

SECOND EDITION

FUNDAMENTALS OF PYTHON: DATA STRUCTURES

KENNETH A. LAMBERT



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***Fundamentals of Python:
Data Structures, Second Edition***
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Table of Contents

	Preface	xi
CHAPTER 1	Basic Python Programming	1
	Basic Program Elements	2
	Programs and Modules	2
	An Example Python Program: Guessing a Number	2
	Editing, Compiling, and Running Python Programs	3
	Program Comments	4
	Lexical Elements	4
	Spelling and Naming Conventions	4
	Syntactic Elements	5
	Literals	5
	Operators and Expressions	6
	Function Calls	7
	The <code>print</code> Function	7
	The <code>input</code> Function	7
	Type Conversion Functions and Mixed-Mode Operations	7
	Optional and Keyword Function Arguments	7
	Variables and Assignment Statements	8
	Python Data Typing	9
	<code>import</code> Statements	9
	Getting Help on Program Components	9
	Control Statements	10
	Conditional Statements	10
	Using <code>if __name__ == "__main__"</code>	11
	Loop Statements	12
	Strings and Their Operations	12
	Operators	13
	Formatting Strings for Output	14
	Objects and Method Calls	15
	Built-In Python Collections and Their Operations	16
	Lists	16
	Tuples	17

Loops Over Sequences	17
Dictionaries.	18
Searching for a Value	18
Pattern Matching with Collections	18
Creating New Functions	19
Function Definitions	19
Recursive Functions	20
Nested Function Definitions	22
Higher-Order Functions	23
Creating Anonymous Functions with <code>lambda</code>	24
Catching Exceptions.	24
Files and Their Operations	25
Text File Output	26
Writing Numbers to a Text File	26
Reading Text from a Text File	27
Reading Numbers from a File	28
Reading and Writing Objects with <code>pickle</code>	29
Creating New Classes	30
CHAPTER 2 An Overview of Collections	37
Collection Types	38
Linear Collections	38
Hierarchical Collections	39
Graph Collections	39
Unordered Collections	40
Sorted Collections.	40
A Taxonomy of Collection Types	40
Operations on Collections	41
Fundamental Operations on All Collection Types	41
Type Conversion	43
Cloning and Equality	43
Iterators and Higher-Order Functions	44
Implementations of Collections	44
CHAPTER 3 Searching, Sorting, and Complexity Analysis .	49
Measuring the Efficiency of Algorithms	50
Measuring the Run Time of an Algorithm.	50
Counting Instructions	53
Measuring the Memory Used by an Algorithm	55
Complexity Analysis	55
Orders of Complexity	56
Big-O Notation	57
The Role of the Constant of Proportionality	58

Search Algorithms	59
Search for the Minimum	59
Sequential Search of a List	60
Best-Case, Worst-Case, and Average-Case Performance	60
Binary Search of a Sorted List	61
Comparing Data Items	62
Basic Sort Algorithms	64
Selection Sort	64
Bubble Sort	65
Insertion Sort	67
Best-Case, Worst-Case, and Average-Case Performance Revisited	68
Faster Sorting	69
Overview of Quicksort	70
Merge Sort	74
An Exponential Algorithm: Recursive Fibonacci	77
Converting Fibonacci to a Linear Algorithm	78

CHAPTER 4 Arrays and Linked Structures **89**

The Array Data Structure	90
Random Access and Contiguous Memory	92
Static Memory and Dynamic Memory	93
Physical Size and Logical Size	94
Operations on Arrays	94
Increasing the Size of an Array	95
Decreasing the Size of an Array	95
Inserting an Item into an Array That Grows	96
Removing an Item from an Array	97
Complexity Trade-Off: Time, Space, and Arrays	98
Two-Dimensional Arrays (Grids)	99
Processing a Grid	100
Creating and Initializing a Grid	100
Defining a Grid Class	101
Ragged Grids and Multidimensional Arrays	101
Linked Structures	102
Singly Linked Structures and Doubly Linked Structures	103
Noncontiguous Memory and Nodes	104
Defining a Singly Linked Node Class	106
Using the Singly Linked Node Class	106
Operations on Singly Linked Structures	108
Traversal	108
Searching	109
Replacement	110
Inserting at the Beginning	111

	Inserting at the End	111
	Removing at the Beginning	112
	Removing at the End.	113
	Inserting at Any Position	114
	Removing at Any Position	116
	Complexity Trade-Off: Time, Space, and Singly Linked Structures.	116
	Variations on a Link	118
	A Circular Linked Structure with a Dummy Header Node. .118	
	Doubly Linked Structures	119
CHAPTER 5	Interfaces, Implementations, and Polymorphism	126
	Developing an Interface	127
	Designing the Bag Interface	127
	Specifying Arguments and Return Values	129
	Constructors and Implementing Classes.	130
	Preconditions, Postconditions, Exceptions, and Documentation.	131
	Coding an Interface in Python	132
	Developing an Array-Based Implementation	134
	Choose and Initialize the Data Structures	134
	Complete the Easy Methods First	135
	Complete the Iterator	136
	Complete the Methods That Use the Iterator	137
	The <code>in</code> Operator and the <code>__contains__</code> Method.	137
	Complete the <code>remove</code> Method	138
	Developing a Link-Based Implementation.	139
	Initialize the Data Structures	139
	Complete the Iterator	140
	Complete the Methods <code>cTear</code> and <code>add</code>	140
	Complete the Method <code>remove</code>	141
	Run-Time Performance of the Two Bag Implementations. . .142	
	Testing the Two Bag Implementations	142
	Diagramming the Bag Resource with UML	144
CHAPTER 6	Inheritance and Abstract Classes	148
	Using Inheritance to Customize an Existing Class.	149
	Subclassing an Existing Class	150
	Revising the <code>__init__</code> Method.	150
	Adding a New <code>__contains__</code> Method.	152
	Modifying the Existing <code>add</code> Method	152

	Modifying the Existing <code>__add__</code> Method	153
	Run-Time Performance of <code>ArraySortedBag</code>	153
	A Note on Class Hierarchies in Python.	154
	Using Abstract Classes to Eliminate Redundant Code	155
	Designing an <code>AbstractBag</code> Class	155
	Redoing the <code>__init__</code> Method in <code>AbstractBag</code>	157
	Modifying the Subclasses of <code>AbstractBag</code>	157
	Generalizing the <code>__add__</code> Method in <code>AbstractBag</code>	158
	An Abstract Class for All Collections	159
	Integrating <code>AbstractCollection</code> into the Collection Hierarchy	159
	Using Two Iterators in the <code>__eq__</code> Method.	161
	A Professional-Quality Framework of Collections	162
CHAPTER 7	Stacks	167
	Overview of Stacks	168
	Using a Stack.	169
	The Stack Interface	169
	Instantiating a Stack.	170
	Example Application: Matching Parentheses	171
	Three Applications of Stacks	174
	Evaluating Arithmetic Expressions	174
	Evaluating Postfix Expressions	175
	Converting Infix to Postfix	176
	Backtracking	179
	Memory Management	181
	Implementations of Stacks	184
	Test Driver	184
	Adding Stacks to the Collection Hierarchy	185
	Array Implementation	186
	Linked Implementation	187
	The Role of the Abstract Stack Class	190
	Time and Space Analysis of the Two Implementations.	191
CHAPTER 8	Queues.	205
	Overview of Queues	206
	The Queue Interface and Its Use	207
	Two Applications of Queues	210
	Simulations	210
	Round-Robin CPU Scheduling	212
	Implementations of Queues.	213
	A Linked Implementation of Queues	213

An Array Implementation . . . . .	.215
Time and Space Analysis for the Two Implementations . . . . .	.217
Priority Queues . . . . .	.226

CHAPTER 9**Lists 239**

Overview of Lists . . . . .	.240
Using Lists . . . . .	.240
Index-Based Operations . . . . .	.241
Content-Based Operations . . . . .	.242
Position-Based Operations . . . . .	.242
Interfaces for Lists . . . . .	.247
Applications of Lists . . . . .	.249
Heap-Storage Management . . . . .	.249
Organization of Files on a Disk . . . . .	.250
Implementation of Other Collections . . . . .	.252
List Implementations . . . . .	.252
The Role of the <code>AbstractList</code> Class . . . . .	.252
An Array-Based Implementation . . . . .	.254
A Linked Implementation . . . . .	.255
Time and Space Analysis for the Two Implementations . . . . .	.258
Implementing a List Iterator . . . . .	.260
Role and Responsibilities of a List Iterator . . . . .	.260
Setting Up and Instantiating a List Iterator Class . . . . .	.261
The Navigational Methods in the List Iterator . . . . .	.262
The Mutator Methods in the List Iterator . . . . .	.263
Design of a List Iterator for a Linked List . . . . .	.264
Time and Space Analysis of List Iterator Implementations . . . . .	.265
Recursive List Processing . . . . .	.270
Basic Operations on a Lisp-Like List . . . . .	.271
Recursive Traversals of a Lisp-Like List . . . . .	.272
Building a Lisp-Like List . . . . .	.273
The Internal Structure of a Lisp-Like List . . . . .	.275
Printing Lisp-Like Lists in IDLE with <code>__repr__</code> . . . . .	.276
Lists and Functional Programming . . . . .	.277

CHAPTER 10**Trees 282**

An Overview of Trees . . . . .	.283
Tree Terminology . . . . .	.283
General Trees and Binary Trees . . . . .	.284
Recursive Definitions of Trees . . . . .	.285
Why Use a Tree? . . . . .	.286
The Shape of Binary Trees . . . . .	.288

Binary Tree Traversals	291
Preorder Traversal.	291
Inorder Traversal	291
Postorder Traversal	292
Level Order Traversal	292
Three Common Applications of Binary Trees	293
Heaps	293
Binary Search Trees	293
Expression Trees	295
Developing a Binary Search Tree	297
The Binary Search Tree Interface	297
Data Structure for the Linked Implementation	299
Complexity Analysis of Binary Search Trees	304
Recursive Descent Parsing and Programming	
Languages	304
Introduction to Grammars	305
Recognizing, Parsing, and Interpreting Sentences	
in a Language	306
Lexical Analysis and the Scanner	307
Parsing Strategies.	307
An Array Implementation of Binary Trees.	313
Implementing Heaps	315

CHAPTER 11 Sets and Dictionaries 322

Using Sets	323
The Python Set Class	324
A Sample Session with Sets	325
Applications of Sets	325
Relationship Between Sets and Bags	325
Relationship Between Sets and Dictionaries	326
Implementations of Sets	326
Array-Based and Linked Implementations of Sets	326
The AbstractSet Class.	327
The ArraySet Class	328
Using Dictionaries.	329
Array-Based and Linked Implementations of Dictionaries	330
The Entry Class	330
The AbstractDict Class	331
The ArrayDict Class	333
Complexity Analysis of the Array-Based and Linked	
Implementations of Sets and Dictionaries.	334
Hashing Strategies	335

	The Relationship of Collisions to Density	336
	Hashing with Nonnumeric Keys	337
	Linear Probing	339
	Quadratic Probing	340
	Chaining	341
	Complexity Analysis	342
	Hashing Implementation of Sets	349
	Hashing Implementation of Dictionaries	352
	Sorted Sets and Dictionaries	354
CHAPTER 12	Graphs	359
	Why Use Graphs?	360
	Graph Terminology	360
	Representations of Graphs	364
	Adjacency Matrix	365
	Adjacency List	366
	Analysis of the Two Representations	367
	Further Run-Time Considerations	368
	Graph Traversals	369
	A Generic Traversal Algorithm	369
	Breadth-First and Depth-First Traversals	370
	Graph Components	372
	Trees Within Graphs	373
	Spanning Trees and Forests	373
	Minimum Spanning Tree	373
	Algorithms for Minimum Spanning Trees	373
	Topological Sort.	376
	The Shortest-Path Problem.	377
	Dijkstra's Algorithm	377
	The Initialization Step	377
	The Computation Step	379
	Representing and Working with Infinity.	380
	Analysis	380
	Floyd's Algorithm	380
	Analysis	382
	Developing a Graph Collection	382
	Example Use of the Graph Collection	383
	The Class <code>LinkedDirectedGraph</code>	384
	The Class <code>LinkedVertex</code>	388
	The Class <code>LinkedEdge</code>	390
	Glossary	401
	Index	410

Preface

Welcome to *Fundamentals of Python: Data Structures, 2nd Edition*. This text is intended for a second semester course in programming and problem solving with data structures. It covers the material taught in a typical Computer Science 2 course (CS2) at the undergraduate level. Although this book uses the Python programming language, you need only have a basic knowledge of programming in a high-level programming language before beginning Chapter 1.

What You'll Learn

The book covers four major aspects of computing:

1. **Programming basics**—Data types, control structures, algorithm development, and program design with functions are basic ideas that you need to master to solve problems with computers. You'll review these core topics in the Python programming language and employ your understanding of them to solve a wide range of problems.
2. **Object-Oriented Programming (OOP)**—Object-Oriented Programming is the dominant programming paradigm used to develop large software systems. You'll be introduced to the fundamental principles of OOP so that you can apply them successfully. Unlike other textbooks, this book helps you develop a professional-quality framework of collection classes to illustrate these principles.
3. **Data structures**—Most useful programs rely on data structures to solve problems. At the most concrete level, data structures include arrays and various types of linked structures. You'll use these data structures to implement various types of collection structures, such as stacks, queues, lists, trees, bags, sets, dictionaries, and graphs. You'll also learn to use complexity analysis to evaluate the space/time trade-offs of different implementations of these collections.
4. **Software development life cycle**—Rather than isolate software development techniques in one or two chapters, this book deals with them throughout in the context of numerous case studies. Among other things, you'll learn that coding a program is often not the most difficult or challenging aspect of problem solving and software development.

Why Python?

Computer technology and applications have become increasingly more sophisticated over the past three decades, and so has the computer science curriculum, especially at the introductory level. Today's students learn a bit of programming and problem solving and are then expected to move quickly into topics like software development, complexity analysis, and data structures that, 30 years ago, were relegated to advanced courses. In addition, the ascent of object-oriented programming as the dominant paradigm has led instructors and textbook authors to bring powerful, industrial-strength programming languages such as C++ and Java into the introductory curriculum. As a result, instead of experiencing the rewards and excitement of solving problems with computers, beginning computer science students often become overwhelmed by the combined tasks of mastering advanced concepts as well as the syntax of a programming language.

This book uses the Python programming language as a way of making the second course in computer science more manageable and attractive for students and instructors alike. Python has the following pedagogical benefits:

- Python has simple, conventional syntax. Python statements are very close to those of pseudocode algorithms, and Python expressions use the conventional notation found in algebra. Thus, you can spend less time dealing with the syntax of a programming language and more time learning to solve interesting problems.
- Python has safe semantics. Any expression or statement whose meaning violates the definition of the language produces an error message.
- Python scales well. It is easy for beginners to write simple programs in Python. Python also includes all the advanced features of a modern programming language, such as support for data structures and object-oriented software development, for use when they become necessary, especially in the second course in computer science.
- Python is highly interactive. You can enter expressions and statements at an interpreter's prompts to try out experimental code and receive immediate feedback. You can also compose longer code segments and save them in script files to be loaded and run as modules or stand-alone applications.
- Python is general purpose. In today's context, this means that the language includes resources for contemporary applications, including media computing and web services.
- Python is free and is in widespread use in the industry. You can download Python to run on a variety of devices. There is a large Python user community, and expertise in Python programming has great resume value.

To summarize these benefits, Python is a comfortable and flexible vehicle for expressing ideas about computation, both for beginners and for experts. If you learn these ideas well in the first year, you should have no problems making a quick transition to other languages needed for courses later in the curriculum. Most importantly, you will spend less time staring at a computer screen and more time thinking about interesting problems to solve.

Organization of This Book

The approach in this book is easygoing, with each new concept introduced only when it is needed.

Chapter 1 provides a review of the features of Python programming that are needed to begin a second course in programming and problem solving in Python. The content of this chapter is organized so that you can skim it quickly if you have experience in Python programming, or you can dig a bit deeper to get up to speed in the language if you are new to Python.

Chapters 2 through 12 covers the major topics in a typical CS2 course, especially the specification, implementation, and application of abstract data types, with the collection types as the primary vehicle and focus. Along the way, you will be thoroughly exposed to object-oriented programming techniques and the elements of good software design. Other important CS2 topics include recursive processing of data, search and sort algorithms, and the tools used in software development, such as complexity analysis and graphical notations (UML) to document designs.

Chapter 2 introduces the concept of an abstract data type (ADT) and provides an overview of various categories of collection ADTs.

Chapters 3 and 4 explore the data structures used to implement most collections and the tools for analyzing their performance trade-offs. Chapter 3 introduces complexity analysis with big-O notation. Enough material is presented to enable you to perform simple analyses of the running time and memory usage of algorithms and data structures, using search and sort algorithms as examples. Chapter 4 covers the details of processing arrays and linear linked structures, the concrete data structures used to implement most collections. You'll learn the underlying models of computer memory that support arrays and linked structures and the time/space trade-offs that they entail.

Chapters 5 and 6 shift the focus to the principles of object-oriented design. These principles are used to organize a professional-quality framework of collection classes that will be covered in detail in later chapters.

Chapter 5 is concerned with the critical difference between interface and implementation. A single interface and several implementations of a bag collection are developed as a first example. Emphasis is placed on the inclusion of conventional methods in an interface, to allow different types of collections to collaborate in applications. For example, one such method creates an iterator, which allows you to traverse any collection with a simple loop. Other topics covered in this chapter include polymorphism and information hiding, which directly stem from the difference between interface and implementation.

Chapter 6 shows how class hierarchies can reduce the amount of redundant code in an object-oriented software system. The related concepts of inheritance, dynamic binding of method calls, and abstract classes are introduced here and used throughout the remaining chapters.

Armed with these concepts and principles, you'll then be ready to consider the other major collection ADTs, which form the subject of Chapters 7 through 12.

Chapters 7 through 9 present the linear collections, stacks, queues, and lists. Each collection is viewed first from the perspective of its users, who are aware only of an interface and a set of performance characteristics possessed by a chosen implementation. The use of each

collection is illustrated with one or more applications, and then several implementations are developed, and their performance trade-offs are analyzed.

Chapters 10 through 12 present advanced data structures and algorithms as a transition to later courses in computer science. Chapter 10 discusses various tree structures, including binary search trees, heaps, and expression trees. Chapter 11 examines the implementation of the unordered collections, bags, sets, and dictionaries, using hashing strategies. Chapter 12 introduces graphs and graph-processing algorithms.

As mentioned earlier, this book is unique in presenting a professional-quality framework of collection types. Instead of encountering a series of apparently unrelated collections, you will explore the place of each collection in an integrated whole. This approach allows you to see what the collection types have in common as well as what makes each one unique. At the same time, you will be exposed to a realistic use of inheritance and class hierarchies, topics in object-oriented software design that are difficult to motivate and exemplify at this level of the curriculum.

Special Features

This book explains and develops concepts carefully, using frequent examples and diagrams. New concepts are then applied in complete programs to show how they aid in solving problems. The chapters place an early and consistent emphasis on good writing habits and neat, readable documentation.

The book includes several other important features:

- **Case studies**—These present complete Python programs ranging from the simple to the substantial. To emphasize the importance and usefulness of the software development life cycle, case studies are discussed in the framework of a user request, followed by analysis, design, implementation, and suggestions for testing, with well-defined tasks performed at each stage. Some case studies are extended in end-of-chapter programming projects.
- **Chapter summaries**—Each chapter after the first one ends with a summary of the major concepts covered in the chapter.
- **Key terms**—When a new term is introduced in the text, it appears in bold face. Definitions of the key terms are also collected in a glossary.
- **Exercises**—Most major sections of each chapter after the first one end with exercise questions that reinforce the reading by asking basic questions about the material in the section. After Chapter 2, each chapter ends with review questions.
- **Programming projects**—Each chapter ends with a set of programming projects of varying difficulty.

New in This Edition

The most obvious change in this edition is the addition of full color. All program examples include the color coding used in Python's IDLE, so students can easily identify program elements such as keywords, comments, and function, method, and class names. Learning

objectives have been added to the beginning of each chapter. Several new figures have been added to illustrate concepts, and many programming projects have been added or reworked. A new section on iterators and higher-order functions has been added to Chapter 2. Finally, a new section on Lisp-like lists, recursive list processing, and functional programming has been added to Chapter 9.

Instructor Resources

MindTap

MindTap activities for *Fundamentals of Python: Data Structures* are designed to help students master the skills they need in today's workforce. Research shows employers need critical thinkers, troubleshooters, and creative problem-solvers to stay relevant in our fast-paced, technology-driven world. MindTap helps you achieve this with assignments and activities that provide hands-on practice and real-life relevance. Students are guided through assignments that help them master basic knowledge and understanding before moving on to more challenging problems.

All MindTap activities and assignments are tied to defined unit learning objectives. Hands-on coding labs provide real-life application and practice. Readings and dynamic visualizations support the lecture, while a post-course assessment measures exactly how much a class stands in terms of progress, engagement, and completion rates. Use the content and learning path as-is, or pick and choose how our materials will wrap around yours. You control what the students see and when they see it. Learn more at <http://www.cengage.com/mindtap/>.

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The following teaching tools are available for download at the Companion Site for this text. Go to instructor.cengage.com and sign in to the instructor account. Search for the textbook and add the text to the instructor dashboard.

- **Instructor's Manual:** The Instructor's Manual that accompanies this textbook includes additional instructional material to assist in class preparation, including items such as Overviews, Chapter Objectives, Teaching Tips, Quick Quizzes, Class Discussion Topics, Additional Projects, Additional Resources, and Key Terms. A sample syllabus is also available.
- **Test Bank:** Cengage Testing Powered by Cognero is a flexible, online system that allows you to:
 - author, edit, and manage test bank content from multiple Cengage solutions
 - create multiple test versions in an instant
 - deliver tests from your LMS, your classroom, or wherever you want
- **PowerPoint Presentations:** This text provides PowerPoint slides to accompany each chapter. Slides may be used to guide classroom presentations, to make available to students for chapter review, or to print as classroom handouts. Files are provided for every figure in the text. Instructors may use the files to customize PowerPoint slides, illustrate quizzes, or create handouts.

- **Solutions:** Solutions to all programming exercises are available. If an input file is needed to run a programming exercise, it is included with the solution file.
- **Source Code:** The source code is available at www.cengage.com. If an input file is needed to run a program, it is included with the source code.



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We have tried to produce a high-quality text, but should you encounter any errors, please report them to lambertk@wlu.edu. A listing of errata, should they be found, as well as other information about the book, will be posted on the website <http://home.wlu.edu/~lambertk/python/>.

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About the Author

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Dedication

To Brenda Wilson, with love and admiration.
Kenneth A. Lambert
Lexington, VA