events	261
	Section B GeoDa	265
	Exercises 4.1 and 4.2 Global Spatial Autocorrelation and Spatial Weights Matrix	265
	Exercise 4.3 Cluster and Outlier Analysis (Anselin Local Moran's $I$ )	270
	Exercise 4.4 Hot Spot Analysis (Getis-Ord $G_i^*$ )	273
<b>5</b>	<b>Multivariate Data in Geography: Data Reduction and Clustering</b>	275
	Learning Objectives	275
	5.1 Multivariate Data Analysis	276



5.2	Principal Component Analysis (PCA)	279
5.3	Factor Analysis (FA)	289
5.4	Multidimensional Scaling (MDS)	290
5.5	Cluster Analysis	292
5.5.1	Hierarchical Clustering	293
5.5.2	<i>k</i> -Means Algorithm (Partitional Clustering)	298
5.6	Regionalization	304
5.6.1	SKATER Method	306
5.6.2	REDCAP Method	309
5.7	Density-Based Clustering: DBSCAN, HDBSCAN, OPTICS	310
5.8	Similarity Analysis: Cosine Similarity	311
5.9	Chapter Concluding Remarks	313
	Questions and Answers	314
	Lab 5 Multivariate Statistics: Clustering	317
	Overall Progress	317
	Scope of the Analysis	317
	Section A ArcGIS	318
	Exercise 5.1 <i>k</i> -Means Clustering	318
	Exercise 5.2 Spatial Clustering (Regionalization)	329
	Exercise 5.3 Similarity Analysis	332
	Exercise 5.4 Synthesis	337
	Section B GeoDa	345
	Exercise 5.1 <i>k</i> -Means Clustering	345
	Exercise 5.2 Spatial Clustering	348
<b>6</b>	<b>Modeling Relationships: Regression and Geographically Weighted Regression</b>	
	Learning Objectives	351
6.1	Simple Linear Regression	352
6.1.1	Simple Linear Regression Assumptions	355
6.1.2	Ordinary Least Squares (Intercept and Slope by OLS)	355
6.2	Multiple Linear Regression (MLR)	356
6.2.1	Multiple Regression Basics	356
6.2.2	Model Overfit: Selecting the Number of Variables by Defining a Functional Relationship	359
6.2.3	Missing Values	360
6.2.4	Outliers and Leverage Points	360
6.2.5	Dummy Variables	361
6.2.6	Methods for Entering Variables in MLR: Explanatory Analysis; Identifying Causes and Effects	363

6.3	Evaluating Linear Regression Results: Metrics, Tests and Plots	365
6.3.1	Multiple $r$	365
6.3.2	Variation and Coefficient of Determination $R$ -Squared	365
6.3.3	Adjusted $R$ -Squared	369
6.3.4	Predicted $R$ -Squared	370
6.3.5	Standard Error (Deviation) of Regression (or Standard Error of the Estimate)	371
6.3.6	F-Test of the Overall Significance	373
6.3.7	$t$ -Statistic (Coefficients' Test)	374
6.3.8	Wald Test (Coefficient's Test)	375
6.3.9	Standardized Coefficients (Beta)	376
6.3.10	Residuals, Residual Plots and Standardized Residuals	378
6.3.11	Influential Points: Outliers and High-Leverage Observations	381
6.4	Multiple Linear Regression Assumptions: Diagnose and Fix	383
6.5	Multicollinearity	387
6.6	Worked Example: Simple and Multiple Linear Regression	391
6.7	Exploratory Regression	400
6.8	Geographically Weighted Regression	403
6.8.1	Spatial Kernel Types	405
6.8.2	Bandwidth	406
6.8.3	Interpreting GWR Results and Practical Guidelines	406
6.9	Chapter Concluding Remarks	409
	Questions and Answers	411
	Lab 6 OLS, Explanatory Regression, GWR	415
	Overall Progress	415
	Scope of the Analysis	415
	Exercise 6.1 Exploratory Regression	416
	Exercise 6.2 OLS Regression	428
	Exercise 6.3 GWR	437
<b>7</b>	<b>Spatial Econometrics</b>	451
	Learning Objectives	451
7.1	Spatial Econometrics	451
7.2	Spatial Dependence: Spatial Regression Models and Diagnostics	453
7.2.1	Diagnostics for Spatial Dependence	454
7.2.2	Selecting between Spatial Lag or Spatial Error Model	457
7.2.3	Estimation Methods	459

---

7.3	Spatial Lag Model	459
7.3.1	Spatial Two-Stage Least Squares (S2SLS)	462
7.3.2	Maximum Likelihood	466
7.4	Spatial Error Model	467
7.5	Spatial Filtering	469
7.6	Spatial Heterogeneity: Spatial Regression Models	470
7.7	Spatial Regimes	471
7.8	Chapter Concluding Remarks	474
	Questions and Answers	474
	Lab 7 Spatial Econometrics	477
	Overall Progress	477
	Scope of the Analysis	477
	Exercise 7.1 OLS	478
	Exercise 7.2 Spatial Error Model	487
	Exercise 7.3 OLS with Spatial Regimes	491
	Exercise 7.4 Spatial Error by Spatial Regimes	501
	References	505
	Index	513