

Introduction to GIS Programming

A Practical Python Guide to Open Source
Geospatial Tools

Qiusheng Wu
2025

Contents

Preface	1
Introduction	3
Who is This Book For?	3
What This Book Covers	4
To Get the Most Out of This Book	5
Conventions Used in This Book	5
Downloading the Code Examples	6
Video Tutorials	6
Get in Touch	7
About the Author	7
I: Software Setup	9
1. Overview of Software Tools	11
1.1. Introduction	11
1.2. Learning Objectives	12
1.3. Essential Desktop Software Tools	12
1.4. Cloud Computing Platforms	14
1.5. Key Takeaways	16
2. Introduction to Python Package Management	18
2.1. Introduction	18
2.2. Learning Objectives	18
2.3. Installing Conda (Miniconda)	19
2.4. Understanding Conda Concepts	19
2.5. Creating Your First Geospatial Environment	20
2.6. Troubleshooting Conda	21
2.7. Essential Conda Commands	22
2.8. Introducing uv: The Fast Alternative	26
2.9. Best Practices for Package Management	28
2.10. Key Takeaways	29
2.11. Exercises	30
3. Setting Up Visual Studio Code	32
3.1. Introduction	32
3.2. Learning Objectives	32
3.3. Installing Visual Studio Code	33
3.4. Essential Extensions for Python Programming	33
3.5. Configuring VS Code	35
3.6. Essential Keyboard Shortcuts	36
3.7. Advanced Tips and Tricks	38
3.8. Troubleshooting Common Issues	38
3.9. References and Further Learning	39
3.10. Key Takeaways	39
3.11. Exercises	40
4. Version Control with Git	42
4.1. Introduction	42
4.2. Learning Objectives	42

4.3.	Installing Git	43
4.4.	Configuring Git	44
4.5.	Understanding Git Concepts	46
4.6.	Essential Git Commands	47
4.7.	Git Best Practices	51
4.8.	Collaboration Workflows	54
4.9.	Troubleshooting Common Issues	55
4.10.	Integration with Development Tools	56
4.11.	Key Takeaways	56
4.12.	Exercises	57
5.	<i>Using Google Colab</i>	59
5.1.	Introduction	59
5.2.	Learning Objectives	60
5.3.	Getting Started with Google Colab	60
5.4.	Essential Colab Features	61
5.5.	Advanced Colab Features	64
5.6.	Key Takeaways	65
5.7.	Exercises	66
6.	<i>Working with JupyterLab</i>	68
6.1.	Introduction	68
6.2.	Learning Objectives	69
6.3.	Installing and Setting Up JupyterLab	69
6.4.	Getting Started with JupyterLab	71
6.5.	Essential Keyboard Shortcuts	73
6.6.	Troubleshooting Common Issues	77
6.7.	Key Takeaways	78
6.8.	Exercises	79
II:	Python Programming Fundamentals	83
7.	<i>Variables and Data Types</i>	85
7.1.	Introduction	85
7.2.	Learning Objectives	85
7.3.	Variables in Python	85
7.4.	Naming Variables	86
7.5.	Data Types	87
7.6.	Escape Characters	88
7.7.	Comments in Python	88
7.8.	Working with Variables and Data Types	88
7.9.	Application in Geospatial Context	89
7.10.	Further Reading	90
7.11.	Key Takeaways	90
7.12.	Exercises	90
8.	<i>Python Data Structures</i>	91
8.1.	Introduction	91
8.2.	Learning Objectives	91
8.3.	Tuples	91
8.4.	Lists	92

8.5. Sets	94
8.6. Dictionaries	96
8.7. Data Structure Selection Guide	99
8.8. Key Takeaways	100
8.9. Exercises	100
9. String Operations	104
9.1. Introduction	104
9.2. Learning Objectives	104
9.3. Creating and Manipulating Strings	104
9.4. String Methods for Geospatial Data	106
9.5. String Formatting	109
9.6. String Operation Decision Guide	112
9.7. Key Takeaways	112
9.8. Exercises	113
10. Loops and Conditional Statements	115
10.1. Introduction	115
10.2. Learning Objectives	115
10.3. For Loops	115
10.4. While Loops	117
10.5. Control Statements: Making Decisions in Your Code	118
10.6. Combining Loops and Control Statements	119
10.7. Loop and Control Statement Decision Guide	121
10.8. Key Takeaways	122
10.9. Exercises	122
11. Functions and Classes	124
11.1. Introduction	124
11.2. Learning Objectives	124
11.3. Functions: Building Reusable Code Blocks	124
11.4. Classes: Organizing Data and Behavior Together	129
11.5. Combining Functions and Classes	131
11.6. Function and Class Design Guidelines	131
11.7. Key Takeaways	132
11.8. Exercises	132
12. Working with Files	134
12.1. Introduction	134
12.2. Learning Objectives	134
12.3. Creating a Sample File	134
12.4. Reading and Writing Files	135
12.5. Exception Handling	136
12.6. Combining File Handling and Exception Handling	138
12.7. Working with Different File Formats	140
12.8. Key Takeaways	141
12.9. Exercises	142
13. Data Analysis with NumPy and Pandas	145
13.1. Introduction	145
13.2. Learning Objectives	145
13.3. Introduction to NumPy	146

13.4.	Introduction to Pandas	155
13.5.	Combining NumPy and Pandas	161
13.6.	Key Takeaways	162
13.7.	Exercises	162
III:	Geospatial Programming with Python	165
14.	<i>Introduction to Geospatial Python</i>	167
14.1.	Introduction to Geospatial Python	167
15.	<i>Vector Data Analysis with GeoPandas</i>	171
15.1.	Introduction	171
15.2.	Learning Objectives	171
15.3.	Core Concepts	171
15.4.	Installing GeoPandas	171
15.5.	Creating GeoDataFrames	172
15.6.	Reading and Writing Geospatial Data	172
15.7.	Simple Accessors and Methods	173
15.8.	Plotting Geospatial Data	174
15.9.	Geometry Manipulations	175
15.10.	Spatial Queries and Relations	175
15.11.	Projections and Coordinate Reference Systems (CRS)	176
15.12.	Key Takeaways	176
15.13.	Exercises	177
16.	<i>Working with Raster Data using Rasterio</i>	178
16.1.	Working with Raster Data using Rasterio	178
17.	<i>Multi-dimensional Data with Xarray</i>	193
17.1.	Introduction	193
17.2.	Learning Objectives	193
17.3.	Core Concepts	194
17.4.	Installing Xarray	195
17.5.	Xarray Data Structures	196
17.6.	Loading a Dataset	196
17.7.	Working with DataArrays	196
17.8.	DataArray Components	196
17.9.	Indexing and Selecting Data	197
17.10.	Performing Operations on DataArrays	197
17.11.	Visualization with Xarray	197
17.12.	Working with Datasets	198
17.13.	Comparison with NumPy	198
17.14.	Advanced Indexing: Label vs. Position-Based Indexing	199
17.15.	High-Level Computations with Xarray	200
17.16.	Reading and Writing Files	201
17.17.	Advanced Xarray Concepts and Techniques	202
17.18.	Real-World Applications and Case Studies	205
17.19.	Best Practices and Performance Optimization	207
17.20.	Key Takeaways	209
17.21.	Exercises	210
18.	<i>Raster Analysis with Rioxarray</i>	211

18.1. Raster Analysis with Rioxarray	211
19. Interactive Visualization with Leafmap	219
19.1. Introduction	219
19.2. Learning Objectives	219
19.3. Installing leafmap	219
19.4. Creating interactive maps	220
19.5. Changing Basemaps	221
19.6. Visualizing Vector Data	223
19.7. Creating Choropleth Maps	226
19.8. Visualizing GeoParquet Data	227
19.9. Visualizing PMTiles	228
19.10. Visualizing Raster Data	231
19.11. Key Takeaways	239
19.12. Exercises	240
20. Geoprocessing with WhiteboxTools	251
20.1. Introduction	251
20.2. Learning Objectives	251
20.3. Why Whitebox?	251
20.4. Useful Resources for Whitebox	252
20.5. Installation	252
20.6. Watershed Analysis	253
20.7. LiDAR Data Analysis	260
20.8. Key Takeaways	263
20.9. Exercises	263
21. 3D Mapping with MapLibre	264
21.1. Introduction	264
21.2. Learning Objectives	264
21.3. Useful Resources	264
21.4. Installation and Setup	264
21.5. Creating Interactive Maps	265
21.6. Adding Map Controls	266
21.7. Adding Layers	269
21.8. Using MapTiler	271
21.9. 3D Mapping	273
21.10. Visualizing Vector Data	283
21.11. Visualizing Raster Data	297
21.12. Interacting with the Map	300
21.13. Customizing Layer Styles	304
21.14. Adding Custom Components	308
21.15. Visualizing PMTiles	318
21.16. Adding DeckGL Layers	326
21.17. Adding Google Earth Engine Data Layers	328
21.18. Animating Geospatial Data	330
21.19. Exporting to HTML	338
21.20. Key Takeaways	338
21.21. Exercises	339
22. Cloud Computing with Geemap	341

22.1.	Introduction	341
22.2.	Learning Objectives	341
22.3.	Introduction to Google Earth Engine	341
22.4.	Introduction to Interactive Maps and Tools	345
22.5.	The Earth Engine Data Catalog	347
22.6.	Earth Engine Data Types	349
22.7.	Earth Engine Raster Data	349
22.8.	Earth Engine Vector Data	351
22.9.	More Tools for Visualizing Earth Engine Data	354
22.10.	Processing of Vector Data	361
22.11.	Processing of Raster Data	363
22.12.	Working with Local Geospatial Data	369
22.13.	Accessing Cloud Optimized GeoTIFFs	374
22.14.	Exporting Earth Engine Data	375
22.15.	Creating Timelapse Animations	378
22.16.	Charting Earth Engine Data	382
22.17.	Key Takeaways	413
22.18.	Exercises	414
23.	<i>Hyperspectral Data Visualization with HyperCoast</i>	419
23.1.	Introduction	419
23.2.	Learning Objectives	419
23.3.	Environment Setup	419
23.4.	Finding Hyperspectral Data	419
23.5.	Downloading Hyperspectral Data	420
23.6.	Reading Hyperspectral Data	420
23.7.	Visualizing Hyperspectral Data	421
23.8.	Creating Image Cubes	422
23.9.	Interactive Slicing	423
23.10.	Interactive Thresholding	424
23.11.	Key Takeaways	425
23.12.	Exercises	425
24.	<i>Spatial Database Analysis with DuckDB</i>	426
24.1.	Introduction	426
24.2.	Learning Objectives	426
24.3.	Downloading Sample Datasets	426
24.4.	Installing DuckDB	426
24.5.	Installing Extensions	426
24.6.	Working with CSV Files	427
24.7.	Working with JSON Files	427
24.8.	Working with Pandas DataFrames	428
24.9.	Working with Parquet Files	428
24.10.	Working with GeoJSON Files	428
24.11.	Working with Shapefiles	429
24.12.	Working with GeoParquet Files	429
24.13.	Key Takeaways	430
24.14.	Exercises	430
25.	<i>GDAL and OGR</i>	431

25.1.	Introduction	431
25.2.	Learning Objectives	431
25.3.	Installation and Setup	432
25.4.	Understanding GDAL Architecture	432
25.5.	Working with Raster Data	433
25.6.	Working with Vector Data	435
25.7.	Coordinate Transformations	438
25.8.	Data Format Conversion	439
25.9.	Working with Real Datasets	440
25.10.	GDAL Command-Line Utilities	441
25.11.	Integration with Other Libraries	442
25.12.	Performance Tips and Best Practices	443
25.13.	Key Takeaways	444
25.14.	Exercises	445
26.	<i>Building Interactive Web Apps with Voila and Solara</i>	448
26.1.	Introduction	448
26.2.	Learning Objectives	448
26.3.	Installing Voila and Solara	448
26.4.	Creating Interactive Maps with Leafmap	449
26.5.	Creating a Voila Dashboard	451
26.6.	Introduction to Hugging Face Spaces	452
26.7.	Deploying a Voila Dashboard on Hugging Face	453
26.8.	Creating an Interactive Web App with Solara	454
26.9.	Deploying a Solara App on Hugging Face	456
26.10.	Key Takeaways	458
26.11.	Exercises	458