

Contents

Preface.....	xxi
Acknowledgments.....	xxv
About the Authors.....	xxvii

Chapter 1 Introduction.....	1
1.1 Overview.....	1
1.2 Learning Objectives.....	2
1.3 What Is a Thematic Map?.....	2
1.4 How Are Thematic Maps Used?.....	2
1.5 Basic Steps for Communicating Map Information.....	5
1.6 Technological Change in Cartography and Its Consequences.....	8
1.7 What Is Geovisualization?.....	11
1.8 Related GIScience Techniques.....	14
1.9 Cognitive Issues in Cartography.....	16
1.10 Social and Ethical Issues in Cartography.....	17
1.11 Summary.....	18
1.12 Study Questions.....	19
References.....	20

Part I Principles of Cartography

Chapter 2 A Historical Perspective on Thematic Cartography.....	25
2.1 Introduction.....	25
2.2 Learning Objectives.....	25
2.3 A Brief History of Cartography.....	26
2.4 History of Thematic Cartography.....	27
2.4.1 The Rise of Social Cartography.....	28
2.5 History of U.S. Academic Cartography.....	30
2.5.1 Period 1: Early Beginnings.....	30
2.5.1.1 John Paul Goode.....	30
2.5.1.2 Erwin Raisz.....	31
2.5.1.3 Guy-Harold Smith.....	31
2.5.1.4 Richard Edes Harrison.....	32
2.5.2 Period 2: The Post-War Era and the Building of Core Academic Programs.....	32
2.5.2.1 University of Wisconsin.....	32
2.5.2.2 University of Kansas.....	33
2.5.2.3 University of Washington.....	34
2.5.3 Period 3: Growth of Secondary Programs.....	35
2.5.4 Period 4: Integration with GIScience.....	36
2.6 European Thematic Cartography.....	36
2.6.1 The Swiss School.....	36
2.6.2 The British Experimental Cartographic Unit.....	36
2.6.3 Bertin and French Thematic Cartography.....	37
2.7 The Paradigms of American Cartography.....	37
2.7.1 Analytical Cartography.....	37
2.7.2 Maps and Society.....	38
2.7.2.1 Privacy.....	39
2.7.2.2 Power and Access.....	39
2.7.2.3 Ethics.....	39
2.7.2.4 Public Participation GIS/Mapping.....	39

2.8	Summary	39
2.9	Study Questions.....	41
	References	41
Chapter 3	Statistical and Graphical Foundation	43
3.1	Introduction	43
3.2	Learning Objectives	43
3.3	Population and Sample	43
3.4	Descriptive versus Inferential Statistics	43
3.5	Analyzing the Distribution of Individual Attributes	45
3.5.1	Tables.....	45
3.5.1.1	Raw Table	45
3.5.1.2	Grouped-Frequency Table	45
3.5.2	Graphs	46
3.5.2.1	Point and Dispersion Graphs	46
3.5.2.2	Histogram	47
3.5.3	Numerical Summaries.....	47
3.5.3.1	Measures of Central Tendency	47
3.5.3.2	Measures of Dispersion	48
3.6	Analyzing the Relationship between Two or More Attributes	49
3.6.1	Tables.....	49
3.6.2	Graphs	50
3.6.3	Numerical Summaries.....	51
3.6.3.1	Bivariate Correlation	51
3.6.3.2	Bivariate Regression	53
3.6.3.3	Reduced Major-Axis Approach	54
3.6.3.4	Multiple Regression and Other Multivariate Techniques.....	54
3.6.3.5	Considerations in Using Correlation-Regression.....	54
3.7	Exploratory Data Analysis	55
3.8	Numerical Summaries for Geographic Data.....	56
3.8.1	Geographic Center	56
3.8.2	Spatial Autocorrelation and Measuring Spatial Pattern.....	57
3.8.3	Measuring Map Complexity.....	58
3.9	Summary	60
3.10	Study Questions.....	60
	References	61
Chapter 4	Principles of Symbolization	63
4.1	Introduction	63
4.2	Learning Objectives	63
4.3	Nature of Geographic Phenomena	63
4.3.1	Spatial Dimension	63
4.3.2	Models of Geographic Phenomena	64
4.3.3	Phenomena versus Data.....	65
4.4	Levels of Measurement.....	67
4.5	Visual Variables.....	67
4.5.1	Visual Variables for Quantitative Phenomena	68
4.5.1.1	Spacing	68
4.5.1.2	Size	69
4.5.1.3	Perspective Height	69
4.5.1.4	Hue, Lightness, and Saturation.....	69
4.5.2	Visual Variables for Qualitative Phenomena	69
4.5.2.1	Orientation and Shape	69
4.5.2.2	Arrangement.....	69
4.5.2.3	Hue.....	69
4.5.3	Some Considerations in Working with Visual Variables	69

4.6	Comparison of Four Common Thematic Mapping Techniques.....	71
4.6.1	Choropleth Map.....	71
4.6.2	Proportional Symbol Map.....	72
4.6.3	Isopleth Map.....	74
4.6.4	Dot Map.....	74
4.6.5	Discussion.....	74
4.7	Selecting Visual Variables for Choropleth Maps.....	74
4.8	Using Senses Other than Vision to Interpret Spatial Patterns.....	77
4.8.1	Sound.....	78
4.8.2	Touch (or Haptics).....	79
4.8.3	Smell.....	80
4.9	Summary.....	81
4.10	Study Questions.....	81
	References.....	82
Chapter 5	Data Classification.....	83
5.1	Introduction.....	83
5.2	Learning Objectives.....	83
5.3	Data to Be Classified.....	83
5.4	Equal Intervals Method.....	85
5.5	Quantiles Method.....	87
5.6	Mean-Standard Deviation Method.....	88
5.7	Natural Breaks.....	89
5.8	Optimal.....	89
5.8.1	The Jenks–Caspall Algorithm.....	89
5.8.2	The Fisher–Jenks Algorithm.....	90
5.8.3	Advantages and Disadvantages of Optimal Classification.....	91
5.9	Head/Tail Breaks: A Novel Classification Method.....	92
5.10	Criteria for Selecting a Classification Method.....	94
5.11	Considering the Spatial Distribution of the Data.....	95
5.12	Summary.....	96
5.13	Study Questions.....	97
	References.....	98
Chapter 6	Scale and Generalization.....	99
6.1	Introduction.....	99
6.2	Learning Objectives.....	99
6.3	Geographic and Cartographic Scale.....	99
6.3.1	Multiple-Scale Databases.....	100
6.4	Definitions of Generalization.....	100
6.4.1	Definitions of Generalization in the Manual Domain.....	100
6.4.2	Definitions of Generalization in the Digital Domain.....	101
6.5	Models of Generalization.....	101
6.5.1	Robinson et al.'s Model.....	101
6.5.2	McMaster and Shea's Model.....	101
6.5.2.1	Why Generalization Is Needed: The Conceptual Objectives of Generalization.....	101
6.5.2.2	When Generalization Is Required.....	103
6.6	The Fundamental Operations of Generalization.....	104
6.6.1	A Framework for the Fundamental Operations.....	104
6.6.2	Vector-Based Operations.....	104
6.6.2.1	Simplification.....	104
6.6.2.2	Smoothing.....	104
6.6.2.3	Aggregation.....	104
6.6.2.4	Amalgamation.....	106

	6.6.2.5	Collapse	106
	6.6.2.6	Merging.....	106
	6.6.2.7	Refinement.....	106
	6.6.2.8	Exaggeration.....	106
	6.6.2.9	Enhancement.....	107
	6.6.2.10	Displacement.....	107
	6.6.3	The Simplification Process.....	107
6.7		An Example of Generalization.....	110
6.8		New Developments in Cartographic Generalization.....	112
	6.8.1	Measurement of Scale Change.....	112
	6.8.2	Fully Automated Generalization.....	112
	6.8.3	Data Models for Generalization.....	113
	6.8.4	New Forms of Cartographic Data.....	113
6.9		Summary.....	114
6.10		Study Questions.....	114
		References.....	114
Chapter 7		The Earth and Its Coordinate System.....	117
	7.1	Introduction.....	117
	7.2	Learning Objectives.....	117
	7.3	Basic Characteristics of Earth's Graticule.....	117
	7.3.1	Latitude.....	118
	7.3.2	Longitude.....	118
	7.3.3	Distance and Directions on Earth's Spherical Surface.....	120
	7.4	Determining Earth's Size and Shape.....	121
	7.4.1	Earth's Size.....	121
	7.4.2	Earth's Shape.....	122
	7.4.2.1	The Prolate versus Oblate Spheroid Controversy.....	122
	7.4.2.2	Reference Ellipsoid and the Graticule.....	124
	7.4.2.3	The Geoid.....	126
	7.4.2.4	Geodetic Datum.....	128
	7.4.2.5	Geodetic Datums and Thematic Cartography.....	130
	7.5	Summary.....	131
	7.6	Study Questions.....	131
		References.....	133
Chapter 8		Elements of Map Projections.....	135
	8.1	Introduction.....	135
	8.2	Learning Objectives.....	135
	8.3	The Map Projection Concept.....	136
	8.4	The Reference Globe and Developable Surfaces.....	136
	8.5	The Mathematics of Map Projections.....	136
	8.6	Map Projection Characteristics.....	139
	8.6.1	Class.....	139
	8.6.2	Case.....	143
	8.6.3	Aspect.....	144
	8.7	Distortion on Map Projections.....	145
	8.7.1	A Visual Look at Distortion.....	145
	8.7.2	Scale Factor.....	146
	8.7.3	Tissot's Indicatrix.....	147
	8.7.4	Distortion Patterns.....	148
	8.7.5	Using Geocart to Visualize Distortion Patterns.....	148
	8.8	Projection Properties.....	152
	8.8.1	Preserving Areas.....	152
	8.8.2	Preserving Angles.....	152

8.8.3	Preserving Distances.....	152
8.8.4	Preserving Directions.....	154
8.8.5	Compromise Projections.....	156
8.9	Summary.....	156
8.10	Study Questions.....	157
	References.....	158
Chapter 9	Selecting an Appropriate Map Projection.....	159
9.1	Introduction.....	159
9.2	Learning Objectives.....	159
9.3	Potential Selection Guidelines.....	160
9.3.1	Snyder's Hierarchical Selection Guideline.....	160
9.3.1.1	World Map Projections.....	160
9.3.1.2	Map Projections for a Hemisphere.....	163
9.3.1.3	Map Projections for a Continent, Ocean, or Smaller Region.....	163
9.3.1.4	Map Projections for Special Properties.....	164
9.4	Examples of Selecting Projections.....	164
9.4.1	Mapping World Literacy Rates.....	164
9.4.2	Mapping Russian Population Distribution.....	167
9.4.3	Mapping Migration to the United States.....	168
9.4.4	Mapping Tornado Paths across Kansas.....	170
9.4.5	Mapping a Flight Path from Fairbanks, AK to Seoul, South Korea.....	174
9.4.5.1	Mapping the Flight Path from Space.....	175
9.4.5.2	Mapping the Flight Path's Direction.....	175
9.4.5.3	Mapping the Flight Path Distance.....	176
9.4.5.4	Mapping the Great Circle Flight Path.....	176
9.4.5.5	Mapping the Rhumb Line.....	177
9.4.5.6	Mapping the Flight Path Using Google Maps.....	177
9.4.6	Discussion.....	178
9.5	Web-Based Interactive Map Projection Selection.....	179
9.6	Summary.....	180
9.7	Study Questions.....	181
	References.....	182
Chapter 10	Principles of Color.....	183
10.1	Introduction.....	183
10.2	Learning Objectives.....	183
10.3	How Color Is Processed by the Human Visual System.....	183
10.3.1	Visible Light and the Electromagnetic Spectrum.....	183
10.3.2	Structure of the Eye.....	184
10.3.3	Theories of Color Perception.....	186
10.3.4	Simultaneous Contrast.....	186
10.3.5	Color Vision Impairment.....	187
10.3.6	Beyond the Eye.....	187
10.4	Models for Specifying Color.....	189
10.4.1	The RGB Model.....	189
10.4.2	The CMYK Model.....	189
10.4.3	The HSV Model.....	190
10.4.4	The Munsell Model.....	190
10.4.5	The CIE Model.....	192
10.4.6	Discussion.....	194
10.5	Terminology and Principles in the Practical Use of Color.....	194
10.5.1	Color Wheels.....	194
10.5.2	Tints, Shades, and Tones.....	196
10.5.3	Qualitative Color Conventions.....	196

10.5.4	Quantitative Color Conventions	198
10.5.5	Theme-Oriented Color Schemes	198
10.6	Summary	199
10.7	Study Questions.....	200
	References	201
Chapter 11	Map Elements.....	203
11.1	Introduction	203
11.2	Learning Objectives	203
11.3	Alignment and Centering	203
11.4	Common Map Elements	203
11.4.1	Frame Line and Neat Line	205
11.4.2	Mapped Area.....	205
11.4.3	Inset.....	207
11.4.4	Title and Subtitle	207
11.4.5	Legend.....	209
11.4.6	Data Source	212
11.4.7	Scale	214
11.4.8	Orientation.....	216
11.4.9	Relative Type Sizes for Certain Map Elements.....	217
11.5	Summary	217
11.6	Study Questions.....	218
	References	218
Chapter 12	Typography.....	219
12.1	Introduction	219
12.2	Learning Objectives	219
12.3	What Is Typography?.....	219
12.3.1	Characteristics of Type.....	219
12.4	General Typographic Guidelines.....	222
12.5	Specific Typographic Guidelines.....	223
12.5.1	All Features (Point, Linear, and Areal)	223
12.5.2	Point Features	224
12.5.3	Linear Features.....	225
12.5.4	Areal Features	226
12.6	Automated Type Placement.....	228
12.7	Summary	228
12.8	Study Questions.....	228
	References	229
Chapter 13	Cartographic Design	231
13.1	Introduction	231
13.2	Learning Objectives	231
13.3	Elements of Cartographic Design.....	231
13.3.1	The Design Process	234
13.3.2	Visual Hierarchy	234
13.3.3	Contrast	235
13.3.4	Figure-Ground.....	237
13.3.5	Balance.....	239
13.4	Case Study: Real Estate Site Suitability Map.....	241
13.4.1	Steps 1–3 of the Map Communication Model.....	243
13.4.2	Step 4 of the Map Communication Model: Design and Construct the Map.....	243
13.4.3	Return to Procedure 4: Implementation of Map Elements and Typography	244
13.4.3.1	Frame Line and Neat Line.....	244
13.4.3.2	Mapped Area	244

13.4.3.3	Inset	247
13.4.3.4	Title and Subtitle.....	247
13.4.3.5	Legend	248
13.4.3.6	Data Source.....	249
13.4.3.7	Scale.....	249
13.4.3.8	Orientation.....	249
13.4.4	Final Procedures.....	249
13.5	Summary	251
13.6	Study Questions.....	251
	References	251
Chapter 14	Map Reproduction.....	253
14.1	Introduction	253
14.2	Learning Objectives	253
14.3	Planning Ahead	253
14.4	Map Editing.....	254
14.5	Raster Image Processing for Print Reproduction	254
14.5.1	Printing the Digital Map	255
14.6	Screening for Print Reproduction.....	255
14.6.1	Halftone and Stochastic Screening	256
14.6.2	Halftone Screening Parameters.....	257
14.6.3	Stochastic Screening Parameters	257
14.7	Aspects of Color Printing.....	258
14.7.1	Process Colors	258
14.7.2	Spot Colors	258
14.7.3	High-Fidelity Process Colors	259
14.7.4	Color Management Systems.....	259
14.8	High-Volume Print Reproduction.....	260
14.8.1	The Prepress Phase.....	260
14.8.2	File Formats for Prepress	260
14.8.3	Proofing Methods	261
14.8.4	Offset Lithographic Printing.....	262
14.9	Summary	264
14.10	Study Questions.....	264
	References	264

Part II Mapping Techniques

Chapter 15	Choropleth Mapping.....	267
15.1	Introduction	267
15.2	Learning Objectives	267
15.3	Selecting Appropriate Data	267
15.4	Factors for Selecting a Color Scheme.....	269
15.4.1	Kind of Data.....	270
15.4.2	Color Naming.....	271
15.4.3	Color Vision Impairment	272
15.4.4	Simultaneous Contrast	273
15.4.5	Map Use Tasks	273
15.4.6	Color Associations.....	274
15.4.7	Aesthetics	274
15.4.8	Age of the Intended Audience.....	274
15.4.9	Presentation vs. Data Exploration	275
15.4.10	Economic Limitations and Client Requirements.....	275

15.5	Systems for Specifying Color Schemes.....	275
15.5.1	Approaches for Classed Maps.....	275
15.5.1.1	Color Ramping and HSV Systems.....	275
15.5.1.2	The Munsell Curve.....	276
15.5.1.3	ColorBrewer.....	276
15.5.2	Approaches for Unclassed Maps.....	277
15.5.2.1	Applying the Munsell Curve.....	277
15.5.2.2	Kovesi's Approach.....	277
15.6	Classed vs. Unclassed Mapping.....	278
15.6.1	Maintaining Numerical Data Relations.....	279
15.6.2	Presentation vs. Data Exploration.....	280
15.6.3	Summarizing the Results of Experimental Studies.....	280
15.6.3.1	Specific Information.....	281
15.6.3.2	General Information.....	281
15.6.3.3	Discussion.....	281
15.7	Legend Design.....	281
15.8	Illuminated Choropleth Mapping.....	282
15.9	Summary.....	283
15.10	Study Questions.....	284
	References.....	285
Chapter 16	Dasymetric Mapping.....	287
16.1	Introduction.....	287
16.2	Learning Objectives.....	287
16.3	Selecting Appropriate Data and Ancillary Information.....	287
16.4	Some Basic Approaches for Dasymetric Mapping.....	288
16.5	Eicher and Brewer's Study.....	290
16.6	Mennis and Hultgren's Intelligent Dasymetric Mapping (IDM).....	292
16.7	Two Approaches for Producing Dasymetric Maps of Population Density.....	293
16.7.1	Approach One: Using Land Cover and Limiting Ancillary Data Sets.....	293
16.7.2	Approach Two: Use Zoning Polygons and Limiting Ancillary Data Sets.....	298
16.7.3	Discussion.....	300
16.8	Socscape: A Web App for Visualizing Racial Diversity.....	302
16.9	Mapping the Global Population Distribution.....	302
16.9.1	Gridded Population of the World.....	302
16.9.2	LandScan.....	303
16.9.3	Global Human Settlement Layer.....	304
16.10	Summary.....	306
16.11	Study Questions.....	307
	References.....	307
Chapter 17	Isarithmic Mapping.....	309
17.1	Introduction.....	309
17.2	Learning Objectives.....	309
17.3	Selecting Appropriate Data.....	309
17.4	Manual Interpolation.....	310
17.5	Automated Interpolation for True Point Data.....	311
17.5.1	Triangulation.....	312
17.5.2	Inverse-Distance Weighting.....	313
17.5.3	Ordinary Kriging.....	315
17.5.3.1	Semivariance and the Semivariogram.....	315
17.5.3.2	Kriging Computations.....	316
17.5.4	Thin-Plate Splines.....	318
17.5.5	Choosing among the Interpolation Methods.....	319
17.6	Tobler's Pycnophylactic Interpolation.....	321

17.7	Symbolization.....	323
17.7.1	Some Basic Symbolization Approaches.....	323
17.7.2	Color Stereoscopic Effect.....	325
17.8	Summary	325
17.9	Study Questions.....	327
	References	328
Chapter 18	Proportional Symbol Mapping.....	329
18.1	Introduction	329
18.2	Learning Objectives	329
18.3	Selecting Appropriate Data	329
18.4	Kinds of Proportional Symbols.....	330
18.5	Scaling Proportional Symbols.....	332
18.5.1	Mathematical Scaling.....	332
18.5.2	Perceptual Scaling.....	334
18.5.2.1	Formulas for Perceptual Scaling	334
18.5.2.2	Problems in Applying the Formulas.....	335
18.5.3	Range-Graded Scaling	337
18.6	Legend Design.....	337
18.6.1	Arranging Symbols	337
18.6.2	Which Symbols to Include	340
18.7	Handling Overlap of Symbols.....	340
18.7.1	How Much Overlap?.....	340
18.7.2	Symbolizing Overlap.....	342
18.8	Necklace Maps	342
18.9	Summary	343
18.10	Study Questions.....	344
	References	344
Chapter 19	Dot Mapping	347
19.1	Introduction	347
19.2	Learning Objectives	347
19.3	Key Issues Involved in Dot Mapping	347
19.3.1	Determining Regions within Which Dots Should Be Placed	347
19.3.2	Selecting Dot Size and Unit Value	349
19.3.3	Placing Dots within Regions.....	350
19.3.3.1	Placing Dots Manually	350
19.3.3.2	Placing Dots Digitally	350
19.3.4	Designing a Legend.....	352
19.4	Graduated Dot Mapping.....	352
19.5	Interactive Dot Mapping on the Web	354
19.6	Summary	355
19.7	Study Questions.....	356
	References	356
Chapter 20	Cartograms.....	359
20.1	Introduction	359
20.2	Learning Objectives	360
20.3	Methods that Attempt to Preserve the Shape of Enumeration Units.....	360
20.3.1	Noncontiguous Cartograms.....	360
20.3.2	Contiguous Cartograms	361
20.3.2.1	Gridded Cartograms.....	363
20.3.3	Mosaic Cartograms	363

20.4	Methods that Do Not Preserve the Shape of Enumeration Units	364
20.4.1	Rectangular Cartograms	364
20.4.1.1	Rectilinear Cartograms	366
20.4.2	Dorling Cartograms	366
20.4.3	Demers Cartograms	369
20.5	Contrasting Various Cartogram Methods	369
20.5.1	Contrasting Cartogram Methods in Terms of Aspects of Accuracy	369
20.5.2	A User Study of Major Cartogram Methods	370
20.6	Alternatives to Conventional Cartograms	371
20.6.1	Combined Choropleth/Proportional Symbol Maps	371
20.6.2	Value-by-Alpha Maps	372
20.6.3	Balanced Cartograms	373
20.7	Summary	374
20.8	Study Questions	375
	References	376
Chapter 21	Flow Mapping	377
21.1	Introduction	377
21.2	Learning Objectives	377
21.3	Basic Types of Flow Maps and Associated Data for Flow Mapping	378
21.4	Issues in Designing Flow Maps	379
21.5	Flow Mapping Prior to Automation	379
21.6	Early Digital Flow Mapping Efforts by Waldo Tobler	381
21.7	Examples of Recent Digital Flow Mapping	382
21.7.1	Stephen and Jenny's Interactive Web-Based Origin-Destination Flow Map	382
21.7.2	Koylu et al.'s Web-Based Software for Designing Origin-Destination Flow Maps	384
21.7.2.1	Koylu and Guo's User Study	384
21.7.2.2	Koylu et al.'s FlowMapper Software	385
21.7.3	Flow Mapping in Virtual Environments	387
21.8	Geovisual Analytics and Flow Mapping	388
21.9	Summary	390
21.10	Study Questions	390
	References	391
Chapter 22	Multivariate Mapping	393
22.1	Introduction	393
22.2	Learning Objectives	393
22.3	Bivariate Mapping	394
22.3.1	Comparing Maps	394
22.3.1.1	Comparing Choropleth Maps	394
22.3.1.2	Comparing Miscellaneous Thematic Maps	395
22.3.1.3	Comparing Maps for Two Points in Time	395
22.3.2	Combining Two Attributes on the Same Map	397
22.3.2.1	Bivariate Choropleth Maps	397
22.3.2.2	Additional Bivariate Mapping Techniques	400
22.4	Multivariate Mapping Involving Three or More Attributes	401
22.4.1	Comparing Maps	401
22.4.2	Combining Attributes on the Same Map	401
22.4.2.1	Trivariate Choropleth Maps	401
22.4.2.2	Multivariate Dot Maps	403
22.4.2.3	Multivariate Point Symbol Maps	404

22.4.2.4	Acquiring Specific and General Information from Multivariate Maps.....	406
22.4.2.5	Ring Maps: An Alternative to Conventional Symbolization Approaches.....	406
22.5	Cluster Analysis.....	408
22.5.1	Basic Steps in Hierarchical Cluster Analysis.....	409
22.5.2	Adding a Contiguity Constraint to a Hierarchical Cluster Analysis.....	414
22.6	Summary	415
22.7	Study Questions.....	416
	References	417

Part III Geovisualization

Chapter 23	Visualizing Terrain.....	423
23.1	Introduction	423
23.2	Learning Objectives	423
23.3	Nature of the Data	423
23.4	Vertical Views	424
23.4.1	Hachures.....	424
23.4.2	Contour-Based Methods.....	425
23.4.2.1	Eynard and Jenny's Work	427
23.4.3	Raisz's Physiographic Method	428
23.4.4	Shaded Relief	428
23.4.5	Morphometric Techniques	429
23.4.5.1	Symbolizing Aspect and Slope: Brewer and Marlow's Approach.....	429
23.4.5.2	Symbolizing Other Morphometric Parameters	430
23.5	Oblique Views	432
23.5.1	Block Diagrams.....	432
23.5.2	Panoramas and Related Oblique Views	434
23.5.3	Plan Oblique Relief	434
23.6	Physical Models.....	435
23.7	Issues in Creating Shaded Relief.....	437
23.7.1	Generalizing the Terrain	437
23.7.2	Selecting an Azimuth and Sun Elevation for Illumination	439
23.7.3	Other Lighting Model Issues.....	440
23.7.4	Representation of Swiss-Style Rock Drawing.....	441
23.7.5	Color Considerations	442
23.8	Summary	443
23.9	Study Questions.....	444
	References	445
Chapter 24	Map Animation	447
24.1	Introduction	447
24.2	Learning Objectives	447
24.3	Early Developments.....	448
24.4	Visual Variables for Animation.....	448
24.5	Examples of Temporal Animations.....	449
24.5.1	Animating Movement and Flows	449
24.5.2	Animating Choropleth Maps.....	450
24.5.2.1	Some Basic Examples of Choropleth Animation	450
24.5.2.2	Should We Generalize Choropleth Animations?.....	451
24.5.2.3	Should We Utilize Classed or Unclassed Maps?	451
24.5.3	Animating Proportional Symbol Maps	452
24.5.4	Animating Isarithmic Maps	452
24.5.5	Other Temporal Animations	452

24.6	Examples of Nontemporal Animations	453
24.6.1	Peterson's Early Work	453
24.6.2	Gershon's Early Work.....	455
24.6.3	Fly-Overs.....	455
24.6.4	Viégas and Wattenberg's <i>Wind Map</i>	455
24.7	Enhancing the Interactivity in Animations	456
24.7.1	Harrower's Work	456
24.7.2	CoronaViz.....	458
24.8	Does Animation Work?	459
24.9	Guidelines for Designing Your Own Animations	461
24.10	Using 3-D Space to Display Temporal Data.....	462
24.11	Summary	464
24.12	Study Questions.....	464
	References	465
Chapter 25	Data Exploration.....	467
25.1	Introduction	467
25.2	Learning Objectives	467
25.3	Goals of Data Exploration.....	467
25.4	Methods of Data Exploration	468
25.4.1	Manipulating Data.....	468
25.4.2	Varying the Symbolization.....	468
25.4.3	Manipulating the User's Viewpoint.....	468
25.4.4	Multiple Map Views	468
25.4.5	Linking Maps with Other Forms of Display	469
25.4.6	Highlighting Portions of a Data Set	469
25.4.7	Probing the Display	469
25.4.8	Toggling Individual Themes On and Off.....	469
25.4.9	Animation.....	470
25.4.10	Access to Miscellaneous Resources.....	470
25.4.11	How Symbols Are Assigned to Attributes	470
25.4.12	Automatic Map Interpretation.....	470
25.5	Examples of Data Exploration.....	470
25.5.1	Moellering's 3-D Mapping Software	470
25.5.2	ExploreMap and Map Sequencing	470
25.5.3	Project Argus.....	471
25.5.4	MapTime	472
25.5.5	CommonGIS.....	474
25.5.6	GeoDa.....	476
25.5.7	Micromaps.....	478
25.5.7.1	Linked Micromaps Plot	478
25.5.7.2	Conditioned Micromaps	480
25.5.8	ViewExposed.....	480
25.5.9	Using Tableau to Create Interactive Data Visualizations.....	482
25.6	Summary	485
25.7	Study Questions.....	485
	References	486
Chapter 26	Geovisual Analytics	489
26.1	Introduction	489
26.2	Learning Objectives	489
26.3	Characteristics and Limitations of Big Data	489
26.4	What Is Geovisual Analytics?	490
26.5	The Self-Organizing Map (SOM)	491
26.6	Examples of Geovisual Analytics	493

26.6.1	TaxiVis: A System for Visualizing Taxi Trips in NYC	494
26.6.2	Mosaic Diagrams: A Technique for Visualizing Spatiotemporal Data.....	496
26.6.3	CarSenToGram: An Approach for Visualizing Twitter Data.....	497
26.6.4	Crowd Lens: A Tool for Visualizing OpenStreetMap Contributions.....	500
26.6.5	Use of a SOM for Sense-of-Place Analysis.....	502
26.7	Summary	505
26.8	Study Questions.....	505
	References	506
Chapter 27	Visualizing Uncertainty	509
27.1	Introduction	509
27.2	Learning Objectives	509
27.3	Basic Elements of Uncertainty	509
27.4	General Methods for Depicting Uncertainty.....	511
27.5	Visual Variables for Depicting Uncertainty.....	511
27.5.1	Some Examples of Intrinsic Visual Variables.....	511
27.5.2	Some Examples of Extrinsic Visual Variables.....	512
27.6	Applications of Visualizing Uncertainty.....	513
27.6.1	Handling the Uncertainty in Choropleth Maps.....	513
27.6.1.1	Using Confidence Levels (CLs) to Create Class Breaks.....	514
27.6.1.2	Using Maximum Likelihood Estimation to Create Class Breaks	515
27.6.1.3	Using the SAAR Software to Visualize Uncertainty	516
27.6.2	Visualizing Climate Change Uncertainty	516
27.6.3	Visualizing Uncertainty in Decision-Making.....	519
27.6.3.1	Visualizing the Uncertainty of Water Balance Models.....	519
27.6.3.2	Visualizing the Uncertainty of Forecasted Hurricane Paths.....	520
27.6.4	Examples of Interactivity and Animation.....	521
27.7	Using Sound to Represent Data Uncertainty.....	523
27.8	Summary	525
27.9	Study Questions.....	525
	References	526
Chapter 28	Virtual Environments and Augmented Reality.....	529
28.1	Introduction	529
28.2	Learning Objectives	529
28.3	Defining VEs and AR	529
28.4	Technologies for Creating VEs.....	531
28.4.1	Personalized Displays	531
28.4.2	Wall-Size Displays	531
28.4.3	Head-Mounted Displays.....	534
28.4.4	Room-Format and Drafting-Table Format Displays	534
28.5	The Four "I" Factors of VEs	535
28.5.1	Immersion.....	535
28.5.2	Interactivity	536
28.5.3	Information Intensity.....	536
28.5.4	Intelligence of Objects.....	537
28.6	Some Key Questions Regarding VEs.....	537
28.6.1	Are Specialized Symbols Necessary for Thematic Maps Created in VEs?.....	537
28.6.2	Are Stereoscopic Maps More Effective than Non-Stereoscopic Maps?	539
28.6.3	What Are Some Examples of VEs That Make Use of Caves and Wall-Size Displays?.....	540
28.6.3.1	Using a CAVE to Create Soils Maps	540
28.6.3.2	Using a Wall-Size Display to Obtain Public Input on Climate Change Scenarios	540
28.6.3.3	HMDs as a Potential Cost-Effective Solution for Collaborative Efforts.....	542
28.6.4	What Progress Has Been Made Toward Developing a Digital Earth?.....	542

28.7 Some Recent Examples of the Utilization of AR..... 543

 28.7.1 The Augmented Reality Sandbox 543

 28.7.2 Using AR to Enhance an Understanding of Topographic Maps..... 544

 28.7.3 Developing Novel Methods for Interacting with AR Environments..... 544

 28.7.4 Holograms 545

28.8 Health, Safety, and Social Issues..... 545

28.9 Summary 546

28.10 Study Questions..... 546

References 547

Glossary 551

Index..... 573