Dusty Phillips, Chetan Giridhar,
Sakis Kasampalis

Python:Master the Art of Design Patterns

Ensure your code sleek, efficient and elegant by mastering powerful Python design patterns

Packt

Python: Master the Art of Design Patterns

Ensure your code is sleek, efficient and elegant by mastering powerful Python design patterns

A course in three modules

BIRMINGHAM - MUMBAI

Python: Master the Art of Design Patterns

Published on: September 2016

Published by Packt Publishing Ltd.
Livery Place
35 Livery Street
Birmingham B3 2PB, UK.

ISBN 978-1-78712-518-6

www.packtpub.com

Credits

Authors

Dusty Phillips

Chetan Giridhar

Sakis Kasampalis

Reviewers

AMahdy AbdElAziz

Grigoriy Beziuk

Krishna Bharadwaj

Justin Cano

Anthony Petitbois

Claudio Rodriguez

Maurice HT Ling

Evan Dempsey

Amitabh Sharma

Yogendra Sharma

Patrycja Szabłowska

Content Development Editor

Trusha Shriyan

Graphics

Kirk D'Phena

Production Coordinator

Shantanu N. Zagade

Preface

Python is an object-oriented, scripting language that is used in wide range of categories. In software engineering, a design pattern is a recommended solution to a software design problem. Although not new, design patterns remain one of the hottest topics in software engineering. Python 3 is more versatile and easier to use than ever. It runs on all major platforms in a huge array of use cases. Coding in Python minimizes development time and increases productivity in comparison to other languages. Clean, maintainable code is easy to both read and write using Python's clear, concise syntax.

If you love designing and want to learn everything about it but have no idea where to begin, then this course is built just for you. This learning path is divided into three modules which will take you in this incredible journey of design patterns.

What this learning path covers

Module 1, Python 3 Object-oriented Programming - Second Edition, This module is loosely divided into four major parts. In the first four chapters, we will dive into the formal principles of object-oriented programming and how Python leverages them. In chapters 5 through 8, we will cover some of Python's idiosyncratic applications of these principles by learning how they are applied to a variety of Python's built-in functions. Chapters 9 through 11 cover design patterns, and the final two chapters discuss two bonus topics related to Python programming that may be of interest.

Module 2, Learning Python Design Patterns - Second Edition, Building on the success of the previous edition, Learning Python Design Patterns, Second Edition will help you implement real-world scenarios with Python's latest release, Python v3.5. We start by introducing design patterns from the Python perspective. As you progress through the module, you will learn about Singleton patterns, Factory patterns, and Façade patterns in detail. After this, we'll look at how to control object access with proxy patterns. It also covers observer patterns, command patterns, and compound patterns. By the end of the module, you will have enhanced your professional abilities in software architecture, design, and development.

Module 3, Mastering Python Design Patterns, This module focuses on design patterns in Python. Python is different than most common programming languages used in popular design patterns books (usually Java [FFBS04] or C++ [GOF95]). It supports duck-typing, functions are first-class citizens, and some patterns (for instance, iterator and decorator) are built-in features. The intent of this module is to demonstrate the most fundamental design patterns, not all patterns that have been documented so far [`j.mp/wikidpc`]. The code examples focus on using idiomatic Python when applicable [`j.mp/idiompyt`]. If you are not familiar with the Zen of Python, it is a good idea to open the Python REPL right now and execute **import this**. The Zen of Python is both amusing and meaningful.

What you need for this learning path

All the examples in this course rely on the Python 3 interpreter. Make sure you are not using Python 2.7 or earlier. At the time of writing, Python 3.4 was the latest release of Python. Most examples will work on earlier revisions of Python 3, but you are encouraged to use the latest version to minimize frustration.

All of the examples should run on any operating system supported by Python. If this is not the case, please report it as a bug.

Some of the examples need a working Internet connection. You'll probably want to have one of these for extracurricular research and debugging anyway!

In addition, some of the examples in this course rely on third-party libraries that do not ship with Python. These are introduced within the course at the time they are used, so you do not need to install them in advance. However, for completeness, here is a list:

- pip
- requests
- pillow
- bitarray

Who this learning path is for

Python developers and software architects who care about software design principles and details of application development aspects in Python. Programmers of other languages who are interested in Python can also benefit from this course.

Reader feedback

Feedback from our readers is always welcome. Let us know what you think about this course—what you liked or disliked. Reader feedback is important for us as it helps us develop titles that you will really get the most out of.

To send us general feedback, simply e-mail `feedback@packtpub.com`, and mention the course's title in the subject of your message.

If there is a topic that you have expertise in and you are interested in either writing or contributing to a book, see our author guide at `www.packtpub.com/authors`.

Customer support

Now that you are the proud owner of a Packt course, we have a number of things to help you to get the most from your purchase.

Downloading the example code

You can download the example code files for this course from your account at `http://www.packtpub.com`. If you purchased this course elsewhere, you can visit `http://www.packtpub.com/support` and register to have the files e-mailed directly to you.

You can download the code files by following these steps:

1. Log in or register to our website using your e-mail address and password.
2. Hover the mouse pointer on the **SUPPORT** tab at the top.
3. Click on **Code Downloads & Errata**.
4. Enter the name of the course in the **Search** box.
5. Select the course for which you're looking to download the code files.
6. Choose from the drop-down menu where you purchased this course from.
7. Click on **Code Download**.

You can also download the code files by clicking on the **Code Files** button on the course's webpage at the Packt Publishing website. This page can be accessed by entering the course's name in the **Search** box. Please note that you need to be logged in to your Packt account.

Once the file is downloaded, please make sure that you unzip or extract the folder using the latest version of:

- WinRAR / 7-Zip for Windows
- Zipeg / iZip / UnRarX for Mac
- 7-Zip / PeaZip for Linux

The code bundle for the course is also hosted on GitHub at `https://github.com/PacktPublishing/Python_Master-the-Art-of-Design-Patterns`. We also have other code bundles from our rich catalog of books, videos, and courses available at `https://github.com/PacktPublishing/`. Check them out!

Errata

Although we have taken every care to ensure the accuracy of our content, mistakes do happen. If you find a mistake in one of our courses—maybe a mistake in the text or the code—we would be grateful if you could report this to us. By doing so, you can save other readers from frustration and help us improve subsequent versions of this course. If you find any errata, please report them by visiting `http://www.packtpub.com/submit-errata`, selecting your course, clicking on the **Errata Submission Form** link, and entering the details of your errata. Once your errata are verified, your submission will be accepted and the errata will be uploaded to our website or added to any list of existing errata under the Errata section of that title.

To view the previously submitted errata, go to `https://www.packtpub.com/books/content/support` and enter the name of the course in the search field. The required information will appear under the **Errata** section.

Piracy

Piracy of copyrighted material on the Internet is an ongoing problem across all media. At Packt, we take the protection of our copyright and licenses very seriously. If you come across any illegal copies of our works in any form on the Internet, please provide us with the location address or website name immediately so that we can pursue a remedy.

Please contact us at `copyright@packtpub.com` with a link to the suspected pirated material.

We appreciate your help in protecting our authors and our ability to bring you valuable content.

Questions

If you have a problem with any aspect of this course, you can contact us at `questions@packtpub.com`, and we will do our best to address the problem.

Module 1: Python 3 Object-Oriented Programming - Second Edition

Module 2: Learning Python Design Patterns - Second Edition

Module 1

Python 3 Object-Oriented Programming - Second Edition

Unleash the power of Python 3 objects

1
Object-oriented Design

In software development, design is often considered as the step done *before* programming. This isn't true; in reality, analysis, programming, and design tend to overlap, combine, and interweave. In this chapter, we will cover the following topics:

- What object-oriented means
- The difference between object-oriented design and object-oriented programming
- The basic principles of an object-oriented design
- Basic **Unified Modeling Language** (**UML**) and when it isn't evil

Introducing object-oriented

Everyone knows what an object is—a tangible thing that we can sense, feel, and manipulate. The earliest objects we interact with are typically baby toys. Wooden blocks, plastic shapes, and over-sized puzzle pieces are common first objects. Babies learn quickly that certain objects do certain things: bells ring, buttons press, and levers pull.

The definition of an object in software development is not terribly different. Software objects are not typically tangible things that you can pick up, sense, or feel, but they are models of something that can do certain things and have certain things done to them. Formally, an object is a collection of **data** and associated **behaviors**.

So, knowing what an object is, what does it mean to be object-oriented? Oriented simply means *directed toward*. So object-oriented means functionally directed towards modeling objects. This is one of the many techniques used for modeling complex systems by describing a collection of interacting objects via their data and behavior.

If you've read any hype, you've probably come across the terms object-oriented analysis, object-oriented design, object-oriented analysis and design, and object-oriented programming. These are all highly related concepts under the general object-oriented umbrella.

In fact, analysis, design, and programming are all stages of software development. Calling them object-oriented simply specifies what style of software development is being pursued.

Object-oriented analysis (**OOA**) is the process of looking at a problem, system, or task (that somebody wants to turn into an application) and identifying the objects and interactions between those objects. The analysis stage is all about *what* needs to be done.

The output of the analysis stage is a set of requirements. If we were to complete the analysis stage in one step, we would have turned a task, such as, I need a website, into a set of requirements. For example:

Website visitors need to be able to (*italic* represents actions, **bold** represents objects):

- *review* our **history**
- *apply* for **jobs**
- *browse*, *compare*, and *order* **products**

In some ways, analysis is a misnomer. The baby we discussed earlier doesn't analyze the blocks and puzzle pieces. Rather, it will explore its environment, manipulate shapes, and see where they might fit. A better turn of phrase might be object-oriented exploration. In software development, the initial stages of analysis include interviewing customers, studying their processes, and eliminating possibilities.

Object-oriented design (**OOD**) is the process of converting such requirements into an implementation specification. The designer must name the objects, define the behaviors, and formally specify which objects can activate specific behaviors on other objects. The design stage is all about *how* things should be done.

The output of the design stage is an implementation specification. If we were to complete the design stage in a single step, we would have turned the requirements defined during object-oriented analysis into a set of classes and interfaces that could be implemented in (ideally) any object-oriented programming language.

Object-oriented programming (**OOP**) is the process of converting this perfectly defined design into a working program that does exactly what the CEO originally requested.

Yeah, right! It would be lovely if the world met this ideal and we could follow these stages one by one, in perfect order, like all the old textbooks told us to. As usual, the real world is much murkier. No matter how hard we try to separate these stages, we'll always find things that need further analysis while we're designing. When we're programming, we find features that need clarification in the design.

Most twenty-first century development happens in an iterative development model. In iterative development, a small part of the task is modeled, designed, and programmed, then the program is reviewed and expanded to improve each feature and include new features in a series of short development cycles.

The rest of this book is about object-oriented programming, but in this chapter, we will cover the basic object-oriented principles in the context of design. This allows us to understand these (rather simple) concepts without having to argue with software syntax or Python interpreters.

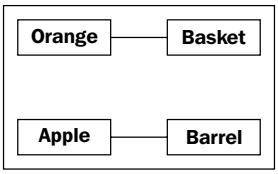
Objects and classes

So, an object is a collection of data with associated behaviors. How do we differentiate between types of objects? Apples and oranges are both objects, but it is a common adage that they cannot be compared. Apples and oranges aren't modeled very often in computer programming, but let's pretend we're doing an inventory application for a fruit farm. To facilitate the example, we can assume that apples go in barrels and oranges go in baskets.

Now, we have four kinds of objects: apples, oranges, baskets, and barrels. In object-oriented modeling, the term used for *kind of object* is **class**. So, in technical terms, we now have four classes of objects.

What's the difference between an object and a class? Classes describe objects. They are like blueprints for creating an object. You might have three oranges sitting on the table in front of you. Each orange is a distinct object, but all three have the attributes and behaviors associated with one class: the general class of oranges.

The relationship between the four classes of objects in our inventory system can be described using a **Unified Modeling Language** (invariably referred to as **UML**, because three letter acronyms never go out of style) class diagram. Here is our first class diagram:



This diagram shows that an **Orange** is somehow associated with a **Basket** and that an **Apple** is also somehow associated with a **Barrel**. Association is the most basic way for two classes to be related.

UML is very popular among managers, and occasionally disparaged by programmers. The syntax of a UML diagram is generally pretty obvious; you don't have to read a tutorial to (mostly) understand what is going on when you see one. UML is also fairly easy to draw, and quite intuitive. After all, many people, when describing classes and their relationships, will naturally draw boxes with lines between them. Having a standard based on these intuitive diagrams makes it easy for programmers to communicate with designers, managers, and each other.

However, some programmers think UML is a waste of time. Citing iterative development, they will argue that formal specifications done up in fancy UML diagrams are going to be redundant before they're implemented, and that maintaining these formal diagrams will only waste time and not benefit anyone.

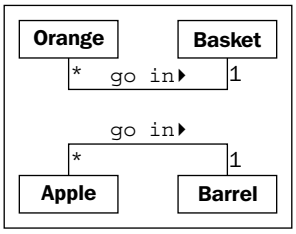
Depending on the corporate structure involved, this may or may not be true. However, every programming team consisting of more than one person will occasionally has to sit down and hash out the details of the subsystem it is currently working on. UML is extremely useful in these brainstorming sessions for quick and easy communication. Even those organizations that scoff at formal class diagrams tend to use some informal version of UML in their design meetings or team discussions.

Further, the most important person you will ever have to communicate with is yourself. We all think we can remember the design decisions we've made, but there will always be the *Why did I do that?* moments hiding in our future. If we keep the scraps of papers we did our initial diagramming on when we started a design, we'll eventually find them a useful reference.

This chapter, however, is not meant to be a tutorial in UML. There are many of these available on the Internet, as well as numerous books available on the topic. UML covers far more than class and object diagrams; it also has a syntax for use cases, deployment, state changes, and activities. We'll be dealing with some common class diagram syntax in this discussion of object-oriented design. You'll find that you can pick up the structure by example, and you'll subconsciously choose the UML-inspired syntax in your own team or personal design sessions.

Our initial diagram, while correct, does not remind us that apples go in barrels or how many barrels a single apple can go in. It only tells us that apples are somehow associated with barrels. The association between classes is often obvious and needs no further explanation, but we have the option to add further clarification as needed.

The beauty of UML is that most things are optional. We only need to specify as much information in a diagram as makes sense for the current situation. In a quick whiteboard session, we might just quickly draw lines between boxes. In a formal document, we might go into more detail. In the case of apples and barrels, we can be fairly confident that the association is, **many apples go in one barrel**, but just to make sure nobody confuses it with, **one apple spoils one barrel**, we can enhance the diagram as shown:



This diagram tells us that oranges **go in** baskets with a little arrow showing what goes in what. It also tells us the number of that object that can be used in the association on both sides of the relationship. One **Basket** can hold many (represented by a *) **Orange** objects. Any one **Orange** can go in exactly one **Basket**. This number is referred to as the multiplicity of the object. You may also hear it described as the cardinality. These are actually slightly distinct terms. Cardinality refers to the actual number of items in the set, whereas multiplicity specifies how small or how large this number could be.

I frequently forget which side of a relationship the multiplicity goes on. The multiplicity nearest to a class is the number of objects of that class that can be associated with any one object at the other end of the association. For the apple goes in barrel association, reading from left to right, many instances of the **Apple** class (that is many **Apple** objects) can go in any one **Barrel**. Reading from right to left, exactly one **Barrel** can be associated with any one **Apple**.

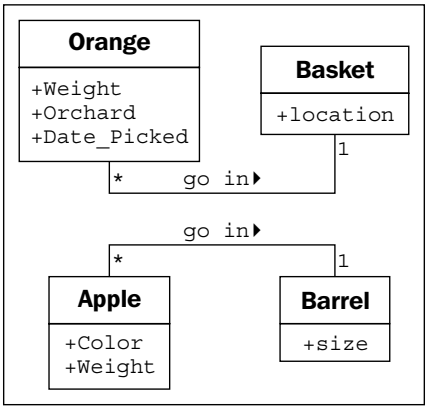
Specifying attributes and behaviors

We now have a grasp of some basic object-oriented terminology. Objects are instances of classes that can be associated with each other. An object instance is a specific object with its own set of data and behaviors; a specific orange on the table in front of us is said to be an instance of the general class of oranges. That's simple enough, but what are these data and behaviors that are associated with each object?

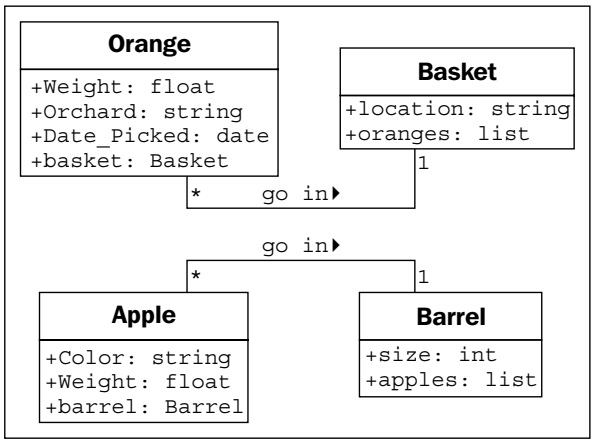
Data describes objects

Let's start with data. Data typically represents the individual characteristics of a certain object. A class can define specific sets of characteristics that are shared by all objects of that class. Any specific object can have different data values for the given characteristics. For example, our three oranges on the table (if we haven't eaten any) could each weigh a different amount. The orange class could then have a weight **attribute**. All instances of the orange class have a weight attribute, but each orange has a different value for this attribute. Attributes don't have to be unique, though; any two oranges may weigh the same amount. As a more realistic example, two objects representing different customers might have the same value for a first name attribute.

Attributes are frequently referred to as **members** or **properties**. Some authors suggest that the terms have different meanings, usually that attributes are settable, while properties are read-only. In Python, the concept of "read-only" is rather pointless, so throughout this book, we'll see the two terms used interchangeably. In addition, as we'll discuss in *Chapter 5*, *When to Use Object-oriented Programming*, the property keyword has a special meaning in Python for a particular kind of attribute.



In our fruit inventory application, the fruit farmer may want to know what orchard the orange came from, when it was picked, and how much it weighs. They might also want to keep track of where each basket is stored. Apples might have a color attribute, and barrels might come in different sizes. Some of these properties may also belong to multiple classes (we may want to know when apples are picked, too), but for this first example, let's just add a few different attributes to our class diagram:



Depending on how detailed our design needs to be, we can also specify the type for each attribute. Attribute types are often primitives that are standard to most programming languages, such as integer, floating-point number, string, byte, or Boolean. However, they can also represent data structures such as lists, trees, or graphs, or most notably, other classes. This is one area where the design stage can overlap with the programming stage. The various primitives or objects available in one programming language may be somewhat different from what is available in other languages.

Usually, we don't need to be overly concerned with data types at the design stage, as implementation-specific details are chosen during the programming stage. Generic names are normally sufficient for design. If our design calls for a list container type, the Java programmers can choose to use a `LinkedList` or an `ArrayList` when implementing it, while the Python programmers (that's us!) can choose between the `list` built-in and a `tuple`.

In our fruit-farming example so far, our attributes are all basic primitives. However, there are some implicit attributes that we can make explicit—the associations. For a given orange, we might have an attribute containing the basket that holds that orange.

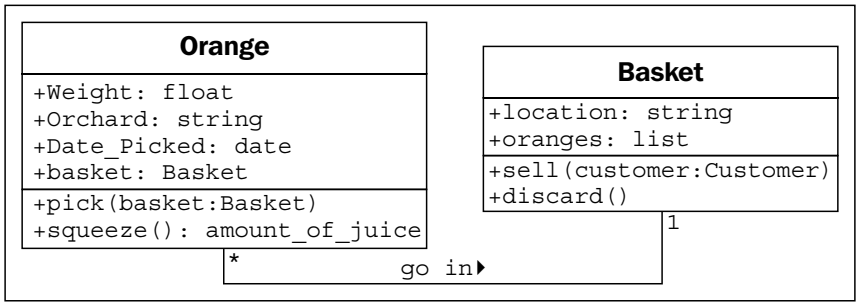
Behaviors are actions

Now, we know what data is, but what are behaviors? Behaviors are actions that can occur on an object. The behaviors that can be performed on a specific class of objects are called **methods**. At the programming level, methods are like functions in structured programming, but they magically have access to all the data associated with this object. Like functions, methods can also accept **parameters** and return **values**.

Parameters to a method are a list of objects that need to be **passed** into the method that is being called (the objects that are passed in from the calling object are usually referred to as **arguments**). These objects are used by the method to perform whatever behavior or task it is meant to do. Returned values are the results of that task.

We've stretched our "comparing apples and oranges" example into a basic (if far-fetched) inventory application. Let's stretch it a little further and see if it breaks. One action that can be associated with oranges is the **pick** action. If you think about implementation, **pick** would place the orange in a basket by updating the **basket** attribute of the orange, and by adding the orange to the **oranges** list on the **Basket**. So, **pick** needs to know what basket it is dealing with. We do this by giving the **pick** method a **basket** parameter. Since our fruit farmer also sells juice, we can add a **squeeze** method to **Orange**. When squeezed, **squeeze** might return the amount of juice retrieved, while also removing the **Orange** from the **basket** it was in.

Basket can have a **sell** action. When a basket is sold, our inventory system might update some data on as-yet unspecified objects for accounting and profit calculations. Alternatively, our basket of oranges might go bad before we can sell them, so we add a **discard** method. Let's add these methods to our diagram:



Adding models and methods to individual objects allows us to create a **system** of interacting objects. Each object in the system is a member of a certain class. These classes specify what types of data the object can hold and what methods can be invoked on it. The data in each object can be in a different state from other objects of the same class, and each object may react to method calls differently because of the differences in state.

Object-oriented analysis and design is all about figuring out what those objects are and how they should interact. The next section describes principles that can be used to make those interactions as simple and intuitive as possible.

Hiding details and creating the public interface

The key purpose of modeling an object in object-oriented design is to determine what the public **interface** of that object will be. The interface is the collection of attributes and methods that other objects can use to interact with that object. They do not need, and are often not allowed, to access the internal workings of the object. A common real-world example is the television. Our interface to the television is the remote control. Each button on the remote control represents a method that can be called on the television object. When we, as the calling object, access these methods, we do not know or care if the television is getting its signal from an antenna, a cable connection, or a satellite dish. We don't care what electronic signals are being sent to adjust the volume, or whether the sound is destined to speakers or headphones. If we open the television to access the internal workings, for example, to split the output signal to both external speakers and a set of headphones, we will void the warranty.

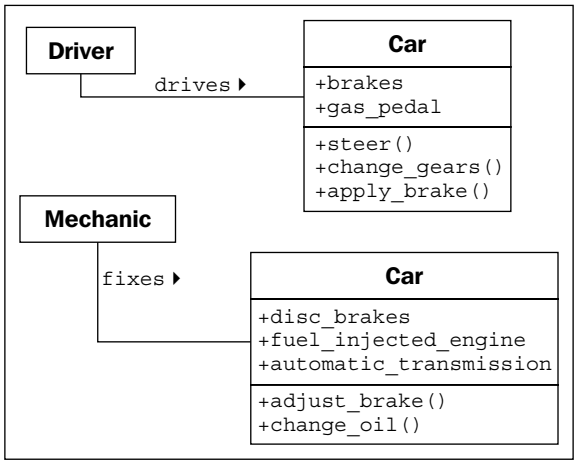
This process of hiding the implementation, or functional details, of an object is suitably called **information hiding**. It is also sometimes referred to as **encapsulation**, but encapsulation is actually a more all-encompassing term. Encapsulated data is not necessarily hidden. Encapsulation is, literally, creating a capsule and so think of creating a time capsule. If you put a bunch of information into a time capsule, lock and bury it, it is both encapsulated and the information is hidden. On the other hand, if the time capsule has not been buried and is unlocked or made of clear plastic, the items inside it are still encapsulated, but there is no information hiding.

The distinction between encapsulation and information hiding is largely irrelevant, especially at the design level. Many practical references use these terms interchangeably. As Python programmers, we don't actually have or need true information hiding, (we'll discuss the reasons for this in *Chapter 2*, *Objects in Python*) so the more encompassing definition for encapsulation is suitable.

The public interface, however, is very important. It needs to be carefully designed as it is difficult to change it in the future. Changing the interface will break any client objects that are calling it. We can change the internals all we like, for example, to make it more efficient, or to access data over the network as well as locally, and the client objects will still be able to talk to it, unmodified, using the public interface. On the other hand, if we change the interface by changing attribute names that are publicly accessed, or by altering the order or types of arguments that a method can accept, all client objects will also have to be modified. While on the topic of public interfaces, keep it simple. Always design the interface of an object based on how easy it is to use, not how hard it is to code (this advice applies to user interfaces as well).

Remember, program objects may represent real objects, but that does not make them real objects. They are models. One of the greatest gifts of modeling is the ability to ignore irrelevant details. The model car I built as a child may look like a real 1956 Thunderbird on the outside, but it doesn't run and the driveshaft doesn't turn. These details were overly complex and irrelevant before I started driving. The model is an **abstraction** of a real concept.

Abstraction is another object-oriented concept related to encapsulation and information hiding. Simply put, abstraction means dealing with the level of detail that is most appropriate to a given task. It is the process of extracting a public interface from the inner details. A driver of a car needs to interact with steering, gas pedal, and brakes. The workings of the motor, drive train, and brake subsystem don't matter to the driver. A mechanic, on the other hand, works at a different level of abstraction, tuning the engine and bleeding the breaks. Here's an example of two abstraction levels for a car:



Now, we have several new terms that refer to similar concepts. Condensing all this jargon into a couple of sentences: abstraction is the process of encapsulating information with separate public and private interfaces. The private interfaces can be subject to information hiding.

The important lesson to take from all these definitions is to make our models understandable to other objects that have to interact with them. This means paying careful attention to small details. Ensure methods and properties have sensible names. When analyzing a system, objects typically represent nouns in the original problem, while methods are normally verbs. Attributes can often be picked up as adjectives, although if the attribute refers to another object that is part of the current object, it will still likely be a noun. Name classes, attributes, and methods accordingly.

Don't try to model objects or actions that *might* be useful in the future. Model exactly those tasks that the system needs to perform, and the design will naturally gravitate towards the one that has an appropriate level of abstraction. This is not to say we should not think about possible future design modifications. Our designs should be open ended so that future requirements can be satisfied. However, when abstracting interfaces, try to model exactly what needs to be modeled and nothing more.

When designing the interface, try placing yourself in the object's shoes and imagine that the object has a strong preference for privacy. Don't let other objects have access to data about you unless you feel it is in your best interest for them to have it. Don't give them an interface to force you to perform a specific task unless you are certain you want them to be able to do that to you.

Composition

So far, we learned to design systems as a group of interacting objects, where each interaction involves viewing objects at an appropriate level of abstraction. But we don't know yet how to create these levels of abstraction. There are a variety of ways to do this; we'll discuss some advanced design patterns in *Chapter 8*, *Strings and Serialization* and *Chapter 9*, *The Iterator Pattern*. But even most design patterns rely on two basic object-oriented principles known as **composition** and **inheritance**. Composition is simpler, so let's start with it.

Composition is the act of collecting several objects together to create a new one. Composition is usually a good choice when one object is part of another object. We've already seen a first hint of composition in the mechanic example. A car is composed of an engine, transmission, starter, headlights, and windshield, among numerous other parts. The engine, in turn, is composed of pistons, a crank shaft, and valves. In this example, composition is a good way to provide levels of abstraction. The car object can provide the interface required by a driver, while also providing access to its component parts, which offers the deeper level of abstraction suitable for a mechanic. Those component parts can, of course, be further broken down if the mechanic needs more information to diagnose a problem or tune the engine.

This is a common introductory example of composition, but it's not overly useful when it comes to designing computer systems. Physical objects are easy to break into component objects. People have been doing this at least since the ancient Greeks originally postulated that atoms were the smallest units of matter (they, of course, didn't have access to particle accelerators). Computer systems are generally less complicated than physical objects, yet identifying the component objects in such systems does not happen as naturally.

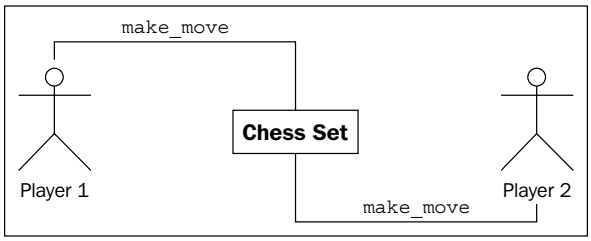
The objects in an object-oriented system occasionally represent physical objects such as people, books, or telephones. More often, however, they represent abstract ideas. People have names, books have titles, and telephones are used to make calls. Calls, titles, accounts, names, appointments, and payments are not usually considered objects in the physical world, but they are all frequently-modeled components in computer systems.

Let's try modeling a more computer-oriented example to see composition in action. We'll be looking at the design of a computerized chess game. This was a very popular pastime among academics in the 80s and 90s. People were predicting that computers would one day be able to defeat a human chess master. When this happened in 1997 (IBM's Deep Blue defeated world chess champion, Gary Kasparov), interest in the problem waned, although there are still contests between computer and human chess players. (The computers usually win.)

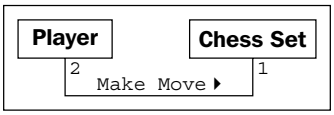
As a basic, high-level analysis, a game of chess is played between two players, using a chess set featuring a board containing sixty-four positions in an 8 X 8 grid. The board can have two sets of sixteen pieces that can be moved, in alternating turns by the two players in different ways. Each piece can take other pieces. The board will be required to draw itself on the computer screen after each turn.

I've identified some of the possible objects in the description using *italics*, and a few key methods using **bold**. This is a common first step in turning an object-oriented analysis into a design. At this point, to emphasize composition, we'll focus on the board, without worrying too much about the players or the different types of pieces.

Let's start at the highest level of abstraction possible. We have two players interacting with a chess set by taking turns making moves:



What is this? It doesn't quite look like our earlier class diagrams. That's because it isn't a class diagram! This is an **object diagram**, also called an instance diagram. It describes the system at a specific state in time, and is describing specific instances of objects, not the interaction between classes. Remember, both players are members of the same class, so the class diagram looks a little different:



The diagram shows that exactly two players can interact with one chess set. It also indicates that any one player can be playing with only one chess set at a time.

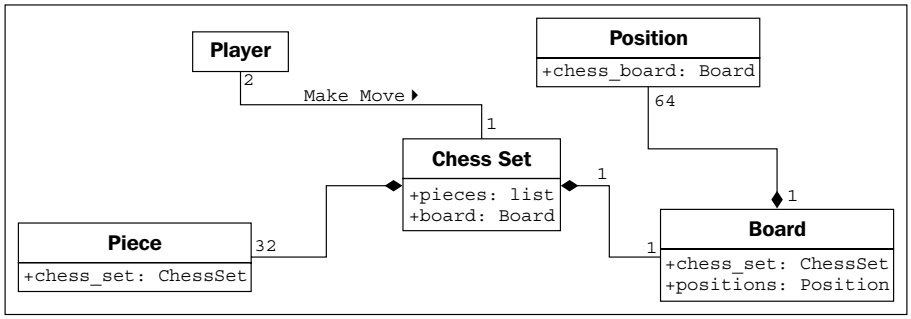
However, we're discussing composition, not UML, so let's think about what the **Chess Set** is composed of. We don't care what the player is composed of at this time. We can assume that the player has a heart and brain, among other organs, but these are irrelevant to our model. Indeed, there is nothing stopping said player from being Deep Blue itself, which has neither a heart nor a brain.

The chess set, then, is composed of a board and 32 pieces. The board further comprises 64 positions. You could argue that pieces are not part of the chess set because you could replace the pieces in a chess set with a different set of pieces. While this is unlikely or impossible in a computerized version of chess, it introduces us to **aggregation**.

Aggregation is almost exactly like composition. The difference is that aggregate objects can exist independently. It would be impossible for a position to be associated with a different chess board, so we say the board is composed of positions. But the pieces, which might exist independently of the chess set, are said to be in an aggregate relationship with that set.

Another way to differentiate between aggregation and composition is to think about the lifespan of the object. If the composite (outside) object controls when the related (inside) objects are created and destroyed, composition is most suitable. If the related object is created independently of the composite object, or can outlast that object, an aggregate relationship makes more sense. Also, keep in mind that composition is aggregation; aggregation is simply a more general form of composition. Any composite relationship is also an aggregate relationship, but not vice versa.

Let's describe our current chess set composition and add some attributes to the objects to hold the composite relationships:



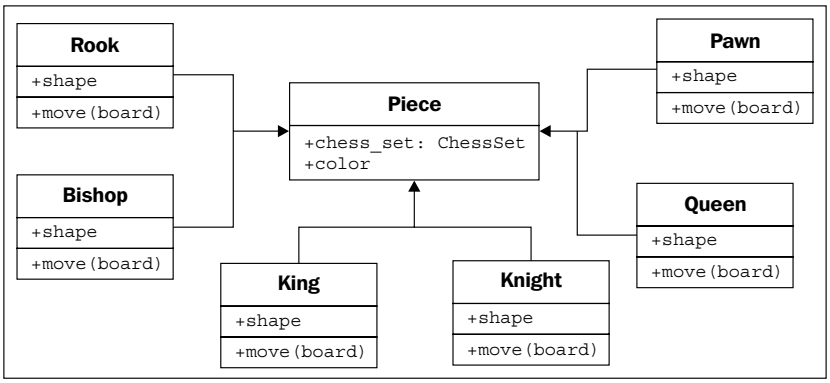
The composition relationship is represented in UML as a solid diamond. The hollow diamond represents the aggregate relationship. You'll notice that the board and pieces are stored as part of the chess set in exactly the same way a reference to them is stored as an attribute on the chess set. This shows that, once again, in practice, the distinction between aggregation and composition is often irrelevant once you get past the design stage. When implemented, they behave in much the same way. However, it can help to differentiate between the two when your team is discussing how the different objects interact. Often, you can treat them as the same thing, but when you need to distinguish between them, it's great to know the difference (this is abstraction at work).

Inheritance

We discussed three types of relationships between objects: association, composition, and aggregation. However, we have not fully specified our chess set, and these tools don't seem to give us all the power we need. We discussed the possibility that a player might be a human or it might be a piece of software featuring artificial intelligence. It doesn't seem right to say that a player is *associated* with a human, or that the artificial intelligence implementation is *part of* the player object. What we really need is the ability to say that "Deep Blue *is a* player" or that "Gary Kasparov *is a* player".

The *is a* relationship is formed by **inheritance**. Inheritance is the most famous, well-known, and over-used relationship in object-oriented programming. Inheritance is sort of like a family tree. My grandfather's last name was Phillips and my father inherited that name. I inherited it from him (along with blue eyes and a penchant for writing). In object-oriented programming, instead of inheriting features and behaviors from a person, one class can inherit attributes and methods from another class.

For example, there are 32 chess pieces in our chess set, but there are only six different types of pieces (pawns, rooks, bishops, knights, king, and queen), each of which behaves differently when it is moved. All of these classes of piece have properties, such as color and the chess set they are part of, but they also have unique shapes when drawn on the chess board, and make different moves. Let's see how the six types of pieces can inherit from a **Piece** class:



The hollow arrows indicate that the individual classes of pieces inherit from the **Piece** class. All the subtypes automatically have a **chess_set** and **color** attribute inherited from the base class. Each piece provides a different shape property (to be drawn on the screen when rendering the board), and a different **move** method to move the piece to a new position on the board at each turn.

We actually know that all subclasses of the **Piece** class need to have a **move** method; otherwise, when the board tries to move the piece, it will get confused. It is possible that we would want to create a new version of the game of chess that has one additional piece (the wizard). Our current design allows us to design this piece without giving it a **move** method. The board would then choke when it asked the piece to move itself.

We can implement this by creating a dummy move method on the **Piece** class. The subclasses can then **override** this method with a more specific implementation. The default implementation might, for example, pop up an error message that says: **That piece cannot be moved**.

Overriding methods in subtypes allows very powerful object-oriented systems to be developed. For example, if we wanted to implement a player class with artificial intelligence, we might provide a `calculate_move` method that takes a **Board** object and decides which piece to move where. A very basic class might randomly choose a piece and direction and move it accordingly. We could then override this method in a subclass with the Deep Blue implementation. The first class would be suitable for play against a raw beginner, the latter would challenge a grand master. The important thing is that other methods in the class, such as the ones that inform the board as to which move was chose need not be changed; this implementation can be shared between the two classes.

In the case of chess pieces, it doesn't really make sense to provide a default implementation of the move method. All we need to do is specify that the move method is required in any subclasses. This can be done by making **Piece** an **abstract class** with the move method declared **abstract**. Abstract methods basically say, "We demand this method exist in any non-abstract subclass, but we are declining to specify an implementation in this class."

Indeed, it is possible to make a class that does not implement any methods at all. Such a class would simply tell us what the class should do, but provides absolutely no advice on how to do it. In object-oriented parlance, such classes are called **interfaces**.

Inheritance provides abstraction

Let's explore the longest word in object-oriented argot. **Polymorphism** is the ability to treat a class differently depending on which subclass is implemented. We've already seen it in action with the pieces system we've described. If we took the design a bit further, we'd probably see that the **Board** object can accept a move from the player and call the **move** function on the piece. The board need not ever know what type of piece it is dealing with. All it has to do is call the **move** method, and the proper subclass will take care of moving it as a **Knight** or a **Pawn**.

Polymorphism is pretty cool, but it is a word that is rarely used in Python programming. Python goes an extra step past allowing a subclass of an object to be treated like a parent class. A board implemented in Python could take any object that has a **move** method, whether it is a bishop piece, a car, or a duck. When **move** is called, the **Bishop** will move diagonally on the board, the car will drive someplace, and the duck will swim or fly, depending on its mood.

This sort of polymorphism in Python is typically referred to as **duck typing**: "If it walks like a duck or swims like a duck, it's a duck". We don't care if it really *is a* duck (inheritance), only that it swims or walks. Geese and swans might easily be able to provide the duck-like behavior we are looking for. This allows future designers to create new types of birds without actually specifying an inheritance hierarchy for aquatic birds. It also allows them to create completely different drop-in behaviors that the original designers never planned for. For example, future designers might be able to make a walking, swimming penguin that works with the same interface without ever suggesting that penguins are ducks.

Multiple inheritance

When we think of inheritance in our own family tree, we can see that we inherit features from more than just one parent. When strangers tell a proud mother that her son has, "his fathers eyes", she will typically respond along the lines of, "yes, but he got my nose."

Object-oriented design can also feature such **multiple inheritance**, which allows a subclass to inherit functionality from multiple parent classes. In practice, multiple inheritance can be a tricky business, and some programming languages (most notably, Java) strictly prohibit it. However, multiple inheritance can have its uses. Most often, it can be used to create objects that have two distinct sets of behaviors. For example, an object designed to connect to a scanner and send a fax of the scanned document might be created by inheriting from two separate `scanner` and `faxer` objects.

As long as two classes have distinct interfaces, it is not normally harmful for a subclass to inherit from both of them. However, it gets messy if we inherit from two classes that provide overlapping interfaces. For example, if we have a motorcycle class that has a `move` method, and a boat class also featuring a `move` method, and we want to merge them into the ultimate amphibious vehicle, how does the resulting class know what to do when we call `move`? At the design level, this needs to be explained, and at the implementation level, each programming language has different ways of deciding which parent class's method is called, or in what order.

Often, the best way to deal with it is to avoid it. If you have a design showing up like this, you're *probably* doing it wrong. Take a step back, analyze the system again, and see if you can remove the multiple inheritance relationship in favor of some other association or composite design.

Inheritance is a very powerful tool for extending behavior. It is also one of the most marketable advancements of object-oriented design over earlier paradigms. Therefore, it is often the first tool that object-oriented programmers reach for. However, it is important to recognize that owning a hammer does not turn screws into nails. Inheritance is the perfect solution for obvious *is a* relationships, but it can be abused. Programmers often use inheritance to share code between two kinds of objects that are only distantly related, with no *is a* relationship in sight. While this is not necessarily a bad design, it is a terrific opportunity to ask just why they decided to design it that way, and whether a different relationship or design pattern would have been more suitable.

Case study

Let's tie all our new object-oriented knowledge together by going through a few iterations of object-oriented design on a somewhat real-world example. The system we'll be modeling is a library catalog. Libraries have been tracking their inventory for centuries, originally using card catalogs, and more recently, electronic inventories. Modern libraries have web-based catalogs that we can query from our homes.

Let's start with an analysis. The local librarian has asked us to write a new card catalog program because their ancient DOS-based program is ugly and out of date. That doesn't give us much detail, but before we start asking for more information, let's consider what we already know about library catalogs.

Catalogs contain lists of books. People search them to find books on certain subjects, with specific titles, or by a particular author. Books can be uniquely identified by an **International Standard Book Number** (**ISBN**). Each book has a **Dewey Decimal System** (**DDS**) number assigned to help find it on a particular shelf.

This simple analysis tells us some of the obvious objects in the system. We quickly identify **Book** as the most important object, with several attributes already mentioned, such as author, title, subject, ISBN, and DDS number, and catalog as a sort of manager for books.

We also notice a few other objects that may or may not need to be modeled in the system. For cataloging purposes, all we need to search a book by author is an `author_name` attribute on the book. However, authors are also objects, and we might want to store some other data about the author. As we ponder this, we might remember that some books have multiple authors. Suddenly, the idea of having a single `author_name` attribute on objects seems a bit silly. A list of authors associated with each book is clearly a better idea.

The relationship between author and book is clearly association, since you would never say, "a book is an author" (it's not inheritance), and saying "a book has an author", though grammatically correct, does not imply that authors are part of books (it's not aggregation). Indeed, any one author may be associated with multiple books.

We should also pay attention to the noun (nouns are always good candidates for objects) *shelf*. Is a shelf an object that needs to be modeled in a cataloging system? How do we identify an individual shelf? What happens if a book is stored at the end of one shelf, and later moved to the beginning of the next shelf because another book was inserted in the previous shelf?

DDS was designed to help locate physical books in a library. As such, storing a DDS attribute with the book should be enough to locate it, regardless of which shelf it is stored on. So we can, at least for the moment, remove shelf from our list of contending objects.

Another questionable object in the system is the user. Do we need to know anything about a specific user, such as their name, address, or list of overdue books? So far, the librarian has told us only that they want a catalog; they said nothing about tracking subscriptions or overdue notices. In the back of our minds, we also note that authors and users are both specific kinds of people; there might be a useful inheritance relationship here in the future.

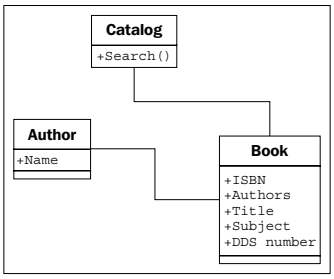
For cataloging purposes, we decide we don't need to identify the user for now. We can assume that a user will be searching the catalog, but we don't have to actively model them in the system, beyond providing an interface that allows them to search.

We have identified a few attributes on the book, but what properties does a catalog have? Does any one library have more than one catalog? Do we need to uniquely identify them? Obviously, the catalog has to have a collection of the books it contains, somehow, but this list is probably not part of the public interface.

What about behaviors? The catalog clearly needs a search method, possibly separate ones for authors, titles, and subjects. Are there any behaviors on books? Would it need a preview method? Or could preview be identified by a first pages attribute instead of a method?

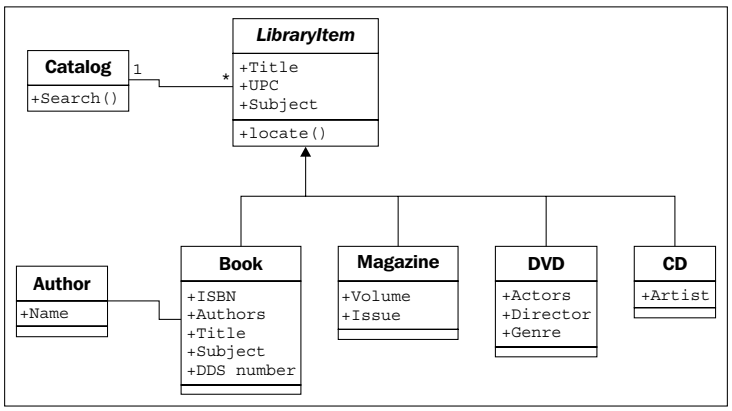
The questions in the preceding discussion are all part of the object-oriented analysis phase. But intermixed with the questions, we have already identified a few key objects that are part of the design. Indeed, what you have just seen are several microiterations between analysis and design.

Likely, these iterations would all occur in an initial meeting with the librarian. Before this meeting, however, we can already sketch out a most basic design for the objects we have concretely identified:



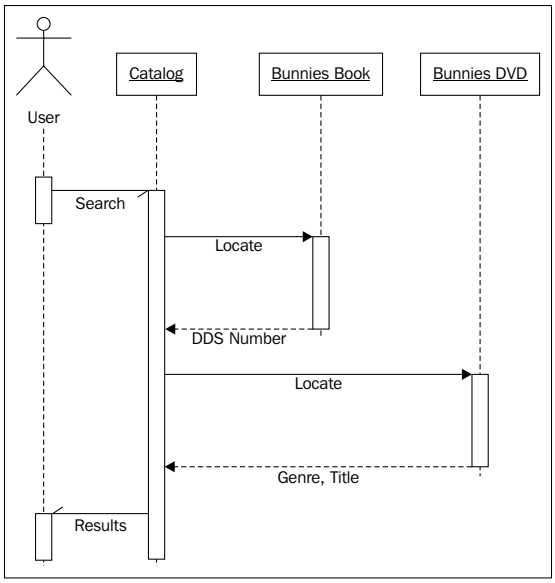
Armed with this basic diagram and a pencil to interactively improve it, we meet up with the librarian. They tell us that this is a good start, but libraries don't serve only books, they also have DVDs, magazines, and CDs, none of which have an ISBN or DDS number. All of these types of items can be uniquely identified by a UPC number though. We remind the librarian that they have to find the items on the shelf, and these items probably aren't organized by UPC. The librarian explains that each type is organized in a different way. The CDs are mostly audio books, and they only have a couple of dozen in stock, so they are organized by the author's last name. DVDs are divided into genre and further organized by title. Magazines are organized by title and then refined by the volume and issue number. Books are, as we had guessed, organized by the DDS number.

With no previous object-oriented design experience, we might consider adding separate lists of DVDs, CDs, magazines, and books to our catalog, and search each one in turn. The trouble is, except for certain extended attributes, and identifying the physical location of the item, these items all behave as much the same. This is a job for inheritance! We quickly update our UML diagram:



The librarian understands the gist of our sketched diagram, but is a bit confused by the **locate** functionality. We explain using a specific use case where the user is searching for the word "bunnies". The user first sends a search request to the catalog. The catalog queries its internal list of items and finds a book and a DVD with "bunnies" in the title. At this point, the catalog doesn't care if it is holding a DVD, book, CD, or magazine; all items are the same, as far as the catalog is concerned. However, the user wants to know how to find the physical items, so the catalog would be remiss if it simply returned a list of titles. So, it calls the **locate** method on the two items it has uncovered. The book's **locate** method returns a DDS number that can be used to find the shelf holding the book. The DVD is located by returning the genre and title of the DVD. The user can then visit the DVD section, find the section containing that genre, and find the specific DVD as sorted by the titles.

As we explain, we sketch a UML **sequence diagram** explaining how the various objects are communicating:



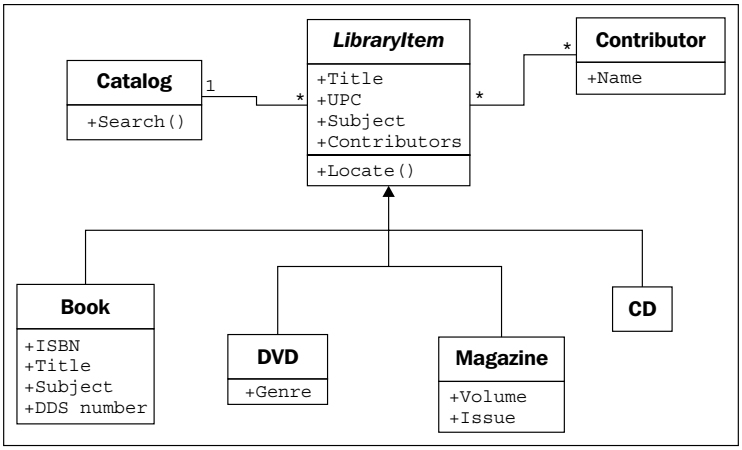
Where, class diagrams describe the relationships between classes, and sequence diagrams describe specific sequences of messages passed between objects. The dashed line hanging from each object is a **lifeline** describing the lifetime of the object. The wider boxes on each lifeline represent active processing in that object (where there's no box, the object is basically sitting idle, waiting for something to happen). The horizontal arrows between the lifelines indicate specific messages. The solid arrows represent methods being called, while the dashed arrows with solid heads represent the method return values.

The half arrowheads indicate asynchronous messages sent to or from an object. An asynchronous message typically means the first object calls a method on the second object, which returns immediately. After some processing, the second object calls a method on the first object to give it a value. This is in contrast to normal method calls, which do the processing in the method, and return a value immediately.

Sequence diagrams, like all UML diagrams, are best used only when they are needed. There is no point in drawing a UML diagram for the sake of drawing a diagram. However, when you need to communicate a series of interactions between two objects, the sequence diagram is a very useful tool.

Unfortunately, our class diagram so far is still a messy design. We notice that actors on DVDs and artists on CDs are all types of people, but are being treated differently from the book authors. The librarian also reminds us that most of their CDs are audio books, which have authors instead of artists.

How can we deal with different kinds of people that contribute to a title? An obvious implementation is to create a `Person` class with the person's name and other relevant details, and then create subclasses of this for the artists, authors, and actors. However, is inheritance really necessary here? For searching and cataloging purposes, we don't really care that acting and writing are two very different activities. If we were doing an economic simulation, it would make sense to give separate actor and author classes, and different `calculate_income` and `perform_job` methods, but for cataloging purposes, it is probably enough to know how the person contributed to the item. We recognize that all items have one or more `Contributor` objects, so we move the author relationship from the book to its parent class:

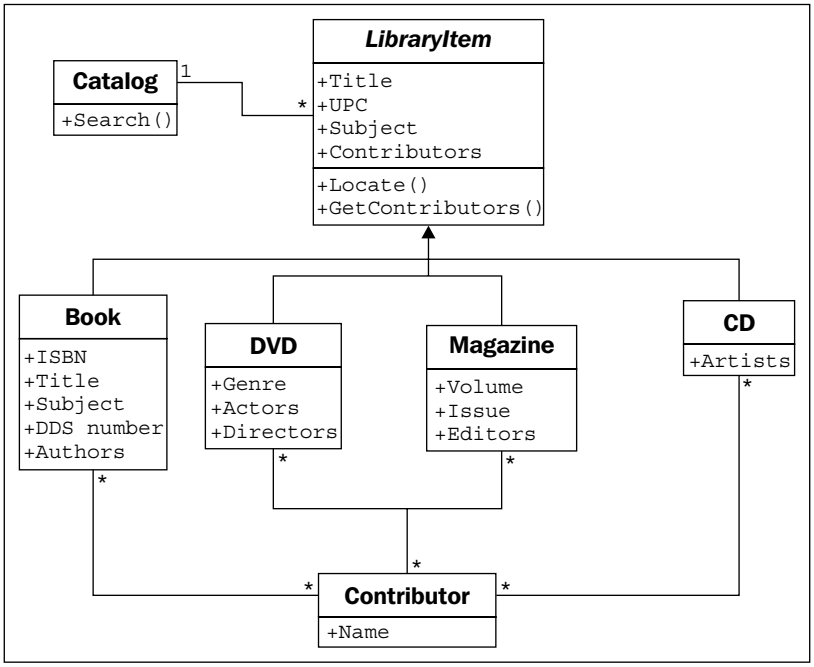


The multiplicity of the **Contributor/LibraryItem** relationship is **many-to-many**, as indicated by the * character at both ends of one relationship. Any one library item might have more than one contributor (for example, several actors and a director on a DVD). And many authors write many books, so they would be attached to multiple library items.

This little change, while it looks a bit cleaner and simpler, has lost some vital information. We can still tell who contributed to a specific library item, but we don't know how they contributed. Were they the director or an actor? Did they write the audio book, or were they the voice that narrated the book?

It would be nice if we could just add a `contributor_type` attribute on the **Contributor** class, but this will fall apart when dealing with multitalented people who have both authored books and directed movies.

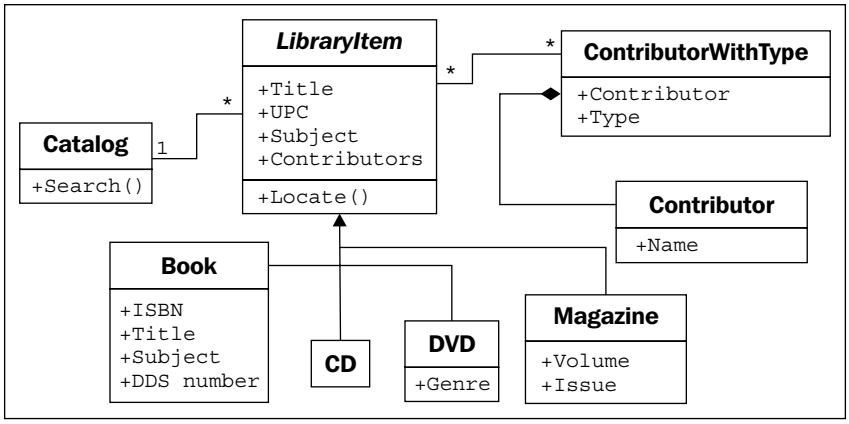
One option is to add attributes to each of our **LibraryItem** subclasses that hold the information we need, such as **Author** on **Book**, or **Artist** on **CD**, and then make the relationship to those properties all point to the **Contributor** class. The problem with this is that we lose a lot of polymorphic elegance. If we want to list the contributors to an item, we have to look for specific attributes on that item, such as **Authors** or **Actors**. We can alleviate this by adding a **GetContributors** method on the **LibraryItem** class that subclasses can override. Then the catalog never has to know what attributes the objects are querying; we've abstracted the public interface:



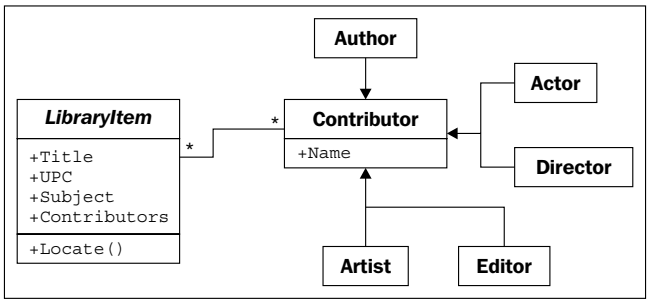
Just looking at this class diagram, it feels like we are doing something wrong. It is bulky and fragile. It may do everything we need, but it feels like it will be hard to maintain or extend. There are too many relationships, and too many classes would be affected by modifications to any one class. It looks like spaghetti and meatballs.

Now that we've explored inheritance as an option, and found it wanting, we might look back at our previous composition-based diagram, where **Contributor** was attached directly to **LibraryItem**. With some thought, we can see that we actually only need to add one more relationship to a brand-new class to identify the type of contributor. This is an important step in object-oriented design. We are now adding a class to the design that is intended to *support* the other objects, rather than modeling any part of the initial requirements. We are **refactoring** the design to facilitate the objects in the system, rather than objects in real life. Refactoring is an essential process in the maintenance of a program or design. The goal of refactoring is to improve the design by moving code around, removing duplicate code or complex relationships in favor of simpler, more elegant designs.

This new class is composed of a **Contributor** and an extra attribute identifying the type of contribution the person has made to the given **LibraryItem**. There can be many such contributions to a particular **LibraryItem**, and one contributor can contribute in the same way to different items. The diagram communicates this design very well:



At first, this composition relationship looks less natural than the inheritance-based relationships. However, it has the advantage of allowing us to add new types of contributions without adding a new class to the design. Inheritance is most useful when the subclasses have some kind of specialization. Specialization is creating or changing attributes or behaviors on the subclass to make it somehow different from the parent class. It seems silly to create a bunch of empty classes solely for identifying different types of objects (this attitude is less prevalent among Java and other "everything is an object" programmers, but it is common among more practical Python designers). If we look at the inheritance version of the diagram, we can see a bunch of subclasses that don't actually do anything:



Sometimes it is important to recognize when not to use object-oriented principles. This example of when not to use inheritance is a good reminder that objects are just tools, and not rules.

Exercises

This is a practical book, not a textbook. As such, I'm not about to assign you a bunch of fake object-oriented analysis problems to create designs for bunch of fake object-oriented problems to analyze and design. Instead, I want to give you some thoughts that you can apply to your own projects. If you have previous object-oriented experience, you won't need to put much effort into these. However, they are useful mental exercises if you've been using Python for a while, but never really cared about all that class stuff.

First, think about a recent programming project you've completed. Identify the most prominent object in the design. Try to think of as many attributes for this object as possible. Did it have: Color? Weight? Size? Profit? Cost? Name? ID number? Price? Style? Think about the attribute types. Were they primitives or classes? Were some of those attributes actually behaviors in disguise? Sometimes what looks like data is actually calculated from other data on the object, and you can use a method to do those calculations. What other methods or behaviors did the object have? Which objects called those methods? What kinds of relationships did they have with this object?

Now, think about an upcoming project. It doesn't matter what the project is; it might be a fun free-time project or a multimillion dollar contract. It doesn't have to be a complete application; it could just be one subsystem. Perform a basic object-oriented analysis. Identify the requirements and the interacting objects. Sketch out a class diagram featuring the highest level of abstraction on that system. Identify the major interacting objects. Identify minor supporting objects. Go into detail for the attributes and methods of some of the most interesting ones. Take different objects to different levels of abstraction. Look for places you can use inheritance or composition. Look for places you should avoid inheritance.

The goal is not to design a system (although you're certainly welcome to do so if inclination meets both ambition and available time). The goal is to think about object-oriented designs. Focusing on projects that you have worked on, or are expecting to work on in the future, simply makes it real.

Now, visit your favorite search engine and look up some tutorials on UML. There are dozens, so find the one that suits your preferred method of study. Sketch some class diagrams or a sequence diagram for the objects you identified earlier. Don't get too hung up on memorizing the syntax (after all, if it is important, you can always look it up again), just get a feel for the language. Something will stay lodged in your brain, and it can make communicating a bit easier if you can quickly sketch a diagram for your next OOP discussion.

Summary

In this chapter, we took a whirlwind tour through the terminology of the object-oriented paradigm, focusing on object-oriented design. We can separate different objects into a taxonomy of different classes and describe the attributes and behaviors of those objects via the class interface. Classes describe objects, abstraction, encapsulation, and information hiding are highly related concepts. There are many different kinds of relationships between objects, including association, composition, and inheritance. UML syntax can be useful for fun and communication.

In the next chapter, we'll explore how to implement classes and methods in Python.

2
Objects in Python

So, we now have a design in hand and are ready to turn that design into a working program! Of course, it doesn't usually happen this way. We'll be seeing examples and hints for good software design throughout the book, but our focus is object-oriented programming. So, let's have a look at the Python syntax that allows us to create object-oriented software.

After completing this chapter, we will understand:

- How to create classes and instantiate objects in Python
- How to add attributes and behaviors to Python objects
- How to organize classes into packages and modules
- How to suggest people don't clobber our data

Creating Python classes

We don't have to write much Python code to realize that Python is a very "clean" language. When we want to do something, we just do it, without having to go through a lot of setup. The ubiquitous "hello world" in Python, as you've likely seen, is only one line.

Similarly, the simplest class in Python 3 looks like this:

```
class MyFirstClass:
    pass
```

There's our first object-oriented program! The class definition starts with the `class` keyword. This is followed by a name (of our choice) identifying the class, and is terminated with a colon.

The class name must follow standard Python variable naming rules (it must start with a letter or underscore, and can only be comprised of letters, underscores, or numbers). In addition, the Python style guide (search the web for "PEP 8") recommends that classes should be named using **CamelCase** notation (start with a capital letter; any subsequent words should also start with a capital).

The class definition line is followed by the class contents indented. As with other Python constructs, indentation is used to delimit the classes, rather than braces or brackets as many other languages use. Use four spaces for indentation unless you have a compelling reason not to (such as fitting in with somebody else's code that uses tabs for indents). Any decent programming editor can be configured to insert four spaces whenever the *Tab* key is pressed.

Since our first class doesn't actually do anything, we simply use the `pass` keyword on the second line to indicate that no further action needs to be taken.

We might think there isn't much we can do with this most basic class, but it does allow us to instantiate objects of that class. We can load the class into the Python 3 interpreter, so we can interactively play with it. To do this, save the class definition mentioned earlier into a file named `first_class.py` and then run the command `python -i first_class.py`. The `-i` argument tells Python to "run the code and then drop to the interactive interpreter". The following interpreter session demonstrates basic interaction with this class:

```
>>> a = MyFirstClass()
>>> b = MyFirstClass()
>>> print(a)
<__main__.MyFirstClass object at 0xb7b7faec>
>>> print(b)
<__main__.MyFirstClass object at 0xb7b7fbac>
>>>
```

This code instantiates two objects from the new class, named `a` and `b`. Creating an instance of a class is a simple matter of typing the class name followed by a pair of parentheses. It looks much like a normal function call, but Python knows we're "calling" a class and not a function, so it understands that its job is to create a new object. When printed, the two objects tell us which class they are and what memory address they live at. Memory addresses aren't used much in Python code, but here, they demonstrate that there are two distinct objects involved.

Adding attributes

Now, we have a basic class, but it's fairly useless. It doesn't contain any data, and it doesn't do anything. What do we have to do to assign an attribute to a given object?

It turns out that we don't have to do anything special in the class definition. We can set arbitrary attributes on an instantiated object using the dot notation:

```
class Point:
    pass

p1 = Point()
p2 = Point()

p1.x = 5
p1.y = 4

p2.x = 3
p2.y = 6

print(p1.x, p1.y)
print(p2.x, p2.y)
```

If we run this code, the two `print` statements at the end tell us the new attribute values on the two objects:

```
5 4
3 6
```

This code creates an empty `Point` class with no data or behaviors. Then it creates two instances of that class and assigns each of those instances `x` and `y` coordinates to identify a point in two dimensions. All we need to do to assign a value to an attribute on an object is use the <*object*>.<*attribute*> = <*value*> syntax. This is sometimes referred to as **dot notation**. The value can be anything: a Python primitive, a built-in data type, or another object. It can even be a function or another class!

Making it do something

Now, having objects with attributes is great, but object-oriented programming is really about the interaction between objects. We're interested in invoking actions that cause things to happen to those attributes. It is time to add behaviors to our classes.

Let's model a couple of actions on our `Point` class. We can start with a called `reset` that moves the point to the origin (the origin is the point where `x` and `y` are both zero). This is a good introductory action because it doesn't require any parameters:

```
class Point:
    def reset(self):
        self.x = 0
        self.y = 0

p = Point()
p.reset()
print(p.x, p.y)
```

This `print` statement shows us the two zeros on the attributes:

```
0 0
```

A method in Python is formatted identically to a function. It starts with the keyword `def` followed by a space and the name of the method. This is followed by a set of parentheses containing the parameter list (we'll discuss that `self` parameter in just a moment), and terminated with a colon. The next line is indented to contain the statements inside the method. These statements can be arbitrary Python code operating on the object itself and any parameters passed in as the method sees fit.

Talking to yourself

The one difference between methods and normal functions is that all methods have one required argument. This argument is conventionally named `self`; I've never seen a programmer use any other name for this variable (convention is a very powerful thing). There's nothing stopping you, however, from calling it `this` or even `Martha`.

The `self` argument to a method is simply a reference to the object that the method is being invoked on. We can access attributes and methods of that object as if it were any another object. This is exactly what we do inside the `reset` method when we set the `x` and `y` attributes of the `self` object.

Notice that when we call the `p.reset()` method, we do not have to pass the `self` argument into it. Python automatically takes care of this for us. It knows we're calling a method on the `p` object, so it automatically passes that object to the method.

However, the method really is just a function that happens to be on a class. Instead of calling the method on the object, we can invoke the function on the class, explicitly passing our object as the `self` argument:

```
p = Point()
Point.reset(p)
print(p.x, p.y)
```

The output is the same as the previous example because internally, the exact same process has occurred.

What happens if we forget to include the `self` argument in our class definition? Python will bail with an error message:

```
>>> class Point:
...     def reset():
...         pass
...
>>> p = Point()
>>> p.reset()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: reset() takes no arguments (1 given)
```

The error message is not as clear as it could be ("You silly fool, you forgot the `self` argument" would be more informative). Just remember that when you see an error message that indicates missing arguments, the first thing to check is whether you forgot `self` in the method definition.

More arguments

So, how do we pass multiple arguments to a method? Let's add a new method that allows us to move a point to an arbitrary position, not just to the origin. We can also include one that accepts another `Point` object as input and returns the distance between them:

```
import math

class Point:
```

```
        def move(self, x, y):
            self.x = x
            self.y = y

        def reset(self):
            self.move(0, 0)

        def calculate_distance(self, other_point):
            return math.sqrt(
                    (self.x - other_point.x)**2 +
                    (self.y - other_point.y)**2)

    # how to use it:
    point1 = Point()
    point2 = Point()

    point1.reset()
    point2.move(5,0)
    print(point2.calculate_distance(point1))
    assert (point2.calculate_distance(point1) ==
            point1.calculate_distance(point2))
    point1.move(3,4)
    print(point1.calculate_distance(point2))
    print(point1.calculate_distance(point1))
```

The `print` statements at the end give us the following output:

```
5.0
4.472135955
0.0
```

A lot has happened here. The class now has three methods. The `move` method accepts two arguments, `x` and `y`, and sets the values on the `self` object, much like the old `reset` method from the previous example. The old `reset` method now calls `move`, since a reset is just a move to a specific known location.

The `calculate_distance` method uses the not-too-complex Pythagorean theorem to calculate the distance between two points. I hope you understand the math (`**` means squared, and `math.sqrt` calculates a square root), but it's not a requirement for our current focus, learning how to write methods.

The sample code at the end of the preceding example shows how to call a method with arguments: simply include the arguments inside the parentheses, and use the same dot notation to access the method. I just picked some random positions to test the methods. The test code calls each method and prints the results on the console. The `assert` function is a simple test tool; the program will bail if the statement after `assert` is `False` (or zero, empty, or `None`). In this case, we use it to ensure that the distance is the same regardless of which point called the other point's `calculate_distance` method.

Initializing the object

If we don't explicitly set the `x` and `y` positions on our `Point` object, either using `move` or by accessing them directly, we have a broken point with no real position. What will happen when we try to access it?

Well, let's just try it and see. "Try it and see" is an extremely useful tool for Python study. Open up your interactive interpreter and type away. The following interactive session shows what happens if we try to access a missing attribute. If you saved the previous example as a file or are using the examples distributed with the book, you can load it into the Python interpreter with the command `python -i filename.py`:

```
>>> point = Point()
>>> point.x = 5
>>> print(point.x)
5
>>> print(point.y)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
AttributeError: 'Point' object has no attribute 'y'
```

Well, at least it threw a useful exception. We'll cover exceptions in detail in *Chapter 4*, *Expecting the Unexpected*. You've probably seen them before (especially the ubiquitous **SyntaxError**, which means you typed something incorrectly!). At this point, simply be aware that it means something went wrong.

The output is useful for debugging. In the interactive interpreter, it tells us the error occurred at **line 1**, which is only partially true (in an interactive session, only one line is executed at a time). If we were running a script in a file, it would tell us the exact line number, making it easy to find the offending code. In addition, it tells us the error is an `AttributeError`, and gives a helpful message telling us what that error means.

We can catch and recover from this error, but in this case, it feels like we should have specified some sort of default value. Perhaps every new object should be `reset()` by default, or maybe it would be nice if we could force the user to tell us what those positions should be when they create the object.

Most object-oriented programming languages have the concept of a **constructor**, a special method that creates and initializes the object when it is created. Python is a little different; it has a constructor *and* an initializer. The constructor function is rarely used unless you're doing something exotic. So, we'll start our discussion with the initialization method.

The Python initialization method is the same as any other method, except it has a special name, `__init__`. The leading and trailing double underscores mean this is a special method that the Python interpreter will treat as a special case.

Never name a function of your own with leading and trailing double underscores. It may mean nothing to Python, but there's always the possibility that the designers of Python will add a function that has a special purpose with that name in the future, and when they do, your code will break.

Let's start with an initialization function on our `Point` class that requires the user to supply `x` and `y` coordinates when the `Point` object is instantiated:

```
class Point:
    def __init__(self, x, y):
        self.move(x, y)

    def move(self, x, y):
        self.x = x
        self.y = y

    def reset(self):
        self.move(0, 0)

# Constructing a Point
point = Point(3, 5)
print(point.x, point.y)
```

Now, our point can never go without a `y` coordinate! If we try to construct a point without including the proper initialization parameters, it will fail with a **not enough arguments** error similar to the one we received earlier when we forgot the `self` argument.

What if we don't want to make those two arguments required? Well, then we can use the same syntax Python functions use to provide default arguments. The keyword argument syntax appends an equals sign after each variable name. If the calling object does not provide this argument, then the default argument is used instead. The variables will still be available to the function, but they will have the values specified in the argument list. Here's an example:

```
class Point:
    def __init__(self, x=0, y=0):
        self.move(x, y)
```

Most of the time, we put our initialization statements in an `__init__` function. But as mentioned earlier, Python has a constructor in addition to its initialization function. You may never need to use the other Python constructor, but it helps to know it exists, so we'll cover it briefly.

The constructor function is called `__new__` as opposed to `__init__`, and accepts exactly one argument; the class that is being constructed (it is called *before* the object is constructed, so there is no `self` argument). It also has to return the newly created object. This has interesting possibilities when it comes to the complicated art of metaprogramming, but is not very useful in day-to-day programming. In practice, you will rarely, if ever, need to use `__new__` and `__init__` will be sufficient.

Explaining yourself

Python is an extremely easy-to-read programming language; some might say it is self-documenting. However, when doing object-oriented programming, it is important to write API documentation that clearly summarizes what each object and method does. Keeping documentation up-to-date is difficult; the best way to do it is to write it right into our code.

Python supports this through the use of **docstrings**. Each class, function, or method header can have a standard Python string as the first line following the definition (the line that ends in a colon). This line should be indented the same as the following code.

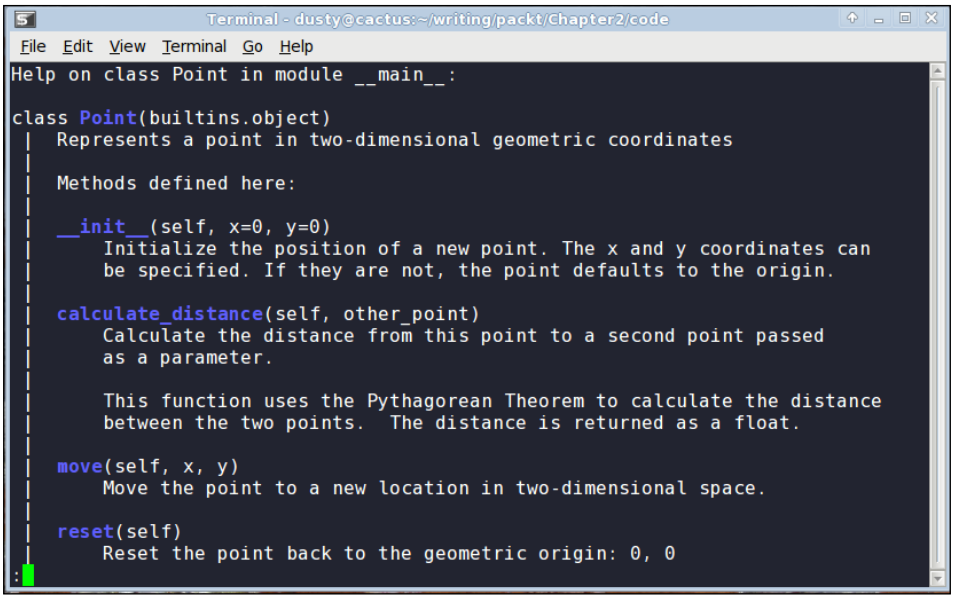
Docstrings are simply Python strings enclosed with apostrophe (`'`) or quote (`"`) characters. Often, docstrings are quite long and span multiple lines (the style guide suggests that the line length should not exceed 80 characters), which can be formatted as multi-line strings, enclosed in matching triple apostrophe (`'''`) or triple quote (`"""`) characters.

A docstring should clearly and concisely summarize the purpose of the class or method it is describing. It should explain any parameters whose usage is not immediately obvious, and is also a good place to include short examples of how to use the API. Any caveats or problems an unsuspecting user of the API should be aware of should also be noted.

To illustrate the use of docstrings, we will end this section with our completely documented `Point` class:

```
import math

class Point:
    'Represents a point in two-dimensional geometric coordinates'

    def __init__(self, x=0, y=0):
        '''Initialize the position of a new point. The x and y
coordinates can be specified. If they are not, the
           point defaults to the origin.'''
        self.move(x, y)

    def move(self, x, y):
        "Move the point to a new location in 2D space."
        self.x = x
        self.y = y

    def reset(self):
        'Reset the point back to the geometric origin: 0, 0'
        self.move(0, 0)

    def calculate_distance(self, other_point):
        """Calculate the distance from this point to a second
        point passed as a parameter.

        This function uses the Pythagorean Theorem to calculate
the distance between the two points. The distance is
        returned as a float."""

        return math.sqrt(
                (self.x - other_point.x)**2 +
                (self.y - other_point.y)**2)
```

Try typing or loading (remember, it's `python -i filename.py`) this file into the interactive interpreter. Then, enter `help(Point)<enter>` at the Python prompt. You should see nicely formatted documentation for the class, as shown in the following screenshot:



Modules and packages

Now, we know how to create classes and instantiate objects, but how do we organize them? For small programs, we can just put all our classes into one file and add a little script at the end of the file to start them interacting. However, as our projects grow, it can become difficult to find the one class that needs to be edited among the many classes we've defined. This is where **modules** come in. Modules are simply Python files, nothing more. The single file in our small program is a module. Two Python files are two modules. If we have two files in the same folder, we can load a class from one module for use in the other module.

For example, if we are building an e-commerce system, we will likely be storing a lot of data in a database. We can put all the classes and functions related to database access into a separate file (we'll call it something sensible: `database.py`). Then, our other modules (for example, customer models, product information, and inventory) can import classes from that module in order to access the database.

The `import` statement is used for importing modules or specific classes or functions from modules. We've already seen an example of this in our `Point` class in the previous section. We used the `import` statement to get Python's built-in `math` module and use its `sqrt` function in our `distance` calculation.

Here's a concrete example. Assume we have a module called `database.py` that contains a class called `Database`, and a second module called `products.py` that is responsible for product-related queries. At this point, we don't need to think too much about the contents of these files. What we know is that `products.py` needs to instantiate the `Database` class from `database.py` so that it can execute queries on the product table in the database.

There are several variations on the `import` statement syntax that can be used to access the class:

```
import database
db = database.Database()
# Do queries on db
```

This version imports the `database` module into the `products` namespace (the list of names currently accessible in a module or function), so any class or function in the `database` module can be accessed using the `database.<something>` notation. Alternatively, we can import just the one class we need using the `from...import` syntax:

```
from database import Database
db = Database()
# Do queries on db
```

If, for some reason, `products` already has a class called `Database`, and we don't want the two names to be confused, we can rename the class when used inside the `products` module:

```
from database import Database as DB
db = DB()
# Do queries on db
```

We can also import multiple items in one statement. If our `database` module also contains a `Query` class, we can import both classes using:

```
from database import Database, Query
```

Some sources say that we can import all classes and functions from the `database` module using this syntax:

```
from database import *
```

Don't do this. Every experienced Python programmer will tell you that you should never use this syntax. They'll use obscure justifications such as "it clutters up the namespace", which doesn't make much sense to beginners. One way to learn why to avoid this syntax is to use it and try to understand your code two years later. But we can save some time and two years of poorly written code with a quick explanation now!

When we explicitly import the `database` class at the top of our file using `from database import Database`, we can easily see where the `Database` class comes from. We might use `db = Database()` 400 lines later in the file, and we can quickly look at the imports to see where that `Database` class came from. Then, if we need clarification as to how to use the `Database` class, we can visit the original file (or import the module in the interactive interpreter and use the `help(database.Database)` command). However, if we use the `from database import *` syntax, it takes a lot longer to find where that class is located. Code maintenance becomes a nightmare.

In addition, most editors are able to provide extra functionality, such as reliable code completion, the ability to jump to the definition of a class, or inline documentation, if normal imports are used. The `import *` syntax usually completely destroys their ability to do this reliably.

Finally, using the `import *` syntax can bring unexpected objects into our local namespace. Sure, it will import all the classes and functions defined in the module being imported from, but it will also import any classes or modules that were themselves imported into that file!

Every name used in a module should come from a well-specified place, whether it is defined in that module, or explicitly imported from another module. There should be no magic variables that seem to come out of thin air. We should *always* be able to immediately identify where the names in our current namespace originated. I promise that if you use this evil syntax, you will one day have extremely frustrating moments of "where on earth can this class be coming from?".

Organizing the modules

As a project grows into a collection of more and more modules, we may find that we want to add another level of abstraction, some kind of nested hierarchy on our modules' levels. However, we can't put modules inside modules; one file can hold only one file after all, and modules are nothing more than Python files.

Files, however, can go in folders and so can modules. A **package** is a collection of modules in a folder. The name of the package is the name of the folder. All we need to do to tell Python that a folder is a package is place a (normally empty) file in the folder named `__init__.py`. If we forget this file, we won't be able to import modules from that folder.

Let's put our modules inside an `ecommerce` package in our working folder, which will also contain a `main.py` file to start the program. Let's additionally add another package in the `ecommerce` package for various payment options. The folder hierarchy will look like this:

```
parent_directory/
    main.py
    ecommerce/
        __init__.py
        database.py
        products.py
        payments/
            __init__.py
            square.py
            stripe.py
```

When importing modules or classes between packages, we have to be cautious about the syntax. In Python 3, there are two ways of importing modules: absolute imports and relative imports.

Absolute imports

Absolute imports specify the complete path to the module, function, or path we want to import. If we need access to the `Product` class inside the `products` module, we could use any of these syntaxes to do an absolute import:

```
import ecommerce.products
product = ecommerce.products.Product()
```

or

```
from ecommerce.products import Product
product = Product()
```

or

```
from ecommerce import products
product = products.Product()
```

The `import` statements use the period operator to separate packages or modules.

These statements will work from any module. We could instantiate a `Product` class using this syntax in `main.py`, in the `database` module, or in either of the two payment modules. Indeed, assuming the packages are available to Python, it will be able to import them. For example, the packages can also be installed to the Python site packages folder, or the `PYTHONPATH` environment variable could be customized to dynamically tell Python what folders to search for packages and modules it is going to import.

So, with these choices, which syntax do we choose? It depends on your personal taste and the application at hand. If there are dozens of classes and functions inside the `products` module that I want to use, I generally import the module name using the `from ecommerce import products` syntax, and then access the individual classes using `products.Product`. If I only need one or two classes from the `products` module, I can import them directly using the `from ecommerce.proucts import Product` syntax. I don't personally use the first syntax very often unless I have some kind of name conflict (for example, I need to access two completely different modules called `products` and I need to separate them). Do whatever you think makes your code look more elegant.

Relative imports

When working with related modules in a package, it seems kind of silly to specify the full path; we know what our parent module is named. This is where **relative imports** come in. Relative imports are basically a way of saying find a class, function, or module as it is positioned relative to the current module. For example, if we are working in the `products` module and we want to import the `Database` class from the `database` module next to it, we could use a relative import:

```
from .database import Database
```

The period in front of `database` says "u*se the database module inside the current package*". In this case, the current package is the package containing the `products.py` file we are currently editing, that is, the `ecommerce` package.

If we were editing the `paypal` module inside the `ecommerce.payments` package, we would want to say "u*se the database package inside the parent package*" instead. This is easily done with two periods, as shown here:

```
from ..database import Database
```

We can use more periods to go further up the hierarchy. Of course, we can also go down one side and back up the other. We don't have a deep enough example hierarchy to illustrate this properly, but the following would be a valid import if we had an `ecommerce.contact` package containing an `email` module and wanted to import the `send_mail` function into our `paypal` module:

```
from ..contact.email import send_mail
```

This import uses two periods to say, *the parent of the payments package*, and then uses the normal `package.module` syntax to go back *up* into the contact package.

Finally, we can import code directly from packages, as opposed to just modules inside packages. In this example, we have an `ecommerce` package containing two modules named `database.py` and `products.py`. The database module contains a `db` variable that is accessed from a lot of places. Wouldn't it be convenient if this could be imported as `import ecommerce.db` instead of `import ecommerce.database.db`?

Remember the `__init__.py` file that defines a directory as a package? This file can contain any variable or class declarations we like, and they will be available as part of the package. In our example, if the `ecommerce/__init__.py` file contained this line:

```
from .database import db
```

We can then access the `db` attribute from `main.py` or any other file using this import:

```
from ecommerce import db
```

It might help to think of the `__init__.py` file as if it was an `ecommerce.py` file if that file were a module instead of a package. This can also be useful if you put all your code in a single module and later decide to break it up into a package of modules. The `__init__.py` file for the new package can still be the main point of contact for other modules talking to it, but the code can be internally organized into several different modules or subpackages.

I recommend not putting all your code in an `__init__.py` file, though. Programmers do not expect actual logic to happen in this file, and much like with `from x import *`, it can trip them up if they are looking for the declaration of a particular piece of code and can't find it until they check `__init__.py`.

Organizing module contents

Inside any one module, we can specify variables, classes, or functions. They can be a handy way to store the global state without namespace conflicts. For example, we have been importing the `Database` class into various modules and then instantiating it, but it might make more sense to have only one `database` object globally available from the `database` module. The `database` module might look like this:

```
class Database:
    # the database implementation
    pass

database = Database()
```

Then we can use any of the import methods we've discussed to access the `database` object, for example:

```
from ecommerce.database import database
```

A problem with the preceding class is that the `database` object is created immediately when the module is first imported, which is usually when the program starts up. This isn't always ideal since connecting to a database can take a while, slowing down startup, or the database connection information may not yet be available. We could delay creating the database until it is actually needed by calling an `initialize_database` function to create the module-level variable:

```
class Database:
    # the database implementation
    pass

database = None

def initialize_database():
    global database
    database = Database()
```

The `global` keyword tells Python that the database variable inside `initialize_database` is the module level one we just defined. If we had not specified the variable as global, Python would have created a new local variable that would be discarded when the method exits, leaving the module-level value unchanged.

As these two examples illustrate, all module-level code is executed immediately at the time it is imported. However, if it is inside a method or function, the function will be created, but its internal code will not be executed until the function is called. This can be a tricky thing for scripts (such as the main script in our e-commerce example) that perform execution. Often, we will write a program that does something useful, and then later find that we want to import a function or class from that module in a different program. However, as soon as we import it, any code at the module level is immediately executed. If we are not careful, we can end up running the first program when we really only meant to access a couple functions inside that module.

To solve this, we should always put our startup code in a function (conventionally, called `main`) and only execute that function when we know we are running the module as a script, but not when our code is being imported from a different script. But how do we know this?

```
class UsefulClass:
    '''This class might be useful to other modules.'''
    pass

def main():
    '''creates a useful class and does something with it for our
module.'''
    useful = UsefulClass()
    print(useful)

if __name__ == "__main__":
    main()
```

Every module has a `__name__` special variable (remember, Python uses double underscores for special variables, such as a class's `__init__` method) that specifies the name of the module when it was imported. When the module is executed directly with `python module.py`, it is never imported, so the `__name__` is arbitrarily set to the string `"__main__"`. Make it a policy to wrap all your scripts in an `if __name__ == "__main__":` test, just in case you write a function you will find useful to be imported by other code someday.

So, methods go in classes, which go in modules, which go in packages. Is that all there is to it?

Actually, no. This is the typical order of things in a Python program, but it's not the only possible layout. Classes can be defined anywhere. They are typically defined at the module level, but they can also be defined inside a function or method, like this:

```
def format_string(string, formatter=None):
    '''Format a string using the formatter object, which
    is expected to have a format() method that accepts
    a string.'''
    class DefaultFormatter:
        '''Format a string in title case.'''
        def format(self, string):
            return str(string).title()

    if not formatter:
        formatter = DefaultFormatter()

    return formatter.format(string)

hello_string = "hello world, how are you today?"
print(" input: " + hello_string)
print("output: " + format_string(hello_string))
```

The output will be as follows:

```
input: hello world, how are you today?
output: Hello World, How Are You Today?
```

The `format_string` function accepts a string and optional formatter object, and then applies the formatter to that string. If no formatter is supplied, it creates a formatter of its own as a local class and instantiates it. Since it is created inside the scope of the function, this class cannot be accessed from anywhere outside of that function. Similarly, functions can be defined inside other functions as well; in general, any Python statement can be executed at any time.

These inner classes and functions are occasionally useful for one-off items that don't require or deserve their own scope at the module level, or only make sense inside a single method. However, it is not common to see Python code that frequently uses this technique.

Who can access my data?

Most object-oriented programming languages have a concept of access control. This is related to abstraction. Some attributes and methods on an object are marked private, meaning only that object can access them. Others are marked protected, meaning only that class and any subclasses have access. The rest are public, meaning any other object is allowed to access them.

Python doesn't do this. Python doesn't really believe in enforcing laws that might someday get in your way. Instead, it provides unenforced guidelines and best practices. Technically, all methods and attributes on a class are publicly available. If we want to suggest that a method should not be used publicly, we can put a note in docstrings indicating that the method is meant for internal use only (preferably, with an explanation of how the public-facing API works!).

By convention, we should also prefix an attribute or method with an underscore character, _. Python programmers will interpret this as "*this is an internal variable, think three times before accessing it directly*". But there is nothing inside the interpreter to stop them from accessing it if they think it is in their best interest to do so. Because if they think so, why should we stop them? We may not have any idea what future uses our classes may be put to.

There's another thing you can do to strongly suggest that outside objects don't access a property or method: prefix it with a double underscore, __. This will perform **name mangling** on the attribute in question. This basically means that the method can still be called by outside objects if they really want to do it, but it requires extra work and is a strong indicator that you demand that your attribute remains private. For example:

```
class SecretString:
    '''A not-at-all secure way to store a secret string.'''

    def __init__(self, plain_string, pass_phrase):
        self.__plain_string = plain_string
        self.__pass_phrase = pass_phrase

    def decrypt(self, pass_phrase):
        '''Only show the string if the pass_phrase is correct.'''
        if pass_phrase == self.__pass_phrase:
            return self.__plain_string
        else:
            return ''
```

If we load this class and test it in the interactive interpreter, we can see that it hides the plain text string from the outside world:

```
>>> secret_string = SecretString("ACME: Top Secret", "antwerp")
>>> print(secret_string.decrypt("antwerp"))
ACME: Top Secret
>>> print(secret_string.__plain_text)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
AttributeError: 'SecretString' object has no attribute
'__plain_text'
```

It looks like it works; nobody can access our `plain_text` attribute without the passphrase, so it must be safe. Before we get too excited, though, let's see how easy it can be to hack our security:

```
>>> print(secret_string._SecretString__plain_string)
ACME: Top Secret
```

Oh no! Somebody has hacked our secret string. Good thing we checked! This is Python name mangling at work. When we use a double underscore, the property is prefixed with `_<classname>`. When methods in the class internally access the variable, they are automatically unmangled. When external classes wish to access it, they have to do the name mangling themselves. So, name mangling does not guarantee privacy, it only strongly recommends it. Most Python programmers will not touch a double underscore variable on another object unless they have an extremely compelling reason to do so.

However, most Python programmers will not touch a single underscore variable without a compelling reason either. Therefore, there are very few good reasons to use a name-mangled variable in Python, and doing so can cause grief. For example, a name-mangled variable may be useful to a subclass, and it would have to do the mangling itself. Let other objects access your hidden information if they want to, just let them know, using a single-underscore prefix or some clear docstrings, that you think this is not a good idea.

Third-party libraries

Python ships with a lovely standard library, which is a collection of packages and modules that are available on every machine that runs Python. However, you'll soon find that it doesn't contain everything you need. When this happens, you have two options:

- Write a supporting package yourself
- Use somebody else's code

We won't be covering the details about turning your packages into libraries, but if you have a problem you need to solve and you don't feel like coding it (the best programmers are extremely lazy and prefer to reuse existing, proven code, rather than write their own), you can probably find the library you want on the **Python Package Index** (**PyPI**) at `http://pypi.python.org/`. Once you've identified a package that you want to install, you can use a tool called `pip` to install it. However, `pip` does not come with Python, but Python 3.4 contains a useful tool called `ensurepip`, which will install it:

```
python -m ensurepip
```

This may fail for you on Linux, Mac OS, or other Unix systems, in which case, you'll need to become root to make it work. On most modern Unix systems, this can be done with `sudo python -m ensurepip`.

If you are using an older version of Python than Python 3.4, you'll need to download and install `pip` yourself, since `ensurepip` doesn't exist. You can do this by following the instructions at `http://pip.readthedocs.org/`.

Once `pip` is installed and you know the name of the package you want to install, you can install it using syntax such as:

```
pip install requests
```

However, if you do this, you'll either be installing the third-party library directly into your system Python directory, or more likely, get an error that you don't have permission to do so. You could force the installation as an administrator, but common consensus in the Python community is that you should only use system installers to install the third-party library to your system Python directory.

Instead, Python 3.4 supplies the `venv` tool. This utility basically gives you a mini Python installation called a *virtual environment* in your working directory. When you activate the mini Python, commands related to Python will work on that directory instead of the system directory. So when you run `pip` or `python`, it won't touch the system Python at all. Here's how to use it:

```
cd project_directory
python -m venv env
source env/bin/activate  # on Linux or MacOS
env/bin/activate.bat     # on Windows
```

Typically, you'll create a different virtual environment for each Python project you work on. You can store your virtual environments anywhere, but I keep mine in the same directory as the rest of my project files (but ignored in version control), so first we `cd` into that directory. Then we run the `venv` utility to create a virtual environment named `env`. Finally, we use one of the last two lines (depending on the operating system, as indicated in the comments) to activate the environment. We'll need to execute this line each time we want to use that particular virtualenv, and then use the command `deactivate` when we are done working on this project.

Virtual environments are a terrific way to keep your third-party dependencies separate. It is common to have different projects that depend on different versions of a particular library (for example, an older website might run on Django 1.5, while newer versions run on Django 1.8). Keeping each project in separate virtualenvs makes it easy to work in either version of Django. Further, it prevents conflicts between system-installed packages and `pip` installed packages if you try to install the same package using different tools.

Case study

To tie it all together, let's build a simple command-line notebook application. This is a fairly simple task, so we won't be experimenting with multiple packages. We will, however, see common usage of classes, functions, methods, and docstrings.

Let's start with a quick analysis: notes are short memos stored in a notebook. Each note should record the day it was written and can have tags added for easy querying. It should be possible to modify notes. We also need to be able to search for notes. All of these things should be done from the command line.

The obvious object is the `Note` object; less obvious one is a `Notebook` container object. Tags and dates also seem to be objects, but we can use dates from Python's standard library and a comma-separated string for tags. To avoid complexity, in the prototype, let's not define separate classes for these objects.

`Note` objects have attributes for `memo` itself, `tags`, and `creation_date`. Each note will also need a unique integer `id` so that users can select them in a menu interface. Notes could have a method to modify note content and another for tags, or we could just let the notebook access those attributes directly. To make searching easier, we should put a `match` method on the `Note` object. This method will accept a string and can tell us if a note matches the string without accessing the attributes directly. This way, if we want to modify the search parameters (to search tags instead of note contents, for example, or to make the search case-insensitive), we only have to do it in one place.

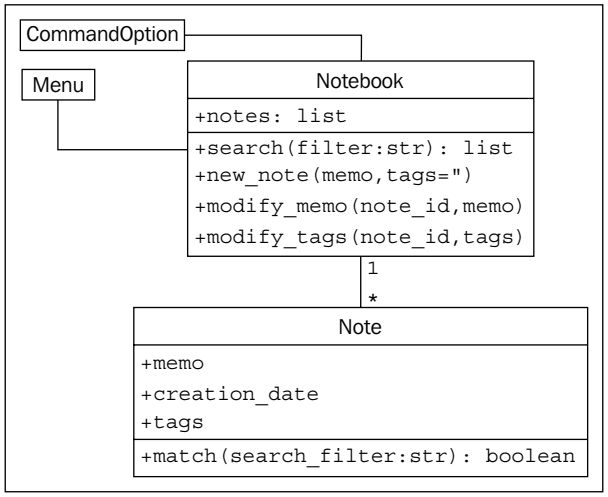
The `Notebook` object obviously has the list of notes as an attribute. It will also need a search method that returns a list of filtered notes.

But how do we interact with these objects? We've specified a command-line app, which can mean either that we run the program with different options to add or edit commands, or we have some kind of a menu that allows us to pick different things to do to the notebook. We should try to design it such that either interface is supported and future interfaces, such as a GUI toolkit or web-based interface, could be added in the future.

As a design decision, we'll implement the menu interface now, but will keep the command-line options version in mind to ensure we design our `Notebook` class with extensibility in mind.

If we have two command-line interfaces, each interacting with the `Notebook` object, then `Notebook` will need some methods for those interfaces to interact with. We need to be able to `add` a new note, and `modify` an existing note by `id`, in addition to the `search` method we've already discussed. The interfaces will also need to be able to list all notes, but they can do that by accessing the `notes` list attribute directly.

We may be missing a few details, but that gives us a really good overview of the code we need to write. We can summarize all this in a simple class diagram:



Before writing any code, let's define the folder structure for this project. The menu interface should clearly be in its own module, since it will be an executable script, and we may have other executable scripts accessing the notebook in the future. The `Notebook` and `Note` objects can live together in one module. These modules can both exist in the same top-level directory without having to put them in a package. An empty `command_option.py` module can help remind us in the future that we were planning to add new user interfaces.

```
parent_directory/
    notebook.py
    menu.py
    command_option.py
```

Now let's see some code. We start by defining the `Note` class as it seems simplest. The following example presents `Note` in its entirety. Docstrings within the example explain how it all fits together.

```
import datetime

# Store the next available id for all new notes
last_id = 0

class Note:
    '''Represent a note in the notebook. Match against a
```

```
        string in searches and store tags for each note.'''

        def __init__(self, memo, tags=''):
            '''initialize a note with memo and optional
            space-separated tags. Automatically set the note's
            creation date and a unique id.'''
            self.memo = memo
            self.tags = tags
            self.creation_date = datetime.date.today()
            global last_id
            last_id += 1
            self.id = last_id

        def match(self, filter):
            '''Determine if this note matches the filter
            text. Return True if it matches, False otherwise.

            Search is case sensitive and matches both text and
            tags.'''
            return filter in self.memo or filter in self.tags
```

Before continuing, we should quickly fire up the interactive interpreter and test our code so far. Test frequently and often because things never work the way you expect them to. Indeed, when I tested my first version of this example, I found out I had forgotten the `self` argument in the `match` function! We'll discuss automated testing in *Chapter 10, Python Design Patterns I*. For now, it suffices to check a few things using the interpreter:

```
>>> from notebook import Note
>>> n1 = Note("hello first")
>>> n2 = Note("hello again")
>>> n1.id
1
>>> n2.id
2
>>> n1.match('hello')
True
>>> n2.match('second')
False
```

It looks like everything is behaving as expected. Let's create our notebook next:

```
class Notebook:
    '''Represent a collection of notes that can be tagged,
    modified, and searched.'''

    def __init__(self):
        '''Initialize a notebook with an empty list.'''
        self.notes = []

    def new_note(self, memo, tags=''):
        '''Create a new note and add it to the list.'''
        self.notes.append(Note(memo, tags))

    def modify_memo(self, note_id, memo):
        '''Find the note with the given id and change its
        memo to the given value.'''
        for note in self.notes:
            if note.id == note_id:
                note.memo = memo
                break

    def modify_tags(self, note_id, tags):
        '''Find the note with the given id and change its
        tags to the given value.'''
        for note in self.notes:
            if note.id == note_id:
                note.tags = tags
                break

    def search(self, filter):
        '''Find all notes that match the given filter
        string.'''
        return [note for note in self.notes if
                note.match(filter)]
```

We'll clean this up in a minute. First, let's test it to make sure it works:

```
>>> from notebook import Note, Notebook
>>> n = Notebook()
>>> n.new_note("hello world")
>>> n.new_note("hello again")
>>> n.notes
[<notebook.Note object at 0xb730a78c>, <notebook.Note object at
  0xb73103ac>]
```

```
>>> n.notes[0].id
1
>>> n.notes[1].id
2
>>> n.notes[0].memo
'hello world'
>>> n.search("hello")
[<notebook.Note object at 0xb730a78c>, <notebook.Note object at
  0xb73103ac>]
>>> n.search("world")
[<notebook.Note object at 0xb730a78c>]
>>> n.modify_memo(1, "hi world")
>>> n.notes[0].memo
'hi world'
```

It does work. The code is a little messy though; our `modify_tags` and `modify_memo` methods are almost identical. That's not good coding practice. Let's see how we can improve it.

Both methods are trying to identify the note with a given ID before doing something to that note. So, let's add a method to locate the note with a specific ID. We'll prefix the method name with an underscore to suggest that the method is for internal use only, but of course, our menu interface can access the method if it wants to:

```
    def _find_note(self, note_id):
        '''Locate the note with the given id.'''
        for note in self.notes:
            if note.id == note_id:
                return note
        return None

    def modify_memo(self, note_id, memo):
        '''Find the note with the given id and change its
        memo to the given value.'''
        self._find_note(note_id).memo = memo
```

This should work for now. Let's have a look at the menu interface. The interface simply needs to present a menu and allow the user to input choices. Here's our first try:

```
import sys
```

```
from notebook import Notebook, Note

class Menu:
    '''Display a menu and respond to choices when run.'''
    def __init__(self):
        self.notebook = Notebook()
        self.choices = {
                "1": self.show_notes,
                "2": self.search_notes,
                "3": self.add_note,
                "4": self.modify_note,
                "5": self.quit
                }

    def display_menu(self):
        print("""
Notebook Menu

1. Show all Notes
2. Search Notes
3. Add Note
4. Modify Note
5. Quit
""")

    def run(self):
        '''Display the menu and respond to choices.'''
        while True:
            self.display_menu()
            choice = input("Enter an option: ")
            action = self.choices.get(choice)
            if action:
                action()
            else:
                print("{0} is not a valid choice".format(choice))

    def show_notes(self, notes=None):
        if not notes:
            notes = self.notebook.notes
        for note in notes:
            print("{0}: {1}\n{2}".format(
                note.id, note.tags, note.memo))

    def search_notes(self):
```

```
            filter = input("Search for: ")
            notes = self.notebook.search(filter)
            self.show_notes(notes)

        def add_note(self):
            memo = input("Enter a memo: ")
            self.notebook.new_note(memo)
            print("Your note has been added.")

        def modify_note(self):
            id = input("Enter a note id: ")
            memo = input("Enter a memo: ")
            tags = input("Enter tags: ")
            if memo:
                self.notebook.modify_memo(id, memo)
            if tags:
                self.notebook.modify_tags(id, tags)

        def quit(self):
            print("Thank you for using your notebook today.")
            sys.exit(0)

    if __name__ == "__main__":
        Menu().run()
```

This code first imports the notebook objects using an absolute import. Relative imports wouldn't work because we haven't placed our code inside a package. The `Menu` class's `run` method repeatedly displays a menu and responds to choices by calling functions on the notebook. This is done using an idiom that is rather peculiar to Python; it is a lightweight version of the command pattern that we will discuss in *Chapter 10*, *Python Design Patterns I*. The choices entered by the user are strings. In the menu's `__init__` method, we create a dictionary that maps strings to functions on the menu object itself. Then, when the user makes a choice, we retrieve the object from the dictionary. The `action` variable actually refers to a specific method, and is called by appending empty brackets (since none of the methods require parameters) to the variable. Of course, the user might have entered an inappropriate choice, so we check if the action really exists before calling it.

Each of the various methods request user input and call appropriate methods on the `Notebook` object associated with it. For the `search` implementation, we notice that after we've filtered the notes, we need to show them to the user, so we make the `show_notes` function serve double duty; it accepts an optional `notes` parameter. If it's supplied, it displays only the filtered notes, but if it's not, it displays all notes. Since the `notes` parameter is optional, `show_notes` can still be called with no parameters as an empty menu item.

If we test this code, we'll find that modifying notes doesn't work. There are two bugs, namely:

- The notebook crashes when we enter a note ID that does not exist. We should never trust our users to enter correct data!
- Even if we enter a correct ID, it will crash because the note IDs are integers, but our menu is passing a string.

The latter bug can be solved by modifying the `Notebook` class's `_find_note` method to compare the values using strings instead of the integers stored in the note, as follows:

```
def _find_note(self, note_id):
    '''Locate the note with the given id.'''
    for note in self.notes:
        if str(note.id) == str(note_id):
            return note
    return None
```

We simply convert both the input (`note_id`) and the note's ID to strings before comparing them. We could also convert the input to an integer, but then we'd have trouble if the user had entered the letter "a" instead of the number "1".

The problem with users entering note IDs that don't exist can be fixed by changing the two `modify` methods on the notebook to check whether `_find_note` returned a note or not, like this:

```
def modify_memo(self, note_id, memo):
    '''Find the note with the given id and change its
    memo to the given value.'''
    note = self._find_note(note_id)
    if note:
        note.memo = memo
        return True
    return False
```

This method has been updated to return `True` or `False`, depending on whether a note has been found. The menu could use this return value to display an error if the user entered an invalid note. This code is a bit unwieldy though; it would look a bit better if it raised an exception instead. We'll cover those in *Chapter 4*, *Expecting the Unexpected*.

Exercises

Write some object-oriented code. The goal is to use the principles and syntax you learned in this chapter to ensure you can use it, instead of just reading about it. If you've been working on a Python project, go back over it and see if there are some objects you can create and add properties or methods to. If it's large, try dividing it into a few modules or even packages and play with the syntax.

If you don't have such a project, try starting a new one. It doesn't have to be something you intend to finish, just stub out some basic design parts. You don't need to fully implement everything, often just a `print("this method will do something")` is all you need to get the overall design in place. This is called **top-down design**, in which you work out the different interactions and describe how they should work before actually implementing what they do. The converse, **bottom-up design**, implements details first and then ties them all together. Both patterns are useful at different times, but for understanding object-oriented principles, a top-down workflow is more suitable.

If you're having trouble coming up with ideas, try writing a to-do application. (Hint: It would be similar to the design of the notebook application, but with extra date management methods.) It can keep track of things you want to do each day, and allow you to mark them as completed.

Now, try designing a bigger project. It doesn't have to actually do anything, but make sure you experiment with the package and module importing syntax. Add some functions in various modules and try importing them from other modules and packages. Use relative and absolute imports. See the difference, and try to imagine scenarios where you would want to use each one.

Summary

In this chapter, we learned how simple it is to create classes and assign properties and methods in Python. Unlike many languages, Python differentiates between a constructor and an initializer. It has a relaxed attitude toward access control. There are many different levels of scope, including packages, modules, classes, and functions. We understood the difference between relative and absolute imports, and how to manage third-party packages that don't come with Python.

In the next chapter, we'll learn how to share implementation using inheritance.

4
Expecting the Unexpected

Programs are very fragile. It would be ideal if code always returned a valid result, but sometimes a valid result can't be calculated. For example, it's not possible to divide by zero, or to access the eighth item in a five-item list.

In the old days, the only way around this was to rigorously check the inputs for every function to make sure they made sense. Typically, functions had special return values to indicate an error condition; for example, they could return a negative number to indicate that a positive value couldn't be calculated. Different numbers might mean different errors occurred. Any code that called this function would have to explicitly check for an error condition and act accordingly. A lot of code didn't bother to do this, and programs simply crashed. However, in the object-oriented world, this is not the case.

In this chapter, we will study **exceptions**, special error objects that only need to be handled when it makes sense to handle them. In particular, we will cover:

- How to cause an exception to occur
- How to recover when an exception has occurred
- How to handle different exception types in different ways
- Cleaning up when an exception has occurred
- Creating new types of exception
- Using the exception syntax for flow control

Raising exceptions

In principle, an exception is just an object. There are many different exception classes available, and we can easily define more of our own. The one thing they all have in common is that they inherit from a built-in class called `BaseException`. These exception objects become special when they are handled inside the program's flow of control. When an exception occurs, everything that was supposed to happen doesn't happen, unless it was supposed to happen when an exception occurred. Make sense? Don't worry, it will!

The easiest way to cause an exception to occur is to do something silly! Chances are you've done this already and seen the exception output. For example, any time Python encounters a line in your program that it can't understand, it bails with `SyntaxError`, which is a type of exception. Here's a common one:

```
>>> print "hello world"
  File "<stdin>", line 1
    print "hello world"
                      ^
SyntaxError: invalid syntax
```

This `print` statement was a valid command in Python 2 and previous versions, but in Python 3, because `print` is now a function, we have to enclose the arguments in parenthesis. So, if we type the preceding command into a Python 3 interpreter, we get the `SyntaxError`.

In addition to `SyntaxError`, some other common exceptions, which we can handle, are shown in the following example:

```
>>> x = 5 / 0
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
ZeroDivisionError: int division or modulo by zero

>>> lst = [1,2,3]
>>> print(lst[3])
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
IndexError: list index out of range

>>> lst + 2
Traceback (most recent call last):
```

```
  File "<stdin>", line 1, in <module>
TypeError: can only concatenate list (not "int") to list

>>> lst.add
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
AttributeError: 'list' object has no attribute 'add'

>>> d = {'a': 'hello'}
>>> d['b']
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
KeyError: 'b'

>>> print(this_is_not_a_var)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
NameError: name 'this_is_not_a_var' is not defined
```

Sometimes these exceptions are indicators of something wrong in our program (in which case we would go to the indicated line number and fix it), but they also occur in legitimate situations. A `ZeroDivisionError` doesn't always mean we received an invalid input. It could also mean we have received a different input. The user may have entered a zero by mistake, or on purpose, or it may represent a legitimate value, such as an empty bank account or the age of a newborn child.

You may have noticed all the preceding built-in exceptions end with the name `Error`. In Python, the words `error` and `exception` are used almost interchangeably. Errors are sometimes considered more dire than exceptions, but they are dealt with in exactly the same way. Indeed, all the error classes in the preceding example have `Exception` (which extends `BaseException`) as their superclass.

Raising an exception

We'll get to handling exceptions in a minute, but first, let's discover what we should do if we're writing a program that needs to inform the user or a calling function that the inputs are somehow invalid. Wouldn't it be great if we could use the same mechanism that Python uses? Well, we can! Here's a simple class that adds items to a list only if they are even numbered integers:

```
    class EvenOnly(list):
        def append(self, integer):
            if not isinstance(integer, int):
                raise TypeError("Only integers can be added")
            if integer % 2:
                raise ValueError("Only even numbers can be added")
            super().append(integer)
```

This class extends the `list` built-in, as we discussed in *Chapter 2, Objects in Python*, and overrides the `append` method to check two conditions that ensure the item is an even integer. We first check if the input is an instance of the `int` type, and then use the modulus operator to ensure it is divisible by two. If either of the two conditions is not met, the `raise` keyword causes an exception to occur. The `raise` keyword is simply followed by the object being raised as an exception. In the preceding example, two objects are newly constructed from the built-in classes `TypeError` and `ValueError`. The raised object could just as easily be an instance of a new exception class we create ourselves (we'll see how shortly), an exception that was defined elsewhere, or even an exception object that has been previously raised and handled. If we test this class in the Python interpreter, we can see that it is outputting useful error information when exceptions occur, just as before:

```
>>> e = EvenOnly()
>>> e.append("a string")
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "even_integers.py", line 7, in add
    raise TypeError("Only integers can be added")
TypeError: Only integers can be added

>>> e.append(3)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "even_integers.py", line 9, in add
    raise ValueError("Only even numbers can be added")
ValueError: Only even numbers can be added
>>> e.append(2)
```

While this class is effective for demonstrating exceptions in action, it isn't very good at its job. It is still possible to get other values into the list using index notation or slice notation. This can all be avoided by overriding other appropriate methods, some of which are double-underscore methods.

The effects of an exception

When an exception is raised, it appears to stop program execution immediately. Any lines that were supposed to run after the exception is raised are not executed, and unless the exception is dealt with, the program will exit with an error message. Take a look at this simple function:

```
def no_return():
    print("I am about to raise an exception")
    raise Exception("This is always raised")
    print("This line will never execute")
    return "I won't be returned"
```

If we execute this function, we see that the first `print` call is executed and then the exception is raised. The second `print` statement is never executed, and the `return` statement never executes either:

```
>>> no_return()
I am about to raise an exception
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "exception_quits.py", line 3, in no_return
    raise Exception("This is always raised")
Exception: This is always raised
```

Furthermore, if we have a function that calls another function that raises an exception, nothing will be executed in the first function after the point where the second function was called. Raising an exception stops all execution right up through the function call stack until it is either handled or forces the interpreter to exit. To demonstrate, let's add a second function that calls the earlier one:

```
def call_exceptor():
    print("call_exceptor starts here...")
    no_return()
    print("an exception was raised...")
    print("...so these lines don't run")
```

When we call this function, we see that the first `print` statement executes, as well as the first line in the `no_return` function. But once the exception is raised, nothing else executes:

```
>>> call_exceptor()
call_exceptor starts here...
I am about to raise an exception
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "method_calls_excepting.py", line 9, in call_exceptor
    no_return()
  File "method_calls_excepting.py", line 3, in no_return
    raise Exception("This is always raised")
Exception: This is always raised
```

We'll soon see that when the interpreter is not actually taking a shortcut and exiting immediately, we can react to and deal with the exception inside either method. Indeed, exceptions can be handled at any level after they are initially raised.

Look at the exception's output (called a traceback) from bottom to top, and notice how both methods are listed. Inside `no_return`, the exception is initially raised. Then, just above that, we see that inside `call_exceptor`, that pesky `no_return` function was called and the exception bubbled up to the calling method. From there, it went up one more level to the main interpreter, which, not knowing what else to do with it, gave up and printed a traceback.

Handling exceptions

Now let's look at the tail side of the exception coin. If we encounter an exception situation, how should our code react to or recover from it? We handle exceptions by wrapping any code that might throw one (whether it is exception code itself, or a call to any function or method that may have an exception raised inside it) inside a `try...except` clause. The most basic syntax looks like this:

```
try:
    no_return()
except:
    print("I caught an exception")
print("executed after the exception")
```

If we run this simple script using our existing `no_return` function, which as we know very well, always throws an exception, we get this output:

```
I am about to raise an exception
I caught an exception
executed after the exception
```

The `no_return` function happily informs us that it is about to raise an exception, but we fooled it and caught the exception. Once caught, we were able to clean up after ourselves (in this case, by outputting that we were handling the situation), and continue on our way, with no interference from that offensive function. The remainder of the code in the `no_return` function still went unexecuted, but the code that called the function was able to recover and continue.

Note the indentation around `try` and `except`. The `try` clause wraps any code that might throw an exception. The `except` clause is then back on the same indentation level as the `try` line. Any code to handle the exception is indented after the `except` clause. Then normal code resumes at the original indentation level.

The problem with the preceding code is that it will catch any type of exception. What if we were writing some code that could raise both a `TypeError` and a `ZeroDivisionError`? We might want to catch the `ZeroDivisionError`, but let the `TypeError` propagate to the console. Can you guess the syntax?

Here's a rather silly function that does just that:

```
def funny_division(divider):
    try:
        return 100 / divider
    except ZeroDivisionError:
        return "Zero is not a good idea!"

print(funny_division(0))
print(funny_division(50.0))
print(funny_division("hello"))
```

The function is tested with `print` statements that show it behaving as expected:

```
Zero is not a good idea!
2.0
Traceback (most recent call last):
  File "catch_specific_exception.py", line 9, in <module>
    print(funny_division("hello"))
  File "catch_specific_exception.py", line 3, in funny_division
    return 100 / anumber
TypeError: unsupported operand type(s) for /: 'int' and 'str'.
```

The first line of output shows that if we enter `0`, we get properly mocked. If we call with a valid number (note that it's not an integer, but it's still a valid divisor), it operates correctly. Yet if we enter a string (you were wondering how to get a `TypeError`, weren't you?), it fails with an exception. If we had used an empty `except` clause that didn't specify a `ZeroDivisionError`, it would have accused us of dividing by zero when we sent it a string, which is not a proper behavior at all.

We can even catch two or more different exceptions and handle them with the same code. Here's an example that raises three different types of exception. It handles `TypeError` and `ZeroDivisionError` with the same exception handler, but it may also raise a `ValueError` if you supply the number `13`:

```
def funny_division2(anumber):
    try:
        if anumber == 13:
            raise ValueError("13 is an unlucky number")
        return 100 / anumber
    except (ZeroDivisionError, TypeError):
        return "Enter a number other than zero"

for val in (0, "hello", 50.0, 13):

    print("Testing {}:".format(val), end=" ")
    print(funny_division2(val))
```

The `for` loop at the bottom loops over several test inputs and prints the results. If you're wondering about that `end` argument in the `print` statement, it just turns the default trailing newline into a space so that it's joined with the output from the next line. Here's a run of the program:

```
Testing 0: Enter a number other than zero
Testing hello: Enter a number other than zero
Testing 50.0: 2.0
Testing 13: Traceback (most recent call last):
  File "catch_multiple_exceptions.py", line 11, in <module>
    print(funny_division2(val))
  File "catch_multiple_exceptions.py", line 4, in funny_division2
    raise ValueError("13 is an unlucky number")
ValueError: 13 is an unlucky number
```

The number `0` and the string are both caught by the `except` clause, and a suitable error message is printed. The exception from the number `13` is not caught because it is a `ValueError`, which was not included in the types of exceptions being handled. This is all well and good, but what if we want to catch different exceptions and do different things with them? Or maybe we want to do something with an exception and then allow it to continue to bubble up to the parent function, as if it had never been caught? We don't need any new syntax to deal with these cases. It's possible to stack `except` clauses, and only the first match will be executed. For the second question, the `raise` keyword, with no arguments, will reraise the last exception if we're already inside an exception handler. Observe in the following code:

```
def funny_division3(anumber):
    try:
        if anumber == 13:
            raise ValueError("13 is an unlucky number")
        return 100 / anumber
    except ZeroDivisionError:
        return "Enter a number other than zero"
    except TypeError:
        return "Enter a numerical value"
    except ValueError:
        print("No, No, not 13!")
        raise
```

The last line reraises the `ValueError`, so after outputting `No, No, not 13!`, it will raise the exception again; we'll still get the original stack trace on the console.

If we stack exception clauses like we did in the preceding example, only the first matching clause will be run, even if more than one of them fits. How can more than one clause match? Remember that exceptions are objects, and can therefore be subclassed. As we'll see in the next section, most exceptions extend the `Exception` class (which is itself derived from `BaseException`). If we catch `Exception` before we catch `TypeError`, then only the `Exception` handler will be executed, because `TypeError` is an `Exception` by inheritance.

This can come in handy in cases where we want to handle some exceptions specifically, and then handle all remaining exceptions as a more general case. We can simply catch `Exception` after catching all the specific exceptions and handle the general case there.

Sometimes, when we catch an exception, we need a reference to the `Exception` object itself. This most often happens when we define our own exceptions with custom arguments, but can also be relevant with standard exceptions. Most exception classes accept a set of arguments in their constructor, and we might want to access those attributes in the exception handler. If we define our own exception class, we can even call custom methods on it when we catch it. The syntax for capturing an exception as a variable uses the `as` keyword:

```
try:
    raise ValueError("This is an argument")
except ValueError as e:
    print("The exception arguments were", e.args)
```

If we run this simple snippet, it prints out the string argument that we passed into `ValueError` upon initialization.

We've seen several variations on the syntax for handling exceptions, but we still don't know how to execute code regardless of whether or not an exception has occurred. We also can't specify code that should be executed only if an exception does not occur. Two more keywords, `finally` and `else`, can provide the missing pieces. Neither one takes any extra arguments. The following example randomly picks an exception to throw and raises it. Then some not-so-complicated exception handling code is run that illustrates the newly introduced syntax:

```
import random
some_exceptions = [ValueError, TypeError, IndexError, None]

try:
    choice = random.choice(some_exceptions)
    print("raising {}".format(choice))
    if choice:
        raise choice("An error")
except ValueError:
    print("Caught a ValueError")
except TypeError:
    print("Caught a TypeError")
except Exception as e:
    print("Caught some other error: %s" %
        ( e.__class__.__name__))
else:
    print("This code called if there is no exception")
finally:
    print("This cleanup code is always called")
```

If we run this example—which illustrates almost every conceivable exception handling scenario—a few times, we'll get different output each time, depending on which exception `random` chooses. Here are some example runs:

```
$ python finally_and_else.py
raising None
This code called if there is no exception
This cleanup code is always called

$ python finally_and_else.py
raising <class 'TypeError'>
Caught a TypeError
This cleanup code is always called

$ python finally_and_else.py
raising <class 'IndexError'>
Caught some other error: IndexError
This cleanup code is always called

$ python finally_and_else.py
raising <class 'ValueError'>
Caught a ValueError
This cleanup code is always called
```

Note how the `print` statement in the `finally` clause is executed no matter what happens. This is extremely useful when we need to perform certain tasks after our code has finished running (even if an exception has occurred). Some common examples include:

- Cleaning up an open database connection
- Closing an open file
- Sending a closing handshake over the network

The `finally` clause is also very important when we execute a `return` statement from inside a `try` clause. The `finally` handle will still be executed before the value is returned.

Also, pay attention to the output when no exception is raised: both the `else` and the `finally` clauses are executed. The `else` clause may seem redundant, as the code that should be executed only when no exception is raised could just be placed after the entire `try...except` block. The difference is that the `else` block will still be executed if an exception is caught and handled. We'll see more on this when we discuss using exceptions as flow control later.

Any of the `except`, `else`, and `finally` clauses can be omitted after a `try` block (although `else` by itself is invalid). If you include more than one, the `except` clauses must come first, then the `else` clause, with the `finally` clause at the end. The order of the `except` clauses normally goes from most specific to most generic.

The exception hierarchy

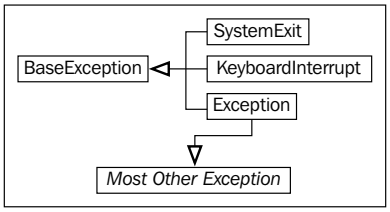
We've already seen several of the most common built-in exceptions, and you'll probably encounter the rest over the course of your regular Python development. As we noticed earlier, most exceptions are subclasses of the `Exception` class. But this is not true of all exceptions. `Exception` itself actually inherits from a class called `BaseException`. In fact, all exceptions must extend the `BaseException` class or one of its subclasses.

There are two key exceptions, `SystemExit` and `KeyboardInterrupt`, that derive directly from `BaseException` instead of `Exception`. The `SystemExit` exception is raised whenever the program exits naturally, typically because we called the `sys.exit` function somewhere in our code (for example, when the user selected an exit menu item, clicked the "close" button on a window, or entered a command to shut down a server). The exception is designed to allow us to clean up code before the program ultimately exits, so we generally don't need to handle it explicitly (because cleanup code happens inside a `finally` clause).

If we do handle it, we would normally reraise the exception, since catching it would stop the program from exiting. There are, of course, situations where we might want to stop the program exiting, for example, if there are unsaved changes and we want to prompt the user if they really want to exit. Usually, if we handle `SystemExit` at all, it's because we want to do something special with it, or are anticipating it directly. We especially don't want it to be accidentally caught in generic clauses that catch all normal exceptions. This is why it derives directly from `BaseException`.

The `KeyboardInterrupt` exception is common in command-line programs. It is thrown when the user explicitly interrupts program execution with an OS-dependent key combination (normally, *Ctrl* + *C*). This is a standard way for the user to deliberately interrupt a running program, and like `SystemExit`, it should almost always respond by terminating the program. Also, like `SystemExit`, it should handle any cleanup tasks inside `finally` blocks.

Here is a class diagram that fully illustrates the exception hierarchy:



When we use the `except:` clause without specifying any type of exception, it will catch all subclasses of `BaseException`; which is to say, it will catch all exceptions, including the two special ones. Since we almost always want these to get special treatment, it is unwise to use the `except:` statement without arguments. If you want to catch all exceptions other than `SystemExit` and `KeyboardInterrupt`, explicitly catch `Exception`.

Furthermore, if you do want to catch all exceptions, I suggest using the syntax `except BaseException:` instead of a raw `except:`. This helps explicitly tell future readers of your code that you are intentionally handling the special case exceptions.

Defining our own exceptions

Often, when we want to raise an exception, we find that none of the built-in exceptions are suitable. Luckily, it's trivial to define new exceptions of our own. The name of the class is usually designed to communicate what went wrong, and we can provide arbitrary arguments in the initializer to include additional information.

All we have to do is inherit from the `Exception` class. We don't even have to add any content to the class! We can, of course, extend `BaseException` directly, but then it will not be caught by generic `except Exception` clauses.

Here's a simple exception we might use in a banking application:

```
class InvalidWithdrawal(Exception):
    pass

raise InvalidWithdrawal("You don't have $50 in your account")
```

The last line illustrates how to raise the newly defined exception. We are able to pass an arbitrary number of arguments into the exception. Often a string message is used, but any object that might be useful in a later exception handler can be stored. The `Exception.__init__` method is designed to accept any arguments and store them as a tuple in an attribute named `args`. This makes exceptions easier to define without needing to override `__init__`.

Of course, if we do want to customize the initializer, we are free to do so. Here's an exception whose initializer accepts the current balance and the amount the user wanted to withdraw. In addition, it adds a method to calculate how overdrawn the request was:

```
class InvalidWithdrawal(Exception):
    def __init__(self, balance, amount):
        super().__init__("account doesn't have ${}".format(
            amount))
        self.amount = amount
        self.balance = balance

    def overage(self):
        return self.amount - self.balance

raise InvalidWithdrawal(25, 50)
```

The `raise` statement at the end illustrates how to construct this exception. As you can see, we can do anything with an exception that we would do with other objects. We could catch an exception and pass it around as a working object, although it is more common to include a reference to the working object as an attribute on an exception and pass that around instead.

Here's how we would handle an `InvalidWithdrawal` exception if one was raised:

```
try:
    raise InvalidWithdrawal(25, 50)
except InvalidWithdrawal as e:
    print("I'm sorry, but your withdrawal is "
            "more than your balance by "
            "${}".format(e.overage()))
```

Here we see a valid use of the `as` keyword. By convention, most Python coders name the exception variable `e`, although, as usual, you are free to call it `ex`, `exception`, or `aunt_sally` if you prefer.

There are many reasons for defining our own exceptions. It is often useful to add information to the exception or log it in some way. But the utility of custom exceptions truly comes to light when creating a framework, library, or API that is intended for access by other programmers. In that case, be careful to ensure your code is raising exceptions that make sense to the client programmer. They should be easy to handle and clearly describe what went on. The client programmer should easily see how to fix the error (if it reflects a bug in their code) or handle the exception (if it's a situation they need to be made aware of).

Exceptions aren't exceptional. Novice programmers tend to think of exceptions as only useful for exceptional circumstances. However, the definition of exceptional circumstances can be vague and subject to interpretation. Consider the following two functions:

```
def divide_with_exception(number, divisor):
    try:
        print("{} / {} = {}".format(
            number, divisor, number / divisor * 1.0))
    except ZeroDivisionError:
        print("You can't divide by zero")

def divide_with_if(number, divisor):
    if divisor == 0:
        print("You can't divide by zero")
    else:
        print("{} / {} = {}".format(
            number, divisor, number / divisor * 1.0))
```

These two functions behave identically. If `divisor` is zero, an error message is printed; otherwise, a message printing the result of division is displayed. We could avoid a `ZeroDivisionError` ever being thrown by testing for it with an `if` statement. Similarly, we can avoid an `IndexError` by explicitly checking whether or not the parameter is within the confines of the list, and a `KeyError` by checking if the key is in a dictionary.

But we shouldn't do this. For one thing, we might write an `if` statement that checks whether or not the index is lower than the parameters of the list, but forget to check negative values.

Remember, Python lists support negative indexing; `-1` refers to the last element in the list.

Eventually, we would discover this and have to find all the places where we were checking code. But if we had simply caught the `IndexError` and handled it, our code would just work.

Python programmers tend to follow a model of *Ask forgiveness rather than permission*, which is to say, they execute code and then deal with anything that goes wrong. The alternative, to *look before you leap*, is generally frowned upon. There are a few reasons for this, but the main one is that it shouldn't be necessary to burn CPU cycles looking for an unusual situation that is not going to arise in the normal path through the code. Therefore, it is wise to use exceptions for exceptional circumstances, even if those circumstances are only a little bit exceptional. Taking this argument further, we can actually see that the exception syntax is also effective for flow control. Like an `if` statement, exceptions can be used for decision making, branching, and message passing.

Imagine an inventory application for a company that sells widgets and gadgets. When a customer makes a purchase, the item can either be available, in which case the item is removed from inventory and the number of items left is returned, or it might be out of stock. Now, being out of stock is a perfectly normal thing to happen in an inventory application. It is certainly not an exceptional circumstance. But what do we return if it's out of stock? A string saying out of stock? A negative number? In both cases, the calling method would have to check whether the return value is a positive integer or something else, to determine if it is out of stock. That seems a bit messy. Instead, we can raise `OutOfStockException` and use the `try` statement to direct program flow control. Make sense? In addition, we want to make sure we don't sell the same item to two different customers, or sell an item that isn't in stock yet. One way to facilitate this is to lock each type of item to ensure only one person can update it at a time. The user must lock the item, manipulate the item (purchase, add stock, count items left…), and then unlock the item. Here's an incomplete `Inventory` example with docstrings that describes what some of the methods should do:

```
class Inventory:
    def lock(self, item_type):
        '''Select the type of item that is going to
        be manipulated. This method will lock the
        item so nobody else can manipulate the
        inventory until it's returned. This prevents
        selling the same item to two different
        customers.'''
        pass

    def unlock(self, item_type):
        '''Release the given type so that other
        customers can access it.'''
        pass

    def purchase(self, item_type):
```

```
        '''If the item is not locked, raise an
        exception. If the item_type  does not exist,
        raise an exception. If the item is currently
        out of stock, raise an exception. If the item
        is available, subtract one item and return
        the number of items left.'''
        pass
```

We could hand this object prototype to a developer and have them implement the methods to do exactly as they say while we work on the code that needs to make a purchase. We'll use Python's robust exception handling to consider different branches, depending on how the purchase was made:

```
item_type = 'widget'
inv = Inventory()
inv.lock(item_type)
try:
    num_left = inv.purchase(item_type)
except InvalidItemType:
    print("Sorry, we don't sell {}".format(item_type))
except OutOfStock:
    print("Sorry, that item is out of stock.")
else:
    print("Purchase complete. There are "
            "{} {}s left".format(num_left, item_type))
finally:
    inv.unlock(item_type)
```

Pay attention to how all the possible exception handling clauses are used to ensure the correct actions happen at the correct time. Even though `OutOfStock` is not a terribly exceptional circumstance, we are able to use an exception to handle it suitably. This same code could be written with an `if...elif...else` structure, but it wouldn't be as easy to read or maintain.

We can also use exceptions to pass messages between different methods. For example, if we wanted to inform the customer as to what date the item is expected to be in stock again, we could ensure our `OutOfStock` object requires a `back_in_stock` parameter when it is constructed. Then, when we handle the exception, we can check that value and provide additional information to the customer. The information attached to the object can be easily passed between two different parts of the program. The exception could even provide a method that instructs the inventory object to reorder or backorder an item.

Using exceptions for flow control can make for some handy program designs. The important thing to take from this discussion is that exceptions are not a bad thing that we should try to avoid. Having an exception occur does not mean that you should have prevented this exceptional circumstance from happening. Rather, it is just a powerful way to communicate information between two sections of code that may not be directly calling each other.

Case study

We've been looking at the use and handling of exceptions at a fairly low level of detail—syntax and definitions. This case study will help tie it all in with our previous chapters so we can see how exceptions are used in the larger context of objects, inheritance, and modules.

Today, we'll be designing a simple central authentication and authorization system. The entire system will be placed in one module, and other code will be able to query that module object for authentication and authorization purposes. We should admit, from the start, that we aren't security experts, and that the system we are designing may be full of security holes. Our purpose is to study exceptions, not to secure a system. It will be sufficient, however, for a basic login and permission system that other code can interact with. Later, if that other code needs to be made more secure, we can have a security or cryptography expert review or rewrite our module, preferably without changing the API.

Authentication is the process of ensuring a user is really the person they say they are. We'll follow the lead of common web systems today, which use a username and private password combination. Other methods of authentication include voice recognition, fingerprint or retinal scanners, and identification cards.

Authorization, on the other hand, is all about determining whether a given (authenticated) user is permitted to perform a specific action. We'll create a basic permission list system that stores a list of the specific people allowed to perform each action.

In addition, we'll add some administrative features to allow new users to be added to the system. For brevity, we'll leave out editing of passwords or changing of permissions once they've been added, but these (highly necessary) features can certainly be added in the future.

There's a simple analysis; now let's proceed with design. We're obviously going to need a `User` class that stores the username and an encrypted password. This class will also allow a user to log in by checking whether a supplied password is valid. We probably won't need a `Permission` class, as those can just be strings mapped to a list of users using a dictionary. We should have a central `Authenticator` class that handles user management and logging in or out. The last piece of the puzzle is an `Authorizor` class that deals with permissions and checking whether a user can perform an activity. We'll provide a single instance of each of these classes in the `auth` module so that other modules can use this central mechanism for all their authentication and authorization needs. Of course, if they want to instantiate private instances of these classes, for non-central authorization activities, they are free to do so.

We'll also be defining several exceptions as we go along. We'll start with a special `AuthException` base class that accepts a `username` and optional `user` object as parameters; most of our self-defined exceptions will inherit from this one.

Let's build the `User` class first; it seems simple enough. A new user can be initialized with a username and password. The password will be stored encrypted to reduce the chances of its being stolen. We'll also need a `check_password` method to test whether a supplied password is the correct one. Here is the class in full:

```
import hashlib

class User:
    def __init__(self, username, password):
        '''Create a new user object. The password
        will be encrypted before storing.'''
        self.username = username
        self.password = self._encrypt_pw(password)
        self.is_logged_in = False

    def _encrypt_pw(self, password):
        '''Encrypt the password with the username and return
        the sha digest.'''
        hash_string = (self.username + password)
        hash_string = hash_string.encode("utf8")
        return hashlib.sha256(hash_string).hexdigest()

    def check_password(self, password):
        '''Return True if the password is valid for this
        user, false otherwise.'''
        encrypted = self._encrypt_pw(password)
        return encrypted == self.password
```

Since the code for encrypting a password is required in both `__init__` and `check_password`, we pull it out to its own method. This way, it only needs to be changed in one place if someone realizes it is insecure and needs improvement. This class could easily be extended to include mandatory or optional personal details, such as names, contact information, and birth dates.

Before we write code to add users (which will happen in the as-yet undefined `Authenticator` class), we should examine some use cases. If all goes well, we can add a user with a username and password; the `User` object is created and inserted into a dictionary. But in what ways can all not go well? Well, clearly we don't want to add a user with a username that already exists in the dictionary. If we did so, we'd overwrite an existing user's data and the new user might have access to that user's privileges. So, we'll need a `UsernameAlreadyExists` exception. Also, for security's sake, we should probably raise an exception if the password is too short. Both of these exceptions will extend `AuthException`, which we mentioned earlier. So, before writing the `Authenticator` class, let's define these three exception classes:

```
class AuthException(Exception):
    def __init__(self, username, user=None):
        super().__init__(username, user)
        self.username = username
        self.user = user

class UsernameAlreadyExists(AuthException):
    pass

class PasswordTooShort(AuthException):
    pass
```

The `AuthException` requires a username and has an optional user parameter. This second parameter should be an instance of the `User` class associated with that username. The two specific exceptions we're defining simply need to inform the calling class of an exceptional circumstance, so we don't need to add any extra methods to them.

Now let's start on the `Authenticator` class. It can simply be a mapping of usernames to user objects, so we'll start with a dictionary in the initialization function. The method for adding a user needs to check the two conditions (password length and previously existing users) before creating a new `User` instance and adding it to the dictionary:

```
class Authenticator:
    def __init__(self):
        '''Construct an authenticator to manage
```

```
            users logging in and out.'''
            self.users = {}

        def add_user(self, username, password):
            if username in self.users:
                raise UsernameAlreadyExists(username)
            if len(password) < 6:
                raise PasswordTooShort(username)
            self.users[username] = User(username, password)
```

We could, of course, extend the password validation to raise exceptions for passwords that are too easy to crack in other ways, if we desired. Now let's prepare the `login` method. If we weren't thinking about exceptions just now, we might just want the method to return `True` or `False`, depending on whether the login was successful or not. But we are thinking about exceptions, and this could be a good place to use them for a not-so-exceptional circumstance. We could raise different exceptions, for example, if the username does not exist or the password does not match. This will allow anyone trying to log a user in to elegantly handle the situation using a `try/except/else` clause. So, first we add these new exceptions:

```
class InvalidUsername(AuthException):
    pass

class InvalidPassword(AuthException):
    pass
```

Then we can define a simple `login` method to our `Authenticator` class that raises these exceptions if necessary. If not, it flags the `user` as logged in and returns:

```
        def login(self, username, password):
            try:
                user = self.users[username]
            except KeyError:
                raise InvalidUsername(username)

            if not user.check_password(password):
                raise InvalidPassword(username, user)

            user.is_logged_in = True
            return True
```

Notice how the `KeyError` is handled. This could have been handled using `if username not in self.users:` instead, but we chose to handle the exception directly. We end up eating up this first exception and raising a brand new one of our own that better suits the user-facing API.

We can also add a method to check whether a particular username is logged in. Deciding whether to use an exception here is trickier. Should we raise an exception if the username does not exist? Should we raise an exception if the user is not logged in?

To answer these questions, we need to think about how the method would be accessed. Most often, this method will be used to answer the yes/no question, "Should I allow them access to <*something*>?" The answer will either be, "Yes, the username is valid and they are logged in", or "No, the username is not valid or they are not logged in". Therefore, a Boolean return value is sufficient. There is no need to use exceptions here, just for the sake of using an exception.

```
        def is_logged_in(self, username):
            if username in self.users:
                return self.users[username].is_logged_in
            return False
```

Finally, we can add a default authenticator instance to our module so that the client code can access it easily using `auth.authenticator`:

```
    authenticator = Authenticator()
```

This line goes at the module level, outside any class definition, so the authenticator variable can be accessed as `auth.authenticator`. Now we can start on the `Authorizor` class, which maps permissions to users. The `Authorizor` class should not permit user access to a permission if they are not logged in, so they'll need a reference to a specific authenticator. We'll also need to set up the permission dictionary upon initialization:

```
    class Authorizor:
        def __init__(self, authenticator):
            self.authenticator = authenticator
            self.permissions = {}
```

Now we can write methods to add new permissions and to set up which users are associated with each permission:

```
        def add_permission(self, perm_name):
            '''Create a new permission that users
            can be added to'''
            try:
                perm_set = self.permissions[perm_name]
            except KeyError:
                self.permissions[perm_name] = set()
            else:
```

```
            raise PermissionError("Permission Exists")

    def permit_user(self, perm_name, username):
        '''Grant the given permission to the user'''
        try:
            perm_set = self.permissions[perm_name]
        except KeyError:
            raise PermissionError("Permission does not exist")
        else:
            if username not in self.authenticator.users:
                raise InvalidUsername(username)
            perm_set.add(username)
```

The first method allows us to create a new permission, unless it already exists, in which case an exception is raised. The second allows us to add a username to a permission, unless either the permission or the username doesn't yet exist.

We use `set` instead of `list` for usernames, so that even if you grant a user permission more than once, the nature of sets means the user is only in the set once. We'll discuss sets further in a later chapter.

A `PermissionError` is raised in both methods. This new error doesn't require a username, so we'll make it extend `Exception` directly, instead of our custom `AuthException`:

```
class PermissionError(Exception):
    pass
```

Finally, we can add a method to check whether a user has a specific `permission` or not. In order for them to be granted access, they have to be both logged into the authenticator and in the set of people who have been granted access to that privilege. If either of these conditions is unsatisfied, an exception is raised:

```
    def check_permission(self, perm_name, username):
        if not self.authenticator.is_logged_in(username):
            raise NotLoggedInError(username)
        try:
            perm_set = self.permissions[perm_name]
        except KeyError:
            raise PermissionError("Permission does not exist")
        else:
            if username not in perm_set:
                raise NotPermittedError(username)
            else:
                return True
```

There are two new exceptions in here; they both take usernames, so we'll define them as subclasses of `AuthException`:

```
class NotLoggedInError(AuthException):
    pass

class NotPermittedError(AuthException):
    pass
```

Finally, we can add a default `authorizor` to go with our default authenticator:

```
authorizor = Authorizor(authenticator)
```

That completes a basic authentication/authorization system. We can test the system at the Python prompt, checking to see whether a user, `joe`, is permitted to do tasks in the paint department:

```
>>> import auth
>>> auth.authenticator.add_user("joe", "joepassword")
>>> auth.authorizor.add_permission("paint")
>>> auth.authorizor.check_permission("paint", "joe")
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "auth.py", line 109, in check_permission
    raise NotLoggedInError(username)
auth.NotLoggedInError: joe
>>> auth.authenticator.is_logged_in("joe")
False
>>> auth.authenticator.login("joe", "joepassword")
True
>>> auth.authorizor.check_permission("paint", "joe")
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "auth.py", line 116, in check_permission
    raise NotPermittedError(username)
auth.NotPermittedError: joe
>>> auth.authorizor.check_permission("mix", "joe")
Traceback (most recent call last):
  File "auth.py", line 111, in check_permission
    perm_set = self.permissions[perm_name]
```

```
KeyError: 'mix'

During handling of the above exception, another exception occurred:
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "auth.py", line 113, in check_permission
    raise PermissionError("Permission does not exist")
auth.PermissionError: Permission does not exist
>>> auth.authorizor.permit_user("mix", "joe")
Traceback (most recent call last):
  File "auth.py", line 99, in permit_user
    perm_set = self.permissions[perm_name]
KeyError: 'mix'

During handling of the above exception, another exception occurred:

Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "auth.py", line 101, in permit_user
    raise PermissionError("Permission does not exist")
auth.PermissionError: Permission does not exist
>>> auth.authorizor.permit_user("paint", "joe")
>>> auth.authorizor.check_permission("paint", "joe")
True
```

While verbose, the preceding output shows all of our code and most of our exceptions in action, but to really understand the API we've defined, we should write some exception handling code that actually uses it. Here's a basic menu interface that allows certain users to change or test a program:

```
import auth

# Set up a test user and permission
auth.authenticator.add_user("joe", "joepassword")
auth.authorizor.add_permission("test program")
auth.authorizor.add_permission("change program")
auth.authorizor.permit_user("test program", "joe")

class Editor:
```

```
    def __init__(self):
        self.username = None
        self.menu_map = {
                "login": self.login,
                "test": self.test,
                "change": self.change,
                "quit": self.quit
           }

    def login(self):
        logged_in = False
        while not logged_in:
            username = input("username: ")
            password = input("password: ")
            try:
                logged_in = auth.authenticator.login(
                        username, password)
            except auth.InvalidUsername:
                print("Sorry, that username does not exist")
            except auth.InvalidPassword:
                print("Sorry, incorrect password")
            else:
                self.username = username
    def is_permitted(self, permission):
        try:
            auth.authorizor.check_permission(
                permission, self.username)
        except auth.NotLoggedInError as e:
            print("{} is not logged in".format(e.username))
            return False
        except auth.NotPermittedError as e:
            print("{} cannot {}".format(
                e.username, permission))
            return False
        else:
            return True

    def test(self):
        if self.is_permitted("test program"):
            print("Testing program now...")

    def change(self):
        if self.is_permitted("change program"):
            print("Changing program now...")

    def quit(self):
```

```
            raise SystemExit()

        def menu(self):
            try:
                answer = ""
                while True:
                    print("""
Please enter a command:
\tlogin\tLogin
\ttest\tTest the program
\tchange\tChange the program
\tquit\tQuit
""")
                    answer = input("enter a command: ").lower()
                    try:
                        func = self.menu_map[answer]
                    except KeyError:
                        print("{} is not a valid option".format(
                            answer))
                    else:
                        func()
            finally:
                print("Thank you for testing the auth module")

Editor().menu()
```

This rather long example is conceptually very simple. The `is_permitted` method is probably the most interesting; this is a mostly internal method that is called by both `test` and `change` to ensure the user is permitted access before continuing. Of course, those two methods are stubs, but we aren't writing an editor here; we're illustrating the use of exceptions and exception handlers by testing an authentication and authorization framework!

Exercises

If you've never dealt with exceptions before, the first thing you need to do is look at any old Python code you've written and notice if there are places you should have been handling exceptions. How would you handle them? Do you need to handle them at all? Sometimes, letting the exception propagate to the console is the best way to communicate to the user, especially if the user is also the script's coder. Sometimes, you can recover from the error and allow the program to continue. Sometimes, you can only reformat the error into something the user can understand and display it to them.

Some common places to look are file I/O (is it possible your code will try to read a file that doesn't exist?), mathematical expressions (is it possible that a value you are dividing by is zero?), list indices (is the list empty?), and dictionaries (does the key exist?). Ask yourself if you should ignore the problem, handle it by checking values first, or handle it with an exception. Pay special attention to areas where you might have used `finally` and `else` to ensure the correct code is executed under all conditions.

Now write some new code. Think of a program that requires authentication and authorization, and try writing some code that uses the `auth` module we built in the case study. Feel free to modify the module if it's not flexible enough. Try to handle all the exceptions in a sensible way. If you're having trouble coming up with something that requires authentication, try adding authorization to the notepad example from *Chapter 2*, *Objects in Python*, or add authorization to the `auth` module itself—it's not a terribly useful module if just anybody can start adding permissions! Maybe require an administrator username and password before allowing privileges to be added or changed.

Finally, try to think of places in your code where you can raise exceptions. It can be in code you've written or are working on; or you can write a new project as an exercise. You'll probably have the best luck for designing a small framework or API that is meant to be used by other people; exceptions are a terrific communication tool between your code and someone else's. Remember to design and document any self-raised exceptions as part of the API, or they won't know whether or how to handle them!

Summary

In this chapter, we went into the gritty details of raising, handling, defining, and manipulating exceptions. Exceptions are a powerful way to communicate unusual circumstances or error conditions without requiring a calling function to explicitly check return values. There are many built-in exceptions and raising them is trivially easy. There are several different syntaxes for handling different exception events.

In the next chapter, everything we've studied so far will come together as we discuss how object-oriented programming principles and structures should best be applied in Python applications.

3
When Objects Are Alike

In the programming world, duplicate code is considered evil. We should not have multiple copies of the same, or similar, code in different places.

There are many ways to merge pieces of code or objects that have a similar functionality. In this chapter, we'll be covering the most famous object-oriented principle: inheritance. As discussed in *Chapter 1*, *Object-oriented Design*, inheritance allows us to create *is a* relationships between two or more classes, abstracting common logic into superclasses and managing specific details in the subclass. In particular, we'll be covering the Python syntax and principles for:

- Basic inheritance
- Inheriting from built-ins
- Multiple inheritance
- Polymorphism and duck typing

Basic inheritance

Technically, every class we create uses inheritance. All Python classes are subclasses of the special class named `object`. This class provides very little in terms of data and behaviors (the behaviors it does provide are all double-underscore methods intended for internal use only), but it does allow Python to treat all objects in the same way.

If we don't explicitly inherit from a different class, our classes will automatically inherit from `object`. However, we can openly state that our class derives from `object` using the following syntax:

```
class MySubClass(object):
    pass
```

This is inheritance! This example is, technically, no different from our very first example in *Chapter 2*, *Objects in Python*, since Python 3 automatically inherits from `object` if we don't explicitly provide a different superclass. A superclass, or parent class, is a class that is being inherited from. A subclass is a class that is inheriting from a superclass. In this case, the superclass is `object`, and `MySubClass` is the subclass. A subclass is also said to be derived from its parent class or that the subclass extends the parent.

As you've probably figured out from the example, inheritance requires a minimal amount of extra syntax over a basic class definition. Simply include the name of the parent class inside parentheses after the class name but before the colon terminating the class definition. This is all we have to do to tell Python that the new class should be derived from the given superclass.

How do we apply inheritance in practice? The simplest and most obvious use of inheritance is to add functionality to an existing class. Let's start with a simple contact manager that tracks the name and e-mail address of several people. The contact class is responsible for maintaining a list of all contacts in a class variable, and for initializing the name and address for an individual contact:

```
class Contact:
    all_contacts = []

    def __init__(self, name, email):
        self.name = name
        self.email = email
        Contact.all_contacts.append(self)
```

This example introduces us to class variables. The `all_contacts` list, because it is part of the class definition, is shared by all instances of this class. This means that there is only one `Contact.all_contacts` list, which we can access as `Contact.all_contacts`. Less obviously, we can also access it as `self.all_contacts` on any object instantiated from `Contact`. If the field can't be found on the object, then it will be found on the class and thus refer to the same single list.

Be careful with this syntax, for if you ever *set* the variable using `self.all_contacts`, you will actually be creating a **new** instance variable associated only with that object. The class variable will still be unchanged and accessible as `Contact.all_contacts`.

This is a simple class that allows us to track a couple pieces of data about each contact. But what if some of our contacts are also suppliers that we need to order supplies from? We could add an `order` method to the `Contact` class, but that would allow people to accidentally order things from contacts who are customers or family friends. Instead, let's create a new `Supplier` class that acts like our `Contact` class, but has an additional `order` method:

```
class Supplier(Contact):
    def order(self, order):
        print("If this were a real system we would send "
                "'{}' order to '{}'".format(order, self.name))
```

Now, if we test this class in our trusty interpreter, we see that all contacts, including suppliers, accept a name and e-mail address in their `__init__`, but only suppliers have a functional order method:

```
>>> c = Contact("Some Body", "somebody@example.net")
>>> s = Supplier("Sup Plier", "supplier@example.net")
>>> print(c.name, c.email, s.name, s.email)
Some Body somebody@example.net Sup Plier supplier@example.net
>>> c.all_contacts
[<__main__.Contact object at 0xb7375ecc>,
 <__main__.Supplier object at 0xb7375f8c>]
>>> c.order("I need pliers")
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
AttributeError: 'Contact' object has no attribute 'order'
>>> s.order("I need pliers")
If this were a real system we would send 'I need pliers' order to
'Sup Plier '
```

So, now our `Supplier` class can do everything a contact can do (including adding itself to the list of `all_contacts`) and all the special things it needs to handle as a supplier. This is the beauty of inheritance.

Extending built-ins

One interesting use of this kind of inheritance is adding functionality to built-in classes. In the `Contact` class seen earlier, we are adding contacts to a list of all contacts. What if we also wanted to search that list by name? Well, we could add a method on the `Contact` class to search it, but it feels like this method actually belongs to the list itself. We can do this using inheritance:

```
class ContactList(list):
    def search(self, name):
        '''Return all contacts that contain the search value
        in their name.'''
        matching_contacts = []
        for contact in self:
            if name in contact.name:
                matching_contacts.append(contact)
        return matching_contacts

class Contact:
    all_contacts = ContactList()

    def __init__(self, name, email):
        self.name = name
        self.email = email
        self.all_contacts.append(self)
```

Instead of instantiating a normal list as our class variable, we create a new `ContactList` class that extends the built-in `list`. Then, we instantiate this subclass as our `all_contacts` list. We can test the new search functionality as follows:

```
>>> c1 = Contact("John A", "johna@example.net")
>>> c2 = Contact("John B", "johnb@example.net")
>>> c3 = Contact("Jenna C", "jennac@example.net")
>>> [c.name for c in Contact.all_contacts.search('John')]
['John A', 'John B']
```

Are you wondering how we changed the built-in syntax `[]` into something we can inherit from? Creating an empty list with `[]` is actually a shorthand for creating an empty list using `list()`; the two syntaxes behave identically:

```
>>> [] == list()
True
```

In reality, the `[]` syntax is actually so-called **syntax sugar** that calls the `list()` constructor under the hood. The `list` data type is a class that we can extend. In fact, the list itself extends the `object` class:

```
>>> isinstance([], object)
True
```

As a second example, we can extend the `dict` class, which is, similar to the list, the class that is constructed when using the `{}` syntax shorthand:

```
class LongNameDict(dict):
    def longest_key(self):
        longest = None
        for key in self:
            if not longest or len(key) > len(longest):
                longest = key
        return longest
```

This is easy to test in the interactive interpreter:

```
>>> longkeys = LongNameDict()
>>> longkeys['hello'] = 1
>>> longkeys['longest yet'] = 5
>>> longkeys['hello2'] = 'world'
>>> longkeys.longest_key()
'longest yet'
```

Most built-in types can be similarly extended. Commonly extended built-ins are `object`, `list`, `set`, `dict`, `file`, and `str`. Numerical types such as `int` and `float` are also occasionally inherited from.

Overriding and super

So, inheritance is great for *adding* new behavior to existing classes, but what about *changing* behavior? Our `contact` class allows only a name and an e-mail address. This may be sufficient for most contacts, but what if we want to add a phone number for our close friends?

As we saw in *Chapter 2, Objects in Python*, we can do this easily by just setting a `phone` attribute on the contact after it is constructed. But if we want to make this third variable available on initialization, we have to override `__init__`. Overriding means altering or replacing a method of the superclass with a new method (with the same name) in the subclass. No special syntax is needed to do this; the subclass's newly created method is automatically called instead of the superclass's method. For example:

```
class Friend(Contact):
    def __init__(self, name, email, phone):
        self.name = name
        self.email = email
        self.phone = phone
```

Any method can be overridden, not just `__init__`. Before we go on, however, we need to address some problems in this example. Our `Contact` and `Friend` classes have duplicate code to set up the `name` and `email` properties; this can make code maintenance complicated as we have to update the code in two or more places. More alarmingly, our `Friend` class is neglecting to add itself to the `all_contacts` list we have created on the `Contact` class.

What we really need is a way to execute the original `__init__` method on the `Contact` class. This is what the `super` function does; it returns the object as an instance of the parent class, allowing us to call the parent method directly:

```
class Friend(Contact):
    def __init__(self, name, email, phone):
        super().__init__(name, email)
        self.phone = phone
```

This example first gets the instance of the parent object using `super`, and calls `__init__` on that object, passing in the expected arguments. It then does its own initialization, namely, setting the `phone` attribute.

Note that the `super()` syntax does not work in older versions of Python. Like the [] and {} syntaxes for lists and dictionaries, it is a shorthand for a more complicated construct. We'll learn more about this shortly when we discuss multiple inheritance, but know for now that in Python 2, you would have to call `super(EmailContact, self).__init__()`. Specifically notice that the first argument is the name of the child class, not the name as the parent class you want to call, as some might expect. Also, remember the class comes before the object. I always forget the order, so the new syntax in Python 3 has saved me hours of having to look it up.

A `super()` call can be made inside any method, not just `__init__`. This means all methods can be modified via overriding and calls to `super`. The call to `super` can also be made at any point in the method; we don't have to make the call as the first line in the method. For example, we may need to manipulate or validate incoming parameters before forwarding them to the superclass.

Multiple inheritance

Multiple inheritance is a touchy subject. In principle, it's very simple: a subclass that inherits from more than one parent class is able to access functionality from both of them. In practice, this is less useful than it sounds and many expert programmers recommend against using it.

As a rule of thumb, if you think you need multiple inheritance, you're probably wrong, but if you know you need it, you're probably right.

The simplest and most useful form of multiple inheritance is called a **mixin**. A mixin is generally a superclass that is not meant to exist on its own, but is meant to be inherited by some other class to provide extra functionality. For example, let's say we wanted to add functionality to our `Contact` class that allows sending an e-mail to `self.email`. Sending e-mail is a common task that we might want to use on many other classes. So, we can write a simple mixin class to do the e-mailing for us:

```
class MailSender:
    def send_mail(self, message):
        print("Sending mail to " + self.email)
        # Add e-mail logic here
```

For brevity, we won't include the actual e-mail logic here; if you're interested in studying how it's done, see the `smtplib` module in the Python standard library.

This class doesn't do anything special (in fact, it can barely function as a standalone class), but it does allow us to define a new class that describes both a `Contact` and a `MailSender`, using multiple inheritance:

```
class EmailableContact(Contact, MailSender):
    pass
```

The syntax for multiple inheritance looks like a parameter list in the class definition. Instead of including one base class inside the parentheses, we include two (or more), separated by a comma. We can test this new hybrid to see the mixin at work:

```
>>> e = EmailableContact("John Smith", "jsmith@example.net")
```

```
>>> Contact.all_contacts
[<__main__.EmailableContact object at 0xb7205fac>]
>>> e.send_mail("Hello, test e-mail here")
Sending mail to jsmith@example.net
```

The `Contact` initializer is still adding the new contact to the `all_contacts` list, and the mixin is able to send mail to `self.email` so we know everything is working.

This wasn't so hard, and you're probably wondering what the dire warnings about multiple inheritance are. We'll get into the complexities in a minute, but let's consider some other options we had, rather than using a mixin here:

- We could have used single inheritance and added the `send_mail` function to the subclass. The disadvantage here is that the e-mail functionality then has to be duplicated for any other classes that need e-mail.
- We can create a standalone Python function for sending an e-mail, and just call that function with the correct e-mail address supplied as a parameter when the e-mail needs to be sent.
- We could have explored a few ways of using composition instead of inheritance. For example, `EmailableContact` could have a `MailSender` object instead of inheriting from it.
- We could monkey-patch (we'll briefly cover monkey-patching in *Chapter 7*, *Python Object-oriented Shortcuts*) the `Contact` class to have a `send_mail` method after the class has been created. This is done by defining a function that accepts the `self` argument, and setting it as an attribute on an existing class.

Multiple inheritance works all right when mixing methods from different classes, but it gets very messy when we have to call methods on the superclass. There are multiple superclasses. How do we know which one to call? How do we know what order to call them in?

Let's explore these questions by adding a home address to our `Friend` class. There are a few approaches we might take. An address is a collection of strings representing the street, city, country, and other related details of the contact. We could pass each of these strings as a parameter into the `Friend` class's `__init__` method. We could also store these strings in a tuple or dictionary and pass them into `__init__` as a single argument. This is probably the best course of action if there are no methods that need to be added to the address.

Another option would be to create a new `Address` class to hold those strings together, and then pass an instance of this class into the `__init__` method of our `Friend` class. The advantage of this solution is that we can add behavior (say, a method to give directions or to print a map) to the data instead of just storing it statically. This is an example of composition, as we discussed in *Chapter 1, Object-oriented Design*. The "has a" relationship of composition is a perfectly viable solution to this problem and allows us to reuse `Address` classes in other entities such as buildings, businesses, or organizations.

However, inheritance is also a viable solution, and that's what we want to explore. Let's add a new class that holds an address. We'll call this new class "AddressHolder" instead of "Address" because inheritance defines an *is a* relationship. It is not correct to say a "Friend" is an "Address" , but since a friend can have an "Address" , we can argue that a "Friend" is an "AddressHolder". Later, we could create other entities (companies, buildings) that also hold addresses. Here's our `AddressHolder` class:

```
class AddressHolder:
    def __init__(self, street, city, state, code):
        self.street = street
        self.city = city
        self.state = state
        self.code = code
```

Very simple; we just take all the data and toss it into instance variables upon initialization.

The diamond problem

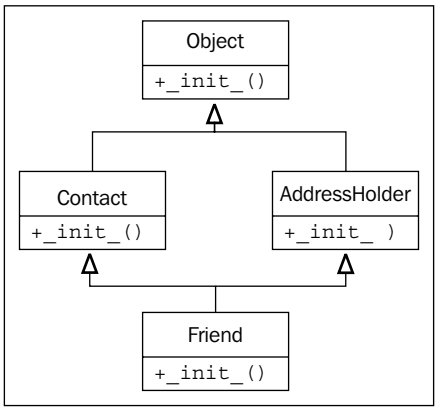
We can use multiple inheritance to add this new class as a parent of our existing `Friend` class. The tricky part is that we now have two parent `__init__` methods both of which need to be initialized. And they need to be initialized with different arguments. How do we do this? Well, we could start with a naive approach:

```
class Friend(Contact, AddressHolder):
    def __init__(
        self, name, email, phone,street, city, state, code):
        Contact.__init__(self, name, email)
        AddressHolder.__init__(self, street, city, state, code)
        self.phone = phone
```

In this example, we directly call the `__init__` function on each of the superclasses and explicitly pass the `self` argument. This example technically works; we can access the different variables directly on the class. But there are a few problems.

First, it is possible for a superclass to go uninitialized if we neglect to explicitly call the initializer. That wouldn't break this example, but it could cause hard-to-debug program crashes in common scenarios. Imagine trying to insert data into a database that has not been connected to, for example.

Second, and more sinister, is the possibility of a superclass being called multiple times because of the organization of the class hierarchy. Look at this inheritance diagram:

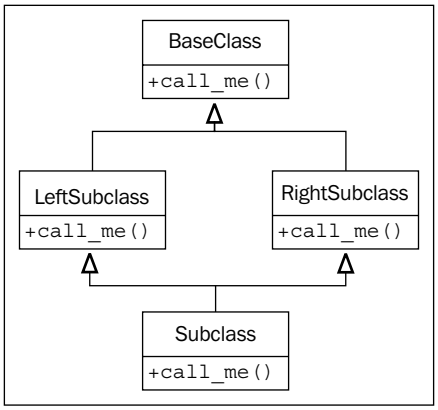


The `__init__` method from the `Friend` class first calls `__init__` on `Contact`, which implicitly initializes the `object` superclass (remember, all classes derive from `object`). `Friend` then calls `__init__` on `AddressHolder`, which implicitly initializes the `object` superclass *again*. This means the parent class has been set up twice. With the `object` class, that's relatively harmless, but in some situations, it could spell disaster. Imagine trying to connect to a database twice for every request!

The base class should only be called once. Once, yes, but when? Do we call `Friend`, then `Contact`, then `Object`, then `AddressHolder`? Or `Friend`, then `Contact`, then `AddressHolder`, then `Object`?

The order in which methods can be called can be adapted on the fly by modifying the `__mro__` (**Method Resolution Order**) attribute on the class. This is beyond the scope of this book. If you think you need to understand it, I recommend *Expert Python Programming*, *Tarek Ziadé*, *Packt Publishing*, or read the original documentation on the topic at `http://www.python.org/download/releases/2.3/mro/`.

Let's look at a second contrived example that illustrates this problem more clearly. Here we have a base class that has a method named `call_me`. Two subclasses override that method, and then another subclass extends both of these using multiple inheritance. This is called diamond inheritance because of the diamond shape of the class diagram:



Let's convert this diagram to code; this example shows when the methods are called:

```
class BaseClass:
    num_base_calls = 0
    def call_me(self):
        print("Calling method on Base Class")
        self.num_base_calls += 1

class LeftSubclass(BaseClass):
    num_left_calls = 0
    def call_me(self):
        BaseClass.call_me(self)
        print("Calling method on Left Subclass")
        self.num_left_calls += 1

class RightSubclass(BaseClass):
    num_right_calls = 0
    def call_me(self):
        BaseClass.call_me(self)
        print("Calling method on Right Subclass")
        self.num_right_calls += 1

class Subclass(LeftSubclass, RightSubclass):
```

```
        num_sub_calls = 0
        def call_me(self):
            LeftSubclass.call_me(self)
            RightSubclass.call_me(self)
            print("Calling method on Subclass")
            self.num_sub_calls += 1
```

This example simply ensures that each overridden `call_me` method directly calls the parent method with the same name. It lets us know each time a method is called by printing the information to the screen. It also updates a static variable on the class to show how many times it has been called. If we instantiate one `Subclass` object and call the method on it once, we get this output:

```
>>> s = Subclass()
>>> s.call_me()
Calling method on Base Class
Calling method on Left Subclass
Calling method on Base Class
Calling method on Right Subclass
Calling method on Subclass
>>> print(
... s.num_sub_calls,
... s.num_left_calls,
... s.num_right_calls,
... s.num_base_calls)
1 1 1 2
```

Thus we can clearly see the base class's `call_me` method being called twice. This could lead to some insidious bugs if that method is doing actual work—like depositing into a bank account—twice.

The thing to keep in mind with multiple inheritance is that we only want to call the "next" method in the class hierarchy, not the "parent" method. In fact, that next method may not be on a parent or ancestor of the current class. The `super` keyword comes to our rescue once again. Indeed, `super` was originally developed to make complicated forms of multiple inheritance possible. Here is the same code written using `super`:

```
    class BaseClass:
        num_base_calls = 0
        def call_me(self):
```

```
            print("Calling method on Base Class")
            self.num_base_calls += 1

    class LeftSubclass(BaseClass):
        num_left_calls = 0
        def call_me(self):
            super().call_me()
            print("Calling method on Left Subclass")
            self.num_left_calls += 1

    class RightSubclass(BaseClass):
        num_right_calls = 0
        def call_me(self):
            super().call_me()
            print("Calling method on Right Subclass")
            self.num_right_calls += 1

    class Subclass(LeftSubclass, RightSubclass):
        num_sub_calls = 0
        def call_me(self):
            super().call_me()
            print("Calling method on Subclass")
            self.num_sub_calls += 1
```

The change is pretty minor; we simply replaced the naive direct calls with calls to `super()`, although the bottom subclass only calls `super` once rather than having to make the calls for both the left and right. The change is simple enough, but look at the difference when we execute it:

```
>>> s = Subclass()
>>> s.call_me()
Calling method on Base Class
Calling method on Right Subclass
Calling method on Left Subclass
Calling method on Subclass
>>> print(s.num_sub_calls, s.num_left_calls, s.num_right_calls,
s.num_base_calls)
1 1 1 1
```

Looks good, our base method is only being called once. But what is `super()` actually doing here? Since the `print` statements are executed after the `super` calls, the printed output is in the order each method is actually executed. Let's look at the output from back to front to see who is calling what.

First, `call_me` of `Subclass` calls `super().call_me()`, which happens to refer to `LeftSubclass.call_me()`. The `LeftSubclass.call_me()` method then calls `super().call_me()`, but in this case, `super()` is referring to `RightSubclass.call_me()`.

Pay particular attention to this: the `super` call is *not* calling the method on the superclass of `LeftSubclass` (which is `BaseClass`). Rather, it is calling `RightSubclass`, even though it is not a direct parent of `LeftSubclass`! This is the *next* method, not the parent method. `RightSubclass` then calls `BaseClass` and the `super` calls have ensured each method in the class hierarchy is executed once.

Different sets of arguments

This is going to make things complicated as we return to our `Friend` multiple inheritance example. In the `__init__` method for `Friend`, we were originally calling `__init__` for both parent classes, *with different sets of arguments*:

```
Contact.__init__(self, name, email)
AddressHolder.__init__(self, street, city, state, code)
```

How can we manage different sets of arguments when using `super`? We don't necessarily know which class `super` is going to try to initialize first. Even if we did, we need a way to pass the "extra" arguments so that subsequent calls to `super`, on other subclasses, receive the right arguments.

Specifically, if the first call to `super` passes the `name` and `email` arguments to `Contact.__init__`, and `Contact.__init__` then calls `super`, it needs to be able to pass the address-related arguments to the "next" method, which is `AddressHolder.__init__`.

This is a problem whenever we want to call superclass methods with the same name, but with different sets of arguments. Most often, the only time you would want to call a superclass with a completely different set of arguments is in `__init__`, as we're doing here. Even with regular methods, though, we may want to add optional parameters that only make sense to one subclass or set of subclasses.

Sadly, the only way to solve this problem is to plan for it from the beginning. We have to design our base class parameter lists to accept keyword arguments for any parameters that are not required by every subclass implementation. Finally, we must ensure the method freely accepts unexpected arguments and passes them on to its `super` call, in case they are necessary to later methods in the inheritance order.

Python's function parameter syntax provides all the tools we need to do this, but it makes the overall code look cumbersome. Have a look at the proper version of the `Friend` multiple inheritance code:

```
class Contact:
    all_contacts = []

    def __init__(self, name='', email='', **kwargs):
        super().__init__(**kwargs)
        self.name = name
        self.email = email
        self.all_contacts.append(self)

class AddressHolder:
    def __init__(self, street='', city='', state='', code='',
            **kwargs):
        super().__init__(**kwargs)
        self.street = street
        self.city = city
        self.state = state
        self.code = code

class Friend(Contact, AddressHolder):
    def __init__(self, phone='', **kwargs):
        super().__init__(**kwargs)
        self.phone = phone
```

We've changed all arguments to keyword arguments by giving them an empty string as a default value. We've also ensured that a `**kwargs` parameter is included to capture any additional parameters that our particular method doesn't know what to do with. It passes these parameters up to the next class with the `super` call.

If you aren't familiar with the `**kwargs` syntax, it basically collects any keyword arguments passed into the method that were not explicitly listed in the parameter list. These arguments are stored in a dictionary named `kwargs` (we can call the variable whatever we like, but convention suggests `kw`, or `kwargs`). When we call a different method (for example, `super().__init__`) with a `**kwargs` syntax, it unpacks the dictionary and passes the results to the method as normal keyword arguments. We'll cover this in detail in *Chapter 7, Python Object-oriented Shortcuts*.

The previous example does what it is supposed to do. But it's starting to look messy, and it has become difficult to answer the question, *What arguments do we need to pass into* `Friend.__init__`? This is the foremost question for anyone planning to use the class, so a docstring should be added to the method to explain what is happening.

Further, even this implementation is insufficient if we want to *reuse* variables in parent classes. When we pass the `**kwargs` variable to `super`, the dictionary does not include any of the variables that were included as explicit keyword arguments. For example, in `Friend.__init__`, the call to `super` does not have `phone` in the `kwargs` dictionary. If any of the other classes need the `phone` parameter, we need to ensure it is in the dictionary that is passed. Worse, if we forget to do this, it will be tough to debug because the superclass will not complain, but will simply assign the default value (in this case, an empty string) to the variable.

There are a few ways to ensure that the variable is passed upwards. Assume the `Contact` class does, for some reason, need to be initialized with a `phone` parameter, and the `Friend` class will also need access to it. We can do any of the following:

- Don't include `phone` as an explicit keyword argument. Instead, leave it in the `kwargs` dictionary. `Friend` can look it up using the syntax `kwargs['phone']`. When it passes `**kwargs` to the `super` call, `phone` will still be in the dictionary.
- Make `phone` an explicit keyword argument but update the `kwargs` dictionary before passing it to `super`, using the standard dictionary syntax `kwargs['phone'] = phone`.
- Make `phone` an explicit keyword argument, but update the `kwargs` dictionary using the `kwargs.update` method. This is useful if you have several arguments to update. You can create the dictionary passed into `update` using either the `dict(phone=phone)` constructor, or the dictionary syntax `{'phone': phone}`.
- Make `phone` an explicit keyword argument, but pass it to the super call explicitly with the syntax `super().__init__(phone=phone, **kwargs)`.

We have covered many of the caveats involved with multiple inheritance in Python. When we need to account for all the possible situations, we have to plan for them and our code will get messy. Basic multiple inheritance can be handy but, in many cases, we may want to choose a more transparent way of combining two disparate classes, usually using composition or one of the design patterns we'll be covering in *Chapter 10*, *Python Design Patterns I* and *Chapter 11*, *Python Design Patterns II*.

Polymorphism

We were introduced to polymorphism in *Chapter 1*, *Object-oriented Design*. It is a fancy name describing a simple concept: different behaviors happen depending on which subclass is being used, without having to explicitly know what the subclass actually is. As an example, imagine a program that plays audio files. A media player might need to load an `AudioFile` object and then `play` it. We'd put a `play()` method on the object, which is responsible for decompressing or extracting the audio and routing it to the sound card and speakers. The act of playing an `AudioFile` could feasibly be as simple as:

```
audio_file.play()
```

However, the process of decompressing and extracting an audio file is very different for different types of files. The `.wav` files are stored uncompressed, while `.mp3`, `.wma`, and `.ogg` files all have totally different compression algorithms.

We can use inheritance with polymorphism to simplify the design. Each type of file can be represented by a different subclass of `AudioFile`, for example, `WavFile`, `MP3File`. Each of these would have a `play()` method, but that method would be implemented differently for each file to ensure the correct extraction procedure is followed. The media player object would never need to know which subclass of `AudioFile` it is referring to; it just calls `play()` and polymorphically lets the object take care of the actual details of playing. Let's look at a quick skeleton showing how this might look:

```
class AudioFile:
    def __init__(self, filename):
        if not filename.endswith(self.ext):
            raise Exception("Invalid file format")

        self.filename = filename

class MP3File(AudioFile):
    ext = "mp3"
    def play(self):
        print("playing {} as mp3".format(self.filename))

class WavFile(AudioFile):
    ext = "wav"
    def play(self):
```

```
            print("playing {} as wav".format(self.filename))

    class OggFile(AudioFile):
        ext = "ogg"
        def play(self):
            print("playing {} as ogg".format(self.filename))
```

All audio files check to ensure that a valid extension was given upon initialization. But did you notice how the `__init__` method in the parent class is able to access the `ext` class variable from different subclasses? That's polymorphism at work. If the filename doesn't end with the correct name, it raises an exception (exceptions will be covered in detail in the next chapter). The fact that `AudioFile` doesn't actually store a reference to the `ext` variable doesn't stop it from being able to access it on the subclass.

In addition, each subclass of `AudioFile` implements `play()` in a different way (this example doesn't actually play the music; audio compression algorithms really deserve a separate book!). This is also polymorphism in action. The media player can use the exact same code to play a file, no matter what type it is; it doesn't care what subclass of `AudioFile` it is looking at. The details of decompressing the audio file are *encapsulated*. If we test this example, it works as we would hope:

```
>>> ogg = OggFile("myfile.ogg")
>>> ogg.play()
playing myfile.ogg as ogg
>>> mp3 = MP3File("myfile.mp3")
>>> mp3.play()
playing myfile.mp3 as mp3
>>> not_an_mp3 = MP3File("myfile.ogg")
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "polymorphic_audio.py", line 4, in __init__
    raise Exception("Invalid file format")
Exception: Invalid file format
```

See how `AudioFile.__init__` is able to check the file type without actually knowing what subclass it is referring to?

Polymorphism is actually one of the coolest things about object-oriented programming, and it makes some programming designs obvious that weren't possible in earlier paradigms. However, Python makes polymorphism less cool because of duck typing. Duck typing in Python allows us to use *any* object that provides the required behavior without forcing it to be a subclass. The dynamic nature of Python makes this trivial. The following example does not extend `AudioFile`, but it can be interacted with in Python using the exact same interface:

```
class FlacFile:
    def __init__(self, filename):
        if not filename.endswith(".flac"):
            raise Exception("Invalid file format")

        self.filename = filename

    def play(self):
        print("playing {} as flac".format(self.filename))
```

Our media player can play this object just as easily as one that extends `AudioFile`.

Polymorphism is one of the most important reasons to use inheritance in many object-oriented contexts. Because any objects that supply the correct interface can be used interchangeably in Python, it reduces the need for polymorphic common superclasses. Inheritance can still be useful for sharing code but, if all that is being shared is the public interface, duck typing is all that is required. This reduced need for inheritance also reduces the need for multiple inheritance; often, when multiple inheritance appears to be a valid solution, we can just use duck typing to mimic one of the multiple superclasses.

Of course, just because an object satisfies a particular interface (by providing required methods or attributes) does not mean it will simply work in all situations. It has to fulfill that interface in a way that makes sense in the overall system. Just because an object provides a `play()` method does not mean it will automatically work with a media player. For example, our chess AI object from *Chapter 1*, *Object-oriented Design*, may have a `play()` method that moves a chess piece. Even though it satisfies the interface, this class would likely break in spectacular ways if we tried to plug it into a media player!

Another useful feature of duck typing is that the duck-typed object only needs to provide those methods and attributes that are actually being accessed. For example, if we needed to create a fake file object to read data from, we can create a new object that has a `read()` method; we don't have to override the `write` method if the code that is going to interact with the object will only be reading from the file. More succinctly, duck typing doesn't need to provide the entire interface of an object that is available, it only needs to fulfill the interface that is actually accessed.

Abstract base classes

While duck typing is useful, it is not always easy to tell in advance if a class is going to fulfill the protocol you require. Therefore, Python introduced the idea of abstract base classes. **Abstract base classes**, or **ABCs**, define a set of methods and properties that a class must implement in order to be considered a duck-type instance of that class. The class can extend the abstract base class itself in order to be used as an instance of that class, but it must supply all the appropriate methods.

In practice, it's rarely necessary to create new abstract base classes, but we may find occasions to implement instances of existing ABCs. We'll cover implementing ABCs first, and then briefly see how to create your own if you should ever need to.

Using an abstract base class

Most of the abstract base classes that exist in the Python Standard Library live in the `collections` module. One of the simplest ones is the `Container` class. Let's inspect it in the Python interpreter to see what methods this class requires:

```
>>> from collections import Container
>>> Container.__abstractmethods__
frozenset(['__contains__'])
```

So, the `Container` class has exactly one abstract method that needs to be implemented, `__contains__`. You can issue `help(Container.__contains__)` to see what the function signature should look like:

```
Help on method __contains__ in module _abcoll:
__contains__(self, x) unbound _abcoll.Container method
```

So, we see that `__contains__` needs to take a single argument. Unfortunately, the help file doesn't tell us much about what that argument should be, but it's pretty obvious from the name of the ABC and the single method it implements that this argument is the value the user is checking to see if the container holds.

This method is implemented by `list`, `str`, and `dict` to indicate whether or not a given value is in that data structure. However, we can also define a silly container that tells us whether a given value is in the set of odd integers:

```
class OddContainer:
    def __contains__(self, x):
        if not isinstance(x, int) or not x % 2:
            return False
        return True
```

Now, we can instantiate an `OddContainer` object and determine that, even though we did not extend `Container`, the class *is a* `Container` object:

```
>>> from collections import Container
>>> odd_container = OddContainer()
>>> isinstance(odd_container, Container)
True
>>> issubclass(OddContainer, Container)
True
```

And that is why duck typing is way more awesome than classical polymorphism. We can create *is a* relationships without the overhead of using inheritance (or worse, multiple inheritance).

The interesting thing about the `Container` ABC is that any class that implements it gets to use the `in` keyword for free. In fact, `in` is just syntax sugar that delegates to the `__contains__` method. Any class that has a `__contains__` method is a `Container` and can therefore be queried by the `in` keyword, for example:

```
>>> 1 in odd_container
True
>>> 2 in odd_container
False
>>> 3 in odd_container
True
>>> "a string" in odd_container
False
```

Creating an abstract base class

As we saw earlier, it's not necessary to have an abstract base class to enable duck typing. However, imagine we were creating a media player with third-party plugins. It is advisable to create an abstract base class in this case to document what API the third-party plugins should provide. The `abc` module provides the tools you need to do this, but I'll warn you in advance, this requires some of Python's most arcane concepts:

```
import abc

class MediaLoader(metaclass=abc.ABCMeta):
    @abc.abstractmethod
    def play(self):
        pass

    @abc.abstractproperty
    def ext(self):
```

```
            pass

        @classmethod
        def __subclasshook__(cls, C):
            if cls is MediaLoader:
                attrs = set(dir(C))
                if set(cls.__abstractmethods__) <= attrs:
                    return True

            return NotImplemented
```

This is a complicated example that includes several Python features that won't be explained until later in this book. It is included here for completeness, but you don't need to understand all of it to get the gist of how to create your own ABC.

The first weird thing is the `metaclass` keyword argument that is passed into the class where you would normally see the list of parent classes. This is a rarely used construct from the mystic art of metaclass programming. We won't be covering metaclasses in this book, so all you need to know is that by assigning the `ABCMeta` metaclass, you are giving your class superpower (or at least superclass) abilities.

Next, we see the `@abc.abstractmethod` and `@abc.abstractproperty` constructs. These are Python decorators. We'll discuss those in *Chapter 5*, *When to Use Object-oriented Programming*. For now, just know that by marking a method or property as being abstract, you are stating that any subclass of this class must implement that method or supply that property in order to be considered a proper member of the class.

See what happens if you implement subclasses that do or don't supply those properties:

```
>>> class Wav(MediaLoader):
...     pass
...
>>> x = Wav()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: Can't instantiate abstract class Wav with abstract methods
ext, play
>>> class Ogg(MediaLoader):
...     ext = '.ogg'
...     def play(self):
...         pass
...
>>> o = Ogg()
```

Since the `Wav` class fails to implement the abstract attributes, it is not possible to instantiate that class. The class is still a legal abstract class, but you'd have to subclass it to actually do anything. The `Ogg` class supplies both attributes, so it instantiates cleanly.

Going back to the `MediaLoader` ABC, let's dissect that `__subclasshook__` method. It is basically saying that any class that supplies concrete implementations of all the abstract attributes of this ABC should be considered a subclass of `MediaLoader`, even if it doesn't actually inherit from the `MediaLoader` class.

More common object-oriented languages have a clear separation between the interface and the implementation of a class. For example, some languages provide an explicit `interface` keyword that allows us to define the methods that a class must have without any implementation. In such an environment, an abstract class is one that provides both an interface and a concrete implementation of some but not all methods. Any class can explicitly state that it implements a given interface.

Python's ABCs help to supply the functionality of interfaces without compromising on the benefits of duck typing.

Demystifying the magic

You can copy and paste the subclass code without understanding it if you want to make abstract classes that fulfill this particular contract. We'll cover most of the unusual syntaxes throughout the book, but let's go over it line by line to get an overview.

```
@classmethod
```

This decorator marks the method as a class method. It essentially says that the method can be called on a class instead of an instantiated object:

```
def __subclasshook__(cls, C):
```

This defines the `__subclasshook__` class method. This special method is called by the Python interpreter to answer the question, *Is the class `C` a subclass of this class?*

```
    if cls is MediaLoader:
```

We check to see if the method was called specifically on this class, rather than, say a subclass of this class. This prevents, for example, the `Wav` class from being thought of as a parent class of the `Ogg` class:

```
        attrs = set(dir(C))
```

All this line does is get the set of methods and properties that the class has, including any parent classes in its class hierarchy:

```
            if set(cls.__abstractmethods__) <= attrs:
```

This line uses set notation to see whether the set of abstract methods in this class have been supplied in the candidate class. Note that it doesn't check to see whether the methods have been implemented, just if they are there. Thus, it's possible for a class to be a subclass and yet still be an abstract class itself.

```
                return True
```

If all the abstract methods have been supplied, then the candidate class is a subclass of this class and we return `True`. The method can legally return one of the three values: `True`, `False`, or `NotImplemented`. `True` and `False` indicate that the class is or is not definitively a subclass of this class:

```
        return NotImplemented
```

If any of the conditionals have not been met (that is, the class is not `MediaLoader` or not all abstract methods have been supplied), then return `NotImplemented`. This tells the Python machinery to use the default mechanism (does the candidate class explicitly extend this class?) for subclass detection.

In short, we can now define the `Ogg` class as a subclass of the `MediaLoader` class without actually extending the `MediaLoader` class:

```
>>> class Ogg():
...     ext = '.ogg'
...     def play(self):
...         print("this will play an ogg file")
...
>>> issubclass(Ogg, MediaLoader)
True
>>> isinstance(Ogg(), MediaLoader)
True
```

Case study

Let's try to tie everything we've learned together with a larger example. We'll be designing a simple real estate application that allows an agent to manage properties available for purchase or rent. There will be two types of properties: apartments and houses. The agent needs to be able to enter a few relevant details about new properties, list all currently available properties, and mark a property as sold or rented. For brevity, we won't worry about editing property details or reactivating a property after it is sold.

The project will allow the agent to interact with the objects using the Python interpreter prompt. In this world of graphical user interfaces and web applications, you might be wondering why we're creating such old-fashioned looking programs. Simply put, both windowed programs and web applications require a lot of overhead knowledge and boilerplate code to make them do what is required. If we were developing software using either of these paradigms, we'd get so lost in GUI programming or web programming that we'd lose sight of the object-oriented principles we're trying to master.

Luckily, most GUI and web frameworks utilize an object-oriented approach, and the principles we're studying now will help in understanding those systems in the future. We'll discuss them both briefly in *Chapter 13*, *Concurrency*, but complete details are far beyond the scope of a single book.

Looking at our requirements, it seems like there are quite a few nouns that might represent classes of objects in our system. Clearly, we'll need to represent a property. Houses and apartments may need separate classes. Rentals and purchases also seem to require separate representation. Since we're focusing on inheritance right now, we'll be looking at ways to share behavior using inheritance or multiple inheritance.

`House` and `Apartment` are both types of properties, so `Property` can be a superclass of those two classes. `Rental` and `Purchase` will need some extra thought; if we use inheritance, we'll need to have separate classes, for example, for `HouseRental` and `HousePurchase`, and use multiple inheritance to combine them. This feels a little clunky compared to a composition or association-based design, but let's run with it and see what we come up with.

Now then, what attributes might be associated with a `Property` class? Regardless of whether it is an apartment or a house, most people will want to know the square footage, number of bedrooms, and number of bathrooms. (There are numerous other attributes that might be modeled, but we'll keep it simple for our prototype.)

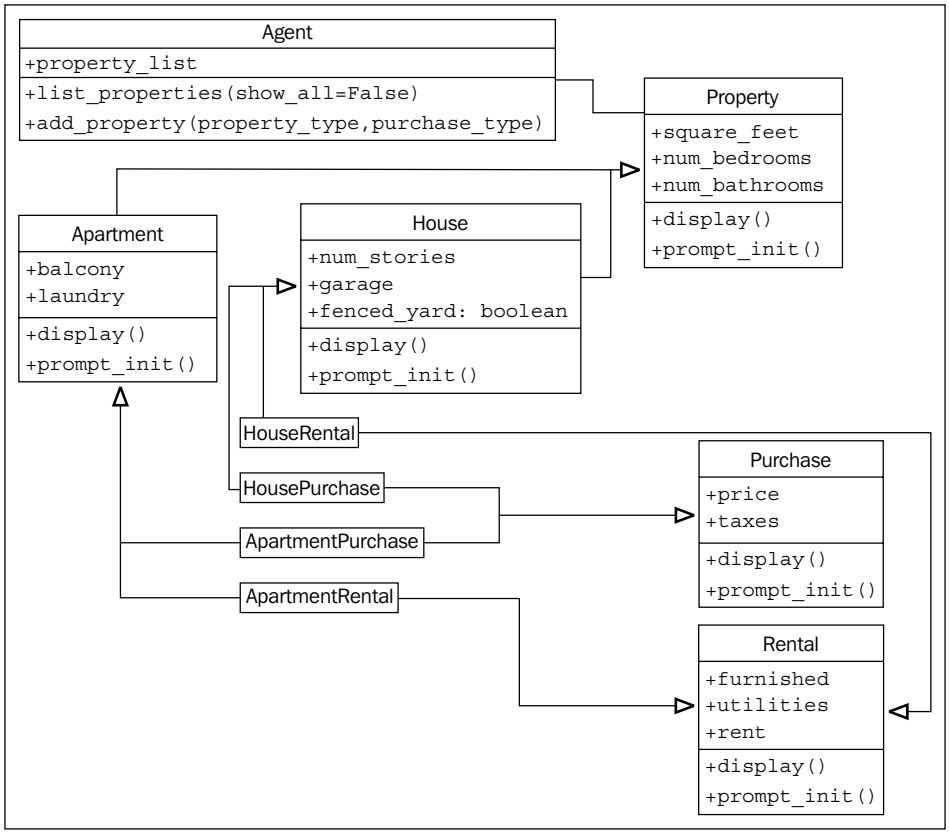
If the property is a house, it will want to advertise the number of stories, whether it has a garage (attached, detached, or none), and whether the yard is fenced. An apartment will want to indicate if it has a balcony, and if the laundry is ensuite, coin, or off-site.

Both property types will require a method to display the characteristics of that property. At the moment, no other behaviors are apparent.

Rental properties will need to store the rent per month, whether the property is furnished, and whether utilities are included, and if not, what they are estimated to be. Properties for purchase will need to store the purchase price and estimated annual property taxes. For our application, we'll only need to display this data, so we can get away with just adding a `display()` method similar to that used in the other classes.

Finally, we'll need an `Agent` object that holds a list of all properties, displays those properties, and allows us to create new ones. Creating properties will entail prompting the user for the relevant details for each property type. This could be done in the `Agent` object, but then `Agent` would need to know a lot of information about the types of properties. This is not taking advantage of polymorphism. Another alternative would be to put the prompts in the initializer or even a constructor for each class, but this would not allow the classes to be applied in a GUI or web application in the future. A better idea is to create a static method that does the prompting and returns a dictionary of the prompted parameters. Then, all the `Agent` has to do is prompt the user for the type of property and payment method, and ask the correct class to instantiate itself.

That's a lot of designing! The following class diagram may communicate our design decisions a little more clearly:



Wow, that's a lot of inheritance arrows! I don't think it would be possible to add another level of inheritance without crossing arrows. Multiple inheritance is a messy business, even at the design stage.

The trickiest aspects of these classes is going to be ensuring superclass methods get called in the inheritance hierarchy. Let's start with the `Property` implementation:

```
class Property:
    def __init__(self, square_feet='', beds='',
            baths='', **kwargs):
        super().__init__(**kwargs)
        self.square_feet = square_feet
        self.num_bedrooms = beds
        self.num_baths = baths

    def display(self):
        print("PROPERTY DETAILS")
        print("================")
        print("square footage: {}".format(self.square_feet))
        print("bedrooms: {}".format(self.num_bedrooms))
        print("bathrooms: {}".format(self.num_baths))
        print()

    def prompt_init():
        return dict(square_feet=input("Enter the square feet: "),
                beds=input("Enter number of bedrooms: "),
                baths=input("Enter number of baths: "))
    prompt_init = staticmethod(prompt_init)
```

This class is pretty straightforward. We've already added the extra `**kwargs` parameter to `__init__` because we know it's going to be used in a multiple inheritance situation. We've also included a call to `super().__init__` in case we are not the last call in the multiple inheritance chain. In this case, we're *consuming* the keyword arguments because we know they won't be needed at other levels of the inheritance hierarchy.

We see something new in the `prompt_init` method. This method is made into a static method immediately after it is initially created. Static methods are associated only with a class (something like class variables), rather than a specific object instance. Hence, they have no `self` argument. Because of this, the `super` keyword won't work (there is no parent object, only a parent class), so we simply call the static method on the parent class directly. This method uses the Python `dict` constructor to create a dictionary of values that can be passed into `__init__`. The value for each key is prompted with a call to `input`.

The `Apartment` class extends `Property`, and is similar in structure:

```
class Apartment(Property):
    valid_laundries = ("coin", "ensuite", "none")
    valid_balconies = ("yes", "no", "solarium")

    def __init__(self, balcony='', laundry='', **kwargs):
        super().__init__(**kwargs)
        self.balcony = balcony
        self.laundry = laundry

    def display(self):
        super().display()
        print("APARTMENT DETAILS")
        print("laundry: %s" % self.laundry)
        print("has balcony: %s" % self.balcony)

    def prompt_init():
        parent_init = Property.prompt_init()
        laundry = ''
        while laundry.lower() not in \
                Apartment.valid_laundries:
            laundry = input("What laundry facilities does "
                    "the property have? ({})".format(
                    ", ".join(Apartment.valid_laundries)))
        balcony = ''
        while balcony.lower() not in \
                Apartment.valid_balconies:
            balcony = input(
                "Does the property have a balcony? "
                "({})".format(
                ", ".join(Apartment.valid_balconies)))
        parent_init.update({
            "laundry": laundry,
            "balcony": balcony
        })
        return parent_init
    prompt_init = staticmethod(prompt_init)
```

The `display()` and `__init__()` methods call their respective parent class methods using `super()` to ensure the `Property` class is properly initialized.

The `prompt_init` static method is now getting dictionary values from the parent class, and then adding some additional values of its own. It calls the `dict.update` method to merge the new dictionary values into the first one. However, that `prompt_init` method is looking pretty ugly; it loops twice until the user enters a valid input using structurally similar code but different variables. It would be nice to extract this validation logic so we can maintain it in only one location; it will likely also be useful to later classes.

With all the talk on inheritance, we might think this is a good place to use a mixin. Instead, we have a chance to study a situation where inheritance is not the best solution. The method we want to create will be used in a static method. If we were to inherit from a class that provided validation functionality, the functionality would also have to be provided as a static method that did not access any instance variables on the class. If it doesn't access any instance variables, what's the point of making it a class at all? Why don't we just make this validation functionality a module-level function that accepts an input string and a list of valid answers, and leave it at that?

Let's explore what this validation function would look like:

```
def get_valid_input(input_string, valid_options):
    input_string += " ({}) ".format(", ".join(valid_options))
    response = input(input_string)
    while response.lower() not in valid_options:
        response = input(input_string)
    return response
```

We can test this function in the interpreter, independent of all the other classes we've been working on. This is a good sign, it means different pieces of our design are not tightly coupled to each other and can later be improved independently, without affecting other pieces of code.

```
>>> get_valid_input("what laundry?", ("coin", "ensuite", "none"))
what laundry? (coin, ensuite, none) hi
what laundry? (coin, ensuite, none) COIN
'COIN'
```

Now, let's quickly update our `Apartment.prompt_init` method to use this new function for validation:

```
        def prompt_init():
            parent_init = Property.prompt_init()
            laundry = get_valid_input(
```

```
                "What laundry facilities does "
                "the property have? ",
                Apartment.valid_laundries)
        balcony = get_valid_input(
            "Does the property have a balcony? ",
            Apartment.valid_balconies)
        parent_init.update({
            "laundry": laundry,
            "balcony": balcony
        })
        return parent_init
    prompt_init = staticmethod(prompt_init)
```

That's much easier to read (and maintain!) than our original version. Now we're ready to build the `House` class. This class has a parallel structure to `Apartment`, but refers to different prompts and variables:

```
class House(Property):
    valid_garage = ("attached", "detached", "none")
    valid_fenced = ("yes", "no")

    def __init__(self, num_stories='',
            garage='', fenced='', **kwargs):
        super().__init__(**kwargs)
        self.garage = garage
        self.fenced = fenced
        self.num_stories = num_stories

    def display(self):
        super().display()
        print("HOUSE DETAILS")
        print("# of stories: {}".format(self.num_stories))
        print("garage: {}".format(self.garage))
        print("fenced yard: {}".format(self.fenced))


    def prompt_init():
        parent_init = Property.prompt_init()
        fenced = get_valid_input("Is the yard fenced? ",
                    House.valid_fenced)
        garage = get_valid_input("Is there a garage? ",
                House.valid_garage)
```

```
        num_stories = input("How many stories? ")

        parent_init.update({
            "fenced": fenced,
            "garage": garage,
            "num_stories": num_stories
        })
        return parent_init
    prompt_init = staticmethod(prompt_init)
```

There's nothing new to explore here, so let's move on to the `Purchase` and `Rental` classes. In spite of having apparently different purposes, they are also similar in design to the ones we just discussed:

```
class Purchase:
    def __init__(self, price='', taxes='', **kwargs):
        super().__init__(**kwargs)
        self.price = price
        self.taxes = taxes

    def display(self):
        super().display()
        print("PURCHASE DETAILS")
        print("selling price: {}".format(self.price))
        print("estimated taxes: {}".format(self.taxes))

    def prompt_init():
        return dict(
            price=input("What is the selling price? "),
            taxes=input("What are the estimated taxes? "))
    prompt_init = staticmethod(prompt_init)

class Rental:
    def __init__(self, furnished='', utilities='',
            rent='', **kwargs):
        super().__init__(**kwargs)
        self.furnished = furnished
        self.rent = rent
        self.utilities = utilities

    def display(self):
        super().display()
        print("RENTAL DETAILS")
```

```
            print("rent: {}".format(self.rent))
            print("estimated utilities: {}".format(
                self.utilities))
            print("furnished: {}".format(self.furnished))

        def prompt_init():
            return dict(
                rent=input("What is the monthly rent? "),
                utilities=input(
                    "What are the estimated utilities? "),
                furnished = get_valid_input(
                    "Is the property furnished? ",
                        ("yes", "no")))
        prompt_init = staticmethod(prompt_init)
```

These two classes don't have a superclass (other than `object`), but we still call `super().__init__` because they are going to be combined with the other classes, and we don't know what order the `super` calls will be made in. The interface is similar to that used for `House` and `Apartment`, which is very useful when we combine the functionality of these four classes in separate subclasses. For example:

```
class HouseRental(Rental, House):
    def prompt_init():
        init = House.prompt_init()
        init.update(Rental.prompt_init())
        return init
    prompt_init = staticmethod(prompt_init)
```

This is slightly surprising, as the class on its own has neither an `__init__` nor `display` method! Because both parent classes appropriately call `super` in these methods, we only have to extend those classes and the classes will behave in the correct order. This is not the case with `prompt_init`, of course, since it is a static method that does not call `super`, so we implement this one explicitly. We should test this class to make sure it is behaving properly before we write the other three combinations:

```
>>> init = HouseRental.prompt_init()
Enter the square feet: 1
Enter number of bedrooms: 2
Enter number of baths: 3
Is the yard fenced?  (yes, no) no
Is there a garage?  (attached, detached, none) none
How many stories? 4
What is the monthly rent? 5
What are the estimated utilities? 6
```

```
Is the property furnished?  (yes, no) no
>>> house = HouseRental(**init)
>>> house.display()
PROPERTY DETAILS
================
square footage: 1
bedrooms: 2
bathrooms: 3

HOUSE DETAILS
# of stories: 4
garage: none
fenced yard: no

RENTAL DETAILS
rent: 5
estimated utilities: 6
furnished: no
```

It looks like it is working fine. The `prompt_init` method is prompting for initializers to all the super classes, and `display()` is also cooperatively calling all three superclasses.

The order of the inherited classes in the preceding example is important. If we had written `class HouseRental(House, Rental)` instead of `class HouseRental(Rental, House)`, `display()` would not have called `Rental.display()`! When `display` is called on our version of `HouseRental`, it refers to the `Rental` version of the method, which calls `super.display()` to get the `House` version, which again calls `super.display()` to get the property version. If we reversed it, `display` would refer to the `House` class's `display()`. When super is called, it calls the method on the `Property` parent class. But `Property` does not have a call to `super` in its `display` method. This means `Rental` class's `display` method would not be called! By placing the inheritance list in the order we did, we ensure that `Rental` calls `super`, which then takes care of the `House` side of the hierarchy. You might think we could have added a `super` call to `Property.display()`, but that will fail because the next superclass of `Property` is `object`, and `object` does not have a `display` method. Another way to fix this is to allow `Rental` and `Purchase` to extend the `Property` class instead of deriving directly from `object`. (Or we could modify the method resolution order dynamically, but that is beyond the scope of this book.)

Now that we have tested it, we are prepared to create the rest of our combined subclasses:

```
class ApartmentRental(Rental, Apartment):
    def prompt_init():
        init = Apartment.prompt_init()
        init.update(Rental.prompt_init())
        return init
    prompt_init = staticmethod(prompt_init)

class ApartmentPurchase(Purchase, Apartment):
    def prompt_init():
        init = Apartment.prompt_init()
        init.update(Purchase.prompt_init())
        return init
    prompt_init = staticmethod(prompt_init)

class HousePurchase(Purchase, House):
    def prompt_init():
        init = House.prompt_init()
        init.update(Purchase.prompt_init())
        return init
    prompt_init = staticmethod(prompt_init)
```

That should be the most intense designing out of our way! Now all we have to do is create the `Agent` class, which is responsible for creating new listings and displaying existing ones. Let's start with the simpler storing and listing of properties:

```
class Agent:
    def __init__(self):
        self.property_list = []

    def display_properties(self):
        for property in self.property_list:
            property.display()
```

Adding a property will require first querying the type of property and whether property is for purchase or rental. We can do this by displaying a simple menu. Once this has been determined, we can extract the correct subclass and prompt for all the details using the `prompt_init` hierarchy we've already developed. Sounds simple? It is. Let's start by adding a dictionary class variable to the `Agent` class:

```
    type_map = {
        ("house", "rental"): HouseRental,
        ("house", "purchase"): HousePurchase,
```

```
        ("apartment", "rental"): ApartmentRental,
        ("apartment", "purchase"): ApartmentPurchase
        }
```

That's some pretty funny looking code. This is a dictionary, where the keys are tuples of two distinct strings, and the values are class objects. Class objects? Yes, classes can be passed around, renamed, and stored in containers just like *normal* objects or primitive data types. With this simple dictionary, we can simply hijack our earlier `get_valid_input` method to ensure we get the correct dictionary keys and look up the appropriate class, like this:

```
    def add_property(self):
        property_type = get_valid_input(
                "What type of property? ",
                ("house", "apartment")).lower()
        payment_type = get_valid_input(
                "What payment type? ",
                ("purchase", "rental")).lower()

        PropertyClass = self.type_map[
            (property_type, payment_type)]
        init_args = PropertyClass.prompt_init()
        self.property_list.append(PropertyClass(**init_args))
```

This may look a bit funny too! We look up the class in the dictionary and store it in a variable named `PropertyClass`. We don't know exactly which class is available, but the class knows itself, so we can polymorphically call `prompt_init` to get a dictionary of values appropriate to pass into the constructor. Then we use the keyword argument syntax to convert the dictionary into arguments and construct the new object to load the correct data.

Now our user can use this `Agent` class to add and view lists of properties. It wouldn't take much work to add features to mark a property as available or unavailable or to edit and remove properties. Our prototype is now in a good enough state to take to a real estate `agent` and demonstrate its functionality. Here's how a demo session might work:

```
>>> agent = Agent()
>>> agent.add_property()
What type of property?  (house, apartment) house
What payment type?  (purchase, rental) rental
Enter the square feet: 900
Enter number of bedrooms: 2
Enter number of baths: one and a half
```

```
Is the yard fenced?  (yes, no) yes
Is there a garage?  (attached, detached, none) detached
How many stories? 1
What is the monthly rent? 1200
What are the estimated utilities? included
Is the property furnished?  (yes, no) no
>>> agent.add_property()
What type of property?  (house, apartment) apartment
What payment type?  (purchase, rental) purchase
Enter the square feet: 800
Enter number of bedrooms: 3
Enter number of baths: 2
What laundry facilities does the property have?  (coin, ensuite,
one) ensuite
Does the property have a balcony? (yes, no, solarium) yes
What is the selling price? $200,000
What are the estimated taxes? 1500
>>> agent.display_properties()
PROPERTY DETAILS
================
square footage: 900
bedrooms: 2
bathrooms: one and a half

HOUSE DETAILS
# of stories: 1
garage: detached
fenced yard: yes
RENTAL DETAILS
rent: 1200
estimated utilities: included
furnished: no
PROPERTY DETAILS
================
square footage: 800
bedrooms: 3
```

```
bathrooms: 2

APARTMENT DETAILS
laundry: ensuite
has balcony: yes
PURCHASE DETAILS
selling price: $200,000
estimated taxes: 1500
```

Exercises

Look around you at some of the physical objects in your workspace and see if you can describe them in an inheritance hierarchy. Humans have been dividing the world into taxonomies like this for centuries, so it shouldn't be difficult. Are there any non-obvious inheritance relationships between classes of objects? If you were to model these objects in a computer application, what properties and methods would they share? Which ones would have to be polymorphically overridden?
What properties would be completely different between them?

Now, write some code. No, not for the physical hierarchy; that's boring. Physical items have more properties than methods. Just think about a pet programming project you've wanted to tackle in the past year, but never got around to. For whatever problem you want to solve, try to think of some basic inheritance relationships. Then implement them. Make sure that you also pay attention to the sorts of relationships that you actually don't need to use inheritance for. Are there any places where you might want to use multiple inheritance? Are you sure? Can you see any place you would want to use a mixin? Try to knock together a quick prototype. It doesn't have to be useful or even partially working. You've seen how you can test code using `python -i` already; just write some code and test it in the interactive interpreter. If it works, write some more. If it doesn't, fix it!

Now, take a look at the real estate example. This turned out to be quite an effective use of multiple inheritance. I have to admit though, I had my doubts when I started the design. Have a look at the original problem and see if you can come up with another design to solve it that uses only single inheritance. How would you do it with abstract base classes? What about a design that doesn't use inheritance at all? Which do you think is the most elegant solution? Elegance is a primary goal in Python development, but each programmer has a different opinion as to what is the most elegant solution. Some people tend to think and understand problems most clearly using composition, while others find multiple inheritance to be the most useful model.

Finally, try adding some new features to the three designs. Whatever features strike your fancy are fine. I'd like to see a way to differentiate between available and unavailable properties, for starters. It's not of much use to me if it's already rented!

Which design is easiest to extend? Which is hardest? If somebody asked you why you thought this, would you be able to explain yourself?

Summary

We've gone from simple inheritance, one of the most useful tools in the object-oriented programmer's toolbox, all the way through to multiple inheritance, one of the most complicated. Inheritance can be used to add functionality to existing classes and built-ins using inheritance. Abstracting similar code into a parent class can help increase maintainability. Methods on parent classes can be called using `super` and argument lists must be formatted safely for these calls to work when using multiple inheritance.

In the next chapter, we'll cover the subtle art of handling exceptional circumstances.

5
When to Use Object-oriented Programming

In previous chapters, we've covered many of the defining features of object-oriented programming. We now know the principles and paradigms of object-oriented design, and we've covered the syntax of object-oriented programming in Python.

Yet, we don't know exactly how and when to utilize these principles and syntax in practice. In this chapter, we'll discuss some useful applications of the knowledge we've gained, picking up some new topics along the way:

- How to recognize objects
- Data and behaviors, once again
- Wrapping data in behavior using properties
- Restricting data using behavior
- The Don't Repeat Yourself principle
- Recognizing repeated code

Treat objects as objects

This may seem obvious; you should generally give separate objects in your problem domain a special class in your code. We've seen examples of this in the case studies in previous chapters; first, we identify objects in the problem and then model their data and behaviors.

Identifying objects is a very important task in object-oriented analysis and programming. But it isn't always as easy as counting the nouns in a short paragraph, as we've been doing. Remember, objects are things that have both data and behavior. If we are working only with data, we are often better off storing it in a list, set, dictionary, or some other Python data structure (which we'll be covering thoroughly in *Chapter 6*, *Python Data Structures*). On the other hand, if we are working only with behavior, but no stored data, a simple function is more suitable.

An object, however, has both data and behavior. Proficient Python programmers use built-in data structures unless (or until) there is an obvious need to define a class. There is no reason to add an extra level of abstraction if it doesn't help organize our code. On the other hand, the "obvious" need is not always self-evident.

We can often start our Python programs by storing data in a few variables. As the program expands, we will later find that we are passing the same set of related variables to a set of functions. This is the time to think about grouping both variables and functions into a class. If we are designing a program to model polygons in two-dimensional space, we might start with each polygon being represented as a list of points. The points would be modeled as two-tuples (*x*, *y*) describing where that point is located. This is all data, stored in a set of nested data structures (specifically, a list of tuples):

```
square = [(1,1), (1,2), (2,2), (2,1)]
```

Now, if we want to calculate the distance around the perimeter of the polygon, we simply need to sum the distances between the two points. To do this, we also need a function to calculate the distance between two points. Here are two such functions:

```
import math

def distance(p1, p2):
    return math.sqrt((p1[0]-p2[0])**2 + (p1[1]-p2[1])**2)

def perimeter(polygon):
    perimeter = 0
    points = polygon + [polygon[0]]
    for i in range(len(polygon)):
        perimeter += distance(points[i], points[i+1])
    return perimeter
```

Now, as object-oriented programmers, we clearly recognize that a `polygon` class could encapsulate the list of points (data) and the `perimeter` function (behavior). Further, a `point` class, such as we defined in *Chapter 2*, *Objects in Python*, might encapsulate the `x` and `y` coordinates and the `distance` method. The question is: is it valuable to do this?

For the previous code, maybe yes, maybe no. With our recent experience in object-oriented principles, we can write an object-oriented version in record time. Let's compare them

```
import math

class Point:
    def __init__(self, x, y):
        self.x = x
        self.y = y

    def distance(self, p2):
        return math.sqrt((self.x-p2.x)**2 + (self.y-p2.y)**2)

class Polygon:
    def __init__(self):
        self.vertices = []

    def add_point(self, point):
        self.vertices.append((point))

    def perimeter(self):
        perimeter = 0
        points = self.vertices + [self.vertices[0]]
        for i in range(len(self.vertices)):
            perimeter += points[i].distance(points[i+1])
        return perimeter
```

As we can see from the highlighted sections, there is twice as much code here as there was in our earlier version, although we could argue that the `add_point` method is not strictly necessary.

Now, to understand the differences a little better, let's compare the two APIs in use. Here's how to calculate the perimeter of a square using the object-oriented code:

```
>>> square = Polygon()
>>> square.add_point(Point(1,1))
>>> square.add_point(Point(1,2))
>>> square.add_point(Point(2,2))
>>> square.add_point(Point(2,1))
>>> square.perimeter()
4.0
```

That's fairly succinct and easy to read, you might think, but let's compare it to the function-based code:

```
>>> square = [(1,1), (1,2), (2,2), (2,1)]
>>> perimeter(square)
4.0
```

Hmm, maybe the object-oriented API isn't so compact! That said, I'd argue that it was easier to *read* than the functional example: How do we know what the list of tuples is supposed to represent in the second version? How do we remember what kind of object (a list of two-tuples? That's not intuitive!) we're supposed to pass into the `perimeter` function? We would need a lot of documentation to explain how these functions should be used.

In contrast, the object-oriented code is relatively self-documenting, we just have to look at the list of methods and their parameters to know what the object does and how to use it. By the time we wrote all the documentation for the functional version, it would probably be longer than the object-oriented code.

Finally, code length is not a good indicator of code complexity. Some programmers get hung up on complicated "one liners" that do an incredible amount of work in one line of code. This can be a fun exercise, but the result is often unreadable, even to the original author the following day. Minimizing the amount of code can often make a program easier to read, but do not blindly assume this is the case.

Luckily, this trade-off isn't necessary. We can make the object-oriented `Polygon` API as easy to use as the functional implementation. All we have to do is alter our `Polygon` class so that it can be constructed with multiple points. Let's give it an initializer that accepts a list of `Point` objects. In fact, let's allow it to accept tuples too, and we can construct the `Point` objects ourselves, if needed:

```
def __init__(self, points=None):
    points = points if points else []
    self.vertices = []
    for point in points:
        if isinstance(point, tuple):
            point = Point(*point)
        self.vertices.append(point)
```

This initializer goes through the list and ensures that any tuples are converted to points. If the object is not a tuple, we leave it as is, assuming that it is either a `Point` object already, or an unknown duck-typed object that can act like a `Point` object.

Still, there's no clear winner between the object-oriented and more data-oriented versions of this code. They both do the same thing. If we have new functions that accept a polygon argument, such as `area(polygon)` or `point_in_polygon(polygon, x, y)`, the benefits of the object-oriented code become increasingly obvious. Likewise, if we add other attributes to the polygon, such as `color` or `texture`, it makes more and more sense to encapsulate that data into a single class.

The distinction is a design decision, but in general, the more complicated a set of data is, the more likely it is to have multiple functions specific to that data, and the more useful it is to use a class with attributes and methods instead.

When making this decision, it also pays to consider how the class will be used. If we're only trying to calculate the perimeter of one polygon in the context of a much greater problem, using a function will probably be quickest to code and easier to use "one time only". On the other hand, if our program needs to manipulate numerous polygons in a wide variety of ways (calculate perimeter, area, intersection with other polygons, move or scale them, and so on), we have most certainly identified an object; one that needs to be extremely versatile.

Additionally, pay attention to the interaction between objects. Look for inheritance relationships; inheritance is impossible to model elegantly without classes, so make sure to use them. Look for the other types of relationships we discussed in *Chapter 1*, *Object-oriented Design*, association and composition. Composition can, technically, be modeled using only data structures; for example, we can have a list of dictionaries holding tuple values, but it is often less complicated to create a few classes of objects, especially if there is behavior associated with the data.

Don't rush to use an object just because you can use an object, but *never* neglect to create a class when you need to use a class.

Adding behavior to class data with properties

Throughout this book, we've been focusing on the separation of behavior and data. This is very important in object-oriented programming, but we're about to see that, in Python, the distinction can be uncannily blurry. Python is very good at blurring distinctions; it doesn't exactly help us to "think outside the box". Rather, it teaches us to stop thinking about the box.

Before we get into the details, let's discuss some bad object-oriented theory. Many object-oriented languages (Java is the most notorious) teach us to never access attributes directly. They insist that we write attribute access like this:

```
class Color:
    def __init__(self, rgb_value, name):
        self._rgb_value = rgb_value
        self._name = name

    def set_name(self, name):
        self._name = name

    def get_name(self):
        return self._name
```

The variables are prefixed with an underscore to suggest that they are private (other languages would actually force them to be private). Then the get and set methods provide access to each variable. This class would be used in practice as follows:

```
>>> c = Color("#ff0000", "bright red")
>>> c.get_name()
'bright red'
>>> c.set_name("red")
>>> c.get_name()
'red'
```

This is not nearly as readable as the direct access version that Python favors:

```
class Color:
    def __init__(self, rgb_value, name):
        self.rgb_value = rgb_value
        self.name = name

c = Color("#ff0000", "bright red")
print(c.name)
c.name = "red"
```

So why would anyone insist upon the method-based syntax? Their reasoning is that someday we may want to add extra code when a value is set or retrieved. For example, we could decide to cache a value and return the cached value, or we might want to validate that the value is a suitable input.

In code, we could decide to change the `set_name()` method as follows:

```
def set_name(self, name):
    if not name:
        raise Exception("Invalid Name")
    self._name = name
```

Now, in Java and similar languages, if we had written our original code to do direct attribute access, and then later changed it to a method like the preceding one, we'd have a problem: anyone who had written code that accessed the attribute directly would now have to access the method. If they don't change the access style from attribute access to a function call, their code will be broken. The mantra in these languages is that we should never make public members private. This doesn't make much sense in Python since there isn't any real concept of private members!

Python gives us the `property` keyword to make methods look like attributes. We can therefore write our code to use direct member access, and if we unexpectedly need to alter the implementation to do some calculation when getting or setting that attribute's value, we can do so without changing the interface. Let's see how it looks:

```
class Color:
    def __init__(self, rgb_value, name):
        self.rgb_value = rgb_value
        self._name = name

    def _set_name(self, name):
        if not name:
            raise Exception("Invalid Name")
        self._name = name

    def _get_name(self):
        return self._name

    name = property(_get_name, _set_name)
```

If we had started with the earlier non-method-based class, which set the `name` attribute directly, we could later change the code to look like the preceding one. We first change the `name` attribute into a (semi-) private `_name` attribute. Then we add two more (semi-) private methods to get and set that variable, doing our validation when we set it.

Finally, we have the `property` declaration at the bottom. This is the magic. It creates a new attribute on the `Color` class called `name`, which now replaces the previous `name` attribute. It sets this attribute to be a property, which calls the two methods we just created whenever the property is accessed or changed. This new version of the `Color` class can be used exactly the same way as the previous version, yet it now does validation when we set the `name` attribute:

```
>>> c = Color("#0000ff", "bright red")
>>> print(c.name)
bright red
>>> c.name = "red"
>>> print(c.name)
red
>>> c.name = ""
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "setting_name_property.py", line 8, in _set_name
    raise Exception("Invalid Name")
Exception: Invalid Name
```

So, if we'd previously written code to access the `name` attribute, and then changed it to use our `property` object, the previous code would still work, unless it was sending an empty `property` value, which is the behavior we wanted to forbid in the first place. Success!

Bear in mind that even with the `name` property, the previous code is not 100 percent safe. People can still access the `_name` attribute directly and set it to an empty string if they want to. But if they access a variable we've explicitly marked with an underscore to suggest it is private, they're the ones that have to deal with the consequences, not us.

Properties in detail

Think of the `property` function as returning an object that proxies any requests to set or access the attribute value through the methods we have specified. The `property` keyword is like a constructor for such an object, and that object is set as the public facing member for the given attribute.

This `property` constructor can actually accept two additional arguments, a deletion function and a docstring for the property. The `delete` function is rarely supplied in practice, but it can be useful for logging that a value has been deleted, or possibly to veto deleting if we have reason to do so. The docstring is just a string describing what the property does, no different from the docstrings we discussed in *Chapter 2*, *Objects in Python*. If we do not supply this parameter, the docstring will instead be copied from the docstring for the first argument: the getter method. Here is a silly example that simply states whenever any of the methods are called:

```
class Silly:
    def _get_silly(self):
        print("You are getting silly")
        return self._silly
    def _set_silly(self, value):
        print("You are making silly {}".format(value))
        self._silly = value
    def _del_silly(self):
        print("Whoah, you killed silly!")
        del self._silly

    silly = property(_get_silly, _set_silly,
            _del_silly, "This is a silly property")
```

If we actually use this class, it does indeed print out the correct strings when we ask it to:

```
>>> s = Silly()
>>> s.silly = "funny"
You are making silly funny
>>> s.silly
You are getting silly
'funny'
>>> del s.silly
Whoah, you killed silly!
```

Further, if we look at the help file for the `Silly` class (by issuing `help(silly)` at the interpreter prompt), it shows us the custom docstring for our `silly` attribute:

```
Help on class Silly in module __main__:

class Silly(builtins.object)
```

```
 |  Data descriptors defined here:
 |
 |  __dict__
 |      dictionary for instance variables (if defined)
 |
 |  __weakref__
 |      list of weak references to the object (if defined)
 |
 |  silly
 |      This is a silly property
```

Once again, everything is working as we planned. In practice, properties are normally only defined with the first two parameters: the getter and setter functions. If we want to supply a docstring for a property, we can define it on the getter function; the property proxy will copy it into its own docstring. The deletion function is often left empty because object attributes are rarely deleted. If a coder does try to delete a property that doesn't have a deletion function specified, it will raise an exception. Therefore, if there is a legitimate reason to delete our property, we should supply that function.

Decorators – another way to create properties

If you've never used Python decorators before, you might want to skip this section and come back to it after we've discussed the decorator pattern in *Chapter 10*, *Python Design Patterns I*. However, you don't need to understand what's going on to use the decorator syntax to make property methods more readable.

The property function can be used with the decorator syntax to turn a get function into a property:

```
class Foo:
    @property
    def foo(self):
        return "bar"
```

This applies the `property` function as a decorator, and is equivalent to the previous `foo = property(foo)` syntax. The main difference, from a readability perspective, is that we get to mark the `foo` function as a property at the top of the method, instead of after it is defined, where it can be easily overlooked. It also means we don't have to create private methods with underscore prefixes just to define a property.

Going one step further, we can specify a setter function for the new property as follows:

```
class Foo:
    @property
    def foo(self):
        return self._foo

    @foo.setter
    def foo(self, value):
        self._foo = value
```

This syntax looks pretty odd, although the intent is obvious. First, we decorate the `foo` method as a getter. Then, we decorate a second method with exactly the same name by applying the `setter` attribute of the originally decorated `foo` method! The `property` function returns an object; this object always comes with its own `setter` attribute, which can then be applied as a decorator to other functions. Using the same name for the get and set methods is not required, but it does help group the multiple methods that access one property together.

We can also specify a deletion function with `@foo.deleter`. We cannot specify a docstring using `property` decorators, so we need to rely on the property copying the docstring from the initial getter method.

Here's our previous `Silly` class rewritten to use `property` as a decorator:

```
class Silly:
    @property
    def silly(self):
        "This is a silly property"
        print("You are getting silly")
        return self._silly

    @silly.setter
    def silly(self, value):
        print("You are making silly {}".format(value))
        self._silly = value

    @silly.deleter
    def silly(self):
        print("Whoah, you killed silly!")
        del self._silly
```

This class operates *exactly* the same as our earlier version, including the help text. You can use whichever syntax you feel is more readable and elegant.

Deciding when to use properties

With the property built-in clouding the division between behavior and data, it can be confusing to know which one to choose. The example use case we saw earlier is one of the most common uses of properties; we have some data on a class that we later want to add behavior to. There are also other factors to take into account when deciding to use a property.

Technically, in Python, data, properties, and methods are all attributes on a class. The fact that a method is callable does not distinguish it from other types of attributes; indeed, we'll see in *Chapter 7*, *Python Object-oriented Shortcuts*, that it is possible to create normal objects that can be called like functions. We'll also discover that functions and methods are themselves normal objects.

The fact that methods are just callable attributes, and properties are just customizable attributes can help us make this decision. Methods should typically represent actions; things that can be done to, or performed by, the object. When you call a method, even with only one argument, it should *do* something. Method names are generally verbs.

Once confirming that an attribute is not an action, we need to decide between standard data attributes and properties. In general, always use a standard attribute until you need to control access to that property in some way. In either case, your attribute is usually a noun. The only difference between an attribute and a property is that we can invoke custom actions automatically when a property is retrieved, set, or deleted.

Let's look at a more realistic example. A common need for custom behavior is caching a value that is difficult to calculate or expensive to look up (requiring, for example, a network request or database query). The goal is to store the value locally to avoid repeated calls to the expensive calculation.

We can do this with a custom getter on the property. The first time the value is retrieved, we perform the lookup or calculation. Then we could locally cache the value as a private attribute on our object (or in dedicated caching software), and the next time the value is requested, we return the stored data. Here's how we might cache a web page:

```
from urllib.request import urlopen

class WebPage:
    def __init__(self, url):
        self.url = url
        self._content = None

    @property
```

```
        def content(self):
            if not self._content:
                print("Retrieving New Page...")
                self._content = urlopen(self.url).read()
            return self._content
```

We can test this code to see that the page is only retrieved once:

```
>>> import time
>>> webpage = WebPage("http://ccphillips.net/")
>>> now = time.time()
>>> content1 = webpage.content
Retrieving New Page...
>>> time.time() - now
22.43316888809204
>>> now = time.time()
>>> content2 = webpage.content
>>> time.time() - now
1.9266459941864014
>>> content2 == content1
True
```

I was on an awful satellite connection when I originally tested this code and it took 20 seconds the first time I loaded the content. The second time, I got the result in 2 seconds (which is really just the amount of time it took to type the lines into the interpreter).

Custom getters are also useful for attributes that need to be calculated on the fly, based on other object attributes. For example, we might want to calculate the average for a list of integers:

```
    class AverageList(list):
        @property
        def average(self):
            return sum(self) / len(self)
```

This very simple class inherits from `list`, so we get list-like behavior for free. We just add a property to the class, and presto, our list can have an average:

```
>>> a = AverageList([1,2,3,4])
>>> a.average
2.5
```

Of course, we could have made this a method instead, but then we should call it `calculate_average()`, since methods represent actions. But a property called `average` is more suitable, both easier to type, and easier to read.

Custom setters are useful for validation, as we've already seen, but they can also be used to proxy a value to another location. For example, we could add a content setter to the `WebPage` class that automatically logs into our web server and uploads a new page whenever the value is set.

Manager objects

We've been focused on objects and their attributes and methods. Now, we'll take a look at designing higher-level objects: the kinds of objects that manage other objects. The objects that tie everything together.

The difference between these objects and most of the examples we've seen so far is that our examples tend to represent concrete ideas. Management objects are more like office managers; they don't do the actual "visible" work out on the floor, but without them, there would be no communication between departments and nobody would know what they are supposed to do (although, this can be true anyway if the organization is badly managed!). Analogously, the attributes on a management class tend to refer to other objects that do the "visible" work; the behaviors on such a class delegate to those other classes at the right time, and pass messages between them.

As an example, we'll write a program that does a find and replace action for text files stored in a compressed ZIP file. We'll need objects to represent the ZIP file and each individual text file (luckily, we don't have to write these classes, they're available in the Python standard library). The manager object will be responsible for ensuring three steps occur in order:

1. Unzipping the compressed file.
2. Performing the find and replace action.
3. Zipping up the new files.

The class is initialized with the `.zip` filename and search and replace strings. We create a temporary directory to store the unzipped files in, so that the folder stays clean. The Python 3.4 `pathlib` library helps out with file and directory manipulation. We'll learn more about that in *Chapter 8*, *Strings and Serialization*, but the interface should be pretty clear in the following example:

```
import sys
import shutil
import zipfile
```

```
from pathlib import Path

class ZipReplace:
    def __init__(self, filename, search_string, replace_string):
        self.filename = filename
        self.search_string = search_string
        self.replace_string = replace_string
        self.temp_directory = Path("unzipped-{}".format(
                filename))
```

Then, we create an overall "manager" method for each of the three steps. This method delegates responsibility to other methods. Obviously, we could do all three steps in one method, or indeed, in one script without ever creating an object. There are several advantages to separating the three steps:

- **Readability**: The code for each step is in a self-contained unit that is easy to read and understand. The method names describe what the method does, and less additional documentation is required to understand what is going on.
- **Extensibility**: If a subclass wanted to use compressed TAR files instead of ZIP files, it could override the `zip` and `unzip` methods without having to duplicate the `find_replace` method.
- **Partitioning**: An external class could create an instance of this class and call the `find_replace` method directly on some folder without having to `zip` the content.

The delegation method is the first in the following code; the rest of the methods are included for completeness:

```
    def zip_find_replace(self):
        self.unzip_files()
        self.find_replace()
        self.zip_files()

    def unzip_files(self):
        self.temp_directory.mkdir()
        with zipfile.ZipFile(self.filename) as zip:
            zip.extractall(str(self.temp_directory))

    def find_replace(self):
        for filename in self.temp_directory.iterdir():
            with filename.open() as file:
                contents = file.read()
            contents = contents.replace(
                    self.search_string, self.replace_string)
```

```
                with filename.open("w") as file:
                    file.write(contents)

        def zip_files(self):
            with zipfile.ZipFile(self.filename, 'w') as file:
                for filename in self.temp_directory.iterdir():
                    file.write(str(filename), filename.name)
            shutil.rmtree(str(self.temp_directory))

    if __name__ == "__main__":
        ZipReplace(*sys.argv[1:4]).zip_find_replace()
```

For brevity, the code for zipping and unzipping files is sparsely documented. Our current focus is on object-oriented design; if you are interested in the inner details of the `zipfile` module, refer to the documentation in the standard library, either online or by typing `import zipfile ; help(zipfile)` into your interactive interpreter. Note that this example only searches the top-level files in a ZIP file; if there are any folders in the unzipped content, they will not be scanned, nor will any files inside those folders.

The last two lines in the example allow us to run the program from the command line by passing the `zip` filename, search string, and replace string as arguments:

```
python zipsearch.py hello.zip hello hi
```

Of course, this object does not have to be created from the command line; it could be imported from another module (to perform batch ZIP file processing) or accessed as part of a GUI interface or even a higher-level management object that knows where to get ZIP files (for example, to retrieve them from an FTP server or back them up to an external disk).

As programs become more and more complex, the objects being modeled become less and less like physical objects. Properties are other abstract objects and methods are actions that change the state of those abstract objects. But at the heart of every object, no matter how complex, is a set of concrete properties and well-defined behaviors.

Removing duplicate code

Often the code in management style classes such as `ZipReplace` is quite generic and can be applied in a variety of ways. It is possible to use either composition or inheritance to help keep this code in one place, thus eliminating duplicate code. Before we look at any examples of this, let's discuss a tiny bit of theory. Specifically, why is duplicate code a bad thing?

There are several reasons, but they all boil down to readability and maintainability. When we're writing a new piece of code that is similar to an earlier piece, the easiest thing to do is copy the old code and change whatever needs to be changed (variable names, logic, comments) to make it work in the new location. Alternatively, if we're writing new code that seems similar, but not identical to code elsewhere in the project, it is often easier to write fresh code with similar behavior, rather than figure out how to extract the overlapping functionality.

But as soon as someone has to read and understand the code and they come across duplicate blocks, they are faced with a dilemma. Code that might have made sense suddenly has to be understood. How is one section different from the other? How are they the same? Under what conditions is one section called? When do we call the other? You might argue that you're the only one reading your code, but if you don't touch that code for eight months it will be as incomprehensible to you as it is to a fresh coder. When we're trying to read two similar pieces of code, we have to understand why they're different, as well as how they're different. This wastes the reader's time; code should always be written to be readable first.

I once had to try to understand someone's code that had three identical copies of the same 300 lines of very poorly written code. I had been working with the code for a month before I finally comprehended that the three "identical" versions were actually performing slightly different tax calculations. Some of the subtle differences were intentional, but there were also obvious areas where someone had updated a calculation in one function without updating the other two. The number of subtle, incomprehensible bugs in the code could not be counted. I eventually replaced all 900 lines with an easy-to-read function of 20 lines or so.

Reading such duplicate code can be tiresome, but code maintenance is even more tormenting. As the preceding story suggests, keeping two similar pieces of code up to date can be a nightmare. We have to remember to update both sections whenever we update one of them, and we have to remember how the multiple sections differ so we can modify our changes when we are editing each of them. If we forget to update both sections, we will end up with extremely annoying bugs that usually manifest themselves as, "but I fixed that already, why is it still happening?"

The result is that people who are reading or maintaining our code have to spend astronomical amounts of time understanding and testing it compared to if we had written the code in a nonrepetitive manner in the first place. It's even more frustrating when we are the ones doing the maintenance; we find ourselves saying, "why didn't I do this right the first time?" The time we save by copy-pasting existing code is lost the very first time we have to maintain it. Code is both read and modified many more times and much more often than it is written. Comprehensible code should always be paramount.

This is why programmers, especially Python programmers (who tend to value elegant code more than average), follow what is known as the **Don't Repeat Yourself** (**DRY**) principle. DRY code is maintainable code. My advice to beginning programmers is to never use the copy and paste feature of their editor. To intermediate programmers, I suggest they think thrice before they hit *Ctrl* + *C*.

But what should we do instead of code duplication? The simplest solution is often to move the code into a function that accepts parameters to account for whatever parts are different. This isn't a terribly object-oriented solution, but it is frequently optimal.

For example, if we have two pieces of code that unzip a ZIP file into two different directories, we can easily write a function that accepts a parameter for the directory to which it should be unzipped instead. This may make the function itself slightly more difficult to read, but a good function name and docstring can easily make up for that, and any code that invokes the function will be easier to read.

That's certainly enough theory! The moral of the story is: always make the effort to refactor your code to be easier to read instead of writing bad code that is only easier to write.

In practice

Let's explore two ways we can reuse existing code. After writing our code to replace strings in a ZIP file full of text files, we are later contracted to scale all the images in a ZIP file to 640 x 480. Looks like we could use a very similar paradigm to what we used in `ZipReplace`. The first impulse might be to save a copy of that file and change the `find_replace` method to `scale_image` or something similar.

But, that's uncool. What if someday we want to change the `unzip` and `zip` methods to also open TAR files? Or maybe we want to use a guaranteed unique directory name for temporary files. In either case, we'd have to change it in two different places!

We'll start by demonstrating an inheritance-based solution to this problem. First we'll modify our original `ZipReplace` class into a superclass for processing generic ZIP files:

```
import os
import shutil
import zipfile
from pathlib import Path


class ZipProcessor:
    def __init__(self, zipname):
        self.zipname = zipname
```

```
            self.temp_directory = Path("unzipped-{}".format(
                    zipname[:-4]))

        def process_zip(self):
            self.unzip_files()
            self.process_files()
            self.zip_files()

        def unzip_files(self):
            self.temp_directory.mkdir()
            with zipfile.ZipFile(self.zipname) as zip:
                zip.extractall(str(self.temp_directory))

        def zip_files(self):
            with zipfile.ZipFile(self.zipname, 'w') as file:
                for filename in self.temp_directory.iterdir():
                    file.write(str(filename), filename.name)
            shutil.rmtree(str(self.temp_directory))
```

We changed the `filename` property to `zipname` to avoid confusion with the `filename` local variables inside the various methods. This helps make the code more readable even though it isn't actually a change in design.

We also dropped the two parameters to `__init__` (`search_string` and `replace_string`) that were specific to `ZipReplace`. Then we renamed the `zip_find_replace` method to `process_zip` and made it call an (as yet undefined) `process_files` method instead of `find_replace`; these name changes help demonstrate the more generalized nature of our new class. Notice that we have removed the `find_replace` method altogether; that code is specific to `ZipReplace` and has no business here.

This new `ZipProcessor` class doesn't actually define a `process_files` method; so if we ran it directly, it would raise an exception. Because it isn't meant to run directly, we removed the main call at the bottom of the original script.

Now, before we move on to our image processing app, let's fix up our original `zipsearch` class to make use of this parent class:

```
from zip_processor import ZipProcessor
import sys
import os

class ZipReplace(ZipProcessor):
    def __init__(self, filename, search_string,
            replace_string):
        super().__init__(filename)
```

```
            self.search_string = search_string
            self.replace_string = replace_string

        def process_files(self):
            '''perform a search and replace on all files in the
            temporary directory'''
            for filename in self.temp_directory.iterdir():
                with filename.open() as file:
                    contents = file.read()
                contents = contents.replace(
                        self.search_string, self.replace_string)
                with filename.open("w") as file:
                    file.write(contents)

    if __name__ == "__main__":
        ZipReplace(*sys.argv[1:4]).process_zip()
```

This code is a bit shorter than the original version, since it inherits its ZIP processing abilities from the parent class. We first import the base class we just wrote and make `ZipReplace` extend that class. Then we use `super()` to initialize the parent class. The `find_replace` method is still here, but we renamed it to `process_files` so the parent class can call it from its management interface. Because this name isn't as descriptive as the old one, we added a docstring to describe what it is doing.

Now, that was quite a bit of work, considering that all we have now is a program that is functionally not different from the one we started with! But having done that work, it is now much easier for us to write other classes that operate on files in a ZIP archive, such as the (hypothetically requested) photo scaler. Further, if we ever want to improve or bug fix the zip functionality, we can do it for all classes by changing only the one `ZipProcessor` base class. Maintenance will be much more effective.

See how simple it is now to create a photo scaling class that takes advantage of the `ZipProcessor` functionality. (Note: this class requires the third-party `pillow` library to get the `PIL` module. You can install it with `pip install pillow`.)

```
from zip_processor import ZipProcessor
import sys
from PIL import Image

class ScaleZip(ZipProcessor):

    def process_files(self):
        '''Scale each image in the directory to 640x480'''
        for filename in self.temp_directory.iterdir():
            im = Image.open(str(filename))
```

```
                scaled = im.resize((640, 480))
                scaled.save(str(filename))

if __name__ == "__main__":
    ScaleZip(*sys.argv[1:4]).process_zip()
```

Look how simple this class is! All that work we did earlier paid off. All we do is open each file (assuming that it is an image; it will unceremoniously crash if a file cannot be opened), scale it, and save it back. The `ZipProcessor` class takes care of the zipping and unzipping without any extra work on our part.

Case study

For this case study, we'll try to delve further into the question, "when should I choose an object versus a built-in type?" We'll be modeling a `Document` class that might be used in a text editor or word processor. What objects, functions, or properties should it have?

We might start with a `str` for the `Document` contents, but in Python, strings aren't mutable (able to be changed). Once a `str` is defined, it is forever. We can't insert a character into it or remove one without creating a brand new string object. That would be leaving a lot of `str` objects taking up memory until Python's garbage collector sees fit to clean up behind us.

So, instead of a string, we'll use a list of characters, which we can modify at will. In addition, a `Document` class would need to know the current cursor position within the list, and should probably also store a filename for the document.

Real text editors use a binary-tree based data structure called a `rope` to model their document contents. This book's title isn't "advanced data structures", so if you're interested in learning more about this fascinating topic, you may want to search the web for the rope data structure.

Now, what methods should it have? There are a lot of things we might want to do to a text document, including inserting, deleting, and selecting characters, cut, copy, paste, the selection, and saving or closing the document. It looks like there are copious amounts of both data and behavior, so it makes sense to put all this stuff into its own `Document` class.

A pertinent question is: should this class be composed of a bunch of basic Python objects such as `str` filenames, `int` cursor positions, and a `list` of characters? Or should some or all of those things be specially defined objects in their own right? What about individual lines and characters, do they need to have classes of their own?

We'll answer these questions as we go, but let's start with the simplest possible `Document` class first and see what it can do:

```
class Document:
    def __init__(self):
        self.characters = []
        self.cursor = 0
        self.filename = ''

    def insert(self, character):
        self.characters.insert(self.cursor, character)
        self.cursor += 1

    def delete(self):
        del self.characters[self.cursor]

    def save(self):
        with open(self.filename, 'w') as f:
            f.write(''.join(self.characters))

    def forward(self):
        self.cursor += 1

    def back(self):
        self.cursor -= 1
```

This simple class allows us full control over editing a basic document. Have a look at it in action:

```
>>> doc = Document()
>>> doc.filename = "test_document"
>>> doc.insert('h')
>>> doc.insert('e')
>>> doc.insert('l')
>>> doc.insert('l')
>>> doc.insert('o')
>>> "".join(doc.characters)
'hello'
>>> doc.back()
>>> doc.delete()
>>> doc.insert('p')
>>> "".join(doc.characters)
'hellp'
```

Looks like it's working. We could connect a keyboard's letter and arrow keys to these methods and the document would track everything just fine.

But what if we want to connect more than just arrow keys. What if we want to connect the *Home* and *End* keys as well? We could add more methods to the `Document` class that search forward or backwards for newline characters (in Python, a newline character, or `\n` represents the end of one line and the beginning of a new one) in the string and jump to them, but if we did that for every possible movement action (move by words, move by sentences, *Page Up*, *Page Down*, end of line, beginning of whitespace, and more), the class would be huge. Maybe it would be better to put those methods on a separate object. So, let us turn the cursor attribute into an object that is aware of its position and can manipulate that position. We can move the forward and back methods to that class, and add a couple more for the *Home* and *End* keys:

```
class Cursor:
    def __init__(self, document):
        self.document = document
        self.position = 0

    def forward(self):
        self.position += 1

    def back(self):
        self.position -= 1

    def home(self):
        while self.document.characters[
                self.position-1] != '\n':
            self.position -= 1
            if self.position == 0:
                # Got to beginning of file before newline
                break

    def end(self):
        while self.position < len(self.document.characters
                ) and self.document.characters[
                    self.position] != '\n':
            self.position += 1
```

This class takes the document as an initialization parameter so the methods have access to the content of the document's character list. It then provides simple methods for moving backwards and forwards, as before, and for moving to the `home` and `end` positions.

This code is not very safe. You can very easily move past the ending position, and if you try to go home on an empty file, it will crash. These examples are kept short to make them readable, but that doesn't mean they are defensive! You can improve the error checking of this code as an exercise; it might be a great opportunity to expand your exception handling skills.

The `Document` class itself is hardly changed, except for removing the two methods that were moved to the `Cursor` class:

```
class Document:
    def __init__(self):
        self.characters = []
        self.cursor = Cursor(self)
        self.filename = ''

       def insert(self, character):
        self.characters.insert(self.cursor.position,
                character)
        self.cursor.forward()

    def delete(self):
        del self.characters[self.cursor.position]

    def save(self):
        f = open(self.filename, 'w')
        f.write(''.join(self.characters))
        f.close()
```

We simply updated anything that accessed the old cursor integer to use the new object instead. We can test that the `home` method is really moving to the newline character:

```
>>> d = Document()
>>> d.insert('h')
>>> d.insert('e')
>>> d.insert('l')
>>> d.insert('l')
>>> d.insert('o')
>>> d.insert('\n')
>>> d.insert('w')
```

```
>>> d.insert('o')
>>> d.insert('r')
>>> d.insert('l')
>>> d.insert('d')
>>> d.cursor.home()
>>> d.insert("*")
>>> print("".join(d.characters))
hello
*world
```

Now, since we've been using that string `join` function a lot (to concatenate the characters so we can see the actual document contents), we can add a property to the `Document` class to give us the complete string:

```
    @property
    def string(self):
        return "".join(self.characters)
```

This makes our testing a little simpler:

```
>>> print(d.string)
hello
world
```

This framework is simple (though it might be a bit time consuming!) to extend to create and edit a complete plaintext document. Now, let's extend it to work for rich text; text that can have **bold**, underlined, or *italic* characters.

There are two ways we could process this; the first is to insert "fake" characters into our character list that act like instructions, such as "bold characters until you find a stop bold character". The second is to add information to each character indicating what formatting it should have. While the former method is probably more common, we'll implement the latter solution. To do that, we're obviously going to need a class for characters. This class will have an attribute representing the character, as well as three Boolean attributes representing whether it is bold, italic, or underlined.

Hmm, wait! Is this `Character` class going to have any methods? If not, maybe we should use one of the many Python data structures instead; a tuple or named tuple would probably be sufficient. Are there any actions that we would want to do to, or invoke on a character?

Well, clearly, we might want to do things with characters, such as delete or copy them, but those are things that need to be handled at the `Document` level, since they are really modifying the list of characters. Are there things that need to be done to individual characters?

Actually, now that we're thinking about what a `Character` class actually is... what is it? Would it be safe to say that a `Character` class is a string? Maybe we should use an inheritance relationship here? Then we can take advantage of the numerous methods that `str` instances come with.

What sorts of methods are we talking about? There's `startswith`, `strip`, `find`, `lower`, and many more. Most of these methods expect to be working on strings that contain more than one character. In contrast, if `Character` were to subclass `str`, we'd probably be wise to override `__init__` to raise an exception if a multi-character string were supplied. Since all those methods we'd get for free wouldn't really apply to our `Character` class, it seems we needn't use inheritance, after all.

This brings us back to our original question; should `Character` even be a class? There is a very important special method on the `object` class that we can take advantage of to represent our characters. This method, called `__str__` (two underscores, like `__init__`), is used in string manipulation functions like `print` and the `str` constructor to convert any class to a string. The default implementation does some boring stuff like printing the name of the module and class and its address in memory. But if we override it, we can make it print whatever we like. For our implementation, we could make it prefix characters with special characters to represent whether they are bold, italic, or underlined. So, we will create a class to represent a character, and here it is:

```
class Character:
    def __init__(self, character,
                 bold=False, italic=False, underline=False):
        assert len(character) == 1
        self.character = character
        self.bold = bold
        self.italic = italic
        self.underline = underline

    def __str__(self):
        bold = "*" if self.bold else ''
        italic = "/" if self.italic else ''
        underline = "_" if self.underline else ''
        return bold + italic + underline + self.character
```

This class allows us to create characters and prefix them with a special character when the `str()` function is applied to them. Nothing too exciting there. We only have to make a few minor modifications to the `Document` and `Cursor` classes to work with this class. In the `Document` class, we add these two lines at the beginning of the `insert` method:

```
def insert(self, character):
    if not hasattr(character, 'character'):
        character = Character(character)
```

This is a rather strange bit of code. Its basic purpose is to check whether the character being passed in is a `Character` or a `str`. If it is a string, it is wrapped in a `Character` class so all objects in the list are `Character` objects. However, it is entirely possible that someone using our code would want to use a class that is neither `Character` nor string, using duck typing. If the object has a character attribute, we assume it is a "`Character`-like" object. But if it does not, we assume it is a "`str`-like" object and wrap it in `Character`. This helps the program take advantage of duck typing as well as polymorphism; as long as an object has a character attribute, it can be used in the `Document` class.

This generic check could be very useful, for example, if we wanted to make a programmer's editor with syntax highlighting: we'd need extra data on the character, such as what type of syntax token the character belongs to. Note that if we are doing a lot of this kind of comparison, it's probably better to implement `Character` as an abstract base class with an appropriate `__subclasshook__`, as discussed in *Chapter 3*, *When Objects Are Alike*.

In addition, we need to modify the string property on `Document` to accept the new `Character` values. All we need to do is call `str()` on each character before we join it:

```
@property
def string(self):
    return "".join((str(c) for c in self.characters))
```

This code uses a generator expression, which we'll discuss in *Chapter 9*, *The Iterator Pattern*. It's a shortcut to perform a specific action on all the objects in a sequence.

Finally, we also need to check `Character.character`, instead of just the string character we were storing before, in the `home` and `end` functions when we're looking to see whether it matches a newline character:

```
def home(self):
    while self.document.characters[
            self.position-1].character != '\n':
        self.position -= 1
        if self.position == 0:
```

```
                # Got to beginning of file before newline
                break

    def end(self):
        while self.position < len(
                self.document.characters) and \
                self.document.characters[
                        self.position
                        ].character != '\n':
            self.position += 1
```

This completes the formatting of characters. We can test it to see that it works:

```
>>> d = Document()
>>> d.insert('h')
>>> d.insert('e')
>>> d.insert(Character('l', bold=True))
>>> d.insert(Character('l', bold=True))
>>> d.insert('o')
>>> d.insert('\n')
>>> d.insert(Character('w', italic=True))
>>> d.insert(Character('o', italic=True))
>>> d.insert(Character('r', underline=True))
>>> d.insert('l')
>>> d.insert('d')
>>> print(d.string)
he*l*lo
/w/o_rld
>>> d.cursor.home()
>>> d.delete()
>>> d.insert('W')
>>> print(d.string)
he*l*lo
W/o_rld
>>> d.characters[0].underline = True
>>> print(d.string)
_he*l*lo
W/o_rld
```

As expected, whenever we print the string, each bold character is preceded by a `*` character, each italic character by a `/` character, and each underlined character by a `_` character. All our functions seem to work, and we can modify characters in the list after the fact. We have a working rich text document object that could be plugged into a proper user interface and hooked up with a keyboard for input and a screen for output. Naturally, we'd want to display real bold, italic, and underlined characters on the screen, instead of using our `__str__` method, but it was sufficient for the basic testing we demanded of it.

Exercises

We've looked at various ways that objects, data, and methods can interact with each other in an object-oriented Python program. As usual, your first thoughts should be how you can apply these principles to your own work. Do you have any messy scripts lying around that could be rewritten using an object-oriented manager? Look through some of your old code and look for methods that are not actions. If the name isn't a verb, try rewriting it as a property.

Think about code you've written in any language. Does it break the DRY principle? Is there any duplicate code? Did you copy and paste code? Did you write two versions of similar pieces of code because you didn't feel like understanding the original code? Go back over some of your recent code now and see whether you can refactor the duplicate code using inheritance or composition. Try to pick a project you're still interested in maintaining; not code so old that you never want to touch it again. It helps keep your interest up when you do the improvements!

Now, look back over some of the examples we saw in this chapter. Start with the cached web page example that uses a property to cache the retrieved data. An obvious problem with this example is that the cache is never refreshed. Add a timeout to the property's getter, and only return the cached page if the page has been requested before the timeout has expired. You can use the `time` module (`time.time() - an_old_time` returns the number of seconds that have elapsed since `an_old_time`) to determine whether the cache has expired.

Now look at the inheritance-based `ZipProcessor`. It might be reasonable to use composition instead of inheritance here. Instead of extending the class in the `ZipReplace` and `ScaleZip` classes, you could pass instances of those classes into the `ZipProcessor` constructor and call them to do the processing part. Implement this.

Which version do you find easier to use? Which is more elegant? What is easier to read? These are subjective questions; the answer varies for each of us. Knowing the answer, however, is important; if you find you prefer inheritance over composition, you have to pay attention that you don't overuse inheritance in your daily coding. If you prefer composition, make sure you don't miss opportunities to create an elegant inheritance-based solution.

Finally, add some error handlers to the various classes we created in the case study. They should ensure single characters are entered, that you don't try to move the cursor past the end or beginning of the file, that you don't delete a character that doesn't exist, and that you don't save a file without a filename. Try to think of as many edge cases as you can, and account for them (thinking about edge cases is about 90 percent of a professional programmer's job!) Consider different ways to handle them; should you raise an exception when the user tries to move past the end of the file, or just stay on the last character?

Pay attention, in your daily coding, to the copy and paste commands. Every time you use them in your editor, consider whether it would be a good idea to improve your program's organization so that you only have one version of the code you are about to copy.

Summary

In this chapter, we focused on identifying objects, especially objects that are not immediately apparent; objects that manage and control. Objects should have both data and behavior, but properties can be used to blur the distinction between the two. The DRY principle is an important indicator of code quality and inheritance and composition can be applied to reduce code duplication.

In the next chapter, we'll cover several of the built-in Python data structures and objects, focusing on their object-oriented properties and how they can be extended or adapted.

6
Python Data Structures

In our examples so far, we've already seen many of the built-in Python data structures in action. You've probably also covered many of them in introductory books or tutorials. In this chapter, we'll be discussing the object-oriented features of these data structures, when they should be used instead of a regular class, and when they should not be used. In particular, we'll be covering:

- Tuples and named tuples
- Dictionaries
- Lists and sets
- How and why to extend built-in objects
- Three types of queues

Empty objects

Let's start with the most basic Python built-in, one that we've seen many times already, the one that we've extended in every class we have created: the `object`. Technically, we can instantiate an `object` without writing a subclass:

```
>>> o = object()
>>> o.x = 5
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
AttributeError: 'object' object has no attribute 'x'
```

Unfortunately, as you can see, it's not possible to set any attributes on an `object` that was instantiated directly. This isn't because the Python developers wanted to force us to write our own classes, or anything so sinister. They did this to save memory; a lot of memory. When Python allows an object to have arbitrary attributes, it takes a certain amount of system memory to keep track of what attributes each object has, for storing both the attribute name and its value. Even if no attributes are stored, memory is allocated for *potential* new attributes. Given the dozens, hundreds, or thousands of objects (every class extends object) in a typical Python program; this small amount of memory would quickly become a large amount of memory. So, Python disables arbitrary properties on `object`, and several other built-ins, by default.

It is possible to restrict arbitrary properties on our own classes using **slots**. Slots are beyond the scope of this book, but you now have a search term if you are looking for more information. In normal use, there isn't much benefit to using slots, but if you're writing an object that will be duplicated thousands of times throughout the system, they can help save memory, just as they do for `object`.

It is, however, trivial to create an empty object class of our own; we saw it in our earliest example:

```
class MyObject:
    pass
```

And, as we've already seen, it's possible to set attributes on such classes:

```
>>> m = MyObject()
>>> m.x = "hello"
>>> m.x
'hello'
```

If we wanted to group properties together, we could store them in an empty object like this. But we are usually better off using other built-ins designed for storing data. It has been stressed throughout this book that classes and objects should only be used when you want to specify *both* data and behaviors. The main reason to write an empty class is to quickly block something out, knowing we'll come back later to add behavior. It is much easier to adapt behaviors to a class than it is to replace a data structure with an object and change all references to it. Therefore, it is important to decide from the outset if the data is just data, or if it is an object in disguise. Once that design decision is made, the rest of the design naturally falls into place.

Tuples and named tuples

Tuples are objects that can store a specific number of other objects in order. They are immutable, so we can't add, remove, or replace objects on the fly. This may seem like a massive restriction, but the truth is, if you need to modify a tuple, you're using the wrong data type (usually a list would be more suitable). The primary benefit of tuples' immutability is that we can use them as keys in dictionaries, and in other locations where an object requires a hash value.

Tuples are used to store data; behavior cannot be stored in a tuple. If we require behavior to manipulate a tuple, we have to pass the tuple into a function (or method on another object) that performs the action.

Tuples should generally store values that are somehow different from each other. For example, we would not put three stock symbols in a tuple, but we might create a tuple of stock symbol, current price, high, and low for the day. The primary purpose of a tuple is to aggregate different pieces of data together into one container. Thus, a tuple can be the easiest tool to replace the "object with no data" idiom.

We can create a tuple by separating the values with a comma. Usually, tuples are wrapped in parentheses to make them easy to read and to separate them from other parts of an expression, but this is not always mandatory. The following two assignments are identical (they record a stock, the current price, the high, and the low for a rather profitable company):

```
>>> stock = "FB", 75.00, 75.03, 74.90
>>> stock2 = ("FB", 75.00, 75.03, 74.90)
```

If we're grouping a tuple inside of some other object, such as a function call, list comprehension, or generator, the parentheses are required. Otherwise, it would be impossible for the interpreter to know whether it is a tuple or the next function parameter. For example, the following function accepts a tuple and a date, and returns a tuple of the date and the middle value between the stock's high and low value:

```
import datetime
def middle(stock, date):
    symbol, current, high, low = stock
    return (((high + low) / 2), date)

mid_value, date = middle(("FB", 75.00, 75.03, 74.90),
        datetime.date(2014, 10, 31))
```

The tuple is created directly inside the function call by separating the values with commas and enclosing the entire tuple in parenthesis. This tuple is then followed by a comma to separate it from the second argument.

This example also illustrates tuple unpacking. The first line inside the function unpacks the `stock` parameter into four different variables. The tuple has to be exactly the same length as the number of variables, or it will raise an exception. We can also see an example of tuple unpacking on the last line, where the tuple returned inside the function is unpacked into two values, `mid_value` and `date`. Granted, this is a strange thing to do, since we supplied the date to the function in the first place, but it gave us a chance to see unpacking at work.

Unpacking is a very useful feature in Python. We can group variables together to make storing and passing them around simpler, but the moment we need to access all of them, we can unpack them into separate variables. Of course, sometimes we only need access to one of the variables in the tuple. We can use the same syntax that we use for other sequence types (lists and strings, for example) to access an individual value:

```
>>> stock = "FB", 75.00, 75.03, 74.90
>>> high = stock[2]
>>> high
75.03
```

We can even use slice notation to extract larger pieces of tuples:

```
>>> stock[1:3]
(75.00, 75.03)
```

These examples, while illustrating how flexible tuples can be, also demonstrate one of their major disadvantages: readability. How does someone reading this code know what is in the second position of a specific tuple? They can guess, from the name of the variable we assigned it to, that it is `high` of some sort, but if we had just accessed the tuple value in a calculation without assigning it, there would be no such indication. They would have to paw through the code to find where the tuple was declared before they could discover what it does.

Accessing tuple members directly is fine in some circumstances, but don't make a habit of it. Such so-called "magic numbers" (numbers that seem to come out of thin air with no apparent meaning within the code) are the source of many coding errors and lead to hours of frustrated debugging. Try to use tuples only when you know that all the values are going to be useful at once and it's normally going to be unpacked when it is accessed. If you have to access a member directly or using a slice and the purpose of that value is not immediately obvious, at least include a comment explaining where it came from.

Named tuples

So, what do we do when we want to group values together, but know we're frequently going to need to access them individually? Well, we could use an empty object, as discussed in the previous section (but that is rarely useful unless we anticipate adding behavior later), or we could use a dictionary (most useful if we don't know exactly how many or which specific data will be stored), as we'll cover in the next section.

If, however, we do not need to add behavior to the object, and we know in advance what attributes we need to store, we can use a named tuple. Named tuples are tuples with attitude. They are a great way to group read-only data together.

Constructing a named tuple takes a bit more work than a normal tuple. First, we have to import `namedtuple`, as it is not in the namespace by default. Then, we describe the named tuple by giving it a name and outlining its attributes. This returns a class-like object that we can instantiate with the required values as many times as we want:

```
from collections import namedtuple
Stock = namedtuple("Stock", "symbol current high low")
stock = Stock("FB", 75.00, high=75.03, low=74.90)
```

The `namedtuple` constructor accepts two arguments. The first is an identifier for the named tuple. The second is a string of space-separated attributes that the named tuple can have. The first attribute should be listed, followed by a space (or comma if you prefer), then the second attribute, then another space, and so on. The result is an object that can be called just like a normal class to instantiate other objects. The constructor must have exactly the right number of arguments that can be passed in as arguments or keyword arguments. As with normal objects, we can create as many instances of this "class" as we like, with different values for each.

The resulting `namedtuple` can then be packed, unpacked, and otherwise treated like a normal tuple, but we can also access individual attributes on it as if it were an object:

```
>>> stock.high
75.03
>>> symbol, current, high, low = stock
>>> current
75.00
```

Remember that creating named tuples is a two-step process. First, use `collections.namedtuple` to create a class, and then construct instances of that class.

Named tuples are perfect for many "data only" representations, but they are not ideal for all situations. Like tuples and strings, named tuples are immutable, so we cannot modify an attribute once it has been set. For example, the current value of my company's stock has gone down since we started this discussion, but we can't set the new value:

```
>>> stock.current = 74.98
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
AttributeError: can't set attribute
```

If we need to be able to change stored data, a dictionary may be what we need instead.

Dictionaries

Dictionaries are incredibly useful containers that allow us to map objects directly to other objects. An empty object with attributes to it is a sort of dictionary; the names of the properties map to the property values. This is actually closer to the truth than it sounds; internally, objects normally represent attributes as a dictionary, where the values are properties or methods on the objects (see the `__dict__` attribute if you don't believe me). Even the attributes on a module are stored, internally, in a dictionary.

Dictionaries are extremely efficient at looking up a value, given a specific key object that maps to that value. They should always be used when you want to find one object based on some other object. The object that is being stored is called the **value**; the object that is being used as an index is called the **key**. We've already seen dictionary syntax in some of our previous examples.

Dictionaries can be created either using the `dict()` constructor or using the `{}` syntax shortcut. In practice, the latter format is almost always used. We can prepopulate a dictionary by separating the keys from the values using a colon, and separating the key value pairs using a comma.

For example, in a stock application, we would most often want to look up prices by the stock symbol. We can create a dictionary that uses stock symbols as keys, and tuples of current, high, and low as values like this:

```
stocks = {"GOOG": (613.30, 625.86, 610.50),
          "MSFT": (30.25, 30.70, 30.19)}
```

As we've seen in previous examples, we can then look up values in the dictionary by requesting a key inside square brackets. If the key is not in the dictionary, it will raise an exception:

```
>>> stocks["GOOG"]
(613.3, 625.86, 610.5)
>>> stocks["RIM"]
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
KeyError: 'RIM'
```

We can, of course, catch the `KeyError` and handle it. But we have other options. Remember, dictionaries are objects, even if their primary purpose is to hold other objects. As such, they have several behaviors associated with them. One of the most useful of these methods is the `get` method; it accepts a key as the first parameter and an optional default value if the key doesn't exist:

```
>>> print(stocks.get("RIM"))
None
>>> stocks.get("RIM", "NOT FOUND")
'NOT FOUND'
```

For even more control, we can use the `setdefault` method. If the key is in the dictionary, this method behaves just like `get`; it returns the value for that key. Otherwise, if the key is not in the dictionary, it will not only return the default value we supply in the method call (just like `get` does), it will also set the key to that same value. Another way to think of it is that `setdefault` sets a value in the dictionary only if that value has not previously been set. Then it returns the value in the dictionary, either the one that was already there, or the newly provided default value.

```
>>> stocks.setdefault("GOOG", "INVALID")
(613.3, 625.86, 610.5)
>>> stocks.setdefault("BBRY", (10.50, 10.62, 10.39))
(10.50, 10.62, 10.39)
>>> stocks["BBRY"]
(10.50, 10.62, 10.39)
```

The `GOOG` stock was already in the dictionary, so when we tried to `setdefault` it to an invalid value, it just returned the value already in the dictionary. `BBRY` was not in the dictionary, so `setdefault` returned the default value and set the new value in the dictionary for us. We then check that the new stock is, indeed, in the dictionary.

Three other very useful dictionary methods are `keys()`, `values()`, and `items()`. The first two return an iterator over all the keys and all the values in the dictionary. We can use these like lists or in `for` loops if we want to process all the keys or values. The `items()` method is probably the most useful; it returns an iterator over tuples of `(key, value)` pairs for every item in the dictionary. This works great with tuple unpacking in a `for` loop to loop over associated keys and values. This example does just that to print each stock in the dictionary with its current value:

```
>>> for stock, values in stocks.items():
...     print("{} last value is {}".format(stock, values[0]))
...
GOOG last value is 613.3
BBRY last value is 10.50
MSFT last value is 30.25
```

Each key/value tuple is unpacked into two variables named `stock` and `values` (we could use any variable names we wanted, but these both seem appropriate) and then printed in a formatted string.

Notice that the stocks do not show up in the same order in which they were inserted. Dictionaries, due to the efficient algorithm (known as hashing) that is used to make key lookup so fast, are inherently unsorted.

So, there are numerous ways to retrieve data from a dictionary once it has been instantiated; we can use square brackets as index syntax, the `get` method, the `setdefault` method, or iterate over the `items` method, among others.

Finally, as you likely already know, we can set a value in a dictionary using the same indexing syntax we use to retrieve a value:

```
>>> stocks["GOOG"] = (597.63, 610.00, 596.28)
>>> stocks['GOOG']
(597.63, 610.0, 596.28)
```

Google's price is lower today, so I've updated the tuple value in the dictionary. We can use this index syntax to set a value for any key, regardless of whether the key is in the dictionary. If it is in the dictionary, the old value will be replaced with the new one; otherwise, a new key/value pair will be created.

We've been using strings as dictionary keys, so far, but we aren't limited to string keys. It is common to use strings as keys, especially when we're storing data in a dictionary to gather it together (instead of using an object with named properties). But we can also use tuples, numbers, or even objects we've defined ourselves as dictionary keys. We can even use different types of keys in a single dictionary:

```
random_keys = {}
random_keys["astring"] = "somestring"
random_keys[5] = "aninteger"
random_keys[25.2] = "floats work too"
random_keys[("abc", 123)] = "so do tuples"

class AnObject:
    def __init__(self, avalue):
        self.avalue = avalue

my_object = AnObject(14)
random_keys[my_object] = "We can even store objects"
my_object.avalue = 12
try:
    random_keys[[1,2,3]] = "we can't store lists though"
except:
    print("unable to store list\n")

for key, value in random_keys.items():
    print("{} has value {}".format(key, value))
```

This code shows several different types of keys we can supply to a dictionary. It also shows one type of object that cannot be used. We've already used lists extensively, and we'll be seeing many more details of them in the next section. Because lists can change at any time (by adding or removing items, for example), they cannot hash to a specific value.

Objects that are **hashable** basically have a defined algorithm that converts the object into a unique integer value for rapid lookup. This hash is what is actually used to look up values in a dictionary. For example, strings map to integers based on the characters in the string, while tuples combine hashes of the items inside the tuple. Any two objects that are somehow considered equal (like strings with the same characters or tuples with the same values) should have the same hash value, and the hash value for an object should never ever change. Lists, however, can have their contents changed, which would change their hash value (two lists should only be equal if their contents are the same). Because of this, they can't be used as dictionary keys. For the same reason, dictionaries cannot be used as keys into other dictionaries.

In contrast, there are no limits on the types of objects that can be used as dictionary values. We can use a string key that maps to a list value, for example, or we can have a nested dictionary as a value in another dictionary.

Dictionary use cases

Dictionaries are extremely versatile and have numerous uses. There are two major ways that dictionaries can be used. The first is dictionaries where all the keys represent different instances of similar objects; for example, our stock dictionary. This is an indexing system. We use the stock symbol as an index to the values. The values could even have been complicated self-defined objects that made buy and sell decisions or set a stop-loss, rather than our simple tuples.

The second design is dictionaries where each key represents some aspect of a single structure; in this case, we'd probably use a separate dictionary for each object, and they'd all have similar (though often not identical) sets of keys. This latter situation can often also be solved with named tuples. These should typically be used when we know exactly what attributes the data must store, and we know that all pieces of the data must be supplied at once (when the item is constructed). But if we need to create or change dictionary keys over time or we don't know exactly what the keys might be, a dictionary is more suitable.

Using defaultdict

We've seen how to use `setdefault` to set a default value if a key doesn't exist, but this can get a bit monotonous if we need to set a default value every time we look up a value. For example, if we're writing code that counts the number of times a letter occurs in a given sentence, we could do this:

```
def letter_frequency(sentence):
    frequencies = {}
    for letter in sentence:
        frequency = frequencies.setdefault(letter, 0)
        frequencies[letter] = frequency + 1
    return frequencies
```

Every time we access the dictionary, we need to check that it has a value already, and if not, set it to zero. When something like this needs to be done every time an empty key is requested, we can use a different version of the dictionary, called `defaultdict`:

```
from collections import defaultdict
def letter_frequency(sentence):
    frequencies = defaultdict(int)
```

```
    for letter in sentence:
        frequencies[letter] += 1
    return frequencies
```

This code looks like it couldn't possibly work. The `defaultdict` accepts a function in its constructor. Whenever a key is accessed that is not already in the dictionary, it calls that function, with no parameters, to create a default value.

In this case, the function it calls is `int`, which is the constructor for an integer object. Normally, integers are created simply by typing an integer number into our code, and if we do create one using the `int` constructor, we pass it the item we want to create (for example, to convert a string of digits into an integer). But if we call `int` without any arguments, it returns, conveniently, the number zero. In this code, if the letter doesn't exist in the `defaultdict`, the number zero is returned when we access it. Then we add one to this number to indicate we've found an instance of that letter, and the next time we find one, that number will be returned and we can increment the value again.

The `defaultdict` is useful for creating dictionaries of containers. If we want to create a dictionary of stock prices for the past 30 days, we could use a stock symbol as the key and store the prices in `list`; the first time we access the stock price, we would want it to create an empty list. Simply pass `list` into the `defaultdict`, and it will be called every time an empty key is accessed. We can do similar things with sets or even empty dictionaries if we want to associate one with a key.

Of course, we can also write our own functions and pass them into the `defaultdict`. Suppose we want to create a `defaultdict` where each new element contains a tuple of the number of items inserted into the dictionary at that time and an empty list to hold other things. Nobody knows why we would want to create such an object, but let's have a look:

```
from collections import defaultdict
num_items = 0
def tuple_counter():
    global num_items
    num_items += 1
    return (num_items, [])

d = defaultdict(tuple_counter)
```

When we run this code, we can access empty keys and insert into the list all in one statement:

```
>>> d = defaultdict(tuple_counter)
>>> d['a'][1].append("hello")
>>> d['b'][1].append('world')
```

```
>>> d
defaultdict(<function tuple_counter at 0x82f2c6c>,
{'a': (1, ['hello']), 'b': (2, ['world'])})
```

When we print `dict` at the end, we see that the counter really was working.

This example, while succinctly demonstrating how to create our own function for `defaultdict`, is not actually very good code; using a global variable means that if we created four different `defaultdict` segments that each used `tuple_counter`, it would count the number of entries in all dictionaries, rather than having a different count for each one. It would be better to create a class and pass a method on that class to `defaultdict`.

Counter

You'd think that you couldn't get much simpler than `defaultdict(int)`, but the "I want to count specific instances in an iterable" use case is common enough that the Python developers created a specific class for it. The previous code that counts characters in a string can easily be calculated in a single line:

```
from collections import Counter
def letter_frequency(sentence):
    return Counter(sentence)
```

The `Counter` object behaves like a beefed up dictionary where the keys are the items being counted and the values are the number of such items. One of the most useful functions is the `most_common()` method. It returns a list of (key, count) tuples ordered by the count. You can optionally pass an integer argument into `most_common()` to request only the top most common elements. For example, you could write a simple polling application as follows:

```
from collections import Counter

responses = [
    "vanilla",
    "chocolate",
    "vanilla",
    "vanilla",
    "caramel",
    "strawberry",
    "vanilla"
]

print(
```

```
        "The children voted for {} ice cream".format(
            Counter(responses).most_common(1)[0][0]
        )
    )
```

Presumably, you'd get the responses from a database or by using a complicated vision algorithm to count the kids who raised their hands. Here, we hardcode it so that we can test the `most_common` method. It returns a list that has only one element (because we requested one element in the parameter). This element stores the name of the top choice at position zero, hence the double `[0][0]` at the end of the call. I think they look like a surprised face, don't you? Your computer is probably amazed it can count data so easily. It's ancestor, Hollerith's Tabulating Machine for the 1890 US census, must be so jealous!

Lists

Lists are the least object-oriented of Python's data structures. While lists are, themselves, objects, there is a lot of syntax in Python to make using them as painless as possible. Unlike many other object-oriented languages, lists in Python are simply available. We don't need to import them and rarely need to call methods on them. We can loop over a list without explicitly requesting an iterator object, and we can construct a list (as with a dictionary) with custom syntax. Further, list comprehensions and generator expressions turn them into a veritable Swiss-army knife of computing functionality.

We won't go into too much detail of the syntax; you've seen it in introductory tutorials across the Web and in previous examples in this book. You can't code Python very long without learning how to use lists! Instead, we'll be covering when lists should be used, and their nature as objects. If you don't know how to create or append to a list, how to retrieve items from a list, or what "slice notation" is, I direct you to the official Python tutorial, post-haste. It can be found online at `http://docs.python.org/3/tutorial/`.

In Python, lists should normally be used when we want to store several instances of the "same" type of object; lists of strings or lists of numbers; most often, lists of objects we've defined ourselves. Lists should always be used when we want to store items in some kind of order. Often, this is the order in which they were inserted, but they can also be sorted by some criteria.

As we saw in the case study from the previous chapter, lists are also very useful when we need to modify the contents: insert to or delete from an arbitrary location of the list, or update a value within the list.

Like dictionaries, Python lists use an extremely efficient and well-tuned internal data structure so we can worry about what we're storing, rather than how we're storing it. Many object-oriented languages provide different data structures for queues, stacks, linked lists, and array-based lists. Python does provide special instances of some of these classes, if optimizing access to huge sets of data is required. Normally, however, the list data structure can serve all these purposes at once, and the coder has complete control over how they access it.

Don't use lists for collecting different attributes of individual items. We do not want, for example, a list of the properties a particular shape has. Tuples, named tuples, dictionaries, and objects would all be more suitable for this purpose. In some languages, they might create a list in which each alternate item is a different type; for example, they might write `['a', 1, 'b', 3]` for our letter frequency list. They'd have to use a strange loop that accesses two elements in the list at once or a modulus operator to determine which position was being accessed.

Don't do this in Python. We can group related items together using a dictionary, as we did in the previous section (if sort order doesn't matter), or using a list of tuples. Here's a rather convoluted example that demonstrates how we could do the frequency example using a list. It is much more complicated than the dictionary examples, and illustrates the effect choosing the right (or wrong) data structure can have on the readability of our code:

```
import string
CHARACTERS  = list(string.ascii_letters) + [" "]

def letter_frequency(sentence):
    frequencies = [(c, 0) for c in CHARACTERS]
    for letter in sentence:
        index = CHARACTERS.index(letter)
        frequencies[index] = (letter,frequencies[index][1]+1)
    return frequencies
```

This code starts with a list of possible characters. The `string.ascii_letters` attribute provides a string of all the letters, lowercase and uppercase, in order. We convert this to a list, and then use list concatenation (the plus operator causes two lists to be merged into one) to add one more character, the space. These are the available characters in our frequency list (the code would break if we tried to add a letter that wasn't in the list, but an exception handler could solve this).

The first line inside the function uses a list comprehension to turn the `CHARACTERS` list into a list of tuples. List comprehensions are an important, non-object-oriented tool in Python; we'll be covering them in detail in the next chapter.

Then we loop over each of the characters in the sentence. We first look up the index of the character in the `CHARACTERS` list, which we know has the same index in our frequencies list, since we just created the second list from the first. We then update that index in the frequencies list by creating a new tuple, discarding the original one. Aside from the garbage collection and memory waste concerns, this is rather difficult to read!

Like dictionaries, lists are objects too, and they have several methods that can be invoked upon them. Here are some common ones:

- The `append(element)` method adds an element to the end of the list
- The `insert(index, element)` method inserts an item at a specific position
- The `count(element)` method tells us how many times an element appears in the list
- The `index()` method tells us the index of an item in the list, raising an exception if it can't find it
- The `find()` method does the same thing, but returns `-1` instead of raising an exception for missing items
- The `reverse()` method does exactly what it says—turns the list around
- The `sort()` method has some rather intricate object-oriented behaviors, which we'll cover now

Sorting lists

Without any parameters, `sort` will generally do the expected thing. If it's a list of strings, it will place them in alphabetical order. This operation is case sensitive, so all capital letters will be sorted before lowercase letters, that is `Z` comes before `a`. If it is a list of numbers, they will be sorted in numerical order. If a list of tuples is provided, the list is sorted by the first element in each tuple. If a mixture containing unsortable items is supplied, the sort will raise a `TypeError` exception.

If we want to place objects we define ourselves into a list and make those objects sortable, we have to do a bit more work. The special method `__lt__`, which stands for "less than", should be defined on the class to make instances of that class comparable. The `sort` method on list will access this method on each object to determine where it goes in the list. This method should return `True` if our class is somehow less than the passed parameter, and `False` otherwise. Here's a rather silly class that can be sorted based on either a string or a number:

```
class WeirdSortee:
    def __init__(self, string, number, sort_num):
        self.string = string
        self.number = number
        self.sort_num = sort_num

    def __lt__(self, object):
        if self.sort_num:
            return self.number < object.number
        return self.string < object.string

    def __repr__(self):
        return"{}:{}".format(self.string, self.number)
```

The `__repr__` method makes it easy to see the two values when we print a list. The `__lt__` method's implementation compares the object to another instance of the same class (or any duck typed object that has `string`, `number`, and `sort_num` attributes; it will fail if those attributes are missing). The following output illustrates this class in action, when it comes to sorting:

```
>>> a = WeirdSortee('a', 4, True)
>>> b = WeirdSortee('b', 3, True)
>>> c = WeirdSortee('c', 2, True)
>>> d = WeirdSortee('d', 1, True)
>>> l = [a,b,c,d]
>>> l
[a:4, b:3, c:2, d:1]
>>> l.sort()
>>> l
[d:1, c:2, b:3, a:4]
```

```
>>> for i in l:
...     i.sort_num = False
...
>>> l.sort()
>>> l
[a:4, b:3, c:2, d:1]
```

The first time we call `sort`, it sorts by numbers because `sort_num` is `True` on all the objects being compared. The second time, it sorts by letters. The `__lt__` method is the only one we need to implement to enable sorting. Technically, however, if it is implemented, the class should normally also implement the similar `__gt__`, `__eq__`, `__ne__`, `__ge__`, and `__le__` methods so that all of the `<`, `>`, `==`, `!=`, `>=`, and `<=` operators also work properly. You can get this for free by implementing `__lt__` and `__eq__`, and then applying the `@total_ordering` class decorator to supply the rest:

```
from functools import total_ordering

@total_ordering
class WeirdSortee:
    def __init__(self, string, number, sort_num):
        self.string = string
        self.number = number
        self.sort_num = sort_num

    def __lt__(self, object):
        if self.sort_num:
            return self.number < object.number
        return self.string < object.string

    def __repr__(self):
        return"{}:{}".format(self.string, self.number)

    def __eq__(self, object):
        return all((
            self.string == object.string,
            self.number == object.number,
            self.sort_num == object.number
        ))
```

This is useful if we want to be able to use operators on our objects. However, if all we want to do is customize our sort orders, even this is overkill. For such a use case, the `sort` method can take an optional `key` argument. This argument is a function that can translate each object in a list into an object that can somehow be compared. For example, we can use `str.lower` as the key argument to perform a case-insensitive sort on a list of strings:

```
>>> l = ["hello", "HELP", "Helo"]
>>> l.sort()
>>> l
['HELP', 'Helo', 'hello']
>>> l.sort(key=str.lower)
>>> l
['hello', 'Helo', 'HELP']
```

Remember, even though `lower` is a method on string objects, it is also a function that can accept a single argument, `self`. In other words, `str.lower(item)` is equivalent to `item.lower()`. When we pass this function as a key, it performs the comparison on lowercase values instead of doing the default case-sensitive comparison.

There are a few sort key operations that are so common that the Python team has supplied them so you don't have to write them yourself. For example, it is often common to sort a list of tuples by something other than the first item in the list. The `operator.itemgetter` method can be used as a key to do this:

```
>>> from operator import itemgetter
>>> l = [('h', 4), ('n', 6), ('o', 5), ('p', 1), ('t', 3), ('y', 2)]
>>> l.sort(key=itemgetter(1))
>>> l
[('p', 1), ('y', 2), ('t', 3), ('h', 4), ('o', 5), ('n', 6)]
```

The `itemgetter` function is the most commonly used one (it works if the objects are dictionaries, too), but you will sometimes find use for `attrgetter` and `methodcaller`, which return attributes on an object and the results of method calls on objects for the same purpose. See the `operator` module documentation for more information.

Sets

Lists are extremely versatile tools that suit most container object applications. But they are not useful when we want to ensure objects in the list are unique. For example, a song library may contain many songs by the same artist. If we want to sort through the library and create a list of all the artists, we would have to check the list to see if we've added the artist already, before we add them again.

This is where sets come in. Sets come from mathematics, where they represent an unordered group of (usually) unique numbers. We can add a number to a set five times, but it will show up in the set only once.

In Python, sets can hold any hashable object, not just numbers. Hashable objects are the same objects that can be used as keys in dictionaries; so again, lists and dictionaries are out. Like mathematical sets, they can store only one copy of each object. So if we're trying to create a list of song artists, we can create a set of string names and simply add them to the set. This example starts with a list of (song, artist) tuples and creates a set of the artists:

```
song_library = [("Phantom Of The Opera", "Sarah Brightman"),
        ("Knocking On Heaven's Door", "Guns N' Roses"),
        ("Captain Nemo", "Sarah Brightman"),
        ("Patterns In The Ivy", "Opeth"),
        ("November Rain", "Guns N' Roses"),
        ("Beautiful", "Sarah Brightman"),
        ("Mal's Song", "Vixy and Tony")]

artists = set()
for song, artist in song_library:
    artists.add(artist)

print(artists)
```

There is no built-in syntax for an empty set as there is for lists and dictionaries; we create a set using the `set()` constructor. However, we can use the curly braces (borrowed from dictionary syntax) to create a set, so long as the set contains values. If we use colons to separate pairs of values, it's a dictionary, as in `{'key': 'value', 'key2': 'value2'}`. If we just separate values with commas, it's a set, as in `{'value', 'value2'}`. Items can be added individually to the set using its `add` method. If we run this script, we see that the set works as advertised:

```
{'Sarah Brightman', "Guns N' Roses", 'Vixy and Tony', 'Opeth'}
```

If you're paying attention to the output, you'll notice that the items are not printed in the order they were added to the sets. Sets, like dictionaries, are unordered. They both use an underlying hash-based data structure for efficiency. Because they are unordered, sets cannot have items looked up by index. The primary purpose of a set is to divide the world into two groups: "things that are in the set", and, "things that are not in the set". It is easy to check whether an item is in the set or to loop over the items in a set, but if we want to sort or order them, we'll have to convert the set to a list. This output shows all three of these activities:

```
>>> "Opeth" in artists
True
>>> for artist in artists:
...     print("{} plays good music".format(artist))
...
Sarah Brightman plays good music
Guns N' Roses plays good music
Vixy and Tony play good music
Opeth plays good music
>>> alphabetical = list(artists)
>>> alphabetical.sort()
>>> alphabetical
["Guns N' Roses", 'Opeth', 'Sarah Brightman', 'Vixy and Tony']
```

While the primary *feature* of a set is uniqueness, that is not its primary *purpose*. Sets are most useful when two or more of them are used in combination. Most of the methods on the set type operate on other sets, allowing us to efficiently combine or compare the items in two or more sets. These methods have strange names, since they use the same terminology used in mathematics. We'll start with three methods that return the same result, regardless of which is the calling set and which is the called set.

The `union` method is the most common and easiest to understand. It takes a second set as a parameter and returns a new set that contains all elements that are in *either* of the two sets; if an element is in both original sets, it will, of course, only show up once in the new set. Union is like a logical `or` operation, indeed, the `|` operator can be used on two sets to perform the union operation, if you don't like calling methods.

Conversely, the intersection method accepts a second set and returns a new set that contains only those elements that are in *both* sets. It is like a logical `and` operation, and can also be referenced using the `&` operator.

Finally, the `symmetric_difference` method tells us what's left; it is the set of objects that are in one set or the other, but not both. The following example illustrates these methods by comparing some artists from my song library to those in my sister's:

```
my_artists = {"Sarah Brightman", "Guns N' Roses",
        "Opeth", "Vixy and Tony"}

auburns_artists = {"Nickelback", "Guns N' Roses",
        "Savage Garden"}

print("All: {}".format(my_artists.union(auburns_artists)))
print("Both: {}".format(auburns_artists.intersection(my_artists)))
print("Either but not both: {}".format(
    my_artists.symmetric_difference(auburns_artists)))
```

If we run this code, we see that these three methods do what the print statements suggest they will do:

```
All: {'Sarah Brightman', "Guns N' Roses", 'Vixy and Tony',
'Savage Garden', 'Opeth', 'Nickelback'}
Both: {"Guns N' Roses"}
Either but not both: {'Savage Garden', 'Opeth', 'Nickelback',
'Sarah Brightman', 'Vixy and Tony'}
```

These methods all return the same result, regardless of which set calls the other. We can say `my_artists.union(auburns_artists)` or `auburns_artists.union(my_artists)` and get the same result. There are also methods that return different results depending on who is the caller and who is the argument.

These methods include `issubset` and `issuperset`, which are the inverse of each other. Both return a `bool`. The `issubset` method returns `True`, if all of the items in the calling set are also in the set passed as an argument. The `issuperset` method returns `True` if all of the items in the argument are also in the calling set. Thus `s.issubset(t)` and `t.issuperset(s)` are identical. They will both return `True` if `t` contains all the elements in `s`.

Finally, the `difference` method returns all the elements that are in the calling set, but not in the set passed as an argument; this is like half a `symmetric_difference`. The `difference` method can also be represented by the `-` operator. The following code illustrates these methods in action:

```
my_artists = {"Sarah Brightman", "Guns N' Roses",
        "Opeth", "Vixy and Tony"}

bands = {"Guns N' Roses", "Opeth"}

print("my_artists is to bands:")
print("issuperset: {}".format(my_artists.issuperset(bands)))
print("issubset: {}".format(my_artists.issubset(bands)))
print("difference: {}".format(my_artists.difference(bands)))
print("*"*20)
print("bands is to my_artists:")
print("issuperset: {}".format(bands.issuperset(my_artists)))
print("issubset: {}".format(bands.issubset(my_artists)))
print("difference: {}".format(bands.difference(my_artists)))
```

This code simply prints out the response of each method when called from one set on the other. Running it gives us the following output:

```
my_artists is to bands:
issuperset: True
issubset: False
difference: {'Sarah Brightman', 'Vixy and Tony'}
********************
bands is to my_artists:
issuperset: False
issubset: True
difference: set()
```

The `difference` method, in the second case, returns an empty set, since there are no items in `bands` that are not in `my_artists`.

The `union`, `intersection`, and `difference` methods can all take multiple sets as arguments; they will return, as we might expect, the set that is created when the operation is called on all the parameters.

So the methods on sets clearly suggest that sets are meant to operate on other sets, and that they are not just containers. If we have data coming in from two different sources and need to quickly combine them in some way, to determine where the data overlaps or is different, we can use set operations to efficiently compare them. Or if we have data incoming that may contain duplicates of data that has already been processed, we can use sets to compare the two and process only the new data.

Finally, it is valuable to know that sets are much more efficient than lists when checking for membership using the `in` keyword. If you use the syntax `value in container` on a set or a list, it will return `True` if one of the elements in `container` is equal to `value` and `False` otherwise. However, in a list, it will look at every object in the container until it finds the value, whereas in a set, it simply hashes the value and checks for membership. This means that a set will find the value in the same amount of time no matter how big the container is, but a list will take longer and longer to search for a value as the list contains more and more values.

Extending built-ins

We discussed briefly in *Chapter 3*, *When Objects Are Alike*, how built-in data types can be extended using inheritance. Now, we'll go into more detail as to when we would want to do that.

When we have a built-in container object that we want to add functionality to, we have two options. We can either create a new object, which holds that container as an attribute (composition), or we can subclass the built-in object and add or adapt methods on it to do what we want (inheritance).

Composition is usually the best alternative if all we want to do is use the container to store some objects using that container's features. That way, it's easy to pass that data structure into other methods and they will know how to interact with it. But we need to use inheritance if we want to change the way the container actually works. For example, if we want to ensure every item in a `list` is a string with exactly five characters, we need to extend `list` and override the `append()` method to raise an exception for invalid input. We'd also minimally have to override `__setitem__(self, index, value)`, a special method on lists that is called whenever we use the `x[index] = "value"` syntax, and the `extend()` method.

Yes, lists are objects. All that special non-object-oriented looking syntax we've been looking at for accessing lists or dictionary keys, looping over containers, and similar tasks is actually "syntactic sugar" that maps to an object-oriented paradigm underneath. We might ask the Python designers why they did this. Isn't object-oriented programming *always* better? That question is easy to answer. In the following hypothetical examples, which is easier to read, as a programmer? Which requires less typing?

```
c = a + b
c = a.add(b)

l[0] = 5
l.setitem(0, 5)
d[key] = value
d.setitem(key, value)

for x in alist:
    #do something with x
it = alist.iterator()
while it.has_next():
    x = it.next()
    #do something with x
```

The highlighted sections show what object-oriented code might look like (in practice, these methods actually exist as special double-underscore methods on associated objects). Python programmers agree that the non-object-oriented syntax is easier both to read and to write. Yet all of the preceding Python syntaxes map to object-oriented methods underneath the hood. These methods have special names (with double-underscores before and after) to remind us that there is a better syntax out there. However, it gives us the means to override these behaviors. For example, we can make a special integer that always returns `0` when we add two of them together:

```
class SillyInt(int):
    def __add__(self, num):
        return 0
```

This is an extremely bizarre thing to do, granted, but it perfectly illustrates these object-oriented principles in action:

```
>>> a = SillyInt(1)
>>> b = SillyInt(2)
>>> a + b
0
```

The awesome thing about the `__add__` method is that we can add it to any class we write, and if we use the `+` operator on instances of that class, it will be called. This is how string, tuple, and list concatenation works, for example.

This is true of all the special methods. If we want to use `x in myobj` syntax for a custom-defined object, we can implement `__contains__`. If we want to use `myobj[i] = value` syntax, we supply a `__setitem__` method and if we want to use `something = myobj[i]`, we implement `__getitem__`.

There are 33 of these special methods on the `list` class. We can use the `dir` function to see all of them:

```
>>> dir(list)


['__add__', '__class__', '__contains__', '__delattr__','__delitem__',
'__doc__', '__eq__', '__format__', '__ge__', '__getattribute__', '__
getitem__', '__gt__', '__hash__', '__iadd__', '__imul__', '__init__',
'__iter__', '__le__', '__len__', '__lt__', '__mul__', '__ne__', '__
new__', '__reduce__', '__reduce_ex__', '__repr__', '__reversed__',
'__rmul__', '__setattr__', '__setitem__', '__sizeof__', '__str__', '__
subclasshook__', 'append', 'count', 'extend', 'index', 'insert', 'pop',
'remove', 'reverse', 'sort'
```

Further, if we desire additional information on how any of these methods works, we can use the `help` function:

```
>>> help(list.__add__)
Help on wrapper_descriptor:


__add__(self, value, /)
    Return self+value.
```

The plus operator on lists concatenates two lists. We don't have room to discuss all of the available special functions in this book, but you are now able to explore all this functionality with `dir` and `help`. The official online Python reference (`https://docs.python.org/3/`) has plenty of useful information as well. Focus, especially, on the abstract base classes discussed in the `collections` module.

So, to get back to the earlier point about when we would want to use composition versus inheritance: if we need to somehow change any of the methods on the class—including the special methods—we definitely need to use inheritance. If we used composition, we could write methods that do the validation or alterations and ask the caller to use those methods, but there is nothing stopping them from accessing the property directly. They could insert an item into our list that does not have five characters, and that might confuse other methods in the list.

Often, the need to extend a built-in data type is an indication that we're using the wrong sort of data type. It is not always the case, but if we are looking to extend a built-in, we should carefully consider whether or not a different data structure would be more suitable.

For example, consider what it takes to create a dictionary that remembers the order in which keys were inserted. One way to do this is to keep an ordered list of keys that is stored in a specially derived subclass of `dict`. Then we can override the methods `keys`, `values`, `__iter__`, and `items` to return everything in order. Of course, we'll also have to override `__setitem__` and `setdefault` to keep our list up to date. There are likely to be a few other methods in the output of `dir(dict)` that need overriding to keep the list and dictionary consistent (`clear` and `__delitem__` come to mind, to track when items are removed), but we won't worry about them for this example.

So we'll be extending `dict` and adding a list of ordered keys. Trivial enough, but where do we create the actual list? We could include it in the `__init__` method, which would work just fine, but we have no guarantees that any subclass will call that initializer. Remember the `__new__` method we discussed in *Chapter 2*, *Objects in Python*? I said it was generally only useful in very special cases. This is one of those special cases. We know `__new__` will be called exactly once, and we can create a list on the new instance that will always be available to our class. With that in mind, here is our entire sorted dictionary:

```
from collections import KeysView, ItemsView, ValuesView
class DictSorted(dict):
    def __new__(*args, **kwargs):
        new_dict = dict.__new__(*args, **kwargs)
        new_dict.ordered_keys = []
        return new_dict

    def __setitem__(self, key, value):
        '''self[key] = value syntax'''
        if key not in self.ordered_keys:
            self.ordered_keys.append(key)
        super().__setitem__(key, value)

    def setdefault(self, key, value):
        if key not in self.ordered_keys:
            self.ordered_keys.append(key)
        return super().setdefault(key, value)

    def keys(self):
        return KeysView(self)

    def values(self):
```

```
        return ValuesView(self)

    def items(self):
        return ItemsView(self)

    def __iter__(self):
        '''for x in self syntax'''
        return self.ordered_keys.__iter__()
```

The `__new__` method creates a new dictionary and then puts an empty list on that object. We don't override `__init__`, as the default implementation works (actually, this is only true if we initialize an empty `DictSorted` object, which is standard behavior. If we want to support other variations of the `dict` constructor, which accept dictionaries or lists of tuples, we'd need to fix `__init__` to also update our `ordered_keys` list). The two methods for setting items are very similar; they both update the list of keys, but only if the item hasn't been added before. We don't want duplicates in the list, but we can't use a set here; it's unordered!

The `keys`, `items`, and `values` methods all return views onto the dictionary. The collections library provides three read-only `View` objects onto the dictionary; they use the `__iter__` method to loop over the keys, and then use `__getitem__` (which we didn't need to override) to retrieve the values. So, we only need to define our custom `__iter__` method to make these three views work. You would think the superclass would create these views properly using polymorphism, but if we don't override these three methods, they don't return properly ordered views.

Finally, the `__iter__` method is the really special one; it ensures that if we loop over the dictionary's keys (using `for...in` syntax), it will return the values in the correct order. It does this by returning the `__iter__` of the `ordered_keys` list, which returns the same iterator object that would be used if we used `for...in` on the list instead. Since `ordered_keys` is a list of all available keys (due to the way we overrode other methods), this is the correct iterator object for the dictionary as well.

Let's look at a few of these methods in action, compared to a normal dictionary:

```
>>> ds = DictSorted()
>>> d = {}
>>> ds['a'] = 1
>>> ds['b'] = 2
>>> ds.setdefault('c', 3)
3
>>> d['a'] = 1
>>> d['b'] = 2
>>> d.setdefault('c', 3)
3
```

```
>>> for k,v in ds.items():
...     print(k,v)
...
a 1
b 2
c 3
>>> for k,v in d.items():
...     print(k,v)
...
a 1
c 3
b 2
```

Ah, our dictionary is sorted and the normal dictionary is not. Hurray!

If you wanted to use this class in production, you'd have to override several other special methods to ensure the keys are up to date in all cases. However, you don't need to do this; the functionality this class provides is already available in Python, using the `OrderedDict` object in the `collections` module. Try importing the class from `collections`, and use `help(OrderedDict)` to find out more about it.

Queues

Queues are peculiar data structures because, like sets, their functionality can be handled entirely using lists. However, while lists are extremely versatile general-purpose tools, they are occasionally not the most efficient data structure for container operations. If your program is using a small dataset (up to hundreds or even thousands of elements on today's processors), then lists will probably cover all your use cases. However, if you need to scale your data into the millions, you may need a more efficient container for your particular use case. Python therefore provides three types of queue data structures, depending on what kind of access you are looking for. All three utilize the same API, but differ in both behavior and data structure.

Before we start our queues, however, consider the trusty list data structure. Python lists are the most advantageous data structure for many use cases:

- They support efficient random access to any element in the list

- They have strict ordering of elements
- They support the append operation efficiently

They tend to be slow, however, if you are inserting elements anywhere but the end of the list (especially so if it's the beginning of the list). As we discussed in the section on sets, they are also slow for checking if an element exists in the list, and by extension, searching. Storing data in a sorted order or reordering the data can also be inefficient.

Let's look at the three types of containers provided by the Python `queue` module.

FIFO queues

FIFO stands for **First In First Out** and represents the most commonly understood definition of the word "queue". Imagine a line of people standing in line at a bank or cash register. The first person to enter the line gets served first, the second person in line gets served second, and if a new person desires service, they join the end of the line and wait their turn.

The Python `Queue` class is just like that. It is typically used as a sort of communication medium when one or more objects is producing data and one or more other objects is consuming the data in some way, probably at a different rate. Think of a messaging application that is receiving messages from the network, but can only display one message at a time to the user. The other messages can be buffered in a queue in the order they are received. FIFO queues are utilized a lot in such concurrent applications. (We'll talk more about concurrency in *Chapter 12*, *Testing Object-oriented Programs*.)

The `Queue` class is a good choice when you don't need to access any data inside the data structure except the next object to be consumed. Using a list for this would be less efficient because under the hood, inserting data at (or removing from) the beginning of a list can require shifting every other element in the list.

Queues have a very simple API. A `Queue` can have "infinite" (until the computer runs out of memory) capacity, but it is more commonly bounded to some maximum size. The primary methods are `put()` and `get()`, which add an element to the back of the line, as it were, and retrieve them from the front, in order. Both of these methods accept optional arguments to govern what happens if the operation cannot successfully complete because the queue is either empty (can't get) or full (can't put). The default behavior is to block or idly wait until the `Queue` object has data or room available to complete the operation. You can have it raise exceptions instead by passing the `block=False` parameter. Or you can have it wait a defined amount of time before raising an exception by passing a `timeout` parameter.

The class also has methods to check whether the `Queue` is `full()` or `empty()` and there are a few additional methods to deal with concurrent access that we won't discuss here. Here is a interactive session demonstrating these principles:

```
>>> from queue import Queue
>>> lineup = Queue(maxsize=3)
>>> lineup.get(block=False)
Traceback (most recent call last):
  File "<ipython-input-5-a1c8d8492c59>", line 1, in <module>
    lineup.get(block=False)
  File "/usr/lib64/python3.3/queue.py", line 164, in get
    raise Empty
queue.Empty
>>> lineup.put("one")
>>> lineup.put("two")
>>> lineup.put("three")
>>> lineup.put("four", timeout=1)
Traceback (most recent call last):
  File "<ipython-input-9-4b9db399883d>", line 1, in <module>
    lineup.put("four", timeout=1)
  File "/usr/lib64/python3.3/queue.py", line 144, in put
raise Full
queue.Full
>>> lineup.full()
True
>>> lineup.get()
'one'
>>> lineup.get()
'two'
>>> lineup.get()
'three'
>>> lineup.empty()
True
```

Underneath the hood, Python implements queues on top of the `collections.deque` data structure. Deques are advanced data structures that permits efficient access to both ends of the collection. It provides a more flexible interface than is exposed by `Queue`. I refer you to the Python documentation if you'd like to experiment more with it.

LIFO queues

LIFO (**Last In First Out**) queues are more frequently called **stacks**. Think of a stack of papers where you can only access the top-most paper. You can put another paper on top of the stack, making it the new top-most paper, or you can take the top-most paper away to reveal the one beneath it.

Traditionally, the operations on stacks are named push and pop, but the Python `queue` module uses the exact same API as for FIFO queues: `put()` and `get()`. However, in a LIFO queue, these methods operate on the "top" of the stack instead of at the front and back of a line. This is an excellent example of polymorphism. If you look at the `Queue` source code in the Python standard library, you'll actually see that there is a superclass with subclasses for FIFO and LIFO queues that implement the few operations (operating on the top of a stack instead of front and back of a `deque` instance) that are critically different between the two.

Here's an example of the LIFO queue in action:

```
>>> from queue import LifoQueue
>>> stack = LifoQueue(maxsize=3)
>>> stack.put("one")
>>> stack.put("two")
>>> stack.put("three")
>>> stack.put("four", block=False)
Traceback (most recent call last):
  File "<ipython-input-21-5473b359e5a8>", line 1, in <module>
    stack.put("four", block=False)
  File "/usr/lib64/python3.3/queue.py", line 133, in put
    raise Full
queue.Full

>>> stack.get()
'three'
>>> stack.get()
```

```
'two'
>>> stack.get()
'one'
>>> stack.empty()
True
>>> stack.get(timeout=1)
Traceback (most recent call last):
  File "<ipython-input-26-28e084a84a10>", line 1, in <module>
    stack.get(timeout=1)
  File "/usr/lib64/python3.3/queue.py", line 175, in get
    raise Empty
queue.Empty
```

You might wonder why you couldn't just use the `append()` and `pop()` methods on a standard list. Quite frankly, that's probably what I would do. I rarely have occasion to use the `LifoQueue` class in production code. Working with the end of a list is an efficient operation; so efficient, in fact, that the `LifoQueue` uses a standard list under the hood!

There are a couple of reasons that you might want to use `LifoQueue` instead of a list. The most important one is that `LifoQueue` supports clean concurrent access from multiple threads. If you need stack-like behavior in a concurrent setting, you should leave the list at home. Second, `LifoQueue` enforces the stack interface. You can't unwittingly insert a value to the wrong position in a `LifoQueue`, for example (although, as an exercise, you can work out how to do this completely wittingly).

Priority queues

The priority queue enforces a very different style of ordering from the previous queue implementations. Once again, they follow the exact same `get()` and `put()` API, but instead of relying on the order that items arrive to determine when they should be returned, the most "important" item is returned. By convention, the most important, or highest priority item is the one that sorts lowest using the less than operator.

A common convention is to store tuples in the priority queue, where the first element in the tuple is the priority for that element, and the second element is the data. Another common paradigm is to implement the `__lt__` method, as we discussed earlier in this chapter. It is perfectly acceptable to have multiple elements with the same priority in the queue, although there are no guarantees on which one will be returned first.

A priority queue might be used, for example, by a search engine to ensure it refreshes the content of the most popular web pages before crawling sites that are less likely to be searched for. A product recommendation tool might use one to display information about the most highly ranked products while still loading data for the lower ranks.

Note that a priority queue will always return the most important element currently in the queue. The `get()` method will block (by default) if the queue is empty, but it will not block and wait for a higher priority element to be added if there is already something in the queue. The queue knows nothing about elements that have not been added yet (or even about elements that have been previously extracted), and only makes decisions based on the current contents of the queue.

This interactive session shows a priority queue in action, using tuples as weights to determine what order items are processed in:

```
>>> heap.put((3, "three"))
>>> heap.put((4, "four"))
>>> heap.put((1, "one") )
>>> heap.put((2, "two"))
>>> heap.put((5, "five"), block=False)
Traceback (most recent call last):
  File "<ipython-input-23-d4209db364ed>", line 1, in <module>
    heap.put((5, "five"), block=False)
  File "/usr/lib64/python3.3/queue.py", line 133, in put
    raise Full
Full
>>> while not heap.empty():
    print(heap.get())
(1, 'one')
(2, 'two')
(3, 'three')
(4, 'four')
```

Priority queues are almost universally implemented using the `heap` data structure. Python's implementation utilizes the `heapq` module to effectively store a heap inside a normal list. I direct you to an algorithm and data-structure's textbook for more information on heaps, not to mention many other fascinating structures we haven't covered here. No matter what the data structure, you can use object-oriented principles to wrap relevant algorithms (behaviors), such as those supplied in the `heapq` module, around the data they are structuring in the computer's memory, just as the `queue` module has done on our behalf in the standard library.

Case study

To tie everything together, we'll be writing a simple link collector, which will visit a website and collect every link on every page it finds in that site. Before we start, though, we'll need some test data to work with. Simply write some HTML files to work with that contain links to each other and to other sites on the Internet, something like this:

```
<html>
    <body>
        <a href="contact.html">Contact us</a>
        <a href="blog.html">Blog</a>
        <a href="esme.html">My Dog</a>
        <a href="/hobbies.html">Some hobbies</a>
        <a href="/contact.html">Contact AGAIN</a>
        <a href="http://www.archlinux.org/">Favorite OS</a>
    </body>
</html>
```

Name one of the files `index.html` so it shows up first when pages are served. Make sure the other files exist, and keep things complicated so there is lots of linking between them. The examples for this chapter include a directory called `case_study_serve` (one of the lamest personal websites in existence!) if you would rather not set them up yourself.

Now, start a simple web server by entering the directory containing all these files and run the following command:

```
python3 -m http.server
```

This will start a server running on port 8000; you can see the pages you made by visiting `http://localhost:8000/` in your web browser.

I doubt anyone can get a website up and running with less work! Never let it be said, "you can't do that easily with Python."

The goal will be to pass our collector the base URL for the site (in this case: `http://localhost:8000/`), and have it create a list containing every unique link on the site. We'll need to take into account three types of URLs (links to external sites, which start with `http://`, absolute internal links, which start with a `/` character, and relative links, for everything else). We also need to be aware that pages may link to each other in a loop; we need to be sure we don't process the same page multiple times, or it may never end. With all this uniqueness going on, it sounds like we're going to need some sets.

Before we get into that, let's start with the basics. What code do we need to connect to a page and parse all the links from that page?

```
from urllib.request import urlopen
from urllib.parse import urlparse
import re
import sys
LINK_REGEX = re.compile(
        "<a [^>]*href=['\"]([^'\"]+)['\"][^>]*>")

class LinkCollector:
    def __init__(self, url):
        self.url = "" + urlparse(url).netloc

    def collect_links(self, path="/"):
        full_url = self.url + path
        page = str(urlopen(full_url).read())
        links = LINK_REGEX.findall(page)
        print(links)

if __name__ == "__main__":
    LinkCollector(sys.argv[1]).collect_links()
```

This is a short piece of code, considering what it's doing. It connects to the server in the argument passed on the command line, downloads the page, and extracts all the links on that page. The `__init__` method uses the `urlparse` function to extract just the hostname from the URL; so even if we pass in `http://localhost:8000/some/page.html`, it will still operate on the top level of the host `http://localhost:8000/`. This makes sense, because we want to collect all the links on the site, although it assumes every page is connected to the index by some sequence of links.

The `collect_links` method connects to and downloads the specified page from the server, and uses a regular expression to find all the links in the page. Regular expressions are an extremely powerful string processing tool. Unfortunately, they have a steep learning curve; if you haven't used them before, I strongly recommend studying any of the entire books or websites on the topic. If you don't think they're worth knowing, try writing the preceding code without them and you'll change your mind.

The example also stops in the middle of the `collect_links` method to print the value of links. This is a common way to test a program as we're writing it: stop and output the value to ensure it is the value we expect. Here's what it outputs for our example:

```
['contact.html', 'blog.html', 'esme.html', '/hobbies.html',
'/contact.html', 'http://www.archlinux.org/']
```

So now we have a collection of all the links in the first page. What can we do with it? We can't just pop the links into a set to remove duplicates because links may be relative or absolute. For example, `contact.html` and `/contact.html` point to the same page. So the first thing we should do is normalize all the links to their full URL, including hostname and relative path. We can do this by adding a `normalize_url` method to our object:

```
    def normalize_url(self, path, link):
        if link.startswith("http://"):
            return link
        elif link.startswith("/"):
            return self.url + link
        else:
            return self.url + path.rpartition(
                '/')[0] + '/' + link
```

This method converts each URL to a complete address that includes protocol and hostname. Now the two contact pages have the same value and we can store them in a set. We'll have to modify `__init__` to create the set, and `collect_links` to put all the links into it.

Then, we'll have to visit all the non-external links and collect them too. But wait a minute; if we do this, how do we keep from revisiting a link when we encounter the same page twice? It looks like we're actually going to need two sets: a set of collected links, and a set of visited links. This suggests that we were wise to choose a set to represent our data; we know that sets are most useful when we're manipulating more than one of them. Let's set these up:

```
class LinkCollector:
    def __init__(self, url):
        self.url = "http://+" + urlparse(url).netloc
        self.collected_links = set()
        self.visited_links = set()

    def collect_links(self, path="/"):
        full_url = self.url + path
        self.visited_links.add(full_url)
        page = str(urlopen(full_url).read())
        links = LINK_REGEX.findall(page)
        links = {self.normalize_url(path, link
            ) for link in links}
        self.collected_links = links.union(
                self.collected_links)
        unvisited_links = links.difference(
                self.visited_links)
```

```
            print(links, self.visited_links,
                    self.collected_links, unvisited_links)
```

The line that creates the normalized list of links uses a `set` comprehension, no different from a list comprehension, except that the result is a set of values. We'll be covering these in detail in the next chapter. Once again, the method stops to print out the current values, so we can verify that we don't have our sets confused, and that `difference` really was the method we wanted to call to collect `unvisited_links`. We can then add a few lines of code that loop over all the unvisited links and add them to the collection as well:

```
            for link in unvisited_links:
                if link.startswith(self.url):
                    self.collect_links(urlparse(link).path)
```

The `if` statement ensures that we are only collecting links from the one website; we don't want to go off and collect all the links from all the pages on the Internet (unless we're Google or the Internet Archive!). If we modify the main code at the bottom of the program to output the collected links, we can see it seems to have collected them all:

```
if __name__ == "__main__":
    collector = LinkCollector(sys.argv[1])
    collector.collect_links()
    for link in collector.collected_links:
        print(link)
```

It displays all the links we've collected, and only once, even though many of the pages in my example linked to each other multiple times:

```
$ python3 link_collector.py http://localhost:8000
http://localhost:8000/
http://en.wikipedia.org/wiki/Cavalier_King_Charles_Spaniel
http://beluminousyoga.com
http://archlinux.me/dusty/
http://localhost:8000/blog.html
http://ccphillips.net/
http://localhost:8000/contact.html
http://localhost:8000/taichi.html
http://www.archlinux.org/
http://localhost:8000/esme.html
http://localhost:8000/hobbies.html
```

Even though it collected links *to* external pages, it didn't go off collecting links *from* any of the external pages we linked to. This is a great little program if we want to collect all the links in a site. But it doesn't give me all the information I might need to build a site map; it tells me which pages I have, but it doesn't tell me which pages link to other pages. If we want to do that instead, we're going to have to make some modifications.

The first thing we should do is look at our data structures. The set of collected links doesn't work anymore; we want to know which links were linked to from which pages. The first thing we could do, then, is turn that set into a dictionary of sets for each page we visit. The dictionary keys will represent the exact same data that is currently in the set. The values will be sets of all the links on that page. Here are the changes:

```
from urllib.request import urlopen
from urllib.parse import urlparse
import re
import sys
LINK_REGEX = re.compile(
        "<a [^>]*href=['\"]([^'\"]+)['\"][^>]*>")

class LinkCollector:
    def __init__(self, url):
        self.url = "http://%s" % urlparse(url).netloc
        self.collected_links = {}
        self.visited_links = set()

    def collect_links(self, path="/"):
        full_url = self.url + path
        self.visited_links.add(full_url)
        page = str(urlopen(full_url).read())
        links = LINK_REGEX.findall(page)
        links = {self.normalize_url(path, link
            ) for link in links}
        self.collected_links[full_url] = links
        for link in links:
            self.collected_links.setdefault(link, set())
        unvisited_links = links.difference(
                self.visited_links)
        for link in unvisited_links:
            if link.startswith(self.url):
                self.collect_links(urlparse(link).path)

    def normalize_url(self, path, link):
        if link.startswith("http://"):
```

```
            return link
        elif link.startswith("/"):
            return self.url + link
        else:
            return self.url + path.rpartition('/'
                    )[0] + '/' + link
if __name__ == "__main__":
    collector = LinkCollector(sys.argv[1])
    collector.collect_links()
    for link, item in collector.collected_links.items():
        print("{}: {}".format(link, item))
```

It is a surprisingly small change; the line that originally created a union of two sets has been replaced with three lines that update the dictionary. The first of these simply tells the dictionary what the collected links for that page are. The second creates an empty set for any items in the dictionary that have not already been added to the dictionary, using `setdefault`. The result is a dictionary that contains all the links as its keys, mapped to sets of links for all the internal links, and empty sets for the external links.

Finally, instead of recursively calling `collect_links`, we can use a queue to store the links that haven't been processed yet. This implementation won't support it, but this would be a good first step to creating a multithreaded version that makes multiple requests in parallel to save time.

```
from urllib.request import urlopen
from urllib.parse import urlparse
import re
import sys
from queue import Queue
LINK_REGEX = re.compile("<a [^>]*href=['\"]([^'\"]+)['\"][^>]*>")


class LinkCollector:
    def __init__(self, url):
        self.url = "http://%s" % urlparse(url).netloc
        self.collected_links = {}
        self.visited_links = set()

    def collect_links(self):
        queue = Queue()
        queue.put(self.url)
        while not queue.empty():
            url = queue.get().rstrip('/')
            self.visited_links.add(url)
            page = str(urlopen(url).read())
```

```
                links = LINK_REGEX.findall(page)
                links = {
                    self.normalize_url(urlparse(url).path, link)
                    for link in links
                }
                self.collected_links[url] = links
                for link in links:
                    self.collected_links.setdefault(link, set())
                unvisited_links = links.difference(self.visited_links)
                for link in unvisited_links:
                    if link.startswith(self.url):
                        queue.put(link)

        def normalize_url(self, path, link):
            if link.startswith("http://"):
                return link.rstrip('/')
            elif link.startswith("/"):
                return self.url + link.rstrip('/')
            else:
                return self.url + path.rpartition('/')[0] + '/' + link.
    rstrip('/')

    if __name__ == "__main__":
        collector = LinkCollector(sys.argv[1])
        collector.collect_links()
        for link, item in collector.collected_links.items():
            print("%s: %s" % (link, item))
```

I had to manually strip any trailing forward slashes in the `normalize_url` method to remove duplicates in this version of the code.

Because the end result is an unsorted dictionary, there is no restriction on what order the links should be processed in. Therefore, we could just as easily have used a `LifoQueue` instead of a `Queue` here. A priority queue probably wouldn't make a lot of sense since there is no obvious priority to attach to a link in this case.

Exercises

The best way to learn how to choose the correct data structure is to do it wrong a few times. Take some code you've recently written, or write some new code that uses a list. Try rewriting it using some different data structures. Which ones make more sense? Which ones don't? Which have the most elegant code?

Try this with a few different pairs of data structures. You can look at examples you've done for previous chapter exercises. Are there objects with methods where you could have used `namedtuple` or `dict` instead? Attempt both and see. Are there dictionaries that could have been sets because you don't really access the values? Do you have lists that check for duplicates? Would a set suffice? Or maybe several sets? Would one of the queue implementations be more efficient? Is it useful to restrict the API to the top of a stack rather than allowing random access to the list?

If you want some specific examples to work with, try adapting the link collector to also save the title used for each link. Perhaps you can generate a site map in HTML that lists all the pages on the site, and contains a list of links to other pages, named with the same link titles.

Have you written any container objects recently that you could improve by inheriting a built-in and overriding some of the "special" double-underscore methods? You may have to do some research (using `dir` and `help`, or the Python library reference) to find out which methods need overriding. Are you sure inheritance is the correct tool to apply; could a composition-based solution be more effective? Try both (if it's possible) before you decide. Try to find different situations where each method is better than the other.

If you were familiar with the various Python data structures and their uses before you started this chapter, you may have been bored. But if that is the case, there's a good chance you use data structures too much! Look at some of your old code and rewrite it to use more self-made objects. Carefully consider the alternatives and try them all out; which one makes for the most readable and maintainable system?

Always critically evaluate your code and design decisions. Make a habit of reviewing old code and take note if your understanding of "good design" has changed since you've written it. Software design has a large aesthetic component, and like artists with oil on canvas, we all have to find the style that suits us best.

Summary

We've covered several built-in data structures and attempted to understand how to choose one for specific applications. Sometimes, the best thing we can do is create a new class of objects, but often, one of the built-ins provides exactly what we need. When it doesn't, we can always use inheritance or composition to adapt them to our use cases. We can even override special methods to completely change the behavior of built-in syntaxes.

In the next chapter, we'll discuss how to integrate the object-oriented and not-so-object-oriented aspects of Python. Along the way, we'll discover that it's more object-oriented than it looks at first sight!

7
Python Object-oriented Shortcuts

There are many aspects of Python that appear more reminiscent of structural or functional programming than object-oriented programming. Although object-oriented programming has been the most visible paradigm of the past two decades, the old models have seen a recent resurgence. As with Python's data structures, most of these tools are syntactic sugar over an underlying object-oriented implementation; we can think of them as a further abstraction layer built on top of the (already abstracted) object-oriented paradigm. In this chapter, we'll be covering a grab bag of Python features that are not strictly object-oriented:

- Built-in functions that take care of common tasks in one call
- File I/O and context managers
- An alternative to method overloading
- Functions as objects

Python built-in functions

There are numerous functions in Python that perform a task or calculate a result on certain types of objects without being methods on the underlying class. They usually abstract common calculations that apply to multiple types of classes. This is duck typing at its best; these functions accept objects that have certain attributes or methods, and are able to perform generic operations using those methods. Many, but not all, of these are special double underscore methods. We've used many of the built-in functions already, but let's quickly go through the important ones and pick up a few neat tricks along the way.

The len() function

The simplest example is the `len()` function, which counts the number of items in some kind of container object, such as a dictionary or list. You've seen it before:

```
>>> len([1,2,3,4])
4
```

Why don't these objects have a length property instead of having to call a function on them? Technically, they do. Most objects that `len()` will apply to have a method called `__len__()` that returns the same value. So `len(myobj)` seems to call `myobj.__len__()`.

Why should we use the `len()` function instead of the `__len__` method? Obviously `__len__` is a special double-underscore method, suggesting that we shouldn't call it directly. There must be an explanation for this. The Python developers don't make such design decisions lightly.

The main reason is efficiency. When we call `__len__` on an object, the object has to look the method up in its namespace, and, if the special `__getattribute__` method (which is called every time an attribute or method on an object is accessed) is defined on that object, it has to be called as well. Further, `__getattribute__` for that particular method may have been written to do something nasty, like refusing to give us access to special methods such as `__len__`! The `len()` function doesn't encounter any of this. It actually calls the `__len__` function on the underlying class, so `len(myobj)` maps to `MyObj.__len__(myobj)`.

Another reason is maintainability. In the future, the Python developers may want to change `len()` so that it can calculate the length of objects that don't have `__len__`, for example, by counting the number of items returned in an iterator. They'll only have to change one function instead of countless `__len__` methods across the board.

There is one other extremely important and often overlooked reason for `len()` being an external function: backwards compatibility. This is often cited in articles as "for historical reasons", which is a mildly dismissive phrase that an author will use to say something is the way it is because a mistake was made long ago and we're stuck with it. Strictly speaking, `len()` isn't a mistake, it's a design decision, but that decision was made in a less object-oriented time. It has stood the test of time and has some benefits, so do get used to it.

Reversed

The `reversed()` function takes any sequence as input, and returns a copy of that sequence in reverse order. It is normally used in `for` loops when we want to loop over items from back to front.

Similar to `len`, `reversed` calls the `__reversed__()` function on the class for the parameter. If that method does not exist, `reversed` builds the reversed sequence itself using calls to `__len__` and `__getitem__`, which are used to define a sequence. We only need to override `__reversed__` if we want to somehow customize or optimize the process:

```
normal_list=[1,2,3,4,5]

class CustomSequence():
    def __len__(self):
        return 5


    def __getitem__(self, index):
        return "x{0}".format(index)

class FunkyBackwards():

    def __reversed__(self):
        return "BACKWARDS!"

for seq in normal_list, CustomSequence(), FunkyBackwards():
    print("\n{}: ".format(seq.__class__.__name__), end="")
    for item in reversed(seq):
        print(item, end=", ")
```

The `for` loops at the end print the reversed versions of a normal list, and instances of the two custom sequences. The output shows that `reversed` works on all three of them, but has very different results when we define `__reversed__` ourselves:

```
list: 5, 4, 3, 2, 1,
CustomSequence: x4, x3, x2, x1, x0,
FunkyBackwards: B, A, C, K, W, A, R, D, S, !,
```

When we reverse `CustomSequence`, the `__getitem__` method is called for each item, which just inserts an `x` before the index. For `FunkyBackwards`, the `__reversed__` method returns a string, each character of which is output individually in the `for` loop.

The preceding two classes aren't very good sequences as they don't define a proper version of `__iter__`, so a forward `for` loop over them will never end.

Enumerate

Sometimes, when we're looping over a container in a `for` loop, we want access to the index (the current position in the list) of the current item being processed. The `for` loop doesn't provide us with indexes, but the `enumerate` function gives us something better: it creates a sequence of tuples, where the first object in each tuple is the index and the second is the original item.

This is useful if we need to use index numbers directly. Consider some simple code that outputs each of the lines in a file with line numbers:

```
import sys
filename = sys.argv[1]

with open(filename) as file:
    for index, line in enumerate(file):
        print("{0}: {1}".format(index+1, line), end='')
```

Running this code using it's own filename as the input file shows how it works:

```
1: import sys
2: filename = sys.argv[1]
3:
4: with open(filename) as file:
5:     for index, line in enumerate(file):
6:         print("{0}: {1}".format(index+1, line), end='')
```

The `enumerate` function returns a sequence of tuples, our `for` loop splits each tuple into two values, and the `print` statement formats them together. It adds one to the index for each line number, since `enumerate`, like all sequences, is zero-based.

We've only touched on a few of the more important Python built-in functions. As you can see, many of them call into object-oriented concepts, while others subscribe to purely functional or procedural paradigms. There are numerous others in the standard library; some of the more interesting ones include:

- `all` and `any`, which accept an iterable object and return `True` if all, or any, of the items evaluate to true (such as a nonempty string or list, a nonzero number, an object that is not `None`, or the literal `True`).
- `eval`, `exec`, and `compile`, which execute string as code inside the interpreter. Be careful with these ones; they are not safe, so don't execute code an unknown user has supplied to you (in general, assume all unknown users are malicious, foolish, or both).

- `hasattr`, `getattr`, `setattr`, and `delattr`, which allow attributes on an object to be manipulated by their string names.
- `zip`, which takes two or more sequences and returns a new sequence of tuples, where each tuple contains a single value from each sequence.
- And many more! See the interpreter help documentation for each of the functions listed in `dir(__builtins__)`.

File I/O

Our examples so far that touch the filesystem have operated entirely on text files without much thought to what is going on under the hood. Operating systems, however, actually represent files as a sequence of bytes, not text. We'll do a deep dive into the relationship between bytes and text in *Chapter 8*, *Strings and Serialization*. For now, be aware that reading textual data from a file is a fairly involved process. Python, especially Python 3, takes care of most of this work for us behind the scenes. Aren't we lucky?

The concept of files has been around since long before anyone coined the term object-oriented programming. However, Python has wrapped the interface that operating systems provide in a sweet abstraction that allows us to work with file (or file-like, vis-á-vis duck typing) objects.

The `open()` built-in function is used to open a file and return a file object. For reading text from a file, we only need to pass the name of the file into the function. The file will be opened for reading, and the bytes will be converted to text using the platform default encoding.

Of course, we don't always want to read files; often we want to write data to them! To open a file for writing, we need to pass a `mode` argument as the second positional argument, with a value of `"w"`:

```
contents = "Some file contents"
file = open("filename", "w")
file.write(contents)
file.close()
```

We could also supply the value `"a"` as a mode argument, to append to the end of the file, rather than completely overwriting existing file contents.

These files with built-in wrappers for converting bytes to text are great, but it'd be awfully inconvenient if the file we wanted to open was an image, executable, or other binary file, wouldn't it?

To open a binary file, we modify the mode string to append `'b'`. So, `'wb'` would open a file for writing bytes, while `'rb'` allows us to read them. They will behave like text files, but without the automatic encoding of text to bytes. When we read such a file, it will return `bytes` objects instead of `str`, and when we write to it, it will fail if we try to pass a text object.

These mode strings for controlling how files are opened are rather cryptic and are neither pythonic nor object-oriented. However, they are consistent with virtually every other programming language out there. File I/O is one of the fundamental jobs an operating system has to handle, and all programming languages have to talk to the OS using the same system calls. Just be glad that Python returns a file object with useful methods instead of the integer that most major operating systems use to identify a file handle!

Once a file is opened for reading, we can call the `read`, `readline`, or `readlines` methods to get the contents of the file. The `read` method returns the entire contents of the file as a `str` or `bytes` object, depending on whether there is `'b'` in the mode. Be careful not to use this method without arguments on huge files. You don't want to find out what happens if you try to load that much data into memory!

It is also possible to read a fixed number of bytes from a file; we pass an integer argument to the `read` method describing how many bytes we want to read. The next call to `read` will load the next sequence of bytes, and so on. We can do this inside a `while` loop to read the entire file in manageable chunks.

The `readline` method returns a single line from the file (where each line ends in a newline, a carriage return, or both, depending on the operating system on which the file was created). We can call it repeatedly to get additional lines. The plural `readlines` method returns a list of all the lines in the file. Like the `read` method, it's not safe to use on very large files. These two methods even work when the file is open in `bytes` mode, but it only makes sense if we are parsing text-like data that has newlines at reasonable positions. An image or audio file, for example, will not have newline characters in it (unless the newline byte happened to represent a certain pixel or sound), so applying `readline` wouldn't make sense.

For readability, and to avoid reading a large file into memory at once, it is often better to use a `for` loop directly on a file object. For text files, it will read each line, one at a time, and we can process it inside the loop body. For binary files, it's better to read fixed-sized chunks of data using the `read()` method, passing a parameter for the maximum number of bytes to read.

Writing to a file is just as easy; the `write` method on file objects writes a string (or bytes, for binary data) object to the file. It can be called repeatedly to write multiple strings, one after the other. The `writelines` method accepts a sequence of strings and writes each of the iterated values to the file. The `writelines` method does *not* append a new line after each item in the sequence. It is basically a poorly named convenience function to write the contents of a sequence of strings without having to explicitly iterate over it using a `for` loop.

Lastly, and I do mean lastly, we come to the `close` method. This method should be called when we are finished reading or writing the file, to ensure any buffered writes are written to the disk, that the file has been properly cleaned up, and that all resources associated with the file are released back to the operating system. Technically, this will happen automatically when the script exits, but it's better to be explicit and clean up after ourselves, especially in long-running processes.

Placing it in context

The need to close files when we are finished with them can make our code quite ugly. Because an exception may occur at any time during file I/O, we ought to wrap all calls to a file in a `try...finally` clause. The file should be closed in the `finally` clause, regardless of whether I/O was successful. This isn't very Pythonic. Of course, there is a more elegant way to do it.

If we run `dir` on a file-like object, we see that it has two special methods named `__enter__` and `__exit__`. These methods turn the file object into what is known as a **context manager**. Basically, if we use a special syntax called the `with` statement, these methods will be called before and after nested code is executed. On file objects, the `__exit__` method ensures the file is closed, even if an exception is raised. We no longer have to explicitly manage the closing of the file. Here is what the `with` statement looks like in practice:

```
with open('filename') as file:
    for line in file:
        print(line, end='')
```

The `open` call returns a file object, which has `__enter__` and `__exit__` methods. The returned object is assigned to the variable named `file` by the `as` clause. We know the file will be closed when the code returns to the outer indentation level, and that this will happen even if an exception is raised.

The `with` statement is used in several places in the standard library where startup or cleanup code needs to be executed. For example, the `urlopen` call returns an object that can be used in a `with` statement to clean up the socket when we're done. Locks in the threading module can automatically release the lock when the statement has been executed.

Most interestingly, because the `with` statement can apply to any object that has the appropriate special methods, we can use it in our own frameworks. For example, remember that strings are immutable, but sometimes you need to build a string from multiple parts. For efficiency, this is usually done by storing the component strings in a list and joining them at the end. Let's create a simple context manager that allows us to construct a sequence of characters and automatically convert it to a string upon exit:

```
class StringJoiner(list):
    def __enter__(self):
        return self

    def __exit__(self, type, value, tb):
        self.result = "".join(self)
```

This code adds the two special methods required of a context manager to the `list` class it inherits from. The `__enter__` method performs any required setup code (in this case, there isn't any) and then returns the object that will be assigned to the variable after `as` in the `with` statement. Often, as we've done here, this is just the context manager object itself. The `__exit__` method accepts three arguments. In a normal situation, these are all given a value of `None`. However, if an exception occurs inside the `with` block, they will be set to values related to the type, value, and traceback for the exception. This allows the `__exit__` method to do any cleanup code that may be required, even if an exception occurred. In our example, we take the irresponsible path and create a result string by joining the characters in the string, regardless of whether an exception was thrown.

While this is one of the simplest context managers we could write, and its usefulness is dubious, it does work with a `with` statement. Have a look at it in action:

```
import random, string
with StringJoiner() as joiner:
    for i in range(15):
        joiner.append(random.choice(string.ascii_letters))

print(joiner.result)
```

This code constructs a string of 15 random characters. It appends these to a `StringJoiner` using the `append` method it inherited from `list`. When the `with` statement goes out of scope (back to the outer indentation level), the `__exit__` method is called, and the `result` attribute becomes available on the joiner object. We print this value to see a random string.

An alternative to method overloading

One prominent feature of many object-oriented programming languages is a tool called **method overloading**. Method overloading simply refers to having multiple methods with the same name that accept different sets of arguments. In statically typed languages, this is useful if we want to have a method that accepts either an integer or a string, for example. In non-object-oriented languages, we might need two functions, called `add_s` and `add_i`, to accommodate such situations. In statically typed object-oriented languages, we'd need two methods, both called `add`, one that accepts strings, and one that accepts integers.

In Python, we only need one method, which accepts any type of object. It may have to do some testing on the object type (for example, if it is a string, convert it to an integer), but only one method is required.

However, method overloading is also useful when we want a method with the same name to accept different numbers or sets of arguments. For example, an e-mail message method might come in two versions, one of which accepts an argument for the "from" e-mail address. The other method might look up a default "from" e-mail address instead. Python doesn't permit multiple methods with the same name, but it does provide a different, equally flexible, interface.

We've seen some of the possible ways to send arguments to methods and functions in previous examples, but now we'll cover all the details. The simplest function accepts no arguments. We probably don't need an example, but here's one for completeness:

```
def no_args():
    pass
```

Here's how it's called:

```
no_args()
```

A function that does accept arguments will provide the names of those arguments in a comma-separated list. Only the name of each argument needs to be supplied.

When calling the function, these positional arguments must be specified in order, and none can be missed or skipped. This is the most common way we've specified arguments in our previous examples:

```
def mandatory_args(x, y, z):
    pass
```

To call it:

```
mandatory_args("a string", a_variable, 5)
```

Any type of object can be passed as an argument: an object, a container, a primitive, even functions and classes. The preceding call shows a hardcoded string, an unknown variable, and an integer passed into the function.

Default arguments

If we want to make an argument optional, rather than creating a second method with a different set of arguments, we can specify a default value in a single method, using an equals sign. If the calling code does not supply this argument, it will be assigned a default value. However, the calling code can still choose to override the default by passing in a different value. Often, a default value of `None`, or an empty string or list is suitable.

Here's a function definition with default arguments:

```
def default_arguments(x, y, z, a="Some String", b=False):
    pass
```

The first three arguments are still mandatory and must be passed by the calling code. The last two parameters have default arguments supplied.

There are several ways we can call this function. We can supply all arguments in order as though all the arguments were positional arguments:

```
default_arguments("a string", variable, 8, "", True)
```

Alternatively, we can supply just the mandatory arguments in order, leaving the keyword arguments to be assigned their default values:

```
default_arguments("a longer string", some_variable, 14)
```

We can also use the equals sign syntax when calling a function to provide values in a different order, or to skip default values that we aren't interested in. For example, we can skip the first keyword arguments and supply the second one:

```
default_arguments("a string", variable, 14, b=True)
```

Surprisingly, we can even use the equals sign syntax to mix up the order of positional arguments, so long as all of them are supplied:

```
>>> default_arguments(y=1,z=2,x=3,a="hi")
3 1 2 hi False
```

With so many options, it may seem hard to pick one, but if you think of the positional arguments as an ordered list, and keyword arguments as sort of like a dictionary, you'll find that the correct layout tends to fall into place. If you need to require the caller to specify an argument, make it mandatory; if you have a sensible default, then make it a keyword argument. Choosing how to call the method normally takes care of itself, depending on which values need to be supplied, and which can be left at their defaults.

One thing to take note of with keyword arguments is that anything we provide as a default argument is evaluated when the function is first interpreted, not when it is called. This means we can't have dynamically generated default values. For example, the following code won't behave quite as expected:

```
number = 5
def funky_function(number=number):
    print(number)

number=6
funky_function(8)
funky_function()
print(number)
```

If we run this code, it outputs the number 8 first, but then it outputs the number 5 for the call with no arguments. We had set the variable to the number 6, as evidenced by the last line of output, but when the function is called, the number 5 is printed; the default value was calculated when the function was defined, not when it was called.

This is tricky with empty containers such as lists, sets, and dictionaries. For example, it is common to ask calling code to supply a list that our function is going to manipulate, but the list is optional. We'd like to make an empty list as a default argument. We can't do this; it will create only one list, when the code is first constructed:

```
>>> def hello(b=[]):
...     b.append('a')
...     print(b)
...
```

```
>>> hello()
['a']
>>> hello()
['a', 'a']
```

Whoops, that's not quite what we expected! The usual way to get around this is to make the default value `None`, and then use the idiom `iargument = argument if argument else []` inside the method. Pay close attention!

Variable argument lists

Default values alone do not allow us all the flexible benefits of method overloading. The thing that makes Python really slick is the ability to write methods that accept an arbitrary number of positional or keyword arguments without explicitly naming them. We can also pass arbitrary lists and dictionaries into such functions.

For example, a function to accept a link or list of links and download the web pages could use such variadic arguments, or **varargs**. Instead of accepting a single value that is expected to be a list of links, we can accept an arbitrary number of arguments, where each argument is a different link. We do this by specifying the `*` operator in the function definition:

```
def get_pages(*links):
    for link in links:
        #download the link with urllib
        print(link)
```

The `*links` parameter says "I'll accept any number of arguments and put them all in a list named `links`". If we supply only one argument, it'll be a list with one element; if we supply no arguments, it'll be an empty list. Thus, all these function calls are valid:

```
get_pages()
get_pages('http://www.archlinux.org')
get_pages('http://www.archlinux.org',
        'http://ccphillips.net/')
```

We can also accept arbitrary keyword arguments. These arrive into the function as a dictionary. They are specified with two asterisks (as in `**kwargs`) in the function declaration. This tool is commonly used in configuration setups. The following class allows us to specify a set of options with default values:

```
class Options:
    default_options = {
```

```
            'port': 21,
            'host': 'localhost',
            'username': None,
            'password': None,
            'debug': False,
            }
    def __init__(self, **kwargs):
        self.options = dict(Options.default_options)
        self.options.update(kwargs)

    def __getitem__(self, key):
        return self.options[key]
```

All the interesting stuff in this class happens in the `__init__` method. We have a dictionary of default options and values at the class level. The first thing the `__init__` method does is make a copy of this dictionary. We do that instead of modifying the dictionary directly in case we instantiate two separate sets of options. (Remember, class-level variables are shared between instances of the class.) Then, `__init__` uses the `update` method on the new dictionary to change any non-default values to those supplied as keyword arguments. The `__getitem__` method simply allows us to use the new class using indexing syntax. Here's a session demonstrating the class in action:

```
>>> options = Options(username="dusty", password="drowssap",
        debug=True)
>>> options['debug']
True
>>> options['port']
21
>>> options['username']
'dusty'
```

We're able to access our options instance using dictionary indexing syntax, and the dictionary includes both default values and the ones we set using keyword arguments.

The keyword argument syntax can be dangerous, as it may break the "explicit is better than implicit" rule. In the preceding example, it's possible to pass arbitrary keyword arguments to the `Options` initializer to represent options that don't exist in the default dictionary. This may not be a bad thing, depending on the purpose of the class, but it makes it hard for someone using the class to discover what valid options are available. It also makes it easy to enter a confusing typo ("Debug" instead of "debug", for example) that adds two options where only one should have existed.

Keyword arguments are also very useful when we need to accept arbitrary arguments to pass to a second function, but we don't know what those arguments will be. We saw this in action in *Chapter 3*, *When Objects Are Alike*, when we were building support for multiple inheritance. We can, of course, combine the variable argument and variable keyword argument syntax in one function call, and we can use normal positional and default arguments as well. The following example is somewhat contrived, but demonstrates the four types in action:

```
import shutil
import os.path
def augmented_move(target_folder, *filenames,
        verbose=False, **specific):
    '''Move all filenames into the target_folder, allowing
    specific treatment of certain files.'''

    def print_verbose(message, filename):
        '''print the message only if verbose is enabled'''
        if verbose:
            print(message.format(filename))

    for filename in filenames:
        target_path = os.path.join(target_folder, filename)
        if filename in specific:
            if specific[filename] == 'ignore':
                print_verbose("Ignoring {0}", filename)
            elif specific[filename] == 'copy':
                print_verbose("Copying {0}", filename)
                shutil.copyfile(filename, target_path)
        else:
            print_verbose("Moving {0}", filename)
            shutil.move(filename, target_path)
```

This example will process an arbitrary list of files. The first argument is a target folder, and the default behavior is to move all remaining non-keyword argument files into that folder. Then there is a keyword-only argument, `verbose`, which tells us whether to print information on each file processed. Finally, we can supply a dictionary containing actions to perform on specific filenames; the default behavior is to move the file, but if a valid string action has been specified in the keyword arguments, it can be ignored or copied instead. Notice the ordering of the parameters in the function; first the positional argument is specified, then the `*filenames` list, then any specific keyword-only arguments, and finally, a `**specific` dictionary to hold remaining keyword arguments.

We create an inner helper function, `print_verbose`, which will print messages only if the `verbose` key has been set. This function keeps code readable by encapsulating this functionality into a single location.

In common cases, assuming the files in question exist, this function could be called as:

```
>>> augmented_move("move_here", "one", "two")
```

This command would move the files `one` and `two` into the `move_here` directory, assuming they exist (there's no error checking or exception handling in the function, so it would fail spectacularly if the files or target directory didn't exist). The move would occur without any output, since `verbose` is `False` by default.

If we want to see the output, we can call it with:

```
>>> augmented_move("move_here", "three", verbose=True)
Moving three
```

This moves one file named `three`, and tells us what it's doing. Notice that it is impossible to specify `verbose` as a positional argument in this example; we must pass a keyword argument. Otherwise, Python would think it was another filename in the `*filenames` list.

If we want to copy or ignore some of the files in the list, instead of moving them, we can pass additional keyword arguments:

```
>>> augmented_move("move_here", "four", "five", "six",
        four="copy", five="ignore")
```

This will move the sixth file and copy the fourth, but won't display any output, since we didn't specify `verbose`. Of course, we can do that too, and keyword arguments can be supplied in any order:

```
>>> augmented_move("move_here", "seven", "eight", "nine",
        seven="copy", verbose=True, eight="ignore")
Copying seven
Ignoring eight
Moving nine
```

Unpacking arguments

There's one more nifty trick involving variable arguments and keyword arguments. We've used it in some of our previous examples, but it's never too late for an explanation. Given a list or dictionary of values, we can pass those values into a function as if they were normal positional or keyword arguments. Have a look at this code:

```
def show_args(arg1, arg2, arg3="THREE"):
    print(arg1, arg2, arg3)

some_args = range(3)
more_args = {
        "arg1": "ONE",
        "arg2": "TWO"}

print("Unpacking a sequence:", end=" ")

show_args(*some_args)
print("Unpacking a dict:", end=" ")

show_args(**more_args)
```

Here's what it looks like when we run it:

```
Unpacking a sequence: 0 1 2
Unpacking a dict: ONE TWO THREE
```

The function accepts three arguments, one of which has a default value. But when we have a list of three arguments, we can use the `*` operator inside a function call to unpack it into the three arguments. If we have a dictionary of arguments, we can use the `**` syntax to unpack it as a collection of keyword arguments.

This is most often useful when mapping information that has been collected from user input or from an outside source (for example, an Internet page or a text file) to a function or method call.

Remember our earlier example that used headers and lines in a text file to create a list of dictionaries with contact information? Instead of just adding the dictionaries to a list, we could use keyword unpacking to pass the arguments to the `__init__` method on a specially built `Contact` object that accepts the same set of arguments. See if you can adapt the example to make this work.

Functions are objects too

Programming languages that overemphasize object-oriented principles tend to frown on functions that are not methods. In such languages, you're expected to create an object to sort of wrap the single method involved. There are numerous situations where we'd like to pass around a small object that is simply called to perform an action. This is most frequently done in event-driven programming, such as graphical toolkits or asynchronous servers; we'll see some design patterns that use it in *Chapter 10*, *Python Design Patterns I* and *Chapter 11*, *Python Design Patterns II*.

In Python, we don't need to wrap such methods in an object, because functions already are objects! We can set attributes on functions (though this isn't a common activity), and we can pass them around to be called at a later date. They even have a few special properties that can be accessed directly. Here's yet another contrived example:

```
def my_function():
    print("The Function Was Called")
my_function.description = "A silly function"

def second_function():
    print("The second was called")
second_function.description = "A sillier function."

def another_function(function):
    print("The description:", end=" ")
    print(function.description)
    print("The name:", end=" ")
    print(function.__name__)
    print("The class:", end=" ")
    print(function.__class__)
    print("Now I'll call the function passed in")
    function()

another_function(my_function)
another_function(second_function)
```

If we run this code, we can see that we were able to pass two different functions into our third function, and get different output for each one:

```
The description: A silly function
The name: my_function
The class: <class 'function'>
Now I'll call the function passed in
```

```
The Function Was Called
The description: A sillier function.
The name: second_function
The class: <class 'function'>
Now I'll call the function passed in
The second was called
```

We set an attribute on the function, named `description` (not very good descriptions, admittedly). We were also able to see the function's `__name__` attribute, and to access its class, demonstrating that the function really is an object with attributes. Then we called the function by using the callable syntax (the parentheses).

The fact that functions are top-level objects is most often used to pass them around to be executed at a later date, for example, when a certain condition has been satisfied. Let's build an event-driven timer that does just this:

```
import datetime
import time

class TimedEvent:
    def __init__(self, endtime, callback):
        self.endtime = endtime
        self.callback = callback

    def ready(self):
        return self.endtime <= datetime.datetime.now()

class Timer:
    def __init__(self):
        self.events = []

    def call_after(self, delay, callback):
        end_time = datetime.datetime.now() + \
                datetime.timedelta(seconds=delay)

        self.events.append(TimedEvent(end_time, callback))

    def run(self):
        while True:
            ready_events = (e for e in self.events if e.ready())
            for event in ready_events:
                event.callback(self)
                self.events.remove(event)
            time.sleep(0.5)
```

In production, this code should definitely have extra documentation using docstrings! The `call_after` method should at least mention that the `delay` parameter is in seconds, and that the `callback` function should accept one argument: the timer doing the calling.

We have two classes here. The `TimedEvent` class is not really meant to be accessed by other classes; all it does is store `endtime` and `callback`. We could even use a `tuple` or `namedtuple` here, but as it is convenient to give the object a behavior that tells us whether or not the event is ready to run, we use a class instead.

The `Timer` class simply stores a list of upcoming events. It has a `call_after` method to add a new event. This method accepts a `delay` parameter representing the number of seconds to wait before executing the callback, and the `callback` function itself: a function to be executed at the correct time. This `callback` function should accept one argument.

The `run` method is very simple; it uses a generator expression to filter out any events whose time has come, and executes them in order. The timer loop then continues indefinitely, so it has to be interrupted with a keyboard interrupt (*Ctrl + C* or *Ctrl + Break*). We sleep for half a second after each iteration so as to not grind the system to a halt.

The important things to note here are the lines that touch callback functions. The function is passed around like any other object and the timer never knows or cares what the original name of the function is or where it was defined. When it's time to call the function, the timer simply applies the parenthesis syntax to the stored variable.

Here's a set of callbacks that test the timer:

```
from timer import Timer
import datetime

def format_time(message, *args):
    now = datetime.datetime.now().strftime("%I:%M:%S")
    print(message.format(*args, now=now))

def one(timer):
    format_time("{now}: Called One")

def two(timer):
    format_time("{now}: Called Two")

def three(timer):
```

```
        format_time("{now}: Called Three")

    class Repeater:
        def __init__(self):
            self.count = 0
        def repeater(self, timer):
            format_time("{now}: repeat {0}", self.count)
            self.count += 1
            timer.call_after(5, self.repeater)

    timer = Timer()
    timer.call_after(1, one)
    timer.call_after(2, one)
    timer.call_after(2, two)
    timer.call_after(4, two)
    timer.call_after(3, three)
    timer.call_after(6, three)
    repeater = Repeater()
    timer.call_after(5, repeater.repeater)
    format_time("{now}: Starting")
    timer.run()
```

This example allows us to see how multiple callbacks interact with the timer. The first function is the `format_time` function. It uses the string `format` method to add the current time to the message, and illustrates variable arguments in action. The `format_time` method will accept any number of positional arguments, using variable argument syntax, which are then forwarded as positional arguments to the string's `format` method. After this, we create three simple callback methods that simply output the current time and a short message telling us which callback has been fired.

The `Repeater` class demonstrates that methods can be used as callbacks too, since they are really just functions. It also shows why the `timer` argument to the callback functions is useful: we can add a new timed event to the timer from inside a presently running callback. We then create a timer and add several events to it that are called after different amounts of time. Finally, we start the timer running; the output shows that events are run in the expected order:

```
02:53:35: Starting
02:53:36: Called One
02:53:37: Called One
02:53:37: Called Two
02:53:38: Called Three
02:53:39: Called Two
02:53:40: repeat 0
```

```
02:53:41: Called Three
02:53:45: repeat 1
02:53:50: repeat 2
02:53:55: repeat 3
02:54:00: repeat 4
```

Python 3.4 introduces a generic event-loop architecture similar to this. We'll be discussing it later in *Chapter 13, Concurrency*.

Using functions as attributes

One of the interesting effects of functions being objects is that they can be set as callable attributes on other objects. It is possible to add or change a function to an instantiated object:

```
class A:
    def print(self):
        print("my class is A")

def fake_print():
    print("my class is not A")

a = A()
a.print()
a.print = fake_print
a.print()
```

This code creates a very simple class with a `print` method that doesn't tell us anything we didn't know. Then we create a new function that tells us something we don't believe.

When we call `print` on an instance of the `A` class, it behaves as expected. If we then set the `print` method to point at a new function, it tells us something different:

```
my class is A
my class is not A
```

It is also possible to replace methods on classes instead of objects, although in that case we have to add the `self` argument to the parameter list. This will change the method for all instances of that object, even ones that have already been instantiated. Obviously, replacing methods like this can be both dangerous and confusing to maintain. Somebody reading the code will see that a method has been called and look up that method on the original class. But the method on the original class is not the one that was called. Figuring out what really happened can become a tricky, frustrating debugging session.

It does have its uses though. Often, replacing or adding methods at run time (called **monkey-patching**) is used in automated testing. If testing a client-server application, we may not want to actually connect to the server while testing the client; this may result in accidental transfers of funds or embarrassing test e-mails being sent to real people. Instead, we can set up our test code to replace some of the key methods on the object that sends requests to the server, so it only records that the methods have been called.

Monkey-patching can also be used to fix bugs or add features in third-party code that we are interacting with, and does not behave quite the way we need it to. It should, however, be applied sparingly; it's almost always a "messy hack". Sometimes, though, it is the only way to adapt an existing library to suit our needs.

Callable objects

Just as functions are objects that can have attributes set on them, it is possible to create an object that can be called as though it were a function.

Any object can be made callable by simply giving it a `__call__` method that accepts the required arguments. Let's make our `Repeater` class, from the timer example, a little easier to use by making it a callable:

```
class Repeater:
    def __init__(self):
        self.count = 0


    def __call__(self, timer):
        format_time("{now}: repeat {0}", self.count)
        self.count += 1

        timer.call_after(5, self)

timer = Timer()

timer.call_after(5, Repeater())
format_time("{now}: Starting")
timer.run()
```

This example isn't much different from the earlier class; all we did was change the name of the `repeater` function to `__call__` and pass the object itself as a callable. Note that when we make the `call_after` call, we pass the argument `Repeater()`. Those two parentheses are creating a new instance of the class; they are not explicitly calling the class. This happens later, inside the timer. If we want to execute the `__call__` method on a newly instantiated object, we'd use a rather odd syntax: `Repeater()()`. The first set of parentheses constructs the object; the second set executes the `__call__` method. If we find ourselves doing this, we may not be using the correct abstraction. Only implement the `__call__` function on an object if the object is meant to be treated like a function.

Case study

To tie together some of the principles presented in this chapter, let's build a mailing list manager. The manager will keep track of e-mail addresses categorized into named groups. When it's time to send a message, we can pick a group and send the message to all e-mail addresses assigned to that group.

Now, before we start working on this project, we ought to have a safe way to test it, without sending e-mails to a bunch of real people. Luckily, Python has our back here; like the test HTTP server, it has a built-in **Simple Mail Transfer Protocol** (**SMTP**) server that we can instruct to capture any messages we send without actually sending them. We can run the server with the following command:

```
python -m smtpd -n -c DebuggingServer localhost:1025
```

Running this command at a command prompt will start an SMTP server running on port 1025 on the local machine. But we've instructed it to use the `DebuggingServer` class (it comes with the built-in SMTP module), which, instead of sending mails to the intended recipients, simply prints them on the terminal screen as it receives them. Neat, eh?

Now, before writing our mailing list, let's write some code that actually sends mail. Of course, Python supports this in the standard library, too, but it's a bit of an odd interface, so we'll write a new function to wrap it all cleanly:

```
import smtplib
from email.mime.text import MIMEText

def send_email(subject, message, from_addr, *to_addrs,
```

```
            host="localhost", port=1025, **headers):

        email = MIMEText(message)
        email['Subject'] = subject
        email['From'] = from_addr
        for header, value in headers.items():
            email[header] = value

        sender = smtplib.SMTP(host, port)
        for addr in to_addrs:
            del email['To']
            email['To'] = addr
            sender.sendmail(from_addr, addr, email.as_string())
        sender.quit()
```

We won't cover the code inside this method too thoroughly; the documentation in the standard library can give you all the information you need to use the `smtplib` and `email` modules effectively.

We've used both variable argument and keyword argument syntax in the function call. The variable argument list allows us to supply a single string in the default case of having a single `to` address, as well as permitting multiple addresses to be supplied if required. Any extra keyword arguments are mapped to e-mail headers. This is an exciting use of variable arguments and keyword arguments, but it's not really a great interface for the person calling the function. In fact, it makes many things the programmer will want to do impossible.

The headers passed into the function represent auxiliary headers that can be attached to a method. Such headers might include `Reply-To`, `Return-Path`, or *X-pretty-much-anything*. But in order to be a valid identifier in Python, a name cannot include the `-` character. In general, that character represents subtraction. So, it's not possible to call a function with `Reply-To = my@email.com`. It appears we were too eager to use keyword arguments because they are a new tool we just learned about in this chapter.

We'll have to change the argument to a normal dictionary; this will work because any string can be used as a key in a dictionary. By default, we'd want this dictionary to be empty, but we can't make the default parameter an empty dictionary. So, we'll have to make the default argument `None`, and then set up the dictionary at the beginning of the method:

```
def send_email(subject, message, from_addr, *to_addrs,
```

```
            host="localhost", port=1025, headers=None):

        headers = {} if headers is None else headers
```

If we have our debugging SMTP server running in one terminal, we can test this code in a Python interpreter:

```
>>> send_email("A model subject", "The message contents",
 "from@example.com", "to1@example.com", "to2@example.com")
```

Then, if we check the output from the debugging SMTP server, we get the following:

```
---------- MESSAGE FOLLOWS ----------
Content-Type: text/plain; charset="us-ascii"
MIME-Version: 1.0
Content-Transfer-Encoding: 7bit
Subject: A model subject
From: from@example.com
To: to1@example.com
X-Peer: 127.0.0.1

The message contents
------------ END MESSAGE ------------
---------- MESSAGE FOLLOWS ----------
Content-Type: text/plain; charset="us-ascii"
MIME-Version: 1.0
Content-Transfer-Encoding: 7bit
Subject: A model subject
From: from@example.com
To: to2@example.com
X-Peer: 127.0.0.1

The message contents
------------ END MESSAGE ------------
```

Excellent, it has "sent" our e-mail to the two expected addresses with subject and message contents included. Now that we can send messages, let's work on the e-mail group management system. We'll need an object that somehow matches e-mail addresses with the groups they are in. Since this is a many-to-many relationship (any one e-mail address can be in multiple groups; any one group can be associated with multiple e-mail addresses), none of the data structures we've studied seems quite ideal. We could try a dictionary of group-names matched to a list of associated e-mail addresses, but that would duplicate e-mail addresses. We could also try a dictionary of e-mail addresses matched to groups, resulting in a duplication of groups. Neither seems optimal. Let's try this latter version, even though intuition tells me the groups to e-mail address solution would be more straightforward.

Since the values in our dictionary will always be collections of unique e-mail addresses, we should probably store them in a `set` container. We can use `defaultdict` to ensure that there is always a `set` container available for each key:

```
from collections import defaultdict
class MailingList:
    '''Manage groups of e-mail addresses for sending e-mails.'''
    def __init__(self):
        self.email_map = defaultdict(set)

    def add_to_group(self, email, group):
        self.email_map[email].add(group)
```

Now, let's add a method that allows us to collect all the e-mail addresses in one or more groups. This can be done by converting the list of groups to a set:

```
    def emails_in_groups(self, *groups):
        groups = set(groups)
        emails = set()
        for e, g in self.email_map.items():
            if g & groups:
                emails.add(e)
        return emails
```

First, look at what we're iterating over: `self.email_map.items()`. This method, of course, returns a tuple of key-value pairs for each item in the dictionary. The values are sets of strings representing the groups. We split these into two variables named `e` and `g`, short for e-mail and groups. We add the e-mail address to the set of return values only if the passed in groups intersect with the e-mail address groups. The `g & groups` syntax is a shortcut for `g.intersection(groups)`; the `set` class does this by implementing the special `__and__` method to call `intersection`.

This code could be made a wee bit more concise using a set comprehension, which we'll discuss in *Chapter 9, The Iterator Pattern*.

Now, with these building blocks, we can trivially add a method to our `MailingList` class that sends messages to specific groups:

```
def send_mailing(self, subject, message, from_addr,
        *groups, headers=None):
    emails = self.emails_in_groups(*groups)
    send_email(subject, message, from_addr,
            *emails, headers=headers)
```

This function relies on variable argument lists. As input, it takes a list of groups as variable arguments. It gets the list of e-mails for the specified groups and passes those as variable arguments into `send_email`, along with other arguments that were passed into this method.

The program can be tested by ensuring the SMTP debugging server is running in one command prompt, and, in a second prompt, loading the code using:

```
python -i mailing_list.py
```

Create a `MailingList` object with:

```
>>> m = MailingList()
```

Then create a few fake e-mail addresses and groups, along the lines of:

```
>>> m.add_to_group("friend1@example.com", "friends")
>>> m.add_to_group("friend2@example.com", "friends")
>>> m.add_to_group("family1@example.com", "family")
>>> m.add_to_group("pro1@example.com", "professional")
```

Finally, use a command like this to send e-mails to specific groups:

```
>>> m.send_mailing("A Party",
"Friends and family only: a party", "me@example.com", "friends",
"family", headers={"Reply-To": "me2@example.com"})
```

E-mails to each of the addresses in the specified groups should show up in the console on the SMTP server.

The mailing list works fine as it is, but it's kind of useless; as soon as we exit the program, our database of information is lost. Let's modify it to add a couple of methods to load and save the list of e-mail groups from and to a file.

In general, when storing structured data on disk, it is a good idea to put a lot of thought into how it is stored. One of the reasons myriad database systems exist is that if someone else has put this thought into how data is stored, you don't have to. We'll be looking at some data serialization mechanisms in the next chapter, but for this example, let's keep it simple and go with the first solution that could possibly work.

The data format I have in mind is to store each e-mail address followed by a space, followed by a comma-separated list of groups. This format seems reasonable, and we're going to go with it because data formatting isn't the topic of this chapter. However, to illustrate just why you need to think hard about how you format data on disk, let's highlight a few problems with the format.

First, the space character is technically legal in e-mail addresses. Most e-mail providers prohibit it (with good reason), but the specification defining e-mail addresses says an e-mail can contain a space if it is in quotation marks. If we are to use a space as a sentinel in our data format, we should technically be able to differentiate between that space and a space that is part of an e-mail. We're going to pretend this isn't true, for simplicity's sake, but real-life data encoding is full of stupid issues like this. Second, consider the comma-separated list of groups. What happens if someone decides to put a comma in a group name? If we decide to make commas illegal in group names, we should add validation to ensure this to our `add_to_group` method. For pedagogical clarity, we'll ignore this problem too. Finally, there are many security implications we need to consider: can someone get themselves into the wrong group by putting a fake comma in their e-mail address? What does the parser do if it encounters an invalid file?

The takeaway from this discussion is to try to use a data-storage method that has been field tested, rather than designing your own data serialization protocol. There are a ton of bizarre edge cases you might overlook, and it's better to use code that has already encountered and fixed those edge cases.

But forget that, let's just write some basic code that uses an unhealthy dose of wishful thinking to pretend this simple data format is safe:

```
email1@mydomain.com group1,group2
email2@mydomain.com group2,group3
```

The code to do this is as follows:

```
        def save(self):
            with open(self.data_file, 'w') as file:
                for email, groups in self.email_map.items():
                    file.write(
```

```
                    '{} {}\n'.format(email, ','.join(groups))
                )

    def load(self):
        self.email_map = defaultdict(set)
        try:
            with open(self.data_file) as file:
                for line in file:
                    email, groups = line.strip().split(' ')
                    groups = set(groups.split(','))
                    self.email_map[email] = groups
        except IOError:
            pass
```

In the `save` method, we open the file in a context manager and write the file as a formatted string. Remember the newline character; Python doesn't add that for us. The `load` method first resets the dictionary (in case it contains data from a previous call to `load`) uses the `for...in` syntax, which loops over each line in the file. Again, the newline character is included in the line variable, so we have to call `.strip()` to take it off. We'll learn more about such string manipulation in the next chapter.

Before using these methods, we need to make sure the object has a `self.data_file` attribute, which can be done by modifying `__init__`:

```
    def __init__(self, data_file):
        self.data_file = data_file
        self.email_map = defaultdict(set)
```

We can test these two methods in the interpreter as follows:

```
>>> m = MailingList('addresses.db')
>>> m.add_to_group('friend1@example.com', 'friends')
>>> m.add_to_group('family1@example.com', 'friends')
>>> m.add_to_group('family1@example.com', 'family')
>>> m.save()
```

The resulting `addresses.db` file contains the following lines, as expected:

```
friend1@example.com friends
family1@example.com friends,family
```

We can also load this data back into a `MailingList` object successfully:

```
>>> m = MailingList('addresses.db')
>>> m.email_map
defaultdict(<class 'set'>, {})
>>> m.load()
>>> m.email_map
defaultdict(<class 'set'>, {'friend2@example.com': {'friends\n'},
'family1@example.com': {'family\n'}, 'friend1@example.com':
{'friends\n'}})
```

As you can see, I forgot to do the `load` command, and it might be easy to forget the `save` command as well. To make this a little easier for anyone who wants to use our `MailingList` API in their own code, let's provide the methods to support a context manager:

```
    def __enter__(self):
        self.load()
        return self

    def __exit__(self, type, value, tb):
        self.save()
```

These simple methods just delegate their work to load and save, but we can now write code like this in the interactive interpreter and know that all the previously stored addresses were loaded on our behalf, and that the whole list will be saved to the file when we are done:

```
>>> with MailingList('addresses.db') as ml:
...     ml.add_to_group('friend2@example.com', 'friends')
...     ml.send_mailing("What's up", "hey friends, how's it going", 'me@
example.com', 'friends')
```

Exercises

If you haven't encountered the `with` statements and context managers before, I encourage you, as usual, to go through your old code and find all the places you were opening files, and make sure they are safely closed using the `with` statement. Look for places that you could write your own context managers as well. Ugly or repetitive `try...finally` clauses are a good place to start, but you may find them useful any time you need to do before and/or after tasks in context.

You've probably used many of the basic built-in functions before now. We covered several of them, but didn't go into a great deal of detail. Play with `enumerate`, `zip`, `reversed`, `any` and `all`, until you know you'll remember to use them when they are the right tool for the job. The `enumerate` function is especially important; because not using it results in some pretty ugly code.

Also explore some applications that pass functions around as callable objects, as well as using the `__call__` method to make your own objects callable. You can get the same effect by attaching attributes to functions or by creating a `__call__` method on an object. In which case would you use one syntax, and when would it be more suitable to use the other?

Our mailing list object could overwhelm an e-mail server if there is a massive number of e-mails to be sent out. Try refactoring it so that you can use different `send_email` functions for different purposes. One such function could be the version we used here. A different version might put the e-mails in a queue to be sent by a server in a different thread or process. A third version could just output the data to the terminal, obviating the need for a dummy SMTP server. Can you construct the mailing list with a callback such that the `send_mailing` function uses whatever is passed in? It would default to the current version if no callback is supplied.

The relationship between arguments, keyword arguments, variable arguments, and variable keyword arguments can be a bit confusing. We saw how painfully they can interact when we covered multiple inheritance. Devise some other examples to see how they can work well together, as well as to understand when they don't.

Summary

We covered a grab bag of topics in this chapter. Each represented an important non-object-oriented feature that is popular in Python. Just because we can use object-oriented principles does not always mean we should!

However, we also saw that Python typically implements such features by providing a syntax shortcut to traditional object-oriented syntax. Knowing the object-oriented principles underlying these tools allows us to use them more effectively in our own classes.

We discussed a series of built-in functions and file I/O operations. There are a whole bunch of different syntaxes available to us when calling functions with arguments, keyword arguments, and variable argument lists. Context managers are useful for the common pattern of sandwiching a piece of code between two method calls. Even functions are objects, and, conversely, any normal object can be made callable.

In the next chapter, we'll learn more about string and file manipulation, and even spend some time with one of the least object-oriented topics in the standard library: regular expressions.

8
Strings and Serialization

Before we get involved with higher level design patterns, let's take a deep dive into one of Python's most common objects: the string. We'll see that there is a lot more to the string than meets the eye, and also cover searching strings for patterns and serializing data for storage or transmission.

In particular, we'll visit:

- The complexities of strings, bytes, and byte arrays
- The ins and outs of string formatting
- A few ways to serialize data
- The mysterious regular expression

Strings

Strings are a basic primitive in Python; we've used them in nearly every example we've discussed so far. All they do is represent an immutable sequence of characters. However, though you may not have considered it before, "character" is a bit of an ambiguous word; can Python strings represent sequences of accented characters? Chinese characters? What about Greek, Cyrillic, or Farsi?

In Python 3, the answer is yes. Python strings are all represented in Unicode, a character definition standard that can represent virtually any character in any language on the planet (and some made-up languages and random characters as well). This is done seamlessly, for the most part. So, let's think of Python 3 strings as an immutable sequence of Unicode characters. So what can we do with this immutable sequence? We've touched on many of the ways strings can be manipulated in previous examples, but let's quickly cover it all in one place: a crash course in string theory!

String manipulation

As you know, strings can be created in Python by wrapping a sequence of characters in single or double quotes. Multiline strings can easily be created using three quote characters, and multiple hardcoded strings can be concatenated together by placing them side by side. Here are some examples:

```
a = "hello"
b = 'world'
c = '''a multiple
line string'''
d = """More
multiple"""
e = ("Three " "Strings "
        "Together")
```

That last string is automatically composed into a single string by the interpreter. It is also possible to concatenate strings using the `+` operator (as in `"hello " + "world"`). Of course, strings don't have to be hardcoded. They can also come from various outside sources such as text files, user input, or encoded on the network.

The automatic concatenation of adjacent strings can make for some hilarious bugs when a comma is missed. It is, however, extremely useful when a long string needs to be placed inside a function call without exceeding the 79 character line-length limit suggested by the Python style guide.

Like other sequences, strings can be iterated over (character by character), indexed, sliced, or concatenated. The syntax is the same as for lists.

The `str` class has numerous methods on it to make manipulating strings easier. The `dir` and `help` commands in the Python interpreter can tell us how to use all of them; we'll consider some of the more common ones directly.

Several Boolean convenience methods help us identify whether or not the characters in a string match a certain pattern. Here is a summary of these methods. Most of these, such as `isalpha`, `isupper`/`islower`, and `startswith`/`endswith` have obvious interpretations. The `isspace` method is also fairly obvious, but remember that all whitespace characters (including tab, newline) are considered, not just the space character.

The `istitle` method returns `True` if the first character of each word is capitalized and all other characters are lowercase. Note that it does not strictly enforce the English grammatical definition of title formatting. For example, Leigh Hunt's poem "The Glove and the Lions" should be a valid title, even though not all words are capitalized. Robert Service's "The Cremation of Sam McGee" should also be a valid title, even though there is an uppercase letter in the middle of the last word.

Be careful with the `isdigit`, `isdecimal`, and `isnumeric` methods, as they are more nuanced than you would expect. Many Unicode characters are considered numbers besides the ten digits we are used to. Worse, the period character that we use to construct floats from strings is not considered a decimal character, so `'45.2'.isdecimal()` returns `False`. The real decimal character is represented by Unicode value 0660, as in 45.2, (or `45\u06602`). Further, these methods do not verify whether the strings are valid numbers; "127.0.0.1" returns `True` for all three methods. We might think we should use that decimal character instead of a period for all numeric quantities, but passing that character into the `float()` or `int()` constructor converts that decimal character to a zero:

```
>>> float('45\u06602')
4502.0
```

Other methods useful for pattern matching do not return Booleans. The `count` method tells us how many times a given substring shows up in the string, while `find`, `index`, `rfind`, and `rindex` tell us the position of a given substring within the original string. The two 'r' (for 'right' or 'reverse') methods start searching from the end of the string. The `find` methods return `-1` if the substring can't be found, while `index` raises a `ValueError` in this situation. Have a look at some of these methods in action:

```
>>> s = "hello world"
>>> s.count('l')
3
>>> s.find('l')
2
>>> s.rindex('m')
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
ValueError: substring not found
```

Most of the remaining string methods return transformations of the string. The `upper`, `lower`, `capitalize`, and `title` methods create new strings with all alphabetic characters in the given format. The `translate` method can use a dictionary to map arbitrary input characters to specified output characters.

For all of these methods, note that the input string remains unmodified; a brand new `str` instance is returned instead. If we need to manipulate the resultant string, we should assign it to a new variable, as in `new_value = value.capitalize()`. Often, once we've performed the transformation, we don't need the old value anymore, so a common idiom is to assign it to the same variable, as in `value = value.title()`.

Finally, a couple of string methods return or operate on lists. The `split` method accepts a substring and splits the string into a list of strings wherever that substring occurs. You can pass a number as a second parameter to limit the number of resultant strings. The `rsplit` behaves identically to `split` if you don't limit the number of strings, but if you do supply a limit, it starts splitting from the end of the string. The `partition` and `rpartition` methods split the string at only the first or last occurrence of the substring, and return a tuple of three values: characters before the substring, the substring itself, and the characters after the substring.

As the inverse of `split`, the `join` method accepts a list of strings, and returns all of those strings combined together by placing the original string between them. The `replace` method accepts two arguments, and returns a string where each instance of the first argument has been replaced with the second. Here are some of these methods in action:

```
>>> s = "hello world, how are you"
>>> s2 = s.split(' ')
>>> s2
['hello', 'world,', 'how', 'are', 'you']
>>> '#'.join(s2)
'hello#world,#how#are#you'
>>> s.replace(' ', '**')
'hello**world,**how**are**you'
>>> s.partition(' ')
('hello', ' ', 'world, how are you')
```

There you have it, a whirlwind tour of the most common methods on the `str` class! Now, let's look at Python 3's method for composing strings and variables to create new strings.

String formatting

Python 3 has a powerful string formatting and templating mechanism that allows us to construct strings comprised of hardcoded text and interspersed variables. We've used it in many previous examples, but it is much more versatile than the simple formatting specifiers we've used.

Any string can be turned into a format string by calling the `format()` method on it. This method returns a new string where specific characters in the input string have been replaced with values provided as arguments and keyword arguments passed into the function. The `format` method does not require a fixed set of arguments; internally, it uses the `*args` and `**kwargs` syntax that we discussed in *Chapter 7*, *Python Object-oriented Shortcuts*.

The special characters that are replaced in formatted strings are the opening and closing brace characters: { and }. We can insert pairs of these in a string and they will be replaced, in order, by any positional arguments passed to the `str.format` method:

```
template = "Hello {}, you are currently {}."
print(template.format('Dusty', 'writing'))
```

If we run these statements, it replaces the braces with variables, in order:

```
Hello Dusty, you are currently writing.
```

This basic syntax is not terribly useful if we want to reuse variables within one string or decide to use them in a different position. We can place zero-indexed integers inside the curly braces to tell the formatter which positional variable gets inserted at a given position in the string. Let's repeat the name:

```
template = "Hello {0}, you are {1}. Your name is {0}."
print(template.format('Dusty', 'writing'))
```

If we use these integer indexes, we have to use them in all the variables. We can't mix empty braces with positional indexes. For example, this code fails with an appropriate `ValueError` exception:

```
template = "Hello {}, you are {}. Your name is {0}."
print(template.format('Dusty', 'writing'))
```

Escaping braces

Brace characters are often useful in strings, aside from formatting. We need a way to escape them in situations where we want them to be displayed as themselves, rather than being replaced. This can be done by doubling the braces. For example, we can use Python to format a basic Java program:

```
template = """
public class {0} {{
    public static void main(String[] args) {{
        System.out.println("{1}");
    }}
}}"""

print(template.format("MyClass", "print('hello world')"));
```

Wherever we see the {{ or }} sequence in the template, that is, the braces enclosing the Java class and method definition, we know the `format` method will replace them with single braces, rather than some argument passed into the `format` method. Here's the output:

```
public class MyClass {
    public static void main(String[] args) {
        System.out.println("print('hello world')");
    }
}
```

The class name and contents of the output have been replaced with two parameters, while the double braces have been replaced with single braces, giving us a valid Java file. Turns out, this is about the simplest possible Python program to print the simplest possible Java program that can print the simplest possible Python program!

Keyword arguments

If we're formatting complex strings, it can become tedious to remember the order of the arguments or to update the template if we choose to insert a new argument. The `format` method therefore allows us to specify names inside the braces instead of numbers. The named variables are then passed to the `format` method as keyword arguments:

```
template = """
From: <{from_email}>
To: <{to_email}>
Subject: {subject}

{message}"""
print(template.format(
    from_email = "a@example.com",
    to_email = "b@example.com",
    message = "Here's some mail for you. "
    " Hope you enjoy the message!",
    subject = "You have mail!"
    ))
```

We can also mix index and keyword arguments (as with all Python function calls, the keyword arguments must follow the positional ones). We can even mix unlabeled positional braces with keyword arguments:

```
print("{} {label} {}".format("x", "y", label="z"))
```

As expected, this code outputs:

```
x z y
```

Container lookups

We aren't restricted to passing simple string variables into the `format` method. Any primitive, such as integers or floats can be printed. More interestingly, complex objects, including lists, tuples, dictionaries, and arbitrary objects can be used, and we can access indexes and variables (but not methods) on those objects from within the `format` string.

For example, if our e-mail message had grouped the from and to e-mail addresses into a tuple, and placed the subject and message in a dictionary, for some reason (perhaps because that's the input required for an existing `send_mail` function we want to use), we can format it like this:

```
emails = ("a@example.com", "b@example.com")
message = {
        'subject': "You Have Mail!",
        'message': "Here's some mail for you!"
        }
template = """
From: <{0[0]}>
To: <{0[1]}>
Subject: {message[subject]}
{message[message]}"""
print(template.format(emails, message=message))
```

The variables inside the braces in the template string look a little weird, so let's look at what they're doing. We have passed one argument as a position-based parameter and one as a keyword argument. The two e-mail addresses are looked up by `0[x]`, where `x` is either `0` or `1`. The initial zero represents, as with other position-based arguments, the first positional argument passed to `format` (the `emails` tuple, in this case).

The square brackets with a number inside are the same kind of index lookup we see in regular Python code, so `0[0]` maps to `emails[0]`, in the `emails` tuple. The indexing syntax works with any indexable object, so we see similar behavior when we access `message[subject]`, except this time we are looking up a string key in a dictionary. Notice that unlike in Python code, we do not need to put quotes around the string in the dictionary lookup.

We can even do multiple levels of lookup if we have nested data structures. I would recommend against doing this often, as template strings rapidly become difficult to understand. If we have a dictionary that contains a tuple, we can do this:

```
emails = ("a@example.com", "b@example.com")
message = {
        'emails': emails,
        'subject': "You Have Mail!",
        'message': "Here's some mail for you!"
        }
template = """
From: <{0[emails][0]}>
To: <{0[emails][1]}>
Subject: {0[subject]}
{0[message]}"""
print(template.format(message))
```

Object lookups

Indexing makes `format` lookup powerful, but we're not done yet! We can also pass arbitrary objects as parameters, and use the dot notation to look up attributes on those objects. Let's change our e-mail message data once again, this time to a class:

```
class EMail:
    def __init__(self, from_addr, to_addr, subject, message):
        self.from_addr = from_addr
        self.to_addr = to_addr
        self.subject = subject
        self.message = message

email = EMail("a@example.com", "b@example.com",
        "You Have Mail!",
         "Here's some mail for you!")

template = """
From: <{0.from_addr}>
To: <{0.to_addr}>
Subject: {0.subject}

{0.message}"""
print(template.format(email))
```

The template in this example may be more readable than the previous examples, but the overhead of creating an e-mail class adds complexity to the Python code. It would be foolish to create a class for the express purpose of including the object in a template. Typically, we'd use this sort of lookup if the object we are trying to format already exists. This is true of all the examples; if we have a tuple, list, or dictionary, we'll pass it into the template directly. Otherwise, we'd just create a simple set of positional and keyword arguments.

Making it look right

It's nice to be able to include variables in template strings, but sometimes the variables need a bit of coercion to make them look right in the output. For example, if we are doing calculations with currency, we may end up with a long decimal that we don't want to show up in our template:

```
subtotal = 12.32
tax = subtotal * 0.07
total = subtotal + tax

print("Sub: ${0} Tax: ${1} Total: ${total}".format(
    subtotal, tax, total=total))
```

If we run this formatting code, the output doesn't quite look like proper currency:

```
Sub: $12.32 Tax: $0.8624 Total: $13.182400000000001
```

Technically, we should never use floating-point numbers in currency calculations like this; we should construct `decimal.Decimal()` objects instead. Floats are dangerous because their calculations are inherently inaccurate beyond a specific level of precision. But we're looking at strings, not floats, and currency is a great example for formatting!

To fix the preceding `format` string, we can include some additional information inside the curly braces to adjust the formatting of the parameters. There are tons of things we can customize, but the basic syntax inside the braces is the same; first, we use whichever of the earlier layouts (positional, keyword, index, attribute access) is suitable to specify the variable that we want to place in the template string. We follow this with a colon, and then the specific syntax for the formatting. Here's an improved version:

```
print("Sub: ${0:0.2f} Tax: ${1:0.2f} "
        "Total: ${total:0.2f}".format(
            subtotal, tax, total=total))
```

The `0.2f` format specifier after the colons basically says, from left to right: for values lower than one, make sure a zero is displayed on the left side of the decimal point; show two places after the decimal; format the input value as a float.

We can also specify that each number should take up a particular number of characters on the screen by placing a value before the period in the precision. This can be useful for outputting tabular data, for example:

```
orders = [('burger', 2, 5),
        ('fries', 3.5, 1),
        ('cola', 1.75, 3)]

print("PRODUCT    QUANTITY    PRICE    SUBTOTAL")
for product, price, quantity in orders:
    subtotal = price * quantity
    print("{0:10s}{1: ^9d}    ${2: <8.2f}${3: >7.2f}".format(
        product, quantity, price, subtotal))
```

Ok, that's a pretty scary looking format string, so let's see how it works before we break it down into understandable parts:

```
PRODUCT    QUANTITY    PRICE    SUBTOTAL
burger        5        $2.00    $  10.00
fries         1        $3.50    $   3.50
cola          3        $1.75    $   5.25
```

Nifty! So, how is this actually happening? We have four variables we are formatting, in each line in the `for` loop. The first variable is a string and is formatted with `{0:10s}`. The `s` means it is a string variable, and the `10` means it should take up ten characters. By default, with strings, if the string is shorter than the specified number of characters, it appends spaces to the right side of the string to make it long enough (beware, however: if the original string is too long, it won't be truncated!). We can change this behavior (to fill with other characters or change the alignment in the format string), as we do for the next value, `quantity`.

The formatter for the `quantity` value is `{1: ^9d}`. The `d` represents an integer value. The `9` tells us the value should take up nine characters. But with integers, instead of spaces, the extra characters are zeros, by default. That looks kind of weird. So we explicitly specify a space (immediately after the colon) as a padding character. The caret character ^ tells us that the number should be aligned in the center of this available padding; this makes the column look a bit more professional. The specifiers have to be in the right order, although all are optional: fill first, then align, then the size, and finally, the type.

We do similar things with the specifiers for price and subtotal. For `price`, we use `{2:<8.2f}` and for `subtotal`, `{3:>7.2f}`. In both cases, we're specifying a space as the fill character, but we use the `<` and `>` symbols, respectively, to represent that the numbers should be aligned to the left or right within the minimum space of eight or seven characters. Further, each float should be formatted to two decimal places.

The "type" character for different types can affect formatting output as well. We've seen the `s`, `d`, and `f` types, for strings, integers, and floats. Most of the other format specifiers are alternative versions of these; for example, `o` represents octal format and `X` represents hexadecimal for integers. The `n` type specifier can be useful for formatting integer separators in the current locale's format. For floating-point numbers, the `%` type will multiply by 100 and format a float as a percentage.

While these standard formatters apply to most built-in objects, it is also possible for other objects to define nonstandard specifiers. For example, if we pass a `datetime` object into `format`, we can use the specifiers used in the `datetime.strftime` function, as follows:

```
import datetime
print("{0:%Y-%m-%d %I:%M%p }".format(
    datetime.datetime.now()))
```

It is even possible to write custom formatters for objects we create ourselves, but that is beyond the scope of this book. Look into overriding the `__format__` special method if you need to do this in your code. The most comprehensive instructions can be found in PEP 3101 at `http://www.python.org/dev/peps/pep-3101/`, although the details are a bit dry. You can find more digestible tutorials using a web search.

The Python formatting syntax is quite flexible but it is a difficult mini-language to remember. I use it every day and still occasionally have to look up forgotten concepts in the documentation. It also isn't powerful enough for serious templating needs, such as generating web pages. There are several third-party templating libraries you can look into if you need to do more than basic formatting of a few strings.

Strings are Unicode

At the beginning of this section, we defined strings as collections of immutable Unicode characters. This actually makes things very complicated at times, because Unicode isn't really a storage format. If you get a string of bytes from a file or a socket, for example, they won't be in Unicode. They will, in fact, be the built-in type `bytes`. Bytes are immutable sequences of... well, bytes. Bytes are the lowest-level storage format in computing. They represent 8 bits, usually described as an integer between 0 and 255, or a hexadecimal equivalent between 0 and FF. Bytes don't represent anything specific; a sequence of bytes may store characters of an encoded string, or pixels in an image.

If we print a byte object, any bytes that map to ASCII representations will be printed as their original character, while non-ASCII bytes (whether they are binary data or other characters) are printed as hex codes escaped by the `\x` escape sequence. You may find it odd that a byte, represented as an integer, can map to an ASCII character. But ASCII is really just a code where each letter is represented by a different byte pattern, and therefore, a different integer. The character "a" is represented by the same byte as the integer 97, which is the hexadecimal number 0x61. Specifically, all of these are an interpretation of the binary pattern 01100001.

Many I/O operations only know how to deal with `bytes`, even if the bytes object refers to textual data. It is therefore vital to know how to convert between `bytes` and Unicode.

The problem is that there are many ways to map `bytes` to Unicode text. Bytes are machine-readable values, while text is a human-readable format. Sitting in between is an encoding that maps a given sequence of bytes to a given sequence of text characters.

However, there are multiple such encodings (ASCII is only one of them). The same sequence of bytes represents completely different text characters when mapped using different encodings! So, `bytes` must be decoded using the same character set with which they were encoded. It's not possible to get text from bytes without knowing how the bytes should be decoded. If we receive unknown bytes without a specified encoding, the best we can do is guess what format they are encoded in, and we may be wrong.

Converting bytes to text

If we have an array of `bytes` from somewhere, we can convert it to Unicode using the `.decode` method on the `bytes` class. This method accepts a string for the name of the character encoding. There are many such names; common ones for Western languages include ASCII, UTF-8, and latin-1.

The sequence of bytes (in hex), 63 6c 69 63 68 e9, actually represents the characters of the word cliché in the latin-1 encoding. The following example will encode this sequence of bytes and convert it to a Unicode string using the latin-1 encoding:

```
characters = b'\x63\x6c\x69\x63\x68\xe9'
print(characters)
print(characters.decode("latin-1"))
```

The first line creates a `bytes` object; the `b` character immediately before the string tells us that we are defining a `bytes` object instead of a normal Unicode string. Within the string, each byte is specified using—in this case—a hexadecimal number. The `\x` character escapes within the byte string, and each say, "the next two characters represent a byte using hexadecimal digits."

Provided we are using a shell that understands the latin-1 encoding, the two `print` calls will output the following strings:

```
b'clich\xe9'
cliché
```

The first `print` statement renders the bytes for ASCII characters as themselves. The unknown (unknown to ASCII, that is) character stays in its escaped hex format. The output includes a `b` character at the beginning of the line to remind us that it is a `bytes` representation, not a string.

The next call decodes the string using latin-1 encoding. The `decode` method returns a normal (Unicode) string with the correct characters. However, if we had decoded this same string using the Cyrillic "iso8859-5" encoding, we'd have ended up with the string 'clichщ'! This is because the `\xe9` byte maps to different characters in the two encodings.

Converting text to bytes

If we need to convert incoming bytes into Unicode, clearly we're also going to have situations where we convert outgoing Unicode into byte sequences. This is done with the `encode` method on the `str` class, which, like the `decode` method, requires a character set. The following code creates a Unicode string and encodes it in different character sets:

```
characters = "cliché"
print(characters.encode("UTF-8"))
print(characters.encode("latin-1"))
print(characters.encode("CP437"))
print(characters.encode("ascii"))
```

The first three encodings create a different set of bytes for the accented character. The fourth one can't even handle that byte:

```
b'clich\xc3\xa9'
b'clich\xe9'
b'clich\x82'
Traceback (most recent call last):
```

```
  File "1261_10_16_decode_unicode.py", line 5, in <module>
    print(characters.encode("ascii"))
UnicodeEncodeError: 'ascii' codec can't encode character '\xe9' in
position 5: ordinal not in range(128)
```

Do you understand the importance of encoding now? The accented character is represented as a different byte for each encoding; if we use the wrong one when we are decoding bytes to text, we get the wrong character.

The exception in the last case is not always the desired behavior; there may be cases where we want the unknown characters to be handled in a different way. The `encode` method takes an optional string argument named `errors` that can define how such characters should be handled. This string can be one of the following:

- `strict`
- `replace`
- `ignore`
- `xmlcharrefreplace`

The `strict` replacement strategy is the default we just saw. When a byte sequence is encountered that does not have a valid representation in the requested encoding, an exception is raised. When the `replace` strategy is used, the character is replaced with a different character; in ASCII, it is a question mark; other encodings may use different symbols, such as an empty box. The `ignore` strategy simply discards any bytes it doesn't understand, while the `xmlcharrefreplace` strategy creates an `xml` entity representing the Unicode character. This can be useful when converting unknown strings for use in an XML document. Here's how each of the strategies affects our sample word:

Strategy	"cliché".encode("ascii", strategy)
`replace`	`b'clich?'`
`ignore`	`b'clich'`
`xmlcharrefreplace`	`b'clich&#233;'`

It is possible to call the `str.encode` and `bytes.decode` methods without passing an encoding string. The encoding will be set to the default encoding for the current platform. This will depend on the current operating system and locale or regional settings; you can look it up using the `sys.getdefaultencoding()` function. It is usually a good idea to specify the encoding explicitly, though, since the default encoding for a platform may change, or the program may one day be extended to work on text from a wider variety of sources.

If you are encoding text and don't know which encoding to use, it is best to use the UTF-8 encoding. UTF-8 is able to represent any Unicode character. In modern software, it is a de facto standard encoding to ensure documents in any language—or even multiple languages—can be exchanged. The various other possible encodings are useful for legacy documents or in regions that still use different character sets by default.

The UTF-8 encoding uses one byte to represent ASCII and other common characters, and up to four bytes for more complex characters. UTF-8 is special because it is backwards-compatible with ASCII; any ASCII document encoded using UTF-8 will be identical to the original ASCII document.

I can never remember whether to use `encode` or `decode` to convert from binary bytes to Unicode. I always wished these methods were named "to_binary" and "from_binary" instead. If you have the same problem, try mentally replacing the word "code" with "binary"; "enbinary" and "debinary" are pretty close to "to_binary" and "from_binary". I have saved a lot of time by not looking up the method help files since devising this mnemonic.

Mutable byte strings

The `bytes` type, like `str`, is immutable. We can use index and slice notation on a `bytes` object and search for a particular sequence of bytes, but we can't extend or modify them. This can be very inconvenient when dealing with I/O, as it is often necessary to buffer incoming or outgoing bytes until they are ready to be sent. For example, if we are receiving data from a socket, it may take several `recv` calls before we have received an entire message.

This is where the `bytearray` built-in comes in. This type behaves something like a list, except it only holds bytes. The constructor for the class can accept a `bytes` object to initialize it. The `extend` method can be used to append another `bytes` object to the existing array (for example, when more data comes from a socket or other I/O channel).

Slice notation can be used on `bytearray` to modify the item inline. For example, this code constructs a `bytearray` from a `bytes` object and then replaces two bytes:

```
b = bytearray(b"abcdefgh")
b[4:6] = b"\x15\xa3"
print(b)
```

The output looks like this:

```
bytearray(b'abcd\x15\xa3gh')
```

Be careful; if we want to manipulate a single element in the `bytearray`, it will expect us to pass an integer between 0 and 255 inclusive as the value. This integer represents a specific `bytes` pattern. If we try to pass a character or `bytes` object, it will raise an exception.

A single byte character can be converted to an integer using the `ord` (short for ordinal) function. This function returns the integer representation of a single character:

```
b = bytearray(b'abcdef')
b[3] = ord(b'g')
b[4] = 68
print(b)
```

The output looks like this:

```
bytearray(b'abcgDf')
```

After constructing the array, we replace the character at index `3` (the fourth character, as indexing starts at `0`, as with lists) with byte 103. This integer was returned by the `ord` function and is the ASCII character for the lowercase `g`. For illustration, we also replaced the next character up with the byte number `68`, which maps to the ASCII character for the uppercase `D`.

The `bytearray` type has methods that allow it to behave like a list (we can append integer bytes to it, for example), but also like a `bytes` object; we can use methods like `count` and `find` the same way they would behave on a `bytes` or `str` object. The difference is that `bytearray` is a mutable type, which can be useful for building up complex sequences of bytes from a specific input source.

Regular expressions

You know what's really hard to do using object-oriented principles? Parsing strings to match arbitrary patterns, that's what. There have been a fair number of academic papers written in which object-oriented design is used to set up string parsing, but the result is always very verbose and hard to read, and they are not widely used in practice.

In the real world, string parsing in most programming languages is handled by regular expressions. These are not verbose, but, boy, are they ever hard to read, at least until you learn the syntax. Even though regular expressions are not object oriented, the Python regular expression library provides a few classes and objects that you can use to construct and run regular expressions.

Regular expressions are used to solve a common problem: Given a string, determine whether that string matches a given pattern and, optionally, collect substrings that contain relevant information. They can be used to answer questions like:

- Is this string a valid URL?
- What is the date and time of all warning messages in a log file?
- Which users in `/etc/passwd` are in a given group?
- What username and document were requested by the URL a visitor typed?

There are many similar scenarios where regular expressions are the correct answer. Many programmers have made the mistake of implementing complicated and fragile string parsing libraries because they didn't know or wouldn't learn regular expressions. In this section, we'll gain enough knowledge of regular expressions to not make such mistakes!

Matching patterns

Regular expressions are a complicated mini-language. They rely on special characters to match unknown strings, but let's start with literal characters, such as letters, numbers, and the space character, which always match themselves. Let's see a basic example:

```
import re

search_string = "hello world"
pattern = "hello world"

match = re.match(pattern, search_string)

if match:
    print("regex matches")
```

The Python Standard Library module for regular expressions is called `re`. We import it and set up a search string and pattern to search for; in this case, they are the same string. Since the search string matches the given pattern, the conditional passes and the `print` statement executes.

Bear in mind that the `match` function matches the pattern to the beginning of the string. Thus, if the pattern were `"ello world"`, no match would be found. With confusing asymmetry, the parser stops searching as soon as it finds a match, so the pattern `"hello wo"` matches successfully. Let's build a small example program to demonstrate these differences and help us learn other regular expression syntax:

```
import sys
```

```
import re

pattern = sys.argv[1]
search_string = sys.argv[2]
match = re.match(pattern, search_string)

if match:
    template = "'{}' matches pattern '{}'"
else:
    template = "'{}' does not match pattern '{}'"

print(template.format(search_string, pattern))
```

This is just a generic version of the earlier example that accepts the pattern and search string from the command line. We can see how the start of the pattern must match, but a value is returned as soon as a match is found in the following command-line interaction:

```
$ python regex_generic.py "hello worl" "hello world"
'hello world' matches pattern 'hello worl'
$ python regex_generic.py "ello world" "hello world"
'hello world' does not match pattern 'ello world'
```

We'll be using this script throughout the next few sections. While the script is always invoked with the command line `python regex_generic.py "<pattern>" "<string>"`, we'll only see the output in the following examples, to conserve space.

If you need control over whether items happen at the beginning or end of a line (or if there are no newlines in the string, at the beginning and end of the string), you can use the `^` and `$` characters to represent the start and end of the string respectively. If you want a pattern to match an entire string, it's a good idea to include both of these:

```
'hello world' matches pattern '^hello world$'
'hello worl' does not match pattern '^hello world$'
```

Matching a selection of characters

Let's start with matching an arbitrary character. The period character, when used in a regular expression pattern, can match any single character. Using a period in the string means you don't care what the character is, just that there is a character there. For example:

```
'hello world' matches pattern 'hel.o world'
'helpo world' matches pattern 'hel.o world'
```

```
'hel o world' matches pattern 'hel.o world'
'helo world' does not match pattern 'hel.o world'
```

Notice how the last example does not match because there is no character at the period's position in the pattern.

That's all well and good, but what if we only want a few specific characters to match? We can put a set of characters inside square brackets to match any one of those characters. So if we encounter the string `[abc]` in a regular expression pattern, we know that those five (including the two square brackets) characters will only match one character in the string being searched, and further, that this one character will be either an `a`, a `b`, or a `c`. See a few examples:

```
'hello world' matches pattern 'hel[lp]o world'
'helpo world' matches pattern 'hel[lp]o world'
'helPo world' does not match pattern 'hel[lp]o world'
```

These square bracket sets should be named character sets, but they are more often referred to as **character classes**. Often, we want to include a large range of characters inside these sets, and typing them all out can be monotonous and error-prone. Fortunately, the regular expression designers thought of this and gave us a shortcut. The dash character, in a character set, will create a range. This is especially useful if you want to match "all lower case letters", "all letters", or "all numbers" as follows:

```
'hello   world' does not match pattern 'hello [a-z] world'
'hello b world' matches pattern 'hello [a-z] world'
'hello B world' matches pattern 'hello [a-zA-Z] world'
'hello 2 world' matches pattern 'hello [a-zA-Z0-9] world'
```

There are other ways to match or exclude individual characters, but you'll need to find a more comprehensive tutorial via a web search if you want to find out what they are!

Escaping characters

If putting a period character in a pattern matches any arbitrary character, how do we match just a period in a string? One way might be to put the period inside square brackets to make a character class, but a more generic method is to use backslashes to escape it. Here's a regular expression to match two digit decimal numbers between 0.00 and 0.99:

```
'0.05' matches pattern '0\.[0-9][0-9]'
'005' does not match pattern '0\.[0-9][0-9]'
'0,05' does not match pattern '0\.[0-9][0-9]'
```

For this pattern, the two characters `\.` match the single `.` character. If the period character is missing or is a different character, it does not match.

This backslash escape sequence is used for a variety of special characters in regular expressions. You can use `\[` to insert a square bracket without starting a character class, and `\(` to insert a parenthesis, which we'll later see is also a special character.

More interestingly, we can also use the escape symbol followed by a character to represent special characters such as newlines (`\n`), and tabs (`\t`). Further, some character classes can be represented more succinctly using escape strings; `\s` represents whitespace characters, `\w` represents letters, numbers, and underscore, and `\d` represents a digit:

```
'(abc]' matches pattern '\(abc\]'
' 1a' matches pattern '\s\d\w'
'\t5n' does not match pattern '\s\d\w'
'5n' matches pattern '\s\d\w'
```

Matching multiple characters

With this information, we can match most strings of a known length, but most of the time we don't know how many characters to match inside a pattern. Regular expressions can take care of this, too. We can modify a pattern by appending one of several hard-to-remember punctuation symbols to match multiple characters.

The asterisk (`*`) character says that the previous pattern can be matched zero or more times. This probably sounds silly, but it's one of the most useful repetition characters. Before we explore why, consider some silly examples to make sure we understand what it does:

```
'hello' matches pattern 'hel*o'
'heo' matches pattern 'hel*o'
'hellllllo' matches pattern 'hel*o'
```

So, the `*` character in the pattern says that the previous pattern (the `l` character) is optional, and if present, can be repeated as many times as possible to match the pattern. The rest of the characters (`h`, `e`, and `o`) have to appear exactly once.

It's pretty rare to want to match a single letter multiple times, but it gets more interesting if we combine the asterisk with patterns that match multiple characters. `.*`, for example, will match any string, whereas `[a-z]*` matches any collection of lowercase words, including the empty string.

For example:

```
'A string.' matches pattern '[A-Z][a-z]* [a-z]*\.'
'No .' matches pattern '[A-Z][a-z]* [a-z]*\.'
'' matches pattern '[a-z]*.*'
```

The plus (+) sign in a pattern behaves similarly to an asterisk; it states that the previous pattern can be repeated one or more times, but, unlike the asterisk is not optional. The question mark (?) ensures a pattern shows up exactly zero or one times, but not more. Let's explore some of these by playing with numbers (remember that `\d` matches the same character class as `[0-9]`:

```
'0.4' matches pattern '\d+\.\d+'
'1.002' matches pattern '\d+\.\d+'
'1.' does not match pattern '\d+\.\d+'
'1%' matches pattern '\d?\d%'
'99%' matches pattern '\d?\d%'
'999%' does not match pattern '\d?\d%'
```

Grouping patterns together

So far we've seen how we can repeat a pattern multiple times, but we are restricted in what patterns we can repeat. If we want to repeat individual characters, we're covered, but what if we want a repeating sequence of characters? Enclosing any set of patterns in parenthesis allows them to be treated as a single pattern when applying repetition operations. Compare these patterns:

```
'abccc' matches pattern 'abc{3}'
'abccc' does not match pattern '(abc){3}'
'abcabcabc' matches pattern '(abc){3}'
```

Combined with complex patterns, this grouping feature greatly expands our pattern-matching repertoire. Here's a regular expression that matches simple English sentences:

```
'Eat.' matches pattern '[A-Z][a-z]*( [a-z]+)*\.$'
'Eat more good food.' matches pattern '[A-Z][a-z]*( [a-z]+)*\.$'
'A good meal.' matches pattern '[A-Z][a-z]*( [a-z]+)*\.$'
```

The first word starts with a capital, followed by zero or more lowercase letters. Then, we enter a parenthetical that matches a single space followed by a word of one or more lowercase letters. This entire parenthetical is repeated zero or more times, and the pattern is terminated with a period. There cannot be any other characters after the period, as indicated by the `$` matching the end of string.

We've seen many of the most basic patterns, but the regular expression language supports many more. I spent my first few years using regular expressions looking up the syntax every time I needed to do something. It is worth bookmarking Python's documentation for the `re` module and reviewing it frequently. There are very few things that regular expressions cannot match, and they should be the first tool you reach for when parsing strings.

Getting information from regular expressions

Let's now focus on the Python side of things. The regular expression syntax is the furthest thing from object-oriented programming. However, Python's `re` module provides an object-oriented interface to enter the regular expression engine.

We've been checking whether the `re.match` function returns a valid object or not. If a pattern does not match, that function returns `None`. If it does match, however, it returns a useful object that we can introspect for information about the pattern.

So far, our regular expressions have answered questions such as "Does this string match this pattern?" Matching patterns is useful, but in many cases, a more interesting question is, "If this string matches this pattern, what is the value of a relevant substring?" If you use groups to identify parts of the pattern that you want to reference later, you can get them out of the match return value as illustrated in the next example:

```
pattern = "^[a-zA-Z.]+@([a-z.]*\.[a-z]+)$"
search_string = "some.user@example.com"
match = re.match(pattern, search_string)

if match:
    domain = match.groups()[0]
    print(domain)
```

The specification describing valid e-mail addresses is extremely complicated, and the regular expression that accurately matches all possibilities is obscenely long. So we cheated and made a simple regular expression that matches some common e-mail addresses; the point is that we want to access the domain name (after the `@` sign) so we can connect to that address. This is done easily by wrapping that part of the pattern in parenthesis and calling the `groups()` method on the object returned by match.

The `groups` method returns a tuple of all the groups matched inside the pattern, which you can index to access a specific value. The groups are ordered from left to right. However, bear in mind that groups can be nested, meaning you can have one or more groups inside another group. In this case, the groups are returned in the order of their left-most brackets, so the outermost group will be returned before its inner matching groups.

In addition to the match function, the `re` module provides a couple other useful functions, `search`, and `findall`. The `search` function finds the first instance of a matching pattern, relaxing the restriction that the pattern start at the first letter of the string. Note that you can get a similar effect by using match and putting a `^.*` character at the front of the pattern to match any characters between the start of the string and the pattern you are looking for.

The `findall` function behaves similarly to search, except that it finds all non-overlapping instances of the matching pattern, not just the first one. Basically, it finds the first match, then it resets the search to the end of that matching string and finds the next one.

Instead of returning a list of match objects, as you would expect, it returns a list of matching strings. Or tuples. Sometimes it's strings, sometimes it's tuples. It's not a very good API at all! As with all bad APIs, you'll have to memorize the differences and not rely on intuition. The type of the return value depends on the number of bracketed groups inside the regular expression:

- If there are no groups in the pattern, `re.findall` will return a list of strings, where each value is a complete substring from the source string that matches the pattern
- If there is exactly one group in the pattern, `re.findall` will return a list of strings where each value is the contents of that group
- If there are multiple groups in the pattern, then `re.findall` will return a list of tuples where each tuple contains a value from a matching group, in order

When you are designing function calls in your own Python libraries, try to make the function always return a consistent data structure. It is often good to design functions that can take arbitrary inputs and process them, but the return value should not switch from single value to a list, or a list of values to a list of tuples depending on the input. Let `re.findall` be a lesson!

The examples in the following interactive session will hopefully clarify the differences:

```
>>> import re
>>> re.findall('a.', 'abacadefagah')
['ab', 'ac', 'ad', 'ag', 'ah']
>>> re.findall('a(.)', 'abacadefagah')
['b', 'c', 'd', 'g', 'h']
>>> re.findall('(a)(.)', 'abacadefagah')
```

```
[('a', 'b'), ('a', 'c'), ('a', 'd'), ('a', 'g'), ('a', 'h')]
>>> re.findall('((a)(.))', 'abacadefagah')
[('ab', 'a', 'b'), ('ac', 'a', 'c'), ('ad', 'a', 'd'), ('ag', 'a', 'g'),
('ah', 'a', 'h')]
```

Making repeated regular expressions efficient

Whenever you call one of the regular expression methods, the engine has to convert the pattern string into an internal structure that makes searching strings fast. This conversion takes a non-trivial amount of time. If a regular expression pattern is going to be reused multiple times (for example, inside a `for` or `while` loop), it would be better if this conversion step could be done only once.

This is possible with the `re.compile` method. It returns an object-oriented version of the regular expression that has been compiled down and has the methods we've explored (`match`, `search`, `findall`) already, among others. We'll see examples of this in the case study.

This has definitely been a condensed introduction to regular expressions. At this point, we have a good feel for the basics and will recognize when we need to do further research. If we have a string pattern matching problem, regular expressions will almost certainly be able to solve them for us. However, we may need to look up new syntaxes in a more comprehensive coverage of the topic. But now we know what to look for! Let's move on to a completely different topic: serializing data for storage.

Serializing objects

Nowadays, we take the ability to write data to a file and retrieve it at an arbitrary later date for granted. As convenient as this is (imagine the state of computing if we couldn't store anything!), we often find ourselves converting data we have stored in a nice object or design pattern in memory into some kind of clunky text or binary format for storage, transfer over the network, or remote invocation on a distant server.

The Python `pickle` module is an object-oriented way to store objects directly in a special storage format. It essentially converts an object (and all the objects it holds as attributes) into a sequence of bytes that can be stored or transported however we see fit.

For basic work, the `pickle` module has an extremely simple interface. It is comprised of four basic functions for storing and loading data; two for manipulating file-like objects, and two for manipulating `bytes` objects (the latter are just shortcuts to the file-like interface, so we don't have to create a `BytesIO` file-like object ourselves).

The `dump` method accepts an object to be written and a file-like object to write the serialized bytes to. This object must have a `write` method (or it wouldn't be file-like), and that method must know how to handle a `bytes` argument (so a file opened for text output wouldn't work).

The `load` method does exactly the opposite; it reads a serialized object from a file-like object. This object must have the proper file-like `read` and `readline` arguments, each of which must, of course, return `bytes`. The `pickle` module will load the object from these bytes and the `load` method will return the fully reconstructed object. Here's an example that stores and then loads some data in a list object:

```
import pickle

some_data = ["a list", "containing", 5,
        "values including another list",
        ["inner", "list"]]

with open("pickled_list", 'wb') as file:
    pickle.dump(some_data, file)

with open("pickled_list", 'rb') as file:
    loaded_data = pickle.load(file)

print(loaded_data)
assert loaded_data == some_data
```

This code works as advertised: the objects are stored in the file and then loaded from the same file. In each case, we open the file using a `with` statement so that it is automatically closed. The file is first opened for writing and then a second time for reading, depending on whether we are storing or loading data.

The `assert` statement at the end would raise an error if the newly loaded object is not equal to the original object. Equality does not imply that they are the same object. Indeed, if we print the `id()` of both objects, we would discover they are different. However, because they are both lists whose contents are equal, the two lists are also considered equal.

The `dumps` and `loads` functions behave much like their file-like counterparts, except they return or accept `bytes` instead of file-like objects. The `dumps` function requires only one argument, the object to be stored, and it returns a serialized `bytes` object. The `loads` function requires a `bytes` object and returns the restored object. The `'s'` character in the method names is short for string; it's a legacy name from ancient versions of Python, where `str` objects were used instead of `bytes`.

Both `dump` methods accept an optional `protocol` argument. If we are saving and loading pickled objects that are only going to be used in Python 3 programs, we don't need to supply this argument. Unfortunately, if we are storing objects that may be loaded by older versions of Python, we have to use an older and less efficient protocol. This should not normally be an issue. Usually, the only program that would load a pickled object would be the same one that stored it. Pickle is an unsafe format, so we don't want to be sending it unsecured over the Internet to unknown interpreters.

The argument supplied is an integer version number. The default version is number 3, representing the current highly efficient storage system used by Python 3 pickling. The number 2 is the older version, which will store an object that can be loaded on all interpreters back to Python 2.3. As 2.6 is the oldest of Python that is still widely used in the wild, version 2 pickling is normally sufficient. Versions 0 and 1 are supported on older interpreters; 0 is an ASCII format, while 1 is a binary format. There is also an optimized version 4 that may one day become the default.

As a rule of thumb, then, if you know that the objects you are pickling will only be loaded by a Python 3 program (for example, only your program will be loading them), use the default pickling protocol. If they may be loaded by unknown interpreters, pass a protocol value of 2, unless you really believe they may need to be loaded by an archaic version of Python.

If we do pass a protocol to `dump` or `dumps`, we should use a keyword argument to specify it: `pickle.dumps(my_object, protocol=2)`. This is not strictly necessary, as the method only accepts two arguments, but typing out the full keyword argument reminds readers of our code what the purpose of the number is. Having a random integer in the method call would be hard to read. Two what? Store two copies of the object, maybe? Remember, code should always be readable. In Python, less code is often more readable than longer code, but not always. Be explicit.

It is possible to call `dump` or `load` on a single open file more than once. Each call to `dump` will store a single object (plus any objects it is composed of or contains), while a call to `load` will load and return just one object. So for a single file, each separate call to `dump` when storing the object should have an associated call to `load` when restoring at a later date.

Customizing pickles

With most common Python objects, pickling "just works". Basic primitives such as integers, floats, and strings can be pickled, as can any container object, such as lists or dictionaries, provided the contents of those containers are also picklable. Further, and importantly, any object can be pickled, so long as all of its attributes are also picklable.

So what makes an attribute unpicklable? Usually, it has something to do with time-sensitive attributes that it would not make sense to load in the future. For example, if we have an open network socket, open file, running thread, or database connection stored as an attribute on an object, it would not make sense to pickle these objects; a lot of operating system state would simply be gone when we attempted to reload them later. We can't just pretend a thread or socket connection exists and make it appear! No, we need to somehow customize how such transient data is stored and restored.

Here's a class that loads the contents of a web page every hour to ensure that they stay up to date. It uses the `threading.Timer` class to schedule the next update:

```
from threading import Timer
import datetime
from urllib.request import urlopen

class UpdatedURL:
    def __init__(self, url):
        self.url = url
        self.contents = ''
        self.last_updated = None
        self.update()

    def update(self):
        self.contents = urlopen(self.url).read()
        self.last_updated = datetime.datetime.now()
        self.schedule()

    def schedule(self):
        self.timer = Timer(3600, self.update)
        self.timer.setDaemon(True)
        self.timer.start()
```

The `url`, `contents`, and `last_updated` are all pickleable, but if we try to pickle an instance of this class, things go a little nutty on the `self.timer` instance:

```
>>> u = UpdatedURL("http://news.yahoo.com/")
>>> import pickle
>>> serialized = pickle.dumps(u)
Traceback (most recent call last):
  File "<pyshell#3>", line 1, in <module>
    serialized = pickle.dumps(u)
_pickle.PicklingError: Can't pickle <class '_thread.lock'>: attribute
lookup lock on _thread failed
```

That's not a very useful error, but it looks like we're trying to pickle something we shouldn't be. That would be the `Timer` instance; we're storing a reference to `self.timer` in the schedule method, and that attribute cannot be serialized.

When `pickle` tries to serialize an object, it simply tries to store the object's `__dict__` attribute; `__dict__` is a dictionary mapping all the attribute names on the object to their values. Luckily, before checking `__dict__`, `pickle` checks to see whether a `__getstate__` method exists. If it does, it will store the return value of that method instead of the `__dict__`.

Let's add a `__getstate__` method to our `UpdatedURL` class that simply returns a copy of the `__dict__` without a timer:

```
def __getstate__(self):
    new_state = self.__dict__.copy()
    if 'timer' in new_state:
        del new_state['timer']
    return new_state
```

If we pickle the object now, it will no longer fail. And we can even successfully restore that object using `loads`. However, the restored object doesn't have a timer attribute, so it will not be refreshing the content like it is designed to do. We need to somehow create a new timer (to replace the missing one) when the object is unpickled.

As we might expect, there is a complementary `__setstate__` method that can be implemented to customize unpickling. This method accepts a single argument, which is the object returned by `__getstate__`. If we implement both methods, `__getstate__` is not required to return a dictionary, since `__setstate__` will know what to do with whatever object `__getstate__` chooses to return. In our case, we simply want to restore the `__dict__`, and then create a new timer:

```
def __setstate__(self, data):
    self.__dict__ = data
    self.schedule()
```

The `pickle` module is very flexible and provides other tools to further customize the pickling process if you need them. However, these are beyond the scope of this book. The tools we've covered are sufficient for many basic pickling tasks. Objects to be pickled are normally relatively simple data objects; we would not likely pickle an entire running program or complicated design pattern, for example.

Serializing web objects

It is not a good idea to load a pickled object from an unknown or untrusted source. It is possible to inject arbitrary code into a pickled file to maliciously attack a computer via the pickle. Another disadvantage of pickles is that they can only be loaded by other Python programs, and cannot be easily shared with services written in other languages.

There are many formats that have been used for this purpose over the years. XML (Extensible Markup Language) used to be very popular, especially with Java developers. YAML (Yet Another Markup Language) is another format that you may see referenced occasionally. Tabular data is frequently exchanged in the CSV (Comma Separated Value) format. Many of these are fading into obscurity and there are many more that you will encounter over time. Python has solid standard or third-party libraries for all of them.

Before using such libraries on untrusted data, make sure to investigate security concerns with each of them. XML and YAML, for example, both have obscure features that, used maliciously, can allow arbitrary commands to be executed on the host machine. These features may not be turned off by default. Do your research.

JavaScript Object Notation (**JSON**) is a human readable format for exchanging primitive data. JSON is a standard format that can be interpreted by a wide array of heterogeneous client systems. Hence, JSON is extremely useful for transmitting data between completely decoupled systems. Further, JSON does not have any support for executable code, only data can be serialized; thus, it is more difficult to inject malicious statements into it.

Because JSON can be easily interpreted by JavaScript engines, it is often used for transmitting data from a web server to a JavaScript-capable web browser. If the web application serving the data is written in Python, it needs a way to convert internal data into the JSON format.

There is a module to do this, predictably named `json`. This module provides a similar interface to the `pickle` module, with `dump`, `load`, `dumps`, and `loads` functions. The default calls to these functions are nearly identical to those in `pickle`, so let us not repeat the details. There are a couple differences; obviously, the output of these calls is valid JSON notation, rather than a pickled object. In addition, the `json` functions operate on `str` objects, rather than `bytes`. Therefore, when dumping to or loading from a file, we need to create text files rather than binary ones.

The JSON serializer is not as robust as the `pickle` module; it can only serialize basic types such as integers, floats, and strings, and simple containers such as dictionaries and lists. Each of these has a direct mapping to a JSON representation, but JSON is unable to represent classes, methods, or functions. It is not possible to transmit complete objects in this format. Because the receiver of an object we have dumped to JSON format is normally not a Python object, it would not be able to understand classes or methods in the same way that Python does, anyway. In spite of the O for Object in its name, JSON is a **data** notation; objects, as you recall, are composed of both data and behavior.

If we do have objects for which we want to serialize only the data, we can always serialize the object's `__dict__` attribute. Or we can semiautomate this task by supplying custom code to create or parse a JSON serializable dictionary from certain types of objects.

In the `json` module, both the object storing and loading functions accept optional arguments to customize the behavior. The `dump` and `dumps` methods accept a poorly named `cls` (short for class, which is a reserved keyword) keyword argument. If passed, this should be a subclass of the `JSONEncoder` class, with the `default` method overridden. This method accepts an arbitrary object and converts it to a dictionary that `json` can digest. If it doesn't know how to process the object, we should call the `super()` method, so that it can take care of serializing basic types in the normal way.

The `load` and `loads` methods also accept such a `cls` argument that can be a subclass of the inverse class, `JSONDecoder`. However, it is normally sufficient to pass a function into these methods using the `object_hook` keyword argument. This function accepts a dictionary and returns an object; if it doesn't know what to do with the input dictionary, it can return it unmodified.

Let's look at an example. Imagine we have the following simple contact class that we want to serialize:

```
class Contact:
    def __init__(self, first, last):
        self.first = first
        self.last = last

    @property
    def full_name(self):
        return("{} {}".format(self.first, self.last))
```

We could just serialize the `__dict__` attribute:

```
>>> c = Contact("John", "Smith")
>>> json.dumps(c.__dict__)
'{"last": "Smith", "first": "John"}'
```

But accessing special (double-underscore) attributes in this fashion is kind of crude. Also, what if the receiving code (perhaps some JavaScript on a web page) wanted that `full_name` property to be supplied? Of course, we could construct the dictionary by hand, but let's create a custom encoder instead:

```
import json
class ContactEncoder(json.JSONEncoder):
    def default(self, obj):
        if isinstance(obj, Contact):
            return {'is_contact': True,
                    'first': obj.first,
                    'last': obj.last,
                    'full': obj.full_name}
        return super().default(obj)
```

The `default` method basically checks to see what kind of object we're trying to serialize; if it's a contact, we convert it to a dictionary manually; otherwise, we let the parent class handle serialization (by assuming that it is a basic type, which `json` knows how to handle). Notice that we pass an extra attribute to identify this object as a contact, since there would be no way to tell upon loading it. This is just a convention; for a more generic serialization mechanism, it might make more sense to store a string type in the dictionary, or possibly even the full class name, including package and module. Remember that the format of the dictionary depends on the code at the receiving end; there has to be an agreement as to how the data is going to be specified.

We can use this class to encode a contact by passing the class (not an instantiated object) to the `dump` or `dumps` function:

```
>>> c = Contact("John", "Smith")
>>> json.dumps(c, cls=ContactEncoder)
'{"is_contact": true, "last": "Smith", "full": "John Smith",
"first": "John"}'
```

For decoding, we can write a function that accepts a dictionary and checks the existence of the `is_contact` variable to decide whether to convert it to a contact:

```
def decode_contact(dic):
        if dic.get('is_contact'):
            return Contact(dic['first'], dic['last'])
        else:
            return dic
```

We can pass this function to the `load` or `loads` function using the `object_hook` keyword argument:

```
>>> data = ('{"is_contact": true, "last": "smith",'
     '"full": "john smith", "first": "john"}')

>>> c = json.loads(data, object_hook=decode_contact)
>>> c
<__main__.Contact object at 0xa02918c>
>>> c.full_name
'john smith'
```

Case study

Let's build a basic regular expression-powered templating engine in Python. This engine will parse a text file (such as an HTML page) and replace certain directives with text calculated from the input to those directives. This is about the most complicated task we would want to do with regular expressions; indeed, a full-fledged version of this would likely utilize a proper language parsing mechanism.

Consider the following input file:

```
/** include header.html **/
<h1>This is the title of the front page</h1>
/** include menu.html **/
<p>My name is /** variable name **/.
This is the content of my front page. It goes below the menu.</p>
<table>
<tr><th>Favourite Books</th></tr>
/** loopover book_list **/
<tr><td>/** loopvar **/</td></tr>

/** endloop **/
</table>
/** include footer.html **/
Copyright &copy; Today
```

This file contains "tags" of the form `/** <directive> <data> **/` where the data is an optional single word and the directives are:

- `include`: Copy the contents of another file here
- `variable`: Insert the contents of a variable here
- `loopover`: Repeat the contents of the loop for a variable that is a list
- `endloop`: Signal the end of looped text
- `loopvar`: Insert a single value from the list being looped over

This template will render a different page depending which variables are passed into it. These variables will be passed in from a so-called context file. This will be encoded as a `json` object with keys representing the variables in question. My context file might look like this, but you would derive your own:

```
{
    "name": "Dusty",
    "book_list": [
        "Thief Of Time",
        "The Thief",
        "Snow Crash",
        "Lathe Of Heaven"
    ]
}
```

Before we get into the actual string processing, let's throw together some object-oriented boilerplate code for processing files and grabbing data from the command line:

```
import re
import sys
import json
from pathlib import Path

DIRECTIVE_RE = re.compile(
    r'/\*\*\s*(include|variable|loopover|endloop|loopvar)'
    r'\s*([^ *]*)\s*\*\*/')


class TemplateEngine:
    def __init__(self, infilename, outfilename, contextfilename):
        self.template = open(infilename).read()
        self.working_dir = Path(infilename).absolute().parent
        self.pos = 0
        self.outfile = open(outfilename, 'w')
```

```
            with open(contextfilename) as contextfile:
                self.context = json.load(contextfile)

        def process(self):
            print("PROCESSING...")


if __name__ == '__main__':
    infilename, outfilename, contextfilename = sys.argv[1:]
    engine = TemplateEngine(infilename, outfilename, contextfilename)
    engine.process()
```

This is all pretty basic, we create a class and initialize it with some variables passed in on the command line.

Notice how we try to make the regular expression a little bit more readable by breaking it across two lines? We use raw strings (the r prefix), so we don't have to double escape all our backslashes. This is common in regular expressions, but it's still a mess. (Regular expressions always are, but they're often worth it.)

The `pos` indicates the current character in the content that we are processing; we'll see a lot more of it in a moment.

Now "all that's left" is to implement that process method. There are a few ways to do this. Let's do it in a fairly explicit way.

The process method has to find each directive that matches the regular expression and do the appropriate work with it. However, it also has to take care of outputting the normal text before, after, and between each directive to the output file, unmodified.

One good feature of the compiled version of regular expressions is that we can tell the `search` method to start searching at a specific position by passing the `pos` keyword argument. If we temporarily define doing the appropriate work with a directive as "ignore the directive and delete it from the output file", our process loop looks quite simple:

```
def process(self):
    match = DIRECTIVE_RE.search(self.template, pos=self.pos)
    while match:
        self.outfile.write(self.template[self.pos:match.start()])
        self.pos = match.end()
        match = DIRECTIVE_RE.search(self.template, pos=self.pos)
    self.outfile.write(self.template[self.pos:])
```

In English, this function finds the first string in the text that matches the regular expression, outputs everything from the current position to the start of that match, and then advances the position to the end of aforesaid match. Once it's out of matches, it outputs everything since the last position.

Of course, ignoring the directive is pretty useless in a templating engine, so let's set up replace that position advancing line with code that delegates to a different method on the class depending on the directive:

```
def process(self):
    match = DIRECTIVE_RE.search(self.template, pos=self.pos)
    while match:
        self.outfile.write(self.template[self.pos:match.start()])
        directive, argument = match.groups()
        method_name = 'process_{}'.format(directive)
        getattr(self, method_name)(match, argument)
        match = DIRECTIVE_RE.search(self.template, pos=self.pos)
    self.outfile.write(self.template[self.pos:])
```

So we grab the directive and the single argument from the regular expression. The directive becomes a method name and we dynamically look up that method name on the `self` object (a little error processing here in case the template writer provides an invalid directive would be better). We pass the match object and argument into that method and assume that method will deal with everything appropriately, including moving the `pos` pointer.

Now that we've got our object-oriented architecture this far, it's actually pretty simple to implement the methods that are delegated to. The `include` and `variable` directives are totally straightforward:

```
def process_include(self, match, argument):
    with (self.working_dir / argument).open() as includefile:
        self.outfile.write(includefile.read())
        self.pos = match.end()

def process_variable(self, match, argument):
    self.outfile.write(self.context.get(argument, ''))
    self.pos = match.end()
```

The first simply looks up the included file and inserts the file contents, while the second looks up the variable name in the context dictionary (which was loaded from `json` in the `__init__` method), defaulting to an empty string if it doesn't exist.

The three methods that deal with looping are a bit more intense, as they have to share state between the three of them. For simplicity (I'm sure you're eager to see the end of this long chapter, we're almost there!), we'll handle this as instance variables on the class itself. As an exercise, you might want to consider better ways to architect this, especially after reading the next three chapters.

```
def process_loopover(self, match, argument):
    self.loop_index = 0
    self.loop_list = self.context.get(argument, [])
    self.pos = self.loop_pos = match.end()

def process_loopvar(self, match, argument):
    self.outfile.write(self.loop_list[self.loop_index])
    self.pos = match.end()

def process_endloop(self, match, argument):
    self.loop_index += 1
    if self.loop_index >= len(self.loop_list):
        self.pos = match.end()
        del self.loop_index
        del self.loop_list
        del self.loop_pos
    else:
        self.pos = self.loop_pos
```

When we encounter the `loopover` directive, we don't have to output anything, but we do have to set the initial state on three variables. The `loop_list` variable is assumed to be a list pulled from the context dictionary. The `loop_index` variable indicates what position in that list should be output in this iteration of the loop, while `loop_pos` is stored so we know where to jump back to when we get to the end of the loop.

The `loopvar` directive outputs the value at the current position in the `loop_list` variable and skips to the end of the directive. Note that it doesn't increment the loop index because the `loopvar` directive could be called multiple times inside a loop.

The `endloop` directive is more complicated. It determines whether there are more elements in the `loop_list`; if there are, it just jumps back to the start of the loop, incrementing the index. Otherwise, it resets all the variables that were being used to process the loop and jumps to the end of the directive so the engine can carry on with the next match.

Note that this particular looping mechanism is very fragile; if a template designer were to try nesting loops or forget an `endloop` call, it would go poorly for them. We would need a lot more error checking and probably want to store more loop state to make this a production platform. But I promised that the end of the chapter was nigh, so let's just head to the exercises, after seeing how our sample template is rendered with its context:

```
<html>
    <body>

<h1>This is the title of the front page</h1>
<a href="link1.html">First Link</a>
<a href="link2.html">Second Link</a>

<p>My name is Dusty.
This is the content of my front page. It goes below the menu.</p>
<table>
<tr><th>Favourite Books</th></tr>

<tr><td>Thief Of Time</td></tr>

<tr><td>The Thief</td></tr>

<tr><td>Snow Crash</td></tr>

<tr><td>Lathe Of Heaven</td></tr>

</table>
    </body>
</html>

Copyright &copy; Today
```

There are some weird newline effects due to the way we planned our template, but it works as expected.

Exercises

We've covered a wide variety of topics in this chapter, from strings to regular expressions, to object serialization, and back again. Now it's time to consider how these ideas can be applied to your own code.

Python strings are very flexible, and Python is an extremely powerful tool for string-based manipulations. If you don't do a lot of string processing in your daily work, try designing a tool that is exclusively intended for manipulating strings. Try to come up with something innovative, but if you're stuck, consider writing a web log analyzer (how many requests per hour? How many people visit more than five pages?) or a template tool that replaces certain variable names with the contents of other files.

Spend a lot of time toying with the string formatting operators until you've got the syntax memorized. Write a bunch of template strings and objects to pass into the format function, and see what kind of output you get. Try the exotic formatting operators, such as percentage or hexadecimal notation. Try out the fill and alignment operators, and see how they behave differently for integers, strings, and floats. Consider writing a class of your own that has a `__format__` method; we didn't discuss this in detail, but explore just how much you can customize formatting.

Make sure you understand the difference between `bytes` and `str` objects. The distinction is very complicated in older versions of Python (there was no `bytes`, and `str` acted like both `bytes` and `str` unless we needed non-ASCII characters in which case there was a separate `unicode` object, which was similar to Python 3's `str` class. It's even more confusing than it sounds!). It's clearer nowadays; `bytes` is for binary data, and `str` is for character data. The only tricky part is knowing how and when to convert between the two. For practice, try writing text data to a file opened for writing `bytes` (you'll have to encode the text yourself), and then reading from the same file.

Do some experimenting with `bytearray`; see how it can act both like a bytes object and a list or container object at the same time. Try writing to a buffer that holds data in the bytes array until it is a certain length before returning it. You can simulate the code that puts data into the buffer by using `time.sleep` calls to ensure data doesn't arrive too quickly.

Study regular expressions online. Study them some more. Especially learn about named groups greedy versus lazy matching, and regex flags, three features that we didn't cover in this chapter. Make conscious decisions about when not to use them. Many people have very strong opinions about regular expressions and either overuse them or refuse to use them at all. Try to convince yourself to use them only when appropriate, and figure out when that is.

If you've ever written an adapter to load small amounts of data from a file or database and convert it to an object, consider using a pickle instead. Pickles are not efficient for storing massive amounts of data, but they can be useful for loading configuration or other simple objects. Try coding it multiple ways: using a pickle, a text file, or a small database. Which do you find easiest to work with?

Try experimenting with pickling data, then modifying the class that holds the data, and loading the pickle into the new class. What works? What doesn't? Is there a way to make drastic changes to a class, such as renaming an attribute or splitting it into two new attributes and still get the data out of an older pickle? (Hint: try placing a private pickle version number on each object and update it each time you change the class; you can then put a migration path in `__setstate__`.)

If you do any web development at all, do some experimenting with the JSON serializer. Personally, I prefer to serialize only standard JSON serializable objects, rather than writing custom encoders or `object_hooks`, but the desired effect really depends on the interaction between the frontend (JavaScript, typically) and backend code.

Create some new directives in the templating engine that take more than one or an arbitrary number of arguments. You might need to modify the regular expression or add new ones. Have a look at the Django project's online documentation, and see if there are any other template tags you'd like to work with. Try mimicking their filter syntax instead of using the variable tag. Revisit this chapter when you've studied iteration and coroutines and see if you can come up with a more compact way of representing the state between related directives, such as the loop.

Summary

We've covered string manipulation, regular expressions, and object serialization in this chapter. Hardcoded strings and program variables can be combined into outputtable strings using the powerful string formatting system. It is important to distinguish between binary and textual data and `bytes` and `str` have specific purposes that must be understood. Both are immutable, but the `bytearray` type can be used when manipulating bytes.

Regular expressions are a complex topic, but we scratched the surface. There are many ways to serialize Python data; pickles and JSON are two of the most popular.

In the next chapter, we'll look at a design pattern that is so fundamental to Python programming that it has been given special syntax support: the iterator pattern.

9
The Iterator Pattern

We've discussed how many of Python's built-ins and idioms that seem, at first blush, to be non-object-oriented are actually providing access to major objects under the hood. In this chapter, we'll discuss how the `for` loop that seems so structured is actually a lightweight wrapper around a set of object-oriented principles. We'll also see a variety of extensions to this syntax that automatically create even more types of object. We will cover:

- What design patterns are
- The iterator protocol—one of the most powerful design patterns
- List, set, and dictionary comprehensions
- Generators and coroutines

Design patterns in brief

When engineers and architects decide to build a bridge, or a tower, or a building, they follow certain principles to ensure structural integrity. There are various possible designs for bridges (suspension or cantilever, for example), but if the engineer doesn't use one of the standard designs, and doesn't have a brilliant new design, it is likely the bridge he/she designs will collapse.

Design patterns are an attempt to bring this same formal definition for correctly designed structures to software engineering. There are many different design patterns to solve different general problems. People who create design patterns first identify a common problem faced by developers in a wide variety of situations. They then suggest what might be considered the ideal solution for that problem, in terms of object-oriented design.

Knowing a design pattern and choosing to use it in our software does not, however, guarantee that we are creating a "correct" solution. In 1907, the Québec Bridge (to this day, the longest cantilever bridge in the world) collapsed before construction was completed, because the engineers who designed it grossly underestimated the weight of the steel used to construct it. Similarly, in software development, we may incorrectly choose or apply a design pattern, and create software that "collapses" under normal operating situations or when stressed beyond its original design limits.

Any one design pattern proposes a set of objects interacting in a specific way to solve a general problem. The job of the programmer is to recognize when they are facing a specific version of that problem, and to adapt the general design in their solution.

In this chapter, we'll be covering the iterator design pattern. This pattern is so powerful and pervasive that the Python developers have provided multiple syntaxes to access the object-oriented principles underlying the pattern. We will be covering other design patterns in the next two chapters. Some of them have language support and some don't, but none of them is as intrinsically a part of the Python coder's daily life as the iterator pattern.

Iterators

In typical design pattern parlance, an iterator is an object with a `next()` method and a `done()` method; the latter returns `True` if there are no items left in the sequence. In a programming language without built-in support for iterators, the iterator would be looped over like this:

```
while not iterator.done():
    item = iterator.next()
    # do something with the item
```

In Python, iteration is a special feature, so the method gets a special name, `__next__`. This method can be accessed using the `next(iterator)` built-in. Rather than a `done` method, the iterator protocol raises `StopIteration` to notify the loop that it has completed. Finally, we have the much more readable `for item in iterator` syntax to actually access items in an iterator instead of messing around with a `while` loop. Let's look at these in more detail.

The iterator protocol

The abstract base class `Iterator`, in the `collections.abc` module, defines the iterator protocol in Python. As mentioned, it must have a `__next__` method that the `for` loop (and other features that support iteration) can call to get a new element from the sequence. In addition, every iterator must also fulfill the `Iterable` interface. Any class that provides an `__iter__` method is iterable; that method must return an `Iterator` instance that will cover all the elements in that class. Since an iterator is already looping over elements, its `__iter__` function traditionally returns itself.

This might sound a bit confusing, so have a look at the following example, but note that this is a very verbose way to solve this problem. It clearly explains iteration and the two protocols in question, but we'll be looking at several more readable ways to get this effect later in this chapter:

```
class CapitalIterable:
    def __init__(self, string):
        self.string = string

    def __iter__(self):
        return CapitalIterator(self.string)


class CapitalIterator:
    def __init__(self, string):
        self.words = [w.capitalize() for w in string.split()]
        self.index = 0

    def __next__(self):
        if self.index == len(self.words):
            raise StopIteration()

        word = self.words[self.index]
        self.index += 1
        return word

    def __iter__(self):
        return self
```

This example defines an `CapitalIterable` class whose job is to loop over each of the words in a string and output them with the first letter capitalized. Most of the work of that iterable is passed to the `CapitalIterator` implementation. The canonical way to interact with this iterator is as follows:

```
>>> iterable = CapitalIterable('the quick brown fox jumps over the lazy
dog')
>>> iterator = iter(iterable)
>>> while True:
...     try:
...         print(next(iterator))
...     except StopIteration:
...         break
...
The
Quick
Brown
Fox
Jumps
Over
The
Lazy
Dog
```

This example first constructs an iterable and retrieves an iterator from it. The distinction may need explanation; the iterable is an object with elements that can be looped over. Normally, these elements can be looped over multiple times, maybe even at the same time or in overlapping code. The iterator, on the other hand, represents a specific location in that iterable; some of the items have been consumed and some have not. Two different iterators might be at different places in the list of words, but any one iterator can mark only one place.

Each time `next()` is called on the iterator, it returns another token from the iterable, in order. Eventually, the iterator will be exhausted (won't have any more elements to return), in which case `Stopiteration` is raised, and we break out of the loop.

Of course, we already know a much simpler syntax for constructing an iterator from an iterable:

```
>>> for i in iterable:
...     print(i)
...
The
Quick
Brown
Fox
Jumps
Over
The
Lazy
Dog
```

As you can see, the `for` statement, in spite of not looking terribly object-oriented, is actually a shortcut to some obviously object-oriented design principles. Keep this in mind as we discuss comprehensions, as they, too, appear to be the polar opposite of an object-oriented tool. Yet, they use the exact same iteration protocol as `for` loops and are just another kind of shortcut.

Comprehensions

Comprehensions are simple, but powerful, syntaxes that allow us to transform or filter an iterable object in as little as one line of code. The resultant object can be a perfectly normal list, set, or dictionary, or it can be a generator expression that can be efficiently consumed in one go.

List comprehensions

List comprehensions are one of the most powerful tools in Python, so people tend to think of them as advanced. They're not. Indeed, I've taken the liberty of littering previous examples with comprehensions and assuming you'd understand them. While it's true that advanced programmers use comprehensions a lot, it's not because they're advanced, it's because they're trivial, and handle some of the most common operations in software development.

Let's have a look at one of those common operations; namely, converting a list of items into a list of related items. Specifically, let's assume we just read a list of strings from a file, and now we want to convert it to a list of integers. We know every item in the list is an integer, and we want to do some activity (say, calculate an average) on those numbers. Here's one simple way to approach it:

```
input_strings = ['1', '5', '28', '131', '3']

output_integers = []
for num in input_strings:
    output_integers.append(int(num))
```

This works fine and it's only three lines of code. If you aren't used to comprehensions, you may not even think it looks ugly! Now, look at the same code using a list comprehension:

```
input_strings = ['1', '5', '28', '131', '3']output_integers =
[int(num) for num in input_strings]
```

We're down to one line and, importantly for performance, we've dropped an `append` method call for each item in the list. Overall, it's pretty easy to tell what's going on, even if you're not used to comprehension syntax.

The square brackets indicate, as always, that we're creating a list. Inside this list is a `for` loop that iterates over each item in the input sequence. The only thing that may be confusing is what's happening between the list's opening brace and the start of the `for` loop. Whatever happens here is applied to *each* of the items in the input list. The item in question is referenced by the `num` variable from the loop. So, it's converting each individual element to an `int` data type.

That's all there is to a basic list comprehension. They are not so advanced after all. Comprehensions are highly optimized C code; list comprehensions are far faster than `for` loops when looping over a huge number of items. If readability alone isn't a convincing reason to use them as much as possible, speed should be.

Converting one list of items into a related list isn't the only thing we can do with a list comprehension. We can also choose to exclude certain values by adding an `if` statement inside the comprehension. Have a look:

```
output_ints = [int(n) for n in input_strings if len(n) < 3]
```

I shortened the name of the variable from `num` to `n` and the result variable to `output_ints` so it would still fit on one line. Other than this, all that's different between this example and the previous one is the `if len(n) < 3` part. This extra code excludes any strings with more than two characters. The `if` statement is applied before the `int` function, so it's testing the length of a string. Since our input strings are all integers at heart, it excludes any number over 99. Now that is all there is to list comprehensions! We use them to map input values to output values, applying a filter along the way to include or exclude any values that meet a specific condition.

Any iterable can be the input to a list comprehension; anything we can wrap in a `for` loop can also be placed inside a comprehension. For example, text files are iterable; each call to `__next__` on the file's iterator will return one line of the file. We could load a tab delimited file where the first line is a header row into a dictionary using the `zip` function:

```
import sys
filename = sys.argv[1]

with open(filename) as file:
    header = file.readline().strip().split('\t')
    contacts = [
            dict(
                zip(header, line.strip().split('\t'))
                ) for line in file
            ]

for contact in contacts:
    print("email: {email} -- {last}, {first}".format(
        **contact))
```

This time, I've added some whitespace to make it somewhat more readable (list comprehensions don't *have* to fit on one line). This example creates a list of dictionaries from the zipped header and split lines for each line in the file.

Er, what? Don't worry if that code or explanation doesn't make sense; it's a bit confusing. One list comprehension is doing a pile of work here, and the code is hard to understand, read, and ultimately, maintain. This example shows that list comprehensions aren't always the best solution; most programmers would agree that a `for` loop would be more readable than this version.

Remember: the tools we are provided with should not be abused! Always pick the right tool for the job, which is always to write maintainable code.

Set and dictionary comprehensions

Comprehensions aren't restricted to lists. We can use a similar syntax with braces to create sets and dictionaries as well. Let's start with sets. One way to create a set is to wrap a list comprehension in the `set()` constructor, which converts it to a set. But why waste memory on an intermediate list that gets discarded, when we can create a set directly?

Here's an example that uses a named tuple to model author/title/genre triads, and then retrieves a set of all the authors that write in a specific genre:

```
from collections import namedtuple

Book = namedtuple("Book", "author title genre")
books = [
        Book("Pratchett", "Nightwatch", "fantasy"),
        Book("Pratchett", "Thief Of Time", "fantasy"),
        Book("Le Guin", "The Dispossessed", "scifi"),
        Book("Le Guin", "A Wizard Of Earthsea", "fantasy"),
        Book("Turner", "The Thief", "fantasy"),
        Book("Phillips", "Preston Diamond", "western"),
        Book("Phillips", "Twice Upon A Time", "scifi"),
        ]

fantasy_authors = {
        b.author for b in books if b.genre == 'fantasy'}
```

The highlighted set comprehension sure is short in comparison to the demo-data setup! If we were to use a list comprehension, of course, Terry Pratchett would have been listed twice.. As it is, the nature of sets removes the duplicates, and we end up with:

```
>>> fantasy_authors
{'Turner', 'Pratchett', 'Le Guin'}
```

We can introduce a colon to create a dictionary comprehension. This converts a sequence into a dictionary using *key: value* pairs. For example, it may be useful to quickly look up the author or genre in a dictionary if we know the title. We can use a dictionary comprehension to map titles to book objects:

```
fantasy_titles = {
        b.title: b for b in books if b.genre == 'fantasy'}
```

Now, we have a dictionary, and can look up books by title using the normal syntax.

In summary, comprehensions are not advanced Python, nor are they "non-object-oriented" tools that should be avoided. They are simply a more concise and optimized syntax for creating a list, set, or dictionary from an existing sequence.

Generator expressions

Sometimes we want to process a new sequence without placing a new list, set, or dictionary into system memory. If we're just looping over items one at a time, and don't actually care about having a final container object created, creating that container is a waste of memory. When processing one item at a time, we only need the current object stored in memory at any one moment. But when we create a container, all the objects have to be stored in that container before we start processing them.

For example, consider a program that processes log files. A very simple log might contain information in this format:

```
Jan 26, 2015 11:25:25    DEBUG        This is a debugging message.
Jan 26, 2015 11:25:36    INFO         This is an information method.
Jan 26, 2015 11:25:46    WARNING      This is a warning. It could be
serious.
Jan 26, 2015 11:25:52    WARNING      Another warning sent.
Jan 26, 2015 11:25:59    INFO         Here's some information.
Jan 26, 2015 11:26:13    DEBUG        Debug messages are only useful
if you want to figure something out.
Jan 26, 2015 11:26:32    INFO         Information is usually harmless,
but helpful.
Jan 26, 2015 11:26:40    WARNING      Warnings should be heeded.
Jan 26, 2015 11:26:54    WARNING      Watch for warnings.
```

Log files for popular web servers, databases, or e-mail servers can contain many gigabytes of data (I recently had to clean nearly 2 terabytes of logs off a misbehaving system). If we want to process each line in the log, we can't use a list comprehension; it would create a list containing every line in the file. This probably wouldn't fit in RAM and could bring the computer to its knees, depending on the operating system.

If we used a `for` loop on the log file, we could process one line at a time before reading the next one into memory. Wouldn't be nice if we could use comprehension syntax to get the same effect?

This is where generator expressions come in. They use the same syntax as comprehensions, but they don't create a final container object. To create a generator expression, wrap the comprehension in `()` instead of `[]` or `{}`.

The following code parses a log file in the previously presented format, and outputs a new log file that contains only the `WARNING` lines:

```
import sys

inname = sys.argv[1]
outname = sys.argv[2]

with open(inname) as infile:
    with open(outname, "w") as outfile:
        warnings = (l for l in infile if 'WARNING' in l)
        for l in warnings:
            outfile.write(l)
```

This program takes the two filenames on the command line, uses a generator expression to filter out the warnings (in this case, it uses the `if` syntax, and leaves the line unmodified), and then outputs the warnings to another file. If we run it on our sample file, the output looks like this:

```
Jan 26, 2015 11:25:46    WARNING     This is a warning. It could be
serious.
Jan 26, 2015 11:25:52    WARNING     Another warning sent.
Jan 26, 2015 11:26:40    WARNING     Warnings should be heeded.
Jan 26, 2015 11:26:54    WARNING     Watch for warnings.
```

Of course, with such a short input file, we could have safely used a list comprehension, but if the file is millions of lines long, the generator expression will have a huge impact on both memory and speed.

Generator expressions are frequently most useful inside function calls. For example, we can call `sum`, `min`, or `max`, on a generator expression instead of a list, since these functions process one object at a time. We're only interested in the result, not any intermediate container.

In general, a generator expression should be used whenever possible. If we don't actually need a list, set, or dictionary, but simply need to filter or convert items in a sequence, a generator expression will be most efficient. If we need to know the length of a list, or sort the result, remove duplicates, or create a dictionary, we'll have to use the comprehension syntax.

Generators

Generator expressions are actually a sort of comprehension too; they compress the more advanced (this time it really is more advanced!) generator syntax into one line. The greater generator syntax looks even less object-oriented than anything we've seen, but we'll discover that once again, it is a simple syntax shortcut to create a kind of object.

Let's take the log file example a little further. If we want to delete the `WARNING` column from our output file (since it's redundant: this file contains only warnings), we have several options, at various levels of readability. We can do it with a generator expression:

```
import sys
inname, outname = sys.argv[1:3]

with open(inname) as infile:
    with open(outname, "w") as outfile:
        warnings = (l.replace('\tWARNING', '')
                for l in infile if 'WARNING' in l)
        for l in warnings:
            outfile.write(l)
```

That's perfectly readable, though I wouldn't want to make the expression much more complicated than that. We could also do it with a normal `for` loop:

```
import sys
inname, outname = sys.argv[1:3]

with open(inname) as infile:
    with open(outname, "w") as outfile:
        for l in infile:
            if 'WARNING' in l:
                outfile.write(l.replace('\tWARNING', ''))
```

That's maintainable, but so many levels of indent in so few lines is kind of ugly. More alarmingly, if we wanted to do something different with the lines, rather than just printing them out, we'd have to duplicate the looping and conditional code, too. Now let's consider a truly object-oriented solution, without any shortcuts:

```
import sys
inname, outname = sys.argv[1:3]

class WarningFilter:
    def __init__(self, insequence):
```

```
            self.insequence = insequence
        def __iter__(self):
            return self
        def __next__(self):
            l = self.insequence.readline()
            while l and 'WARNING' not in l:
                l = self.insequence.readline()
            if not l:
                raise StopIteration
            return l.replace('\tWARNING', '')

    with open(inname) as infile:
        with open(outname, "w") as outfile:
            filter = WarningFilter(infile)
            for l in filter:
                outfile.write(l)
```

No doubt about it: that is so ugly and difficult to read that you may not even be able to tell what's going on. We created an object that takes a file object as input, and provides a `__next__` method like any iterator.

This `__next__` method reads lines from the file, discarding them if they are not `WARNING` lines. When it encounters a `WARNING` line, it returns it. Then the `for` loop will call `__next__` again to process the next `WARNING` line. When we run out of lines, we raise `StopIteration` to tell the loop we're finished iterating. It's pretty ugly compared to the other examples, but it's also powerful; now that we have a class in our hands, we can do whatever we want with it.

With that background behind us, we finally get to see generators in action. This next example does *exactly* the same thing as the previous one: it creates an object with a `__next__` method that raises `StopIteration` when it's out of inputs:

```
    import sys
    inname, outname = sys.argv[1:3]

    def warnings_filter(insequence):
        for l in insequence:
            if 'WARNING' in l:
                yield l.replace('\tWARNING', '')

    with open(inname) as infile:
        with open(outname, "w") as outfile:
```

```
filter = warnings_filter(infile)
for l in filter:
    outfile.write(l)
```

OK, that's pretty readable, maybe... at least it's short. But what on earth is going on here, it makes no sense whatsoever. And what is `yield`, anyway?

In fact, `yield` is the key to generators. When Python sees `yield` in a function, it takes that function and wraps it up in an object not unlike the one in our previous example. Think of the `yield` statement as similar to the `return` statement; it exits the function and returns a line. Unlike `return`, however, when the function is called again (via `next()`), it will start where it left off—on the line after the `yield` statement—instead of at the beginning of the function. In this example, there is no line "after" the `yield` statement, so it jumps to the next iteration of the `for` loop. Since the `yield` statement is inside an `if` statement, it only yields lines that contain `WARNING`.

While it looks like this is just a function looping over the lines, it is actually creating a special type of object, a generator object:

```
>>> print(warnings_filter([]))
<generator object warnings_filter at 0xb728c6bc>
```

I passed an empty list into the function to act as an iterator. All the function does is create and return a generator object. That object has `__iter__` and `__next__` methods on it, just like the one we created in the previous example. Whenever `__next__` is called, the generator runs the function until it finds a `yield` statement. It then returns the value from `yield`, and the next time `__next__` is called, it picks up where it left off.

This use of generators isn't that advanced, but if you don't realize the function is creating an object, it can seem like magic. This example was quite simple, but you can get really powerful effects by making multiple calls to `yield` in a single function; the generator will simply pick up at the most recent `yield` and continue to the next one.

Yield items from another iterable

Often, when we build a generator function, we end up in a situation where we want to yield data from another iterable object, possibly a list comprehension or generator expression we constructed inside the generator, or perhaps some external items that were passed into the function. This has always been possible by looping over the iterable and individually yielding each item. However, in Python version 3.3, the Python developers introduced a new syntax to make this a little more elegant.

Let's adapt the generator example a bit so that instead of accepting a sequence of lines, it accepts a filename. This would normally be frowned upon as it ties the object to a particular paradigm. When possible we should operate on iterators as input; this way the same function could be used regardless of whether the log lines came from a file, memory, or a web-based log aggregator. So the following example is contrived for pedagogical reasons.

This version of the code illustrates that your generator can do some basic setup before yielding information from another iterable (in this case, a generator expression):

```
import sys
inname, outname = sys.argv[1:3]

def warnings_filter(infilename):
    with open(infilename) as infile:
        yield from (
            l.replace('\tWARNING', '')
            for l in infile
            if 'WARNING' in l
        )

filter = warnings_filter(inname)
with open(outname, "w") as outfile:
    for l in filter:
        outfile.write(l)
```

This code combines the `for` loop from the previous example into a generator expression. Notice how I put the three clauses of the generator expression (the transformation, the loop, and the filter) on separate lines to make them more readable. Notice also that this transformation didn't help enough; the previous example with a `for` loop was more readable.

So let's consider an example that is more readable than its alternative. It can be useful to construct a generator that yields data from multiple other generators. The `itertools.chain` function, for example, yields data from iterables in sequence until they have all been exhausted. This can be implemented far too easily using the `yield from` syntax, so let's consider a classic computer science problem: walking a general tree.

A common implementation of the general tree data structure is a computer's filesystem. Let's model a few folders and files in a Unix filesystem so we can use `yield from` to walk them effectively:

```
class File:
    def __init__(self, name):
```

```
        self.name = name

class Folder(File):
    def __init__(self, name):
        super().__init__(name)
        self.children = []

root = Folder('')
etc = Folder('etc')
root.children.append(etc)
etc.children.append(File('passwd'))
etc.children.append(File('groups'))
httpd = Folder('httpd')
etc.children.append(httpd)
httpd.children.append(File('http.conf'))
var = Folder('var')
root.children.append(var)
log = Folder('log')
var.children.append(log)
log.children.append(File('messages'))
log.children.append(File('kernel'))
```

This setup code looks like a lot of work, but in a real filesystem, it would be even more involved. We'd have to read data from the hard drive and structure it into the tree. Once in memory, however, the code that outputs every file in the filesystem is quite elegant:

```
def walk(file):
    if isinstance(file, Folder):
        yield file.name + '/'
        for f in file.children:
            yield from walk(f)
    else:
        yield file.name
```

If this code encounters a directory, it recursively asks `walk()` to generate a list of all files subordinate to each of its children, and then yields all that data plus its own filename. In the simple case that it has encountered a normal file, it just yields that name.

As an aside, solving the preceding problem without using a generator is tricky enough that this problem is a common interview question. If you answer it as shown like this, be prepared for your interviewer to be both impressed and somewhat irritated that you answered it so easily. They will likely demand that you explain exactly what is going on. Of course, armed with the principles you've leaned in this chapter, you won't have any problem.

The `yield from` syntax is a useful shortcut when writing chained generators, but it is more commonly used for a different purpose: piping data through coroutines. We'll see many examples of this in *Chapter 13*, *Concurrency*, but for now, let's discover what a coroutine is.

Coroutines

Coroutines are extremely powerful constructs that are often confused with generators. Many authors inappropriately describe coroutines as "generators with a bit of extra syntax." This is an easy mistake to make, as, way back in Python 2.5, when coroutines were introduced, they were presented as "we added a `send` method to the generator syntax." This is further complicated by the fact that when you create a coroutine in Python, the object returned is a generator. The difference is actually a lot more nuanced and will make more sense after you've seen a few examples.

While coroutines in Python are currently tightly coupled to the generator syntax, they are only superficially related to the iterator protocol we have been discussing. The upcoming (as this is published) Python 3.5 release makes coroutines a truly standalone object and will provide a new syntax to work with them.

The other thing to bear in mind is that coroutines are pretty hard to understand. They are not used all that often in the wild, and you could likely skip this section and happily develop in Python for years without missing or even encountering them. There are a couple libraries that use coroutines extensively (mostly for concurrent or asynchronous programming), but they are normally written such that you can use coroutines without actually understanding how they work! So if you get lost in this section, don't despair.

But you won't get lost, having studied the following examples. Here's one of the simplest possible coroutines; it allows us to keep a running tally that can be increased by arbitrary values:

```
def tally():
    score = 0
```

```
        while True:
            increment = yield score
            score += increment
```

This code looks like black magic that couldn't possibly work, so we'll see it working before going into a line-by-line description. This simple object could be used by a scoring application for a baseball team. Separate tallies could be kept for each team, and their score could be incremented by the number of runs accumulated at the end of every half-inning. Look at this interactive session:

```
>>> white_sox = tally()
>>> blue_jays = tally()
>>> next(white_sox)
0
>>> next(blue_jays)
0
>>> white_sox.send(3)
3
>>> blue_jays.send(2)
2
>>> white_sox.send(2)
5
>>> blue_jays.send(4)
6
```

First we construct two `tally` objects, one for each team. Yes, they look like functions, but as with the generator objects in the previous section, the fact that there is a `yield` statement inside the function tells Python to put a great deal of effort into turning the simple function into an object.

We then call `next()` on each of the coroutine objects. This does the same thing as calling next on any generator, which is to say, it executes each line of code until it encounters a `yield` statement, returns the value at that point, and then *pauses* until the next `next()` call.

So far, then, there's nothing new. But look back at the `yield` statement in our coroutine:

```
    increment = yield score
```

Unlike with generators, this yield function looks like it's supposed to return a value and assign it to a variable. This is, in fact, exactly what's happening. The coroutine is still paused at the `yield` statement and waiting to be activated again by another call to `next()`.

Or rather, as you see in the interactive session, a call to a method called `send()`. The `send()` method does *exactly* the same thing as `next()` except that in addition to advancing the generator to the next `yield` statement. It also allows you to pass in a value from outside the generator. This value is assigned to the left side of the `yield` statement.

The thing that is really confusing for many people is the order in which this happens:

- `yield` occurs and the generator pauses
- `send()` occurs from outside the function and the generator wakes up
- The value sent in is assigned to the left side of the `yield` statement
- The generator continues processing until it encounters another `yield` statement

So, in this particular example, after we construct the coroutine and advance it to the `yield` statement with a call to `next()`, each successive call to `send()` passes a value into the coroutine, which adds this value to its score, goes back to the top of the `while` loop, and keeps processing until it hits the `yield` statement. The `yield` statement returns a value, and this value becomes the return value of the most recent call to `send`. Don't miss that: the `send()` method does not just submit a value to the generator, it also returns the value from the upcoming `yield` statement, just like `next()`. This is how we define the difference between a generator and a coroutine: a generator only produces values, while a coroutine can also consume them.

The behavior and syntax of `next(i)`, `i.__next__()`, and `i.send(value)` are rather unintuitive and frustrating. The first is a normal function, the second is a special method, and the last is a normal method. But all three do the same thing: advance the generator until it yields a value and pause. Further, the `next()` function and associated method can be replicated by calling `i.send(None)`. There is value to having two different method names here, since it helps the reader of our code easily see whether they are interacting with a coroutine or a generator. I just find the fact that in one case it's a function call and in the other it's a normal method somewhat irritating.

Back to log parsing

Of course, the previous example could easily have been coded using a couple integer variables and calling `x += increment` on them. Let's look at a second example where coroutines actually save us some code. This example is a somewhat simplified (for pedagogical reasons) version of a problem I had to solve in my real job. The fact that it logically follows from the earlier discussions about processing a log file is completely serendipitous; those examples were written for the first edition of this book, whereas this problem came up four years later!

The Linux kernel log contains lines that look somewhat, but not quite completely, unlike this:

```
unrelated log messages
sd 0:0:0:0 Attached Disk Drive
unrelated log messages
sd 0:0:0:0 (SERIAL=ZZ12345)
unrelated log messages
sd 0:0:0:0 [sda] Options
unrelated log messages
XFS ERROR [sda]
unrelated log messages
sd 2:0:0:1 Attached Disk Drive
unrelated log messages
sd 2:0:0:1 (SERIAL=ZZ67890)
unrelated log messages
sd 2:0:0:1 [sdb] Options
unrelated log messages
sd 3:0:1:8 Attached Disk Drive
unrelated log messages
sd 3:0:1:8 (SERIAL=WW11111)
unrelated log messages
sd 3:0:1:8 [sdc] Options
unrelated log messages
XFS ERROR [sdc]
unrelated log messages
```

There are a whole bunch of interspersed kernel log messages, some of which pertain to hard disks. The hard disk messages might be interspersed with other messages, but they occur in a predictable format and order, in which a specific drive with a known serial number is associated with a bus identifier (such as `0:0:0:0`), and a block device identifier (such as `sda`) is associated with that bus. Finally, if the drive has a corrupt filesystem, it might fail with an XFS error.

Now, given the preceding log file, the problem we need to solve is how to obtain the serial number of any drives that have XFS errors on them. This serial number might later be used by a data center technician to identify and replace the drive.

We know we can identify the individual lines using regular expressions, but we'll have to change the regular expressions as we loop through the lines, since we'll be looking for different things depending on what we found previously. The other difficult bit is that if we find an error string, the information about which bus contains that string, and what serial number is attached to the drive on that bus has already been processed. This can easily be solved by iterating through the lines of the file in reverse order.

Before you look at this example, be warned—the amount of code required for a coroutine-based solution is scarily small:

```
import re

def match_regex(filename, regex):
    with open(filename) as file:
        lines = file.readlines()
    for line in reversed(lines):
        match = re.match(regex, line)
        if match:
            regex = yield match.groups()[0]

def get_serials(filename):
    ERROR_RE = 'XFS ERROR (\[sd[a-z]\])'
    matcher = match_regex(filename, ERROR_RE)
    device = next(matcher)
    while True:
        bus = matcher.send(
            '(sd \S+) {}.*'.format(re.escape(device)))
        serial = matcher.send('{} \(SERIAL=([^)]*)\)'.format(bus))
        yield serial
        device = matcher.send(ERROR_RE)

for serial_number in get_serials('EXAMPLE_LOG.log'):
    print(serial_number)
```

This code neatly divides the job into two separate tasks. The first task is to loop over all the lines and spit out any lines that match a given regular expression. The second task is to interact with the first task and give it guidance as to what regular expression it is supposed to be searching for at any given time.

Look at the `match_regex` coroutine first. Remember, it doesn't execute any code when it is constructed; rather, it just creates a coroutine object. Once constructed, someone outside the coroutine will eventually call `next()` to start the code running, at which point it stores the state of two variables, `filename` and `regex`. It then reads all the lines in the file and iterates over them in reverse. Each line is compared to the regular expression that was passed in until it finds a match. When the match is found, the coroutine yields the first group from the regular expression and waits.

At some point in the future, other code will send in a new regular expression to search for. Note that the coroutine never cares what regular expression it is trying to match; it's just looping over lines and comparing them to a regular expression. It's somebody else's responsibility to decide what regular expression to supply.

In this case, that somebody else is the `get_serials` generator. It doesn't care about the lines in the file, in fact it isn't even aware of them. The first thing it does is create a `matcher` object from the `match_regex` coroutine constructor, giving it a default regular expression to search for. It advances the coroutine to its first `yield` and stores the value it returns. It then goes into a loop that instructs the matcher object to search for a bus ID based on the stored device ID, and then a serial number based on that bus ID.

It idly yields that serial number to the outside `for` loop before instructing the matcher to find another device ID and repeat the cycle.

Basically, the coroutine's (`match_regex`, as it uses the `regex = yield` syntax) job is to search for the next important line in the file, while the generator's (`get_serial`, which uses the `yield` syntax without assignment) job is to decide which line is important. The generator has information about this particular problem, such as what order lines will appear in the file. The coroutine, on the other hand, could be plugged into any problem that required searching a file for given regular expressions.

Closing coroutines and throwing exceptions

Normal generators signal their exit from inside by raising `StopIteration`. If we chain multiple generators together (for example, by iterating over one generator from inside another), the `StopIteration` exception will be propagated outward. Eventually, it will hit a `for` loop that will see the exception and know that it's time to exit the loop.

Coroutines don't normally follow the iteration mechanism; rather than pulling data through one until an exception is encountered, data is usually pushed into it (using `send`). The entity doing the pushing is normally the one in charge of telling the coroutine when it's finished; it does this by calling the `close()` method on the coroutine in question.

When called, the `close()` method will raise a `GeneratorExit` exception at the point the coroutine was waiting for a value to be sent in. It is normally good policy for coroutines to wrap their `yield` statements in a `try...finally` block so that any cleanup tasks (such as closing associated files or sockets) can be performed.

If we need to raise an exception inside a coroutine, we can use the `throw()` method in a similar way. It accepts an exception type with optional `value` and `traceback` arguments. The latter is useful when we encounter an exception in one coroutine and want to cause an exception to occur in an adjacent coroutine while maintaining the traceback.

Both of these features are vital if you're building robust coroutine-based libraries, but we are unlikely to encounter them in our day-to-day coding lives.

The relationship between coroutines, generators, and functions

We've seen coroutines in action, so now let's go back to that discussion of how they are related to generators. In Python, as is so often the case, the distinction is quite blurry. In fact, all coroutines are generator objects, and authors often use the two terms interchangeably. Sometimes, they describe coroutines as a subset of generators (only generators that return values from yield are considered coroutines). This is technically true in Python, as we've seen in the previous sections.

However, in the greater sphere of theoretical computer science, coroutines are considered the more general principles, and generators are a specific type of coroutine. Further, normal functions are yet another distinct subset of coroutines.

A coroutine is a routine that can have data passed in at one or more points and get it out at one or more points. In Python, the point where data is passed in and out is the `yield` statement.

A function, or subroutine, is the simplest type of coroutine. You can pass data in at one point, and get data out at one other point when the function returns. While a function can have multiple `return` statements, only one of them can be called for any given invocation of the function.

Finally, a generator is a type of coroutine that can have data passed in at one point, but can pass data out at multiple points. In Python, the data would be passed out at a `yield` statement, but you can't pass data back in. If you called `send`, the data would be silently discarded.

So in theory, generators are types of coroutines, functions are types of coroutines, and there are coroutines that are neither functions nor generators. That's simple enough, eh? So why does it feel more complicated in Python?

In Python, generators and coroutines are both constructed using a syntax that looks like we are constructing a function. But the resulting object is not a function at all; it's a totally different kind of object. Functions are, of course, also objects. But they have a different interface; functions are callable and return values, generators have data pulled out using `next()`, and coroutines have data pushed in using `send`.

Case study

One of the fields in which Python is the most popular these days is data science. Let's implement a basic machine learning algorithm! Machine learning is a huge topic, but the general idea is to make predictions or classifications about future data by using knowledge gained from past data. Uses of such algorithms abound, and data scientists are finding new ways to apply machine learning every day. Some important machine learning applications include computer vision (such as image classification or facial recognition), product recommendation, identifying spam, and speech recognition. We'll look at a simpler problem: given an RGB color definition, what name would humans identify that color as?

There are more than 16 million colors in the standard RGB color space, and humans have come up with names for only a fraction of them. While there are thousands of names (some quite ridiculous; just go to any car dealership or makeup store), let's build a classifier that attempts to divide the RGB space into the basic colors:

- Red
- Purple
- Blue
- Green
- Yellow
- Orange
- Grey
- White
- Pink

The first thing we need is a dataset to train our algorithm on. In a production system, you might scrape a *list of colors* website or survey thousands of people. Instead, I created a simple application that renders a random color and asks the user to select one of the preceding nine options to classify it. This application is included with the example code for this chapter in the `kivy_color_classifier` directory, but we won't be going into the details of this code as its only purpose here is to generate sample data.

Kivy has an incredibly well-engineered object-oriented API that you may want to explore on your own time. If you would like to develop graphical programs that run on many systems, from your laptop to your cell phone, you might want to check out my book, *Creating Apps In Kivy*, *O'Reilly*.

For the purposes of this case study, the important thing about that application is the output, which is a **comma-separated value** (**CSV**) file that contains four values per row: the red, green, and blue values (represented as a floating-point number between zero and one), and one of the preceding nine names that the user assigned to that color. The dataset looks something like this:

```
0.30928279150905513,0.7536768153744394,0.3244011790604804,Green
0.4991001855115986,0.6394567277907686,0.6340502030888825,Grey
0.21132621004927998,0.3307376167520666,0.704037576789711,Blue
0.7260420945787928,0.4025279573860123,0.49781705131696363,Pink
0.706469868610228,0.28530423638868196,0.7880240251003464,Purple
0.692243900051664,0.7053550777777416,0.1845069151913028,Yellow
0.3628979381122397,0.11079495501215897,0.26924540840045075,Purple
0.611273677646518,0.48798521783547677,0.5346130557761224,Purple
.
.
.
0.4014121109376566,0.42176706818252674,0.9601866228083298,Blue
0.17750449496124632,0.8008214961070862,0.5073944321437429,Green
```

I made 200 datapoints (a very few of them untrue) before I got bored and decided it was time to start machine learning on this dataset. These datapoints are shipped with the examples for this chapter if you would like to use my data (nobody's ever told me I'm color-blind, so it should be somewhat reasonable).

We'll be implementing one of the simpler machine-learning algorithms, referred to as k-nearest neighbor. This algorithm relies on some kind of "distance" calculation between points in the dataset (in our case, we can use a three-dimensional version of the Pythagorean theorem). Given a new datapoint, it finds a certain number (referred to as k, as in k-nearest neighbors) of datapoints that are closest to it when measured by that distance calculation. Then it combines those datapoints in some way (an average might work for linear calculations; for our classification problem, we'll use the mode), and returns the result.

We won't go into too much detail about what the algorithm does; rather, we'll focus on some of the ways we can apply the iterator pattern or iterator protocol to this problem.

Let's now write a program that performs the following steps in order:

1. Load the sample data from the file and construct a model from it.
2. Generate 100 random colors.
3. Classify each color and output it to a file in the same format as the input.

Once we have this second CSV file, another Kivy program can load the file and render each color, asking a human user to confirm or deny the accuracy of the prediction, thus informing us of how accurate our algorithm and initial data set are.

The first step is a fairly simple generator that loads CSV data and converts it into a format that is amenable to our needs:

```
import csv

dataset_filename = 'colors.csv'

def load_colors(filename):
    with open(filename) as dataset_file:
        lines = csv.reader(dataset_file)
        for line in lines:
            yield tuple(float(y) for y in line[0:3]), line[3]
```

We haven't seen the `csv.reader` function before. It returns an iterator over the lines in the file. Each value returned by the iterator is a list of strings. In our case, we could have just split on commas and been fine, but `csv.reader` also takes care of managing quotation marks and various other nuances of the comma-separated value format.

We then loop over these lines and convert them to a tuple of color and name, where the color is a tuple of three floating value integers. This tuple is constructed using a generator expression. There might be more readable ways to construct this tuple; do you think the code brevity and the speed of a generator expression is worth the obfuscation? Instead of returning a list of color tuples, it yields them one at a time, thus constructing a generator object.

Now, we need a hundred random colors. There are so many ways this can be done:

- A list comprehension with a nested generator expression: `[tuple(random() for r in range(3)) for r in range(100)]`
- A basic generator function
- A class that implements the `__iter__` and `__next__` protocols

- Push the data through a pipeline of coroutines
- Even just a basic `for` loop

The generator version seems to be most readable, so let's add that function to our program:

```
from random import random


def generate_colors(count=100):
    for i in range(count):
        yield (random(), random(), random())
```

Notice how we parameterize the number of colors to generate. We can now reuse this function for other color-generating tasks in the future.

Now, before we do the classification step, we need a function to calculate the "distance" between two colors. Since it's possible to think of colors as being three dimensional (red, green, and blue could map to *x*, *y*, and *z* axes, for example), let's use a little basic math:

```
import math

def color_distance(color1, color2):
    channels = zip(color1, color2)
    sum_distance_squared = 0
    for c1, c2 in channels:
        sum_distance_squared += (c1 - c2) ** 2
    return math.sqrt(sum_distance_squared)
```

This is a pretty basic-looking function; it doesn't look like it's even using the iterator protocol. There's no `yield` function, no comprehensions. However, there is a `for` loop, and that call to the `zip` function is doing some real iteration as well (remember that `zip` yields tuples containing one element from each input iterator).

Note, however, that this function is going to be called a lot of times inside our k-nearest neighbors algorithm. If our code ran too slow and we were able to identify this function as a bottleneck, we might want to replace it with a less readable, but more optimized, generator expression:

```
def color_distance(color1, color2):
    return math.sqrt(sum((x[0] - x[1]) ** 2 for x in zip(
    color1, color2)))
```

However, I strongly recommend not making such optimizations until you have proven that the readable version is too slow.

Now that we have some plumbing in place, let's do the actual k-nearest neighbor implementation. This seems like a good place to use a coroutine. Here it is with some test code to ensure it's yielding sensible values:

```
def nearest_neighbors(model_colors, num_neighbors):
    model = list(model_colors)
    target = yield
    while True:
        distances = sorted(
            ((color_distance(c[0], target), c) for c in model),
        )
        target = yield [
            d[1] for d in distances[0:num_neighbors]
        ]


model_colors = load_colors(dataset_filename)
target_colors = generate_colors(3)
get_neighbors = nearest_neighbors(model_colors, 5)
next(get_neighbors)

for color in target_colors:
    distances = get_neighbors.send(color)
    print(color)
    for d in distances:
        print(color_distance(color, d[0]), d[1])
```

The coroutine accepts two arguments, the list of colors to be used as a model, and the number of neighbors to query. It converts the model to a list because it's going to be iterated over multiple times. In the body of the coroutine, it accepts a tuple of RGB color values using the `yield` syntax. Then it combines a call to `sorted` with an odd generator expression. See if you can figure out what that generator expression is doing.

It returns a tuple of `(distance, color_data)` for each color in the model. Remember, the model itself contains tuples of `(color, name)`, where `color` is a tuple of three RGB values. Therefore, the generator is returning an iterator over a weird data structure that looks like this:

```
(distance, (r, g, b), color_name)
```

The `sorted` call then sorts the results by their first element, which is distance. This is a complicated piece of code and isn't object-oriented at all. You may want to break it down into a normal `for` loop to ensure you understand what the generator expression is doing. It might also be a good exercise to imagine how this code would look if you were to pass a key argument into the sorted function instead of constructing a tuple.

The `yield` statement is a bit less complicated; it pulls the second value from each of the first k `(distance, color_data)` tuples. In more concrete terms, it yields the `((r, g, b), color_name)` tuple for the k values with the lowest distance. Or, if you prefer more abstract terms, it yields the target's k-nearest neighbors in the given model.

The remaining code is just boilerplate to test this method; it constructs the model and a color generator, primes the coroutine, and prints the results in a `for` loop.

The two remaining tasks are to choose a color based on the nearest neighbors, and to output the results to a CSV file. Let's make two more coroutines to take care of these tasks. Let's do the output first because it can be tested independently:

```
def write_results(filename="output.csv"):
    with open(filename, "w") as file:
        writer = csv.writer(file)
        while True:
            color, name = yield
            writer.writerow(list(color) + [name])

results = write_results()
next(results)
for i in range(3):
    print(i)
    results.send(((i, i, i), i * 10))
```

This coroutine maintains an open file as state and writes lines of code to it as they are sent in using `send()`. The test code ensures the coroutine is working correctly, so now we can connect the two coroutines with a third one.

The second coroutine uses a bit of an odd trick:

```
from collections import Counter
def name_colors(get_neighbors):
    color = yield
    while True:
        near = get_neighbors.send(color)
        name_guess = Counter(
            n[1] for n in near).most_common(1)[0][0]
        color = yield name_guess
```

This coroutine accepts, *as its argument*, an existing coroutine. In this case, it's an instance of `nearest_neighbors`. This code basically proxies all the values sent into it through that `nearest_neighbors` instance. Then it does some processing on the result to get the most common color out of the values that were returned. In this case, it would probably make just as much sense to adapt the original coroutine to return a name, since it isn't being used for anything else. However, there are many cases where it is useful to pass coroutines around; this is how we do it.

Now all we have to do is connect these various coroutines and pipelines together, and kick off the process with a single function call:

```
def process_colors(dataset_filename="colors.csv"):
    model_colors = load_colors(dataset_filename)
    get_neighbors = nearest_neighbors(model_colors, 5)
    get_color_name = name_colors(get_neighbors)
    output = write_results()
    next(output)
    next(get_neighbors)
    next(get_color_name)

    for color in generate_colors():
        name = get_color_name.send(color)
        output.send((color, name))

process_colors()
```

So, this function, unlike almost every other function we've defined, is a perfectly normal function without any `yield` statements. It doesn't get turned into a coroutine or generator object. It does, however, construct a generator and three coroutines. Notice how the `get_neighbors` coroutine is passed into the constructor for `name_colors`? Pay attention to how all three coroutines are advanced to their first `yield` statements by calls to `next`.

Once all the pipes are created, we use a `for` loop to send each of the generated colors into the `get_color_name` coroutine, and then we pipe each of the values yielded by that coroutine to the output coroutine, which writes it to a file.

And that's it! I created a second Kivy app that loads the resulting CSV file and presents the colors to the user. The user can select either *Yes* or *No* depending on whether they think the choice made by the machine-learning algorithm matches the choice they would have made. This is not scientifically accurate (it's ripe for observation bias), but it's good enough for playing around. Using my eyes, it succeeded about 84 percent of the time, which is better than my grade 12 average. Not bad for our first ever machine learning experience, eh?

You might be wondering, "what does this have to do with object-oriented programming? There isn't even one class in this code!". In some ways, you'd be right; neither coroutines nor generators are commonly considered object-oriented. However, the functions that create them return objects; in fact, you could think of those functions as constructors. The constructed object has appropriate `send()` and `__next__()` methods. Basically, the coroutine/generator syntax is a syntax shortcut for a particular kind of object that would be quite verbose to create without it.

This case study has been an exercise in bottom-up design. We created various low-level objects that did specific tasks and hooked them all together at the end. I find this to be a common practice when developing with coroutines. The alternative, top-down design sometimes results in more monolithic pieces of code instead of unique individual pieces. In general, we want to find a happy medium between methods that are too large and methods that are too small and it's hard to see how they fit together. This is true, of course, regardless of whether the iterator protocol is being used as we did here.

Exercises

If you don't use comprehensions in your daily coding very often, the first thing you should do is search through some existing code and find some `for` loops. See if any of them can be trivially converted to a generator expression or a list, set, or dictionary comprehension.

Test the claim that list comprehensions are faster than `for` loops. This can be done with the built-in `timeit` module. Use the help documentation for the `timeit.timeit` function to find out how to use it. Basically, write two functions that do the same thing, one using a list comprehension, and one using a `for` loop. Pass each function into `timeit.timeit`, and compare the results. If you're feeling adventurous, compare generators and generator expressions as well. Testing code using `timeit` can become addictive, so bear in mind that code does not need to be hyperfast unless it's being executed an immense number of times, such as on a huge input list or file.

Play around with generator functions. Start with basic iterators that require multiple values (mathematical sequences are canonical examples; the Fibonacci sequence is overused if you can't think of anything better). Try some more advanced generators that do things like take multiple input lists and somehow yield values that merge them. Generators can also be used on files; can you write a simple generator that shows those lines that are identical in two files?

Coroutines abuse the iterator protocol but don't actually fulfill the iterator pattern. Can you build a non-coroutine version of the code that gets a serial number from a log file? Take an object-oriented approach so that you can store an additional state on a class. You'll learn a lot about coroutines if you can create an object that is a drop-in replacement for the existing coroutine.

See if you can abstract the coroutines used in the case study so that the k-nearest-neighbor algorithm can be used on a variety of datasets. You'll likely want to construct a coroutine that accepts other coroutines or functions that do the distance and recombination calculations as parameters, and then calls into those functions to find the actual nearest neighbors.

Summary

In this chapter, we learned that design patterns are useful abstractions that provide "best practice" solutions for common programming problems. We covered our first design pattern, the iterator, as well as numerous ways that Python uses and abuses this pattern for its own nefarious purposes. The original iterator pattern is extremely object-oriented, but it is also rather ugly and verbose to code around. However, Python's built-in syntax abstracts the ugliness away, leaving us with a clean interface to these object-oriented constructs.

Comprehensions and generator expressions can combine container construction with iteration in a single line. Generator objects can be constructed using the `yield` syntax. Coroutines look like generators on the outside but serve a much different purpose.

We'll cover several more design patterns in the next two chapters.

10
Python Design Patterns I

In the last chapter, we were briefly introduced to design patterns, and covered the iterator pattern, a pattern so useful and common that it has been abstracted into the core of the programming language itself. In this chapter, we'll be reviewing other common patterns, and how they are implemented in Python. As with iteration, Python often provides an alternative syntax to make working with such problems simpler. We will cover both the "traditional" design, and the Python version for these patterns. In summary, we'll see:

- Numerous specific patterns
- A canonical implementation of each pattern in Python
- Python syntax to replace certain patterns

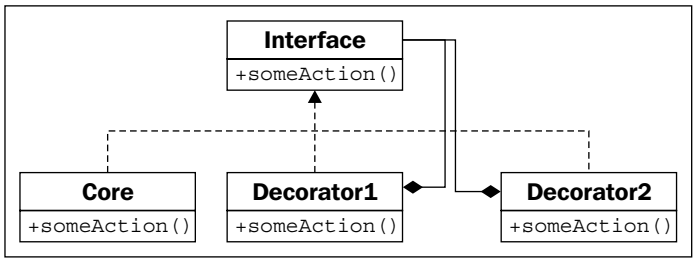
The decorator pattern

The decorator pattern allows us to "wrap" an object that provides core functionality with other objects that alter this functionality. Any object that uses the decorated object will interact with it in exactly the same way as if it were undecorated (that is, the interface of the decorated object is identical to that of the core object).

There are two primary uses of the decorator pattern:

- Enhancing the response of a component as it sends data to a second component
- Supporting multiple optional behaviors

The second option is often a suitable alternative to multiple inheritance. We can construct a core object, and then create a decorator around that core. Since the decorator object has the same interface as the core object, we can even wrap the new object in other decorators. Here's how it looks in UML:



Here, **Core** and all the decorators implement a specific **Interface**. The decorators maintain a reference to another instance of that **Interface** via composition. When called, the decorator does some added processing before or after calling its wrapped interface. The wrapped object may be another decorator, or the core functionality. While multiple decorators may wrap each other, the object in the "center" of all those decorators provides the core functionality.

A decorator example

Let's look at an example from network programming. We'll be using a TCP socket. The `socket.send()` method takes a string of input bytes and outputs them to the receiving socket at the other end. There are plenty of libraries that accept sockets and access this function to send data on the stream. Let's create such an object; it will be an interactive shell that waits for a connection from a client and then prompts the user for a string response:

```
import socket

def respond(client):
    response = input("Enter a value: ")
    client.send(bytes(response, 'utf8'))
    client.close()

server = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
server.bind(('localhost',2401))
server.listen(1)
try:
    while True:
```

```
            client, addr = server.accept()
            respond(client)
    finally:
        server.close()
```

The `respond` function accepts a socket parameter and prompts for data to be sent as a reply, then sends it. To use it, we construct a server socket and tell it to listen on port `2401` (I picked the port randomly) on the local computer. When a client connects, it calls the `respond` function, which requests data interactively and responds appropriately. The important thing to notice is that the `respond` function only cares about two methods of the socket interface: `send` and `close`. To test this, we can write a very simple client that connects to the same port and outputs the response before exiting:

```
import socket

client = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
client.connect(('localhost', 2401))
print("Received: {0}".format(client.recv(1024)))
client.close()
```

To use these programs:

1. Start the server in one terminal.
2. Open a second terminal window and run the client.
3. At the **Enter a value:** prompt in the server window, type a value and press enter.
4. The client will receive what you typed, print it to the console, and exit. Run the client a second time; the server will prompt for a second value.

Now, looking again at our server code, we see two sections. The `respond` function sends data into a socket object. The remaining script is responsible for creating that socket object. We'll create a pair of decorators that customize the socket behavior without having to extend or modify the socket itself.

Let's start with a "logging" decorator. This object outputs any data being sent to the server's console before it sends it to the client:

```
class LogSocket:
    def __init__(self, socket):
        self.socket = socket

    def send(self, data):
```

```
            print("Sending {0} to {1}".format(
                data, self.socket.getpeername()[0]))
            self.socket.send(data)

        def close(self):
            self.socket.close()
```

This class decorates a socket object and presents the `send` and `close` interface to client sockets. A better decorator would also implement (and possibly customize) all of the remaining socket methods. It should properly implement all of the arguments to `send`, (which actually accepts an optional flags argument) as well, but let's keep our example simple! Whenever `send` is called on this object, it logs the output to the screen before sending data to the client using the original socket.

We only have to change one line in our original code to use this decorator. Instead of calling `respond` with the socket, we call it with a decorated socket:

```
respond(LogSocket(client))
```

While that's quite simple, we have to ask ourselves why we didn't just extend the socket class and override the `send` method. We could call `super().send` to do the actual sending, after we logged it. There is nothing wrong with this design either.

When faced with a choice between decorators and inheritance, we should only use decorators if we need to modify the object dynamically, according to some condition. For example, we may only want to enable the logging decorator if the server is currently in debugging mode. Decorators also beat multiple inheritance when we have more than one optional behavior. As an example, we can write a second decorator that compresses data using `gzip` compression whenever `send` is called:

```
import gzip
from io import BytesIO

class GzipSocket:
    def __init__(self, socket):
        self.socket = socket

    def send(self, data):
        buf = BytesIO()
        zipfile = gzip.GzipFile(fileobj=buf, mode="w")
        zipfile.write(data)
        zipfile.close()
        self.socket.send(buf.getvalue())

    def close(self):
        self.socket.close()
```

The `send` method in this version compresses the incoming data before sending it on to the client.

Now that we have these two decorators, we can write code that dynamically switches between them when responding. This example is not complete, but it illustrates the logic we might follow to mix and match decorators:

```
client, addr = server.accept()
if log_send:
    client = LoggingSocket(client)
if client.getpeername()[0] in compress_hosts:
    client = GzipSocket(client)
respond(client)
```

This code checks a hypothetical configuration variable named `log_send`. If it's enabled, it wraps the socket in a `LoggingSocket` decorator. Similarly, it checks whether the client that has connected is in a list of addresses known to accept compressed content. If so, it wraps the client in a `GzipSocket` decorator. Notice that none, either, or both of the decorators may be enabled, depending on the configuration and connecting client. Try writing this using multiple inheritance and see how confused you get!

Decorators in Python

The decorator pattern is useful in Python, but there are other options. For example, we may be able to use monkey-patching, which we discussed in *Chapter 7*, *Python Object-oriented Shortcuts*, to get a similar effect. Single inheritance, where the "optional" calculations are done in one large method can be an option, and multiple inheritance should not be written off just because it's not suitable for the specific example seen previously!

In Python, it is very common to use this pattern on functions. As we saw in a previous chapter, functions are objects too. In fact, function decoration is so common that Python provides a special syntax to make it easy to apply such decorators to functions.

For example, we can look at the logging example in a more general way. Instead of logging, only send calls on sockets, we may find it helpful to log all calls to certain functions or methods. The following example implements a decorator that does just this:

```
import time

def log_calls(func):
    def wrapper(*args, **kwargs):
        now = time.time()
```

```
            print("Calling {0} with {1} and {2}".format(
                func.__name__, args, kwargs))
            return_value = func(*args, **kwargs)
            print("Executed {0} in {1}ms".format(
                func.__name__, time.time() - now))
            return return_value
        return wrapper

def test1(a,b,c):
    print("\ttest1 called")

def test2(a,b):
    print("\ttest2 called")

def test3(a,b):
    print("\ttest3 called")
    time.sleep(1)

test1 = log_calls(test1)
test2 = log_calls(test2)
test3 = log_calls(test3)

test1(1,2,3)
test2(4,b=5)
test3(6,7)
```

This decorator function is very similar to the example we explored earlier; in those cases, the decorator took a socket-like object and created a socket-like object. This time, our decorator takes a function object and returns a new function object. This code is comprised of three separate tasks:

- A function, `log_calls`, that accepts another function
- This function defines (internally) a new function, named `wrapper`, that does some extra work before calling the original function
- This new function is returned

Three sample functions demonstrate the decorator in use. The third one includes a sleep call to demonstrate the timing test. We pass each function into the decorator, which returns a new function. We assign this new function to the original variable name, effectively replacing the original function with a decorated one.

This syntax allows us to build up decorated function objects dynamically, just as we did with the socket example; if we don't replace the name, we can even keep decorated and non-decorated versions for different situations.

Often these decorators are general modifications that are applied permanently to different functions. In this situation, Python supports a special syntax to apply the decorator at the time the function is defined. We've already seen this syntax when we discussed the `property` decorator; now, let's understand how it works.

Instead of applying the decorator function after the method definition, we can use the `@decorator` syntax to do it all at once:

```
@log_calls
def test1(a,b,c):
    print("\ttest1 called")
```

The primary benefit of this syntax is that we can easily see that the function has been decorated at the time it is defined. If the decorator is applied later, someone reading the code may miss that the function has been altered at all. Answering a question like, "Why is my program logging function calls to the console?" can become much more difficult! However, the syntax can only be applied to functions we define, since we don't have access to the source code of other modules. If we need to decorate functions that are part of somebody else's third-party library, we have to use the earlier syntax.

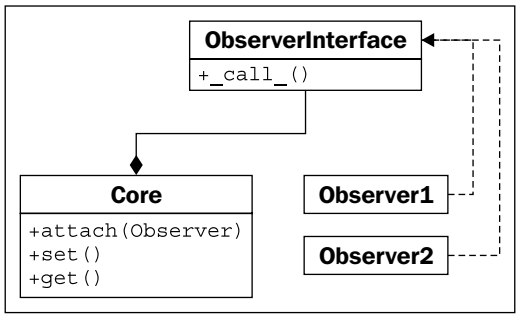
There is more to the decorator syntax than we've seen here. We don't have room to cover the advanced topics here, so check the Python reference manual or other tutorials for more information. Decorators can be created as callable objects, not just functions that return functions. Classes can also be decorated; in that case, the decorator returns a new class instead of a new function. Finally, decorators can take arguments to customize them on a per-function basis.

The observer pattern

The observer pattern is useful for state monitoring and event handling situations. This pattern allows a given object to be monitored by an unknown and dynamic group of "observer" objects.

Whenever a value on the core object changes, it lets all the observer objects know that a change has occurred, by calling an `update()` method. Each observer may be responsible for different tasks whenever the core object changes; the core object doesn't know or care what those tasks are, and the observers don't typically know or care what other observers are doing.

Here, it is in UML:



An observer example

The observer pattern might be useful in a redundant backup system. We can write a core object that maintains certain values, and then have one or more observers create serialized copies of that object. These copies might be stored in a database, on a remote host, or in a local file, for example. Let's implement the core object using properties:

```
class Inventory:
    def __init__(self):
        self.observers = []
        self._product = None
        self._quantity = 0

    def attach(self, observer):
        self.observers.append(observer)

    @property
    def product(self):
        return self._product
    @product.setter
    def product(self, value):
        self._product = value
        self._update_observers()

    @property
    def quantity(self):
        return self._quantity
    @quantity.setter
    def quantity(self, value):
        self._quantity = value
```

```
            self._update_observers()

        def _update_observers(self):
            for observer in self.observers:
                observer()
```

This object has two properties that, when set, call the `_update_observers` method on itself. All this method does is loop over the available observers and let each one know that something has changed. In this case, we call the observer object directly; the object will have to implement `__call__` to process the update. This would not be possible in many object-oriented programming languages, but it's a useful shortcut in Python that can help make our code more readable.

Now let's implement a simple observer object; this one will just print out some state to the console:

```
class ConsoleObserver:
    def __init__(self, inventory):
        self.inventory = inventory

    def __call__(self):
        print(self.inventory.product)
        print(self.inventory.quantity)
```

There's nothing terribly exciting here; the observed object is set up in the initializer, and when the observer is called, we do "something." We can test the observer in an interactive console:

```
>>> i = Inventory()
>>> c = ConsoleObserver(i)
>>> i.attach(c)
>>> i.product = "Widget"
Widget
0
>>> i.quantity = 5
Widget
5
```

After attaching the observer to the inventory object, whenever we change one of the two observed properties, the observer is called and its action is invoked. We can even add two different observer instances:

```
>>> i = Inventory()
>>> c1 = ConsoleObserver(i)
```

```
>>> c2 = ConsoleObserver(i)
>>> i.attach(c1)
>>> i.attach(c2)
>>> i.product = "Gadget"
Gadget
0
Gadget
0
```

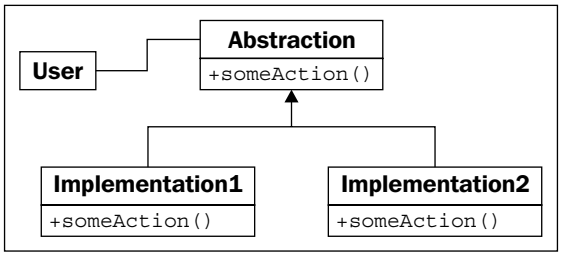
This time when we change the product, there are two sets of output, one for each observer. The key idea here is that we can easily add totally different types of observers that back up the data in a file, database, or Internet application at the same time.

The observer pattern detaches the code being observed from the code doing the observing. If we were not using this pattern, we would have had to put code in each of the properties to handle the different cases that might come up; logging to the console, updating a database or file, and so on. The code for each of these tasks would all be mixed in with the observed object. Maintaining it would be a nightmare, and adding new monitoring functionality at a later date would be painful.

The strategy pattern

The strategy pattern is a common demonstration of abstraction in object-oriented programming. The pattern implements different solutions to a single problem, each in a different object. The client code can then choose the most appropriate implementation dynamically at runtime.

Typically, different algorithms have different trade-offs; one might be faster than another, but uses a lot more memory, while a third algorithm may be most suitable when multiple CPUs are present or a distributed system is provided. Here is the strategy pattern in UML:



The **User** code connecting to the strategy pattern simply needs to know that it is dealing with the **Abstraction** interface. The actual implementation chosen performs the same task, but in different ways; either way, the interface is identical.

A strategy example

The canonical example of the strategy pattern is sort routines; over the years, numerous algorithms have been invented for sorting a collection of objects; quick sort, merge sort, and heap sort are all fast sort algorithms with different features, each useful in its own right, depending on the size and type of inputs, how out of order they are, and the requirements of the system.

If we have client code that needs to sort a collection, we could pass it to an object with a `sort()` method. This object may be a `QuickSorter` or `MergeSorter` object, but the result will be the same in either case: a sorted list. The strategy used to do the sorting is abstracted from the calling code, making it modular and replaceable.

Of course, in Python, we typically just call the `sorted` function or `list.sort` method and trust that it will do the sorting in a near-optimal fashion. So, we really need to look at a better example.

Let's consider a desktop wallpaper manager. When an image is displayed on a desktop background, it can be adjusted to the screen size in different ways. For example, assuming the image is smaller than the screen, it can be tiled across the screen, centered on it, or scaled to fit. There are other, more complicated, strategies that can be used as well, such as scaling to the maximum height or width, combining it with a solid, semi-transparent, or gradient background color, or other manipulations. While we may want to add these strategies later, let's start with the basic ones.

Our strategy objects takes two inputs; the image to be displayed, and a tuple of the width and height of the screen. They each return a new image the size of the screen, with the image manipulated to fit according to the given strategy. You'll need to install the `pillow` module with `pip3 install pillow` for this example to work:

```
from PIL import Image


class TiledStrategy:
    def make_background(self, img_file, desktop_size):
        in_img = Image.open(img_file)
        out_img = Image.new('RGB', desktop_size)
        num_tiles = [
```

```
            o // i + 1 for o, i in
            zip(out_img.size, in_img.size)
        ]
        for x in range(num_tiles[0]):
            for y in range(num_tiles[1]):
                out_img.paste(
                    in_img,
                    (
                        in_img.size[0] * x,
                        in_img.size[1] * y,
                        in_img.size[0] * (x+1),
                        in_img.size[1] * (y+1)
                    )
                )
        return out_img


class CenteredStrategy:
    def make_background(self, img_file, desktop_size):
        in_img = Image.open(img_file)
        out_img = Image.new('RGB', desktop_size)
        left = (out_img.size[0] - in_img.size[0]) // 2
        top = (out_img.size[1] - in_img.size[1]) // 2
        out_img.paste(
            in_img,
            (
                left,
                top,
                left+in_img.size[0],
                top + in_img.size[1]
            )
        )
        return out_img


class ScaledStrategy:
    def make_background(self, img_file, desktop_size):
        in_img = Image.open(img_file)
        out_img = in_img.resize(desktop_size)
        return out_img
```

Here we have three strategies, each using `PIL` to perform their task. Individual strategies have a `make_background` method that accepts the same set of parameters. Once selected, the appropriate strategy can be called to create a correctly sized version of the desktop image. `TiledStrategy` loops over the number of input images that would fit in the width and height of the image and copies it into each location, repeatedly. `CenteredStrategy` figures out how much space needs to be left on the four edges of the image to center it. `ScaledStrategy` forces the image to the output size (ignoring aspect ratio).

Consider how switching between these options would be implemented without the strategy pattern. We'd need to put all the code inside one great big method and use an awkward `if` statement to select the expected one. Every time we wanted to add a new strategy, we'd have to make the method even more ungainly.

Strategy in Python

The preceding canonical implementation of the strategy pattern, while very common in most object-oriented libraries, is rarely seen in Python programming.

These classes each represent objects that do nothing but provide a single function. We could just as easily call that function `__call__` and make the object callable directly. Since there is no other data associated with the object, we need do no more than create a set of top-level functions and pass them around as our strategies instead.

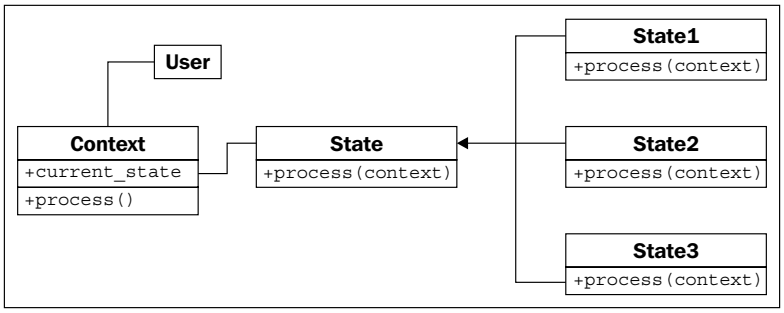
Opponents of design pattern philosophy will therefore say, "because Python has first-class functions, the strategy pattern is unnecessary". In truth, Python's first-class functions allow us to implement the strategy pattern in a more straightforward way. Knowing the pattern exists can still help us choose a correct design for our program, but implement it using a more readable syntax. The strategy pattern, or a top-level function implementation of it, should be used when we need to allow client code or the end user to select from multiple implementations of the same interface.

The state pattern

The state pattern is structurally similar to the strategy pattern, but its intent and purpose are very different. The goal of the state pattern is to represent state-transition systems: systems where it is obvious that an object can be in a specific state, and that certain activities may drive it to a different state.

To make this work, we need a manager, or context class that provides an interface for switching states. Internally, this class contains a pointer to the current state; each state knows what other states it is allowed to be in and will transition to those states depending on actions invoked upon it.

So we have two types of classes, the context class and multiple state classes. The context class maintains the current state, and forwards actions to the state classes. The state classes are typically hidden from any other objects that are calling the context; it acts like a black box that happens to perform state management internally. Here's how it looks in UML:



A state example

To illustrate the state pattern, let's build an XML parsing tool. The context class will be the parser itself. It will take a string as input and place the tool in an initial parsing state. The various parsing states will eat characters, looking for a specific value, and when that value is found, change to a different state. The goal is to create a tree of node objects for each tag and its contents. To keep things manageable, we'll parse only a subset of XML - tags and tag names. We won't be able to handle attributes on tags. It will parse text content of tags, but won't attempt to parse "mixed" content, which has tags inside of text. Here is an example "simplified XML" file that we'll be able to parse:

```
<book>
    <author>Dusty Phillips</author>
    <publisher>Packt Publishing</publisher>
    <title>Python 3 Object Oriented Programming</title>
    <content>
        <chapter>
            <number>1</number>
            <title>Object Oriented Design</title>
        </chapter>
        <chapter>
            <number>2</number>
            <title>Objects In Python</title>
        </chapter>
    </content>
</book>
```

Before we look at the states and the parser, let's consider the output of this program. We know we want a tree of `Node` objects, but what does a `Node` look like? Well, clearly it'll need to know the name of the tag it is parsing, and since it's a tree, it should probably maintain a pointer to the parent node and a list of the node's children in order. Some nodes have a text value, but not all of them. Let's look at this `Node` class first:

```
class Node:
    def __init__(self, tag_name, parent=None):
        self.parent = parent
        self.tag_name = tag_name
        self.children = []
        self.text=""

    def __str__(self):
        if self.text:
            return self.tag_name + ": " + self.text
        else:
            return self.tag_name
```

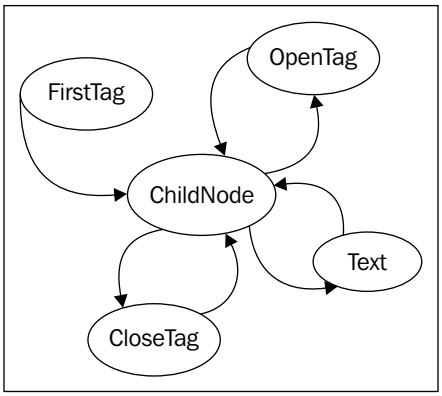
This class sets default attribute values upon initialization. The `__str__` method is supplied to help visualize the tree structure when we're finished.

Now, looking at the example document, we need to consider what states our parser can be in. Clearly it's going to start in a state where no nodes have yet been processed. We'll need a state for processing opening tags and closing tags. And when we're inside a tag with text contents, we'll have to process that as a separate state, too.

Switching states can be tricky; how do we know if the next node is an opening tag, a closing tag, or a text node? We could put a little logic in each state to work this out, but it actually makes more sense to create a new state whose sole purpose is figuring out which state we'll be switching to next. If we call this transition state **ChildNode**, we end up with the following states:

- **FirstTag**
- **ChildNode**
- **OpenTag**
- **CloseTag**
- **Text**

The **FirstTag** state will switch to **ChildNode**, which is responsible for deciding which of the other three states to switch to; when those states are finished, they'll switch back to **ChildNode**. The following state-transition diagram shows the available state changes:



The states are responsible for taking "what's left of the string", processing as much of it as they know what to do with, and then telling the parser to take care of the rest of it. Let's construct the `Parser` class first:

```
class Parser:
    def __init__(self, parse_string):
        self.parse_string = parse_string
        self.root = None
        self.current_node = None

        self.state = FirstTag()

    def process(self, remaining_string):
        remaining = self.state.process(remaining_string, self)
        if remaining:
            self.process(remaining)

    def start(self):
        self.process(self.parse_string)
```

The initializer sets up a few variables on the class that the individual states will access. The `parse_string` instance variable is the text that we are trying to parse. The `root` node is the "top" node in the XML structure. The `current_node` instance variable is the one that we are currently adding children to.

The important feature of this parser is the `process` method, which accepts the remaining string, and passes it off to the current state. The parser (the `self` argument) is also passed into the state's process method so that the state can manipulate it. The state is expected to return the remainder of the unparsed string when it is finished processing. The parser then recursively calls the `process` method on this remaining string to construct the rest of the tree.

Now, let's have a look at the `FirstTag` state:

```
class FirstTag:
    def process(self, remaining_string, parser):
        i_start_tag = remaining_string.find('<')
        i_end_tag = remaining_string.find('>')
        tag_name = remaining_string[i_start_tag+1:i_end_tag]
        root = Node(tag_name)
        parser.root = parser.current_node = root
        parser.state = ChildNode()
        return remaining_string[i_end_tag+1:]
```

This state finds the index (the `i_` stands for index) of the opening and closing angle brackets on the first tag. You may think this state is unnecessary, since XML requires that there be no text before an opening tag. However, there may be whitespace that needs to be consumed; this is why we search for the opening angle bracket instead of assuming it is the first character in the document. Note that this code is assuming a valid input file. A proper implementation would be rigorously testing for invalid input, and would attempt to recover or display an extremely descriptive error message.

The method extracts the name of the tag and assigns it to the root node of the parser. It also assigns it to `current_node`, since that's the one we'll be adding children to next.

Then comes the important part: the method changes the current state on the parser object to a `ChildNode` state. It then returns the remainder of the string (after the opening tag) to allow it to be processed.

The `ChildNode` state, which seems quite complicated, turns out to require nothing but a simple conditional:

```
class ChildNode:
    def process(self, remaining_string, parser):
        stripped = remaining_string.strip()
        if stripped.startswith("</"):
            parser.state = CloseTag()
```

```
        elif stripped.startswith("<"):
            parser.state = OpenTag()
        else:
            parser.state = TextNode()
        return stripped
```

The `strip()` call removes whitespace from the string. Then the parser determines if the next item is an opening or closing tag, or a string of text. Depending on which possibility occurs, it sets the parser to a particular state, and then tells it to parse the remainder of the string.

The `OpenTag` state is similar to the `FirstTag` state, except that it adds the newly created node to the previous `current_node` object's `children` and sets it as the new `current_node`. It places the processor back in the `ChildNode` state before continuing:

```
class OpenTag:
    def process(self, remaining_string, parser):
        i_start_tag = remaining_string.find('<')
        i_end_tag = remaining_string.find('>')
        tag_name = remaining_string[i_start_tag+1:i_end_tag]
        node = Node(tag_name, parser.current_node)
        parser.current_node.children.append(node)
        parser.current_node = node
        parser.state = ChildNode()
        return remaining_string[i_end_tag+1:]
```

The `CloseTag` state basically does the opposite; it sets the parser's `current_node` back to the parent node so any further children in the outside tag can be added to it:

```
class CloseTag:
    def process(self, remaining_string, parser):
        i_start_tag = remaining_string.find('<')
        i_end_tag = remaining_string.find('>')
        assert remaining_string[i_start_tag+1] == "/"
        tag_name = remaining_string[i_start_tag+2:i_end_tag]
        assert tag_name == parser.current_node.tag_name
        parser.current_node = parser.current_node.parent
        parser.state = ChildNode()
        return remaining_string[i_end_tag+1:].strip()
```

The two `assert` statements help ensure that the parse strings are consistent. The `if` statement at the end of the method ensures that the processor terminates when it is finished. If the parent of a node is `None`, it means that we are working on the root node.

Finally, the `TextNode` state very simply extracts the text before the next close tag and sets it as a value on the current node:

```
class TextNode:
    def process(self, remaining_string, parser):
        i_start_tag = remaining_string.find('<')
        text = remaining_string[:i_start_tag]
        parser.current_node.text = text
        parser.state = ChildNode()
        return remaining_string[i_start_tag:]
```

Now we just have to set up the initial state on the parser object we created. The initial state is a `FirstTag` object, so just add the following to the `__init__` method:

```
        self.state = FirstTag()
```

To test the class, let's add a main script that opens an file from the command line, parses it, and prints the nodes:

```
if __name__ == "__main__":
    import sys
    with open(sys.argv[1]) as file:
        contents = file.read()
        p = Parser(contents)
        p.start()

        nodes = [p.root]
        while nodes:
            node = nodes.pop(0)
            print(node)
            nodes = node.children + nodes
```

This code opens the file, loads the contents, and parses the result. Then it prints each node and its children in order. The `__str__` method we originally added on the node class takes care of formatting the nodes for printing. If we run the script on the earlier example, it outputs the tree as follows:

```
book
author: Dusty Phillips
publisher: Packt Publishing
title: Python 3 Object Oriented Programming
content
chapter
number: 1
```

```
title: Object Oriented Design
chapter
number: 2
title: Objects In Python
```

Comparing this to the original simplified XML document tells us the parser is working.

State versus strategy

The state pattern looks very similar to the strategy pattern; indeed, the UML diagrams for the two are identical. The implementation, too, is identical; we could even have written our states as first-class functions instead of wrapping them in objects, as was suggested for strategy.

While the two patterns have identical structures, they solve completely different problems. The strategy pattern is used to choose an algorithm at runtime; generally, only one of those algorithms is going to be chosen for a particular use case. The state pattern, on the other hand is designed to allow switching between different states dynamically, as some process evolves. In code, the primary difference is that the strategy pattern is not typically aware of other strategy objects. In the state pattern, either the state or the context needs to know which other states that it can switch to.

State transition as coroutines

The state pattern is the canonical object-oriented solution to state-transition problems. However, the syntax for this pattern is rather verbose. You can get a similar effect by constructing your objects as coroutines. Remember the regular expression log file parser we built in *Chapter 9*, *The Iterator Pattern*? That was a state-transition problem in disguise. The main difference between that implementation and one that defines all the objects (or functions) used in the state pattern is that the coroutine solution allows us to encode more of the boilerplate in language constructs. There are two implementations, but neither one is inherently better than the other, but you may find that coroutines are more readable, for a given definition of "readable" (you have to understand the syntax of coroutines, first!).

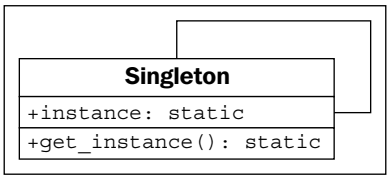
The singleton pattern

The singleton pattern is one of the most controversial patterns; many have accused it of being an "anti-pattern", a pattern that should be avoided, not promoted. In Python, if someone is using the singleton pattern, they're almost certainly doing something wrong, probably because they're coming from a more restrictive programming language.

So why discuss it at all? Singleton is one of the most famous of all design patterns. It is useful in overly object-oriented languages, and is a vital part of traditional object-oriented programming. More relevantly, the idea behind singleton is useful, even if we implement that idea in a totally different way in Python.

The basic idea behind the singleton pattern is to allow exactly one instance of a certain object to exist. Typically, this object is a sort of manager class like those we discussed in *Chapter 5*, *When to Use Object-oriented Programming*. Such objects often need to be referenced by a wide variety of other objects, and passing references to the manager object around to the methods and constructors that need them can make code hard to read.

Instead, when a singleton is used, the separate objects request the single instance of the manager object from the class, so a reference to it need not to be passed around. The UML diagram doesn't fully describe it, but here it is for completeness:



In most programming environments, singletons are enforced by making the constructor private (so no one can create additional instances of it), and then providing a static method to retrieve the single instance. This method creates a new instance the first time it is called, and then returns that same instance each time it is called again.

Singleton implementation

Python doesn't have private constructors, but for this purpose, it has something even better. We can use the `__new__` class method to ensure that only one instance is ever created:

```
class OneOnly:
    _singleton = None
    def __new__(cls, *args, **kwargs):
        if not cls._singleton:
            cls._singleton = super(OneOnly, cls
                ).__new__(cls, *args, **kwargs)
        return cls._singleton
```

When `__new__` is called, it normally constructs a new instance of that class. When we override it, we first check if our singleton instance has been created; if not, we create it using a `super` call. Thus, whenever we call the constructor on `OneOnly`, we always get the exact same instance:

```
>>> o1 = OneOnly()
>>> o2 = OneOnly()
>>> o1 == o2
True
>>> o1
<__main__.OneOnly object at 0xb71c008c>
>>> o2
<__main__.OneOnly object at 0xb71c008c>
```

The two objects are equal and located at the same address; thus, they are the same object. This particular implementation isn't very transparent, since it's not obvious that a singleton object has been created. Whenever we call a constructor, we expect a new instance of that object; in this case, that contract is violated. Perhaps, good docstrings on the class could alleviate this problem if we really think we need a singleton.

But we don't need it. Python coders frown on forcing the users of their code into a specific mindset. We may think only one instance of a class will ever be required, but other programmers may have different ideas. Singletons can interfere with distributed computing, parallel programming, and automated testing, for example. In all those cases, it can be very useful to have multiple or alternative instances of a specific object, even though a "normal' operation may never require one.

Module variables can mimic singletons

Normally, in Python, the singleton pattern can be sufficiently mimicked using module-level variables. It's not as "safe" as a singleton in that people could reassign those variables at any time, but as with the private variables we discussed in *Chapter 2*, *Objects in Python*, this is acceptable in Python. If someone has a valid reason to change those variables, why should we stop them? It also doesn't stop people from instantiating multiple instances of the object, but again, if they have a valid reason to do so, why interfere?

Ideally, we should give them a mechanism to get access to the "default singleton" value, while also allowing them to create other instances if they need them. While technically not a singleton at all, it provides the most Pythonic mechanism for singleton-like behavior.

To use module-level variables instead of a singleton, we instantiate an instance of the class after we've defined it. We can improve our state pattern to use singletons. Instead of creating a new object every time we change states, we can create a module-level variable that is always accessible:

```
class FirstTag:
    def process(self, remaining_string, parser):
        i_start_tag = remaining_string.find('<')
        i_end_tag = remaining_string.find('>')
        tag_name = remaining_string[i_start_tag+1:i_end_tag]
        root = Node(tag_name)
        parser.root = parser.current_node = root
        parser.state = child_node
        return remaining_string[i_end_tag+1:]

class ChildNode:
    def process(self, remaining_string, parser):
        stripped = remaining_string.strip()
        if stripped.startswith("</"):
            parser.state = close_tag
        elif stripped.startswith("<"):
            parser.state = open_tag
        else:
            parser.state = text_node
        return stripped

class OpenTag:
    def process(self, remaining_string, parser):
        i_start_tag = remaining_string.find('<')
        i_end_tag = remaining_string.find('>')
        tag_name = remaining_string[i_start_tag+1:i_end_tag]
        node = Node(tag_name, parser.current_node)
        parser.current_node.children.append(node)
        parser.current_node = node
        parser.state = child_node
        return remaining_string[i_end_tag+1:]
class TextNode:
    def process(self, remaining_string, parser):
        i_start_tag = remaining_string.find('<')
        text = remaining_string[:i_start_tag]
        parser.current_node.text = text
        parser.state = child_node
```

```
            return remaining_string[i_start_tag:]

    class CloseTag:
        def process(self, remaining_string, parser):
            i_start_tag = remaining_string.find('<')
            i_end_tag = remaining_string.find('>')
            assert remaining_string[i_start_tag+1] == "/"
            tag_name = remaining_string[i_start_tag+2:i_end_tag]
            assert tag_name == parser.current_node.tag_name
            parser.current_node = parser.current_node.parent
            parser.state = child_node
            return remaining_string[i_end_tag+1:].strip()

    first_tag = FirstTag()
    child_node = ChildNode()
    text_node = TextNode()
    open_tag = OpenTag()
close_tag = CloseTag()
```

All we've done is create instances of the various state classes that can be reused. Notice how we can access these module variables inside the classes, even before the variables have been defined? This is because the code inside the classes is not executed until the method is called, and by this point, the entire module will have been defined.

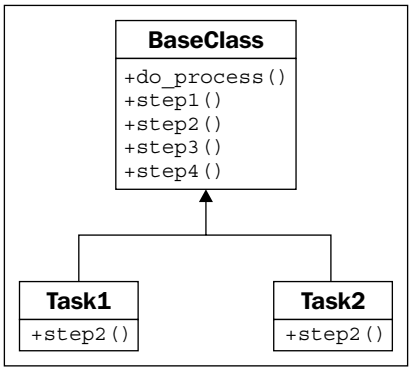
The difference in this example is that instead of wasting memory creating a bunch of new instances that must be garbage collected, we are reusing a single state object for each state. Even if multiple parsers are running at once, only these state classes need to be used.

When we originally created the state-based parser, you may have wondered why we didn't pass the parser object to `__init__` on each individual state, instead of passing it into the process method as we did. The state could then have been referenced as `self.parser`. This is a perfectly valid implementation of the state pattern, but it would not have allowed leveraging the singleton pattern. If the state objects maintain a reference to the parser, then they cannot be used simultaneously to reference other parsers.

Remember, these are two different patterns with different purposes; the fact that singleton's purpose may be useful for implementing the state pattern does not mean the two patterns are related.

The template pattern

The template pattern is useful for removing duplicate code; it's an implementation to support the **Don't Repeat Yourself** principle we discussed in *Chapter 5*, *When to Use Object-oriented Programming*. It is designed for situations where we have several different tasks to accomplish that have some, but not all, steps in common. The common steps are implemented in a base class, and the distinct steps are overridden in subclasses to provide custom behavior. In some ways, it's like a generalized strategy pattern, except similar sections of the algorithms are shared using a base class. Here it is in the UML format:



A template example

Let's create a car sales reporter as an example. We can store records of sales in an SQLite database table. SQLite is a simple file-based database engine that allows us to store records using SQL syntax. Python 3 includes SQLite in its standard library, so there are no extra modules required.

We have two common tasks we need to perform:

- Select all sales of new vehicles and output them to the screen in a comma-delimited format
- Output a comma-delimited list of all salespeople with their gross sales and save it to a file that can be imported to a spreadsheet

These seem like quite different tasks, but they have some common features. In both cases, we need to perform the following steps:

1. Connect to the database.
2. Construct a query for new vehicles or gross sales.

3. Issue the query.
4. Format the results into a comma-delimited string.
5. Output the data to a file or e-mail.

The query construction and output steps are different for the two tasks, but the remaining steps are identical. We can use the template pattern to put the common steps in a base class, and the varying steps in two subclasses.

Before we start, let's create a database and put some sample data in it, using a few lines of SQL:

```
import sqlite3

conn = sqlite3.connect("sales.db")

conn.execute("CREATE TABLE Sales (salesperson text, "
        "amt currency, year integer, model text, new boolean)")
conn.execute("INSERT INTO Sales values"
        " ('Tim', 16000, 2010, 'Honda Fit', 'true')")
conn.execute("INSERT INTO Sales values"
        " ('Tim', 9000, 2006, 'Ford Focus', 'false')")
conn.execute("INSERT INTO Sales values"
        " ('Gayle', 8000, 2004, 'Dodge Neon', 'false')")
conn.execute("INSERT INTO Sales values"
        " ('Gayle', 28000, 2009, 'Ford Mustang', 'true')")
conn.execute("INSERT INTO Sales values"
        " ('Gayle', 50000, 2010, 'Lincoln Navigator', 'true')")
conn.execute("INSERT INTO Sales values"
        " ('Don', 20000, 2008, 'Toyota Prius', 'false')")
conn.commit()
conn.close()
```

Hopefully you can see what's going on here even if you don't know SQL; we've created a table to hold the data, and used six insert statements to add sales records. The data is stored in a file named `sales.db`. Now we have a sample we can work with in developing our template pattern.

Since we've already outlined the steps that the template has to perform, we can start by defining the base class that contains the steps. Each step gets its own method (to make it easy to selectively override any one step), and we have one more managerial method that calls the steps in turn. Without any method content, here's how it might look:

```
class QueryTemplate:
    def connect(self):
        pass
```

```
    def construct_query(self):
        pass
    def do_query(self):
        pass
    def format_results(self):
        pass
    def output_results(self):
        pass

    def process_format(self):
        self.connect()
        self.construct_query()
        self.do_query()
        self.format_results()
        self.output_results()
```

The `process_format` method is the primary method to be called by an outside client. It ensures each step is executed in order, but it does not care if that step is implemented in this class or in a subclass. For our examples, we know that three methods are going to be identical between our two classes:

```
import sqlite3

class QueryTemplate:
    def connect(self):
        self.conn = sqlite3.connect("sales.db")

    def construct_query(self):
        raise NotImplementedError()

    def do_query(self):
        results = self.conn.execute(self.query)
        self.results = results.fetchall()

    def format_results(self):
        output = []
        for row in self.results:
            row =[str(i) for i in row]
            output.append(", ".join(row))
        self.formatted_results = "\n".join(output)

    def output_results(self):
        raise NotImplementedError()
```

To help with implementing subclasses, the two methods that are not specified raise `NotImplementedError`. This is a common way to specify abstract interfaces in Python when abstract base classes seem too heavyweight. The methods could have empty implementations (with `pass`), or could be fully unspecified. Raising `NotImplementedError`, however, helps the programmer understand that the class is meant to be subclassed and these methods overridden; empty methods or methods that do not exist are harder to identify as needing to be implemented and to debug if we forget to implement them.

Now we have a template class that takes care of the boring details, but is flexible enough to allow the execution and formatting of a wide variety of queries. The best part is, if we ever want to change our database engine from SQLite to another database engine (such as py-postgresql), we only have to do it here, in this template class, and we don't have to touch the two (or two hundred) subclasses we might have written.

Let's have a look at the concrete classes now:

```
import datetime
class NewVehiclesQuery(QueryTemplate):
    def construct_query(self):
        self.query = "select * from Sales where new='true'"

    def output_results(self):
        print(self.formatted_results)

class UserGrossQuery(QueryTemplate):
    def construct_query(self):
        self.query = ("select salesperson, sum(amt) " +
        " from Sales group by salesperson")

    def output_results(self):
        filename = "gross_sales_{0}".format(
                datetime.date.today().strftime("%Y%m%d")
                )
        with open(filename, 'w') as outfile:
            outfile.write(self.formatted_results)
```

These two classes are actually pretty short, considering what they're doing: connecting to a database, executing a query, formatting the results, and outputting them. The superclass takes care of the repetitive work, but lets us easily specify those steps that vary between tasks. Further, we can also easily change steps that are provided in the base class. For example, if we wanted to output something other than a comma-delimited string (for example: an HTML report to be uploaded to a website), we can still override `format_results`.

Exercises

While writing this chapter, I discovered that it can be very difficult, and extremely educational, to come up with good examples where specific design patterns should be used. Instead of going over current or old projects to see where you can apply these patterns, as I've suggested in previous chapters, think about the patterns and different situations where they might come up. Try to think outside your own experiences. If your current projects are in the banking business, consider how you'd apply these design patterns in a retail or point-of-sale application. If you normally write web applications, think about using design patterns while writing a compiler.

Look at the decorator pattern and come up with some good examples of when to apply it. Focus on the pattern itself, not the Python syntax we discussed; it's a bit more general than the actual pattern. The special syntax for decorators is, however, something you may want to look for places to apply in existing projects too.

What are some good areas to use the observer pattern? Why? Think about not only how you'd apply the pattern, but how you would implement the same task without using observer? What do you gain, or lose, by choosing to use it?

Consider the difference between the strategy and state patterns. Implementation-wise, they look very similar, yet they have different purposes. Can you think of cases where the patterns could be interchanged? Would it be reasonable to redesign a state-based system to use strategy instead, or vice versa? How different would the design actually be?

The template pattern is such an obvious application of inheritance to reduce duplicate code that you may have used it before, without knowing its name. Try to think of at least half a dozen different scenarios where it would be useful. If you can do this, you'll be finding places for it in your daily coding all the time.

Summary

This chapter discussed several common design patterns in detail, with examples, UML diagrams, and a discussion of the differences between Python and statically typed object-oriented languages. The decorator pattern is often implemented using Python's more generic decorator syntax. The observer pattern is a useful way to decouple events from actions taken on those events. The strategy pattern allows different algorithms to be chosen to accomplish the same task. The state pattern looks similar, but is used instead to represent systems can move between different states using well-defined actions. The singleton pattern, popular in some statically typed languages, is almost always an anti-pattern in Python.

In the next chapter, we'll wrap up our discussion of design patterns.

11
Python Design Patterns II

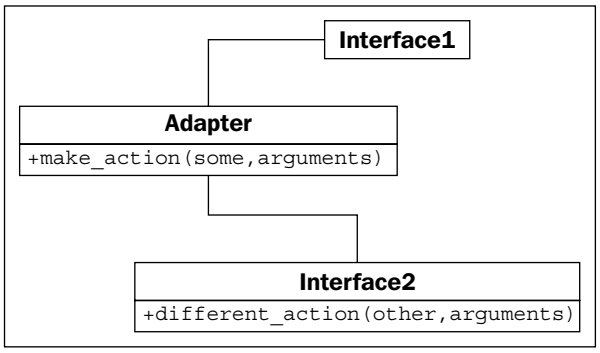
In this chapter we will be introduced to several more design patterns. Once again, we'll cover the canonical examples as well as any common alternative implementations in Python. We'll be discussing:

- The adapter pattern
- The facade pattern
- Lazy initialization and the flyweight pattern
- The command pattern
- The abstract factory pattern
- The composition pattern

The adapter pattern

Unlike most of the patterns we reviewed in *Chapter 8*, *Strings and Serialization*, the adapter pattern is designed to interact with existing code. We would not design a brand new set of objects that implement the adapter pattern. Adapters are used to allow two pre-existing objects to work together, even if their interfaces are not compatible. Like the display adapters that allow VGA projectors to be plugged into HDMI ports, an adapter object sits between two different interfaces, translating between them on the fly. The adapter object's sole purpose is to perform this translation job. Adapting may entail a variety of tasks, such as converting arguments to a different format, rearranging the order of arguments, calling a differently named method, or supplying default arguments.

In structure, the adapter pattern is similar to a simplified decorator pattern. Decorators typically provide the same interface that they replace, whereas adapters map between two different interfaces. Here it is in UML form:



Here, **Interface1** is expecting to call a method called **make_action(some, arguments)**. We already have this perfect **Interface2** class that does everything we want (and to avoid duplication, we don't want to rewrite it!), but it provides a method called **different_action(other, arguments)** instead. The **Adapter** class implements the **make_action** interface and maps the arguments to the existing interface.

The advantage here is that the code that maps from one interface to another is all in one place. The alternative would be really ugly; we'd have to perform the translation in multiple places whenever we need to access this code.

For example, imagine we have the following preexisting class, which takes a string date in the format "YYYY-MM-DD" and calculates a person's age on that day:

```
class AgeCalculator:
    def __init__(self, birthday):
        self.year, self.month, self.day = (
                int(x) for x in birthday.split('-'))

    def calculate_age(self, date):
        year, month, day = (
                int(x) for x in date.split('-'))
        age = year - self.year
        if (month,day) < (self.month,self.day):
            age -= 1
        return age
```

This is a pretty simple class that does what it's supposed to do. But we have to wonder what the programmer was thinking, using a specifically formatted string instead of using Python's incredibly useful built-in `datetime` library. As conscientious programmers who reuse code whenever possible, most of the programs we write will interact with `datetime` objects, not strings.

We have several options to address this scenario; we could rewrite the class to accept `datetime` objects, which would probably be more accurate anyway. But if this class had been provided by a third party and we don't know or can't change its internal structure, we need to try something else. We could use the class as it is, and whenever we want to calculate the age on a `datetime.date` object, we could call `datetime.date.strftime('%Y-%m-%d')` to convert it to the proper format. But that conversion would be happening in a lot of places, and worse, if we mistyped the `%m` as `%M`, it would give us the current minute instead of the entered month! Imagine if you wrote that in a dozen different places only to have to go back and change it when you realized your mistake. It's not maintainable code, and it breaks the DRY principle.

Instead, we can write an adapter that allows a normal date to be plugged into a normal `AgeCalculator` class:

```
import datetime
class DateAgeAdapter:
    def _str_date(self, date):
        return date.strftime("%Y-%m-%d")

    def __init__(self, birthday):
        birthday = self._str_date(birthday)
        self.calculator = AgeCalculator(birthday)

    def get_age(self, date):
        date = self._str_date(date)
        return self.calculator.calculate_age(date)
```

This adapter converts `datetime.date` and `datetime.time` (they have the same interface to `strftime`) into a string that our original `AgeCalculator` can use. Now we can use the original code with our new interface. I changed the method signature to `get_age` to demonstrate that the calling interface may also be looking for a different method name, not just a different type of argument.

Creating a class as an adapter is the usual way to implement this pattern, but, as usual, there are other ways to do it in Python. Inheritance and multiple inheritance can be used to add functionality to a class. For example, we could add an adapter on the `date` class so that it works with the original `AgeCalculator` class:

```
import datetime
class AgeableDate(datetime.date):
    def split(self, char):
        return self.year, self.month, self.day
```

It's code like this that makes one wonder if Python should even be legal. We have added a `split` method to our subclass that takes a single argument (which we ignore) and returns a tuple of year, month, and day. This works flawlessly with the original `AgeCalculator` class because the code calls `strip` on a specially formatted string, and `strip`, in that case, returns a tuple of year, month, and day. The `AgeCalculator` code only cares if `strip` exists and returns acceptable values; it doesn't care if we really passed in a string. It really works:

```
>>> bd = AgeableDate(1975, 6, 14)
>>> today = AgeableDate.today()
>>> today
AgeableDate(2015, 8, 4)
>>> a = AgeCalculator(bd)
>>> a.calculate_age(today)
40
```

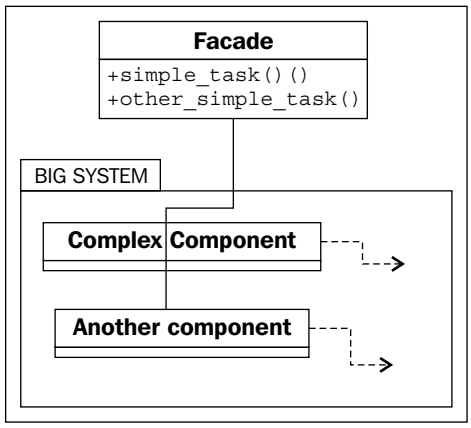
It works but it's a stupid idea. In this particular instance, such an adapter would be hard to maintain. We'd soon forget why we needed to add a `strip` method to a `date` class. The method name is ambiguous. That can be the nature of adapters, but creating an adapter explicitly instead of using inheritance usually clarifies its purpose.

Instead of inheritance, we can sometimes also use monkey-patching to add a method to an existing class. It won't work with the `datetime` object, as it doesn't allow attributes to be added at runtime, but in normal classes, we can just add a new method that provides the adapted interface that is required by calling code. Alternatively, we could extend or monkey-patch the `AgeCalculator` itself to replace the `calculate_age` method with something more amenable to our needs.

Finally, it is often possible to use a function as an adapter; this doesn't obviously fit the actual design of the adapter pattern, but if we recall that functions are essentially objects with a `__call__` method, it becomes an obvious adapter adaptation.

The facade pattern

The facade pattern is designed to provide a simple interface to a complex system of components. For complex tasks, we may need to interact with these objects directly, but there is often a "typical" usage for the system for which these complicated interactions aren't necessary. The facade pattern allows us to define a new object that encapsulates this typical usage of the system. Any time we want access to common functionality, we can use the single object's simplified interface. If another part of the project needs access to more complicated functionality, it is still able to interact with the system directly. The UML diagram for the facade pattern is really dependent on the subsystem, but in a cloudy way, it looks like this:



A facade is, in many ways, like an adapter. The primary difference is that the facade is trying to abstract a simpler interface out of a complex one, while the adapter is only trying to map one existing interface to another.

Let's write a simple facade for an e-mail application. The low-level library for sending e-mail in Python, as we saw in *Chapter 7*, *Python Object-oriented Shortcuts*, is quite complicated. The two libraries for receiving messages are even worse.

It would be nice to have a simple class that allows us to send a single e-mail, and list the e-mails currently in the inbox on an IMAP or POP3 connection. To keep our example short, we'll stick with IMAP and SMTP: two totally different subsystems that happen to deal with e-mail. Our facade performs only two tasks: sending an e-mail to a specific address, and checking the inbox on an IMAP connection. It makes some common assumptions about the connection, such as the host for both SMTP and IMAP is at the same address, that the username and password for both is the same, and that they use standard ports. This covers the case for many e-mail servers, but if a programmer needs more flexibility, they can always bypass the facade and access the two subsystems directly.

The class is initialized with the hostname of the e-mail server, a username, and a password to log in:

```
import smtplib
import imaplib

class EmailFacade:
    def __init__(self, host, username, password):
        self.host = host
        self.username = username
        self.password = password
```

The `send_email` method formats the e-mail address and message, and sends it using `smtplib`. This isn't a complicated task, but it requires quite a bit of fiddling to massage the "natural" input parameters that are passed into the facade to the correct format to enable `smtplib` to send the message:

```
    def send_email(self, to_email, subject, message):
        if not "@" in self.username:
            from_email = "{0}@{1}".format(
                    self.username, self.host)
        else:
            from_email = self.username
        message = ("From: {0}\r\n"
                "To: {1}\r\n"
                "Subject: {2}\r\n\r\n{3}").format(
                    from_email,
                    to_email,
                    subject,
                    message)

        smtp = smtplib.SMTP(self.host)
        smtp.login(self.username, self.password)
        smtp.sendmail(from_email, [to_email], message)
```

The `if` statement at the beginning of the method is catching whether or not the `username` is the entire "from" e-mail address or just the part on the left side of the `@` symbol; different hosts treat the login details differently.

Finally, the code to get the messages currently in the inbox is a ruddy mess; the IMAP protocol is painfully over-engineered, and the `imaplib` standard library is only a thin layer over the protocol:

```
    def get_inbox(self):
        mailbox = imaplib.IMAP4(self.host)
```

```
        mailbox.login(bytes(self.username, 'utf8'),
            bytes(self.password, 'utf8'))
        mailbox.select()
        x, data = mailbox.search(None, 'ALL')
        messages = []
        for num in data[0].split():
            x, message = mailbox.fetch(num, '(RFC822)')
            messages.append(message[0][1])
        return messages
```

Now, if we add all this together, we have a simple facade class that can send and receive messages in a fairly straightforward manner, much simpler than if we had to interact with these complex libraries directly.

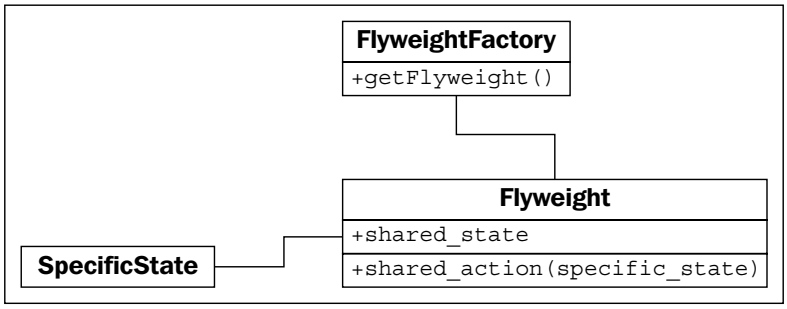
Although it is rarely named in the Python community, the facade pattern is an integral part of the Python ecosystem. Because Python emphasizes language readability, both the language and its libraries tend to provide easy-to-comprehend interfaces to complicated tasks. For example, `for` loops, `list` comprehensions, and generators are all facades into a more complicated iterator protocol. The `defaultdict` implementation is a facade that abstracts away annoying corner cases when a key doesn't exist in a dictionary. The third-party requests library is a powerful facade over less readable libraries for HTTP requests.

The flyweight pattern

The flyweight pattern is a memory optimization pattern. Novice Python programmers tend to ignore memory optimization, assuming the built-in garbage collector will take care of them. This is often perfectly acceptable, but when developing larger applications with many related objects, paying attention to memory concerns can have a huge payoff.

The flyweight pattern basically ensures that objects that share a state can use the same memory for that shared state. It is often implemented only after a program has demonstrated memory problems. It may make sense to design an optimal configuration from the beginning in some situations, but bear in mind that premature optimization is the most effective way to create a program that is too complicated to maintain.

Let's have a look at the UML diagram for the flyweight pattern:



Each **Flyweight** has no specific state; any time it needs to perform an operation on **SpecificState**, that state needs to be passed into the **Flyweight** by the calling code. Traditionally, the factory that returns a flyweight is a separate object; its purpose is to return a flyweight for a given key identifying that flyweight. It works like the singleton pattern we discussed in *Chapter 10*, *Python Design Patterns I*; if the flyweight exists, we return it; otherwise, we create a new one. In many languages, the factory is implemented, not as a separate object, but as a static method on the `Flyweight` class itself.

Think of an inventory system for car sales. Each individual car has a specific serial number and is a specific color. But most of the details about that car are the same for all cars of a particular model. For example, the Honda Fit DX model is a bare-bones car with few features. The LX model has A/C, tilt, cruise, and power windows and locks. The Sport model has fancy wheels, a USB charger, and a spoiler. Without the flyweight pattern, each individual car object would have to store a long list of which features it did and did not have. Considering the number of cars Honda sells in a year, this would add up to a huge amount of wasted memory. Using the flyweight pattern, we can instead have shared objects for the list of features associated with a model, and then simply reference that model, along with a serial number and color, for individual vehicles. In Python, the flyweight factory is often implemented using that funky `__new__` constructor, similar to what we did with the singleton pattern. Unlike singleton, which only needs to return one instance of the class, we need to be able to return different instances depending on the keys. We could store the items in a dictionary and look them up based on the key. This solution is problematic, however, because the item will remain in memory as long as it is in the dictionary. If we sold out of LX model Fits, the Fit flyweight is no longer necessary, yet it will still be in the dictionary. We could, of course, clean this up whenever we sell a car, but isn't that what a garbage collector is for?

We can solve this by taking advantage of Python's `weakref` module. This module provides a `WeakValueDictionary` object, which basically allows us to store items in a dictionary without the garbage collector caring about them. If a value is in a weak referenced dictionary and there are no other references to that object stored anywhere in the application (that is, we sold out of LX models), the garbage collector will eventually clean up for us.

Let's build the factory for our car flyweights first:

```
import weakref

class CarModel:
    _models = weakref.WeakValueDictionary()

    def __new__(cls, model_name, *args, **kwargs):
        model = cls._models.get(model_name)
        if not model:
            model = super().__new__(cls)
            cls._models[model_name] = model

        return model
```

Basically, whenever we construct a new flyweight with a given name, we first look up that name in the weak referenced dictionary; if it exists, we return that model; if not, we create a new one. Either way, we know the `__init__` method on the flyweight will be called every time, regardless of whether it is a new or existing object. Our `__init__` method can therefore look like this:

```
    def __init__(self, model_name, air=False, tilt=False,
            cruise_control=False, power_locks=False,
            alloy_wheels=False, usb_charger=False):
        if not hasattr(self, "initted"):
            self.model_name = model_name
            self.air = air
            self.tilt = tilt
            self.cruise_control = cruise_control
            self.power_locks = power_locks
            self.alloy_wheels = alloy_wheels
            self.usb_charger = usb_charger
            self.initted=True
```

The `if` statement ensures that we only initialize the object the first time `__init__` is called. This means we can call the factory later with just the model name and get the same flyweight object back. However, because the flyweight will be garbage-collected if no external references to it exist, we have to be careful not to accidentally create a new flyweight with null values.

Let's add a method to our flyweight that hypothetically looks up a serial number on a specific model of vehicle, and determines if it has been involved in any accidents. This method needs access to the car's serial number, which varies from car to car; it cannot be stored with the flyweight. Therefore, this data must be passed into the method by the calling code:

```
        def check_serial(self, serial_number):
            print("Sorry, we are unable to check "
                    "the serial number {0} on the {1} "
                    "at this time".format(
                        serial_number, self.model_name))
```

We can define a class that stores the additional information, as well as a reference to the flyweight:

```
    class Car:
        def __init__(self, model, color, serial):
            self.model = model
            self.color = color
            self.serial = serial

        def check_serial(self):
            return self.model.check_serial(self.serial)
```

We can also keep track of the available models as well as the individual cars on the lot:

```
>>> dx = CarModel("FIT DX")
>>> lx = CarModel("FIT LX", air=True, cruise_control=True,
... power_locks=True, tilt=True)
>>> car1 = Car(dx, "blue", "12345")
>>> car2 = Car(dx, "black", "12346")
>>> car3 = Car(lx, "red", "12347")
```

Now, let's demonstrate the weak referencing at work:

```
>>> id(lx)
3071620300
>>> del lx
>>> del car3
>>> import gc
>>> gc.collect()
0
```

```
>>> lx = CarModel("FIT LX", air=True, cruise_control=True,
... power_locks=True, tilt=True)
>>> id(lx)
3071576140
>>> lx = CarModel("FIT LX")
>>> id(lx)
3071576140
>>> lx.air
True
```

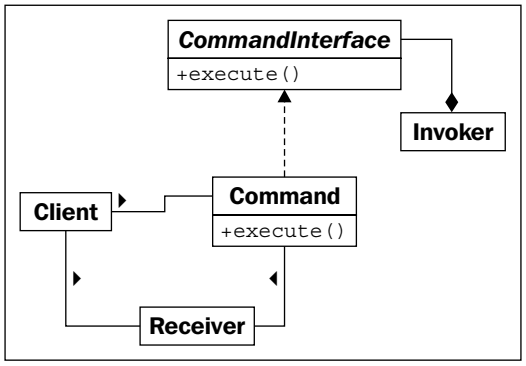
The `id` function tells us the unique identifier for an object. When we call it a second time, after deleting all references to the LX model and forcing garbage collection, we see that the ID has changed. The value in the `CarModel __new__` factory dictionary was deleted and a fresh one created. If we then try to construct a second `CarModel` instance, however, it returns the same object (the IDs are the same), and, even though we did not supply any arguments in the second call, the `air` variable is still set to `True`. This means the object was not initialized the second time, just as we designed.

Obviously, using the flyweight pattern can be more complicated than just storing features on a single car class. When should we choose to use it? The flyweight pattern is designed for conserving memory; if we have hundreds of thousands of similar objects, combining similar properties into a flyweight can have an enormous impact on memory consumption. It is common for programming solutions that optimize CPU, memory, or disk space result in more complicated code than their unoptimized brethren. It is therefore important to weigh up the tradeoffs when deciding between code maintainability and optimization. When choosing optimization, try to use patterns such as flyweight to ensure that the complexity introduced by optimization is confined to a single (well documented) section of the code.

The command pattern

The command pattern adds a level of abstraction between actions that must be done, and the object that invokes those actions, normally at a later time. In the command pattern, client code creates a `Command` object that can be executed at a later date. This object knows about a receiver object that manages its own internal state when the command is executed on it. The `Command` object implements a specific interface (typically it has an `execute` or `do_action` method, and also keeps track of any arguments required to perform the action. Finally, one or more `Invoker` objects execute the command at the correct time.

Here's the UML diagram:



A common example of the command pattern is actions on a graphical window. Often, an action can be invoked by a menu item on the menu bar, a keyboard shortcut, a toolbar icon, or a context menu. These are all examples of `Invoker` objects. The actions that actually occur, such as `Exit`, `Save`, or `Copy`, are implementations of `CommandInterface`. A GUI window to receive exit, a document to receive save, and `ClipboardManager` to receive copy commands, are all examples of possible `Receivers`.

Let's implement a simple command pattern that provides commands for `Save` and `Exit` actions. We'll start with some modest receiver classes:

```
import sys

class Window:
    def exit(self):
        sys.exit(0)

class Document:
    def __init__(self, filename):
        self.filename = filename
        self.contents = "This file cannot be modified"

    def save(self):
        with open(self.filename, 'w') as file:
            file.write(self.contents)
```

These mock classes model objects that would likely be doing a lot more in a working environment. The window would need to handle mouse movement and keyboard events, and the document would need to handle character insertion, deletion, and selection. But for our example these two classes will do what we need.

Now let's define some invoker classes. These will model toolbar, menu, and keyboard events that can happen; again, they aren't actually hooked up to anything, but we can see how they are decoupled from the command, receiver, and client code:

```
class ToolbarButton:
    def __init__(self, name, iconname):
        self.name = name
        self.iconname = iconname

    def click(self):
        self.command.execute()

class MenuItem:
    def __init__(self, menu_name, menuitem_name):
        self.menu = menu_name
        self.item = menuitem_name

    def click(self):
        self.command.execute()

class KeyboardShortcut:
    def __init__(self, key, modifier):
        self.key = key
        self.modifier = modifier

    def keypress(self):
        self.command.execute()
```

Notice how the various action methods each call the `execute` method on their respective commands? This code doesn't show the `command` attribute being set on each object. They could be passed into the `__init__` function, but because they may be changed (for example, with a customizable keybinding editor), it makes more sense to set the attributes on the objects afterwards.

Now, let's hook up the commands themselves:

```
class SaveCommand:
    def __init__(self, document):
        self.document = document

    def execute(self):
        self.document.save()

class ExitCommand:
```

```
    def __init__(self, window):
        self.window = window

    def execute(self):
        self.window.exit()
```

These commands are straightforward; they demonstrate the basic pattern, but it is important to note that we can store state and other information with the command if necessary. For example, if we had a command to insert a character, we could maintain state for the character currently being inserted.

Now all we have to do is hook up some client and test code to make the commands work. For basic testing, we can just include this at the end of the script:

```
window = Window()
document = Document("a_document.txt")
save = SaveCommand(document)
exit = ExitCommand(window)

save_button = ToolbarButton('save', 'save.png')
save_button.command = save
save_keystroke = KeyboardShortcut("s", "ctrl")
save_keystroke.command = save
exit_menu = MenuItem("File", "Exit")
exit_menu.command = exit
```

First we create two receivers and two commands. Then we create several of the available invokers and set the correct command on each of them. To test, we can use `python3 -i filename.py` and run code like `exit_menu.click()`, which will end the program, or `save_keystroke.keystroke()`, which will save the fake file.

Unfortunately, the preceding examples do not feel terribly Pythonic. They have a lot of "boilerplate code" (code that does not accomplish anything, but only provides structure to the pattern), and the `Command` classes are all eerily similar to each other. Perhaps we could create a generic command object that takes a function as a callback?

In fact, why bother? Can we just use a function or method object for each command? Instead of an object with an `execute()` method, we can write a function and use that as the command directly. This is a common paradigm for the command pattern in Python:

```
import sys

class Window:
```

```
        def exit(self):
            sys.exit(0)

    class MenuItem:
        def click(self):
            self.command()

    window = Window()
    menu_item = MenuItem()
    menu_item.command = window.exit
```

Now that looks a lot more like Python. At first glance, it looks like we've removed the command pattern altogether, and we've tightly connected the `menu_item` and `Window` classes. But if we look closer, we find there is no tight coupling at all. Any callable can be set up as the command on the `MenuItem`, just as before. And the `Window.exit` method can be attached to any invoker. Most of the flexibility of the command pattern has been maintained. We have sacrificed complete decoupling for readability, but this code is, in my opinion, and that of many Python programmers, more maintainable than the fully abstracted version.

Of course, since we can add a `__call__` method to any object, we aren't restricted to functions. The previous example is a useful shortcut when the method being called doesn't have to maintain state, but in more advanced usage, we can use this code as well:

```
class Document:
    def __init__(self, filename):
        self.filename = filename
        self.contents = "This file cannot be modified"

    def save(self):
        with open(self.filename, 'w') as file:
            file.write(self.contents)

class KeyboardShortcut:
    def keypress(self):
        self.command()
class SaveCommand:
    def __init__(self, document):
        self.document = document

    def __call__(self):
```

```
            self.document.save()

document = Document("a_file.txt")
shortcut = KeyboardShortcut()
save_command = SaveCommand(document)
shortcut.command = save_command
```

Here we have something that looks like the first command pattern, but a bit more idiomatic. As you can see, making the invoker call a callable instead of a command object with an execute method has not restricted us in any way. In fact, it's given us more flexibility. We can link to functions directly when that works, yet we can build a complete callable command object when the situation calls for it.

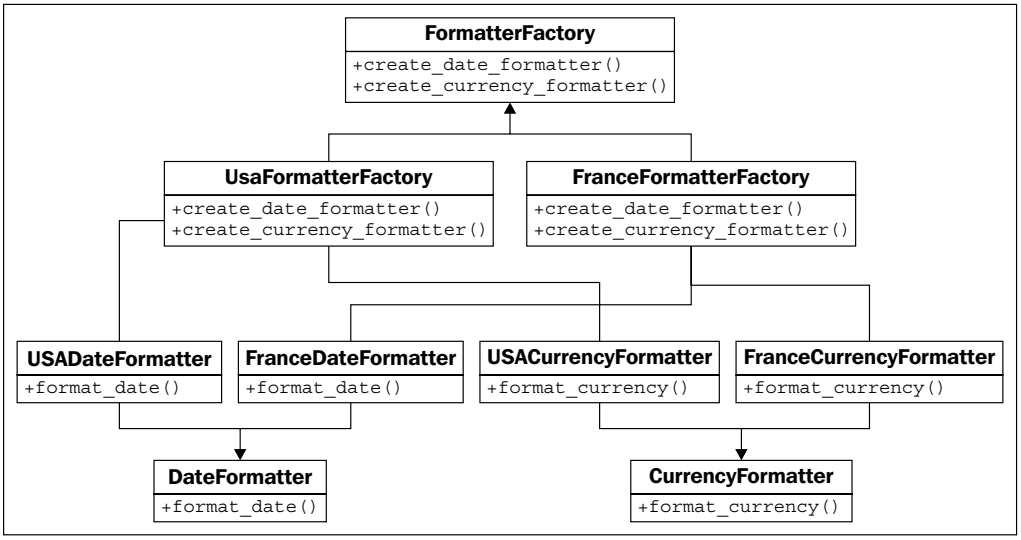
The command pattern is often extended to support undoable commands. For example, a text program may wrap each insertion in a separate command with not only an `execute` method, but also an `undo` method that will delete that insertion. A graphics program may wrap each drawing action (rectangle, line, freehand pixels, and so on) in a command that has an `undo` method that resets the pixels to their original state. In such cases, the decoupling of the command pattern is much more obviously useful, because each action has to maintain enough of its state to undo that action at a later date.

The abstract factory pattern

The abstract factory pattern is normally used when we have multiple possible implementations of a system that depend on some configuration or platform issue. The calling code requests an object from the abstract factory, not knowing exactly what class of object will be returned. The underlying implementation returned may depend on a variety of factors, such as current locale, operating system, or local configuration.

Common examples of the abstract factory pattern include code for operating-system independent toolkits, database backends, and country-specific formatters or calculators. An operating-system-independent GUI toolkit might use an abstract factory pattern that returns a set of WinForm widgets under Windows, Cocoa widgets under Mac, GTK widgets under Gnome, and QT widgets under KDE. Django provides an abstract factory that returns a set of object relational classes for interacting with a specific database backend (MySQL, PostgreSQL, SQLite, and others) depending on a configuration setting for the current site. If the application needs to be deployed in multiple places, each one can use a different database backend by changing only one configuration variable. Different countries have different systems for calculating taxes, subtotals, and totals on retail merchandise; an abstract factory can return a particular tax calculation object.

The UML class diagram for an abstract factory pattern is hard to understand without a specific example, so let's turn things around and create a concrete example first. We'll create a set of formatters that depend on a specific locale and help us format dates and currencies. There will be an abstract factory class that picks the specific factory, as well as a couple example concrete factories, one for France and one for the USA. Each of these will create formatter objects for dates and times, which can be queried to format a specific value. Here's the diagram:



Comparing that image to the earlier simpler text shows that a picture is not always worth a thousand words, especially considering we haven't even allowed for factory selection code here.

Of course, in Python, we don't have to implement any interface classes, so we can discard `DateFormatter`, `CurrencyFormatter`, and `FormatterFactory`. The formatting classes themselves are pretty straightforward, if verbose:

```
class FranceDateFormatter:
    def format_date(self, y, m, d):
        y, m, d = (str(x) for x in (y,m,d))
        y = '20' + y if len(y) == 2 else y
        m = '0' + m if len(m) == 1 else m
        d = '0' + d if len(d) == 1 else d
        return("{0}/{1}/{2}".format(d,m,y))

class USADateFormatter:
```

```
        def format_date(self, y, m, d):
            y, m, d = (str(x) for x in (y,m,d))
            y = '20' + y if len(y) == 2 else y
            m = '0' + m if len(m) == 1 else m
            d = '0' + d if len(d) == 1 else d
            return("{0}-{1}-{2}".format(m,d,y))

    class FranceCurrencyFormatter:
        def format_currency(self, base, cents):
            base, cents = (str(x) for x in (base, cents))
            if len(cents) == 0:
                cents = '00'
            elif len(cents) == 1:
                cents = '0' + cents

            digits = []
            for i,c in enumerate(reversed(base)):
                if i and not i % 3:
                    digits.append(' ')
                digits.append(c)
            base = ''.join(reversed(digits))
            return "{0}€{1}".format(base, cents)

    class USACurrencyFormatter:
        def format_currency(self, base, cents):
            base, cents = (str(x) for x in (base, cents))
            if len(cents) == 0:
                cents = '00'
            elif len(cents) == 1:
                cents = '0' + cents
            digits = []
            for i,c in enumerate(reversed(base)):
                if i and not i % 3:
                    digits.append(',')
                digits.append(c)
            base = ''.join(reversed(digits))
            return "${0}.{1}".format(base, cents)
```

These classes use some basic string manipulation to try to turn a variety of possible inputs (integers, strings of different lengths, and others) into the following formats:

	USA	**France**
Date	mm-dd-yyyy	dd/mm/yyyy
Currency	$14,500.50	14 500€50

There could obviously be more validation on the input in this code, but let's keep it simple and dumb for this example.

Now that we have the formatters set up, we just need to create the formatter factories:

```
class USAFormatterFactory:
    def create_date_formatter(self):
        return USADateFormatter()
    def create_currency_formatter(self):
        return USACurrencyFormatter()

class FranceFormatterFactory:
    def create_date_formatter(self):
        return FranceDateFormatter()
    def create_currency_formatter(self):
        return FranceCurrencyFormatter()
```

Now we set up the code that picks the appropriate formatter. Since this is the kind of thing that only needs to be set up once, we could make it a singleton—except singletons aren't very useful in Python. Let's just make the current formatter a module-level variable instead:

```
country_code = "US"
factory_map = {
        "US": USAFormatterFactory,
        "FR": FranceFormatterFactory}
formatter_factory = factory_map.get(country_code)()
```

In this example, we hardcode the current country code; in practice, it would likely introspect the locale, the operating system, or a configuration file to choose the code. This example uses a dictionary to associate the country codes with factory classes. Then we grab the correct class from the dictionary and instantiate it.

It is easy to see what needs to be done when we want to add support for more countries: create the new formatter classes and the abstract factory itself. Bear in mind that `Formatter` classes might be reused; for example, Canada formats its currency the same way as the USA, but its date format is more sensible than its Southern neighbor.

Abstract factories often return a singleton object, but this is not required; in our code, it's returning a new instance of each formatter every time it's called. There's no reason the formatters couldn't be stored as instance variables and the same instance returned for each factory.

Looking back at these examples, we see that, once again, there appears to be a lot of boilerplate code for factories that just doesn't feel necessary in Python. Often, the requirements that might call for an abstract factory can be more easily fulfilled by using a separate module for each factory type (for example: the USA and France), and then ensuring that the correct module is being accessed in a factory module. The package structure for such modules might look like this:

```
localize/
    __init__.py
    backends/
        __init__.py
        USA.py
        France.py
        …
```

The trick is that `__init__.py` in the `localize` package can contain logic that redirects all requests to the correct backend. There is a variety of ways this could be done.

If we know that the backend is never going to change dynamically (that is, without a restart), we can just put some `if` statements in `__init__.py` that check the current country code, and use the usually unacceptable `from .backends.USA import *` syntax to import all variables from the appropriate backend. Or, we could import each of the backends and set a `current_backend` variable to point at a specific module:

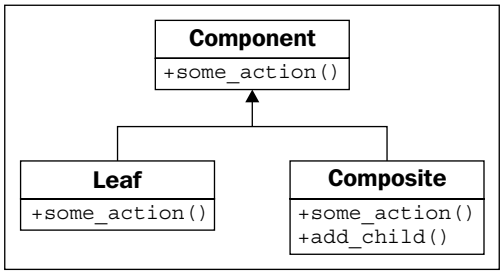
```
from .backends import USA, France

if country_code == "US":
    current_backend = USA
```

Depending on which solution we choose, our client code would have to call either `localize.format_date` or `localize.current_backend.format_date` to get a date formatted in the current country's locale. The end result is much more Pythonic than the original abstract factory pattern, and, in typical usage, just as flexible.

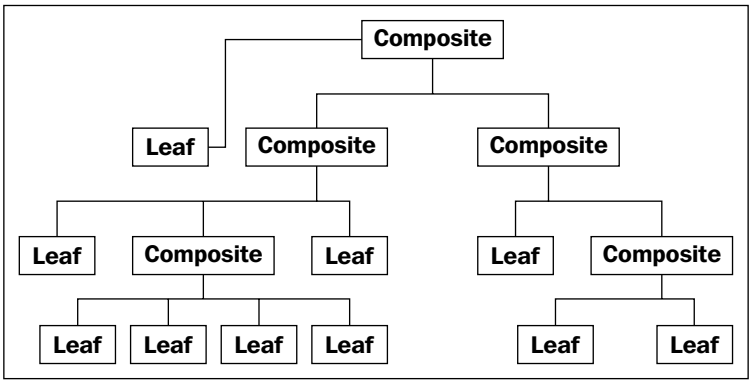
The composite pattern

The composite pattern allows complex tree-like structures to be built from simple components. These components, called composite objects, are able to behave sort of like a container and sort of like a variable depending on whether they have child components. Composite objects are container objects, where the content may actually be another composite object.

Traditionally, each component in a composite object must be either a leaf node (that cannot contain other objects) or a composite node. The key is that both composite and leaf nodes can have the same interface. The UML diagram is very simple:



This simple pattern, however, allows us to create complex arrangements of elements, all of which satisfy the interface of the component object. Here is a concrete instance of such a complicated arrangement:



The composite pattern is commonly useful in file/folder-like trees. Regardless of whether a node in the tree is a normal file or a folder, it is still subject to operations such as moving, copying, or deleting the node. We can create a component interface that supports these operations, and then use a composite object to represent folders, and leaf nodes to represent normal files.

Of course, in Python, once again, we can take advantage of duck typing to implicitly provide the interface, so we only need to write two classes. Let's define these interfaces first:

```
class Folder:
    def __init__(self, name):
        self.name = name
        self.children = {}

    def add_child(self, child):
        pass

    def move(self, new_path):
        pass

    def copy(self, new_path):
        pass

    def delete(self):
        pass

class File:
    def __init__(self, name, contents):
        self.name = name
        self.contents = contents

    def move(self, new_path):
        pass

    def copy(self, new_path):
        pass

    def delete(self):
        pass
```

For each folder (composite) object, we maintain a dictionary of children. Often, a list is sufficient, but in this case, a dictionary will be useful for looking up children by name. Our paths will be specified as node names separated by the `/` character, similar to paths in a Unix shell.

Thinking about the methods involved, we can see that moving or deleting a node behaves in a similar way, regardless of whether or not it is a file or folder node. Copying, however, has to do a recursive copy for folder nodes, while copying a file node is a trivial operation.

To take advantage of the similar operations, we can extract some of the common methods into a parent class. Let's take that discarded `Component` interface and change it to a base class:

```
class Component:
    def __init__(self, name):
        self.name = name

    def move(self, new_path):
        new_folder =get_path(new_path)
        del self.parent.children[self.name]
        new_folder.children[self.name] = self
        self.parent = new_folder

    def delete(self):
        del self.parent.children[self.name]

class Folder(Component):
    def __init__(self, name):
        super().__init__(name)
        self.children = {}

    def add_child(self, child):
        pass

    def copy(self, new_path):
        pass

class File(Component):
    def __init__(self, name, contents):
        super().__init__(name)
        self.contents = contents

    def copy(self, new_path):
        pass

root = Folder('')
def get_path(path):
```

```
    names = path.split('/')[1:]
    node = root
    for name in names:
        node = node.children[name]
    return node
```

We've created the `move` and `delete` methods on the `Component` class. Both of them access a mysterious `parent` variable that we haven't set yet. The `move` method uses a module-level `get_path` function that finds a node from a predefined root node, given a path. All files will be added to this root node or a child of that node. For the `move` method, the target should be a currently existing folder, or we'll get an error. As with many of the examples in technical books, error handling is woefully absent, to help focus on the principles under consideration.

Let's set up that mysterious `parent` variable first; this happens, in the folder's `add_child` method:

```
    def add_child(self, child):
        child.parent = self
        self.children[child.name] = child
```

Well, that was easy enough. Let's see if our composite file hierarchy is working properly:

```
$ python3 -i 1261_09_18_add_child.py


>>> folder1 = Folder('folder1')
>>> folder2 = Folder('folder2')
>>> root.add_child(folder1)
>>> root.add_child(folder2)
>>> folder11 = Folder('folder11')
>>> folder1.add_child(folder11)
>>> file111 = File('file111', 'contents')
>>> folder11.add_child(file111)
>>> file21 = File('file21', 'other contents')
>>> folder2.add_child(file21)
>>> folder2.children
{'file21': <__main__.File object at 0xb7220a4c>}
>>> folder2.move('/folder1/folder11')
>>> folder11.children
{'folder2': <__main__.Folder object at 0xb722080c>, 'file111': <__main__.
File object at 0xb72209ec>}
```

```
>>> file21.move('/folder1')
>>> folder1.children
{'file21': <__main__.File object at 0xb7220a4c>, 'folder11': <__main__.
Folder object at 0xb722084c>}
```

Yes, we can create folders, add folders to other folders, add files to folders, and move them around! What more could we ask for in a file hierarchy?

Well, we could ask for copying to be implemented, but to conserve trees, let's leave that as an exercise.

The composite pattern is extremely useful for a variety of tree-like structures, including GUI widget hierarchies, file hierarchies, tree sets, graphs, and HTML DOM. It can be a useful pattern in Python when implemented according to the traditional implementation, as the example earlier demonstrated. Sometimes, if only a shallow tree is being created, we can get away with a list of lists or a dictionary of dictionaries, and do not need to implement custom component, leaf, and composite classes. Other times, we can get away with implementing only one composite class, and treating leaf and composite objects as a single class. Alternatively, Python's duck typing can make it easy to add other objects to a composite hierarchy, as long as they have the correct interface.

Exercises

Before diving into exercises for each design pattern, take a moment to implement the `copy` method for the `File` and `Folder` objects in the previous section. The `File` method should be quite trivial; just create a new node with the same name and contents, and add it to the new parent folder. The `copy` method on `Folder` is quite a bit more complicated, as you first have to duplicate the folder, and then recursively copy each of its children to the new location. You can call the `copy()` method on the children indiscriminately, regardless of whether each is a file or a folder object. This will drive home just how powerful the composite pattern can be.

Now, as with the previous chapter, look at the patterns we've discussed, and consider ideal places where you might implement them. You may want to apply the adapter pattern to existing code, as it is usually applicable when interfacing with existing libraries, rather than new code. How can you use an adapter to force two interfaces to interact with each other correctly?

Can you think of a system complex enough to justify using the facade pattern? Consider how facades are used in real-life situations, such as the driver-facing interface of a car, or the control panel in a factory. It is similar in software, except the users of the facade interface are other programmers, rather than people trained to use them. Are there complex systems in your latest project that could benefit from the facade pattern?

It's possible you don't have any huge, memory-consuming code that would benefit from the flyweight pattern, but can you think of situations where it might be useful? Anywhere that large amounts of overlapping data need to be processed, a flyweight is waiting to be used. Would it be useful in the banking industry? In web applications? At what point does the flyweight pattern make sense? When is it overkill?

What about the command pattern? Can you think of any common (or better yet, uncommon) examples of places where the decoupling of action from invocation would be useful? Look at the programs you use on a daily basis, and imagine how they are implemented internally. It's likely that many of them use the command pattern for one purpose or another.

The abstract factory pattern, or the somewhat more Pythonic derivatives we discussed, can be very useful for creating one-touch-configurable systems. Can you think of places where such systems are useful?

Finally, consider the composite pattern. There are tree-like structures all around us in programming; some of them, like our file hierarchy example, are blatant; others are fairly subtle. What situations might arise where the composite pattern would be useful? Can you think of places where you can use it in your own code? What if you adapted the pattern slightly; for example, to contain different types of leaf or composite nodes for different types of objects?

Summary

In this chapter, we went into detail on several more design patterns, covering their canonical descriptions as well as alternatives for implementing them in Python, which is often more flexible and versatile than traditional object-oriented languages. The adapter pattern is useful for matching interfaces, while the facade pattern is suited to simplifying them. Flyweight is a complicated pattern and only useful if memory optimization is required. In Python, the command pattern is often more aptly implemented using first class functions as callbacks. Abstract factories allow run-time separation of implementations depending on configuration or system information. The composite pattern is used universally for tree-like structures.

In the next chapter, we'll discuss how important it is to test Python programs, and how to do it.

12
Testing Object-oriented Programs

Skilled Python programmers agree that testing is one of the most important aspects of software development. Even though this chapter is placed near the end of the book, it is not an afterthought; everything we have studied so far will help us when writing tests. We'll be studying:

- The importance of unit testing and test-driven development
- The standard `unittest` module
- The `py.test` automated testing suite
- The `mock` module
- Code coverage
- Cross-platform testing with `tox`

Why test?

A large collection of programmers already know how important it is to test their code. If you're among them, feel free to skim this section. You'll find the next section—where we actually see how to do the tests in Python—much more scintillating. If you're not convinced of the importance of testing, I promise that your code is broken, you just don't know it. Read on!

Some people argue that testing is more important in Python code because of its dynamic nature; compiled languages such as Java and C++ are occasionally thought to be somehow "safer" because they enforce type checking at compile time. However, Python tests rarely check types. They're checking values. They're making sure that the right attributes have been set at the right time or that the sequence has the right length, order, and values. These higher-level things need to be tested in any language. The real reason Python programmers test more than programmers of other languages is that it is so easy to test in Python!

But why test? Do we really need to test? What if we didn't test? To answer those questions, write a tic-tac-toe game from scratch without any testing at all. Don't run it until it is completely written, start to finish. Tic-tac-toe is fairly simple to implement if you make both players human players (no artificial intelligence). You don't even have to try to calculate who the winner is. Now run your program. And fix all the errors. How many were there? I recorded eight on my tic-tac-toe implementation, and I'm not sure I caught them all. Did you?

We need to test our code to make sure it works. Running the program, as we just did, and fixing the errors is one crude form of testing. Python programmers are able to write a few lines of code and run the program to make sure those lines are doing what they expect. But changing a few lines of code can affect parts of the program that the developer hadn't realized will be influenced by the changes, and therefore won't test it. Furthermore, as a program grows, the various paths that the interpreter can take through that code also grow, and it quickly becomes impossible to manually test all of them.

To handle this, we write automated tests. These are programs that automatically run certain inputs through other programs or parts of programs. We can run these test programs in seconds and cover more possible input situations than one programmer would think to test every time they change something.

There are four main reasons to write tests:

- To ensure that code is working the way the developer thinks it should
- To ensure that code continues working when we make changes
- To ensure that the developer understood the requirements
- To ensure that the code we are writing has a maintainable interface

The first point really doesn't justify the time it takes to write a test; we can simply test the code directly in the interactive interpreter. But when we have to perform the same sequence of test actions multiple times, it takes less time to automate those steps once and then run them whenever necessary. It is a good idea to run tests whenever we change code, whether it is during initial development or maintenance releases. When we have a comprehensive set of automated tests, we can run them after code changes and know that we didn't inadvertently break anything that was tested.

The last two points are more interesting. When we write tests for code, it helps us design the API, interface, or pattern that code takes. Thus, if we misunderstood the requirements, writing a test can help highlight that misunderstanding. On the other side, if we're not certain how we want to design a class, we can write a test that interacts with that class so we have an idea what the most natural way to test it would be. In fact, it is often beneficial to write the tests before we write the code we are testing.

Test-driven development

"Write tests first" is the mantra of test-driven development. Test-driven development takes the "untested code is broken code" concept one step further and suggests that only unwritten code should be untested. Do not write any code until you have written the tests for this code. So the first step is to write a test that proves the code would work. Obviously, the test is going to fail, since the code hasn't been written. Then write the code that ensures the test passes. Then write another test for the next segment of code.

Test-driven development is fun. It allows us to build little puzzles to solve. Then we implement the code to solve the puzzles. Then we make a more complicated puzzle, and we write code that solves the new puzzle without unsolving the previous one.

There are two goals to the test-driven methodology. The first is to ensure that tests really get written. It's so very easy, after we have written code, to say: "Hmm, it seems to work. I don't have to write any tests for this. It was just a small change, nothing could have broken." If the test is already written before we write the code, we will know exactly when it works (because the test will pass), and we'll know in the future if it is ever broken by a change we, or someone else has made.

Secondly, writing tests first forces us to consider exactly how the code will be interacted with. It tells us what methods objects need to have and how attributes will be accessed. It helps us break up the initial problem into smaller, testable problems, and then to recombine the tested solutions into larger, also tested, solutions. Writing tests can thus become a part of the design process. Often, if we're writing a test for a new object, we discover anomalies in the design that force us to consider new aspects of the software.

As a concrete example, imagine writing code that uses an object-relational mapper to store object properties in a database. It is common to use an automatically assigned database ID in such objects. Our code might use this ID for various purposes. If we are writing a test for such code, before we write it, we may realize that our design is faulty because objects do not have these IDs until they have been saved to the database. If we want to manipulate an object without saving it in our test, it will highlight this problem before we have written code based on the faulty premise.

Testing makes software better. Writing tests before we release the software makes it better before the end user sees or purchases the buggy version (I have worked for companies that thrive on the "the users can test it" philosophy. It's not a healthy business model!). Writing tests before we write software makes it better the first time it is written.

Unit testing

Let's start our exploration with Python's built-in test library. This library provides a common interface for **unit tests**. Unit tests focus on testing the least amount of code possible in any one test. Each one tests a single unit of the total amount of available code.

The Python library for this is called, unsurprisingly, `unittest`. It provides several tools for creating and running unit tests, the most important being the `TestCase` class. This class provides a set of methods that allow us to compare values, set up tests, and clean up when they have finished.

When we want to write a set of unit tests for a specific task, we create a subclass of `TestCase`, and write individual methods to do the actual testing. These methods must all start with the name `test`. When this convention is followed, the tests automatically run as part of the test process. Normally, the tests set some values on an object and then run a method, and use the built-in comparison methods to ensure that the right results were calculated. Here's a very simple example:

```
import unittest

class CheckNumbers(unittest.TestCase):
    def test_int_float(self):
        self.assertEqual(1, 1.0)

if __name__ == "__main__":
    unittest.main()
```

This code simply subclasses the `TestCase` class and adds a method that calls the `TestCase.assertEqual` method. This method will either succeed or raise an exception, depending on whether the two parameters are equal. If we run this code, the `main` function from `unittest` will give us the following output:

```
.
----------------------------------------------------------------------
Ran 1 test in 0.000s

OK
```

Did you know that floats and integers can compare as equal? Let's add a failing test:

```
        def test_str_float(self):
            self.assertEqual(1, "1")
```

The output of this code is more sinister, as integers and strings are not considered equal:

```
.F
======================================================================
FAIL: test_str_float (__main__.CheckNumbers)
----------------------------------------------------------------------
Traceback (most recent call last):
  File "simplest_unittest.py", line 8, in test_str_float
    self.assertEqual(1, "1")
AssertionError: 1 != '1'

----------------------------------------------------------------------
Ran 2 tests in 0.001s

FAILED (failures=1)
```

The dot on the first line indicates that the first test (the one we wrote before) passed successfully; the letter `F` after it shows that the second test failed. Then, at the end, it gives us some informative output telling us how and where the test failed, along with a summary of the number of failures.

We can have as many test methods on one `TestCase` class as we like; as long as the method name begins with `test`, the test runner will execute each one as a separate test. Each test should be completely independent of other tests. Results or calculations from a previous test should have no impact on the current test. The key to writing good unit tests is to keep each test method as short as possible, testing a small unit of code with each test case. If your code does not seem to naturally break up into such testable units, it's probably a sign that your design needs rethinking.

Assertion methods

The general layout of a test case is to set certain variables to known values, run one or more functions, methods, or processes, and then "prove" that correct expected results were returned or calculated by using `TestCase` assertion methods.

There are a few different assertion methods available to confirm that specific results have been achieved. We just saw `assertEqual`, which will cause a test failure if the two parameters do not pass an equality check. The inverse, `assertNotEqual`, will fail if the two parameters do compare as equal. The `assertTrue` and `assertFalse` methods each accept a single expression, and fail if the expression does not pass an `if` test. These tests are not checking for the Boolean values `True` or `False`. Rather, they test the same condition as though an `if` statement were used: `False`, `None`, `0`, or an empty list, dictionary, string, set, or tuple would pass a call to the `assertFalse` method, while nonzero numbers, containers with values in them, or the value `True` would succeed when calling the `assertTrue` method.

There is an `assertRaises` method that can be used to ensure a specific function call raises a specific exception or, optionally, it can be used as a context manager to wrap inline code. The test passes if the code inside the `with` statement raises the proper exception; otherwise, it fails. Here's an example of both versions:

```
import unittest

def average(seq):
    return sum(seq) / len(seq)

class TestAverage(unittest.TestCase):
    def test_zero(self):
        self.assertRaises(ZeroDivisionError,
                average,
```

```
                []):

        def test_with_zero(self):
            with self.assertRaises(ZeroDivisionError):
                average([])

if __name__ == "__main__":
    unittest.main()
```

The context manager allows us to write the code the way we would normally write it (by calling functions or executing code directly), rather than having to wrap the function call in another function call.

There are also several other assertion methods, summarized in the following table:

Methods	Description

`assertGreater`
`assertGreaterEqual`
`assertLess`
`assertLessEqual`
	Accept two comparable objects and ensure the named inequality holds.

`assertIn` `assertNotIn`	Ensure an element is (or is not) an element in a container object.
`assertIsNone` `assertIsNotNone`	Ensure an element is (or is not) the exact value `None` (but not another falsey value).
`assertSameElements`	Ensure two container objects have the same elements, ignoring the order.

`assertSequenceEqualassertDictEqual`
`assertSetEqual`
`assertListEqual`
`assertTupleEqual`
	Ensure two containers have the same elements in the same order. If there's a failure, show a code diff comparing the two lists to see where they differ. The last four methods also test the type of the list.

Each of the assertion methods accepts an optional argument named `msg`. If supplied, it is included in the error message if the assertion fails. This is useful for clarifying what was expected or explaining where a bug may have occurred to cause the assertion to fail.

Reducing boilerplate and cleaning up

After writing a few small tests, we often find that we have to do the same setup code for several related tests. For example, the following `list` subclass has three methods for statistical calculations:

```
from collections import defaultdict

class StatsList(list):
    def mean(self):
        return sum(self) / len(self)

    def median(self):
        if len(self) % 2:
            return self[int(len(self) / 2)]
        else:
            idx = int(len(self) / 2)
            return (self[idx] + self[idx-1]) / 2

    def mode(self):
        freqs = defaultdict(int)
        for item in self:
            freqs[item] += 1
        mode_freq = max(freqs.values())
        modes = []
        for item, value in freqs.items():
            if value == mode_freq:
                modes.append(item)
        return modes
```

Clearly, we're going to want to test situations with each of these three methods that have very similar inputs; we'll want to see what happens with empty lists or with lists containing non-numeric values or with lists containing a normal dataset. We can use the `setUp` method on the `TestCase` class to do initialization for each test. This method accepts no arguments, and allows us to do arbitrary setup before each test is run. For example, we can test all three methods on identical lists of integers as follows:

```
from stats import StatsList
import unittest

class TestValidInputs(unittest.TestCase):
    def setUp(self):
        self.stats = StatsList([1,2,2,3,3,4])

    def test_mean(self):
```

```
            self.assertEqual(self.stats.mean(), 2.5)

        def test_median(self):
            self.assertEqual(self.stats.median(), 2.5)
            self.stats.append(4)
            self.assertEqual(self.stats.median(), 3)

        def test_mode(self):
            self.assertEqual(self.stats.mode(), [2,3])
            self.stats.remove(2)
            self.assertEqual(self.stats.mode(), [3])

    if __name__ == "__main__":
        unittest.main()
```

If we run this example, it indicates that all tests pass. Notice first that the `setUp` method is never explicitly called inside the three `test_*` methods. The test suite does this on our behalf. More importantly notice how `test_median` alters the list, by adding an additional `4` to it, yet when `test_mode` is called, the list has returned to the values specified in `setUp` (if it had not, there would be two fours in the list, and the `mode` method would have returned three values). This shows that `setUp` is called individually before each test, to ensure the test class starts with a clean slate. Tests can be executed in any order, and the results of one test should not depend on any other tests.

In addition to the `setUp` method, `TestCase` offers a no-argument `tearDown` method, which can be used for cleaning up after each and every test on the class has run. This is useful if cleanup requires anything other than letting an object be garbage collected. For example, if we are testing code that does file I/O, our tests may create new files as a side effect of testing; the `tearDown` method can remove these files and ensure the system is in the same state it was before the tests ran. Test cases should never have side effects. In general, we group test methods into separate `TestCase` subclasses depending on what setup code they have in common. Several tests that require the same or similar setup will be placed in one class, while tests that require unrelated setup go in another class.

Organizing and running tests

It doesn't take long for a collection of unit tests to grow very large and unwieldy. It quickly becomes complicated to load and run all the tests at once. This is a primary goal of unit testing; it should be trivial to run all tests on our program and get a quick "yes or no" answer to the question, "Did my recent changes break any existing tests?".

Python's `discover` module basically looks for any modules in the current folder or subfolders with names that start with the characters `test`. If it finds any `TestCase` objects in these modules, the tests are executed. It's a painless way to ensure we don't miss running any tests. To use it, ensure your test modules are named `test_<something>.py` and then run the command `python3 -m unittest discover`.

Ignoring broken tests

Sometimes, a test is known to fail, but we don't want the test suite to report the failure. This may be because a broken or unfinished feature has had tests written, but we aren't currently focusing on improving it. More often, it happens because a feature is only available on a certain platform, Python version, or for advanced versions of a specific library. Python provides us with a few decorators to mark tests as expected to fail or to be skipped under known conditions.

The decorators are:

- `expectedFailure()`
- `skip(reason)`
- `skipIf(condition, reason)`
- `skipUnless(condition, reason)`

These are applied using the Python decorator syntax. The first one accepts no arguments, and simply tells the test runner not to record the test as a failure when it fails. The `skip` method goes one step further and doesn't even bother to run the test. It expects a single string argument describing why the test was skipped. The other two decorators accept two arguments, one a Boolean expression that indicates whether or not the test should be run, and a similar description. In use, these three decorators might be applied like this:

```
import unittest
import sys

class SkipTests(unittest.TestCase):
    @unittest.expectedFailure
    def test_fails(self):
        self.assertEqual(False, True)

    @unittest.skip("Test is useless")
```

```
        def test_skip(self):
            self.assertEqual(False, True)

        @unittest.skipIf(sys.version_info.minor == 4,
                "broken on 3.4")
        def test_skipif(self):
            self.assertEqual(False, True)

        @unittest.skipUnless(sys.platform.startswith('linux'),
                "broken unless on linux")
        def test_skipunless(self):
            self.assertEqual(False, True)

    if __name__ == "__main__":
        unittest.main()
```

The first test fails, but it is reported as an expected failure; the second test is never run. The other two tests may or may not be run depending on the current Python version and operating system. On my Linux system running Python 3.4, the output looks like this:

```
xssF
======================================================================
FAIL: test_skipunless (__main__.SkipTests)
----------------------------------------------------------------------
Traceback (most recent call last):
  File "skipping_tests.py", line 21, in test_skipunless
    self.assertEqual(False, True)
AssertionError: False != True


----------------------------------------------------------------------
Ran 4 tests in 0.001s


FAILED (failures=1, skipped=2, expected failures=1)
```

The `x` on the first line indicates an expected failure; the two `s` characters represent skipped tests, and the `F` indicates a real failure, since the conditional to `skipUnless` was `True` on my system.

Testing with py.test

The Python `unittest` module requires a lot of boilerplate code to set up and initialize tests. It is based on the very popular JUnit testing framework for Java. It even uses the same method names (you may have noticed they don't conform to the PEP-8 naming standard, which suggests underscores rather than CamelCase to separate words in a method name) and test layout. While this is effective for testing in Java, it's not necessarily the best design for Python testing.

Because Python programmers like their code to be elegant and simple, other test frameworks have been developed, outside the standard library. Two of the more popular ones are `py.test` and `nose`. The former is more robust and has had Python 3 support for much longer, so we'll discuss it here.

Since `py.test` is not part of the standard library, you'll need to download and install it yourself; you can get it from the `py.test` home page at `http://pytest.org/`. The website has comprehensive installation instructions for a variety of interpreters and platforms, but you can usually get away with the more common python package installer, pip. Just type `pip install pytest` on your command line and you'll be good to go.

`py.test` has a substantially different layout from the `unittest` module. It doesn't require test cases to be classes. Instead, it takes advantage of the fact that Python functions are objects, and allows any properly named function to behave like a test. Rather than providing a bunch of custom methods for asserting equality, it uses the `assert` statement to verify results. This makes tests more readable and maintainable. When we run `py.test`, it will start in the current folder and search for any modules in that folder or subpackages whose names start with the characters `test_`. If any functions in this module also start with `test`, they will be executed as individual tests. Furthermore, if there are any classes in the module whose name starts with `Test`, any methods on that class that start with `test_` will also be executed in the test environment.

Let's port the simplest possible `unittest` example we wrote earlier to `py.test`:

```
def test_int_float():
    assert 1 == 1.0
```

For the exact same test, we've written two lines of more readable code, in comparison to the six lines required in our first `unittest` example.

However, we are not forbidden from writing class-based tests. Classes can be useful for grouping related tests together or for tests that need to access related attributes or methods on the class. This example shows an extended class with a passing and a failing test; we'll see that the error output is more comprehensive than that provided by the `unittest` module:

```
class TestNumbers:
    def test_int_float(self):
        assert 1 == 1.0

    def test_int_str(self):
        assert 1 == "1"
```

Notice that the class doesn't have to extend any special objects to be picked up as a test (although `py.test` will run standard `unittest TestCases` just fine). If we run `py.test <filename>`, the output looks like this:

```
============== test session starts ==============
python: platform linux2 -- Python 3.4.1 -- pytest-2.6.4
test object 1: class_pytest.py

class_pytest.py .F

=================== FAILURES====================
___________ TestNumbers.test_int_str _____________

self = <class_pytest.TestNumbers object at 0x85b4fac>

    def test_int_str(self):
>       assert 1 == "1"
E       assert 1 == '1'

class_pytest.py:7: AssertionError
====== 1 failed, 1 passed in 0.10 seconds =======
```

The output starts with some useful information about the platform and interpreter. This can be useful for sharing bugs across disparate systems. The third line tells us the name of the file being tested (if there are multiple test modules picked up, they will all be displayed), followed by the familiar `.F` we saw in the `unittest` module; the `.` character indicates a passing test, while the letter `F` demonstrates a failure.

After all tests have run, the error output for each of them is displayed. It presents a summary of local variables (there is only one in this example: the `self` parameter passed into the function), the source code where the error occurred, and a summary of the error message. In addition, if an exception other than an `AssertionError` is raised, `py.test` will present us with a complete traceback, including source code references.

By default, `py.test` suppresses output from `print` statements if the test is successful. This is useful for test debugging; when a test is failing, we can add `print` statements to the test to check the values of specific variables and attributes as the test runs. If the test fails, these values are output to help with diagnosis. However, once the test is successful, the `print` statement output is not displayed, and they can be easily ignored. We don't have to "clean up" the output by removing `print` statements. If the tests ever fail again, due to future changes, the debugging output will be immediately available.

One way to do setup and cleanup

`py.test` supports setup and teardown methods similar to those used in `unittest`, but it provides even more flexibility. We'll discuss these briefly, since they are familiar, but they are not used as extensively as in the `unittest` module, as `py.test` provides us with a powerful funcargs facility, which we'll discuss in the next section.

If we are writing class-based tests, we can use two methods called `setup_method` and `teardown_method` in basically the same way that `setUp` and `tearDown` are called in `unittest`. They are called before and after each test method in the class to perform setup and cleanup duties. There is one difference from the `unittest` methods though. Both methods accept an argument: the function object representing the method being called.

In addition, `py.test` provides other setup and teardown functions to give us more control over when setup and cleanup code is executed. The `setup_class` and `teardown_class` methods are expected to be class methods; they accept a single argument (there is no `self` argument) representing the class in question.

Finally, we have the `setup_module` and `teardown_module` functions, which are run immediately before and after all tests (in functions or classes) in that module. These can be useful for "one time" setup, such as creating a socket or database connection that will be used by all tests in the module. Be careful with this one, as it can accidentally introduce dependencies between tests if the object being set up stores the state.

That short description doesn't do a great job of explaining exactly when these methods are called, so let's look at an example that illustrates exactly when it happens:

```
def setup_module(module):
    print("setting up MODULE {0}".format(
        module.__name__))

def teardown_module(module):
    print("tearing down MODULE {0}".format(
        module.__name__))

def test_a_function():
    print("RUNNING TEST FUNCTION")

class BaseTest:
    def setup_class(cls):
        print("setting up CLASS {0}".format(
            cls.__name__))

    def teardown_class(cls):
        print("tearing down CLASS {0}\n".format(
            cls.__name__))

    def setup_method(self, method):
        print("setting up METHOD {0}".format(
            method.__name__))

    def teardown_method(self, method):
        print("tearing down  METHOD {0}".format(
            method.__name__))

class TestClass1(BaseTest):
    def test_method_1(self):
        print("RUNNING METHOD 1-1")

    def test_method_2(self):
```

```
            print("RUNNING METHOD 1-2")

    class TestClass2(BaseTest):
        def test_method_1(self):
            print("RUNNING METHOD 2-1")

        def test_method_2(self):
            print("RUNNING METHOD 2-2")
```

The sole purpose of the `BaseTest` class is to extract four methods that would be otherwise identical to the test classes, and use inheritance to reduce the amount of duplicate code. So, from the point of view of `py.test`, the two subclasses have not only two test methods each, but also two setup and two teardown methods (one at the class level, one at the method level).

If we run these tests using `py.test` with the `print` function output suppression disabled (by passing the `-s` or `--capture=no` flag), they show us when the various functions are called in relation to the tests themselves:

```
py.test setup_teardown.py -s
setup_teardown.py
setting up MODULE setup_teardown
RUNNING TEST FUNCTION
.setting up CLASS TestClass1
setting up METHOD test_method_1
RUNNING METHOD 1-1
.tearing down  METHOD test_method_1
setting up METHOD test_method_2
RUNNING METHOD 1-2
.tearing down  METHOD test_method_2
tearing down CLASS TestClass1
setting up CLASS TestClass2
setting up METHOD test_method_1
RUNNING METHOD 2-1
.tearing down  METHOD test_method_1
setting up METHOD test_method_2
RUNNING METHOD 2-2
.tearing down  METHOD test_method_2
tearing down CLASS TestClass2

tearing down MODULE setup_teardown
```

The setup and teardown methods for the module are executed at the beginning and end of the session. Then the lone module-level test function is run. Next, the setup method for the first class is executed, followed by the two tests for that class. These tests are each individually wrapped in separate `setup_method` and `teardown_method` calls. After the tests have executed, the class teardown method is called. The same sequence happens for the second class, before the `teardown_module` method is finally called, exactly once.

A completely different way to set up variables

One of the most common uses for the various setup and teardown functions is to ensure certain class or module variables are available with a known value before each test method is run.

`py.test` offers a completely different way to do this using what are known as **funcargs**, short for function arguments. Funcargs are basically named variables that are predefined in a test configuration file. This allows us to separate configuration from execution of tests, and allows the funcargs to be used across multiple classes and modules.

To use them, we add parameters to our test function. The names of the parameters are used to look up specific arguments in specially named functions. For example, if we wanted to test the `StatsList` class we used while demonstrating `unittest`, we would again want to repeatedly test a list of valid integers. But we can write our tests like so instead of using a setup method:

```
from stats import StatsList

def pytest_funcarg__valid_stats(request):
    return StatsList([1,2,2,3,3,4])


def test_mean(valid_stats):
    assert valid_stats.mean() == 2.5

def test_median(valid_stats):
    assert valid_stats.median() == 2.5
    valid_stats.append(4)
    assert valid_stats.median() == 3

def test_mode(valid_stats):
    assert valid_stats.mode() == [2,3]
    valid_stats.remove(2)
    assert valid_stats.mode() == [3]
```

Each of the three test methods accepts a parameter named `valid_stats`; this parameter is created by calling the `pytest_funcarg__valid_stats` function defined at the top of the file. It can also be defined in a file called `conftest.py` if the funcarg is needed by multiple modules. The `conftest.py` file is parsed by `py.test` to load any "global" test configuration; it is a sort of catch-all for customizing the `py.test` experience.

As with other `py.test` features, the name of the factory for returning a funcarg is important; funcargs are functions that are named `pytest_funcarg__<identifier>`, where `<identifier>` is a valid variable name that can be used as a parameter in a test function. This function accepts a mysterious `request` parameter, and returns the object to be passed as an argument into the individual test functions. The funcarg is created afresh for each call to an individual test function; this allows us, for example, to change the list in one test and know that it will be reset to its original values in the next test.

Funcargs can do a lot more than return basic variables. That `request` object passed into the funcarg factory provides some extremely useful methods and attributes to modify the funcarg's behavior. The `module`, `cls`, and `function` attributes allow us to see exactly which test is requesting the funcarg. The `config` attribute allows us to check command-line arguments and other configuration data.

More interestingly, the request object provides methods that allow us to do additional cleanup on the funcarg, or to reuse it across tests, activities that would otherwise be relegated to setup and teardown methods of a specific scope.

The `request.addfinalizer` method accepts a callback function that performs cleanup after each test function that uses the funcarg has been called. This provides the equivalent of a teardown method, allowing us to clean up files, close connections, empty lists, or reset queues. For example, the following code tests the `os.mkdir` functionality by creating a temporary directory `funcarg`:

```
import tempfile
import shutil
import os.path

def pytest_funcarg__temp_dir(request):
    dir = tempfile.mkdtemp()
    print(dir)

    def cleanup():
        shutil.rmtree(dir)
    request.addfinalizer(cleanup)
```

```
    return dir

def test_osfiles(temp_dir):
    os.mkdir(os.path.join(temp_dir, 'a'))
    os.mkdir(os.path.join(temp_dir, 'b'))
    dir_contents = os.listdir(temp_dir)
    assert len(dir_contents) == 2
    assert 'a' in dir_contents
    assert 'b' in dir_contents
```

The funcarg creates a new empty temporary directory for files to be created in. Then it adds a finalizer call to remove that directory (using `shutil.rmtree`, which recursively removes a directory and anything inside it) after the test has completed. The filesystem is then left in the same state in which it started.

We can use the `request.cached_setup` method to create function argument variables that last longer than one test. This is useful when setting up an expensive operation that can be reused by multiple tests as long as the resource reuse doesn't break the atomic or unit nature of the tests (so that one test does not rely on and is not impacted by a previous one). For example, if we were to test the following echo server, we may want to run only one instance of the server in a separate process, and then have multiple tests connect to that instance:

```
import socket

s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
s.setsockopt(socket.SOL_SOCKET, socket.SO_REUSEADDR, 1)
s.bind(('localhost',1028))
s.listen(1)

    while True:
        client, address = s.accept()
        data = client.recv(1024)
        client.send(data)
        client.close()
```

All this code does is listen on a specific port and wait for input from a client socket. When it receives input, it sends the same value back. To test this, we can start the server in a separate process and cache the result for use in multiple tests. Here's how the test code might look:

```
import subprocess
import socket
```

```
import time

def pytest_funcarg__echoserver(request):
    def setup():
        p = subprocess.Popen(
                ['python3', 'echo_server.py'])
        time.sleep(1)
        return p

    def cleanup(p):
        p.terminate()

    return request.cached_setup(
            setup=setup,
            teardown=cleanup,
            scope="session")

def pytest_funcarg__clientsocket(request):
    s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
    s.connect(('localhost', 1028))
    request.addfinalizer(lambda: s.close())
    return s

def test_echo(echoserver, clientsocket):
    clientsocket.send(b"abc")
    assert clientsocket.recv(3) == b'abc'

def test_echo2(echoserver, clientsocket):
    clientsocket.send(b"def")
    assert clientsocket.recv(3) == b'def'
```

We've created two funcargs here. The first runs the echo server in a separate process, and returns the process object. The second instantiates a new socket object for each test, and closes it when the test has completed, using `addfinalizer`. The first funcarg is the one we're currently interested in. It looks much like a traditional unit test setup and teardown. We create a `setup` function that accepts no parameters and returns the correct argument; in this case, a process object that is actually ignored by the tests, since they only care that the server is running. Then, we create a `cleanup` function (the name of the function is arbitrary since it's just an object we pass into another function), which accepts a single argument: the argument returned by `setup`. This cleanup code terminates the process.

Instead of returning a funcarg directly, the parent function returns the results of a call to `request.cached_setup`. It accepts two arguments for the `setup` and `teardown` functions (which we just created), and a `scope` argument. This last argument should be one of the three strings "function", "module", or "session"; it determines just how long the argument will be cached. We set it to "session" in this example, so it is cached for the duration of the entire `py.test` run. The process will not be terminated or restarted until all tests have run. The "module" scope, of course, caches it only for tests in that module, and the "function" scope treats the object more like a normal funcarg, in that it is reset after each test function is run.

Skipping tests with py.test

As with the `unittest` module, it is frequently necessary to skip tests in `py.test`, for a variety of reasons: the code being tested hasn't been written yet, the test only runs on certain interpreters or operating systems, or the test is time consuming and should only be run under certain circumstances.

We can skip tests at any point in our code using the `py.test.skip` function. It accepts a single argument: a string describing why it has been skipped. This function can be called anywhere; if we call it inside a test function, the test will be skipped. If we call it at the module level, all the tests in that module will be skipped. If we call it inside a funcarg function, all tests that call that funcarg will be skipped.

Of course, in all these locations, it is often desirable to skip tests only if certain conditions are or are not met. Since we can execute the `skip` function at any place in Python code, we can execute it inside an `if` statement. So we may write a test that looks like this:

```
import sys
import py.test

def test_simple_skip():
    if sys.platform != "fakeos":
        py.test.skip("Test works only on fakeOS")

    fakeos.do_something_fake()
    assert fakeos.did_not_happen
```

That's some pretty silly code, really. There is no Python platform named `fakeos`, so this test will skip on all operating systems. It shows how we can skip conditionally, and since the `if` statement can check any valid conditional, we have a lot of power over when tests are skipped. Often, we check `sys.version_info` to check the Python interpreter version, `sys.platform` to check the operating system, or `some_library.__version__` to check whether we have a recent enough version of a given API.

Since skipping an individual test method or function based on a certain conditional is one of the most common uses of test skipping, `py.test` provides a convenience decorator that allows us to do this in one line. The decorator accepts a single string, which can contain any executable Python code that evaluates to a Boolean value. For example, the following test will only run on Python 3 or higher:

```
import py.test

@py.test.mark.skipif("sys.version_info <= (3,0)")
def test_python3():
    assert b"hello".decode() == "hello"
```

The `py.test.mark.xfail` decorator behaves similarly, except that it marks a test as expected to fail, similar to `unittest.expectedFailure()`. If the test is successful, it will be recorded as a failure; if it fails, it will be reported as expected behavior. In the case of `xfail`, the conditional argument is optional; if it is not supplied, the test will be marked as expected to fail under all conditions.

Imitating expensive objects

Sometimes, we want to test code that requires an object be supplied that is either expensive or difficult to construct. While this may mean your API needs rethinking to have a more testable interface (which typically means a more usable interface), we sometimes find ourselves writing test code that has a ton of boilerplate to set up objects that are only incidentally related to the code under test.

For example, imagine we have some code that keeps track of flight statuses in a key-value store (such as `redis` or `memcache`) such that we can store the timestamp and the most recent status. A basic version of such code might look like this:

```
import datetime
import redis

class FlightStatusTracker:
    ALLOWED_STATUSES = {'CANCELLED', 'DELAYED', 'ON TIME'}

    def __init__(self):
        self.redis = redis.StrictRedis()

    def change_status(self, flight, status):
```

```
        status = status.upper()
        if status not in self.ALLOWED_STATUSES:
            raise ValueError(
                   "{} is not a valid status".format(status))

        key = "flightno:{}".format(flight)
        value = "{}|{}".format(
            datetime.datetime.now().isoformat(), status)
        self.redis.set(key, value)
```

There are a lot of things we ought to test in that `change_status` method. We should check that it raises the appropriate error if a bad status is passed in. We need to ensure that it converts statuses to uppercase. We can see that the key and value have the correct formatting when the `set()` method is called on the `redis` object.

One thing we don't have to check in our unit tests, however, is that the `redis` object is properly storing the data. This is something that absolutely should be tested in integration or application testing, but at the unit test level, we can assume that the py-redis developers have tested their code and that this method does what we want it to. As a rule, unit tests should be self-contained and not rely on the existence of outside resources, such as a running Redis instance.

Instead, we only need to test that the `set()` method was called the appropriate number of times and with the appropriate arguments. We can use `Mock()` objects in our tests to replace the troublesome method with an object we can introspect. The following example illustrates the use of mock:

```
from unittest.mock import Mock
import py.test
def pytest_funcarg__tracker():
    return FlightStatusTracker()

def test_mock_method(tracker):
    tracker.redis.set = Mock()
    with py.test.raises(ValueError) as ex:
        tracker.change_status("AC101", "lost")
    assert ex.value.args[0] == "LOST is not a valid status"
    assert tracker.redis.set.call_count == 0
```

This test, written using `py.test` syntax, asserts that the correct exception is raised when an inappropriate argument is passed in. In addition, it creates a mock object for the `set` method and makes sure that it is never called. If it was, it would mean there was a bug in our exception handling code.

Simply replacing the method worked fine in this case, since the object being replaced was destroyed in the end. However, we often want to replace a function or method only for the duration of a test. For example, if we want to test the timestamp formatting in the mock method, we need to know exactly what `datetime.datetime.now()` is going to return. However, this value changes from run to run. We need some way to pin it to a specific value so we can test it deterministically.

Remember monkey-patching? Temporarily setting a library function to a specific value is an excellent use of it. The mock library provides a patch context manager that allows us to replace attributes on existing libraries with mock objects. When the context manager exits, the original attribute is automatically restored so as not to impact other test cases. Here's an example:

```
from unittest.mock import patch
def test_patch(tracker):
    tracker.redis.set = Mock()
    fake_now = datetime.datetime(2015, 4, 1)
    with patch('datetime.datetime') as dt:
        dt.now.return_value = fake_now
        tracker.change_status("AC102", "on time")
    dt.now.assert_called_once_with()
    tracker.redis.set.assert_called_once_with(
        "flightno:AC102",
        "2015-04-01T00:00:00|ON TIME")
```

In this example, we first construct a value called `fake_now`, which we will set as the return value of the `datetime.datetime.now` function. We have to construct this object before we patch `datetime.datetime` because otherwise we'd be calling the patched `now` function before we constructed it!

The `with` statement invites the patch to replace the `datetime.datetime` module with a mock object, which is returned as the value `dt`. The neat thing about mock objects is that any time you access an attribute or method on that object, it returns another mock object. Thus when we access `dt.now`, it gives us a new mock object. We set the `return_value` of that object to our `fake_now` object; that way, whenever the `datetime.datetime.now` function is called, it will return our object instead of a new mock object.

Then, after calling our `change_status` method with known values, we use the mock class's `assert_called_once_with` function to ensure that the `now` function was indeed called exactly once with no arguments. We then call it a second time to prove that the `redis.set` method was called with arguments that were formatted as we expected them to be.

The previous example is a good indication of how writing tests can guide our API design. The `FlightStatusTracker` object looks sensible at first glance; we construct a `redis` connection when the object is constructed, and we call into it when we need it. When we write tests for this code, however, we discover that even if we mock out that `self.redis` variable on a `FlightStatusTracker`, the `redis` connection still has to be constructed. This call actually fails if there is no Redis server running, and our tests also fail.

We could solve this problem by mocking out the `redis.StrictRedis` class to return a mock in a `setUp` method. A better idea, however, might be to rethink our example. Instead of constructing the `redis` instance inside`__init__`, perhaps we should allow the user to pass one in, as in the following example:

```
    def __init__(self, redis_instance=None):
        self.redis = redis_instance if redis_instance else redis.
StrictRedis()
```

This allows us to pass a mock in when we are testing, so the `StrictRedis` method never gets constructed. However, it also allows any client code that talks to `FlightStatusTracker` to pass in their own `redis` instance. There are a variety of reasons they might want to do this. They may have already constructed one for other parts of their code. They may have created an optimized implementation of the `redis` API. Perhaps they have one that logs metrics to their internal monitoring systems. By writing a unit test, we've uncovered a use case that makes our API more flexible from the start, rather than waiting for clients to demand we support their exotic needs.

This has been a brief introduction to the wonders of mocking code. Mocks are part of the standard `unittest` library since Python 3.3, but as you see from these examples, they can also be used with `py.test` and other libraries. Mocks have other more advanced features that you may need to take advantage of as your code gets more complicated. For example, you can use the `spec` argument to invite a mock to imitate an existing class so that it raises an error if code tries to access an attribute that does not exist on the imitated class. You can also construct mock methods that return different arguments each time they are called by passing a list as the `side_effect` argument. The `side_effect` parameter is quite versatile; you can also use it to execute arbitrary functions when the mock is called or to raise an exception.

In general, we should be quite stingy with mocks. If we find ourselves mocking out multiple elements in a given unit test, we may end up testing the mock framework rather than our real code. This serves no useful purpose whatsoever; after all, mocks are well-tested already! If our code is doing a lot of this, it's probably another sign that the API we are testing is poorly designed. Mocks should exist at the boundaries between the code under test and the libraries they interface with. If this isn't happening, we may need to change the API so that the boundaries are redrawn in a different place.

How much testing is enough?

We've already established that untested code is broken code. But how can we tell how well our code is tested? How do we know how much of our code is actually being tested and how much is broken? The first question is the more important one, but it's hard to answer. Even if we know we have tested every line of code in our application, we do not know that we have tested it properly. For example, if we write a stats test that only checks what happens when we provide a list of integers, it may still fail spectacularly if used on a list of floats or strings or self-made objects. The onus of designing complete test suites still lies with the programmer.

The second question—how much of our code is actually being tested—is easy to verify. Code coverage is essentially an estimate of the number of lines of code that are executed by a program. If we know that number and the number of lines that are in the program, we can get an estimate of what percentage of the code was really tested, or covered. If we additionally have an indicator as to which lines were not tested, we can more easily write new tests to ensure those lines are less broken.

The most popular tool for testing code coverage is called, memorably enough, `coverage.py`. It can be installed like most other third-party libraries using the command `pip install coverage`.

We don't have space to cover all the details of the coverage API, so we'll just look at a few typical examples. If we have a Python script that runs all our unit tests for us (for example, using `unittest.main`, a custom test runner or `discover`), we can use the following command to perform a coverage analysis:

```
coverage run coverage_unittest.py
```

This command will exit normally, but it creates a file named `.coverage` that holds the data from the run. We can now use the `coverage report` command to get an analysis of code coverage:

```
>>> coverage report
```

The output is as follows:

```
Name                             Stmts   Exec  Cover
--------------------------------------------------
coverage_unittest                    7      7   100%
stats                               19      6    31%
--------------------------------------------------
TOTAL                               26     13    50%
```

This basic report lists the files that were executed (our unit test and a module it imported). The number of lines of code in each file, and the number that were executed by the test are also listed. The two numbers are then combined to estimate the amount of code coverage. If we pass the `-m` option to the report command, it will additionally add a column that looks like this:

```
Missing
-----------
8-12, 15-23
```

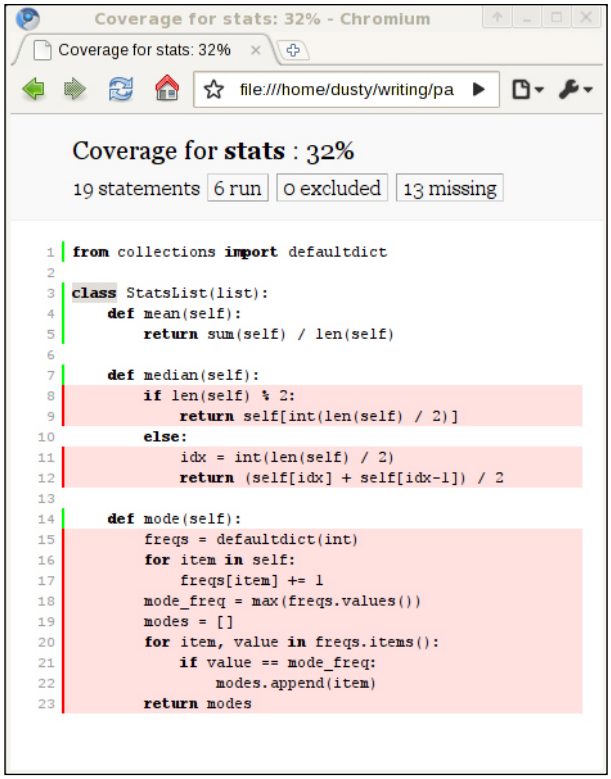
The ranges of lines listed here identify lines in the `stats` module that were not executed during the test run.

The example we just ran the code coverage tool on uses the same stats module we created earlier in the chapter. However, it deliberately uses a single test that fails to test a lot of code in the file. Here's the test:

```
from stats import StatsList
import unittest

class TestMean(unittest.TestCase):
    def test_mean(self):
        self.assertEqual(StatsList([1,2,2,3,3,4]).mean(), 2.5)

if __name__ == "__main__":

    unittest.main()
```

This code doesn't test the median or mode functions, which correspond to the line numbers that the coverage output told us were missing.

The textual report is sufficient, but if we use the command `coverage html`, we can get an even fancier interactive HTML report that we can view in a web browser. The web page even highlights which lines in the source code were and were not tested. Here's how it looks:



We can use the `coverage.py` module with `py.test` as well. We'll need to install the `py.test` plugin for code coverage, using `pip install pytest-coverage`. The plugin adds several command-line options to `py.test`, the most useful being `--cover-report`, which can be set to `html`, `report`, or `annotate` (the latter actually modifies the source code to highlight any lines that were not covered).

Unfortunately, if we could somehow run a coverage report on this section of the chapter, we'd find that we have not covered most of what there is to know about code coverage! It is possible to use the coverage API to manage code coverage from within our own programs (or test suites), and `coverage.py` accepts numerous configuration options that we haven't touched on. We also haven't discussed the difference between statement coverage and branch coverage (the latter is much more useful, and the default in recent versions of `coverage.py`) or other styles of code coverage.

Bear in mind that while 100 percent code coverage is a lofty goal that we should all strive for, 100 percent coverage is not enough! Just because a statement was tested does not mean that it was tested properly for all possible inputs.

Case study

Let's walk through test-driven development by writing a small, tested, cryptography application. Don't worry, you won't need to understand the mathematics behind complicated modern encryption algorithms such as Threefish or RSA. Instead, we'll be implementing a sixteenth-century algorithm known as the Vigenère cipher. The application simply needs to be able to encode and decode a message, given an encoding keyword, using this cipher.

First, we need to understand how the cipher works if we apply it manually (without a computer). We start with a table like this:

```
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
B C D E F G H I J K L M N O P Q R S T U V W X Y Z A
C D E F G H I J K L M N O P Q R S T U V W X Y Z A B
D E F G H I J K L M N O P Q R S T U V W X Y Z A B C
E F G H I J K L M N O P Q R S T U V W X Y Z A B C D
F G H I J K L M N O P Q R S T U V W X Y Z A B C D E
G H I J K L M N O P Q R S T U V W X Y Z A B C D E F
H I J K L M N O P Q R S T U V W X Y Z A B C D E F G
I J K L M N O P Q R S T U V W X Y Z A B C D E F G H
J K L M N O P Q R S T U V W X Y Z A B C D E F G H I
K L M N O P Q R S T U V W X Y Z A B C D E F G H I J
L M N O P Q R S T U V W X Y Z A B C D E F G H I J K
M N O P Q R S T U V W X Y Z A B C D E F G H I J K L
N O P Q R S T U V W X Y Z A B C D E F G H I J K L M
O P Q R S T U V W X Y Z A B C D E F G H I J K L M N
P Q R S T U V W X Y Z A B C D E F G H I J K L M N O
Q R S T U V W X Y Z A B C D E F G H I J K L M N O P
R S T U V W X Y Z A B C D E F G H I J K L M N O P Q
S T U V W X Y Z A B C D E F G H I J K L M N O P Q R
T U V W X Y Z A B C D E F G H I J K L M N O P Q R S
U V W X Y Z A B C D E F G H I J K L M N O P Q R S T
V W X Y Z A B C D E F G H I J K L M N O P Q R S T U
W X Y Z A B C D E F G H I J K L M N O P Q R S T U V
X Y Z A B C D E F G H I J K L M N O P Q R S T U V W
Y Z A B C D E F G H I J K L M N O P Q R S T U V W X
Z A B C D E F G H I J K L M N O P Q R S T U V W X Y
```

Given a keyword, TRAIN, we can encode the message ENCODED IN PYTHON as follows:

1. Repeat the keyword and message together such that it is easy to map letters from one to the other:

   ```
   E N C O D E D I N P Y T H O N   T R A I N T R A I N T R A I N
   ```

2. For each letter in the plain text, find the row that begins with that letter in the table.
3. Find the column with the letter associated with the keyword letter for the chosen plaintext letter.
4. The encoded character is at the intersection of this row and column.

For example, the row starting with E intersects the column starting with T at the character X. So, the first letter in the ciphertext is X. The row starting with N intersects the column starting with R at the character E, leading to the ciphertext XE. C intersects A at C, and O intersects I at W. D and N map to Q while E and T map to X. The full encoded message is XECWQXUIVCRKHWA.

Decoding basically follows the opposite procedure. First, find the row with the character for the shared keyword (the T row), then find the location in that row where the encoded character (the X) is located. The plaintext character is at the top of the column for that row (the E).

Implementing it

Our program will need an `encode` method that takes a keyword and plaintext and returns the ciphertext, and a `decode` method that accepts a keyword and ciphertext and returns the original message.

But rather than just writing those methods, let's follow a test-driven development strategy. We'll be using `py.test` for our unit testing. We need an `encode` method, and we know what it has to do; let's write a test for that method first:

```
def test_encode():
    cipher = VigenereCipher("TRAIN")
    encoded = cipher.encode("ENCODEDINPYTHON")
    assert encoded == "XECWQXUIVCRKHWA"
```

This test fails, naturally, because we aren't importing a `VigenereCipher` class anywhere. Let's create a new module to hold that class.

Let's start with the following `VigenereCipher` class:

```
class VigenereCipher:
    def __init__(self, keyword):
        self.keyword = keyword

    def encode(self, plaintext):
        return "XECWQXUIVCRKHWA"
```

If we add a `from vigenere_cipher import VigenereCipher` line to the top of our test class and run `py.test`, the preceding test will pass! We've finished our first test-driven development cycle.

Obviously, returning a hardcoded string is not the most sensible implementation of a cipher class, so let's add a second test:

```
def test_encode_character():
    cipher = VigenereCipher("TRAIN")
    encoded = cipher.encode("E")
    assert encoded == "X"
```

Ah, now that test will fail. It looks like we're going to have to work harder. But I just thought of something: what if someone tries to encode a string with spaces or lowercase characters? Before we start implementing the encoding, let's add some tests for these cases, so we don't we forget them. The expected behavior will be to remove spaces, and to convert lowercase letters to capitals:

```
def test_encode_spaces():
    cipher = VigenereCipher("TRAIN")
    encoded = cipher.encode("ENCODED IN PYTHON")
    assert encoded == "XECWQXUIVCRKHWA"

def test_encode_lowercase():
    cipher = VigenereCipher("TRain")
    encoded = cipher.encode("encoded in Python")
    assert encoded == "XECWQXUIVCRKHWA"
```

If we run the new test suite, we find that the new tests pass (they expect the same hardcoded string). But they ought to fail later if we forget to account for these cases.

Now that we have some test cases, let's think about how to implement our encoding algorithm. Writing code to use a table like we used in the earlier manual algorithm is possible, but seems complicated, considering that each row is just an alphabet rotated by an offset number of characters. It turns out (I asked Wikipedia) that we can use modulo arithmetic to combine the characters instead of doing a table lookup. Given plaintext and keyword characters, if we convert the two letters to their numerical values (with A being 0 and Z being 25), add them together, and take the remainder mod 26, we get the ciphertext character! This is a straightforward calculation, but since it happens on a character-by-character basis, we should probably put it in its own function. And before we do that, we should write a test for the new function:

```
from vigenere_cipher import combine_character
def test_combine_character():
    assert combine_character("E", "T") == "X"
    assert combine_character("N", "R") == "E"
```

Now we can write the code to make this function work. In all honesty, I had to run the test several times before I got this function completely correct; first I returned an integer, and then I forgot to shift the character back up to the normal ASCII scale from the zero-based scale. Having the test available made it easy to test and debug these errors. This is another bonus of test-driven development.

```
def combine_character(plain, keyword):
    plain = plain.upper()
    keyword = keyword.upper()
    plain_num = ord(plain) - ord('A')
    keyword_num = ord(keyword) - ord('A')
    return chr(ord('A') + (plain_num + keyword_num) % 26)
```

Now that `combine_characters` is tested, I thought we'd be ready to implement our `encode` function. However, the first thing we want inside that function is a repeating version of the keyword string that is as long as the plaintext. Let's implement a function for that first. Oops, I mean let's implement the test first!

```
def test_extend_keyword():
    cipher = VigenereCipher("TRAIN")
    extended = cipher.extend_keyword(16)
    assert extended == "TRAINTRAINTRAINT"
```

Before writing this test, I expected to write `extend_keyword` as a standalone function that accepted a keyword and an integer. But as I started drafting the test, I realized it made more sense to use it as a helper method on the `VigenereCipher` class. This shows how test-driven development can help design more sensible APIs. Here's the method implementation:

```
def extend_keyword(self, number):
    repeats = number // len(self.keyword) + 1
    return (self.keyword * repeats)[:number]
```

Once again, this took a few runs of the test to get right. I ended up adding a second versions of the test, one with fifteen and one with sixteen letters, to make sure it works if the integer division has an even number.

Now we're finally ready to write our `encode` method:

```
def encode(self, plaintext):
    cipher = []
    keyword = self.extend_keyword(len(plaintext))
    for p,k in zip(plaintext, keyword):
        cipher.append(combine_character(p,k))
    return "".join(cipher)
```

That looks correct. Our test suite should pass now, right?

Actually, if we run it, we'll find that two tests are still failing. We totally forgot about the spaces and lowercase characters! It is a good thing we wrote those tests to remind us. We'll have to add this line at the beginning of the method:

```
plaintext = plaintext.replace(" ", "").upper()
```

If we have an idea about a corner case in the middle of implementing something, we can create a test describing that idea. We don't even have to implement the test; we can just run `assert False` to remind us to implement it later. The failing test will never let us forget the corner case and it can't be ignored like filing a task can. If it takes a while to get around to fixing the implementation, we can mark the test as an expected failure.

Now all the tests pass successfully. This chapter is pretty long, so we'll condense the examples for decoding. Here are a couple tests:

```
def test_separate_character():
    assert separate_character("X", "T") == "E"
```

```
        assert separate_character("E", "R") == "N"

    def test_decode():
        cipher = VigenereCipher("TRAIN")
        decoded = cipher.decode("XECWQXUIVCRKHWA")
        assert decoded == "ENCODEDINPYTHON"
```

Here's the `separate_character` function:

```
    def separate_character(cypher, keyword):
        cypher = cypher.upper()
        keyword = keyword.upper()
        cypher_num = ord(cypher) - ord('A')
        keyword_num = ord(keyword) - ord('A')
        return chr(ord('A') + (cypher_num - keyword_num) % 26)
```

And the `decode` method:

```
        def decode(self, ciphertext):
            plain = []
            keyword = self.extend_keyword(len(ciphertext))
            for p,k in zip(ciphertext, keyword):
                plain.append(separate_character(p,k))
            return "".join(plain)
```

These methods have a lot of similarity to those used for encoding. The great thing about having all these tests written and passing is that we can now go back and modify our code, knowing it is still safely passing the tests. For example, if we replace our existing `encode` and `decode` methods with these refactored methods, our tests still pass:

```
        def _code(self, text, combine_func):
            text = text.replace(" ", "").upper()
            combined = []
            keyword = self.extend_keyword(len(text))
            for p,k in zip(text, keyword):
                combined.append(combine_func(p,k))
            return "".join(combined)

        def encode(self, plaintext):
            return self._code(plaintext, combine_character)

        def decode(self, ciphertext):
            return self._code(ciphertext, separate_character)
```

This is the final benefit of test-driven development, and the most important. Once the tests are written, we can improve our code as much as we like and be confident that our changes didn't break anything we have been testing for. Furthermore, we know exactly when our refactor is finished: when the tests all pass.

Of course, our tests may not comprehensively test everything we need them to; maintenance or code refactoring can still cause undiagnosed bugs that don't show up in testing. Automated tests are not foolproof. If bugs do occur, however, it is still possible to follow a test-driven plan; step one is to write a test (or multiple tests) that duplicates or "proves" that the bug in question is occurring. This will, of course, fail. Then write the code to make the tests stop failing. If the tests were comprehensive, the bug will be fixed, and we will know if it ever happens again, as soon as we run the test suite.

Finally, we can try to determine how well our tests operate on this code. With the `py.test` coverage plugin installed, `py.test --coverage-report=report` tells us that our test suite has 100 percent code coverage. This is a great statistic, but we shouldn't get too cocky about it. Our code hasn't been tested when encoding messages that have numbers, and its behavior with such inputs is thus undefined.

Exercises

Practice test-driven development. That is your first exercise. It's easier to do this if you're starting a new project, but if you have existing code you need to work on, you can start by writing tests for each new feature you implement. This can become frustrating as you become more enamored with automated tests. The old, untested code will start to feel rigid and tightly coupled, and will become uncomfortable to maintain; you'll start feeling like changes you make are breaking the code and you have no way of knowing, for lack of tests. But if you start small, adding tests will improve, the codebase improves over time.

So to get your feet wet with test-driven development, start a fresh project. Once you've started to appreciate the benefits (you will) and realize that the time spent writing tests is quickly regained in terms of more maintainable code, you'll want to start writing tests for existing code. This is when you should start doing it, not before. Writing tests for code that we "know" works is boring. It is hard to get interested in the project until you realize just how broken the code we thought was working really is.

Try writing the same set of tests using both the built-in `unittest` module and `py.test`. Which do you prefer? `unittest` is more similar to test frameworks in other languages, while `py.test` is arguably more Pythonic. Both allow us to write object-oriented tests and to test object-oriented programs with ease.

We used `py.test` in our case study, but we didn't touch on any features that wouldn't have been easily testable using `unittest`. Try adapting the tests to use test skipping or funcargs. Try the various setup and teardown methods, and compare their use to funcargs. Which feels more natural to you?

In our case study, we have a lot of tests that use a similar `VigenereCipher` object; try reworking this code to use a funcarg. How many lines of code does it save?

Try running a coverage report on the tests you've written. Did you miss testing any lines of code? Even if you have 100 percent coverage, have you tested all the possible inputs? If you're doing test-driven development, 100 percent coverage should follow quite naturally, as you will write a test before the code that satisfies that test. However, if writing tests for existing code, it is more likely that there will be edge conditions that go untested.

Think carefully about the values that are somehow different: empty lists when you expect full ones, zero or one or infinity compared to intermediate integers, floats that don't round to an exact decimal place, strings when you expected numerals, or the ubiquitous `None` value when you expected something meaningful. If your tests cover such edge cases, your code will be in good shape.

Summary

We have finally covered the most important topic in Python programming: automated testing. Test-driven development is considered a best practice. The standard library `unittest` module provides a great out-of-the-box solution for testing, while the `py.test` framework has some more Pythonic syntaxes. Mocks can be used to emulate complex classes in our tests. Code coverage gives us an estimate of how much of our code is being run by our tests, but it does not tell us that we have tested the right things.

In the next chapter, we'll jump into a completely different topic: concurrency.

13
Concurrency

Concurrency is the art of making a computer do (or appear to do) multiple things at once. Historically, this meant inviting the processor to switch between different tasks many times per second. In modern systems, it can also literally mean doing two or more things simultaneously on separate processor cores.

Concurrency is not inherently an object-oriented topic, but Python's concurrent systems are built on top of the object-oriented constructs we've covered throughout the book. This chapter will introduce you to the following topics:

- Threads
- Multiprocessing
- Futures
- AsyncIO

Concurrency is complicated. The basic concepts are fairly simple, but the bugs that can occur are notoriously difficult to track down. However, for many projects, concurrency is the only way to get the performance we need. Imagine if a web server couldn't respond to a user's request until the previous one was completed! We won't be going into all the details of just how hard it is (another full book would be required) but we'll see how to do basic concurrency in Python, and some of the most common pitfalls to avoid.

Threads

Most often, concurrency is created so that work can continue happening while the program is waiting for I/O to happen. For example, a server can start processing a new network request while it waits for data from a previous request to arrive. An interactive program might render an animation or perform a calculation while waiting for the user to press a key. Bear in mind that while a person can type more than 500 characters per minute, a computer can perform billions of instructions per second. Thus, a ton of processing can happen between individual key presses, even when typing quickly.

It's theoretically possible to manage all this switching between activities within your program, but it would be virtually impossible to get right. Instead, we can rely on Python and the operating system to take care of the tricky switching part, while we create objects that appear to be running independently, but simultaneously. These objects are called **threads**; in Python they have a very simple API. Let's take a look at a basic example:

```
from threading import Thread

class InputReader(Thread):
    def run(self):
        self.line_of_text = input()

print("Enter some text and press enter: ")
thread = InputReader()
thread.start()

count = result = 1
while thread.is_alive():
    result = count * count
    count += 1

print("calculated squares up to {0} * {0} = {1}".format(
    count, result))
print("while you typed '{}'".format(thread.line_of_text))
```

This example runs two threads. Can you see them? Every program has one thread, called the main thread. The code that executes from the beginning is happening in this thread. The second thread, more obviously, exists as the `InputReader` class.

To construct a thread, we must extend the `Thread` class and implement the `run` method. Any code inside the `run` method (or that is called from within that method) is executed in a separate thread.

The new thread doesn't start running until we call the `start()` method on the object. In this case, the thread immediately pauses to wait for input from the keyboard. In the meantime, the original thread continues executing at the point `start` was called. It starts calculating squares inside a `while` loop. The condition in the `while` loop checks if the `InputReader` thread has exited its `run` method yet; once it does, it outputs some summary information to the screen.

If we run the example and type the string "hello world", the output looks as follows:

```
Enter some text and press enter:
hello world
calculated squares up to 1044477 * 1044477 = 1090930114576
while you typed 'hello world'
```

You will, of course, calculate more or less squares while typing the string as the numbers are related to both our relative typing speeds, and to the processor speeds of the computers we are running.

A thread only starts running in concurrent mode when we call the `start` method. If we want to take out the concurrent call to see how it compares, we can call `thread.run()` in the place that we originally called `thread.start()`. The output is telling:

```
Enter some text and press enter:
hello world
calculated squares up to 1 * 1 = 1
while you typed 'hello world'
```

In this case, the thread never becomes alive and the `while` loop never executes. We wasted a lot of CPU power sitting idle while we were typing.

There are a lot of different patterns for using threads effectively. We won't be covering all of them, but we will look at a common one so we can learn about the `join` method. Let's check the current temperature in the capital city of every province in Canada:

```
from threading import Thread
import json
from urllib.request import urlopen
import time

CITIES = [
    'Edmonton', 'Victoria', 'Winnipeg', 'Fredericton',
    "St. John's", 'Halifax', 'Toronto', 'Charlottetown',
```

```
        'Quebec City', 'Regina'
    ]

    class TempGetter(Thread):
        def __init__(self, city):
            super().__init__()
            self.city = city

        def run(self):
            url_template = (
                'http://api.openweathermap.org/data/2.5/'
                'weather?q={},CA&units=metric')
            response = urlopen(url_template.format(self.city))
            data = json.loads(response.read().decode())
            self.temperature = data['main']['temp']

    threads = [TempGetter(c) for c in CITIES]
    start = time.time()
    for thread in threads:
        thread.start()

    for thread in threads:
        thread.join()

    for thread in threads:
        print(
            "it is {0.temperature:.0f}°C in {0.city}".format(thread))
    print(
        "Got {} temps in {} seconds".format(
        len(threads), time.time() - start))
```

This code constructs 10 threads before starting them. Notice how we can override the constructor to pass them into the `Thread` object, remembering to call `super` to ensure the `Thread` is properly initialized. Pay attention to this: the new thread isn't running yet, so the `__init__` method is still executing from inside the main thread. Data we construct in one thread is accessible from other running threads.

After the 10 threads have been started, we loop over them again, calling the `join()` method on each. This method essentially says "wait for the thread to complete before doing anything". We call this ten times in sequence; the for loop won't exit until all ten threads have completed.

At this point, we can print the temperature that was stored on each thread object. Notice once again that we can access data that was constructed within the thread from the main thread. In threads, all state is shared by default.

Executing this code on my 100 mbit connection takes about two tenths of a second:

```
it is 5°C in Edmonton
it is 11°C in Victoria
it is 0°C in Winnipeg
it is -10°C in Fredericton
it is -12°C in St. John's
it is -8°C in Halifax
it is -6°C in Toronto
it is -13°C in Charlottetown
it is -12°C in Quebec City
it is 2°C in Regina
    Got 10 temps in 0.18970298767089844 seconds
```

If we run this code in a single thread (by changing the `start()` call to `run()` and commenting out the `join()` call), it takes closer to 2 seconds because each 0.2 second request has to complete before the next one begins. This speedup of 10 times shows just how useful concurrent programming can be.

The many problems with threads

Threads can be useful, especially in other programming languages, but modern Python programmers tend to avoid them for several reasons. As we'll see, there are other ways to do concurrent programming that are receiving more attention from the Python developers. Let's discuss some of these pitfalls before moving on to more salient topics.

Shared memory

The main problem with threads is also their primary advantage. Threads have access to all the memory and thus all the variables in the program. This can too easily cause inconsistencies in the program state. Have you ever encountered a room where a single light has two switches and two different people turn them on at the same time? Each person (thread) expects their action to turn the lamp (a variable) on, but the resulting value (the lamp is off) is inconsistent with those expectations. Now imagine if those two threads were transferring funds between bank accounts or managing the cruise control in a vehicle.

The solution to this problem in threaded programming is to "synchronize" access to any code that reads or writes a shared variable. There are a few different ways to do this, but we won't go into them here so we can focus on more Pythonic constructs. The synchronization solution works, but it is way too easy to forget to apply it. Worse, bugs due to inappropriate use of synchronization are really hard to track down because the order in which threads perform operations is inconsistent. We can't easily reproduce the error. Usually, it is safest to force communication between threads to happen using a lightweight data structure that already uses locks appropriately. Python offers the `queue.Queue` class to do this; it's functionality is basically the same as the `multiprocessing.Queue` that we will discuss in the next section.

In some cases, these disadvantages might be outweighed by the one advantage of allowing shared memory: it's fast. If multiple threads need access to a huge data structure, shared memory can provide that access quickly. However, this advantage is usually nullified by the fact that, in Python, it is impossible for two threads running on different CPU cores to be performing calculations at exactly the same time. This brings us to our second problem with threads.

The global interpreter lock

In order to efficiently manage memory, garbage collection, and calls to machine code in libraries, Python has a utility called the **global interpreter lock**, or **GIL**. It's impossible to turn off, and it means that threads are useless in Python for one thing that they excel at in other languages: parallel processing. The GIL's primary effect, for our purposes is to prevent any two threads from doing work at the exact same time, even if they have work to do. In this case, "doing work" means using the CPU, so it's perfectly ok for multiple threads to access the disk or network; the GIL is released as soon as the thread starts to wait for something.

The GIL is quite highly disparaged, mostly by people who don't understand what it is or all the benefits it brings to Python. It would definitely be nice if our language didn't have this restriction, but the Python reference developers have determined that, for now at least, it brings more value than it costs. It makes the reference implementation easier to maintain and develop, and during the single-core processor days when Python was originally developed, it actually made the interpreter faster. The net result of the GIL, however, is that it limits the benefits that threads bring us, without alleviating the costs.

While the GIL is a problem in the reference implementation of Python that most people use, it has been solved in some of the nonstandard implementations such as IronPython and Jython. Unfortunately, at the time of publication, none of these support Python 3.

Thread overhead

One final limitation of threads as compared to the asynchronous system we will be discussing later is the cost of maintaining the thread. Each thread takes up a certain amount of memory (both in the Python process and the operating system kernel) to record the state of that thread. Switching between the threads also uses a (small) amount of CPU time. This work happens seamlessly without any extra coding (we just have to call `start()` and the rest is taken care of), but the work still has to happen somewhere.

This can be alleviated somewhat by structuring our workload so that threads can be reused to perform multiple jobs. Python provides a `ThreadPool` feature to handle this. It is shipped as part of the multiprocessing library and behaves identically to the `ProcessPool`, that we will discuss shortly, so let's defer discussion until the next section.

Multiprocessing

The multiprocessing API was originally designed to mimic the thread API. However, it has evolved and in recent versions of Python 3, it supports more features more robustly. The multiprocessing library is designed when CPU-intensive jobs need to happen in parallel and multiple cores are available (given that a four core Raspberry Pi can currently be purchased for $35, there are usually multiple cores available). Multiprocessing is not useful when the processes spend a majority of their time waiting on I/O (for example, network, disk, database, or keyboard), but they are the way to go for parallel computation.

The multiprocessing module spins up new operating system processes to do the work. On Windows machines, this is a relatively expensive operation; on Linux, processes are implemented in the kernel the same way threads are, so the overhead is limited to the cost of running separate Python interpreters in each process.

Let's try to parallelize a compute-heavy operation using similar constructs to those provided by the `threading` API:

```
from multiprocessing import Process, cpu_count
import time
import os

class MuchCPU(Process):
    def run(self):
        print(os.getpid())
        for i in range(200000000):
            pass

if __name__ == '__main__':
    procs =  [MuchCPU() for f in range(cpu_count())]
    t = time.time()
    for p in procs:
        p.start()
    for p in procs:
        p.join()
    print('work took {} seconds'.format(time.time() - t))
```

This example just ties up the CPU for 200 million iterations. You may not consider this to be useful work, but it's a cold day and I appreciate the heat my laptop generates under such load.

The API should be familiar; we implement a subclass of `Process` (instead of `Thread`) and implement a `run` method. This method prints out the process ID (a unique number the operating system assigns to each process on the machine) before doing some intense (if misguided) work.

Pay special attention to the `if __name__ == '__main__':` guard around the module level code that prevents it to run if the module is being imported, rather than run as a program. This is good practice in general, but when using multiprocessing on some operating systems, it is essential. Behind the scenes, multiprocessing may have to import the module inside the new process in order to execute the `run()` method. If we allowed the entire module to execute at that point, it would start creating new processes recursively until the operating system ran out of resources.

We construct one process for each processor core on our machine, then start and join each of those processes. On my 2014 era quad-core laptop, the output looks like this:

```
6987
6988
```

```
6989
6990
work took 12.96659541130066 seconds
```

The first four lines are the process ID that was printed inside each `MuchCPU` instance. The last line shows that the 200 million iterations can run in about 13 seconds on my machine. During that 13 seconds, my process monitor indicated that all four of my cores were running at 100 percent.

If we subclass `threading.Thread` instead of `multiprocessing.Process` in `MuchCPU`, the output looks like this:

```
7235
7235
7235
7235
work took 28.577413082122803 seconds
```

This time, the four threads are running inside the same process and take close to three times as long to run. This is the cost of the global interpreter lock; in other languages or implementations of Python, the threaded version would run at least as fast as the multiprocessing version, We might expect it to be four times as long, but remember that many other programs are running on my laptop. In the multiprocessing version, these programs also need a share of the four CPUs. In the threading version, those programs can use the other three CPUs instead.

Multiprocessing pools

In general, there is no reason to have more processes than there are processors on the computer. There are a few reasons for this:

- Only `cpu_count()` processes can run simultaneously
- Each process consumes resources with a full copy of the Python interpreter
- Communication between processes is expensive
- Creating processes takes a nonzero amount of time

Given these constraints, it makes sense to create at most `cpu_count()` processes when the program starts and then have them execute tasks as needed. It is not difficult to implement a basic series of communicating processes that does this, but it can be tricky to debug, test, and get right. Of course, Python being Python, we don't have to do all this work because the Python developers have already done it for us in the form of multiprocessing pools.

The primary advantage of pools is that they abstract away the overhead of figuring out what code is executing in the main process and which code is running in the subprocess. As with the threading API that multiprocessing mimics, it can often be hard to remember who is executing what. The pool abstraction restricts the number of places that code in different processes interact with each other, making it much easier to keep track of.

- Pools also seamlessly hide the process of passing data between processes. Using a pool looks much like a function call; you pass data into a function, it is executed in another process or processes, and when the work is done, a value is returned. It is important to understand that under the hood, a lot of work is being done to support this: objects in one process are being pickled and passed into a pipe.
- Another process retrieves data from the pipe and unpickles it. Work is done in the subprocess and a result is produced. The result is pickled and passed into a pipe. Eventually, the original process unpickles it and returns it.

All this pickling and passing data into pipes takes time and memory. Therefore, it is ideal to keep the amount and size of data passed into and returned from the pool to a minimum, and it is only advantageous to use the pool if a lot of processing has to be done on the data in question.

Armed with this knowledge, the code to make all this machinery work is surprisingly simple. Let's look at the problem of calculating all the prime factors of a list of random numbers. This is a common and expensive part of a variety of cryptography algorithms (not to mention attacks on those algorithms!). It requires years of processing power to crack the extremely large numbers used to secure your bank accounts. The following implementation, while readable, is not at all efficient, but that's ok because we want to see it using lots of CPU time:

```
import random
from multiprocessing.pool import Pool

def prime_factor(value):
    factors = []
    for divisor in range(2, value-1):
        quotient, remainder = divmod(value, divisor)
        if not remainder:
            factors.extend(prime_factor(divisor))
            factors.extend(prime_factor(quotient))
            break
```

```
        else:
            factors = [value]
        return factors

    if __name__ == '__main__':
        pool = Pool()

        to_factor = [
            random.randint(100000, 50000000) for i in range(20)
        ]
        results = pool.map(prime_factor, to_factor)
        for value, factors in zip(to_factor, results):
            print("The factors of {} are {}".format(value, factors))
```

Let's focus on the parallel processing aspects as the brute force recursive algorithm for calculating factors is pretty clear. We first construct a multiprocessing pool instance. By default, this pool creates a separate process for each of the CPU cores in the machine it is running on.

The `map` method accepts a function and an iterable. The pool pickles each of the values in the iterable and passes it into an available process, which executes the function on it. When that process is finished doing it's work, it pickles the resulting list of factors and passes it back to the pool. Once all the pools are finished processing work (which could take some time), the results list is passed back to the original process, which has been waiting patiently for all this work to complete.

It is often more useful to use the similar `map_async` method, which returns immediately even though the processes are still working. In that case, the results variable would not be a list of values, but a promise to return a list of values later by calling `results.get()`. This promise object also has methods like `ready()`, and `wait()`, which allow us to check whether all the results are in yet.

Alternatively, if we don't know all the values we want to get results for in advance, we can use the `apply_async` method to queue up a single job. If the pool has a process that isn't already working, it will start immediately; otherwise, it will hold onto the task until there is a free process available.

Pools can also be `close`d, which refuses to take any further tasks, but processes everything currently in the queue, or `terminate`d, which goes one step further and refuses to start any jobs still on the queue, although any jobs currently running are still permitted to complete.

Queues

If we need more control over communication between processes, we can use a `Queue`. `Queue` data structures are useful for sending messages from one process into one or more other processes. Any picklable object can be sent into a `Queue`, but remember that pickling can be a costly operation, so keep such objects small. To illustrate queues, let's build a little search engine for text content that stores all relevant entries in memory.

This is not the most sensible way to build a text-based search engine, but I have used this pattern to query numerical data that needed to use CPU-intensive processes to construct a chart that was then rendered to the user.

This particular search engine scans all files in the current directory in parallel. A process is constructed for each core on the CPU. Each of these is instructed to load some of the files into memory. Let's look at the function that does the loading and searching:

```
def search(paths, query_q, results_q):
    lines = []
    for path in paths:
        lines.extend(l.strip() for l in path.open())

    query = query_q.get()
    while query:
        results_q.put([l for l in lines if query in l])
        query = query_q.get()
```

Remember, this function is run in a different process (in fact, it is run in `cpucount()` different processes) from the main thread. It is passes a list of `path.path` objects and two `multiprocessing.Queue` objects; one for incoming queries and one to send outgoing results. These queues have a similar interface to the `Queue` class we discussed in *Chapter 6*, *Python Data Structures*. However, they are doing extra work to pickle the data in the queue and pass it into the subprocess over a pipe. These two queues are set up in the main process and passed through the pipes into the search function inside the child processes.

The search code is pretty dumb, both in terms of efficiency and of capabilities; it loops over every line stored in memory and puts the matching ones in a list. The list is placed on a queue and passed back to the main process.

Let's look at the main process, which sets up these queues:

```
if __name__ == '__main__':
    from multiprocessing import Process, Queue, cpu_count
    from path import path
    cpus = cpu_count()
```

```
pathnames = [f for f in path('.').listdir() if f.isfile()]
paths = [pathnames[i::cpus] for i in range(cpus)]
query_queues = [Queue() for p in range(cpus)]
results_queue = Queue()

search_procs = [
    Process(target=search, args=(p, q, results_queue))
    for p, q in zip(paths, query_queues)
]
for proc in search_procs: proc.start()
```

For easier description, let's assume `cpu_count` is four. Notice how the import statements are placed inside the `if` guard? This is a small optimization that prevents them from being imported in each subprocess (where they aren't needed) on certain operating systems. We list all the paths in the current directory and then split the list into four approximately equal parts. We also construct a list of four `Queue` objects to send data into each subprocess. Finally, we construct a `single` results queue; this is passed into all four of the subprocesses. Each of them can put data into the queue and it will be aggregated in the main process.

Now let's look at the code that makes a search actually happen:

```
for q in query_queues:
    q.put("def")
    q.put(None)  # Signal process termination

for i in range(cpus):
    for match in results_queue.get():
        print(match)
for proc in search_procs: proc.join()
```

This code performs a single search for `"def"` (because it's a common phrase in a directory full of Python files!). In a more production ready system, we would probably hook a socket up to this search code. In that case, we'd have to change the inter-process protocol so that the message coming back on the return queue contained enough information to identify which of many queries the results were attached to.

This use of queues is actually a local version of what could become a distributed system. Imagine if the searches were being sent out to multiple computers and then recombined. We won't discuss it here, but the multiprocessing module includes a manager class that can take a lot of the boilerplate out of the preceding code. There is even a version of the `multiprocessing.Manager` that can manage subprocesses on remote systems to construct a rudimentary distributed application. Check the Python multiprocessing documentation if you are interested in pursuing this further.

The problems with multiprocessing

As threads do, multiprocessing also has problems, some of which we have already discussed. There is no best way to do concurrency; this is especially true in Python. We always need to examine the parallel problem to figure out which of the many available solutions is the best one for that problem. Sometimes, there is no best solution.

In the case of multiprocessing, the primary drawback is that sharing data between processes is very costly. As we have discussed, all communication between processes, whether by queues, pipes, or a more implicit mechanism requires pickling the objects. Excessive pickling quickly dominates processing time. Multiprocessing works best when relatively small objects are passed between processes and a tremendous amount of work needs to be done on each one. On the other hand, if no communication between processes is required, there may not be any point in using the module at all; we can spin up four separate Python processes and use them independently.

The other major problem with multiprocessing is that, like threads, it can be hard to tell which process a variable or method is being accessed in. In multiprocessing, if you access a variable from another process it will usually overwrite the variable in the currently running process while the other process keeps the old value. This is really confusing to maintain, so don't do it.

Futures

Let's start looking at a more asynchronous way of doing concurrency. Futures wrap either multiprocessing or threading depending on what kind of concurrency we need (tending towards I/O versus tending towards CPU). They don't completely solve the problem of accidentally altering shared state, but they allow us to structure our code such that it is easier to track down when we do so. Futures provide distinct boundaries between the different threads or processes. Similar to the multiprocessing pool, they are useful for "call and answer" type interactions in which processing can happen in another thread and then at some point in the future (they are aptly named, after all), you can ask it for the result. It's really just a wrapper around multiprocessing pools and thread pools, but it provides a cleaner API and encourages nicer code.

A future is an object that basically wraps a function call. That function call is run in the background in a thread or process. The future object has methods to check if the future has completed and to get the results after it has completed.

Let's do another file search example. In the last section, we implemented a version of the `unix grep` command. This time, let's do a simple version of the `find` command. The example will search the entire filesystem for paths that contain a given string of characters:

```
from concurrent.futures import ThreadPoolExecutor
from pathlib import Path
from os.path import sep as pathsep
from collections import deque

def find_files(path, query_string):
    subdirs = []
    for p in path.iterdir():
        full_path = str(p.absolute())
        if p.is_dir() and not p.is_symlink():
            subdirs.append(p)
        if query_string in full_path:
                print(full_path)

    return subdirs

query = '.py'
futures = deque()
basedir = Path(pathsep).absolute()

with ThreadPoolExecutor(max_workers=10) as executor:
    futures.append(
        executor.submit(find_files, basedir, query))
    while futures:
        future = futures.popleft()
        if future.exception():
            continue
        elif future.done():
            subdirs = future.result()
            for subdir in subdirs:
                futures.append(executor.submit(
                    find_files, subdir, query))
        else:
            futures.append(future)
```

This code consists of a function named `find_files` that is run in a separate thread (or process, if we used `ProcessPoolExecutor`). There isn't anything particularly special about this function, but note how it does not access any global variables. All interaction with the external environment is passed into the function or returned from it. This is not a technical requirement, but it is the best way to keep your brain inside your skull when programming with futures.

Accessing outside variables without proper synchronization results in something called a **race** condition. For example, imagine two concurrent writes trying to increment an integer counter. They start at the same time and both read the value as 5. Then they both increment the value and write back the result as 6. But if two processes are trying to increment a variable, the expected result would be that it gets incremented by two, so the result should be 7. Modern wisdom is that the easiest way to avoid doing this is to keep as much state as possible private and share them through known-safe constructs, such as queues.

We set up a couple variables before we get started; we'll be searching for all files that contain the characters `'.py'` for this example. We have a queue of futures that we'll discuss shortly. The `basedir` variable points to the root of the filesystem; `'/'` on Unix machines and probably `C:\` on Windows.

First, let's have a short course on search theory. This algorithm implements breadth first search in parallel. Rather than recursively searching every directory using a depth first search, it adds all the subdirectories in the current folder to the queue, then all the subdirectories of each of those folders and so on.

The meat of the program is known as an event loop. We can construct a `ThreadPoolExecutor` as a context manager so that it is automatically cleaned up and its threads closed when it is done. It requires a `max_workers` argument to indicate the number of threads running at a time; if more than this many jobs are submitted, it queues up the rest until a worker thread becomes available. When using `ProcessPoolExecutor`, this is normally constrained to the number of CPUs on the machine, but with threads, it can be much higher, depending how many are waiting on I/O at a time. Each thread takes up a certain amount of memory, so it shouldn't be too high; it doesn't take all that many threads before the speed of the disk, rather than number of parallel requests, is the bottleneck.

Once the executor has been constructed, we submit a job to it using the root directory. The `submit()` method immediately returns a `Future` object, which promises to give us a result eventually. The future is placed on the queue. The loop then repeatedly removes the first future from the queue and inspects it. If it is still running, it gets added back to the end of the queue. Otherwise, we check if the function raised an exception with a call to `future.exception()`. If it did, we just ignore it (it's usually a permission error, although a real app would need to be more careful about what the exception was). If we didn't check this exception here, it would be raised when we called `result()` and could be handled through the normal `try...except` mechanism.

Assuming no exception occurred, we can call `result()` to get the return value of the function call. Since the function returns a list of subdirectories that are not symbolic links (my lazy way of preventing an infinite loop), `result()` returns the same thing. These new subdirectories are submitted to the executor and the resulting futures are tossed onto the queue to have their contents searched in a later iteration.

So that's all that is required to develop a future-based I/O-bound application. Under the hood, it's using the same thread or process APIs we've already discussed, but it provides a more understandable interface and makes it easier to see the boundaries between concurrently running functions (just don't try to access global variables from inside the future!).

AsyncIO

AsyncIO is the current state of the art in Python concurrent programming. It combines the concept of futures and an event loop with the coroutines we discussed in *Chapter 9, The Iterator Pattern*. The result is about as elegant and easy to understand as it is possible to get when writing concurrent code, though that isn't saying a lot!

AsyncIO can be used for a few different concurrent tasks, but it was specifically designed for network I/O. Most networking applications, especially on the server side, spend a lot of time waiting for data to come in from the network. This can be solved by handling each client in a separate thread, but threads use up memory and other resources. AsyncIO uses coroutines instead of threads.

The library also provides its own event loop, obviating the need for the several lines long while loop in the previous example. However, event loops come with a cost. When we run code in an async task on the event loop, that code must return immediately, blocking neither on I/O nor on long-running calculations. This is a minor thing when writing our own code, but it means that any standard library or third-party functions that block on I/O have to have non-blocking versions created.

AsyncIO solves this by creating a set of coroutines that use the `yield from` syntax to return control to the event loop immediately. The event loop takes care of checking whether the blocking call has completed and performing any subsequent tasks, just like we did manually in the previous section.

AsyncIO in action

A canonical example of a blocking function is the `time.sleep` call. Let's use the asynchronous version of this call to illustrate the basics of an AsyncIO event loop:

```
import asyncio
import random

@asyncio.coroutine
def random_sleep(counter):
    delay = random.random() * 5
    print("{} sleeps for {:.2f} seconds".format(counter, delay))
    yield from asyncio.sleep(delay)
    print("{} awakens".format(counter))

@asyncio.coroutine
def five_sleepers():
    print("Creating five tasks")
    tasks = [
        asyncio.async(random_sleep(i)) for i in range(5)]
    print("Sleeping after starting five tasks")
    yield from asyncio.sleep(2)
    print("Waking and waiting for five tasks")
    yield from asyncio.wait(tasks)

asyncio.get_event_loop().run_until_complete(five_sleepers())
print("Done five tasks")
```

This is a fairly basic example, but it covers several features of AsyncIO programming. It is easiest to understand in the order that it executes, which is more or less bottom to top.

The second last line gets the event loop and instructs it to run a future until it is finished. The future in question is named `five_sleepers`. Once that future has done its work, the loop will exit and our code will terminate. As asynchronous programmers, we don't need to know too much about what happens inside that `run_until_complete` call, but be aware that a lot is going on. It's a souped up coroutine version of the futures loop we wrote in the previous chapter that knows how to deal with iteration, exceptions, function returns, parallel calls, and more.

Now look a little more closely at that `five_sleepers` future. Ignore the decorator for a few paragraphs; we'll get back to it. The coroutine first constructs five instances of the `random_sleep` future. The resulting futures are wrapped in an `asyncio.async` task, which adds them to the loop's task queue so they can execute concurrently when control is returned to the event loop.

That control is returned whenever we call `yield from`. In this case, we call `yield from asyncio.sleep` to pause execution of this coroutine for two seconds. During this break, the event loop executes the tasks that it has queued up; namely the five `random_sleep` futures. These coroutines each print a starting message, then send control back to the event loop for a specific amount of time. If any of the sleep calls inside `random_sleep` are shorter than two seconds, the event loop passes control back into the relevant future, which prints its awakening message before returning. When the sleep call inside `five_sleepers` wakes up, it executes up to the next yield from call, which waits for the remaining `random_sleep` tasks to complete. When all the sleep calls have finished executing, the `random_sleep` tasks return, which removes them from the event queue. Once all five of those are completed, the `asyncio.wait` call and then the `five_sleepers` method also return. Finally, since the event queue is now empty, the `run_until_complete` call is able to terminate and the program ends.

The `asyncio.coroutine` decorator mostly just documents that this coroutine is meant to be used as a future in an event loop. In this case, the program would run just fine without the decorator. However, the `asyncio.coroutine` decorator can also be used to wrap a normal function (one that doesn't yield) so that it can be treated as a future. In this case, the entire function executes before returning control to the event loop; the decorator just forces the function to fulfill the coroutine API so the event loop knows how to handle it.

Reading an AsyncIO future

An AsyncIO coroutine executes each line in order until it encounters a `yield from` statement, at which point it returns control to the event loop. The event loop then executes any other tasks that are ready to run, including the one that the original coroutine was waiting on. Whenever that child task completes, the event loop sends the result back into the coroutine so that it can pick up executing until it encounters another `yield from` statement or returns.

This allows us to write code that executes synchronously until we explicitly need to wait for something. This removes the nondeterministic behavior of threads, so we don't need to worry nearly so much about shared state.

It's still a good idea to avoid accessing shared state from inside a coroutine. It makes your code much easier to reason about. More importantly, even though an ideal world might have all asynchronous execution happen inside coroutines, the reality is that some futures are executed behind the scenes inside threads or processes. Stick to a "share nothing" philosophy to avoid a ton of difficult bugs.

In addition, AsyncIO allows us to collect logical sections of code together inside a single coroutine, even if we are waiting for other work elsewhere. As a specific instance, even though the `yield from asyncio.sleep` call in the `random_sleep` coroutine is allowing a ton of stuff to happen inside the event loop, the coroutine itself looks like it's doing everything in order. This ability to read related pieces of asynchronous code without worrying about the machinery that waits for tasks to complete is the primary benefit of the AsyncIO module.

AsyncIO for networking

AsyncIO was specifically designed for use with network sockets, so let's implement a DNS server. More accurately, let's implement one extremely basic feature of a DNS server.

The domain name system's basic purpose is to translate domain names, such as www.amazon.com into IP addresses such as 72.21.206.6. It has to be able to perform many types of queries and know how to contact other DNS servers if it doesn't have the answer required. We won't be implementing any of this, but the following example is able to respond directly to a standard DNS query to look up IPs for my three most recent employers:

```
import asyncio
from contextlib import suppress

ip_map = {
    b'facebook.com.': '173.252.120.6',
    b'yougov.com.': '213.52.133.246',
    b'wipo.int.': '193.5.93.80'
}

def lookup_dns(data):
    domain = b''
    pointer, part_length = 13, data[12]
    while part_length:
```

```
            domain += data[pointer:pointer+part_length] + b'.'
            pointer += part_length + 1
            part_length = data[pointer - 1]

        ip = ip_map.get(domain, '127.0.0.1')

        return domain, ip

    def create_response(data, ip):
        ba = bytearray
        packet = ba(data[:2]) + ba([129, 128]) + data[4:6] * 2
        packet += ba(4) + data[12:]
        packet += ba([192, 12, 0, 1, 0, 1, 0, 0, 0, 60, 0, 4])
        for x in ip.split('.'): packet.append(int(x))
        return packet

    class DNSProtocol(asyncio.DatagramProtocol):
        def connection_made(self, transport):
            self.transport = transport

        def datagram_received(self, data, addr):
            print("Received request from {}".format(addr[0]))
            domain, ip = lookup_dns(data)
            print("Sending IP {} for {} to {}".format(
                domain.decode(), ip, addr[0]))
            self.transport.sendto(
                create_response(data, ip), addr)

    loop = asyncio.get_event_loop()
    transport, protocol = loop.run_until_complete(
        loop.create_datagram_endpoint(
            DNSProtocol, local_addr=('127.0.0.1', 4343)))
    print("DNS Server running")

    with suppress(KeyboardInterrupt):
        loop.run_forever()
    transport.close()
    loop.close()
```

This example sets up a dictionary that dumbly maps a few domains to IPv4 addresses. It is followed by two functions that extract information from a binary DNS query packet and construct the response. We won't be discussing these; if you want to know more about DNS read RFC ("request for comment", the format for defining most Internet protocols) 1034 and 1035.

You can test this service by running the following command in another terminal:

```
nslookup -port=4343 facebook.com localhost
```

Let's get on with the entrée. AsyncIO networking revolves around the intimately linked concepts of transports and protocols. A protocol is a class that has specific methods that are called when relevant events happen. Since DNS runs on top of **UDP** (**User Datagram Protocol**); we build our protocol class as a subclass of `DatagramProtocol`. This class has a variety of events that it can respond to; we are specifically interested in the initial connection occurring (solely so we can store the transport for future use) and the `datagram_received` event. For DNS, each received datagram must be parsed and responded to, at which point the interaction is over.

So, when a datagram is received, we process the packet, look up the IP, and construct a response using the functions we aren't talking about (they're black sheep in the family). Then we instruct the underlying transport to send the resulting packet back to the requesting client using its `sendto` method.

The transport essentially represents a communication stream. In this case, it abstracts away all the fuss of sending and receiving data on a UDP socket on an event loop. There are similar transports for interacting with TCP sockets and subprocesses, for example.

The UDP transport is constructed by calling the loop's `create_datagram_endpoint` coroutine. This constructs the appropriate UDP socket and starts listening on it. We pass it the address that the socket needs to listen on, and importantly, the protocol class we created so that the transport knows what to call when it receives data.

Since the process of initializing a socket takes a non-trivial amount of time and would block the event loop, the `create_datagram_endpoint` function is a coroutine. In our example, we don't really need to do anything while we wait for this initialization, so we wrap the call in `loop.run_until_complete`. The event loop takes care of managing the future, and when it's complete, it returns a tuple of two values: the newly initialized transport and the protocol object that was constructed from the class we passed in.

Behind the scenes, the transport has set up a task on the event loop that is listening for incoming UDP connections. All we have to do, then, is start the event loop running with the call to `loop.run_forever()` so that task can process these packets. When the packets arrive, they are processed on the protocol and everything just works.

The only other major thing to pay attention to is that transports (and, indeed, event loops) are supposed to be closed when we are finished with them. In this case, the code runs just fine without the two calls to `close()`, but if we were constructing transports on the fly (or just doing proper error handling!), we'd need to be quite a bit more conscious of it.

You may have been dismayed to see how much boilerplate is required in setting up a protocol class and underlying transport. AsyncIO provides an abstraction on top of these two key concepts called streams. We'll see an example of streams in the TCP server in the next example.

Using executors to wrap blocking code

AsyncIO provides its own version of the futures library to allow us to run code in a separate thread or process when there isn't an appropriate non-blocking call to be made. This essentially allows us to combine threads and processes with the asynchronous model. One of the more useful applications of this feature is to get the best of both worlds when an application has bursts of I/O-bound and CPU-bound activity. The I/O-bound portions can happen in the event-loop while the CPU-intensive work can be spun off to a different process. To illustrate this, let's implement "sorting as a service" using AsyncIO:

```
import asyncio
import json
from concurrent.futures import ProcessPoolExecutor

def sort_in_process(data):
    nums = json.loads(data.decode())
    curr = 1
    while curr < len(nums):
        if nums[curr] >= nums[curr-1]:
            curr += 1
        else:
            nums[curr], nums[curr-1] = \
                nums[curr-1], nums[curr]
            if curr > 1:
```

```
                curr -= 1

    return json.dumps(nums).encode()

@asyncio.coroutine
def sort_request(reader, writer):
    print("Received connection")
    length = yield from reader.read(8)
    data = yield from reader.readexactly(
        int.from_bytes(length, 'big'))
    result = yield from asyncio.get_event_loop().run_in_executor(
        None, sort_in_process, data)
    print("Sorted list")
    writer.write(result)
    writer.close()
    print("Connection closed")

loop = asyncio.get_event_loop()
loop.set_default_executor(ProcessPoolExecutor())
server = loop.run_until_complete(
    asyncio.start_server(sort_request, '127.0.0.1', 2015))
print("Sort Service running")

loop.run_forever()
server.close()
loop.run_until_complete(server.wait_closed())
loop.close()
```

This is an example of good code implementing some really stupid ideas. The whole idea of sort as a service is pretty ridiculous. Using our own sorting algorithm instead of calling Python's `sorted` is even worse. The algorithm we used is called gnome sort, or in some cases, "stupid sort". It is a slow sort algorithm implemented in pure Python. We defined our own protocol instead of using one of the many perfectly suitable application protocols that exist in the wild. Even the idea of using multiprocessing for parallelism might be suspect here; we still end up passing all the data into and out of the subprocesses. Sometimes, it's important to take a step back from the program you are writing and ask yourself if you are trying to meet the right goals.

But let's look at some of the smart features of this design. First, we are passing bytes into and out of the subprocess. This is a lot smarter than decoding the JSON in the main process. It means the (relatively expensive) decoding can happen on a different CPU. Also, pickled JSON strings are generally smaller than pickled lists, so less data is passing between processes.

Second, the two methods are very linear; it looks like code is being executed one line after another. Of course, in AsyncIO, this is an illusion, but we don't have to worry about shared memory or concurrency primitives.

Streams

The previous example should look familiar by now as it has a similar boilerplate to other AsyncIO programs. However, there are a few differences. You'll notice we called `start_server` instead of `create_server`. This method hooks into AsyncIO's streams instead of using the underlying transport/protocol code. Instead of passing in a protocol class, we can pass in a normal coroutine, which receives reader and writer parameters. These both represent streams of bytes that can be read from and written like files or sockets. Second, because this is a TCP server instead of UDP, there is some socket cleanup required when the program finishes. This cleanup is a blocking call, so we have to run the `wait_closed` coroutine on the event loop.

Streams are fairly simple to understand. Reading is a potentially blocking call so we have to call it with `yield from`. Writing doesn't block; it just puts the data on a queue, which AsyncIO sends out in the background.

Our code inside the `sort_request` method makes two read requests. First, it reads 8 bytes from the wire and converts them to an integer using big endian notation. This integer represents the number of bytes of data the client intends to send. So in the next call, to `readexactly`, it reads that many bytes. The difference between `read` and `readexactly` is that the former will read up to the requested number of bytes, while the latter will buffer reads until it receives all of them, or until the connection closes.

Executors

Now let's look at the executor code. We import the exact same `ProcessPoolExecutor` that we used in the previous section. Notice that we don't need a special AsyncIO version of it. The event loop has a handy `run_in_executor` coroutine that we can use to run futures on. By default, the loop runs code in `ThreadPoolExecutor`, but we can pass in a different executor if we wish. Or, as we did in this example, we can set a different default when we set up the event loop by calling `loop.set_default_executor()`.

As you probably recall from the previous section, there is not a lot of boilerplate for using futures with an executor. However, when we use them with AsyncIO, there is none at all! The coroutine automatically wraps the function call in a future and submits it to the executor. Our code blocks until the future completes, while the event loop continues processing other connections, tasks, or futures. When the future is done, the coroutine wakes up and continues on to write the data back to the client.

You may be wondering if, instead of running multiple processes inside an event loop, it might be better to run multiple event loops in different processes. The answer is: "maybe". However, depending on the exact problem space, we are probably better off running independent copies of a program with a single event loop than to try to coordinate everything with a master multiprocessing process.

We've hit most of the high points of AsyncIO in this section, and the chapter has covered many other concurrency primitives. Concurrency is a hard problem to solve, and no one solution fits all use cases. The most important part of designing a concurrent system is deciding which of the available tools is the correct one to use for the problem. We have seen advantages and disadvantages of several concurrent systems, and now have some insights into which are the better choices for different types of requirements.

Case study

To wrap up this chapter, and the book, let's build a basic image compression tool. It will take black and white images (with 1 bit per pixel, either on or off) and attempt to compress it using a very basic form of compression known as run-length encoding. You may find black and white images a bit far-fetched. If so, you haven't enjoyed enough hours at `http://xkcd.com`!

I've included some sample black and white BMP images (which are easy to read data into and leave a lot of opportunity to improve on file size) with the example code for this chapter.

We'll be compressing the images using a simple technique called run-length encoding. This technique basically takes a sequence of bits and replaces any strings of repeated bits with the number of bits that are repeated. For example, the string 000011000 might be replaced with 04 12 03 to indicate that 4 zeros are followed by 2 ones and then 3 more zeroes. To make things a little more interesting, we will break each row into 127 bit chunks.

I didn't pick 127 bits arbitrarily. 127 different values can be encoded into 7 bits, which means that if a row contains all ones or all zeros, we can store it in a single byte; the first bit indicating whether it is a row of 0s or a row of 1s, and the remaining 7 bits indicating how many of that bit exists.

Breaking up the image into blocks has another advantage; we can process individual blocks in parallel without them depending on each other. However, there's a major disadvantage as well; if a run has just a few ones or zeros in it, then it will take up `more` space in the compressed file. When we break up long runs into blocks, we may end up creating more of these small runs and bloat the size of the file.

When dealing with files, we have to think about the exact layout of the bytes in the compressed file. Our file will store two byte little-endian integers at the beginning of the file representing the width and height of the completed file. Then it will write bytes representing the 127 bit chunks of each row.

Now before we start designing a concurrent system to build such compressed images, we should ask a fundamental question: Is this application I/O-bound or CPU-bound?

My answer, honestly, is "I don't know". I'm not sure whether the app will spend more time loading data from disk and writing it back or doing the compression in memory. I suspect that it is a CPU bound app in principle, but once we start passing image strings into subprocesses, we may lose any benefit of parallelism. The optimal solution to this problem is probably to write a C or Cython extension, but let's see how far we can get in pure Python.

We'll build this application using bottom-up design. That way we'll have some building blocks that we can combine into different concurrency patterns to see how they compare. Let's start with the code that compresses a 127-bit chunk using run-length encoding:

```
from bitarray import bitarray
def compress_chunk(chunk):
    compressed = bytearray()
    count = 1
    last = chunk[0]
    for bit in chunk[1:]:
        if bit != last:
            compressed.append(count | (128 * last))
            count = 0
            last = bit
        count += 1
    compressed.append(count | (128 * last))
    return compressed
```

This code uses the `bitarray` class for manipulating individual zeros and ones. It is distributed as a third-party module, which you can install with the command `pip install bitarray`. The chunk that is passed into `compress_chunks` is an instance of this class (although the example would work just as well with a list of Booleans). The primary benefit of the bitarray in this case is that when pickling them between processes, they take up an 8th of the space of a list of Booleans or a bytestring of 1s and 0s. Therefore, they pickle faster. They are also a bit (pun intended) easier to work with than doing a ton of bitwise operations.

The method compresses the data using run-length encoding and returns a bytearray containing the packed data. Where a bitarray is like a list of ones and zeros, a bytearray is like a list of byte objects (each byte, of course, containing 8 ones or zeros).

The algorithm that performs the compression is pretty simple (although I'd like to point out that it took me two days to implement and debug it. Simple to understand does not necessarily imply easy to write!). It first sets the `last` variable to the type of bit in the current run (either `True` or `False`). It then loops over the bits, counting each one, until it finds one that is different. When it does, it constructs a new byte by making the leftmost bit of the byte (the 128 position) either a zero or a one, depending on what the `last` variable contained. Then it resets the counter and repeats the operation. Once the loop is done, it creates one last byte for the last run, and returns the result.

While we're creating building blocks, let's make a function that compresses a row of image data:

```
def compress_row(row):
    compressed = bytearray()
    chunks = split_bits(row, 127)
    for chunk in chunks:
        compressed.extend(compress_chunk(chunk))
    return compressed
```

This function accepts a bitarray named row. It splits it into chunks that are each 127 bits wide using a function that we'll define very shortly. Then it compresses each of those chunks using the previously defined `compress_chunk`, concatenating the results into a `bytearray`, which it returns.

We define `split_bits` as a simple generator:

```
def split_bits(bits, width):
    for i in range(0, len(bits), width):
        yield bits[i:i+width]
```

Now, since we aren't certain yet whether this will run more effectively in threads or processes, let's wrap these functions in a method that runs everything in a provided executor:

```
def compress_in_executor(executor, bits, width):
    row_compressors = []
    for row in split_bits(bits, width):
        compressor = executor.submit(compress_row, row)
```

```
            row_compressors.append(compressor)

        compressed = bytearray()
        for compressor in row_compressors:
            compressed.extend(compressor.result())
        return compressed
```

This example barely needs explaining; it splits the incoming bits into rows based on the width of the image using the same `split_bits` function we have already defined (hooray for bottom-up design!).

Note that this code will compress any sequence of bits, although it would bloat, rather than compress binary data that has frequent changes in bit values. Black and white images are definitely good candidates for the compression algorithm in question. Let's now create a function that loads an image file using the third-party pillow module, converts it to bits, and compresses it. We can easily switch between executors using the venerable comment statement:

```
from PIL import Image
def compress_image(in_filename, out_filename, executor=None):
    executor = executor if executor else ProcessPoolExecutor()
    with Image.open(in_filename) as image:
        bits = bitarray(image.convert('1').getdata())
        width, height = image.size

    compressed = compress_in_executor(executor, bits, width)

    with open(out_filename, 'wb') as file:
        file.write(width.to_bytes(2, 'little'))
        file.write(height.to_bytes(2, 'little'))
        file.write(compressed)

def single_image_main():
    in_filename, out_filename = sys.argv[1:3]
    #executor = ThreadPoolExecutor(4)
    executor = ProcessPoolExecutor()
    compress_image(in_filename, out_filename, executor)
```

The `image.convert()` call changes the image to black and white (one bit) mode, while `getdata()` returns an iterator over those values. We pack the results into a bitarray so they transfer across the wire more quickly. When we output the compressed file, we first write the width and height of the image followed by the compressed data, which arrives as a bytearray, which can be written directly to the binary file.

Having written all this code, we are finally able to test whether thread pools or process pools give us better performance. I created a large (7200 x 5600 pixels) black and white image and ran it through both pools. The `ProcessPool` takes about 7.5 seconds to process the image on my system, while the `ThreadPool` consistently takes about 9. Thus, as we suspected, the cost of pickling bits and bytes back and forth between processes is eating almost all the efficiency gains from running on multiple processors (though looking at my CPU monitor, it does fully utilize all four cores on my machine).

So it looks like compressing a single image is most effectively done in a separate process, but only barely because we are passing so much data back and forth between the parent and subprocesses. Multiprocessing is more effective when the amount of data passed between processes is quite low.

So let's extend the app to compress all the bitmaps in a directory in parallel. The only thing we'll have to pass into the subprocesses are filenames, so we should get a speed gain compared to using threads. Also, to be kind of crazy, we'll use the existing code to compress individual images. This means we'll be running a `ProcessPoolExecutor` inside each subprocess to create even more subprocesses. I don't recommend doing this in real life!

```
from pathlib import Path
def compress_dir(in_dir, out_dir):
    if not out_dir.exists():
        out_dir.mkdir()

    executor = ProcessPoolExecutor()
    for file in (
            f for f in in_dir.iterdir() if f.suffix == '.bmp'):
        out_file = (out_dir / file.name).with_suffix('.rle')
        executor.submit(
            compress_image, str(file), str(out_file))

def dir_images_main():
    in_dir, out_dir = (Path(p) for p in sys.argv[1:3])
    compress_dir(in_dir, out_dir)
```

This code uses the `compress_image` function we defined previously, but runs it in a separate process for each image. It doesn't pass an executor into the function, so `compress_image` creates a `ProcessPoolExecutor` once the new process has started running.

Now that we are running executors inside executors, there are four combinations of threads and process pools that we can be using to compress images. They each have quite different timing profiles:

	Process pool per image	**Thread pool per image**
Process pool per row	42 seconds	53 seconds
Thread pool per row	34 seconds	64 seconds

As we might expect, using threads for each image and again using threads for each row is the slowest, since the GIL prevents us from doing any work in parallel. Given that we were slightly faster when using separate processes for each row when we were using a single image, you may be surprised to see that it is faster to use a `ThreadPool` feature for rows if we are processing each image in a separate process. Take some time to understand why this might be.

My machine contains only four processor cores. Each row in each image is being processed in a separate pool, which means that all those rows are competing for processing power. When there is only one image, we get a (very modest) speedup by running each row in parallel. However, when we increase the number of images being processed at once, the cost of passing all that row data into and out of a subprocess is actively stealing processing time from each of the other images. So, if we can process each image on a separate processor, where the only thing that has to get pickled into the subprocess pipe is a couple filenames, we get a solid speedup.

Thus, we see that different workloads require different concurrency paradigms. Even if we are just using futures we have to make informed decisions about what kind of executor to use.

Also note that for typically-sized images, the program runs quickly enough that it really doesn't matter which concurrency structures we use. In fact, even if we didn't use any concurrency at all, we'd probably end up with about the same user experience.

This problem could also have been solved using the threading and/or multiprocessing modules directly, though there would have been quite a bit more boilerplate code to write. You may be wondering whether or not AsyncIO would be useful here. The answer is: "probably not". Most operating systems don't have a good way to do non-blocking reads from the filesystem, so the library ends up wrapping all the calls in futures anyway.

For completeness, here's the code that I used to decompress the RLE images to confirm that the algorithm was working correctly (indeed, it wasn't until I fixed bugs in both compression and decompression, and I'm still not sure if it is perfect. I should have used test-driven development!):

```
from PIL import Image
import sys

def decompress(width, height, bytes):
    image = Image.new('1', (width, height))

    col = 0
    row = 0
    for byte in bytes:
        color = (byte & 128) >> 7
        count = byte & ~128
        for i in range(count):
            image.putpixel((row, col), color)
            row += 1
        if not row % width:
            col += 1
            row = 0
    return image


with open(sys.argv[1], 'rb') as file:
    width = int.from_bytes(file.read(2), 'little')
    height = int.from_bytes(file.read(2), 'little')

    image = decompress(width, height, file.read())
    image.save(sys.argv[2], 'bmp')
```

This code is fairly straightforward. Each run is encoded in a single byte. It uses some bitwise math to extract the color of the pixel and the length of the run. Then it sets each pixel from that run in the image, incrementing the row and column of the next pixel to check at appropriate intervals.

Exercises

We've covered several different concurrency paradigms in this chapter and still don't have a clear idea of when each one is useful. As we saw in the case study, it is often a good idea to prototype a few different strategies before committing to one.

Concurrency in Python 3 is a huge topic and an entire book of this size could not cover everything there is to know about it. As your first exercise, I encourage you to check out several third-party libraries that may provide additional context:

- execnet, a library that permits local and remote share-nothing concurrency
- Parallel python, an alternative interpreter that can execute threads in parallel
- Cython, a python-compatible language that compiles to C and has primitives to release the gil and take advantage of fully parallel multi-threading.
- PyPy-STM, an experimental implementation of software transactional memory on top of the ultra-fast PyPy implementation of the Python interpreter
- Gevent

If you have used threads in a recent application, take a look at the code and see if you can make it more readable and less bug-prone by using futures. Compare thread and multiprocessing futures to see if you can gain anything by using multiple CPUs.

Try implementing an AsyncIO service for some basic HTTP requests. You may need to look up the structure of an HTTP request on the web; they are fairly simple ASCII packets to decipher. If you can get it to the point that a web browser can render a simple GET request, you'll have a good understanding of AsyncIO network transports and protocols.

Make sure you understand the race conditions that happen in threads when you access shared data. Try to come up with a program that uses multiple threads to set shared values in such a way that the data deliberately becomes corrupt or invalid.

Remember the link collector we covered for the case study in *Chapter 6*, *Python Data Structures*? Can you make it run faster by making requests in parallel? Is it better to use raw threads, futures, or AsyncIO for this?

Try writing the run-length encoding example using threads or multiprocessing directly. Do you get any speed gains? Is the code easier or harder to reason about? Is there any way to speed up the decompression script by using concurrency or parallelism?

Summary

This chapter ends our exploration of object-oriented programming with a topic that isn't very object-oriented. Concurrency is a difficult problem and we've only scratched the surface. While the underlying OS abstractions of processes and threads do not provide an API that is remotely object-oriented, Python offers some really good object-oriented abstractions around them. The threading and multiprocessing packages both provide an object-oriented interface to the underlying mechanics. Futures are able to encapsulate a lot of the messy details into a single object. AsyncIO uses coroutine objects to make our code read as though it runs synchronously, while hiding ugly and complicated implementation details behind a very simple loop abstraction.

Thank you for reading *Python 3 Object-oriented Programming*, *Second Edition*. I hope you've enjoyed the ride and are eager to start implementing object-oriented software in all your future projects!

Module 2

Learning Python Design Patterns - Second Edition

Leverage the power of Python design patterns to solve real-world problems in software architecture and design

1
Introduction to Design Patterns

In this chapter, we will go through the basics of object-oriented programming and discuss the object-oriented design principles in detail. This will get us prepared for the advanced topics covered later in the book. This chapter will also give a brief introduction to the concept of design patterns so that you will be able to appreciate the context and application of design patterns in software development. Here we also classify the design patterns under three main aspects—creational, structural, and Behavioral patterns. So, essentially, we will cover the following topics in this chapter:

- Understanding object-oriented programming
- Discussing object-oriented design principles
- Understanding the concept of design patterns and their taxonomy and context
- Discussing patterns for dynamic languages
- Classifying patterns—creational pattern, structural pattern, and behavioral pattern

Understanding object-oriented programming

Before you start learning about design patterns, it's always good to cover the basics and go through object-oriented paradigms in Python. The object-oriented world presents the concept of *objects* that have attributes (data members) and procedures (member functions). These functions are responsible for manipulating the attributes. For instance, take an example of the `Car` object. The `Car` object will have attributes such as `fuel level`, `isSedan`, `speed`, and `steering wheel` and `coordinates`, and the methods would be `accelerate()` to increase the speed and `takeLeft()` to make the car turn left. Python has been an object-oriented language since it was first released. As they say, *everything in Python is an object*. Each class instance or variable has its own memory address or identity. Objects, which are instances of classes, interact among each other to serve the purpose of an application under development. Understanding the core concepts of object-oriented programming involves understanding the concepts of objects, classes, and methods.

Objects

The following points describe objects:

- They represent entities in your application under development.
- Entities interact among themselves to solve real-world problems.
- For example, Person is an entity and Car is an entity. Person drives Car to move from one location to the other.

Classes

Classes help developers to represent real-world entities:

- Classes define objects in attributes and behaviors. Attributes are data members and behaviors are manifested by the member functions
- Classes consist of constructors that provide the initial state for these objects
- Classes are like templates and hence can be easily reused

For example, class `Person` will have attributes `name` and `age` and member function `gotoOffice()` that defines his behavior for travelling to office for work.

Methods

The following points talk about what methods do in the object-oriented world:

- They represent the behavior of the object
- Methods work on attributes and also implement the desired functionality

A good example of a class and object created in Python v3.5 is given here:

```
class Person(object):
    def __init__(self, name, age):  #constructor
        self.name = name    #data members/ attributes
        self.age = age
    def get_person(self,):   # member function
         return "<Person (%s, %s)>" % (self.name, self.age)


p = Person("John", 32)    # p is an object of type Person
print("Type of Object:", type(p), "Memory Address:", id(p))
```

The output of the preceding code should look as follows:

```
Type of Object: <class '__main__.Person'> Memory Address: 4329015224
```

Major aspects of object-oriented programming

Now that we have understood the basics of object-oriented programming, let's dive into the major aspects of OOP.

Encapsulation

The key features of encapsulation are as follows:

- An object's behavior is kept hidden from the outside world or objects keep their state information private.
- Clients can't change the object's internal state by directly acting on them; rather, clients request the object by sending messages. Based on the type of requests, objects may respond by changing their internal state using special member functions such as `get` and `set`.

- In Python, the concept of encapsulation (data and method hiding) is not implicit, as it doesn't have keywords such as **public**, **private**, and **protected** (in languages such as C++ or Java) that are required to support encapsulation. Of course, accessibility can be made private by prefixing __ in the variable or function name.

Polymorphism

The major features of polymorphism are as follows:

- Polymorphism can be of two types:
    - An object provides different implementations of the method based on input parameters
    - The same interface can be used by objects of different types
- In Python, polymorphism is a feature built-in for the language. For example, the + operator can act on two integers to add them or can work with strings to concatenate them

In the following example, strings, tuples, or lists can all be accessed with an integer index. This shows how Python demonstrates polymorphism in built-in types:

```
a = "John"
b = (1,2,3)
c = [3,4,6,8,9]
print(a[1], b[0], c[2])
```

Inheritance

The following points help us understand the inheritance process better:

- Inheritance indicates that one class derives (most of its) functionality from the parent class.
- Inheritance is described as an option to reuse functionality defined in the base class and allow independent extensions of the original software implementation.
- Inheritance creates hierarchy via the relationships among objects of different classes. Python, unlike Java, supports multiple inheritance (inheriting from multiple base classes).

In the following code example, `class A` is the base class and `class B` derives its features from `class A`. So, the methods of `class A` can be accessed by the object of `class B`:

```
class A:
    def a1(self):
        print("a1")

class B(A):
    def b(self):
        print("b")


b = B()
b.a1()
```

Abstraction

The key features of abstraction are as follows:

- It provides you with a simple interface to the clients, where the clients can interact with class objects and call methods defined in the interface
- It abstracts the complexity of internal classes with an interface so that the client need not be aware of internal implementations

In the following example, internal details of the `Adder` class are abstracted with the `add()` method:

```
class Adder:
    def __init__(self):
        self.sum = 0
    def add(self, value):
        self.sum += value

acc = Adder()
for i in range(99):
    acc.add(i)


print(acc.sum)
```

Composition

Composition refers to the following points:

- It is a way to combine objects or classes into more complex data structures or software implementations
- In composition, an object is used to call member functions in other modules thereby making base functionality available across modules without inheritance

In the following example, the object of `class A` is composited under `class B`:

```
class A(object):
    def a1(self):
        print("a1")

class B(object):
    def b(self):
        print("b")
        A().a1()


objectB = B()
objectB.b()
```

Object-oriented design principles

Now, let's talk about another set of concepts that are going to be crucial for us. These are nothing but the object-oriented design principles that will act as a toolbox for us while learning design patterns in detail.

The open/close principle

The open/close principle states that *classes or objects and methods should be open for extension but closed for modifications*.

What this means in simple language is, when you develop your software application, make sure that you write your classes or modules in a generic way so that whenever you feel the need to extend the behavior of the class or object, then you shouldn't have to change the class itself. Rather, a simple extension of the class should help you build the new behavior.

For example, the open/close principle is manifested in a case where a user has to create a class implementation by extending the abstract base class to implement the required behavior instead of changing the abstract class.

Advantages of this design principle are as follows:

- Existing classes are not changed and hence the chances of regression are less
- It also helps maintain backward compatibility for the previous code

The inversion of control principle

The inversion of control principle states that *high-level modules shouldn't be dependent on low-level modules; they should both be dependent on abstractions. Details should depend on abstractions and not the other way round*.

This principle suggests that any two modules shouldn't be dependent on each other in a tight way. In fact, the base module and dependent module should be decoupled with an abstraction layer in between.

This principle also suggests that the details of your class should represent the abstractions. In some cases, the philosophy gets inverted and implementation details itself decide the abstraction, which should be avoided.

Advantages of the inversion of control principle are as follows:

- The tight coupling of modules is no more prevalent and hence no complexity/rigidity in the system
- As there is a clear abstraction layer between dependent modules (provided by a hook or parameter), it's easy to deal with dependencies across modules in a better way

The interface segregation principle

As the interface segregation principle states, *clients should not be forced to depend on interfaces they don't use*.

This principle talks about software developers writing their interfaces well. For instance, it reminds the developers/architects to develop methods that relate to the functionality. If there is any method that is not related to the interface, the class dependent on the interface has to implement it unnecessarily.

For example, a `Pizza` interface shouldn't have a method called `add_chicken()`. The `Veg Pizza` class based on the `Pizza` interface shouldn't be forced to implement this method.

Advantages of this design principle are as follows:

- It forces developers to write thin interfaces and have methods that are specific to the interface
- It helps you not to populate interfaces by adding unintentional methods

The single responsibility principle

As the single responsibility principle states, *a class should have only one reason to change*.

This principle says that when we develop classes, it should cater to the given functionality well. If a class is taking care of two functionalities, it is better to split them. It refers to functionality as a reason to change. For example, a class can undergo changes because of the difference in behavior expected from it, but if a class is getting changed for two reasons (basically, changes in two functionalities), then the class should be definitely split.

Advantages of this design principle are as follows:

- Whenever there is a change in one functionality, this particular class needs to change, and nothing else
- Additionally, if a class has multiple functionalities, the dependent classes will have to undergo changes for multiple reasons, which gets avoided

The substitution principle

The substitution principle states that *derived classes must be able to completely substitute the base classes*.

This principle is pretty straightforward in the sense that it says when application developers write derived classes, they should extend the base classes. It also suggests that the derived class should be as close to the base class as possible so much so that the derived class itself should replace the base class without any code changes.

The concept of design patterns

Finally, now is the time that we start talking about design patterns! What are design patterns?

Design patterns were first introduced by **GoF** (**Gang of Four**), where they mentioned them as being solutions to given problems. If you would like to know more, GoF refers to the four authors of the book, *Design Patterns: Elements of Reusable Object-Oriented Software*. The book's authors are *Erich Gamma*, *Richard Helm*, *Ralph Johnson*, and *John Vlissides*, with a foreword by *Grady Booch*. This book covers software engineering solutions to the commonly occurring problems in software design. There were 23 design patterns first identified, and the first implementation was done with respect to the Java program language. Design patterns are discoveries and not an invention in themselves.

The key features of design patterns are as follows:

- They are language-neutral and can be implemented across multiple languages
- They are dynamic, as new patterns get introduced every now and then
- They are open for customization and hence useful for developers

Initially, when you hear about design patterns, you may feel the following:

- It's a panacea to all the design problems that you've had so far
- It's an extraordinary, specially clever way of solving a problem
- Many experts in software development world agree to these solutions
- There's something repeatable about the design, hence the word pattern

You too must have attempted to solve the problems that a design patterns intends to, but maybe your solution was incomplete, and the completeness that we're looking for is inherent or implicit in the design pattern. When we say completeness, it can refer to many factors such as the design, scalability, reuse, memory utilization, and others. Essentially, a design pattern is about learning from others' successes rather than your own failures!

Another interesting discussion that comes up on design patterns is—when do I use them? Is it in the analysis or design phase of **Software Development Life Cycle** (**SDLC**)?

Interestingly, design patterns are solutions to known issues. So they can be very much used in analysis or design, and as expected, in the development phase because of the direct relation in the application code.

Advantages of design patterns

The advantages of design patterns are as follows:

- They are reusable across multiple projects
- The architectural level of problems can be solved
- They are time-tested and well-proven, which is the experience of developers and architects
- They have reliability and dependence

Taxonomy of design patterns

Not every piece of code or design can be termed as a design pattern. For example, a programming construct or data structure that solves one problem can't be termed as a pattern. Let's understand terms in a very simplistic way below:

- **Snippet**: This is code in some language for a certain purpose, for example, DB connectivity in Python can be a code snippet
- **Design**: A better solution to solve this particular problem
- **Standard**: This is a way to solve some kind of problems, and can be very generic and applicable to a situation at hand
- **Pattern**: This is a time-tested, efficient, and scalable solution that will resolve the entire class of known issues

Context – the applicability of design patterns

To use design patterns efficiently, application developers must be aware of the context where design patterns apply. We can classify the context into the following main categories:

- **Participants**: They are classes that are used in design patterns. Classes play different roles to accomplish multiple goals in the pattern.
- **Non-functional requirements**: Requirements such as memory optimization, usability, and performance fall under this category. These factors impact the complete software solution and are thus critical.
- **Trade-offs**: Not all design patterns fit in application development as it is, and trade-offs are necessary. These are decisions that you take while using a design pattern in an application.
- **Results**: Design patterns can have a negative impact on other parts of the code if the context is not appropriate. Developers should understand the consequences and use of design patterns.

Patterns for dynamic languages

Python is a dynamic language like Lisp. The dynamic nature of Python can be represented as follows:

- Types or classes are objects at runtime.
- Variables can have type as a value and can be modified at runtime. For example, `a = 5` and `a = "John"`, the `a` variable is assigned at runtime and type also gets changed.
- Dynamic languages have more flexibility in terms of class restrictions.
- For example, in Python, polymorphism is built into the language, there are no keywords such as `private` and `protected` and everything is public by default.
- Represents a case where design patterns can be easily implemented in dynamic languages.

Classifying patterns

The book by GoF on design patterns spoke about 23 design patterns and classified them under three main categories:

- Creational patterns
- Structural patterns
- Behavioral patterns

The classification of patterns is done based primarily on how the objects get created, how classes and objects are structured in a software application, and also covers the way objects interact among themselves. Let's talk about each of the categories in detail in this section.

Creational patterns:

The following are the properties of Creational patterns:

- They work on the basis of how objects can be created
- They isolate the details of object creation
- Code is independent of the type of object to be created

An example of a creational pattern is the Singleton pattern.

Structural patterns

The following are the properties of Structural patterns:

- They design the structure of objects and classes so that they can compose to achieve larger results
- The focus is on simplifying the structure and identifying the relationship between classes and objects
- They focus on class inheritance and composition

An example of a behavior pattern is the Adapter pattern

Behavioral patterns

The following are the properties of Behavioral patterns:

- They are concerned with the interaction among objects and responsibility of objects
- Objects should be able to interact and still be loosely coupled

An example of a behavioral pattern is the Observer pattern

Summary

In this chapter, you learned about the basic concepts of object-oriented programming, such as objects, classes, variables, and features such as polymorphism, inheritance, and abstraction with code examples.

We are also now aware of object-oriented design principles that we, as developers/ architects, should consider while designing an application.

Finally, we went on to explore more about design patterns and their applications and context in which they can be applied and also discussed their classifications.

At the end of this chapter, we're now ready to take the next step and study design patterns in detail.

2
The Singleton Design Pattern

In the previous chapter, we explored design patterns and their classifications. As we are aware, design patterns can be classified under three main categories: structural, behavioral, and creational patterns.

In this chapter, we will go through the Singleton design pattern—one of the simplest and well-known Creational design patterns used in application development. This chapter will give you a brief introduction to the Singleton pattern, take you through a real-world example where this pattern can be used, and explain it in detail with the help of Python implementations. You will learn about the Monostate (or Borg) design pattern that is a variant of the Singleton design pattern.

In this chapter, we will cover the following topics in brief:

- An understanding of the Singleton design pattern
- A real-world example of the Singleton pattern
- The Singleton pattern implementation in Python
- The Monostate (Borg) pattern

At the end of the chapter, we have a short summary on Singletons. This will help you think independently about some of the aspects of the Singleton design pattern.

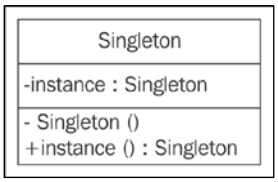
Understanding the Singleton design pattern

Singleton provides you with a mechanism to have one, and only one, object of a given type and provides a global point of access. Hence, Singletons are typically used in cases such as logging or database operations, printer spoolers, and many others, where there is a need to have only one instance that is available across the application to avoid conflicting requests on the same resource. For example, we may want to use one database object to perform operations on the DB to maintain data consistency or one object of the logging class across multiple services to dump log messages in a particular log file sequentially.

In brief, the intentions of the Singleton design pattern are as follows:

- Ensuring that one and only one object of the class gets created
- Providing an access point for an object that is global to the program
- Controlling concurrent access to resources that are shared

The following is the UML diagram for Singleton:



A simple way of implementing Singleton is by making the constructor private and creating a static method that does the object initialization. This way, one object gets created on the first call and the class returns the same object thereafter.

In Python, we will implement it in a different way as there's no option to create private constructors. Let's take a look at how Singletons are implemented in the Python language.

Implementing a classical Singleton in Python

Here is a sample code of the Singleton pattern in Python v3.5. In this example, we will do two major things:

1. We will allow the creation of only one instance of the `Singleton` class.
2. If an instance exists, we will serve the same object again.

The following code shows this:

```
class Singleton(object):
     def __new__(cls):
       if not hasattr(cls, 'instance'):
         cls.instance = super(Singleton, cls).__new__(cls)
       return cls.instance

s = Singleton()
print("Object created", s)

s1 = Singleton()
print("Object created", s1)
```

The output of the preceding snippet is given here:

```
Object created <__main__.Singleton object at 0x102078ba8>
Object created <__main__.Singleton object at 0x102078ba8>
```

In the preceding code snippet, we override the `__new__` method (Python's special method to instantiate objects) to control the object creation. The s object gets created with the `__new__` method, but before this, it checks whether the object already exists. The `hasattr` method (Python's special method to know if an object has a certain property) is used to see if the `cls` object has the instance property, which checks whether the class already has an object. Till the time the `s1` object is requested, `hasattr()` detects that an object already exists and hence `s1` allocates the existing object instance (located at `0x102078ba8`).

Lazy instantiation in the Singleton pattern

One of the use cases for the Singleton pattern is lazy instantiation. For example, in the case of module imports, we may accidently create an object even when it's not needed. Lazy instantiation makes sure that the object gets created when it's actually needed. Consider lazy instantiation as the way to work with reduced resources and create them only when needed.

In the following code example, when we say `s=Singleton()`, it calls the `__init__` method but no new object gets created. However, actual object creation happens when we call `Singleton.getInstance()`. This is how lazy instantiation is achieved.

```
class Singleton:
    __instance = None
    def __init__(self):
        if not Singleton.__instance:
```

```
            print(" __init__ method called..")
        else:
            print("Instance already created:", self.getInstance())
    @classmethod
    def getInstance(cls):
        if not cls.__instance:
            cls.__instance = Singleton()
        return cls.__instance


s = Singleton() ## class initialized, but object not created
print("Object created", Singleton.getInstance()) # Object gets created
here
s1 = Singleton() ## instance already created
```

Module-level Singletons

All modules are Singletons by default because of Python's importing behavior. Python works in the following way:

1. Checks whether a Python module has been imported.
2. If imported, returns the object for the module. If not imported, imports and instantiates it.
3. So when a module gets imported, it is initialized. However, when the same module is imported again, it's not initialized again, which relates to the Singleton behavior of having only one object and returning the same object.

The Monostate Singleton pattern

We discussed the Gang of Four and their book in *Chapter 1*, *Introduction to Design Patterns*. GoF's Singleton design pattern says that there should be one and only one object of a class. However, as per Alex Martelli, typically what a programmer needs is to have instances sharing the same state. He suggests that developers should be bothered about the state and behavior rather than the identity. As the concept is based on all objects sharing the same state, it is also known as the Monostate pattern.

The Monostate pattern can be achieved in a very simple way in Python. In the following code, we assign the `__dict__` variable (a special variable of Python) with the `__shared_state` class variable. Python uses `__dict__` to store the state of every object of a class. In the following code, we intentionally assign `__shared_state` to all the created instances. So when we create two instances, `'b'` and `'b1'`, we get two different objects unlike Singleton where we have just one object. However, the object states, `b.__dict__` and `b1.__dict__` are the same. Now, even if the object variable `x` changes for object `b`, the change is copied over to the `__dict__` variable that is shared by all objects and even `b1` gets this change of the `x` setting from one to four:

```
class Borg:
    __shared_state = {"1":"2"}
    def __init__(self):
        self.x = 1
        self.__dict__ = self.__shared_state
        pass

b = Borg()
b1 = Borg()
b.x = 4

print("Borg Object 'b': ", b) ## b and b1 are distinct objects
print("Borg Object 'b1': ", b1)
print("Object State 'b':", b.__dict__)## b and b1 share same state
print("Object State 'b1':", b1.__dict__)
```

The following is the output of the preceding snippet:

```
Borg Object 'b':  <__main__.Borg object at 0x102078da0>
Borg Object 'b1':  <__main__.Borg object at 0x102078dd8>
Object State 'b': {'x': 4, '1': '2'}
Object State 'b1': {'x': 4, '1': '2'}
```

Another way to implement the Borg pattern is by tweaking the `__new__` method itself. As we know, the `__new__` method is responsible for the creation of the object instance:

```
class Borg(object):
     _shared_state = {}
     def __new__(cls, *args, **kwargs):
       obj = super(Borg, cls).__new__(cls, *args, **kwargs)
       obj.__dict__ = cls._shared_state
       return obj
```

Singletons and metaclasses

Let's start with a brief introduction to metaclasses. A metaclass is a class of a class, which means that the class is an instance of its metaclass. With metaclasses, programmers get an opportunity to create classes of their own type from the predefined Python classes. For instance, if you have an object, `MyClass`, you can create a metaclass, `MyKls`, that redefines the behavior of `MyClass` to the way that you need. Let's understand them in detail.

In Python, everything is an object. If we say `a=5`, then `type(a)` returns `<type 'int'>`, which means `a` is of the int type. However, `type(int)` returns `<type 'type'>`, which suggests the presence of a metaclass as int is a class of the `type` type.

The definition of class is decided by its metaclass, so when we create a class with `class A`, Python creates it by `A = type(name, bases, dict)`:

- `name`: This is the name of the class
- `base`: This is the base class
- `dict`: This is the attribute variable

Now, if a class has a predefined metaclass (by the name of `MetaKls`), Python creates the class by `A = MetaKls(name, bases, dict)`.

Let's look at a sample metaclass implementation in Python 3.5:

```
class MyInt(type):
    def __call__(cls, *args, **kwds):
        print("***** Here's My int *****", args)
        print("Now do whatever you want with these objects...")
        return type.__call__(cls, *args, **kwds)


class int(metaclass=MyInt):
    def __init__(self, x, y):
        self.x = x
        self.y = y


i = int(4,5)
```

The following is the output of the preceding code:

```
***** Here's My int ***** (4, 5)
Now do whatever you want with these objects...
```

Python's special `__call__` method gets called when an object needs to be created for an already existing class. In this code, when we instantiate the `int` class with `int(4,5)`, the `__call__` method of the `MyInt` metaclass gets called, which means that the metaclass now controls the instantiation of the object. Wow, isn't this great?!

The preceding philosophy is used in the Singleton design pattern as well. As the metaclass has more control over class creation and object instantiation, it can be used to create Singletons. (Note: To control the creation and initialization of a class, metaclasses override the `__new__` and `__init__` method.)

The Singleton implementation with metclasses can be explained better with the following example code:

```
class MetaSingleton(type):
    _instances = {}
    def __call__(cls, *args, **kwargs):
        if cls not in cls._instances:
            cls._instances[cls] = super(MetaSingleton, \
                cls).__call__(*args, **kwargs)
        return cls._instances[cls]

class Logger(metaclass=MetaSingleton):
    pass

logger1 = Logger()
logger2 = Logger()
print(logger1, logger2)
```

A real-world scenario – the Singleton pattern, part 1

As a practical use case, we will look at a database application to show the use of Singletons. Consider an example of a cloud service that involves multiple read and write operations on the database. The complete cloud service is split across multiple services that perform database operations. An action on the UI (web app) internally will call an API, which eventually results in a DB operation.

It's clear that the shared resource across different services is the database itself. So, if we need to design the cloud service better, the following points must be taken care of:

- Consistency across operations in the database—one operation shouldn't result in conflicts with other operations
- Memory and CPU utilization should be optimal for the handling of multiple operations on the database

A sample Python implementation is given here:

```
import sqlite3
class MetaSingleton(type):
    _instances = {}
    def __call__(cls, *args, **kwargs):
        if cls not in cls._instances:
            cls._instances[cls] = super(MetaSingleton, \
                cls).__call__(*args, **kwargs)
        return cls._instances[cls]

class Database(metaclass=MetaSingleton):
  connection = None
  def connect(self):
    if self.connection is None:
        self.connection = sqlite3.connect("db.sqlite3")
        self.cursorobj = self.connection.cursor()
    return self.cursorobj

db1 = Database().connect()
db2 = Database().connect()

print ("Database Objects DB1", db1)
print ("Database Objects DB2", db2)
```

The output of the preceding code is given here:

```
Database Objects DB1 <sqlite3.Cursor object at 0x102464570>
Database Objects DB2 <sqlite3.Cursor object at 0x102464570>
```

In the preceding code, we can see following points being covered:

1. We created a metaclass by the name of `MetaSingleton`. Like we explained in the previous section, the special `__call__` method of Python is used in the metaclass to create a Singleton.
2. The `database` class is decorated by the `MetaSingleton` class and starts acting like a Singleton. So, when the `database` class is instantiated, it creates only one object.
3. When the web app wants to perform certain operations on the DB, it instantiates the database class multiple times, but only one object gets created. As there is only one object, calls to the database are synchronized. Additionally, this is inexpensive on system resources and we can avoid the situation of memory or CPU resource.

Consider that instead of having one webapp, we have a clustered setup with multiple web apps but only one DB. Now, this is not a good situation for Singletons because, with every web app addition, a new Singleton gets created and a new object gets added that queries the database. This results in unsynchronized database operations and is heavy on resources. In such cases, database connection pooling is better than implementing Singletons.

A real-world scenario – the Singleton pattern, part 2

Let's consider another scenario where we implement health check services (such as Nagios) for our infrastructure. We create the `HealthCheck` class, which is implemented as a Singleton. We also maintain a list of servers against which the health check needs to run. If a server is removed from this list, the health check software should detect it and remove it from the servers configured to check.

In the following code, the `hc1` and `hc2` objects are the same as the class in Singleton.

Servers are added to the infrastructure for the health check with the `addServer()` method. First, the iteration of the health check runs against these servers. The `changeServer()` method removes the last server and adds a new one to the infrastructure scheduled for the health check. So, when the health check runs in the second iteration, it picks up the changed list of servers.

All this is possible with Singletons. When the servers get added or removed, the health check must be the same object that has the knowledge of the changes made to the infrastructure:

```
class HealthCheck:
    _instance = None
    def __new__(cls, *args, **kwargs):
        if not HealthCheck._instance:
            HealthCheck._instance = super(HealthCheck, \
                cls).__new__(cls, *args, **kwargs)
        return HealthCheck._instance
    def __init__(self):
        self._servers = []
    def addServer(self):
        self._servers.append("Server 1")
        self._servers.append("Server 2")
        self._servers.append("Server 3")
        self._servers.append("Server 4")
    def changeServer(self):
        self._servers.pop()
        self._servers.append("Server 5")

hc1 = HealthCheck()
hc2 = HealthCheck()

hc1.addServer()
print("Schedule health check for servers (1)..")
for i in range(4):
    print("Checking ", hc1._servers[i])

hc2.changeServer()
print("Schedule health check for servers (2)..")
for i in range(4):
    print("Checking ", hc2._servers[i])
```

The output of the code is as follows:

```
Schedule health check for servers (1)..
Checking  Server 1
Checking  Server 2
Checking  Server 3
Checking  Server 4
Schedule health check for servers (2)..
Checking  Server 1
Checking  Server 2
Checking  Server 3
Checking  Server 5
```

Drawbacks of the Singleton pattern

While Singletons are used in multiple places to good effect, there can be a few gotchas with this pattern. As Singletons have a global point of access, the following issues can occur:

- Global variables can be changed by mistake at one place and, as the developer may think that they have remained unchanged, the variables get used elsewhere in the application.
- Multiple references may get created to the same object. As Singleton creates only one object, multiple references can get created at this point to the same object.
- All classes that are dependent on global variables get tightly coupled as a change to the global data by one class can inadvertently impact the other class.

As part of this chapter, you learned a lot on Singletons. Here are a few points that we should remember about Singletons:

- There are many real-world applications where we need to create only one object, such as thread pools, caches, dialog boxes, registry settings, and so on. If we create multiple instances for each of these applications, it will result in the overuse of resources. Singletons work very well in such situations.
- Singleton; a time-tested and proven method of presenting a global point of access without many downsides.
- Of course, there are a few downsides; Singletons can have an inadvertent impact working with global variables or instantiating classes that are resource-intensive but end up not utilizing them.

Summary

In this chapter, you learned about the Singleton design pattern and the context in which it's used. We understood that Singletons are used when there is a need to have only one object for a class.

We also looked at various ways in which Singletons can be implemented in Python. The classical implementation allowed multiple instantiation attempts but returned the same object.

We also discussed the Borg or Monostate pattern, which is a variation of the Singleton pattern. Borg allows the creation of multiple objects that share the same state unlike the single pattern described by GoF.

We went on to explore the webapp application where Singleton can be applied for consistent database operations across multiple services.

Finally, we also looked at situations where Singletons can go wrong and what situations developers need to avoid.

At the end of this chapter, we're now comfortable enough to take the next step and study other creational patterns and benefit from them.

In the next chapter, we'll take a look at another creational pattern and the Factory design pattern. We'll cover the `Factory` method and Abstract Factory patterns and understand them in the Python implementation.

3
The Factory Pattern – Building Factories to Create Objects

In the previous chapter, you learned about Singleton design patterns—what they are and how they are used in the real world along with the Python implementation. The Singleton design pattern is one of the Creational design patterns. In this chapter, we move ahead and learn about another creational pattern, the Factory pattern.

The Factory pattern is arguably the most used design pattern. In this chapter, we will understand the concept of Factory and go through the Simple Factory pattern. You will then learn about the Factory method pattern and Abstract Factory pattern with a UML diagram, real-world scenarios, and Python v3.5 implementations. We'll also compare the Factory method and Abstract Factory method.

In this chapter, we will cover the following topics in brief:

- Understanding the Simple Factory design pattern
- Discussing the Factory method and Abstract Factory method and their differences
- Implementing real-world scenarios with the Python code implementation
- Discussing the advantages and disadvantages of the patterns and their comparisons

Understanding the Factory pattern

In object-oriented programming, the term factory means a class that is responsible for creating objects of other types. Typically, the class that acts as a factory has an object and methods associated with it. The client calls this method with certain parameters; objects of desired types are created in turn and returned to the client by the factory.

So the question here really is, why do we need a factory when the client can directly create an object? The answer is, a factory provides certain advantages that are listed here:

- The first advantage is loose coupling in which object creation can be independent of the class implementation.
- The client need not be aware of the class that creates the object which, in turn, is utilized by the client. It is only necessary to know the interface, methods, and parameters that need to be passed to create objects of the desired type. This simplifies implementations for the client.
- Adding another class to the factory to create objects of another type can be easily done without the client changing the code. At a minimum, the client needs to pass just another parameter.
- The factory can also reuse the existing objects. However, when the client does direct object creation, this always creates a new object.

Let's consider the situation of a manufacturing company that manufactures toys—cars or dolls. Let's say that a machine in the company is currently manufacturing toy cars. Then, the CEO of the company feels that there is an urgent need to manufacture dolls based on the demand in the market. This situation calls for the Factory pattern. In this case, the machine becomes the interface and the CEO is the client. The CEO is only bothered about the object (or the toy) to be manufactured and knows the interface—the machine—that can create the object.

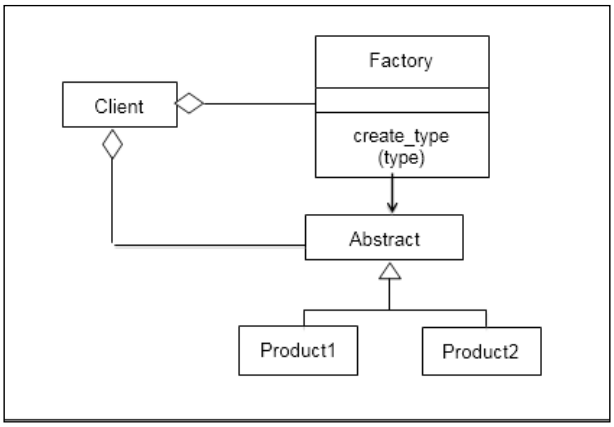
There are three variants of the Factory pattern:

- **Simple Factory pattern**: This allows interfaces to create objects without exposing the object creation logic.
- **Factory method pattern**: This allows interfaces to create objects, but defers the decision to the subclasses to determine the class for object creation.
- **Abstract Factory pattern**: An Abstract Factory is an interface to create related objects without specifying/exposing their classes. The pattern provides objects of another factory, which internally creates other objects.

The Simple Factory pattern

For some, Simple Factory is not a pattern in itself. It is more of a concept that developers need to know before they know more about the Factory method and Abstract Factory method. The Factory helps create objects of different types rather than direct object instantiation.

Let's understand this with the help of the following diagram. Here, the client class uses the Factory class, which has the `create_type()` method. When the client calls the `create_type()` method with the type parameters, based on the parameters passed, the Factory returns **Product1** or **Product2**:



A UML Diagram of Simple Factory

Let's now understand the Simple Factory pattern with the help of a Python v3.5 code example. In the following snippet, we create an Abstract product called `Animal`. `Animal` is an abstract base class (`ABCMeta` is Python's special metaclass to make a class `Abstract`) and has the `do_say()` method. We create two products (`Cat` and `Dog`) from the Animal interface and implement `do_say()` with appropriate sounds that these animals make. `ForestFactory` is a factory that has the `make_sound()` method. Based on the type of argument passed by the client, an appropriate Animal instance is created at runtime and the right sound is printed out:

```
from abc import ABCMeta, abstractmethod

class Animal(metaclass = ABCMeta):
    @abstractmethod
    def do_say(self):
        pass

class Dog(Animal):
    def do_say(self):
        print("Bhow Bhow!!")

class Cat(Animal):
    def do_say(self):
```

```
            print("Meow Meow!!")


    ## forest factory defined
    class ForestFactory(object):
        def make_sound(self, object_type):
            return eval(object_type)().do_say()

    ## client code
    if __name__ == '__main__':
        ff = ForestFactory()
        animal = input("Which animal should make_sound Dog or Cat?")
        ff.make_sound(animal)
```

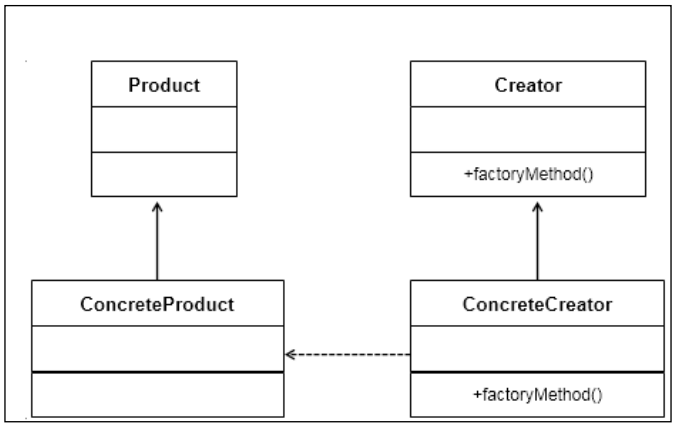
The following is the output of the preceding code snippet:

```
Which animal should make_sound Dog or Cat?Cat
Meow Meow!!
```

The Factory Method pattern

The following points help us understand the factory method pattern:

- We define an interface to create objects, but instead of the factory being responsible for the object creation, the responsibility is deferred to the subclass that decides the class to be instantiated.
- The Factory method creation is through inheritance and not through instantiation.
- The Factory method makes the design more customizable. It can return the same instance or subclass rather than an object of a certain type (as in the simple factory method).



A UML diagram for the Factory method

In the preceding UML diagram, we have an abstract class, `Creator`, that contains `factoryMethod()`. The `factoryMethod()` method has the responsibility of creating objects of a certain type. The `ConcreteCreator` class has `factoryMethod()` that implements the `Creator` abstract class, and this method can change the created object at runtime. `ConcreteCreator` creates `ConcreteProduct` and makes sure that the object it creates implements the `Product` class and provides implementation for all the methods in the `Product` interface.

In brief, `factoryMethod()` of the `Creator` interface and the `ConcreteCreator` class decides which subclass of Product to create. Thus, the Factory method pattern defines an interface to create an object, but defers the decision ON which class to instantiate to its subclasses.

Implementing the Factory Method

Let's take a real-world scenario to understand the Factory method implementation. Consider that we would like to create profiles of different types on social networks such as LinkedIn and Facebook for a person or company. Now, each of these profiles would have certain sections. In LinkedIn, you would have a section on patents that an individual has filed or publications s/he has written. On Facebook, you'll see sections in an album of pictures of your recent visit to a holiday place. Additionally, in both these profiles, there'd be a common section on personal information. So, in brief, we want to create profiles of different types with the right sections being added to the profile.

Let's now take a look at the implementation. In the following code example, we will start by defining the `Product` interface. We will create a `Section` abstract class that defines how a section will be. We will keep it very simple and provide an abstract method, `describe()`.

We now create multiple `ConcreteProduct` classes, `PersonalSection`, `AlbumSection`, `PatentSection`, and `PublicationSection`. These classes implement the `describe()` abstract method and print their respective section names:

```
from abc import ABCMeta, abstractmethod


class Section(metaclass=ABCMeta):
    @abstractmethod
    def describe(self):
        pass


class PersonalSection(Section):
    def describe(self):
        print("Personal Section")


class AlbumSection(Section):
    def describe(self):
        print("Album Section")


class PatentSection(Section):
    def describe(self):
        print("Patent Section")


class PublicationSection(Section):
    def describe(self):
        print("Publication Section")
```

We create a `Creator` abstract class that is named `Profile`. The `Profile [Creator]` abstract class provides a factory method, `createProfile()`. The `createProfile()` method should be implemented by `ConcreteClass` to actually create the profiles with appropriate sections. The `Profile` abstract class is not aware of the sections that each profile should have. For example, a Facebook profile should have personal information and album sections. So we will let the subclass decide this.

We create two `ConcreteCreator` classes, `linkedin` and `facebook`. Each of these classes implement the `createProfile()` abstract method that actually creates (instantiates) multiple sections (`ConcreteProducts`) at runtime:

```
class Profile(metaclass=ABCMeta):
    def __init__(self):
        self.sections = []
        self.createProfile()
    @abstractmethod
    def createProfile(self):
        pass
    def getSections(self):
        return self.sections
    def addSections(self, section):
        self.sections.append(section)


class linkedin(Profile):
    def createProfile(self):
        self.addSections(PersonalSection())
        self.addSections(PatentSection())
        self.addSections(PublicationSection())


class facebook(Profile):
    def createProfile(self):
        self.addSections(PersonalSection())
        self.addSections(AlbumSection())
```

We finally write client code that determines which `Creator` class to instantiate in order to create a profile of the desired choice:

```
if __name__ == '__main__':
    profile_type = input("Which Profile you'd like to create?
[LinkedIn or FaceBook]")
    profile = eval(profile_type.lower())()
    print("Creating Profile..", type(profile).__name__)
    print("Profile has sections --", profile.getSections())
```

If you now run the complete code, it'll first ask you to enter the name of the profile that you'd like to create. In the following screenshot, we say `Facebook`. It then instantiates the `facebook [ConcreateCreator]` class. This internally creates `ConcreteProduct(s)`, that is, it instantiates `PersonalSection` and `AlbumSection`. If `Linkedin` is chosen, then `PersonalSection`, `PatentSection`, and `PublicationSection` are created.

The following is the output of the preceding code snippet:

```
Which Profile you'd like to create? [LinkedIn or FaceBook]FaceBook
Creating Profile.. facebook
Profile has sections -- [<__main__.PersonalSection object at 0x101988b00>, <__main__.AlbumSection object at 0x101988b38>]
```

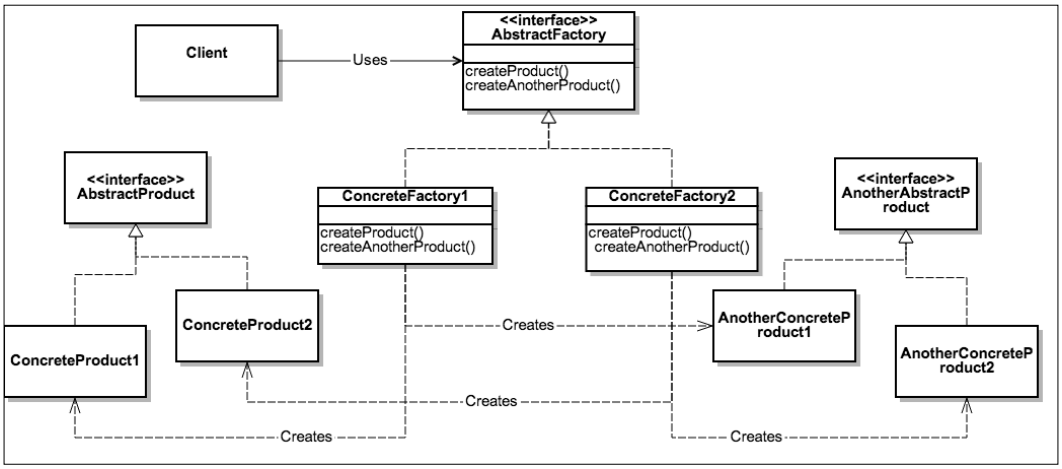
Advantages of the Factory method pattern

As you have now learned the Factory method pattern and how to implement Factory methods, let's see the advantages of the Factory method pattern:

- It brings in a lot of flexibility and makes the code generic, not being tied to a certain class for instantiation. This way, we're dependent on the interface (Product) and not on the `ConcreteProduct` class.
- There's loose coupling, as the code that creates the object is separate from the code that uses it. The client need not bother about what argument to pass and which class to instantiate. The addition of new classes is easy and involves low maintenance.

The Abstract Factory pattern

The main objective of the Abstract Factory pattern is to provide an interface to create families of related objects without specifying the concrete class. While the factory method defers the creation of the instance to the subclasses, the goal of Abstract Factory method is to create families of related objects:



A UML Diagram for the Abstract Factory pattern

As shown in the diagram, `ConcreteFactory1` and `ConcreteFactory2` are created from the `AbstractFactory` interface. This interface has methods to create multiple products.

`ConcreteFactory1` and `ConcreteFactory2` implement AbstractFactory and create instances of `ConcreteProduct1`, `ConcreteProduct2`, `AnotherConcreteProduct1`, and `AnotherConcreteProduct2`.

`ConcreteProduct1` and `ConcreteProduct2` are in turn created from the `AbstractProduct` interface, and `AnotherConcreteProduct1` and `AnotherConcreteProduct2` are created from the `AnotherAbstractProduct` interface.

In effect, Abstract Factory patterns make sure that the client is isolated from the creation of objects but allowed to use the objects created. The client has the ability to access objects only through an interface. If products of one family are to be used, Abstract Factory pattern helps the client use the objects from one/ family at a time. For example, if an application under development is supposed to be platform-independent, then it needs to abstract dependencies such as OS, file system calls, among others. Abstract Factory pattern takes care of creating the required services for the entire platform so that the client doesn't have to create platform objects directly.

Implementing the Abstract Factory pattern

Consider the case of your favorite pizza place. It serves multiple types of pizzas, right? Wait, hold on, I know you want to order one right away, but let's just get back to the example for now!

Now, imagine that we create a pizza store where you are served with delicious Indian and American pizzas. For this, we first create an abstract base class, `PizzaFactory` (`AbstractFactory` in the preceding UML diagram). The `PizzaFactory` class has two abstract methods, `createVegPizza()` and `createNonVegPizza()`, that need to be implemented by `ConcreteFactory`. In this example, we create two concrete factories, namely, `IndianPizzaFactory` and `USPizzaFactory`. Look at the following code implementation for the concrete factories:

```
from abc import ABCMeta, abstractmethod


class PizzaFactory(metaclass=ABCMeta):

    @abstractmethod
    def createVegPizza(self):
        pass

    @abstractmethod
    def createNonVegPizza(self):
        pass

class IndianPizzaFactory(PizzaFactory):

    def createVegPizza(self):
        return DeluxVeggiePizza()

    def createNonVegPizza(self):
        return ChickenPizza()


class USPizzaFactory(PizzaFactory):

    def createVegPizza(self):
        return MexicanVegPizza()

    def createNonVegPizza(self):
        return HamPizza()
```

Now, let's move ahead and define `AbstractProducts`. In the following code, we create two abstract classes, `VegPizza` and `NonVegPizza` (`AbstractProduct` and `AnotherAbstractProduct` in the preceding UML diagram]. They individually have a method defined, `prepare()` and `serve()`.

The thought process here is that vegetarian pizzas are prepared with an appropriate crust, vegetables, and seasoning, and nonvegetarian pizzas are served with nonvegetarian toppings on top of vegetarian pizzas.

We then define `ConcreteProducts` for each of the `AbstractProducts`. Now, in this case, we create `DeluxVeggiePizza` and `MexicanVegPizza` and implement the `prepare()` method. `ConcreteProducts1` and `ConcreteProducts2` would represent these classes from the UML diagram.

Later, we define `ChickenPizza` and `HamPizza` and implement the `serve()` method—these represent `AnotherConcreteProducts1` and `AnotherConcreteProducts2`:

```
class VegPizza(metaclass=ABCMeta):
    @abstractmethod
    def prepare(self, VegPizza):
        pass

class NonVegPizza(metaclass=ABCMeta):
    @abstractmethod
    def serve(self, VegPizza):
        pass

class DeluxVeggiePizza(VegPizza):
    def prepare(self):
        print("Prepare ", type(self).__name__)

class ChickenPizza(NonVegPizza):
    def serve(self, VegPizza):
        print(type(self).__name__, " is served with Chicken on ",
type(VegPizza).__name__)

class MexicanVegPizza(VegPizza):
    def prepare(self):
        print("Prepare ", type(self).__name__)

class HamPizza(NonVegPizza):
    def serve(self, VegPizza):
        print(type(self).__name__, " is served with Ham on ",
type(VegPizza).__name__)
```

When an end user approaches `PizzaStore` and asks for an American nonvegetarian pizza, `USPizzaFactory` is responsible for preparing the vegetarian pizza as the base and serving the nonvegetarian pizza with ham on top!

```
class PizzaStore:
    def __init__(self):
        pass
    def makePizzas(self):
        for factory in [IndianPizzaFactory(), USPizzaFactory()]:
            self.factory = factory
            self.NonVegPizza = self.factory.createNonVegPizza()
            self.VegPizza = self.factory.createVegPizza()
            self.VegPizza.prepare()
            self.NonVegPizza.serve(self.VegPizza)


pizza = PizzaStore()
pizza.makePizzas()
```

The following is the output of the preceding code example:

```
Prepare  DeluxVeggiePizza
ChickenPizza  is served with Chicken on  DeluxVeggiePizza
Prepare  MexicanVegPizza
HamPizza  is served with Ham on  MexicanVegPizza
```

The Factory method versus Abstract Factory method

Now that you have learned the Factory method and Abstract Factory method, let's see the comparison of the two:

Factory method	**Abstract Factory method**
This exposes a method to the client to create the objects	Abstract Factory method contains one or more factory methods to create a family of related objects
This uses inheritance and subclasses to decide which object to create	This uses composition to delegate responsibility to create objects of another class
The factory method is used to create one product	Abstract Factory method is about creating families of related products

Summary

In this chapter, you learned about the Factory design pattern and the context in which it's used. We understood the basics of the Factory, and how it is effectively used in software architecture.

We looked at Simple Factory, where an appropriate instance is created at runtime based on the type of the argument passed by the client.

We also discussed the Factory method pattern, which is a variation of Simple Factory. In this pattern, we defined an interface to create objects, but the creation of objects is deferred to the subclass.

We went on to explore the Abstract Factory method, which provides an interface to create families of related objects without specifying the concrete class.

We also worked out a real-world Python implementation for all the three patterns, and compared the Factory method with Abstract Factory method.

At the end of this chapter, we're now ready to take the next step and study other types of patterns, so stay tuned.

4
The Façade Pattern – Being Adaptive with Façade

In the previous chapter, you learned about the Factory design pattern. We discussed about three variations—Simple Factory, Factory method, and Abstract Factory pattern. You also learned how each of them is used in the real world and looked at Python implementations. We also compared the Factory method with Abstract Factory patterns and listed the pros and cons. As we are now aware, both the Factory design pattern and Singleton design pattern (*Chapter 2*, *The Singleton Design Pattern*) are classified as Creational design patterns.

In this chapter, we will move ahead and learn about another type of design pattern, the Structural design pattern. We will get introduced to the Façade design pattern and how it is used in software application development. We will work with a sample use case and implement it in Python v3.5.

In brief, we will cover the following topics in this chapter:

- An introduction to Structural design patterns
- An understanding of the Façade design pattern with a UML diagram
- A real-world use case with the Python v3.5 code implementation
- The Façade pattern and principle of least knowledge

Understanding Structural design patterns

The following points will help us understand more about Structural patterns:

- Structural patterns describe how objects and classes can be combined to form larger structures.
- Structural patterns can be thought of as design patterns that ease the design by identifying simpler ways to realize or demonstrate relationships between entities. Entities mean objects or classes in the object-oriented world.
- While the Class patterns describe abstraction with the help of inheritance and provide a more useful program interface, Object patterns describe how objects can be associated and composed to form larger objects. Structural patterns are a combination of Class and Object patterns.

The following are a few examples of different Structural design patterns. You'd notice how each of these involve interaction between objects or classes to achieve high-level design or architectural goals.

Some of the examples of Structural design patterns are as follows:

- **Adapter pattern**: Adapting an interface to another one so that it meets the client's expectations. It tries to match interfaces of different classes based on the client's needs.
- **Bridge pattern**: This decouples an object's interface from its implementation so that both can work independently.
- **Decorator pattern**: This defines additional responsibilities for an object at runtime or dynamically. We add certain attributes to objects with an interface.

There are a few more Structural patterns that you will learn in this book. So, let's start by first taking up the Façade design pattern.

Understanding the Façade design pattern

The façade is generally referred to as the face of the building, especially an attractive one. It can be also referred to as a behavior or appearance that gives a false idea of someone's true feelings or situation. When people walk past a façade, they can appreciate the exterior face but aren't aware of the complexities of the structure within. This is how a façade pattern is used. Façade hides the complexities of the internal system and provides an interface to the client that can access the system in a very simplified way.

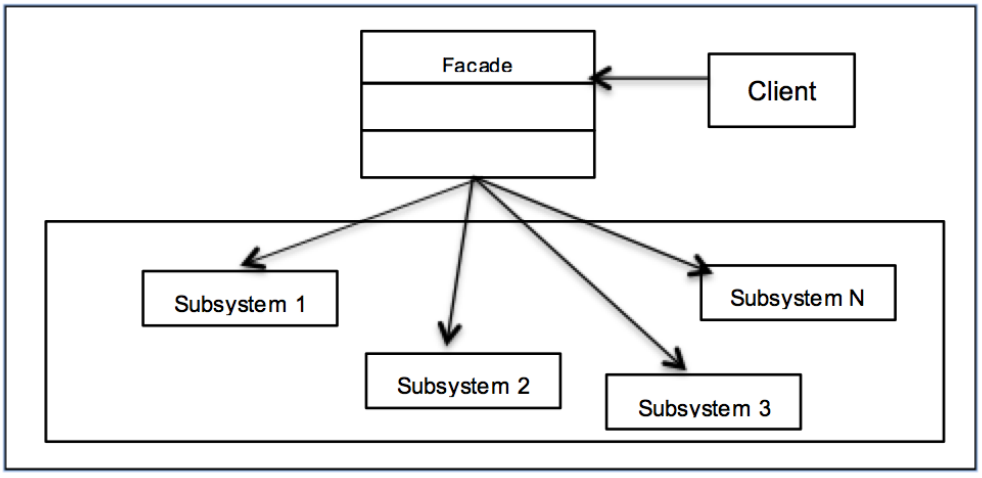
Consider the example of a storekeeper. Now, when you, as a customer, visit a store to buy certain items, you're not aware of the layout of the store. You typically approach the storekeeper, who is well aware of the store system. Based on your requirements, the storekeeper picks up items and hands them over to you. Isn't this easy? The customer need not know how the store looks and s/he gets the stuff done through a simple interface, the storekeeper.

The Façade design pattern essentially does the following:

- It provides a unified interface to a set of interfaces in a subsystem and defines a high-level interface that helps the client use the subsystem in an easy way.
- Façade discusses representing a complex subsystem with a single interface object. It doesn't **encapsulate** the subsystem but actually combines the underlying subsystems.
- It promotes the decoupling of the implementation with multiple clients.

A UML class diagram

We will now discuss the Façade pattern with the help of the following UML diagram:



As we observe the UML diagram, you'll realize that there are three main participants in this pattern:

- **Façade**: The main responsibility of a façade is to wrap up a complex group of subsystems so that it can provide a pleasing look to the outside world.
- **System**: This represents a set of varied subsystems that make the whole system compound and difficult to view or work with.
- **Client**: The client interacts with the Façade so that it can easily communicate with the subsystem and get the work completed. It doesn't have to bother about the complex nature of the system.

You will now learn a little more about the three main participants from the data structure's perspective.

Façade

The following points will give us a better idea of Façade:

- It is an interface that knows which subsystems are responsible for a request
- It delegates the client's requests to the appropriate subsystem objects using composition

For example, if the client is looking for some work to be accomplished, it need not have to go to individual subsystems but can simply contact the interface (Façade) that gets the work done

System

In the Façade world, System is an entity that performs the following:

- It implements subsystem functionality and is represented by a class. Ideally, a System is represented by a group of classes that are responsible for different operations.
- It handles the work assigned by the Façade object but has no knowledge of the façade and keeps no reference to it.

For instance, when the client requests the Façade for a certain service, Façade chooses the right subsystem that delivers the service based on the type of service

Client

Here's how we can describe the client:

- The client is a class that instantiates the Façade
- It makes requests to the Façade to get the work done from the subsystems

Implementing the Façade pattern in the real world

To demonstrate the applications of the Façade pattern, let's take an example that we'd have experienced in our lifetime.

Consider that you have a marriage in your family and you are in charge of all the arrangements. Whoa! That's a tough job on your hands. You have to book a hotel or place for marriage, talk to a caterer for food arrangements, organize a florist for all the decorations, and finally handle the musical arrangements expected for the event.

In yesteryears, you'd have done all this by yourself, for example by talking to the relevant folks, coordinating with them, negotiating on the pricing, but now life is simpler. You go and talk to an event manager who handles this for you. S/he will make sure that they talk to the individual service providers and get the best deal for you.

Putting it in the Façade pattern perspective:

- **Client**: It's you who need all the marriage preparations to be completed in time before the wedding. They should be top class and guests should love the celebrations.
- **Façade**: The event manager who's responsible for talking to all the folks that need to work on specific arrangements such as food, and flower decorations, among others
- **Subsystems**: They represent the systems that provide services such as catering, hotel management, and flower decorations

Let's develop an application in Python v3.5 and implement this use case. We start with the client first. It's you! Remember, you're the one who has been given the responsibility to make sure that the marriage preparations are done and the event goes fine!

Let's now move ahead and talk about the Façade class. As discussed earlier, the Façade class simplifies the interface for the client. In this case, `EventManager` acts as a façade and simplifies the work for `You`. Façade talks to the subsystems and does all the booking and preparations for the marriage on your behalf. Here is the Python code for the `EventManager` class:

```
class EventManager(object):

    def __init__(self):
        print("Event Manager:: Let me talk to the folks\n")

    def arrange(self):
        self.hotelier = Hotelier()
        self.hotelier.bookHotel()

        self.florist = Florist()
        self.florist.setFlowerRequirements()

        self.caterer = Caterer()
        self.caterer.setCuisine()

        self.musician = Musician()
        self.musician.setMusicType()
```

Now that we're done with the Façade and client, let's dive into the subsystems. We have developed the following classes for this scenario:

- `Hotelier` is for the hotel bookings. It has a method to check whether the hotel is free on that day (`__isAvailable`).
- The `Florist` class is responsible for flower decorations. Florist has the `setFlowerRequirements()` method to be used to set the expectations on the kind of flowers needed for the marriage decoration.
- The `Caterer` class is used to deal with the caterer and is responsible for the food arrangements. Caterer exposes the `setCuisine()` method to accept the type of cuisine to be served at the marriage.
- The `Musician` class is designed for musical arrangements at the marriage. It uses the `setMusicType()` method to understand the music requirements for the event.

Let us now look at the `Hotelier` object, followed by `Florist` object and their methods:

```
class Hotelier(object):
    def __init__(self):
        print("Arranging the Hotel for Marriage? --")

    def __isAvailable(self):
        print("Is the Hotel free for the event on given day?")
        return True

    def bookHotel(self):
        if self.__isAvailable():
            print("Registered the Booking\n\n")


class Florist(object):
    def __init__(self):
        print("Flower Decorations for the Event? --")

    def setFlowerRequirements(self):
        print("Carnations, Roses and Lilies would be used for
Decorations\n\n")


class Caterer(object):
    def __init__(self):
        print("Food Arrangements for the Event --")

    def setCuisine(self):
        print("Chinese & Continental Cuisine to be served\n\n")


class Musician(object):
    def __init__(self):
        print("Musical Arrangements for the Marriage --")

    def setMusicType(self):
        print("Jazz and Classical will be played\n\n")
```

However, you're being clever here and passing on the responsibility to the event manager, aren't you? Let's now look at the `You` class. In this example, you create an object of the `EventManager` class so that the manager can work with the relevant folks on marriage preparations while you relax.

```
class You(object):
    def __init__(self):
        print("You:: Whoa! Marriage Arrangements??!!!")
    def askEventManager(self):
        print("You:: Let's Contact the Event Manager\n\n")
        em = EventManager()
        em.arrange()
    def __del__(self):
        print("You:: Thanks to Event Manager, all preparations done!
Phew!")

you = You()
you.askEventManager()
```

The output of the preceding code is given here:

```
You:: Whoa! Marriage Arrangements??!!!
You:: Let's Contact the Event Manager


Event Manager:: Let me talk to the folks

Arranging the Hotel for Marriage? --
Is the Hotel free for the event on given day?
Registered the Booking..


Flower Decorations for the Event? --
Carnations, Roses and Lilies would be used for Decorations


Food Arrangements for the Event --
Chinese & Continental Cuisine to be served


Musical Arrangements for the Marriage --
Jazz and Classical will be played


You:: Thanks to Event Manager, all preparations done! Phew!
```

We can relate to the Facade pattern with the real world scenario, in the following way:

- The `EventManager` class is the Façade that simplifies the interface for `You`
- `EventManager` uses composition to create objects of the subsystems such as `Hotelier`, `Caterer`, and others

The principle of least knowledge

As you have learned in the initial parts of the chapter, the Façade provides a unified system that makes subsystems easy to use. It also decouples the client from the subsystem of components. The design principle that is employed behind the Façade pattern is the **principle of least knowledge**.

The principle of least knowledge guides us to reduce the interactions between objects to just a few *friends* that are close enough to you. In real terms, it means the following:

- When designing a system, for every object created, one should look at the number of classes that it interacts with and the way in which the interaction happens.
- Following the principle, make sure that we avoid situations where there are many classes created that are tightly coupled to each other.
- If there are a lot of dependencies between classes, the system becomes hard to maintain. Any changes in one part of the system can lead to unintentional changes to other parts of the system, which means that the system is exposed to regressions and this should be avoided.

Frequently asked questions

Q1. What is the Law of Demeter and how is it related to the Factory pattern?

A: The Law of Demeter is a design guideline that talks about the following:

1. Each unit should have only limited knowledge of other units in the system
2. A unit should talk to its friends only
3. A unit should not know about the internal details of the object that it manipulates

The principle of least knowledge and Law of Demeter are the same and both point to the philosophy of *loose coupling*. The principle of least knowledge fits the use case of the Façade pattern as the name is intuitive and the word principle acts as a guideline, not being strict, and being useful only when needed.

Q2. Can there be multiple Façades for a subsystem?

A: Yes, one could implement more than one façade for a group of subsystem components.

Q3. What are the disadvantages of the principle of least knowledge?

A: A Façade provides a simplified interface for the clients to interact with subsystems. In the spirit of providing a simplified interface, an application can have multiple unnecessary interfaces that add to the complexity of the system and reduce runtime performance.

Q4. Can the client access the subsystems independently?

A: Yes, in fact, the Façade pattern provides simplified interfaces so that the client need not be bothered about the complexity of the subsystems.

Q5. Does the Façade add any functionality of its own?

A: A Façade can add its "thinking" to the subsystems, such as making sure that the order of innovation for subsystems can be decided by the Façade.

Summary

We began the chapter by first understanding the Structural design patterns. You then learned about the Façade design pattern and the context in which it's used. We understood the basis of Façade and how it is effectively used in software architecture. We looked at how Façade design patterns create a simplified interface for clients to use. They simplify the complexity of subsystems so that the client benefits.

The Façade doesn't encapsulate the subsystem, and the client is free to access the subsystems even without going through the Façade. You also learned the pattern with a UML diagram and sample code implementation in Python v3.5. We understood the principle of least knowledge and how its philosophy governs the Façade design patterns.

We also covered a section on FAQs that would help you get more ideas on the pattern and its possible disadvantages. We're now geared up to learn more Structural patterns in the chapters to come.

5
The Proxy Pattern – Controlling Object Access

In the previous chapter, we started with a brief introduction to Structural patterns and went ahead to discuss about the Façade design pattern. We understood the concept of Façade with a UML diagram and also learned how it's applied in the real world with the help of Python implementations. You learned about the upsides and downsides of the Façade pattern in the FAQs section.

In this chapter, we take a step forward and deal with the Proxy pattern that falls under the hood of the Structural design patterns. We will get introduced to the Proxy pattern as a concept and go ahead with a discussion on the design pattern and see how it is used in software application development. We will work with a sample use case and implement it in Python v3.5.

In this chapter, we will cover the following topics in brief:

- An introduction to proxy and Proxy design patterns
- A UML diagram for the Proxy pattern
- Variations of Proxy patterns
- A real-world use case with the Python v3.5 code implementation
- Advantages of the Proxy pattern
- Comparison - Façade and the Proxy pattern
- Frequently asked questions

Understanding the Proxy design pattern

Proxy, in general terms, is a system that intermediates between the seeker and provider. Seeker is the one that makes the request, and provider delivers the resources in response to the request. In the web world, we can relate this to a proxy server. The clients (users in the World Wide Web), when they make a request to the website, first connect to a proxy server asking for resources such as a web page. The proxy server internally evaluates this request, sends it to an appropriate server, and gets back the response, which is then delivered to the client. Thus, a proxy server encapsulates requests, enables privacy, and works well in distributed architectures.

In the context of design patterns, `Proxy` is a class that acts as an interface to real objects. Objects can be of several types such as network connections, large objects in memory and file, among others. In short, `Proxy` is a wrapper or agent object that wraps the real serving object. Proxy could provide additional functionality to the object that it wraps and doesn't change the object's code. The main intention of the Proxy pattern is to provide a surrogate or placeholder for another object in order to control access to a real object.

The Proxy pattern is used in multiple scenarios such as the following:

- It represents a complex system in a simpler way. For example, a system that involves multiple complex calculations or procedures should have a simpler interface that can act as a proxy for the benefit of the client.
- It adds security to the existing real objects. In many cases, the client is not allowed to access the real object directly. This is because the real object can get compromised with malicious activities. This way proxies act as a shield against malicious intentions and protect the real object.
- It provides a local interface for remote objects on different servers. A clear example of this is with the distributed systems where the client wants to run certain commands on the remote system, but the client may not have direct permissions to make this happen. So it contacts a local object (proxy) with the request, which is then executed by the proxy on the remote machine.
- It provides a light handle for a higher memory-consuming object. Sometimes, you may not want to load the main objects unless they're really necessary. This is because real objects are really heavy and may need high resource utilization. A classic example is that of profile pictures of users on a website. You're much better off showing smaller profile images in the list view, but of course, you'll need to load the actual image to show the detailed view of the user profile.

Let's understand the pattern with a simple example. Consider the example of an `Actor` and his `Agent`. When production houses want to approach an `Actor` for a movie, typically, they talk to the `Agent` and not to the `Actor` directly. Based on the schedule of the `Actor` and other engagements, the `Agent` gets back to the production house on the availability and interest in working in the movie. Now, in this scenario, instead of production houses directly talking to the `Actor`, the `Agent` acts as a `Proxy` that handles all the scheduling & payments for the `Actor`.

The following Python code implements this scenario where the `Actor` is the `Proxy`. The `Agent` object is used to find out if the `Actor` is busy. If the `Actor` is busy, the `Actor().occupied()` method is called and if the `Actor` is not busy, the `Actor().available()` method gets returned.

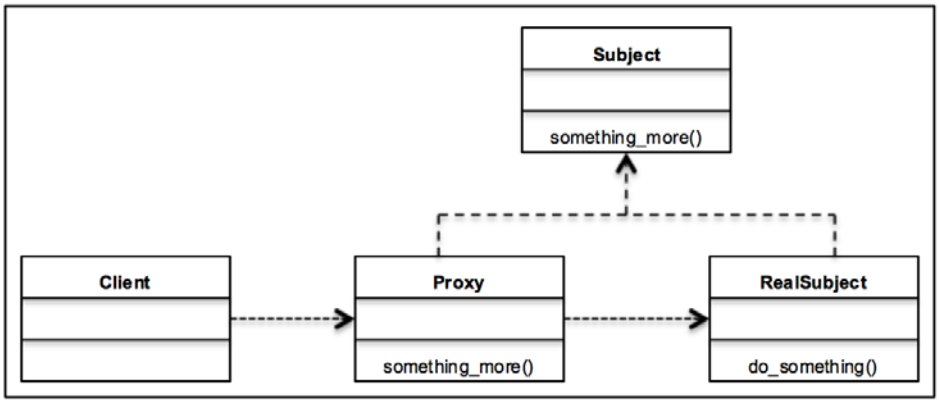
```
class Actor(object):
    def __init__(self):
        self.isBusy = False

    def occupied(self):
        self.isBusy = True
        print(type(self).__name__ , "is occupied with current movie")

    def available(self):
        self.isBusy = False
        print(type(self).__name__ , "is free for the movie")

    def getStatus(self):
        return self.isBusy

class Agent(object):
    def __init__(self):
        self.principal = None

    def work(self):
        self.actor = Actor()
        if self.actor.getStatus():
            self.actor.occupied()
        else:
            self.actor.available()


if __name__ == '__main__':
    r = Agent()
    r.work()
```

The Proxy design pattern essentially does the following:

- It provides a surrogate for another object so that you can control access to the original object
- It is used as a layer or interface to support distributed access
- It adds delegation and protects the real component from undesired impact

A UML class diagram for the Proxy pattern

We will now discuss the Proxy pattern with the help of the following UML diagram. As we discussed in the previous paragraph, the Proxy pattern has three main actors: the production house, `Agent`, and the `Actor`. Let's put these in a UML diagram and see how the classes look:



As we observe the UML diagram, you'll realize that there are three main participants in this pattern:

- `Proxy`: This maintains a reference that lets the `Proxy` access the real object. It provides an interface identical to the `Subject` so that `Proxy` can substitute the real subject. Proxies are also responsible for creating and deleting the `RealSubject`.
- `Subject`: It provides a representation for both, the `RealSubject` and `Proxy`. As `Proxy` and `RealSubject` implement `Subject`, `Proxy` can be used wherever `RealSubject` is expected.
- `RealSubject`: It defines the real object that the `Proxy` represents.

From the data structure's perspective, the UML diagram can be represented as follows:

- `Proxy`: It is a class that controls access to the `RealSubject` class. It handles the client's requests and is responsible for creating or deleting `RealSubject`.
- `Subject/RealSubject`: `Subject` is an interface that defines what `RealSubject` and `Proxy` should look like. `RealSubject` is an actual implementation of the `Subject` interface. It provides the real functionality that is then used by the client.
- `Client`: It accesses the `Proxy` class for the work to be accomplished. The `Proxy` class internally controls access to `RealSubject` and directs the work requested by `Client`.

Understanding different types of Proxies

There are multiple common situations where Proxies are used. We talked about some of them in the beginning of this chapter. Based on how the Proxies are used, we can categorize them as virtual proxy, remote proxy, protective proxy, and smart proxy. Let's learn a little more about them in this section.

A virtual proxy

Here, you'll learn in detail about the virtual proxy. It is a placeholder for objects that are very heavy to instantiate. For example, you want to load a large image on your website. Now this request will take a long time to load. Typically, developers will create a placeholder icon on the web page suggesting that there's an image. However, the image will only be loaded when the user actually clicks on the icon thus saving the cost of loading a heavy image in memory. Thus, in virtual proxies, the real object is created when the client first requests or accesses the object.

A remote proxy

A remote proxy can be defined in the following terms. It provides a local representation of a real object that resides on a remote server or different address space. For example, you want to build a monitoring system for your application that has multiple web servers, DB servers, celery task servers, caching servers, among others. If we want to monitor the CPU and disk utilization of these servers, we need to have an object that is available in the context of where the monitoring application runs but can perform remote commands to get the actual parameter values. In such cases, having a remote proxy object that is a local representation of the remote object would help.

A protective proxy

You'll understand more about the protective proxy with the following points. This proxy controls access to the sensitive matter object of `RealSubject`. For example, in today's world of distributed systems, web applications have multiple services that work together to provide functionality. Now, in such systems, an authentication service acts as a protective proxy server that is responsible for authentication and authorization. In this case, Proxy internally helps in protecting the core functionality of the website for unrecognized or unauthorized agents. Thus, the surrogate object checks that the caller has access permissions required to forward the request.

A smart proxy

Smart proxies interpose additional actions when an object is accessed. For example, consider that there's a core component in the system that stores states in a centralized location. Typically, such a component gets called by multiple different services to complete their tasks and can result in issues with shared resources. Instead of services directly invoking the core component, a smart proxy is built-in and checks whether the real object is locked before it is accessed in order to ensure that no other object can change it.

The Proxy pattern in the real world

We will take up a payment use case to demonstrate a real-world scenario for the Proxy pattern. Let's say that you go to shop at a mall and like a nice denim shirt there. You would like to purchase the shirt but you don't have enough cash to do so.

In yesteryears, you'd go to an ATM, take out the money, then come to the mall, and pay for it. Even earlier, you had a bank check for which you had to go to the bank, withdraw money, and then come back to pay for your expense.

Thanks to the banks, we now have something called a debit card. So now, when you want to purchase something, you present your debit card to the merchant. When you punch in your card details, the money is debited in the merchant's account for your expense.

Let's develop an application in Python v3.5 and implement the above use case. We start with the client first. You went to the shopping mall and now would like to purchase a nice denim shirt. Lets see how `Client` code is written:

- Your behavior is represented by the `You` class—the client
- To buy the shirt, the `make_payment()` method is provided by the class
- The special `__init__()` method calls the Proxy and instantiates it

- The `make_payment()` method invokes the Proxy's method internally to make the payment
- The `__del__()` method returns in case the payment is successful

Thus, the code example is as follows:

```
class You:
    def __init__(self):
        print("You:: Lets buy the Denim shirt")
        self.debitCard = DebitCard()
        self.isPurchased = None

    def make_payment(self):
        self.isPurchased = self.debitCard.do_pay()

    def __del__(self):
        if self.isPurchased:
            print("You:: Wow! Denim shirt is Mine :-)")
        else:
            print("You:: I should earn more :(")

you = You()
you.make_payment()
```

Now let's talk about the `Subject` class. As we know, the `Subject` class is an interface that is implemented by the `Proxy` and `RealSubject`.

- In this example, the subject is the `Payment` class. It is an abstract base class and represents an interface.
- `Payment` has the `do_pay()` method that needs to be implemented by the `Proxy` and `RealSubject`.

Let's see these methods in action in the following code:

```
from abc import ABCMeta, abstractmethod

class Payment(metaclass=ABCMeta):

    @abstractmethod
    def do_pay(self):
        pass
```

We also developed the `Bank` class that represents `RealSubject` in this scenario:

- `Bank` will actually make the payment from your account in the merchant's account.
- `Bank` has multiple methods to process the payment. The `setCard()` method is used by the `Proxy` to send the debit card details to the bank.
- The `__getAccount()` method is a private method of `Bank` that is used to get the account details of the debit card holder. For simplicity, we have enforced the debit card number to be the same as the account number.
- `Bank` also has the `__hasFunds()` method to see if the account holder has enough funds in the account to pay for the shirt.
- The `do_pay()` method that is implemented by the `Bank` class (from the Payment interface) is actually responsible for making the payment to the merchant based on available funds:

```
class Bank(Payment):

    def __init__(self):
        self.card = None
        self.account = None

    def __getAccount(self):
        self.account = self.card # Assume card number is account
number
        return self.account

    def __hasFunds(self):
        print("Bank:: Checking if Account", self.__getAccount(),
"has enough funds")
        return True

    def setCard(self, card):
        self.card = card

    def do_pay(self):
        if self.__hasFunds():
            print("Bank:: Paying the merchant")
            return True
        else:
            print("Bank:: Sorry, not enough funds!")
            return False
```

Let's now understand the last piece, which is the `Proxy`:

- The `DebitCard` class is the `Proxy` here. When `You` wants to make a payment, it calls the `do_pay()` method. This is because `You` doesn't want go to the bank to withdraw money and pay the merchant.
- The `DebitCard` class acts as a surrogate for the `RealSubject`, `Bank`.
- The `payWithCard()` method internally controls the object creation of `RealSubject`, the `Bank` class, and presents the card details to `Bank`.
- `Bank` goes through the internal checks on the account and does the payment, as described in previous code snippet:

```
class DebitCard(Payment):

    def __init__(self):
        self.bank = Bank()

    def do_pay(self):
        card = input("Proxy:: Punch in Card Number: ")
        self.bank.setCard(card)
        return self.bank.do_pay()
```

For a positive case, when funds are enough, the output is as follows:

```
You:: Lets buy the Denim shirt
Proxy:: Punch in Card Number: 23-2134-222
Bank:: Checking if Account 23-2134-222 has enough funds
Bank:: Paying the merchant
You:: Wow! Denim shirt is Mine :-)
```

For a negative case—insufficient funds—the output is as follows:

```
You:: Lets buy the Denim shirt
Proxy:: Punch in Card Number: 23-2134-222
Bank:: Checking if Account 23-2134-222 has enough funds
Bank:: Sorry, not enough funds!
You:: I should earn more :(
```

Advantages of the Proxy pattern

As we've seen how the Proxy pattern works in the real world, let's browse through the advantages of the Proxy pattern:

- Proxies can help improve the performance of the application by caching heavy objects or, typically, the frequently accessed objects
- Proxies also authorize the access to `RealSubject`; thus, this pattern helps in delegation only if the permissions are right
- Remote proxies also facilitate interaction with remote servers that can work as network connections and database connections and can be used to monitor systems

Comparing the Façade and Proxy patterns

Both the façade and proxy patterns are structural design patterns. They are similar in the sense that they both have a proxy/façade object in front of the real objects. Differences are really in the intent or purpose of the patterns, as shown in the following table:

Proxy pattern	**Façade pattern**
It provides you with a surrogate or placeholder for another object to control access to it	It provides you with an interface to large subsystems of classes
A Proxy object has the same interface as that of the target object and holds references to target objects	It minimizes the communication and dependencies between subsystems
It acts as an intermediary between the client and object that is wrapped	A Façade object provides a single, simplified interface

Frequently asked questions

Q1. What is the difference between the Decorator pattern and Proxy pattern?

A: A Decorator adds behavior to the object that it decorates at runtime, while a Proxy controls access to an object. The relationship between Proxy and `RealSubject` is at compile time and not dynamic.

Q2. What are the disadvantages of the Proxy pattern?

A: The Proxy pattern can increase the response time. For instance, if the Proxy is not well-architectured or has some performance issues, it can add to the response time of `RealSubject`. Generally, it all depends on how well a Proxy is written.

Q3. Can the client access `RealSubject` independently?

A: Yes, but there are certain advantages that Proxies provide such as virtual, remote, and others, so it's advantageous to use the Proxy pattern.

Q4. Does the Proxy add any functionality of its own?

A: A Proxy can add additional functionality to `RealSubject` without changing the object's code. Proxy and `RealSubject` would implement the same interface.

Summary

We began the chapter by understanding what Proxies are. We understood the basics of a Proxy and how it is used effectively in software architecture. You then learned about the Proxy design pattern and the context in which it's used. We looked at how the Proxy design patterns control access to the real object that provides the required functionality.

We also saw the pattern with a UML diagram and sample code implementation in Python v3.5.

Proxy patterns are implemented in four different ways: virtual proxy, remote proxy, protective proxy, and smart proxy. You learned about each of these with a real-world scenario.

We compared the Façade and Proxy design patterns so that the difference between their use cases and intentions are clear to you.

We also covered a section on FAQs that would help you get more ideas on the pattern and its possible advantages/disadvantages.

At the end of this chapter, we're now geared up to learn more Structural patterns in the chapters to come.

6
The Observer Pattern – Keeping Objects in the Know

In the previous chapter, we started with a brief introduction to Proxy and went ahead to discuss the Proxy design pattern. We understood the concept of the Proxy pattern with a UML diagram and also learned how it's applied in the real world with the help of Python implementations. You learned about the ups and downs of the Proxy pattern with the FAQ section.

In this chapter, we will talk about the third type of design pattern—the behavioral design pattern. We will be introduced to the Observer design pattern, which falls under the hood of Behavioral patterns. We will discuss how the Observer design pattern is used in software application development. We will work with a sample use case and implement it in Python v3.5.

In this chapter, we will cover the following topics in brief:

- An introduction to behavioral design patterns
- The Observer pattern and its UML diagram
- A real-world use case with the Python v3.5 code implementation
- The power of loose coupling
- Frequently asked questions

At the end of the chapter, we will summarize the entire discussion—consider this a takeaway.

Introducing Behavioral patterns

In the previous chapters of the book, you learned about creational patterns (Singleton) and structural patterns (Façade). In this section, we will get a brief idea of Behavioral patterns.

Creational patterns work on the basis of how objects can be created. They isolate the details of object creation. Code is independent of the type of object to be created. Structural patterns design the structure of objects and classes so that they can work together to achieve larger results. Their main focus is on simplifying the structure and identifying relationships between classes and objects.

Behavioral patterns, as the name suggests, focus on the responsibilities that an object has. They deal with the interaction among objects to achieve larger functionality. Behavioral patterns suggest that while the objects should be able to interact with each other, they should still be loosely coupled. We will learn about the principle of loose coupling later in this chapter.

The Observer design pattern is one of the simplest Behavioral patterns. So, let's gear up and understand more about them.

Understanding the Observer design pattern

In the Observer design pattern, an object (Subject) maintains a list of dependents (Observers) so that the Subject can notify all the Observers about the changes that it undergoes using any of the methods defined by the Observer.

In the world of distributed applications, multiple services interact with each other to perform a larger operation that a user wants to achieve. Services can perform multiple operations, but the operation they perform is directly or heavily dependent on the state of the objects of the service that it interacts with.

Consider a use case for user registration where the user service is responsible for user operations on the website. Let's say that we have another service called e-mail service that observes the state of the user and sends e-mails to the user. For example, if the user has just signed up, the user service will call a method of the e-mail service that will send an e-mail to the user for account verification. If the account is verified but has fewer credits, the e-mail service will monitor the user service and send an e-mail alert for low credits to the user.

Thus, if there's a core service in the application on which many other services are dependent, the core service becomes the Subject that has to be observed/monitored by the Observer for changes. The Observer should, in turn, make changes to the state of its own objects or take certain actions based on the changes that happen in the Subject. The above scenario, where the dependent service monitor's state changes in the core service, presents a classical case for the Observer design pattern.

In the case of a broadcast or publish/subscribe system, you'll find the usage of the Observer design pattern. Consider the example of a blog. Let's suppose that you're a tech enthusiast who loves to read about the latest articles on Python on this blog. What will you do? You subscribe to the blog. Like you, there would be multiple subscribers that are also registered with the blog. So, whenever there is a new blog, you get notified, or if there is a change on the published blog, you are also made aware of the edits. The way in which you're notified of the change can be an e-mail. Now if you apply this scenario to the Observer pattern, the blog is the Subject that maintains the list of subscribers or Observers. So when a new entry is added to the blog, all Observers are notified via e-mail or any other notification mechanism as defined by the Observer.

The main intentions of the Observer pattern are as follows:

- It defines a one-to-many dependency between objects so that any change in one object will be notified to the other dependent objects automatically
- It encapsulates the core component of the Subject

The Observer pattern is used in the following multiple scenarios:

- Implementation of the Event service in distributed systems
- A framework for a news agency
- The stock market also represents a great case for the Observer pattern

The following Python code implements the Observer design pattern:

```
class Subject:
    def __init__(self):
        self.__observers = []

    def register(self, observer):
        self.__observers.append(observer)

    def notifyAll(self, *args, **kwargs):
        for observer in self.__observers:
            observer.notify(self, *args, **kwargs)
```

```
class Observer1:
    def __init__(self, subject):
        subject.register(self)

    def notify(self, subject, *args):
        print(type(self).__name__,':: Got', args, 'From', subject)


class Observer2:
    def __init__(self, subject):
        subject.register(self)

    def notify(self, subject, *args):
        print(type(self).__name__, ':: Got', args, 'From', subject)


subject = Subject()
observer1 = Observer1(subject)
observer2 = Observer2(subject)
subject.notifyAll('notification')
```

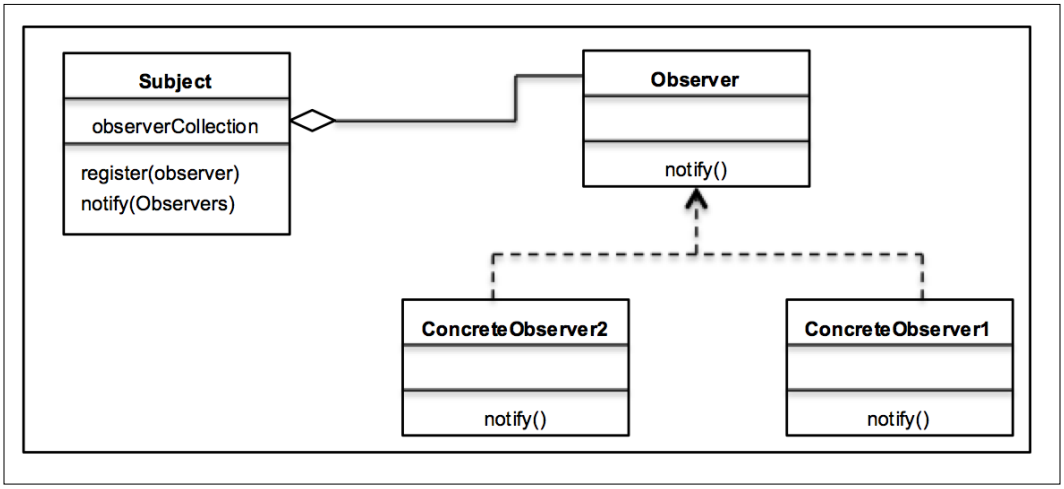
The output of the preceding code is as follows:

```
Observer1 :: Got ('notification',) From <__main__.Subject object at 0x102178630>
Observer2 :: Got ('notification',) From <__main__.Subject object at 0x102178630>
```

A UML class diagram for the Observer pattern

Let's now understand more about the Observer pattern with the help of the following UML diagram.

As we discussed in the previous paragraph, the Observer pattern has two main actors: the `Subject` and `Observer`. Let's put these in a UML diagram and see how the classes look:



As we look at the UML diagram, you'll realize that there are three main participants in this pattern:

- `Subject`: The `Subject` class is aware of the `Observer`. The `Subject` class has methods such as `register()` and `deregister()` that are used by `Observers` to register themselves with the `Subject` class. A `Subject`, thus can handle multiple `Observers`.
- `Observer`: It defines an interface for objects that are observing the Subject. It defines methods that need to be implemented by the `Observer` to get notified of changes in the Subject.
- `ConcreteObserver`: It stores the state that should be consistent with that of the `Subject's` state. It implements the `Observer` interface to keep the state consistent with changes in the Subject.

The flow is straightforward. `ConcreteObservers` register themselves with the Subject by implementing the interface provided by the `Observer`. Whenever there is a change in state, the Subject notifies all `ConcreteObservers` with the notify method provided by the `Observers`.

The Observer pattern in the real world

We will take up a news agency case to demonstrate the real-world scenario for the Observer pattern. News agencies typically gather news from various locations and publish them to the subscribers. Let's look at the design considerations for this use case.

With information being sent/received in real time, a news agency should be able to publish the news as soon as possible to its subscribers. Additionally, because of the advancements in the technology industry, it's not just the newspapers, but also the subscribers that can be of different types such as an e-mail, mobile, SMS, or voice call. We should also be able to add any other type of subscriber in the future and budgeting for any new technology.

Let's develop an application in Python v3.5 and implement the preceding use case. We will start with the Subject, which is the news publisher:

- Subject behavior is represented by the `NewsPublisher` class
- `NewsPublisher` provides you with an interface so that subscribers can work with it
- The `attach()` method is used by the `Observer` to register with `NewsPublisher` and the `detach()` method helps in deregistering the `Observer`
- The `subscriber()` method returns the list of all the subscribers that have already registered with the `Subject`
- The `notifySubscriber()` method iterates over all the subscribers that have registered with `NewsPublisher`
- The `addNews()` method is used by the publisher to create new news and `getNews()` is used to return the latest news, which is then notified to the `Observer`

Let's first look at the `NewsPublisher` class:

```
class NewsPublisher:
    def __init__(self):
        self.__subscribers = []
        self.__latestNews = None

    def attach(self, subscriber):
        self.__subscribers.append(subscriber)

    def detach(self):
        return self.__subscribers.pop()

    def subscribers(self):
        return [type(x).__name__ for x in self.__subscribers]

    def notifySubscribers(self):
        for sub in self.__subscribers:
            sub.update()
```

```
    def addNews(self, news):
        self.__latestNews = news

    def getNews(self):
        return "Got News:", self.__latestNews
```

Let's talk about the `Observer` interface now:

- In this example, `Subscriber` represents the `Observer`. It is an abstract base class and represents any other `ConcreteObserver`.
- `Subscriber` has the `update()` method that needs to be implemented by `ConcreteObservers`.
- The `update()` method is implemented by `ConcreteObserver` so that they get notified by the `Subject` (`NewsPublishers`) about any news getting published.

Lets us now look at the code for the `Subscriber` abstract class:

```
from abc import ABCMeta, abstractmethod

class Subscriber(metaclass=ABCMeta):

    @abstractmethod
    def update(self):
        pass
```

We also developed certain classes that represent `ConcreteObserver`:

- In this case, we have two main observers: `EmailSubscriber` and `SMSSubscriber` that implement the subscriber interface
- In addition to these two, we have another Observer, `AnyOtherObserver`, that demonstrates the loose coupling of `Observers` with the `Subject`
- The `__init__()` method of each of these `ConcreteObservers` registers them with `NewsPublisher` with the `attach()` method
- The `update()` method of `ConcreteObserver` is used internally by `NewsPublisher` to notify about the news additions

Here's how the `SMSSubscriber` class is implemented:

```
class SMSSubscriber:
    def __init__(self, publisher):
        self.publisher = publisher
        self.publisher.attach(self)
```

```
        def update(self):
            print(type(self).__name__, self.publisher.getNews())

    class EmailSubscriber:
        def __init__(self, publisher):
            self.publisher = publisher
            self.publisher.attach(self)

        def update(self):
            print(type(self).__name__, self.publisher.getNews())

    class AnyOtherSubscriber:
        def __init__(self, publisher):
            self.publisher = publisher
            self.publisher.attach(self)

        def update(self):
            print(type(self).__name__, self.publisher.getNews())
```

Now that all the required subscribers have been implemented, lets look at the `NewsPublisher` and `SMSSubscribers` class in action:

- The client creates an object for `NewsPublisher` that is used by `ConcreteObservers` for various operations
- `SMSSubscriber`, `EmailSubscriber`, and `AnyOtherSubscriber` classes are initialized with publisher objects.
- In Python, when we create objects, the `__init__()` method gets called. In the `ConcreteObserver` class, the `__init__()` method internally uses the `attach()` method of `NewsPublisher` to register itself for news updates.
- We then print the list of all the subscribers (`ConcreteObservers`) that got registered with the `Subject`.
- The object of `NewsPublisher (news_publisher)` is then used to create new news with the `addNews()` method.
- The `notifySubscribers()` method of `NewsPublisher` is used to notify all subscribers of the news addition. The `notifySubscribers()` method internally calls the `update()` method implemented by `ConcreteObservers` so that they get the latest news.
- `NewsPublisher` also has the `detach()` method that removes the subscriber from the list of registered subscribers.

The following code implementation represents the interactions between the `Subject` and `Observers`:

```
if __name__ == '__main__':
    news_publisher = NewsPublisher()
```

```
    for Subscribers in [SMSSubscriber, EmailSubscriber,
AnyOtherSubscriber]:
        Subscribers(news_publisher)
    print("\nSubscribers:", news_publisher.subscribers())

    news_publisher.addNews('Hello World!')
    news_publisher.notifySubscribers()

    print("\nDetached:", type(news_publisher.detach()).__name__)
    print("\nSubscribers:", news_publisher.subscribers())

    news_publisher.addNews('My second news!')
    news_publisher.notifySubscribers()
```

The output of the preceding code is as follows:

```
Subscribers: ['SMSSubscriber', 'EmailSubscriber', 'AnyOtherSubscriber']
SMSSubscriber ('Got News:', 'Hello World!')
EmailSubscriber ('Got News:', 'Hello World!')
AnyOtherSubscriber ('Got News:', 'Hello World!')

Detached: AnyOtherSubscriber

Subscribers: ['SMSSubscriber', 'EmailSubscriber']
SMSSubscriber ('Got News:', 'My second news!')
EmailSubscriber ('Got News:', 'My second news!')
```

The Observer pattern methods

There are two different ways of notifying the `Observer` of the changes that happen in the `Subject`. They can be classified as push or pull models.

The pull model

In the pull model, `Observers` play an active role as follows:

- The `Subject` broadcasts to all the registered `Observers` when there is any change
- The `Observer` is responsible for getting the changes or pulling data from the subscriber when there is an amendment
- The pull model is ineffective as it involves two steps—the first step where the `Subject` notifies the `Observer` and the second step where the `Observer` pulls the required data from the Subject

The push model

In the push model, the `Subject` is the one that plays a dominant role as follows:

- Unlike the pull model, the changes are pushed by the `Subject` to the `Observer`.
- In this model, the Subject can send detailed information to the `Observer` (even though it may not be needed). This can result in sluggish response times when a large amount of data is sent by the `Subject` but is never actually used by the `Observer`.
- Only the required data is sent from the `Subject` so that the performance is better.

Loose coupling and the Observer pattern

Loose coupling is an important design principle that should be used in software applications. The main purpose of loose coupling is to strive for loosely-coupled designs between objects that interact with each other. Coupling refers to the degree of knowledge that one object has about the other object that it interacts with.

Loosely-coupled designs allow us to build flexible object-oriented systems that can handle changes because they reduce the dependency between multiple objects.

The loose coupling architecture ensures following features:

- It reduces the risk that a change made within one element might create an unanticipated impact on the other elements
- It simplifies testing, maintenance, and troubleshooting problems
- The system can be easily broken down into definable elements

The Observer pattern provides you with an object design where the `Subject` and `Observer` are loosely coupled. The following points will explain this better:

- The only thing that the `Subject` knows about an `Observer` is that it implements a certain interface. It need not know the `ConcreteObserver` class.
- Any new `Observer` can be added at any point in time (as we saw in the sample example earlier in this chapter).
- The `Subject` need not be modified at all to add any new `Observer`. In the example, we saw that `AnyOtherObserver` can be added/removed without any changes in the `Subject`.
- Subjects or `Observers` are not tied up and can be used independently of each other. So the `Observer` can be reused anywhere else, if needed.

- Changes in the `Subject` or `Observer` will not affect each other. As both are independent or loosely coupled, they are free to make their own changes.

The Observer pattern – advantages and disadvantages

The Observer pattern provides you with the following advantages:

- It supports the principle of loose coupling between objects that interact with each other
- It allows sending data to other objects effectively without any change in the `Subject` or `Observer` classes
- `Observers` can be added/removed at any point in time

The following are the disadvantages of the Observer pattern:

- The Observer interface has to be implemented by `ConcreteObserver`, which involves inheritance. There is no option for composition, as the Observer interface can be instantiated.
- If not correctly implemented, the `Observer` can add complexity and lead to inadvertent performance issues.
- In software application, notifications can, at times, be undependable and result in race conditions or inconsistency.

Frequently asked questions

Q1. Can there be many `Subjects` and `Observers`?

A: There can be a case for a software application to have multiple `Subjects` and Observers. For this to work, `Observers` need to be notified of changes in the `Subjects` and which `Subject` underwent a change.

Q2. Who is responsible for triggering the update?

A: As you learned earlier, the Observer pattern can work in both push and pull models. Typically, the Subject triggers the update method when there are changes, but sometimes based on the application need, the **Observer** can also trigger notifications. However, care needs to be taken that the frequency should not be too high, otherwise it can lead to performance degradation, especially when the updates to the Subject are less frequent.

Q3. Can the `Subject` or `Observer` be used for access for any other use case?

A: Yes, that's the power of loose coupling that is manifested in the Observer pattern. The `Subject/Observer` can both be independently used.

Summary

We began the chapter by understanding the behavioral design patterns. We understood the basis of the Observer pattern and how it is effectively used in software architecture. We looked at how Observer design patterns are used to notify the `Observer` of the changes happening in the `Subject`. They manage the interaction between objects and manage one-to-many dependencies on the objects.

You also learned the pattern with a UML diagram and sample code implementation in Python v3.5.

Observer patterns are implemented in two different ways: push and pull models. You learned about each of these and discussed their implementation and performance impact.

We understood the principle of loose coupling in software design and how the Observer pattern leverages this principle in application development.

We also covered a section on FAQs that would help you get more ideas about the pattern and its possible advantages/disadvantages.

At the end of this chapter, we're now geared up to learn more Behavioral patterns in the chapters to come.

7
The Command Pattern – Encapsulating Invocation

In the previous chapter, we started with an introduction to behavioral design patterns. You learned the concept of `Observers` and discussed the Observer design pattern. We understood the concept of the Observer design pattern with a UML diagram and also learned how it's applied in the real world with the help of Python implementations. We discussed the pros and cons of the Observer pattern. You also learned about the Observer pattern with an FAQ section and summarized the discussion at the end of the chapter.

In this chapter, we will talk about the Command design pattern. Like the Observer pattern, the Command pattern falls under the hood of Behavioral patterns. We will get introduced to the Command design pattern and discuss how it is used in software application development. We will work with a sample use case and implement it in Python v3.5.

In this chapter, we will cover the following topics in brief:

- An introduction to Command design patterns
- The Command pattern and its UML diagram
- A real-world use case with the Python v3.5 code implementation
- The Command pattern's pros and cons
- Frequently asked questions

Introducing the Command pattern

As we saw in the previous chapter, Behavioral patterns focus on the responsibilities that an object has. It deals with the interaction among objects to achieve larger functionality. The Command pattern is a behavioral design pattern in which an object is used to encapsulate all the information needed to perform an action or trigger an event at a later time. This information includes the following:

- The method name
- An object that owns the method
- Values for method parameters

Let's understand the pattern with a very simple software example. Consider the case of an installation wizard. A typical wizard may contain multiple phases or screens that capture a user's preferences. While the user browses through the wizard, s/he makes certain choices. Wizards are typically implemented with the Command pattern. A wizard is first launched with an object called the `Command` object. The preferences or choices made by the user in multiple phases of the wizard are then stored in the `Command` object. When the user clicks on the **Finish** button on the last screen of the wizard, the `Command` object runs an `execute()` method, which considers all the stored choices and runs the appropriate installation procedure. Thus, all the information regarding the choices are encapsulated in an object that can be used later to take an action.

Another easy example is that of the printer spooler. A spooler can be implemented as a `Command` object that stores information such as the page type (*A5-A1*), portrait/landscape, collated/non-collated. When the user prints something (say, an image), the spooler runs the `execute()` method on the `Command` object and the image is printed with the set preferences.

Understanding the Command design pattern

The Command pattern works with the following terms—`Command`, `Receiver`, `Invoker`, and `Client`:

- A `Command` object knows about the `Receiver` objects and invokes a method of the `Receiver` object.
- Values for parameters of the receiver method are stored in the `Command` object

- The invoker knows how to execute a command
- The client creates a `Command` object and sets its receiver

The main intentions of the Command pattern are as follows:

- Encapsulating a request as an object
- Allowing the parameterization of clients with different requests
- Allowing to save the requests in a queue (we will talk about this later in the chapter)
- Providing an object-oriented callback

The Command pattern can be used in the following multiple scenarios:

- Parameterizing objects depending on the action to be performed
- Adding actions to a queue and executing requests at different points
- Creating a structure for high-level operations that are based on smaller operations

The following Python code implements the Command design pattern. We talked about the example of the wizard earlier in the chapter. Consider that we want to develop a wizard for installation or, popularly, installer. Typically, an installation implies the copying or moving of files in the filesystem based on the choices that a user makes. In the following example, in the client code, we start by creating the `Wizard` object and use the `preferences()` method that stores the choices made by the user during various screens of the wizard. On the wizard, when **Finish** button is clicked, the `execute()` method is called. The `execute()` method picks up the preference and starts the installation:

```
class Wizard():

    def __init__(self, src, rootdir):
        self.choices = []
        self.rootdir = rootdir
        self.src = src

    def preferences(self, command):
        self.choices.append(command)

    def execute(self):
        for choice in self.choices:
```

```
            if list(choice.values())[0]:
                print("Copying binaries --", self.src, " to ", self.
rootdir)
            else:
                print("No Operation")


if __name__ == '__main__':
  ## Client code
  wizard = Wizard('python3.5.gzip', '/usr/bin/')
  ## Users chooses to install Python only
  wizard.preferences({'python':True})
  wizard.preferences({'java':False})
  wizard.execute()
```

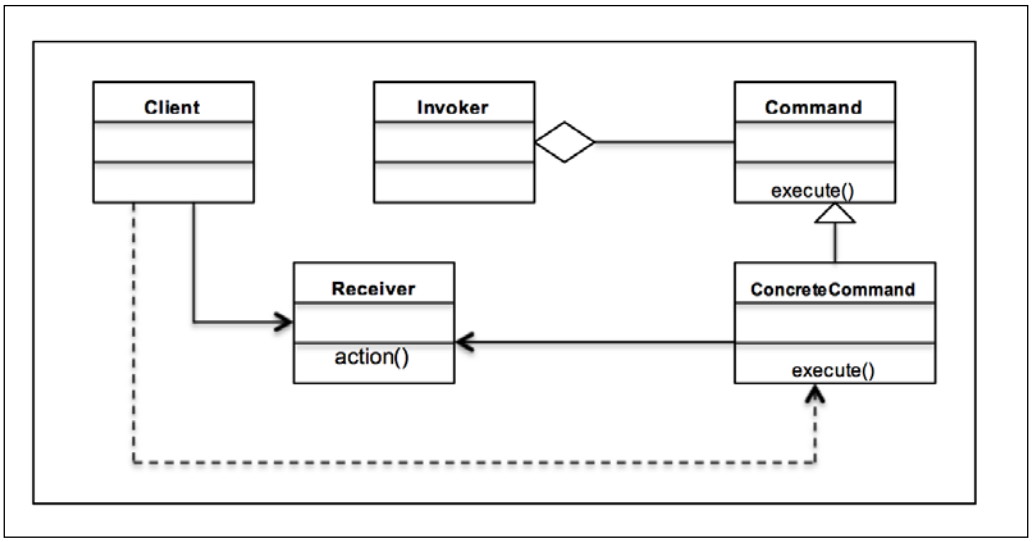
The output of the preceding code is as follows:

```
Copying binaries -- python3.5.gzip  to  /usr/bin
No Operation
```

A UML class diagram for the Command pattern

Let's now understand more about the Command pattern with the help of the following UML diagram.

As we discussed in the previous paragraph, the Command pattern has these main participants: the `Command`, `ConcreteCommand`, `Receiver`, `Invoker`, and `Client`. Let's put these in a UML diagram and see how the classes look:



As we look at the UML diagram, you'll realize that there are five main participants in this pattern:

- `Command`: This declares an interface to execute an operation
- `ConcreteCommand`: This defines a binding between the `Receiver` object and action
- `Client`: This creates a `ConcreteCommand` object and sets its receiver
- `Invoker`: This asks `ConcreteCommand` to carry out the request
- `Receiver`: This knows how to perform the operations associated with carrying out the request

The flow is straightforward. The client asks for a command to be executed. The invoker takes the command, encapsulates it, and places it in a queue. The `ConcreteCommand` class is in charge of the requested command and asks the receiver to perform the given action. The following code example is to understand the pattern with all the participants involved:

```
from abc import ABCMeta, abstractmethod

class Command(metaclass=ABCMeta):
    def __init__(self, recv):
        self.recv = recv

    def execute(self):
        pass


class ConcreteCommand(Command):
    def __init__(self, recv):
        self.recv = recv

    def execute(self):
        self.recv.action()


class Receiver:
    def action(self):
        print("Receiver Action")


class Invoker:
    def command(self, cmd):
        self.cmd = cmd

    def execute(self):
        self.cmd.execute()


if __name__ == '__main__':
    recv = Receiver()
    cmd = ConcreteCommand(recv)
    invoker = Invoker()
    invoker.command(cmd)
    invoker.execute()
```

Implementing the Command pattern in the real world

We will take up an example of the stock exchange (much talked about in the Internet world) to demonstrate the implementation of the Command pattern. What happens in a stock exchange? You, as a user of the stock exchange, create orders to buy or sell stocks. Typically, you don't buy or sell them; it's the agent or broker who plays the intermediary between you and the stock exchange. The agent is responsible for taking your request to the stock exchange and getting the work done. Imagine that you want to sell a stock on Monday morning when the exchange opens up. You can still make the request to sell stock on Sunday night to your agent even though the exchange is not yet open. The agent then queues this request to be executed on Monday morning when the exchange is open for the trading. This presents a classical case for the Command pattern.

Design considerations

Based on the UML diagram, you learned that the Command pattern has four main participants—`Command`, `ConcreteCommand`, `Invoker`, and `Receiver`. For the preceding scenario, we should create an `Order` interface that defines the order that a client places. We should define `ConcreteCommand` classes to buy or sell a stock. A class also needs to be defined for the stock exchange. We should define the `Receiver` class that will actually execute the trade and the agent (known as the invoker) that invokes the order and gets it executed by the receiver.

Let's develop an application in Python v3.5 and implement the preceding use case. We start with the `Command` object, `Order`:

- The `Command` object is represented by the `Order` class
- `Order` provides you with an interface (Python's abstract base class) so that `ConcreteCommand` can implement the behavior
- The `execute()` method is the abstract method that needs to be defined by the `ConcreteCommand` classes to execute the `Order` class

The following code represents the abstract class `Order` and the abstract method `execute()`:

```
from abc import ABCMeta, abstractmethod

class Order(metaclass=ABCMeta):

    @abstractmethod
    def execute(self):
        pass
```

We have also developed certain classes that represent `ConcreteCommand`:

- In this case, we have two main concrete classes: `BuyStockOrder` and `SellStockOrder` that implement the `Order` interface
- Both the `ConcreteCommand` classes use the object of the stock trading system so that they can define appropriate actions for the trading system
- The `execute()` method of each of these `ConcreteCommand` classes uses the stock trade object to execute the actions to buy and sell

Let's now look at concrete classes that implement the interface:

```
class BuyStockOrder(Order):
    def __init__(self, stock):
        self.stock = stock

    def execute(self):
        self.stock.buy()


class SellStockOrder(Order):
    def __init__(self, stock):
        self.stock = stock

    def execute(self):
        self.stock.sell()
```

Now, let's talk about the stock trading system and how it's implemented:

- The `StockTrade` class represents the `Receiver` object in this example
- It defines multiple methods (actions) to execute the orders placed by `ConcreteCommand` objects
- The `buy()` and `sell()` methods are defined by the receiver which are called by `BuyStockOrder` and `SellStockOrder` respectively to buy or sell the stock in the exchange

Let's take a look at the `StockTrade` class:

```
class StockTrade:
    def buy(self):
        print("You will buy stocks")

    def sell(self):
        print("You will sell stocks")
```

Another part of the implementation is the invoker:

- The `Agent` class represents the invoker.
- Agent is the intermediary between the client and `StockExchange` and executes the orders placed by the client.
- Agent defines a data member, `__orderQueue` (a list), that acts as a queue. Any new orders placed by the client are added to the queue.
- The `placeOrder()` method of Agent is responsible for queuing the orders and also executing the orders.

The following code depicts the `Agent` class which performs the role of `Invoker`:

```
class Agent:
    def __init__(self):
        self.__orderQueue = []

    def placeOrder(self, order):
        self.__orderQueue.append(order)
        order.execute()
```

Let us now put all the above classes into perspective and look at how the client is implemented:

- The client first sets its receiver, the `StockTrade` class
- It creates orders to buy and sell stocks with `BuyStockOrder` and `SellStockOrder` (`ConcreteCommand`) that executes the action on `StockTrade`
- The invoker object is created by instantiating the `Agent` class
- The `placeOrder()` method of `Agent` is used to get the orders that the client places

The following is the code for the client is implemented:

```
if __name__ == '__main__':
    #Client
    stock = StockTrade()
    buyStock = BuyStockOrder(stock)
    sellStock = SellStockOrder(stock)

    #Invoker
    agent = Agent()
    agent.placeOrder(buyStock)
    agent.placeOrder(sellStock)
```

The following is the output of the preceding code:

```
You will buy stocks
You will sell stocks
```

There are multiple ways in which the Command pattern is used in software applications. We will discuss two specific implementations that are very relevant to the cloud applications:

- Redo or rollback operations:
    - While implementing the rollback or redo operations, developers can do two different things.
    - These are to create a snapshot in the filesystem or memory, and when asked for a rollback, revert to this snapshot.
    - With the Command pattern, you can store the sequence of commands, and when asked for a redo, rerun the same set of actions.
- Asynchronous task execution:
    - In distributed systems, we often need the facility to perform the asynchronous execution of tasks so that the core service is never blocked in case of more requests.
    - In the Command pattern, the invoker object can maintain a queue of requests and send these tasks to the `Receiver` object so that they can be acted on independent of the main application thread.

Advantages and disadvantages of Command patterns

The Command pattern has the following advantages:

- It decouples the classes that invoke the operation from the object that knows how to execute the operation
- It allows you to create a sequence of commands by providing a queue system
- Extensions to add a new command is easy and can be done without changing the existing code
- You can also define a rollback system with the Command pattern, for example, in the Wizard example, we could write a rollback method

The following are the disadvantages of the Command pattern:

- There are a high number of classes and objects working together to achieve a goal. Application developers need to be careful developing these classes correctly.
- Every individual command is a `ConcreteCommand` class that increases the volume of classes for implementation and maintenance.

Frequently asked questions

Q1. Can there be no `Receiver` and `ConcreteCommand` implement execute method?

A: Yes, it is definitely possible to do so. Many software applications use the Command pattern in this way too. The only thing to note here is the interaction between the invoker and receiver. If the receiver is not defined, the level of decoupling goes down; moreover, the facility to parameterize commands is lost.

Q2. What data structure do I use to implement the queue mechanism in the invoker object?

A: In the stock exchange example that we studied earlier in the chapter, we used a list to implement the queue. However, the Command pattern talks about a stack implementation that is really helpful in the case of redo or rollback development.

Summary

We began the chapter by understanding the Command design pattern and how it is effectively used in software architecture.

We looked at how Command design patterns are used to encapsulate all the information needed to trigger an event or action at a later point in time.

You also learned the pattern with a UML diagram and sample code implementation in Python v3.5 along with the explanation.

We also covered an FAQ section that would help you get more ideas on the pattern and its possible advantages/disadvantages.

We will now take up other behavioral design patterns in the chapters to come.

8
The Template Method Pattern – Encapsulating Algorithm

In the previous chapter, we started with an introduction to the Command design pattern in which an object is used to encapsulate all the information needed to perform an action or trigger an event at a later time. We understood the concept of the Command design pattern with a UML diagram and also saw how it's applied in the real world with the help of the Python implementation. We discussed the pros and cons of Command patterns, explored more in the FAQ section, and summarized the discussion at the end of the chapter.

In this chapter, we will talk about the Template design pattern, such as the Command pattern and Template pattern that falls under the hood of Behavioral patterns. We will get introduced to the Template design pattern and discuss how it is used in software application development. We will also work with a sample use case and implement it in Python v3.5.

In this chapter, we will cover the following topics in brief:

- An introduction to the Template Method design pattern
- The Template pattern and its UML diagram
- A real-world use case with the Python v3.5 code implementation
- The Template pattern – pros and cons
- The Hollywood principle, Template Method, and Template hook
- Frequently asked questions

At the end of this chapter, you will be able to analyze situations where the Template design pattern is applicable and efficiently use them to solve design-related problems. We will also summarize the entire discussion on the Template Method pattern as a takeaway.

Defining the Template Method pattern

As we saw in the previous chapter, Behavioral patterns focus on the responsibilities that an object has. It deals with the interaction among objects to achieve larger functionality. The Template Method pattern is a behavioral design pattern that defines the program skeleton or an algorithm in a method called the Template Method. For example, you could define the steps to prepare a beverage as an algorithm in a Template Method. The Template Method pattern also helps redefine or customize certain steps of the algorithm by deferring the implementation of some of these steps to subclasses. This means that the subclasses can redefine their own behavior. For example, in this case, subclasses can implement steps to prepare tea using the Template Method to prepare a beverage. It is important to note that the change in the steps (as done by the subclasses) don't impact the original algorithm's structure. Thus, the facility of overriding by subclasses in the Template Method pattern allows the creation of different behaviors or algorithms.

To talk about the Template Method pattern in software development terminology, an abstract class is used to define the steps of the algorithm. These steps are also known as *primitive operations* in the context of the Template Method pattern. These steps are defined with abstract methods, and the Template Method defines the algorithm. The `ConcreteClass` (that subclasses the abstract class) implements subclass-specific steps of the algorithm.

The Template Method pattern is used in the following cases:

- When multiple algorithms or classes implement similar or identical logic
- The implementation of algorithms in subclasses helps reduce code duplication
- Multiple algorithms can be defined by letting the subclasses implement the behavior through overriding

Let's understand the pattern with a very simple day-to-day example. Think of what all you do when you prepare tea or coffee. In the case of coffee, you perform the following steps to prepare the beverage:

1. Boil water.
2. Brew coffee beans.
3. Pour it in the coffee cup.
4. Add sugar and milk to the cup.
5. Stir, and the coffee is done.

Now, if you want to prepare a cup of tea, you will perform the following steps:

1. Boil water.
2. Steep the tea bag.
3. Pour the tea in a cup.
4. Add lemon to the tea.
5. Stir, and the tea is done.

If you analyze both the preparations, you will find that both the procedures are more or less the same. In this case, we can use the Template Method pattern effectively. How do we implement it? We define a `Beverage` class that has abstract methods common to preparing tea and coffee, such as `boilWater()`. We also define the `preparation()` Template Method that will call out the sequence of steps in preparing the beverage (the algorithm). We let the concrete classes, `PrepareCoffee` and `PrepareTea`, define the customized steps to achieve the goals of preparing coffee and tea. This is how the Template Method pattern avoids code duplication.

Another easy example is that of the compiler used by computer languages. A compiler essentially does two things: collects the source and compiles to the target object. Now, if we need to define a cross compiler for iOS devices, we can implement this with the help of the Template Method pattern. We will read about this example in detail later in the chapter.

Understanding the Template Method design pattern

In short, the main intentions of the Template Method pattern are as follows:

- Defining a skeleton of an algorithm with primitive operations
- Redefining certain operations of the subclass without changing the algorithm's structure
- Achieving code reuse and avoiding duplicate efforts
- Leveraging common interfaces or implementations

The Template Method pattern works with the following terms—`AbstractClass`, `ConcreteClass`, Template Method, and `Client`:

- `AbstractClass`: This declares an interface to define the steps of the algorithm
- `ConcreteClass`: This defines subclass-specific step definitions
- `template_method()`: This defines the algorithm by calling the step methods

We talked about the example of a compiler earlier in the chapter. Consider that we want to develop our own cross compiler for an iOS device and run the program.

We first develop an abstract class (compiler) that defines the algorithm of a compiler. The operations done by the compiler are collecting the source of the code written in a program language and then compiling it to get the object code (binary format). We define these steps as the `collectSource()` and `compileToObject()` abstract methods and also define the `run()` method that is responsible for executing the program. The algorithm is defined by the `compileAndRun()` method, which internally calls the `collectSource()`, `compileToObject()`, and `run()` methods to define the algorithm of the compiler. The `iOSCompiler` concrete class now implements the abstract methods and compiles/runs the Swift code on the iOS device.

The Swift programming language is used to develop applications on the iOS platform.

The following Python code implements the Template Method design pattern:

```
from abc import  ABCMeta, abstractmethod

class Compiler(metaclass=ABCMeta):
    @abstractmethod
    def collectSource(self):
        pass

    @abstractmethod
    def compileToObject(self):
        pass

    @abstractmethod
    def run(self):
        pass

    def compileAndRun(self):
        self.collectSource()
        self.compileToObject()
        self.run()


class iOSCompiler(Compiler):
    def collectSource(self):
        print("Collecting Swift Source Code")

    def compileToObject(self):
        print("Compiling Swift code to LLVM bitcode")

    def run(self):
        print("Program runing on runtime environment")


iOS = iOSCompiler()
iOS.compileAndRun()
```

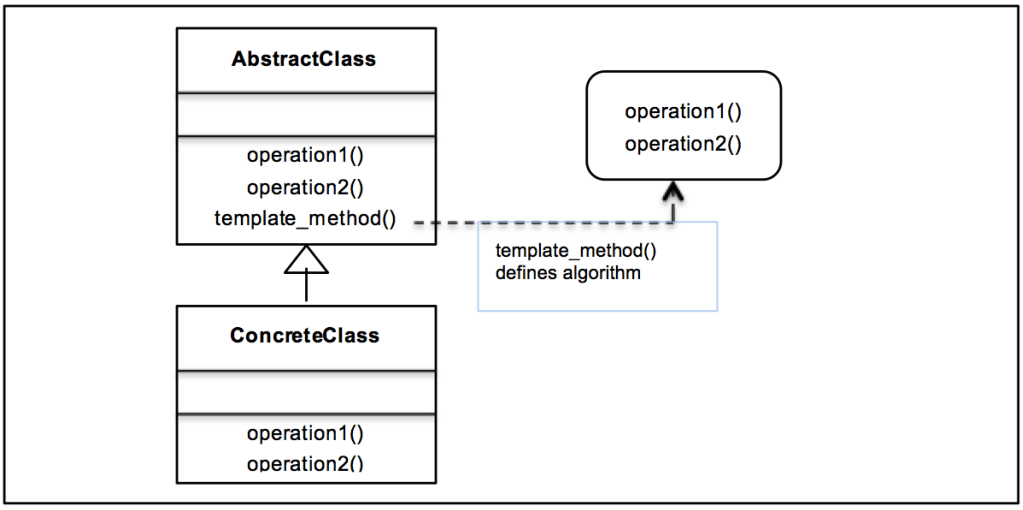
The output of the preceding code should look as follows:

```
Collecting Swift Source Code
Compiling Swift code to LLVM bitcode
Program runing on runtime environment
```

A UML class diagram for the Template Method pattern

Let's understand more about the Template method pattern with the help of a UML diagram.

As we discussed in the previous section, the Template method pattern has the following main participants: the abstract class, concrete class, Template method, and client. Let's put these in a UML diagram and see how the classes look:



As we look at the UML diagram, you'll realize that there are four main participants in this pattern:

- `AbstractClass`: This defines the operations or steps of an algorithm with the help of abstract methods. These steps are overridden by concrete subclasses.
- `template_method()`: This defines the skeleton of the algorithm. Multiple steps as defined by abstract methods are called in the Template method to define the sequence or the algorithm itself.
- `ConcreteClass`: This implements the steps (as defined by the abstract methods) to perform subclass-specific steps of the algorithm.

The following is a code example to understand the pattern with all the participants involved:

```
from abc import ABCMeta, abstractmethod

class AbstractClass(metaclass=ABCMeta):
    def __init__(self):
        pass

    @abstractmethod
    def operation1(self):
        pass

    @abstractmethod
    def operation2(self):
        pass

    def template_method(self):
        print("Defining the Algorithm. Operation1 follows Operation2")
        self.operation2()
        self.operation1()


class ConcreteClass(AbstractClass):

    def operation1(self):
        print("My Concrete Operation1")

    def operation2(self):
```

```
            print("Operation 2 remains same")


    class Client:
        def main(self):
            self.concreate = ConcreteClass()
            self.concreate.template_method()

    client = Client()
    client.main()
```

The output of the preceding code should look as follows:

```
Defining the Algorithm. Operation1 follows Operation2
Operation 2 remains same
My Concrete Operation1
```

The Template Method pattern in the real world

Let's take a very easy-to-understand scenario to implement the Template method pattern. Imagine the case of a travel agency, say, Dev Travels. Now how do they typically work? They define various trips to various locations and come up with a holiday package for you. A package is essentially a trip that you, as a customer, undertakes. A trip has details such as the places visited, transportation used, and other factors that define the trip itinerary. This same trip can be customized differently based on the needs of the customers. This calls for the Template Method pattern, doesn't it?

Design Considerations:

- For the preceding scenario, based on the UML diagram, we should create an `AbstractClass` interface that defines a trip
- The trip should contain multiple abstract methods that define the transportation used, places visited on `day1`, `day2`, and `day3`, assuming that it's a three-day long weekend trip, and also define the return journey

- The `itinerary()` Template Method will actually define the trip's itinerary
- We should define `ConcreteClasses` that would help us customize trips differently based on the customer's needs

Let's develop an application in Python v3.5 and implement the preceding use case. We start with the abstract class, `Trip`:

- The abstract object is represented by the `Trip` class. It is an interface (Python's abstract base class) that defines the details such as the transportation used and places to visit on different days.
- The `setTransport` is an abstract method that should be implemented by `ConcreteClass` to set the mode of transportation.
- The `day1(),day2(),day3()` abstract methods define the places visited on the given day.
- The `itinerary()` Template Method creates the complete itinerary (the algorithm, in this case, the trip). The sequence of the trip is to first define the transportation mode, then the places to visit on each day, and the `returnHome`.

The following code implements the scenario of Dev Travels:

```
from abc import abstractmethod, ABCMeta

class Trip(metaclass=ABCMeta):

    @abstractmethod
    def setTransport(self):
        pass

    @abstractmethod
    def day1(self):
        pass

    @abstractmethod
    def day2(self):
        pass

    @abstractmethod
    def day3(self):
        pass
```

```
    @abstractmethod
    def returnHome(self):
        pass

    def itinerary(self):
        self.setTransport()
        self.day1()
        self.day2()
        self.day3()
        self.returnHome()
```

We have also developed certain classes that represent the concrete class:

- In this case, we have two main concrete classes—`VeniceTrip` and `MaldivesTrip`—that implement the `Trip` interface
- Concrete classes represent two different trips taken by the tourists based on their choice and interests
- `VeniceTrip` and `MaldivesTrip` both implement `setTransport()`, `day1()`, `day2()`, `day3()`, and `returnHome()`

Let's define the concrete classes in Python code:

```
class VeniceTrip(Trip):
    def setTransport(self):
        print("Take a boat and find your way in the Grand Canal")

    def day1(self):
        print("Visit St Mark's Basilica in St Mark's Square")

    def day2(self):
        print("Appreciate Doge's Palace")

    def day3(self):
        print("Enjoy the food near the Rialto Bridge")

    def returnHome(self):
        print("Get souvenirs for friends and get back")


class MaldivesTrip(Trip):
    def setTransport(self):
```

```
        print("On foot, on any island, Wow!")

    def day1(self):
        print("Enjoy the marine life of Banana Reef")

    def day2(self):
        print("Go for the water sports and snorkelling")

    def day3(self):
        print("Relax on the beach and enjoy the sun")

    def returnHome(self):
        print("Dont feel like leaving the beach..")
```

Now, let's talk about the travel agency and tourists who want to have an awesome vacation:

- The `TravelAgency` class represents the `Client` object in this example
- It defines the `arrange_trip()` method that provides customers with the choice of whether they want to have a historical trip or beach trip
- Based on the choice made by the tourist, an appropriate class is instantiated
- This object then calls the `itinerary()` Template Method and the trip is arranged for the tourists as per the choice of the customers

The following is the implementation for the Dev travel agency and how they arrange for the trip based on the customer's choice:

```
class TravelAgency:
    def arrange_trip(self):
        choice = input("What kind of place you'd like to go historical
or to a beach?")
        if choice == 'historical':
            self.trip = VeniceTrip()
            self.trip.itinerary()
        if choice == 'beach':
            self.trip = MaldivesTrip()
            self.trip.itinerary()

TravelAgency().arrange_trip()
```

The output of the preceding code should look as follows:

```
What kind of place you'd like to go historical or to a beach?beach
On foot, on any island, Wow!
Enjoy the marine life of Banana Reef
Go for the water sports and snorkelling
Relax on the beach and enjoy the sun
Dont feel like leaving the beach..
```

If you decide to go on a historical trip, this will be the output of the code:

```
What kind of place you'd like to go historical or to a beach?historical
Take a boat and find your way in the Grand Canal
Visit St Mark's Basilica in St Mark's Square
Appreciate Doge's Palace
Enjoy the food near the Rialto Bridge
Get souvenirs for friends and get back
```

The Template Method pattern – hooks

A hook is a method that is declared in the abstract class. It is generally given a default implementation. The idea behind hooks is to give a subclass the ability to *hook into* the algorithm whenever needed. It's not imperative for the subclass to use hooks and it can easily ignore this.

For example, in the beverage example, we can add a simple hook to see if condiments need to be served along with tea or coffee based on the wish of the customer.

Another example of hook can be in the case of the travel agency example. Now, if we have a few elderly tourists, they may not want to go out on all three days of the trip as they may get tired easily. In this case, we can develop a hook that will ensure `day2` is lightly loaded, which means that they can go to a few nearby places and be back with the plan of `day3`.

Basically, we use abstract methods when the subclass must provide the implementation, and hook is used when it is optional for the subclass to implement it.

The Hollywood principle and the Template Method

The Hollywood principle is the design principle that is summarized by *Don't call us, we'll call you*. It comes from the Hollywood philosophy where the production houses call actors if there is any role for the actor.

In the object-oriented world, we allow low-level components to hook themselves into the system with the Hollywood principle. However, the high-level components determine how the low-level systems are needed and when they are needed. In other words, high-level components treat low-level components as *Don't call us, we'll call you*.

This relates to the Template Method pattern in the sense that it's the high-level abstract class that arranges the steps to define the algorithm. Based on how the algorithm is, low-level classes are called on to define the concrete implementation for the steps.

The advantages and disadvantages of the Template Method pattern

The Template Method pattern provides you with the following advantages:

- As we saw earlier in the chapter, there is no code duplication.
- Code reuse happens with the Template Method pattern as it uses inheritance and not composition. Only a few methods need to be overridden.
- Flexibility lets subclasses decide how to implement steps in an algorithm.

The disadvantages of Template Method patterns are as follows:

- Debugging and understanding the sequence of flow in the Template Method pattern can be confusing at times. You may end up implementing a method that shouldn't be implemented or not implementing an abstract method at all. Documentation and strict error handling has to be done by the programmer.
- Maintenance of the template framework can be a problem as changes at any level (low-level or high-level) can disturb the implementation. Hence, maintenance can be painful with the Template Method pattern.

Frequently asked questions

Q1. Should a low-level component be disallowed from calling a method in a higher-level component?

A: No, a low-level component would definitely call the higher-level component through inheritance. However, what the programmer needs to make sure is that there is no circular dependency where the low-level and high-level components are dependent on each other.

Q2. Isn't the strategy pattern similar to the Template pattern?

A: The strategy pattern and Template pattern both encapsulate algorithms. Template depends on inheritance while strategy uses composition. The Template Method pattern is a compile-time algorithm selection by sub-classing while the strategy pattern is a runtime selection.

Summary

We began the chapter by understanding the Template Method design pattern and how it is effectively used in software architecture.

We also looked at how the Template Method design pattern is used to encapsulate the algorithm and provide the flexibility of implementing different behavior by overriding the methods in the subclasses.

You learned the pattern with a UML diagram and sample code implementation in Python v3.5 along with the explanation.

We also covered a section on FAQs that would help you get a better idea of the pattern and its possible advantages/disadvantages.

We will now talk about a composite pattern in the next chapter—the MVC design pattern.

9
Model-View-Controller – Compound Patterns

In the previous chapter, we started with an introduction to Template Method design pattern, in which subclasses redefine the concrete steps of the algorithm, thus achieving flexibility and code reuse. You learned about the Template Method and how it is used to construct the algorithm with a sequence of steps. We discussed the UML diagram, its pros and cons, learned more about it in the FAQ section, and summarized the discussion at the end of the chapter.

In this chapter, we will talk about Compound patterns. We will get introduced to the **Model-View-Controller** (**MVC**) design pattern and discuss how it is used in software application development. We will work with a sample use case and implement it in Python v3.5.

We will cover the following topics in brief in this chapter:

- An introduction to Compound patterns and the Model-View-Controller
- The MVC pattern and its UML diagram
- A real-world use case with the Python v3.5 code implementation
- MVC pattern—pros and cons
- Frequently asked questions

At the end of the chapter, we will summarize the entire discussion—consider this as a takeaway.

An introduction to Compound patterns

Throughout this book, we explored various design patterns. As we saw, design patterns are classified under three main categories: structural, creational, and behavioral design patterns. You also learned about each of these with examples.

However, in software implementation, patterns don't work in isolation. Every software design or solution is not implemented with just one design pattern. Actually, patterns are often used together and combined to achieve a given design solution. As GoF defines, "*a compound pattern combines two or more patterns into a solution that solves a recurring or general problem*." A Compound pattern is not a set of patterns working together; it is a general solution to a problem.

We're now going to look at the Model-View-Controller Compound pattern. It's the best example of Compound patterns and has been used in many design solutions over the years.

The Model-View-Controller pattern

MVC is a software pattern to implement user interfaces and an architecture that can be easily modified and maintained. Essentially, the MVC pattern talks about separating the application into three essential parts: model, view, and controller. These three parts are interconnected and help in separating the ways in which information is represented to the way information is presented.

This is how the MVC pattern works: the model represents the data and business logic (how information is stored and queried), view is nothing but the representation (how it is presented) of the data, and controller is the glue between the two, the one that directs the model and view to behave in a certain way based on what a user needs. Interestingly, the view and controller are dependent on the model but not the other way round. This is primarily because a user is concerned about the data. Models can be worked with independently and this is the key aspect of the MVC pattern.

Consider the case of a website. This is one of the classical examples to describe the MVC pattern. What happens on a website? You click on a button, a few operations happen, and you get to see what you desired. How does this happen?

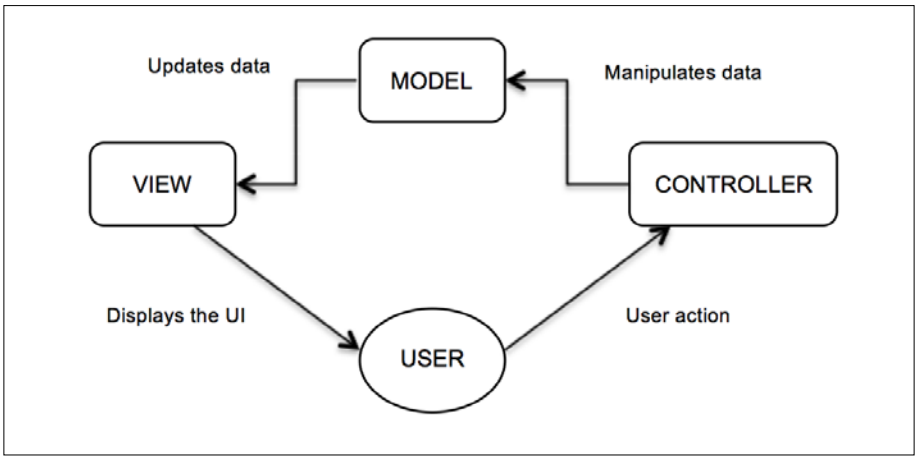
- You are the user and you interact with the view. The view is the web page that is presented to you. You click on the buttons on the view and it tells the controller what needs to be done.

- Controllers take the input from the view and send it to the model. The model gets manipulated based on the actions done by the user.
- Controllers can also ask the view to change based on the action it receives from the user, such as changing the buttons, presenting additional UI elements, and so on.
- The model notifies the change in state to the view. This can be based on a few internal changes or external triggers such as clicking on a button.
- The view then displays the state that it gets directly from the model. For example, if a user logs in to the website, he/she might be presented with a dashboard view (post login). All the details that need to be populated on the dashboard are given by the model to the view.

The MVC design pattern works with the following terms—Model, View, Controller and the Client:

- **Model**: This declares a class to store and manipulate data
- **View**: This declares a class to build user interfaces and data displays
- **Controller**: This declares a class that connects the model and view
- **User**: This declares a class that requests for certain results based on certain actions

The following image explains the flow of the MVC pattern:



To talk about the MVC pattern in software development terminologies, let's look into the main classes involved in the MVC pattern:

- The `model` class is used to define all the operations that happen on the data (such as create, modify, and delete) and provides methods on how to use the data.
- The `view` class is a representation of the user interface. It will have methods that help us build web or GUI interfaces based on the context and need of the application. It should not contain any logic of its own and just display the data that it receives.
- The `controller` class is used to receive data from the request and send it to other parts of the system. It has methods that are used to route requests.

The MVC pattern is used in the following cases:

- When there is a need to change the presentation without changes in the business logic
- Multiple controllers can be used to work with multiple views to change the representation on the user interface
- Once again, the model can be changed without changes in the view as they can work independently of each other

In short, the main intention of the MVC pattern is as follows:

- Keeping the data and presentation of the data separate.
- Easy maintenance of the class and implementation.
- Flexibility to change the way in which data is stored and displayed. Both are independent and hence have the flexibility to change.

Let's look at the model, view, and controller in detail as covered in *Learning Python Design Patterns*, *Gennadiy Zlobin*, *Packt Publishing* as well.

Model – knowledge of the application

Model is the cornerstone of an application because it is independent of the view and controller. The view and controller in turn are dependent on the model.

Model also provides data that is requested by the client. Typically, in applications, the model is represented by the database tables that store and return information. Model has state and methods to change states but is not aware of how the data would be seen by the client.

It is critical that the model stays consistent across multiple operations; otherwise, the client may get corrupted or display stale data, which is completely undesirable.

As the model is completely independent, developers working on this piece can focus on maintenance without the need for the latest view changes.

View – the appearance

The view is a representation of data on the interface that the client sees. The view can be developed independently but should not contain any complex logic. Logic should still reside in the controller or model.

In today's world, views need to be flexible enough and should cater to multiple platforms such as desktop, mobiles, tables, and multiple screen sizes.

Views should avoid interacting directly with the databases and rely on models to get the required data.

Controller – the glue

The controller, as the name suggests, controls the interaction of the user on the interface. When the user clicks on certain elements on the interface, based on the interaction (button click or touch), the controller makes a call to the model that in turn creates, updates, or deletes the data.

Controllers also pass the data to the view that renders the information for the user to view on the interface.

The Controller shouldn't make database calls or get involved in presenting the data. The controller should act as the glue between the model and view and be as thin as possible.

Let's now get into action and develop one sample app. The Python code shown next implements the MVC design pattern. Consider that we want to develop an application that tells a user about the marketing services delivered by a cloud company, which include e-mail, SMS, and voice facilities.

We first develop the `model` class (Model) that defines the services provided by the product, namely, e-mail, SMS, and voice. Each of these services have designated rates, such as 1,000 e-mails would charge the client $2, and for 1,000 messages, the charges are $10, and $15 for 1,000 voice messages. Thus, the model represents the data about the product services and prices.

We then define the `view` class (View) that provides a method to present the information back to the client. The methods are `list_services()` and `list_pricing()`; as the name suggests, one method is used to print the services offered by the product and the other is to list the pricing for the services.

We then define the `Controller` class that defines two methods, `get_services()` and `get_pricing()`. Each of these methods queries the model and gets the data. The data is then fed to the view and thus presented to the client.

The `Client` class instantiates the controller. The `controller` object is used to call appropriate methods based on the client's request:

```
class Model(object):
    services = {
                'email': {'number': 1000, 'price': 2,},
                'sms': {'number': 1000, 'price': 10,},
                'voice': {'number': 1000, 'price': 15,},
    }


class View(object):
    def list_services(self, services):
        for svc in services:
            print(svc, ' ')

    def list_pricing(self, services):
        for svc in services:
            print("For" , Model.services[svc]['number'],
                                svc, "message you pay $",
                            Model.services[svc]['price'])


class Controller(object):
    def __init__(self):
        self.model = Model()
        self.view = View()

    def get_services(self):
        services = self.model.services.keys()
        return(self.view.list_services(services))

    def get_pricing(self):
```

```
            services = self.model.services.keys()
            return(self.view.list_pricing(services))


    class Client(object):
        controller = Controller()
        print("Services Provided:")
        controller.get_services()
        print("Pricing for Services:")
        controller.get_pricing()
```

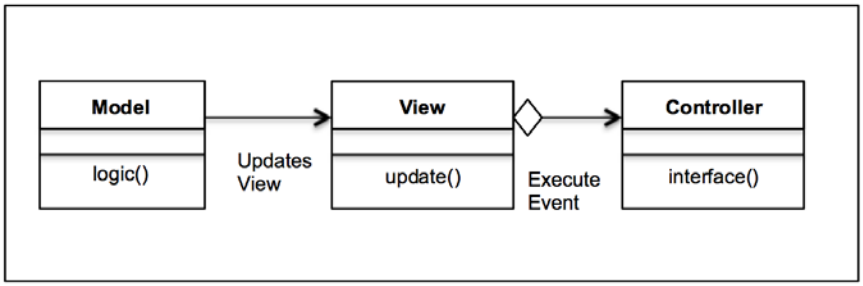
The following is the output of the preceding code:

```
Services Provided:
sms
email
voice
Pricing for Services:
For 1000 sms message you pay $ 10
For 1000 email message you pay $ 2
For 1000 voice message you pay $ 15
```

A UML class diagram for the MVC design pattern

Let's now understand more about the MVC pattern with the help of the following UML diagram.

As we discussed in the previous sections, the MVC pattern has the following main participants: the `Model`, `View`, and `Controller` class.



In the UML diagram, we can see three main classes in this pattern:

- The `Model` class: This defines the business logic or operations attached to certain tasks from the client.
- The `View` class: This defines the view or representation that is viewed by the client. The model presents the data to the view based on the business logic.
- The `Controller` class: This is essentially an interface that is between the view and model. When the client takes certain actions, the controller directs the query from the view to model.

The following is a code example to understand the pattern with all the participants involved:

```
class Model(object):
    def logic(self):
        data = 'Got it!'
        print("Model: Crunching data as per business logic")
        return data


class View(object):
    def update(self, data):
        print("View: Updating the view with results: ", data)


class Controller(object):
    def __init__(self):
        self.model = Model()
        self.view = View()

    def interface(self):
        print("Controller: Relayed the Client asks")
        data = self.model.logic()
        self.view.update(data)


class Client(object):
    print("Client: asks for certain information")
    controller = Controller()
    controller.interface()
```

The following is the output of the preceding code:

```
Client: asks for certain information
Controller: Relayed the Cient asks
Model: Crunching data as per business logic
View: Updating the view with results:  Got it!
```

The MVC pattern in the real world

Our good old web application frameworks are based on the philosophies of MVC. Take the example of Django or Rails (Ruby): they structure their projects in the Model-View-Controller format except that it is represented as **MTV** (**Model**, **Template**, **View**) where the model is the database, templates are the views, and controllers are the views/routes.

As an example, let's take up the Tornado web application framework (`http://www.tornadoweb.org/en/stable/`) to develop a single-page app. This application is used to manage a user's tasks and the user has permissions to add tasks, update tasks, and delete tasks.

Let's see the design considerations:

- Let's start with the controllers first. In Tornado, controllers have been defined as views/app routes. We need to define multiple views such as listing the tasks, creating new tasks, closing the tasks, and handling an operation if a request could not be served.
- We should also define models, the database operations to list, create, or delete the tasks.
- Finally, the views are represented by templates in Tornado. Based on our app, we would need a template to show tasks, create or delete tasks, and also a template if a URL is not found.

Modules

We will use the following modules for this application:

- Torando==4.3
- SQLite3==2.6.0

Let's start by importing the Python modules in our app:

```
importtornado
import tornado.web
import tornado.ioloop
import tornado.httpserver
import sqlite3
```

The following code represents the database operations, essentially, the models in MVC. In Tornado, DB operations are performed under different handlers. Handlers perform operations on the DB based on the route requested by the user in the web app. Here, we talk about the four handlers that we have created in this example:

- `IndexHandler`: This returns all the tasks that are stored in the database. It returns a dictionary with key tasks. It performs the `SELECT` database operation to get these tasks.
- `NewHandler`: As the name suggests, this is useful to add new tasks. It checks whether there is a `POST` call to create a new task and does an `INSERT` operation in the DB.
- `UpdateHandler`: This is useful in marking a task as complete or reopening a given task. In this case, the `UPDATE` database operation occurs to set a task with the status as open/closed.
- `DeleteHandler`: This deletes a given task from the database. Once deleted, the task is no more visible in the list of tasks.

We have also developed an `_execute()` method that takes a SQLite query as an input and performs the required DB operation. The `_execute()` method does the following operations on the SQLite DB:

- Creating a SQLite DB connection
- Getting the cursor object
- Using the cursor object to make a transaction
- Committing the query
- Closing the connection

Let's look at the handlers in the Python implementation:

```
class IndexHandler(tornado.web.RequestHandler):
    def get(self):
        query = "select * from task"
```

```
        todos = _execute(query)
        self.render('index.html', todos=todos)

class NewHandler(tornado.web.RequestHandler):
    def post(self):
        name = self.get_argument('name', None)
        query = "create table if not exists task (id INTEGER \
            PRIMARY KEY, name TEXT, status NUMERIC) "
        _execute(query)
        query = "insert into task (name, status) \
            values ('%s', %d) " %(name, 1)
        _execute(query)
        self.redirect('/')

    def get(self):
        self.render('new.html')


class UpdateHandler(tornado.web.RequestHandler):
    def get(self, id, status):
        query = "update task set status=%d where \
            id=%s" %(int(status), id)
        _execute(query)
        self.redirect('/')


class DeleteHandler(tornado.web.RequestHandler):
    def get(self, id):
        query = "delete from task where id=%s" % id
        _execute(query)
        self.redirect('/')
```

If you look up these methods, you'll notice something called `self.render()`. This essentially represents the views in MVC (templates in the Tornado framework). We have three main templates:

- `index.html`: This is a template to list all the tasks
- `new.html`: This is the view to create a new task
- `base.html`: This is the base template from which other templates are inherited

Consider the following code:

```
base.html
<html>
<!DOCTYPE>
<html>
<head>
        {% block header %}{% end %}
</head>
<body>
        {% block body %}{% end %}
</body>
</html>

index.html

{% extends 'base.html' %}
<title>ToDo</title>
{% block body %}
<h3>Your Tasks</h3>
<table border="1" >
<tralign="center">
<td>Id</td>
<td>Name</td>
<td>Status</td>
<td>Update</td>
<td>Delete</td>
</tr>
    {% for todo in todos %}
<tralign="center">
<td>{{todo[0]}}</td>
<td>{{todo[1]}}</td>
            {% if todo[2] %}
<td>Open</td>
            {% else %}
<td>Closed</td>
            {% end %}
            {% if todo[2] %}
<td><a href="/todo/update/{{todo[0]}}/0">Close Task</a></td>
            {% else %}
<td><a href="/todo/update/{{todo[0]}}/1">Open Task</a></td>
            {% end %}
```

```
<td><a href="/todo/delete/{{todo[0]}}">X</a></td>
</tr>
    {% end %}
</table>

<div>
<h3><a href="/todo/new">Add Task</a></h3>
</div>
{% end %}
```

new.html

```
{% extends 'base.html' %}
<title>ToDo</title>
{% block body %}
<div>
<h3>Add Task to your List</h3>
<form action="/todo/new" method="post" id="new">
<p><input type="text" name="name" placeholder="Enter task"/>
<input type="submit" class="submit" value="add" /></p>
</form>
</div>
{% end %}
```

In Tornado, we also have the application routes that are controllers in MVC. We have four application routes in this example:

- `/`: This is the route to list all the tasks
- `/todo/new`: This is the route to create new tasks
- `/todo/update`: This is the route to update the task status to open/closed
- `/todo/delete`: This is the route to delete a completed task

The code example is as follows:

```
class RunApp(tornado.web.Application):
    def __init__(self):
        Handlers = [
            (r'/', IndexHandler),
            (r'/todo/new', NewHandler),
            (r'/todo/update/(\d+)/status/(\d+)', UpdateHandler),
```

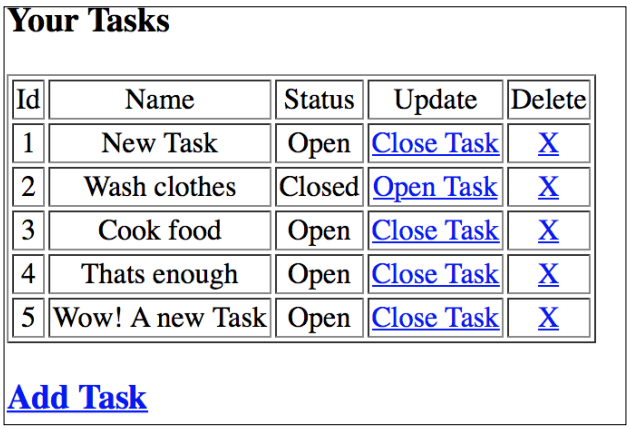
```
            (r'/todo/delete/(\d+)', DeleteHandler),
        ]
        settings = dict(
            debug=True,
            template_path='templates',
            static_path="static",
        )
        tornado.web.Application.__init__(self, Handlers, \
            **settings)
```

We also have application settings and can start the HTTP web server to run the application:

```
if__name__ == '__main__':
    http_server = tornado.httpserver.HTTPServer(RunApp())
    http_server.listen(5000)
    tornado.ioloop.IOLoop.instance().start()
```

When we run the Python program:

1. The server gets started and runs on port `5000`. The appropriate views, templates, and controllers have been configured.
2. On browsing `http://localhost:5000/`, we can see the list of tasks. the following screenshot shows the output in the browser:



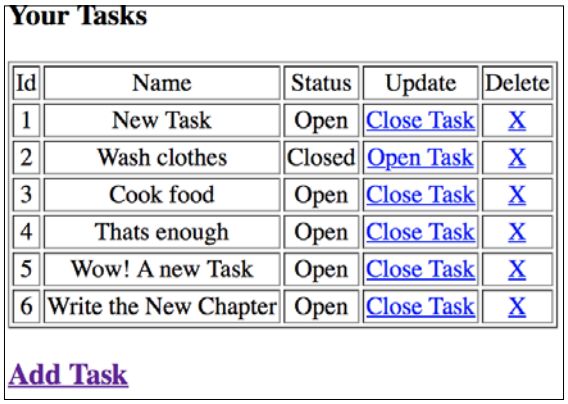
Your Tasks

Id	Name	Status	Update	Delete
1	New Task	Open	Close Task	X
2	Wash clothes	Closed	Open Task	X
3	Cook food	Open	Close Task	X
4	Thats enough	Open	Close Task	X
5	Wow! A new Task	Open	Close Task	X

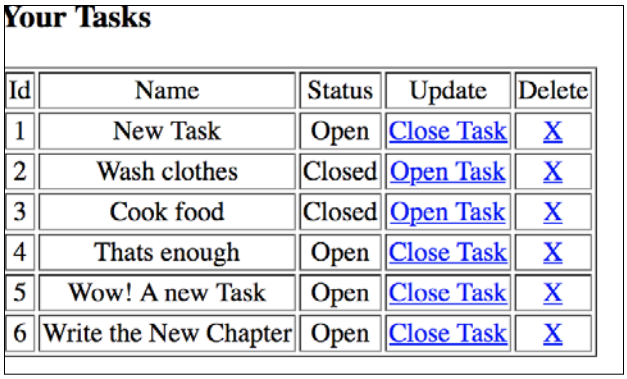
Add Task

3. We can also add a new task. Once you click on **add**, a new task gets added. In the following screenshot, a new task `Write the New Chapter` is added and listed in the task list:

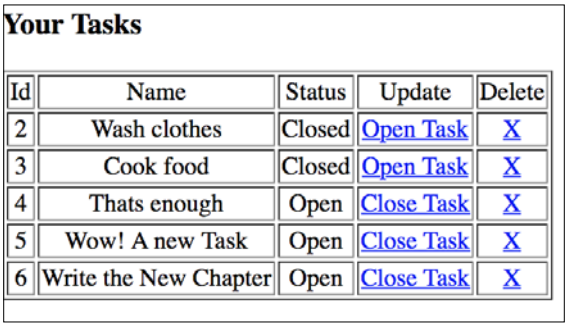
When we enter the new task and click on the ADD button, the task gets added to the list of existing tasks:



4. We can close tasks from the UI as well. For example, we update the **Cook food** task and the list gets updated. We can reopen the task if we choose to:



5. We can also delete a task. In this case, we delete the first task, **New Task**, and the task list will get updated to remove the task:



Your Tasks

Id	Name	Status	Update	Delete
2	Wash clothes	Closed	Open Task	X
3	Cook food	Closed	Open Task	X
4	Thats enough	Open	Close Task	X
5	Wow! A new Task	Open	Close Task	X
6	Write the New Chapter	Open	Close Task	X

Benefits of the MVC pattern

The following are the benefits of the MVC pattern:

- With MVC, developers can split the software application into three major parts: model, view, and controller. This helps in achieving easy maintenance, enforcing loose coupling, and decreasing complexity.
- MVC allows independent changes on the frontend without any, or very few, changes on the backend logic, and so the development efforts can still run independently.
- On similar lines, models or business logic can be changed without any changes in the view.
- Additionally, the controller can be changed without any impact on views or models.
- MVC also helps in hiring people with specific capabilities such as platform engineers and UI engineers who can work independently in their field of expertise.

Frequently asked questions

Q1. Isn't MVC a pattern? Why is it called a Compound pattern?

A: Compound patterns are essentially groups of patterns put together to solve large design problems in software application development. The MVC pattern is the most popular and widely used Compound pattern. As it is so widely used and reliable, it is treated as a pattern itself.

Q2. Is MVC used only in websites?

A: No, a website is the best example to describe MVC. However, MVC can be used in multiple areas such as GUI applications or any other place where you need loose coupling and splitting of components in an independent way. Typical examples of MVC include blogs, movie database applications, and video streaming web apps. While MVC is useful in many places, it's overkill if you use it for the landing pages, marketing content, or quick single-page applications.

Q3. Can multiple views work with multiple models?

A: Yes, often you'd end up in a situation where the data needs to be collated from multiple models and presented in one view. One-to-one mapping is rare in today's web app world.

Summary

We began the chapter by understanding Compound patterns and looked at the Model-View-Controller pattern and how it is effectively used in software architecture. We then looked at how the MVC pattern is used to ensure loose coupling and maintain a multilayer framework for independent task development.

You also learned the pattern with a UML diagram and sample code implementation in Python v3.5 along with the explanation. We also covered a section on FAQs that would help you get more ideas on the pattern and its possible advantages/disadvantages.

In the next chapter, we will talk about the Anti patterns. See you there!

10
The State Design Pattern

In this chapter, we will cover the State design pattern. Like the Command or Template design patterns, State pattern falls under the hood of Behavioral patterns. You will be introduced to the State design pattern, and we will discuss how it is used in software application development. We will work with a sample use case, a real-world scenario, and implement this in Python v3.5.

We will briefly cover these topics in this chapter:

- Introduction to the State design pattern
- The State design pattern and its UML diagram
- A real-world use case with the Python v3.5 code implementation
- State pattern: advantages and disadvantages

At the end of this chapter, you will appreciate the application and context of the State design pattern.

Defining the State design pattern

Behavioral patterns focus on the responsibilities that an object has. They deal with the interaction among objects to achieve larger functionality. The State design pattern is a Behavioral design pattern, which is also sometimes referred to as an **objects for states** pattern. In this pattern, an object can encapsulate multiple behaviors based on its internal state. A State pattern is also considered as a way for an object to change its behavior at runtime.

Changing behavior at runtime is something that Python excels at!

For example, consider the case of a simple radio. A radio has AM/FM (a toggle switch) channels and a scan button to scan across multiple FM/AM channels. When a user switches on the radio, the base state of the radio is already set (say, it is set to FM). On clicking the Scan button, the radio gets tuned to multiple valid FM frequencies or channels. When the base State is now changed to AM, the scan button helps the user to tune into multiple AM channels. Hence, based on the base state (AM/FM) of the radio, the scan button's behavior dynamically changes when tuning into AM or FM channels.

Thus, the State pattern allows an object to change its behavior when its internal state changes. It will appear as though the object itself has changed its class. The State design pattern is used to develop Finite State Machines and helps to accommodate State Transaction Actions.

Understanding the State design pattern

The State design patterns works with the help of three main participants:

- `State`: This is considered to be an interface that encapsulates the object's behavior. This behavior is associated with the state of the object.
- `ConcreteState`: This is a subclass that implements the `State` interface. `ConcreteState` implements the actual behavior associated with the object's particular state.
- `Context`: This defines the interface of interest to clients. `Context` also maintains an instance of the `ConcreteState` subclass that internally defines the implementation of the object's particular state.

Let's take a look at the structural code implementation of the State design pattern with these three participants. In this code implementation, we define a `State` interface that has a `Handle()` abstract method. The `ConcreteState` classes, `ConcreteStateA` and `ConcreteStateB`, implement the State interface and, thus, define the `Handle()` methods specific to the `ConcreteState` classes. So, when the `Context` class is set for a state, the `Handle()` method of this state's `ConcreteClass` gets called. In the following example, since `Context` is set to `stateA`, the `ConcreteStateA.Handle()` method gets called and prints `ConcreteStateA`:

```
from abc import abstractmethod, ABCMeta

class State(metaclass=ABCMeta):

    @abstractmethod
    def Handle(self):
```

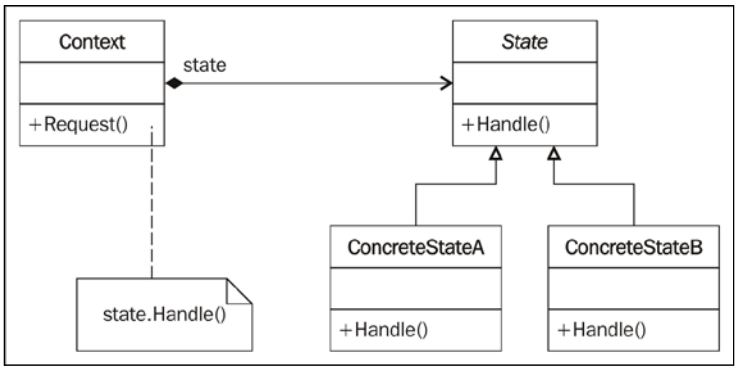
```
        pass


class ConcreteStateB(State):
    def Handle(self):
        print("ConcreteStateB")


class ConcreteStateA(State):
    def Handle(self):
        print("ConcreteStateA")


class Context(State):

    def __init__(self):
        self.state = None

    def getState(self):
        return self.state

    def setState(self, state):
        self.state = state

    def Handle(self):
        self.state.Handle()


context = Context()
stateA = ConcreteStateA()
stateB = ConcreteStateB()

context.setState(stateA)
context.Handle()
```

We will see the following output:

```
ConcreteStateA
```

Understanding the State design pattern with a UML diagram

As we saw in the previous section, there are three main participants in the UML diagram: `State`, `ConcreteState`, and `Context`. In this section, we will try to manifest them on a UML class diagram.



Let's understand the elements of UML diagram in detail:

- `State`: This is an interface that defines the `Handle()` abstract method. The `Handle()` method needs to be implemented by `ConcreteState`.
- `ConcreteState`: In this UML diagram, we have defined two `ConcreteClasses`: `ConcreteStateA`, and `ConcreteStateB`. These implement the `Handle()` method and define the actual action to be taken based on the `State` change.
- `Context`: This is a class that accepts the client's request. It also maintains a reference to the object's current state. Based on the request, the concrete behavior gets called.

A simple example of the State design pattern

Let's understand all three participants with a simple example. Say, we want to implement a TV remote with a simple button to perform on/off actions. If the TV is on, the remote button will switch off the TV and vice versa. In this case, the `State` interface will define the method (say, `doThis()`) to perform actions such as switching on/off the TV. We also need to define `ConcreteClass` for different states. In this example, we have two major states, `StartState` and `StopState`, which indicate when the TV is switched on and the state in which the TV is switched off, respectively.

For this scenario, the `TVContext` class will implement the `State` interface and keep a reference to the current state. Based on the request, `TVContext` forwards the request to `ConcreteState`, which implements the actual behavior (for a given state) and performs the necessary action. So, in this case, the base state is `StartState` (as defined earlier) and the request received by the `TVContext` class is to switch Off the TV. `TVContext` class understands the need and accordingly forwards the request to `StopState` concrete class which inturn calls the `doThis()` method to actually switch off the TV:

```
from abc import abstractmethod, ABCMeta

class State(metaclass=ABCMeta):

    @abstractmethod
    def doThis(self):
        pass


class StartState (State):
    def doThis(self):
        print("TV Switching ON..")


class StopState (State):
    def doThis(self):
        print("TV Switching OFF..")


class TVContext(State):

    def __init__(self):
        self.state = None

    def getState(self):
        return self.state

    def setState(self, state):
        self.state = state

    def doThis(self):
        self.state.doThis()


context = TVContext()
context.getState()
```

```
start = StartState()
stop = StopState()

context.setState(stop)
context.doThis()
```

Here is the output for the preceding code:

```
TV Switching OFF..
```

The State design pattern with v3.5 implementation

Let's now take a look at a real-world use case for the State design pattern. Think of a computer system (desktop/laptop). It can have multiple states such as `On`, `Off`, `Suspend`, or `Hibernate`. Now, if we want to manifest these states with the help of State design pattern, how will we do it?

Say, we start with the `ComputerState` interface:

- The state should define two attributes, which are `name` and `allowed`. The `name` attribute represents the state of the object, and `allowed` is a list that defines the state's object, which it is allowed to get into.
- The state must define a `switch()` method, which will actually change the state of the object (in this case, the computer).

Let's take a look at the code implementation of the `ComputerState` interface:

```
class ComputerState(object):
    name = "state"
    allowed = []

    def switch(self, state):
        if state.name in self.allowed:
            print('Current:',self,' => switched to new state',state.
name)
            self.__class__ = state
        else:
            print('Current:',self,' => switching to',state.name,'not
possible.')

    def __str__(self):
        return self.name
```

Let's now take a look at `ConcreteState`, which implements the `State` interface. We will define four states:

- `On`: This switches *on* the computer. The allowed states here are `Off`, `Suspend`, and `Hibernate`.
- `Off`: This switches *off* the computer. The allowed state here is just `On`.
- `Hibernate`: This state puts the computer in the *hibernate* mode. The computer can only get switched on when it's in this state.
- `Suspend`: This state *suspends* the computer, and once the computer is suspended, it can be switched on.

Let's now take a look at the code:

```
class Off(ComputerState):
    name = "off"
    allowed = ['on']

class On(ComputerState):
    name = "on"
    allowed = ['off','suspend','hibernate']

class Suspend(ComputerState):
    name = "suspend"
    allowed = ['on']

class Hibernate(ComputerState):
    name = "hibernate"
    allowed = ['on']
```

Now, we explore the context class (`Computer`). The context does two main things:

- `__init__()`: This method defines the base state of the computer
- `change()`: This method will change the state of the object, and the actual change in behavior is implemented by the `ConcreteState` classes (`on`, `off`, `suspend`, and `hibernate`)

Here is the implementation of the preceding methods:

```
class Computer(object):
    def __init__(self, model='HP'):
        self.model = model
        self.state = Off()

    def change(self, state):
        self.state.switch(state)
```

The following is the code for the client. We create the object of the `Computer` class (`Context`) and pass a state to it. The state can be either of these: `On`, `Off`, `Suspend`, and `Hibernate`. Based on the new state, the context calls its `change(state)` method, which eventually switches the actual state of the computer:

```
if __name__ == "__main__":
    comp = Computer()
    # Switch on
    comp.change(On)
    # Switch off
    comp.change(Off)

    # Switch on again
    comp.change(On)
    # Suspend
    comp.change(Suspend)
    # Try to hibernate - cannot!
    comp.change(Hibernate)
    # switch on back
    comp.change(On)
    # Finally off
    comp.change(Off)
```

Now, we can observe the following output:

```
Current: off  => switched to new state on
Current: on  => switched to new state off
Current: off  => switched to new state on
Current: on  => switched to new state suspend
Current: suspend  => switching to hibernate not possible
Current: suspend  => switched to new state on
Current: on  => switched to new state off
```

`__class__` is a built-in attribute of every class. It is a reference to the class. For instance, `self.__class__.__name__` represents the name of the class. In this example, we use `__class__ attribute` of Python to change the `State`. So, when we pass the state to the `change()` method, the class of the objects gets dynamically changed at runtime. The `comp.change(On)` code, changes the object state to `On` and subsequently to different states like `Suspend`, `Hibernate`, and `Off`.

Advantages/disadvantages of the State pattern

Here are the benefits of the State design pattern:

- In the State design pattern, an object's behavior is the result of the function of its state, and the behavior gets changed at runtime depending on the state. This removes the dependency on the if/else or switch/case conditional logic. For example, in the TV remote scenario, we could have also implemented the behavior by simply writing one class and method that will ask for a parameter and perform an action (switch the TV on/off) with an `if/else` block.
- With State pattern, the benefits of implementing polymorphic behavior are evident, and it is also easier to add states to support additional behavior.
- The State design pattern also improves **Cohesion** since state-specific behaviors are aggregated into the `ConcreteState` classes, which are placed in one location in the code.
- With the State design pattern, it is very easy to add a behavior by just adding one more `ConcreteState` class. State pattern thus improves the flexibility to extend the behavior of the application and overall improves code maintenance.

We have seen the advantages of state patterns. However, they also have a few pitfalls:

- **Class Explosion**: Since every state needs to be defined with the help of `ConcreteState`, there is a chance that we might end up writing many more classes with a small functionality. Consider the case of finite state machines—if there are many states but each state is not too different from another state, we'd still need to write them as separate `ConcreteState` classes. This increases the amount of code we need to write, and it becomes difficult to review the structure of a state machine.
- With the introduction of every new behavior (even though adding behavior is just adding one more `ConcreteState`), the `Context` class needs to be updated to deal with each behavior. This makes the `Context` behavior more brittle with every new behavior.

Summary

To summarize what we've learned so far, in State design patterns, the object's behavior is decided based on its state. The state of the object can be changed at runtime. Python's ability to change behavior at runtime makes it very easy to apply and implement the State design pattern. The State pattern also gives us control over deciding the states that objects can take up such as those in the computer example that we saw earlier in the chapter. The `Context` class provides an easier interface for clients, and `ConcreteState` makes sure it is easy to add behaviors to the objects. Thus, the State pattern improves cohesion, flexibility to extend, and removes redundant code blocks. We academically studied the pattern in the form of a UML diagram and learned about the implementation aspects of the State pattern with help of the Python v3.5 code implementation. We also took a look at the few pitfalls you might encounter when it comes to the State pattern, and the code which can significantly increase when it comes to adding more states or behaviors. I hope you had a nice time going through this chapter!

11
AntiPatterns

In the previous chapter, we started with an introduction to Compound patterns. You learned how design patterns work together to solve a real-world design problem. We went further to explore the Model-View-Controller design pattern—the king of Compound patterns. We understood that the MVC pattern is used when we need loose coupling between components and separation of the way in which data is stored from the way data is presented. We also went through the UML diagram of the MVC pattern and read about how the individual components (model, view, and controller) work among themselves. We also saw how it's applied in the real world with the help of the Python implementation. We discussed the benefits of the MVC pattern, learned more about it in the FAQs section, and summarized the discussion at the end of chapter.

In this chapter, we will talk about AntiPatterns. This is different from all the other chapters in the book; here, we will cover what we shouldn't do as architects or software engineers. We will understand what AntiPatterns are and how they are visible in software design or development aspects with the help of theoretical and practical examples.

In brief, we will cover the following topics in this chapter:

- An introduction to AntiPatterns
- AntiPatterns with examples
- Common pitfalls during development

At the end of the chapter, we will summarize the entire discussion—consider this as a takeaway.

An introduction to AntiPatterns

Software design principles represent a set of rules or guidelines that help software developers make design-level decisions. According to Robert Martin, there are four aspects of a bad design:

- **Immobile**: An application is developed in such a way that it becomes very hard to reuse
- **Rigid**: An application is developed in such a manner that any small change may in turn result in moving of too many parts of the software
- **Fragile**: Any change in the current application results in breaking the existing system fairly easily
- **Viscose**: Changes are done by the developer in the code or environment itself to avoid difficult architectural level changes

The above aspects of bad design, if applied, result in solutions that should not be implemented in the software architecture or development.

An AntiPattern is an outcome of a solution to recurring problems so that the outcome is ineffective and becomes counterproductive. What does this mean? Let's say that you come across a software design problem. You get down to solving this problem. However, what if the solution has a negative impact on the design or causes any performance issues in the application? Hence, AntiPatterns are common defective processes and implementations within software applications.

AntiPatterns may be the result of the following:

- A developer not knowing the software development practices
- A developer not applying design patterns in the correct context

AntiPatterns can prove beneficial as they provide an opportunity for the following reasons:

- Recognize recurring problems in the software industry and provide a detailed remedy for most of these issues
- Develop tools to recognize these problems and determine the underlying causes
- Describe the measures that can be taken at several levels of improving the application and architecture

AntiPatterns can be classified under two main categories:

1. Software development AntiPatterns
2. Software architecture AntiPatterns

Software development AntiPatterns

When you start software development for an application or project, you think of the code structure. This structure is consistent with the product architecture, design, customer use cases, and many other development considerations.

Often, when the software is developed, it gets deviated from the original code structure due to the following reasons:

- The thought process of the developer evolves with development
- Use cases tend to change based on customer feedback
- Data structures designed initially may undergo change with functionality or scalability considerations

Due to the preceding reasons, software often undergoes refactoring. Refactoring is taken with a negative connotation by many, but in reality, refactoring is one of the critical parts of the software development journey, which provides developers an opportunity to relook the data structures and think about scalability and ever-evolving customer's needs.

The following examples provide you with an overview of different AntiPatterns observed in software development and architecture. We will cover only a few of them along with causes, symptoms, and consequences.

Spaghetti code

This is the most common and most heard of AntiPattern in software development. Do you know how spaghetti looks? So complicated, isn't it? Software control flows also get tangled if structures are developed in an ad hoc manner. Spaghetti code is difficult to maintain and optimize.

The typical causes of Spaghetti include the following:

- Ignorance on object-oriented programming and analysis
- Product architecture or design that is not considered
- Quick fix mentality

You know you're stuck with Spaghetti when the following points are true:

- Minimum reuse of structures is possible
- Maintenance efforts are too high
- Extension and flexibility to change is reduced

Golden Hammer

In the software industry, you would have seen many examples where a given solution (technology, design, or module) is used in many places because the solution would have yielded benefits in multiple projects. As we have seen with examples throughout this book, a solution is best suited in a given context and applied to certain types of problems. However, teams or software developers tend to go with one proven solution irrespective of whether it suits the need. This is the reason that it's called Golden Hammer, a hammer for all the nails possible (a solution to all problems).

The typical causes of Golden Hammer include the following:

- It comes as a recommendation from the top (architects or technology leaders) who are not close to the given problem at hand
- A solution has yielded a lot of benefits in the past but in projects with a different context and requirements
- A company is stuck with this technology as they have invested money in training the staff or the staff is comfortable with it

The consequences of a Golden Hammer are as follows:

- One solution is obsessively applied to all software projects
- The product is described, not by the features, but the technology used in development
- In the company corridors, you hear developers talking, "That could have been better than using this."
- Requirements are not completed and not in sync with user expectations

Lava Flow

This AntiPattern is related to Dead Code, or an unusable piece of code, lying in the software application for the fear of breaking something else if it is modified. As more time passes, this piece of code continues to remain in the software and solidifies its position, like lava turning into a hard rock. It may happen in cases where you start developing software to support a certain use case but the use case itself changes with time.

The causes of a Lava Flow include the following:

- A lot of trial and error code in the production
- Single-handedly written code that is not reviewed and is handed over to other development teams without any training
- The initial thought of the software architecture or design is implemented in the code base, but no one understands it anymore

The symptoms of a Lava Flow are as follows:

- Low code coverage (if at all done) for developed tests
- A lot of occurrences of commented code without reasons
- Obsolete interfaces, or developers try to work around existing code

Copy-and-paste or cut-and-paste programming

As you know, this is one of the most common AntiPatterns. Experienced developers put their code snippets online (GitHub or Stack Overflow) that are solutions to some commonly occurring issues. Developers often copy these snippets as is and use in their application to move further in the application development. In this case, there is no validation that this is the most optimized code or even that the code actually fits the context. This leads to inflexible software application that is hard to maintain.

The causes of copy-and-paste or cut-and-paste are as follows:

- Novice developers not used to writing code or not aware how to develop
- Quick bug fix or moving forward with development
- Code duplication for need of a code structure or standardization across modules
- A lack of long-term thinking or forethought

The consequences of cut-and-paste or copy-and-paste include the following:

- Similar type of issues across software application
- Higher maintenance costs and increased bug life cycle
- Less modular code base with the same code running into a number of lines
- Inheriting issues that existed in the first place

Software architecture AntiPatterns

Software architecture is an important piece of overall system architecture. While system architecture focuses on aspects such as the design, tools, and hardware among other things, software architecture looks at modeling the software that is well understood by the development and test teams, product managers, and other stakeholders. This architecture plays a critical role in determining the success of the implementation and how the product works for the customers.

We will discuss some of the architecture-level AntiPatterns that we observe in the real world with development and implementation software architecture.

Reinventing the wheel

We often hear technology leaders talking about NOT reinventing the wheel. What does it essentially mean? For some, this may mean code or library reuse. Actually, it points to architecture reuse. For example, you have solved a problem and come up with an architecture-level solution. If you encounter a similar problem in any other application, the thought process (architecture or design) that was developed earlier should be reused. There is no point in revisiting the same problem and devising a solution, which is essentially reinventing the wheel.

The causes that lead to reinventing the wheel are as follows:

- An absence of a central documentation or repository that talks about architecture-level problems and solutions implemented
- A lack of communication between technology leaders in the community or company
- Building from scratch is the process followed in the organization; basically, immature processes and loose process implementation and adherence

The consequences of this AntiPattern include the following:

- Too many solutions to solve one standard problem, with many of them not being well thought out
- More time and resource utilization for the engineering team leading to overbudgeting and more time to market
- A closed system architecture (architecture useful for only one product), duplication of efforts, and poor risk management

Vendor lock-in

As the name of the AntiPattern suggests, product companies tend to be dependent on some of the technologies provided by their vendors. These technologies are so glued to their system that it is very difficult to move away.

The following are the causes of a vendor lock-in:

- Familiarity with folks in authority in the vendor company and possible discounts in the technology purchase
- Technology chosen based on the marketing and sales pitch instead of technology evaluation
- Using a proven technology (proven indicates that the return on investments with this technology were really high in the previous experience) in the current project even when it's not suited for project needs or requirements
- Technologists/developers are already trained in using this technology

The consequences of a vendor lock-in are as follows:

- Release cycles and product maintenance cycles of a company's product releases are directly dependent on the vendor's release time frame
- The product is developed around the technology rather than on the customer's requirements
- The product's time to market is unreliable and doesn't meet customer's expectations

Design by committee

Sometimes, based on the process in an organization, a group of people sit together and design a particular system. The resulting software architecture is often complex or substandard because it involves too many thought processes, and technologists who may not have the right skillset or experience in designing the products have put forward the ideas.

The causes of design by committee are as follows:

- The process in the organization involves getting the architecture or design approved by many stakeholders
- No single point of contact or architect responsible for the design
- The design priorities set by marketing or technologists rather than set by customer feedback

The symptoms observed with this AntiPattern include the following:

- Conflicting viewpoints between developers and architects even after the design is finalized
- Overly complex design that is very difficult to document
- Any change in the specification or design undergoes review by many, resulting in implementation delays

Summary

To summarize this chapter, you learned about AntiPatterns, what they are, and their classifications. We understood that AntiPatterns could be related to software development or software architecture. We looked at the commonly occurring AntiPatterns and learned about their causes, symptoms, and consequences.
I am sure you will learn from these and avoid such situations in your project.

This is it folks, this was the last chapter of the book. Hope you enjoyed it and the book helped you improve your skills. Wish you all the very best!

Module 3

Mastering Python Design Patterns

Start learning Python programming to a better standard by mastering the art of Python design patterns

1
The Factory Pattern

Creational design patterns deal with an object creation [`j.mp/wikicrea`]. The aim of a creational design pattern is to provide better alternatives for situations where a direct object creation (which in Python happens by the `__init__()` function [`j.mp/divefunc`], [Lott14, page 26]) is not convenient.

In the Factory design pattern, a client asks for an object without knowing where the object is coming from (that is, which class is used to generate it). The idea behind a factory is to simplify an object creation. It is easier to track which objects are created if this is done through a central function, in contrast to letting a client create objects using a direct class instantiation [Eckel08, page 187]. A factory reduces the complexity of maintaining an application by decoupling the code that creates an object from the code that uses it [Zlobin13, page 30].

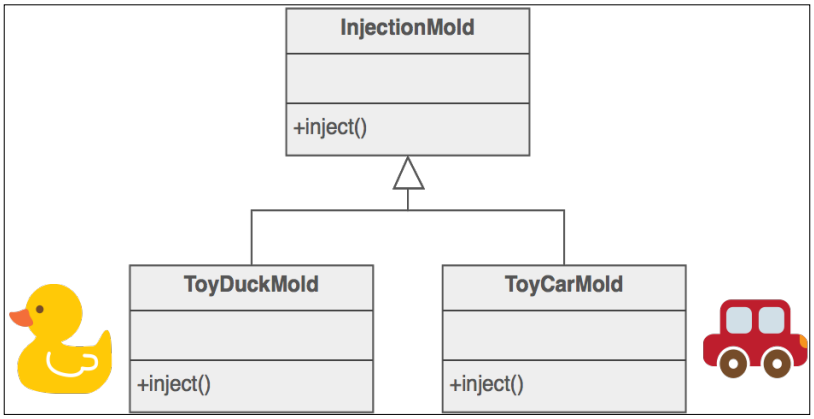
Factories typically come in two forms: the **Factory Method**, which is a method (or in Pythonic terms, a function) that returns a different object per input parameter [`j.mp/factorympat`]; the Abstract Factory, which is a group of Factory Methods used to create a family of related products [GOF95, page 100], [`j.mp/absfpat`].

Factory Method

In the Factory Method, we execute a single function, passing a parameter that provides information about *what* we want. We are not required to know any details about *how* the object is implemented and *where* it is coming from.

A real-life example

An example of the Factory Method pattern used in reality is in plastic toy construction. The molding powder used to construct plastic toys is the same, but different figures can be produced using different plastic molds. This is like having a Factory Method in which the input is the name of the figure that we want (duck and car) and the output is the plastic figure that we requested. The toy construction case is shown in the following figure, which is provided by `www.sourcemaking.com` [`j.mp/factorympat`].



A software example

The Django framework uses the Factory Method pattern for creating the fields of a form. The `forms` module of Django supports the creation of different kinds of fields (`CharField`, `EmailField`) and customizations (`max_length`, `required`) [`j.mp/djangofacm`].

Use cases

If you realize that you cannot track the objects created by your application because the code that creates them is in many different places instead of a single function/method, you should consider using the Factory Method pattern [Eckel08, page 187]. The Factory Method centralizes an object creation and tracking your objects becomes much easier. Note that it is absolutely fine to create more than one Factory Method, and this is how it is typically done in practice. Each Factory Method logically groups the creation of objects that have similarities. For example, one Factory Method might be responsible for connecting you to different databases (MySQL, SQLite), another Factory Method might be responsible for creating the geometrical object that you request (circle, triangle), and so on.

The Factory Method is also useful when you want to decouple an object creation from an object usage. We are not coupled/bound to a specific class when creating an object, we just provide partial information about what we want by calling a function. This means that introducing changes to the function is easy without requiring any changes to the code that uses it [Zlobin13, page 30].

Another use case worth mentioning is related to improving the performance and memory usage of an application. A Factory Method can improve the performance and memory usage by creating new objects only if it is absolutely necessary [Zlobin13, page 28]. When we create objects using a direct class instantiation, extra memory is allocated every time a new object is created (unless the class uses caching internally, which is usually not the case). We can see that in practice in the following code (file `id.py`), it creates two instances of the same class `A` and uses the `id()` function to compare their memory addresses. The addresses are also printed in the output so that we can inspect them. The fact that the memory addresses are different means that two distinct objects are created as follows:

```
class A(object):
    pass

if __name__ == '__main__':
    a = A()
    b = A()

    print(id(a) == id(b))
    print(a, b)
```

Executing `id.py` on my computer gives the following output:

```
>> python3 id.py
False
<__main__.A object at 0x7f5771de8f60> <__main__.A object at
0x7f5771df2208>
```

Note that the addresses that you see if you execute the file are not the same as I see because they depend on the current memory layout and allocation. But the result must be the same: the two addresses should be different. There's one exception that happens if you write and execute the code in the Python **Read-Eval-Print Loop** (**REPL**) (interactive prompt), but that's a REPL-specific optimization which is not happening normally.

Implementation

Data comes in many forms. There are two main file categories for storing/retrieving data: human-readable files and binary files. Examples of human-readable files are XML, Atom, YAML, and JSON. Examples of binary files are the `.sq3` file format used by SQLite and the `.mp3` file format used to listen to music.

In this example, we will focus on two popular human-readable formats: XML and JSON. Although human-readable files are generally slower to parse than binary files, they make data exchange, inspection, and modification much easier. For this reason, it is advised to prefer working with human-readable files, unless there are other restrictions that do not allow it (mainly unacceptable performance and proprietary binary formats).

In this problem, we have some input data stored in an XML and a JSON file, and we want to parse them and retrieve some information. At the same time, we want to centralize the client's connection to those (and all future) external services. We will use the Factory Method to solve this problem. The example focuses only on XML and JSON, but adding support for more services should be straightforward.

First, let's take a look at the data files. The XML file, `person.xml`, is based on the Wikipedia example [`j.mp/wikijson`] and contains information about individuals (`firstName`, `lastName`, `gender`, and so on) as follows:

```
<persons>
  <person>
    <firstName>John</firstName>
    <lastName>Smith</lastName>
    <age>25</age>
    <address>
      <streetAddress>21 2nd Street</streetAddress>
      <city>New York</city>
      <state>NY</state>
      <postalCode>10021</postalCode>
    </address>
    <phoneNumbers>
      <phoneNumber type="home">212 555-1234</phoneNumber>
      <phoneNumber type="fax">646 555-4567</phoneNumber>
    </phoneNumbers>
    <gender>
      <type>male</type>
    </gender>
  </person>
  <person>
    <firstName>Jimy</firstName>
```

```
    <lastName>Liar</lastName>
    <age>19</age>
    <address>
      <streetAddress>18 2nd Street</streetAddress>
      <city>New York</city>
      <state>NY</state>
      <postalCode>10021</postalCode>
    </address>
    <phoneNumbers>
      <phoneNumber type="home">212 555-1234</phoneNumber>
    </phoneNumbers>
    <gender>
      <type>male</type>
    </gender>
  </person>
  <person>
    <firstName>Patty</firstName>
    <lastName>Liar</lastName>
    <age>20</age>
    <address>
      <streetAddress>18 2nd Street</streetAddress>
      <city>New York</city>
      <state>NY</state>
      <postalCode>10021</postalCode>
    </address>
    <phoneNumbers>
      <phoneNumber type="home">212 555-1234</phoneNumber>
      <phoneNumber type="mobile">001 452-8819</phoneNumber>
    </phoneNumbers>
    <gender>
      <type>female</type>
    </gender>
  </person>
</persons>
```

The JSON file, `donut.json`, comes from the GitHub account of Adobe [`j.mp/adobejson`] and contains donut information (`type`, price/unit that is, `ppu`, `topping`, and so on) as follows:

```
[
  {
    "id": "0001",
    "type": "donut",
    "name": "Cake",
    "ppu": 0.55,
```

```
      "batters": {
        "batter": [
          { "id": "1001", "type": "Regular" },
          { "id": "1002", "type": "Chocolate" },
          { "id": "1003", "type": "Blueberry" },
          { "id": "1004", "type": "Devil's Food" }
        ]
      },
      "topping": [
        { "id": "5001", "type": "None" },
        { "id": "5002", "type": "Glazed" },
        { "id": "5005", "type": "Sugar" },
        { "id": "5007", "type": "Powdered Sugar" },
        { "id": "5006", "type": "Chocolate with Sprinkles" },
        { "id": "5003", "type": "Chocolate" },
        { "id": "5004", "type": "Maple" }
      ]
    },
    {
      "id": "0002",
      "type": "donut",
      "name": "Raised",
      "ppu": 0.55,
      "batters": {
        "batter": [
          { "id": "1001", "type": "Regular" }
        ]
      },
      "topping": [
        { "id": "5001", "type": "None" },
        { "id": "5002", "type": "Glazed" },
        { "id": "5005", "type": "Sugar" },
        { "id": "5003", "type": "Chocolate" },
        { "id": "5004", "type": "Maple" }
      ]
    },
    {
      "id": "0003",
      "type": "donut",
      "name": "Old Fashioned",
      "ppu": 0.55,
      "batters": {
        "batter": [
```

```
            { "id": "1001", "type": "Regular" },
            { "id": "1002", "type": "Chocolate" }
          ]
        },
        "topping": [
          { "id": "5001", "type": "None" },
          { "id": "5002", "type": "Glazed" },
          { "id": "5003", "type": "Chocolate" },
          { "id": "5004", "type": "Maple" }
        ]
      }
]
```

We will use two libraries that are part of the Python distribution for working with XML and JSON: `xml.etree.ElementTree` and `json` as follows:

```
import xml.etree.ElementTree as etree
import json
```

The `JSONConnector` class parses the JSON file and has a `parsed_data()` method that returns all data as a dictionary (`dict`). The `property` decorator is used to make `parsed_data()` appear as a normal variable instead of a method as follows:

```
class JSONConnector:

    def __init__(self, filepath):
        self.data = dict()
        with open(filepath, mode='r', encoding='utf-8') as f:
            self.data = json.load(f)

    @property
    def parsed_data(self):
        return self.data
```

The `XMLConnector` class parses the XML file and has a `parsed_data()` method that returns all data as a list of `xml.etree.Element` as follows:

```
class XMLConnector:

    def __init__(self, filepath):
        self.tree = etree.parse(filepath)

    @property
    def parsed_data(self):
        return self.tree
```

The `connection_factory()` function is a Factory Method. It returns an instance of `JSONConnector` or `XMLConnector` depending on the extension of the input file path as follows:

```
def connection_factory(filepath):
    if filepath.endswith('json'):
        connector = JSONConnector
    elif filepath.endswith('xml'):
        connector = XMLConnector
    else:
        raise ValueError('Cannot connect to {}'.format(filepath))
    return connector(filepath)
```

The `connect_to()` function is a wrapper of `connection_factory()`. It adds exception handling as follows:

```
def connect_to(filepath):
    factory = None
    try:
        factory = connection_factory(filepath)
    except ValueError as ve:
        print(ve)
    return factory
```

The `main()` function demonstrates how the Factory Method design pattern can be used. The first part makes sure that exception handling is effective as follows:

```
def main():
    sqlite_factory = connect_to('data/person.sq3')
```

The next part shows how to work with the XML files using the Factory Method. **XPath** is used to find all `person` elements that have the last name `Liar`. For each matched person, the basic name and phone number information are shown as follows:

```
    xml_factory = connect_to('data/person.xml')
    xml_data = xml_factory.parsed_data()
    liars = xml_data.findall
    (".//{person}[{lastName}='{}']".format('Liar'))
    print('found: {} persons'.format(len(liars)))
    for liar in liars:
        print('first name:
        {}'.format(liar.find('firstName').text))
        print('last name: {}'.format(liar.find('lastName').text))
        [print('phone number ({}):'.format(p.attrib['type']),
        p.text) for p in liar.find('phoneNumbers')]
```

The final part shows how to work with the JSON files using the Factory Method. Here, there's no pattern matching, and therefore the `name`, `price`, and `topping` of all donuts are shown as follows:

```
json_factory = connect_to('data/donut.json')
json_data = json_factory.parsed_data
print('found: {} donuts'.format(len(json_data)))
for donut in json_data:
    print('name: {}'.format(donut['name']))
    print('price: ${}'.format(donut['ppu']))
    [print('topping: {} {}'.format(t['id'], t['type'])) for t
    in donut['topping']]
```

For completeness, here is the complete code of the Factory Method implementation (`factory_method.py`) as follows:

```
import xml.etree.ElementTree as etree
import json

class JSONConnector:
    def __init__(self, filepath):
        self.data = dict()
        with open(filepath, mode='r', encoding='utf-8') as f:
            self.data = json.load(f)

    @property
    def parsed_data(self):
        return self.data

class XMLConnector:
    def __init__(self, filepath):
        self.tree = etree.parse(filepath)

    @property
    def parsed_data(self):
        return self.tree

def connection_factory(filepath):
    if filepath.endswith('json'):
        connector = JSONConnector
    elif filepath.endswith('xml'):
        connector = XMLConnector
    else:
        raise ValueError('Cannot connect to {}'.format(filepath))
    return connector(filepath)
```

```
    def connect_to(filepath):
        factory = None
        try:
           factory = connection_factory(filepath)
        except ValueError as ve:
            print(ve)
        return factory

    def main():
        sqlite_factory = connect_to('data/person.sq3')
        print()

        xml_factory = connect_to('data/person.xml')
        xml_data = xml_factory.parsed_data
        liars = xml_data.findall(".//{}[{}='{}']".format('person',
        'lastName', 'Liar'))
        print('found: {} persons'.format(len(liars)))
        for liar in liars:
            print('first name:
            {}'.format(liar.find('firstName').text))
            print('last name: {}'.format(liar.find('lastName').text))
            [print('phone number ({}):'.format(p.attrib['type']),
            p.text) for p in liar.find('phoneNumbers')]
        print()

        json_factory = connect_to('data/donut.json')
        json_data = json_factory.parsed_data
        print('found: {} donuts'.format(len(json_data)))
        for donut in json_data:
        print('name: {}'.format(donut['name']))
        print('price: ${}'.format(donut['ppu']))
        [print('topping: {} {}'.format(t['id'], t['type'])) for t
        in donut['topping']]

    if __name__ == '__main__':
        main()
```

Here is the output of this program as follows:

```
>>> python3 factory_method.py
Cannot connect to data/person.sq3

found: 2 persons
first name: Jimy
```

```
last name: Liar
phone number (home): 212 555-1234
first name: Patty
last name: Liar
phone number (home): 212 555-1234
phone number (mobile): 001 452-8819

found: 3 donuts
name: Cake
price: $0.55
topping: 5001 None
topping: 5002 Glazed
topping: 5005 Sugar
topping: 5007 Powdered Sugar
topping: 5006 Chocolate with Sprinkles
topping: 5003 Chocolate
topping: 5004 Maple
name: Raised
price: $0.55
topping: 5001 None
topping: 5002 Glazed
topping: 5005 Sugar
topping: 5003 Chocolate
topping: 5004 Maple
name: Old Fashioned
price: $0.55
topping: 5001 None
topping: 5002 Glazed
topping: 5003 Chocolate
topping: 5004 Maple
```

Notice that although `JSONConnector` and `XMLConnector` have the same interfaces, what is returned by `parsed_data()` is not handled in a uniform way. Different python code must be used to work with each connector. Although it would be nice to be able to use the same code for all connectors, this is at most times not realistic unless we use some kind of common mapping for the data which is very often provided by external data providers. Assuming that you can use exactly the same code for handling the XML and JSON files, what changes are required to support a third format, for example, SQLite? Find an SQLite file or create your own and try it.

As it is now, the code does not forbid a direct instantiation of a connector. Is it possible to do this? Try doing it.

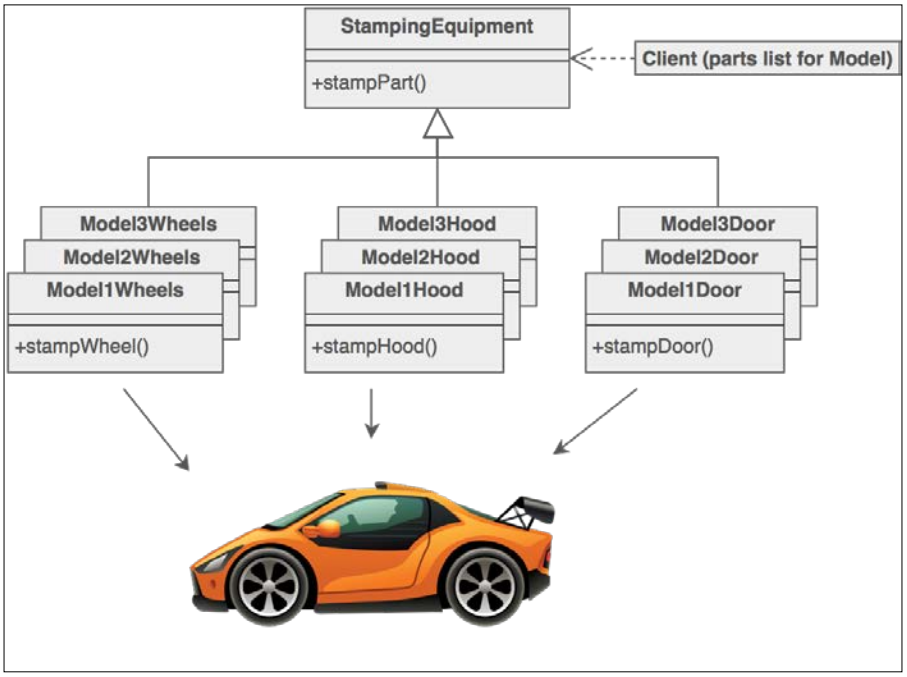
Hint: Functions in Python can have nested classes.

Abstract Factory

The Abstract Factory design pattern is a generalization of Factory Method. Basically, an Abstract Factory is a (logical) group of Factory Methods, where each Factory Method is responsible for generating a different kind of object [Eckel08, page 193].

A real-life example

Abstract Factory is used in car manufacturing. The same machinery is used for stamping the parts (doors, panels, hoods, fenders, and mirrors) of different car models. The model that is assembled by the machinery is configurable and easy to change at any time. We can see an example of the car manufacturing Abstract Factory in the following figure, which is provided by `www.sourcemaking.com` [`j.mp/absfpat`].



A software example

The **django_factory** package is an Abstract Factory implementation for creating Django models in tests. It is used for creating instances of models that support test-specific attributes. This is important because the tests become readable and avoid sharing unnecessary code [`j.mp/djangoabs`].

Use cases

Since the Abstract Factory pattern is a generalization of the Factory Method pattern, it offers the same benefits: it makes tracking an object creation easier, it decouples an object creation from an object usage, and it gives us the potential to improve the memory usage and performance of our application.

But a question is raised: how do we know when to use the Factory Method versus using an Abstract Factory? The answer is that we usually start with the Factory Method which is simpler. If we find out that our application requires many Factory Methods which it makes sense to combine for creating a family of objects, we end up with an Abstract Factory.

A benefit of the Abstract Factory that is usually not very visible from a user's point of view when using the Factory Method is that it gives us the ability to modify the behavior of our application dynamically (in runtime) by changing the active Factory Method. The classic example is giving the ability to change the look and feel of an application (for example, Apple-like, Windows-like, and so on) for the user while the application is in use, without the need to terminate it and start it again [GOF95, page 99].

Implementation

To demonstrate the Abstract Factory pattern, I will reuse one of my favorite examples, included in *Python 3 Patterns & Idioms*, *Bruce Eckel*, [Eckel08, page 193]. Imagine that we are creating a game or we want to include a mini-game as part of our application to entertain our users. We want to include at least two games, one for children and one for adults. We will decide which game to create and launch in runtime, based on user input. An Abstract Factory takes care of the game creation part.

Let's start with the kid's game. It is called `FrogWorld`. The main hero is a frog who enjoys eating bugs. Every hero needs a good name, and in our case the name is given by the user in runtime. The `interact_with()` method is used to describe the interaction of the frog with an obstacle (for example, bug, puzzle, and other frog) as follows:

```
class Frog:
    def __init__(self, name):
        self.name = name

    def __str__(self):
        return self.name

    def interact_with(self, obstacle):
        print('{} the Frog encounters {} and {}!'.format(self,
        obstacle, obstacle.action()))
```

There can be many different kinds of obstacles but for our example an obstacle can only be a `Bug`. When the frog encounters a bug, only one action is supported: it eats it!

```
class Bug:
    def __str__(self):
        return 'a bug'

    def action(self):
        return 'eats it'
```

The `FrogWorld` class is an Abstract Factory. Its main responsibilities are creating the main character and the obstacle(s) of the game. Keeping the creation methods separate and their names generic (for example, `make_character()`, `make_obstacle()`) allows us to dynamically change the active factory (and therefore the active game) without any code changes. In a statically typed language, the Abstract Factory would be an abstract class/interface with empty methods, but in Python this is not required because the types are checked in runtime [Eckel08, page 195], [`j.mp/ginstromdp`] as follows:

```
class FrogWorld:
    def __init__(self, name):
        print(self)
        self.player_name = name

    def __str__(self):
        return '\n\n\t------ Frog World -------'
```

```
    def make_character(self):
        return Frog(self.player_name)

    def make_obstacle(self):
        return Bug()
```

The `WizardWorld` game is similar. The only differences are that the wizard battles against monsters like orks instead of eating bugs!

```
class Wizard:
    def __init__(self, name):
        self.name = name

    def __str__(self):
        return self.name

    def interact_with(self, obstacle):
        print('{} the Wizard battles against {} and
        {}!'.format(self, obstacle, obstacle.action()))

class Ork:
    def __str__(self):
        return 'an evil ork'

    def action(self):
        return 'kills it'

class WizardWorld:
    def __init__(self, name):
        print(self)
        self.player_name = name

    def __str__(self):
        return '\n\n\t------ Wizard World -------'

    def make_character(self):
        return Wizard(self.player_name)

    def make_obstacle(self):
        return Ork()
```

The `GameEnvironment` is the main entry point of our game. It accepts `factory` as an input, and uses it to create the world of the game. The `play()` method initiates the interaction between the created `hero` and the `obstacle` as follows:

```
class GameEnvironment:
    def __init__(self, factory):
        self.hero = factory.make_character()
        self.obstacle = factory.make_obstacle()

    def play(self):
        self.hero.interact_with(self.obstacle)
```

The `validate_age()` function prompts the user to give a valid age. If the age is not valid, it returns a tuple with the first element set to `False`. If the age is fine, the first element of the tuple is set to `True` and that's the case where we actually care about the second element of the tuple, which is the age given by the user as follows:

```
def validate_age(name):
    try:
        age = input('Welcome {}. How old are you? '.format(name))
        age = int(age)
    except ValueError as err:
        print("Age {} is invalid, please try
        again...".format(age))
        return (False, age)
    return (True, age)
```

Last but not least comes the `main()` function. It asks for the user's name and age, and decides which game should be played by the age of the user as follows:

```
def main():
    name = input("Hello. What's your name? ")
    valid_input = False
    while not valid_input:
        valid_input, age = validate_age(name)
    game = FrogWorld if age < 18 else WizardWorld
    environment = GameEnvironment(game(name))
    environment.play()
```

And the complete code of the Abstract Factory implementation (`abstract_factory.py`) is given as follows:

```
class Frog:
    def __init__(self, name):
        self.name = name
```

```
        def __str__(self):
            return self.name

        def interact_with(self, obstacle):
            print('{} the Frog encounters {} and {}!'.format(self,
            obstacle, obstacle.action()))

    class Bug:
        def __str__(self):
            return 'a bug'

        def action(self):
            return 'eats it'

    class FrogWorld:
        def __init__(self, name):
            print(self)
            self.player_name = name

        def __str__(self):
            return '\n\n\t------ Frog World -------'

        def make_character(self):
            return Frog(self.player_name)

        def make_obstacle(self):
            return Bug()

    class Wizard:
        def __init__(self, name):
            self.name = name

        def __str__(self):
            return self.name

        def interact_with(self, obstacle):
            print('{} the Wizard battles against {} and
            {}!'.format(self, obstacle, obstacle.action()))

    class Ork:
        def __str__(self):
            return 'an evil ork'
```

```
        def action(self):
            return 'kills it'

    class WizardWorld:
        def __init__(self, name):
            print(self)
            self.player_name = name

        def __str__(self):
            return '\n\n\t------ Wizard World -------'

        def make_character(self):
            return Wizard(self.player_name)

        def make_obstacle(self):
            return Ork()

    class GameEnvironment:
        def __init__(self, factory):
            self.hero = factory.make_character()
            self.obstacle = factory.make_obstacle()

        def play(self):
            self.hero.interact_with(self.obstacle)

    def validate_age(name):
        try:
            age = input('Welcome {}. How old are you? '.format(name))
            age = int(age)
        except ValueError as err:
            print("Age {} is invalid, please try
            again...".format(age))
            return (False, age)
        return (True, age)

    def main():
        name = input("Hello. What's your name? ")
        valid_input = False
        while not valid_input:
            valid_input, age = validate_age(name)
        game = FrogWorld if age < 18 else WizardWorld
        environment = GameEnvironment(game(name))
        environment.play()

    if __name__ == '__main__':
        main()
```

A sample output of this program is as follows:

```
>>> python3 abstract_factory.py
Hello. What's your name? Nick
Welcome Nick. How old are you? 17
        ------ Frog World -------
Nick the Frog encounters a bug and eats it!
```

Try extending the game to make it more complete. You can go as far as you want: many obstacles, many enemies, and whatever else you like.

Summary

In this chapter, we have seen how to use the Factory Method and the Abstract Factory design patterns. Both patterns are used when we want to (a) track an object creation, (b) decouple an object creation from an object usage, or even (c) improve the performance and resource usage of an application. Case (c) was not demonstrated in the chapter. You might consider it as a good exercise.

The Factory Method design pattern is implemented as a single function that doesn't belong to any class, and is responsible for the creation of a single kind of object (a shape, a connection point, and so on). We saw how the Factory Method relates to toy construction, mentioned how it is used by Django for creating different form fields, and discussed other possible use cases for it. As an example, we implemented a Factory Method that provides access to the XML and JSON files.

The Abstract Factory design pattern is implemented as a number of Factory Methods that belong to a single class and are used to create a family of related objects (the parts of a car, the environment of a game, and so forth). We mentioned how the Abstract Factory is related with car manufacturing, how the django_factory Django package makes use of it to create clean tests, and covered the use cases of it. The implementation of the Abstract Factory is a mini-game that shows how we can use many related factories in a single class.

In the next chapter, we will talk about the Builder pattern, which is another creational pattern that can be used for fine-controlling the creation of complex objects.

2
The Builder Pattern

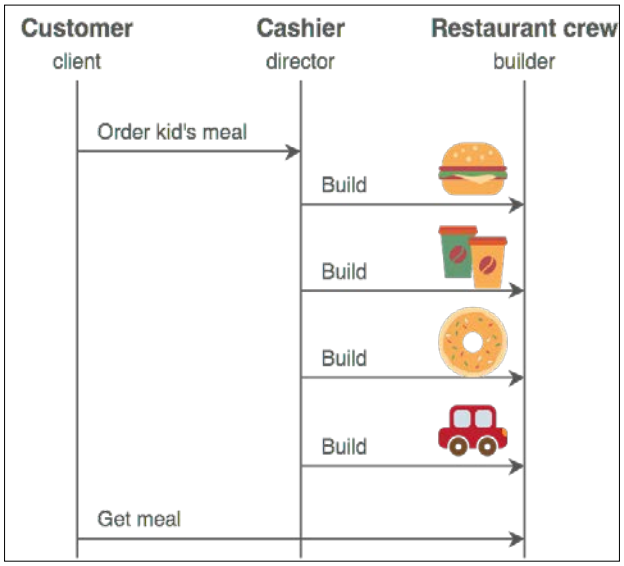
Imagine that we want to create an object that is composed of multiple parts and the composition needs to be done step by step. The object is not complete unless all its parts are fully created. That's where the **Builder design pattern** can help us. The Builder pattern separates the construction of a complex object from its representation. By keeping the construction separate from the representation, the same construction can be used to create several different representations [GOF95, page 110], [`j.mp/builderpat`].

A practical example can help us understand what the purpose of the Builder pattern is. Suppose that we want to create an HTML page generator, the basic structure (construction part) of an HTML page is always the same: it begins with `<html>` and finishes with `</html>`; inside the HTML section are the `<head>` and `</head>` elements, inside the head section are the `<title>` and `</title>` elements, and so forth. But the representation of the page can differ. Each page has its own title, its own headings, and different `<body>` contents. Moreover, the page is usually built in steps: one function adds the title, another adds the main heading, another the footer, and so on. Only after the whole structure of a page is complete can it be shown to the client using a final render function. We can take it even further and extend the HTML generator so that it can generate totally different HTML pages. One page might contain tables, another page might contain image galleries, yet another page contains the contact form, and so on.

The HTML page generation problem can be solved using the Builder pattern. In this pattern, there are two main participants: the **builder** and the **director**. The builder is responsible for creating the various parts of the complex object. In the HTML example, these parts are the title, heading, body, and the footer of the page. The director controls the building process using a builder instance. The HTML example means for calling the builder's functions for setting the title, the heading, and so on. Using a different builder instance allows us to create a different HTML page without touching any code of the director.

A real-life example

The Builder design pattern is used in fast-food restaurants. The same procedure is always used to prepare a burger and the packaging (box and paper bag), even if there are many different kinds of burgers (classic, cheeseburger, and more) and different packages (small-sized box, medium-sized box, and so forth). The difference between a classic burger and a cheeseburger is in the representation, and not in the construction procedure. The director is the cashier who gives instructions about what needs to be prepared to the crew, and the builder is the person from the crew that takes care of the specific order. The following figure provided by `www.sourcemaking.com` shows a **Unified Modeling Language** (**UML**) sequence diagram of the communication that takes place between the customer (client), the cashier (director), and the crew (builder) when a kid's menu is ordered [`j.mp/builderpat`].



A software example

The HTML example that was mentioned at the beginning of the chapter is actually used by **django-widgy**, a third-party tree editor for Django that can be used as a **Content Management System** (**CMS**). The django-widgy editor contains a page builder that can be used for creating HTML pages with different layouts [`j.mp/widgypb`].

The **django-query-builder** library is another third-party Django library that relies on the Builder pattern. The django-query-builder library can be used for building SQL queries dynamically. Using this, we can control all aspects of a query and create a different range of queries, from simple to very complex [`j.mp/djangowidgy`].

Use cases

We use the Builder pattern when we know that an object must be created in multiple steps, and different representations of the same construction are required. These requirements exist in many applications such as page generators (like the HTML page generator mentioned in this chapter), document converters [GOF95, page 110], and **User Interface** (**UI**) form creators [`j.mp/pipbuild`].

Some resources mention that the Builder pattern can also be used as a solution to the telescopic constructor problem [`j.mp/wikibuilder`]. The telescopic constructor problem occurs when we are forced to create a new constructor for supporting different ways of creating an object. The problem is that we end up with many constructors and long parameter lists, which are hard to manage. An example of the telescopic constructor is listed at the stackoverflow website [`j.mp/sobuilder`]. Fortunately, this problem does not exist in Python, because it can be solved in at least two ways:

- With named parameters [`j.mp/sobuipython`]
- With argument list unpacking [`j.mp/arglistpy`]

At this point, the distinction between the Builder pattern and the Factory pattern might not be very clear. The main difference is that a Factory pattern creates an object in a single step, whereas a Builder pattern creates an object in multiple steps, and almost always through the use of a director. Some targeted implementations of the Builder pattern like Java's **StringBuilder** bypass the use of a director, but that's the exception to the rule.

Another difference is that while a Factory pattern returns a created object immediately, in the Builder pattern the client code explicitly asks the director to return the final object when it needs it [GOF95, page 113], [`j.mp/builderpat`].

The new computer analogy might help to distinguish between a Builder pattern and a Factory pattern. Assume that you want to buy a new computer. If you decide to buy a specific preconfigured computer model, for example, the latest Apple 1.4 GHz Mac mini, you use the Factory pattern. All the hardware specifications are already predefined by the manufacturer, who knows what to do without consulting you. The manufacturer typically receives just a single instruction. Code-wise, this would look like the following (`apple-factory.py`):

```
MINI14 = '1.4GHz Mac mini'

class AppleFactory:
    class MacMini14:
        def __init__(self):
            self.memory = 4 # in gigabytes
```

```
            self.hdd = 500 # in gigabytes
            self.gpu = 'Intel HD Graphics 5000'

        def __str__(self):
            info = ('Model: {}'.format(MINI14),
                    'Memory: {}GB'.format(self.memory),
                    'Hard Disk: {}GB'.format(self.hdd),
                    'Graphics Card: {}'.format(self.gpu))
            return '\n'.join(info)

    def build_computer(self, model):
        if (model == MINI14):
            return self.MacMini14()
        else:
            print("I don't know how to build {}".format(model))

if __name__ == '__main__':
    afac = AppleFactory()
    mac_mini = afac.build_computer(MINI14)
    print(mac_mini)
```

Notice the nested `MacMini14` class. This is a neat way of forbidding the direct instantiation of a class.

Another option is buying a custom PC. In this case, you use the Builder pattern. You are the director that gives orders to the manufacturer (builder) about your ideal computer specifications. Code-wise, this looks like the following (`computer-builder.py`):

```
class Computer:
    def __init__(self, serial_number):
        self.serial = serial_number
        self.memory = None      # in gigabytes
        self.hdd = None         # in gigabytes
        self.gpu = None

    def __str__(self):
        info = ('Memory: {}GB'.format(self.memory),
                'Hard Disk: {}GB'.format(self.hdd),
                'Graphics Card: {}'.format(self.gpu))
        return '\n'.join(info)
```

```
class ComputerBuilder:
    def __init__(self):
        self.computer = Computer('AG23385193')

    def configure_memory(self, amount):
        self.computer.memory = amount

    def configure_hdd(self, amount):
        self.computer.hdd = amount

    def configure_gpu(self, gpu_model):
        self.computer.gpu = gpu_model

class HardwareEngineer:
    def __init__(self):
        self.builder = None

    def construct_computer(self, memory, hdd, gpu):
        self.builder = ComputerBuilder()
        [step for step in (self.builder.configure_memory(memory),
                           self.builder.configure_hdd(hdd),
                           self.builder.configure_gpu(gpu))]

    @property
    def computer(self):
        return self.builder.computer

def main():
    engineer = HardwareEngineer()
    engineer.construct_computer(hdd=500, memory=8, gpu='GeForce
    GTX 650 Ti')
    computer = engineer.computer
    print(computer)

if __name__ == '__main__':
    main()
```

The basic changes are the introduction of a builder `ComputerBuilder`, a director `HardwareEngineer`, and the step-by-step construction of a computer, which now supports different configurations (notice that `memory`, `hdd`, and `gpu` are parameters and not preconfigured). What do we need to do if we want to support the construction of tablets? Implement this as an exercise.

You might also want to change the computer `serial_number` into something that is different for each computer, because as it is now it means that all computers will have the same serial number (which is impractical).

Implementation

Let's see how we can use the Builder design pattern to make a pizza ordering application. The pizza example is particularly interesting because a pizza is prepared in steps that should follow a specific order. To add the sauce, you first need to prepare the dough. To add the topping, you first need to add the sauce. And you can't start baking the pizza unless both the sauce and the topping are placed on the dough. Moreover, each pizza usually requires a different baking time, depending on the thickness of its dough and the topping used.

We start with importing the required modules and declaring a few `Enum` parameters [`j.mp/pytenum`] plus a constant that are used many times in the application. The `STEP_DELAY` constant is used to add a time delay between the different steps of preparing a pizza (prepare the dough, add the sauce, and so on) as follows:

```
from enum import Enum

PizzaProgress = Enum('PizzaProgress', 'queued preparation baking
ready')
PizzaDough = Enum('PizzaDough', 'thin thick')
PizzaSauce = Enum('PizzaSauce', 'tomato creme_fraiche')
PizzaTopping = Enum('PizzaTopping', 'mozzarella double_mozzarella
bacon ham mushrooms red_onion oregano')
STEP_DELAY = 3                  # in seconds for the sake of the
example
```

Our end product is a pizza, which is described by the `Pizza` class. When using the Builder pattern, the end product does not have many responsibilities, since it is not supposed to be instantiated directly. A builder creates an instance of the end product and makes sure that it is properly prepared. That's why the `Pizza` class is so minimal. It basically initializes all data to sane default values. An exception is the `prepare_dough()` method. The `prepare_dough()` method is defined in the `Pizza` class instead of a builder for two reasons:

- To clarify the fact that the end product is typically minimal does not mean that you should never assign it any responsibilities
- To promote code reuse through composition [GOF95, page 32]

```
class Pizza:
    def __init__(self, name):
        self.name = name
        self.dough = None
        self.sauce = None
        self.topping = []
```

```
    def __str__(self):
        return self.name

    def prepare_dough(self, dough):
        self.dough = dough
        print('preparing the {} dough of your
        {}...'.format(self.dough.name, self))
        time.sleep(STEP_DELAY)
        print('done with the {} dough'.format(self.dough.name))
```

There are two builders: one for creating a margarita pizza (`MargaritaBuilder`) and another for creating a creamy bacon pizza (`CreamyBaconBuilder`). Each builder creates a `Pizza` instance and contains methods that follow the pizza-making procedure: `prepare_dough()`, `add_sauce()`, `add_topping()`, and `bake()`. To be precise, `prepare_dough()` is just a wrapper to the `prepare_dough()` method of the `Pizza` class. Notice how each builder takes care of all the pizza-specific details. For example, the topping of the margarita pizza is `double mozzarella` and `oregano`, while the topping of the creamy bacon pizza is `mozzarella`, `bacon`, `ham`, `mushrooms`, `red onion`, and `oregano` as follows:

```
class MargaritaBuilder:
    def __init__(self):
        self.pizza = Pizza('margarita')
        self.progress = PizzaProgress.queued
        self.baking_time = 5      # in seconds for the sake of the
        example

    def prepare_dough(self):
        self.progress = PizzaProgress.preparation
        self.pizza.prepare_dough(PizzaDough.thin)

    def add_sauce(self):
        print('adding the tomato sauce to your margarita...')
        self.pizza.sauce = PizzaSauce.tomato
        time.sleep(STEP_DELAY)
        print('done with the tomato sauce')

    def add_topping(self):
        print('adding the topping (double mozzarella, oregano) to
        your margarita')
        self.pizza.topping.append([i for i in
        (PizzaTopping.double_mozzarella, PizzaTopping.oregano)])
        time.sleep(STEP_DELAY)
        print('done with the topping (double mozzarella,
        oregano)')
```

```
        def bake(self):
            self.progress = PizzaProgress.baking
            print('baking your margarita for {}
            seconds'.format(self.baking_time))
            time.sleep(self.baking_time)
            self.progress = PizzaProgress.ready
            print('your margarita is ready')

    class CreamyBaconBuilder:
        def __init__(self):
            self.pizza = Pizza('creamy bacon')
            self.progress = PizzaProgress.queued
            self.baking_time = 7      # in seconds for the sake of the
            example

        def prepare_dough(self):
            self.progress = PizzaProgress.preparation
            self.pizza.prepare_dough(PizzaDough.thick)

        def add_sauce(self):
            print('adding the crème fraîche sauce to your creamy
            bacon')

            self.pizza.sauce = PizzaSauce.creme_fraiche
            time.sleep(STEP_DELAY)

            print('done with the crème fraîche sauce')

        def add_topping(self):
            print('adding the topping (mozzarella, bacon, ham,
            mushrooms, red onion, oregano) to your creamy bacon')
            self.pizza.topping.append([t for t in
            (PizzaTopping.mozzarella, PizzaTopping.bacon,
            PizzaTopping.ham,PizzaTopping.mushrooms,
            PizzaTopping.red_onion, PizzaTopping.oregano)])
            time.sleep(STEP_DELAY)
            print('done with the topping (mozzarella, bacon, ham,
            mushrooms, red onion, oregano)')

        def bake(self):
            self.progress = PizzaProgress.baking
            print('baking your creamy bacon for {}
            seconds'.format(self.baking_time))
            time.sleep(self.baking_time)
            self.progress = PizzaProgress.ready
            print('your creamy bacon is ready')
```

The director in this example is the waiter. The core of the `Waiter` class is the `construct_pizza()` method, which accepts a builder as a parameter and executes all the pizza preparation steps in the right order. Choosing the appropriate builder, which can even be done in runtime, gives us the ability to create different pizza styles without modifying any code of the director (`Waiter`). The `Waiter` class also contains the `pizza()` method, which returns the end product (prepared pizza) as a variable to the caller as follows:

```
class Waiter:
    def __init__(self):
        self.builder = None

    def construct_pizza(self, builder):
        self.builder = builder
        [step() for step in (builder.prepare_dough,
        builder.add_sauce, builder.add_topping, builder.bake)]

    @property
    def pizza(self):
        return self.builder.pizza
```

The `validate_style()` function is similar to the `validate_age()` function as described in *Chapter 1*, *The Factory Pattern*. It is used to make sure that the user gives valid input, which in this case is a character that is mapped to a pizza builder. The `m` character uses the `MargaritaBuilder` class and the `c` character uses the `CreamyBaconBuilder` class. These mappings are in the builder parameter. A tuple is returned, with the first element set to `True` if the input is valid, or `False` if it is invalid as follows:

```
def validate_style(builders):
    try:
        pizza_style = input('What pizza would you like,
        [m]argarita or [c]reamy bacon? ')
        builder = builders[pizza_style]()
        valid_input = True
    except KeyError as err:
        print('Sorry, only margarita (key m) and creamy bacon (key
        c) are available')
        return (False, None)
    return (True, builder)
```

The last part is the `main()` function. The `main()` function contains a code for instantiating a pizza builder. The pizza builder is then used by the `Waiter` director for preparing the pizza. The created pizza can be delivered to the client at any later point:

```
def main():
    builders = dict(m=MargaritaBuilder, c=CreamyBaconBuilder)
    valid_input = False
    while not valid_input:
        valid_input, builder = validate_style(builders)
    print()
    waiter = Waiter()
    waiter.construct_pizza(builder)
    pizza = waiter.pizza
    print()
    print('Enjoy your {}!'.format(pizza))
```

To put all these things together, here's the complete code of this example (`builder.py`):

```
from enum import Enum
import time

PizzaProgress = Enum('PizzaProgress', 'queued preparation baking
ready')
PizzaDough = Enum('PizzaDough', 'thin thick')
PizzaSauce = Enum('PizzaSauce', 'tomato creme_fraiche')
PizzaTopping = Enum('PizzaTopping', 'mozzarella double_mozzarella
bacon ham mushrooms red_onion oregano')
STEP_DELAY = 3                  # in seconds for the sake of the
example

class Pizza:
    def __init__(self, name):
        self.name = name
        self.dough = None
        self.sauce = None
        self.topping = []

    def __str__(self):
        return self.name

    def prepare_dough(self, dough):
        self.dough = dough
        print('preparing the {} dough of your
        {}...'.format(self.dough.name, self))
```

```
        time.sleep(STEP_DELAY)
        print('done with the {} dough'.format(self.dough.name))

class MargaritaBuilder:
    def __init__(self):
        self.pizza = Pizza('margarita')
        self.progress = PizzaProgress.queued
        self.baking_time = 5      # in seconds for the sake of the
        example

    def prepare_dough(self):
        self.progress = PizzaProgress.preparation
        self.pizza.prepare_dough(PizzaDough.thin)

    def add_sauce(self):
        print('adding the tomato sauce to your margarita...')
        self.pizza.sauce = PizzaSauce.tomato
        time.sleep(STEP_DELAY)
        print('done with the tomato sauce')

    def add_topping(self):
        print('adding the topping (double mozzarella, oregano) to
        your margarita')
        self.pizza.topping.append([i for i in
        (PizzaTopping.double_mozzarella, PizzaTopping.oregano)])
        time.sleep(STEP_DELAY)
        print('done with the topping (double mozzarrella,
oregano)')

    def bake(self):
        self.progress = PizzaProgress.baking
        print('baking your margarita for {}
        seconds'.format(self.baking_time))
        time.sleep(self.baking_time)
        self.progress = PizzaProgress.ready
        print('your margarita is ready')

class CreamyBaconBuilder:
    def __init__(self):
        self.pizza = Pizza('creamy bacon')
        self.progress = PizzaProgress.queued
        self.baking_time = 7      # in seconds for the sake of the
        example
```

```
        def prepare_dough(self):
            self.progress = PizzaProgress.preparation
            self.pizza.prepare_dough(PizzaDough.thick)

        def add_sauce(self):
            print('adding the crème fraîche sauce to your creamy
            bacon')
            self.pizza.sauce = PizzaSauce.creme_fraiche
            time.sleep(STEP_DELAY)
            print('done with the crème fraîche sauce')

        def add_topping(self):
            print('adding the topping (mozzarella, bacon, ham,
            mushrooms, red onion, oregano) to your creamy bacon')
            self.pizza.topping.append([t for t in
            (PizzaTopping.mozzarella, PizzaTopping.bacon,
            PizzaTopping.ham,PizzaTopping.mushrooms,
            PizzaTopping.red_onion, PizzaTopping.oregano)])
            time.sleep(STEP_DELAY)
            print('done with the topping (mozzarella, bacon, ham,
            mushrooms, red onion, oregano)')

        def bake(self):
            self.progress = PizzaProgress.baking
            print('baking your creamy bacon for {}
            seconds'.format(self.baking_time))
            time.sleep(self.baking_time)
            self.progress = PizzaProgress.ready
            print('your creamy bacon is ready')

    class Waiter:
        def __init__(self):
            self.builder = None

        def construct_pizza(self, builder):
            self.builder = builder
            [step() for step in (builder.prepare_dough,
            builder.add_sauce, builder.add_topping, builder.bake)]

        @property
        def pizza(self):
            return self.builder.pizza
```

```
def validate_style(builders):
    try:
        pizza_style = input('What pizza would you like,
        [m]argarita or [c]reamy bacon? ')
        builder = builders[pizza_style]()
        valid_input = True
    except KeyError as err:
        print('Sorry, only margarita (key m) and creamy bacon (key
        c) are available')
        return (False, None)
    return (True, builder)

def main():
    builders = dict(m=MargaritaBuilder, c=CreamyBaconBuilder)
    valid_input = False
    while not valid_input:
        valid_input, builder = validate_style(builders)
    print()
    waiter = Waiter()
    waiter.construct_pizza(builder)
    pizza = waiter.pizza
    print()
    print('Enjoy your {}!'.format(pizza))

if __name__ == '__main__':
    main()
```

A sample output of this example is as follows:

```
>>> python3 builder.py
What pizza would you like, [m]argarita or [c]reamy bacon? r
Sorry, only margarita (key m) and creamy bacon (key c) are available
What pizza would you like, [m]argarita or [c]reamy bacon? m

preparing the thin dough of your margarita...
done with the thin dough
adding the tomato sauce to your margarita...
done with the tomato sauce
adding the topping (double mozzarella, oregano) to your margarita
done with the topping (double mozzarella, oregano)
baking your margarita for 5 seconds
your margarita is ready

Enjoy your margarita!
```

Supporting only two pizza types is a shame. Implement a Hawaiian pizza builder. Consider using inheritance after thinking about the advantages and disadvantages. Check the ingredients of a typical Hawaiian pizza and decide which class you need to extend: `MargaritaBuilder` or `CreamyBaconBuilder`? Perhaps both [`j.mp/pymulti`]?

In the book, *Effective Java (2nd edition)*, Joshua Bloch describes an interesting variation of the Builder pattern where calls to builder methods are chained. This is accomplished by defining the builder itself as an inner class and returning itself from each of the setter-like methods on it. The `build()` method returns the final object. This pattern is called the Fluent Builder. Here's a Python implementation, which was kindly provided by a reviewer of the book:

```
class Pizza:
    def __init__(self, builder):
        self.garlic = builder.garlic
        self.extra_cheese  = builder.extra_cheese

    def __str__(self):
        garlic = 'yes' if self.garlic else 'no'
        cheese = 'yes' if self.extra_cheese else 'no'
        info = ('Garlic: {}'.format(garlic),
            'Extra cheese: {}'.format(cheese))
        return '\n'.join(info)

    class PizzaBuilder:
        def __init__(self):
            self.extra_cheese = False
            self.garlic = False

        def add_garlic(self):
            self.garlic = True
            return self

        def add_extra_cheese(self):
            self.extra_cheese = True
            return self

        def build(self):
            return Pizza(self)

if __name__ == '__main__':
    pizza =
    Pizza.PizzaBuilder().add_garlic().add_extra_cheese().build()
    print(pizza)
```

Adapt the pizza example to make use of the Fluent Builder pattern. Which version of the two do you prefer? What are the pros and cons of each version?

Summary

In this chapter, we have seen how to use the Builder design pattern. We use the Builder pattern for creating an object in situations where using the Factory pattern (either a Factory Method or an Abstract Factory) is not a good option. A Builder pattern is usually a better candidate than a Factory pattern when:

- We want to create a complex object (an object composed of many parts and created in different steps that might need to follow a specific order).
- Different representations of an object are required, and we want to keep the construction of an object decoupled from its representation
- We want to create an object at one point in time but access it at a later point

We saw how the Builder pattern is used in fast-food restaurants for preparing meals, and how two third-party Django packages, django-widgy and django-query-builder, use it for generating HTML pages and dynamic SQL queries, respectively. We focused on the differences between a Builder pattern and a Factory pattern, and gave a preconfigured (Factory) versus customer (Builder) computer order analogy to clarify them.

In the implementation part, we have seen how to create a pizza ordering application, which has preparation dependencies. There are many recommended interesting exercises in this chapter, including implementing a Fluent Builder.

In the next chapter, you will learn about the last creational design pattern covered in this book: the Prototype pattern, which is used for cloning an object.

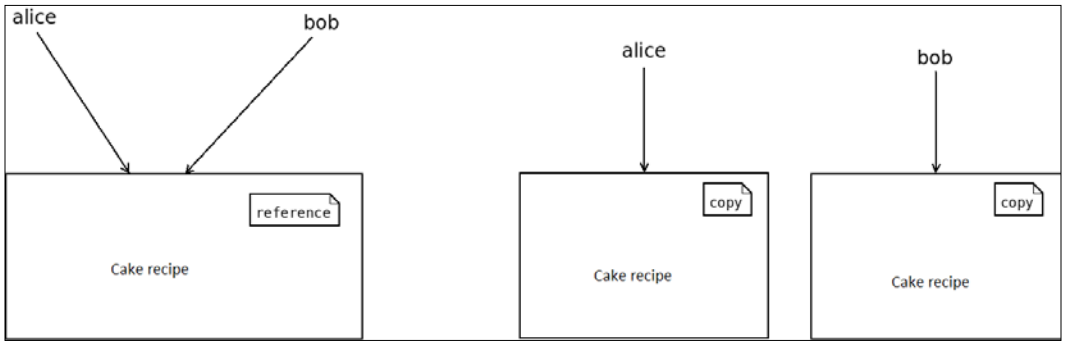
3
The Prototype Pattern

Sometimes, we need to create an exact copy of an object. For instance, assume that you want to create an application for storing, sharing, and editing (such as modifying, adding notes, and removing) culinary recipes. User Bob finds a cake recipe and after making a few modifications he thinks that his cake is delicious, and he wants to share it with his friend, Alice. But what does sharing a recipe mean? If Bob wants to do some further experimentation with his recipe after sharing it with Alice, will the new changes also be visible in Alice's recipe? Can Bob keep two copies of the cake recipe? His delicious cake recipe should remain unaffected by any changes made in the experimental cake recipe.

Such problems can be solved by allowing the users to have more than one independent copy of the same recipe. Each copy is called a clone, because it is an exact copy of the original object at a specific point in time. The time aspect is important, since it affects what the clone contains. For example, if Bob shares the cake recipe with Alice before making his own improvements to achieve perfection, Alice will never be able to bake her own version of the delicious cake that Bob created! She will only be able to bake the original cake recipe found by Bob.

Note the difference between a copy and a reference. If we have two references to the same cake recipe, whatever changes Bob makes to the recipe will be visible to Alice's version of the recipe, and vice versa. What we want is both Bob and Alice to have their own copy, so that they can make independent changes without affecting each other's recipe. Bob actually needs two copies of the cake recipe: the delicious version and the experimental version.

The difference between a reference and a copy is shown in the following figure:



On the left part, we can see two references. Both Alice and Bob refer to the same recipe, which essentially means that they share it and all modifications are visible by both. On the right part, we can see two different copies of the same recipe. In this case, independent modifications are allowed and the changes of Alice do not affect the changes of Bob, and vice versa.

The **Prototype design pattern** helps us with creating object clones. In its simplest version, the Prototype pattern is just a `clone()` function that accepts an object as an input parameter and returns a clone of it. In Python, this can be done using the `copy.deepcopy()` function. Let's see an example. In the following code (file `clone.py`), there are two classes, `A` and `B`. `A` is the parent class and `B` is the derived class. In the main part, we create an instance of class `B b`, and use `deepcopy()` to create a clone of `b` named `c`. The result is that all the members of the hierarchy (at the point of time the cloning happens) are copied in the clone `c`. As an interesting exercise, you can try using deepcopy() with composition instead of inheritance which is shown in the following code:

```
import copy

class A:
    def __init__(self):
        self.x = 18
        self.msg = 'Hello'

class B(A):
    def __init__(self):
        A.__init__(self)
        self.y = 34
```

```
        def __str__(self):
            return '{}, {}, {}'.format(self.x, self.msg, self.y)

    if __name__ == '__main__':
        b = B()
        c = copy.deepcopy(b)
        print([str(i) for i in (b, c)])
        print([i for i in (b, c)])
```

When executing `clone.py` on my computer, I get the following:

```
>>> python3 clone.py
['18, Hello, 34', '18, Hello, 34']
[<__main__.B object at 0x7f92dac33240>, <__main__.B object at
0x7f92dac33208>]
```

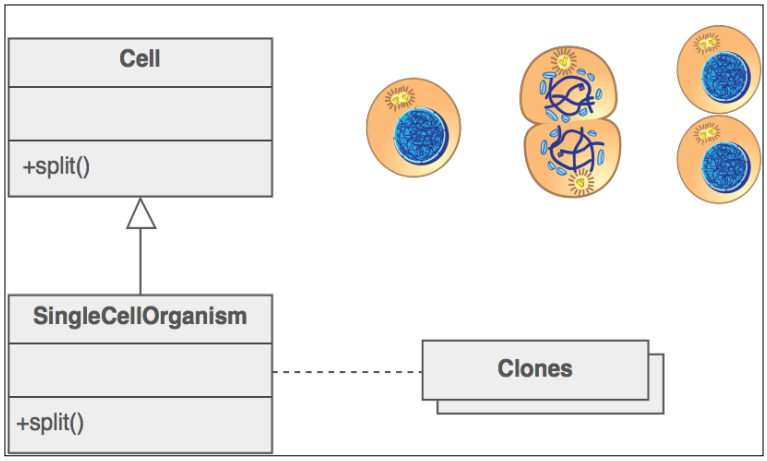
Although your output of the second line will most likely not be the same as mine, what's important is to notice that the two objects reside in two different memory addresses (the 0x... part). This means that the two objects are two independent copies.

In the *Implementation* section, later in this chapter, we will see how to use `copy.deepcopy()` with some extra boilerplate code wrapped in a class, for keeping a registry of the objects that are cloned.

A real-life example

The Prototype design pattern is all about cloning an object. Mitosis, the process in a cell division by which the nucleus divides resulting in two new nuclei, each of which has exactly the same chromosome and DNA content as the original cell, is an example of biological cloning [`j.mp/mmitosis`].

The following figure, provided by `www.sourcemaking.com`, shows an example of the mitotic division of a cell [`j.mp/pprotpat`]:



Another popular example of (artificial) cloning is Dolly, the sheep [`j.mp/wikidolly`].

A software example

There are many Python applications that make use of the Prototype pattern [`j.mp/pythonprot`], but it is almost never referred to as Prototype since cloning objects is a built-in feature of the language.

One application that uses Prototype is the **Visualization Toolkit** (**VTK**) [`j.mp/pyvto`]. VTK is an open source cross-platform system for 3D computer graphics, image processing, and visualization. VTK uses Prototype for creating clones of geometrical elements such as points, lines, hexahedrons, and so forth [`j.mp/vtkcell`].

Another project that uses Prototype is **music21**. According to the project's page, "music21 is a set of tools for helping scholars and other active listeners answer questions about music quickly and simply" [`j.mp/pmusic21`]. The music21 toolkit uses Prototype for copying musical notes and scores [`j.mp/py21code`].

Use cases

The Prototype pattern is useful when we have an existing object and we want to create an exact copy of it. A copy of an object is usually required when we know that parts of the object will be modified but we want to keep the original object untouched. In such cases, it doesn't make sense to recreate the original object from scratch [`j.mp/protpat`].

Another case where Prototype comes in handy is when we want to duplicate a complex object. By duplicating a complex object, we can think of an object that is populated from a database and has references to other objects that are also populated from a database. It is a lot of effort to create an object clone by querying the database(s) multiple times again. Using Prototype for such cases is more convenient.

So far, we have covered only the reference versus copy issue, but a copy can be further divided into a deep copy versus a shallow copy. A deep copy is what we have seen so far: all data of the original object are simply copied in the clone, without making any exceptions. A shallow copy relies on references. We can introduce data sharing, and techniques like copy-on-write to improve the performance (such as clone creation time) and the memory usage. Using shallow copies might be worthwhile if the available resources are limited (such as embedded systems) or performance is critical (such as high-performance computing).

In Python, we can do shallow copies using the `copy.copy()` function. Quoting the official Python documentation, the differences between a shallow copy (`copy.copy()`) and a deep copy (`copy.deepcopy()`) in Python are [`j.mp/py3copy`] as follows:

- "A *shallow copy* constructs a new compound object and then (to the extent possible) inserts *references* into it to the objects found in the original.
- A *deep copy* constructs a new compound object and then, recursively, inserts *copies* into it of the objects found in the original."

Can you think of any examples where using shallow copies is better than using deep copies?

Implementation

In programming, it is not uncommon for a book to be available in multiple editions. For example, the classic textbook on C programming *The C Programming Language* by Kernighan and Ritchie is available in two editions. The first edition was published in 1978. At that time, C was not standardized. The second edition of the book was published 10 years later and covers the standard (ANSI) version of C. What are the differences between the two editions? To mention a few, the price, the length (number of pages), and the publication date. But there are also many similarities: the authors, the publishers, and the tags/keywords that describe the book are exactly the same. This indicates that creating a new book from scratch is not always the best approach. If we know that there are many similarities between two book editions, we can use cloning and modify only the different parts of the new edition.

Let's see how we can use the Prototype pattern for creating an application that shows book information. We begin with the representation of a book. Apart from the usual initialization, the `Book` class demonstrates an interesting technique. It shows how we can avoid the telescopic constructor problem. In the `__init__()` method, only three parameters are fixed: `name`, `authors`, and `price`. But clients can pass more parameters in the form of keywords (name=value) using the `rest` variable-length list. The line `self.__dict__.update(rest)` adds the contents of `rest` to the internal dictionary of the `Book` class to make them part of it.

But there's a catch. Since we don't know all the names of the added parameters, we need to access the internal `dict` for making use of them in `__str__()`. And since the contents of a dictionary do not follow any specific order, we use an `OrderedDict` to force an order; otherwise, every time the program is executed, different outputs will be shown. Of course, you should not take my words for granted. As an exercise, remove the usage of `OrderedDict` and `sorted()` and run the example to see if I'm right:

```
class Book:
    def __init__(self, name, authors, price, **rest):
        '''Examples of rest: publisher, length, tags, publication
        date'''
        self.name = name
        self.authors = authors
        self.price = price      # in US dollars
        self.__dict__.update(rest)

    def __str__(self):
        mylist=[]
        ordered = OrderedDict(sorted(self.__dict__.items()))
        for i in ordered.keys():
            mylist.append('{}: {}'.format(i, ordered[i]))
            if i == 'price':
                mylist.append('$')
            mylist.append('\n')
        return ''.join(mylist)
```

The `Prototype` class implements the Prototype design pattern. The heart of the `Prototype` class is the `clone()` method, which does the actual cloning using the familiar `copy.deepcopy()` function. But the `Prototype` class does a bit more than supporting cloning. It contains the `register()` and `unregister()` methods, which can be used to keep track of the objects that are cloned in a dictionary. Note that this is just a convenience, and not a necessity.

Moreover, the `clone()` method uses the same trick that `__str__()` uses in the `Book` class, but this time for a different reason. Using the variable-length list `attr`, we can pass only the variables that really need to be modified when cloning an object as follows:

```
class Prototype:
    def __init__(self):
        self.objects = dict()

    def register(self, identifier, obj):
        self.objects[identifier] = obj

    def unregister(self, identifier):
        del self.objects[identifier]

    def clone(self, identifier, **attr):
        found = self.objects.get(identifier)
        if not found:
            raise ValueError('Incorrect object identifier:
            {}'.format(identifier))
        obj = copy.deepcopy(found)
        obj.__dict__.update(attr)
        return obj
```

The `main()` function shows *The C Programming Language* book cloning example mentioned at the beginning of this section in practice. When cloning the first edition of the book to create the second edition, we only need to pass the modified values of the existing parameters. But we can also pass extra parameters. In this case, `edition` is a new parameter that was not needed in the first book but is useful information for the clone:

```
def main():
    b1 = Book('The C Programming Language', ('Brian W. Kernighan',
    'Dennis M.Ritchie'), price=118, publisher='Prentice Hall',
    length=228, publication_date='1978-02-22', tags=('C',
    'programming', 'algorithms', 'data structures'))

    prototype = Prototype()
    cid = 'k&r-first'
    prototype.register(cid, b1)
    b2 = prototype.clone(cid, name='The C Programming Language
    (ANSI)', price=48.99, length=274,
    publication_date='1988-04-01', edition=2)

    for i in (b1, b2):
        print(i)
    print("ID b1 : {} != ID b2 : {}".format(id(b1), id(b2)))
```

Notice the usage of the `id()` function which returns the memory address of an object. When we clone an object using a deep copy, the memory addresses of the clone must be different from the memory addresses of the original object.

The `prototype.py` file is as follows:

```
import copy
from collections import OrderedDict

class Book:
    def __init__(self, name, authors, price, **rest):
        '''Examples of rest: publisher, length, tags, publication
        date'''
        self.name = name
        self.authors = authors
        self.price = price      # in US dollars
        self.__dict__.update(rest)

    def __str__(self):
        mylist=[]
        ordered = OrderedDict(sorted(self.__dict__.items()))
        for i in ordered.keys():
            mylist.append('{}: {}'.format(i, ordered[i]))
            if i == 'price':
                mylist.append('$')
            mylist.append('\n')
        return ''.join(mylist)

class Prototype:
    def __init__(self):
        self.objects = dict()

    def register(self, identifier, obj):
        self.objects[identifier] = obj

    def unregister(self, identifier):
        del self.objects[identifier]

    def clone(self, identifier, **attr):
        found = self.objects.get(identifier)
        if not found:
            raise ValueError('Incorrect object identifier:
            {}'.format(identifier))
        obj = copy.deepcopy(found)
```

```
            obj.__dict__.update(attr)
            return obj

    def main():
        b1 = Book('The C Programming Language', ('Brian W. Kernighan',
        'Dennis M.Ritchie'), price=118, publisher='Prentice Hall',
        length=228, publication_date='1978-02-22', tags=('C',
        'programming', 'algorithms', 'data structures'))

        prototype = Prototype()
        cid = 'k&r-first'
        prototype.register(cid, b1)
        b2 = prototype.clone(cid, name='The C Programming Language
        (ANSI)', price=48.99, length=274,
        publication_date='1988-04-01', edition=2)

        for i in (b1, b2):
            print(i)
        print("ID b1 : {} != ID b2 : {}".format(id(b1), id(b2)))

    if __name__ == '__main__':
        main()
```

The output of `id()` depends on the current memory allocation of the computer and you should expect it to differ on every execution of this program. But no matter what the actual addresses are, they should not be the same in any chance.

A sample output when I execute this program on my machine is as follows:

```
>>> python3 prototype.py
authors: ('Brian W. Kernighan', 'Dennis M. Ritchie')
length: 228
name: The C Programming Language
price: 118$
publication_date: 1978-02-22
publisher: Prentice Hall
tags: ('C', 'programming', 'algorithms', 'data structures')

authors: ('Brian W. Kernighan', 'Dennis M. Ritchie')
edition: 2
length: 274
name: The C Programming Language (ANSI)
price: 48.99$
```

```
publication_date: 1988-04-01
publisher: Prentice Hall
tags: ('C', 'programming', 'algorithms', 'data structures')


ID b1 : 140004970829304 != ID b2 : 140004970829472
```

Indeed, Prototype works as expected. The second edition of *The C Programming Language* book reuses all the information that was set in the first edition, and all the differences that we defined are only applied to the second edition. The first edition remains unaffected. Our confidence can be increased by looking at the output of the `id()` function: the two addresses are different.

As an exercise, you can come up with your own example of Prototype. A few ideas are as follows:

- The recipe example that was mentioned in this chapter
- The database-populated object that was mentioned in this chapter
- Copying an image so that you can add your own modifications without touching the original

Summary

In this chapter, we have seen how to use the Prototype design pattern. Prototype is used for creating exact copies of objects. Creating a copy of an object can actually mean two things:

- Relying on references, which happens when a shallow copy is created
- Duplicating everything, which happens when a deep copy is created

In the first case, we want to focus on improving the performance and the memory usage of our application by introducing data sharing between objects. But we need to be careful about modifying data, because all modifications are visible to all copies. Shallow copies were not introduced in this chapter, but you might want to experiment with them.

In the second case, we want to be able to make modifications to one copy without affecting the rest. That's useful for cases like the cake-recipe example that we have seen. Here, no data sharing is done and so we need to be careful about the resource consumption and the overhead that is introduced by our clones.

We showed a simple example of a deep copying which in Python is done using the `copy.deepcopy()` function. We also mentioned examples of cloning found in real life, focusing on mitosis.

Many software projects use Prototype, but in Python it is not mentioned as such because it is a built-in feature. Among them are the VTK, which uses Prototype for creating clones of geometrical elements, and music21, which uses it for duplicating musical scores and notes.

Finally, we discussed the use cases of Prototype and implemented a program that supports cloning books so that all information that does not change in a new edition can be reused, but at the same time modified information can be updated and new information can be added.

Prototype is the last creational design pattern covered in this book. The next chapter begins with Adapter, a structural design pattern that can be used to make two incompatible software interfaces compatible.

4
The Adapter Pattern

Structural design patterns deal with the relationships between the entities (such as classes and objects) of a system. A structural design pattern focuses on providing a simple way of composing objects for creating new functionality [GOF95, page 155], [`j.mp/structpat`].

Adapter is a structural design pattern that helps us make two incompatible interfaces compatible. First, let's answer what incompatible interfaces really mean. If we have an old component and we want to use it in a new system, or a new component that we want to use in an old system, the two can rarely communicate without requiring any code changes. But changing the code is not always possible, either because we don't have access to it (for example, the component is provided as an external library) or because it is impractical. In such cases, we can write an extra layer that makes all the required modifications for enabling the communication between the two interfaces. This layer is called the Adapter.

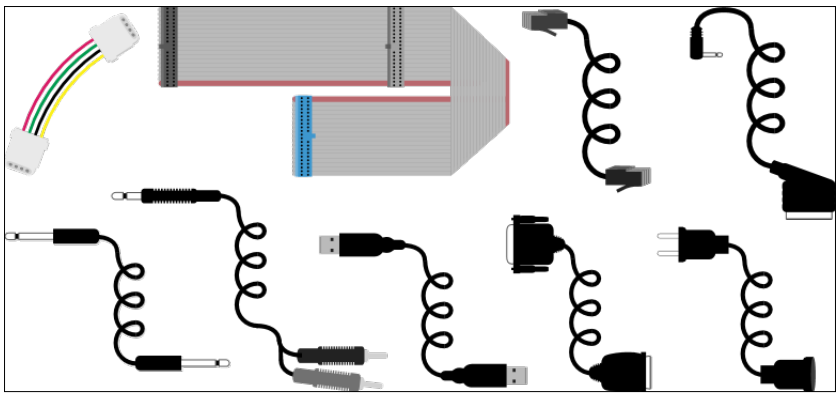
E-commerce systems are known examples. Assume that we use an e-commerce system that contains a `calculate_total(order)` function. The function calculates the total amount of an order, but only in **Danish Kroner** (**DKK**). It is reasonable for our customers to ask us to add support for more popular currencies, such as **United States Dollars** (**USD**) and **Euros** (**EUR**). If we own the source code of the system we can extend it by adding new functions for doing the conversions from DKK to USD and from DKK to EUR. But what if we don't have access to the source code of the application because it is provided to us only as an external library? In this case, we can still use the library (for example, call its methods), but we cannot modify/extend it. The solution is to write a wrapper (also known as Adapter) that converts the data from the given DKK format to the expected USD or EUR format.

The Adapter pattern is not useful only for data conversions. In general, if you want to use an interface that expects `function_a()` but you only have `function_b()`, you can use an Adapter to *convert* (adapt) `function_b()` to `function_a()` [Eckel08, page 207], [`j.mp/adapterpat`]. This is not only true for functions but also for function parameters. An example is a function that expects the parameters x, y, and z but you only have a function that works with the parameters x and y at hand. We will see how to use the Adapter pattern in the implementation section.

A real-life example

Probably all of us use the Adapter pattern every day, but in hardware instead of software. If you have a smartphone or a tablet, you need to use something (for example, the lightning connector of an iPhone) with a USB adapter for connecting it to your computer. If you are traveling from most European countries to the UK, you need to use a plug adapter for charging your laptop. The same is true if you are traveling from Europe to USA, or the other way around. Adapters are everywhere!

The following image, courtesy of `sourcemaking.com`, shows several examples of hardware adapters [`j.mp/adapterpat`]:



A software example

Grok is a Python framework that runs on top of Zope 3 and focuses on agile development. The Grok framework uses Adapters for making it possible for existing objects to conform to specific APIs without the need to modify them [`j.mp/grokada`].

The Python **Traits** package also uses the Adapter pattern for transforming an object that does not implement of a specific interface (or set of interfaces) to an object that does [`j.mp/pytraitsad`].

Use cases

The Adapter pattern is used for making things work after they have been implemented [`j.mp/adapterpat`]. Usually one of the two incompatible interfaces is either foreign or old/legacy. If the interface is foreign, it means that we have no access to the source code. If it is old it is usually impractical to refactor it. We can take it even further and argue that altering the implementation of a legacy component to meet our needs is not only impractical, but it also violates the open/close principle [`j.mp/adaptsimp`]. The **open/close principle** is one of the fundamental principles of Object-Oriented design (the O of SOLID). It states that a software entity should be open for extension, but closed for modification. That basically means that we should be able to extend the behavior of an entity without making source code modifications. Adapter respects the open/closed principle [`j.mp/openclosedp`].

Therefore, using an Adapter for making things work after they have been implemented is a better approach because it:

- Does not require access to the source code of the foreign interface
- Does not violate the open/closed principle

Implementation

There are many ways of implementing the Adapter design pattern in Python [Eckel08, page 207]. All the techniques demonstrated by *Bruce Eckel* use inheritance, but Python provides an alternative, and in my opinion, a more idiomatic way of implementing an Adapter. The alternative technique should be familiar to you, since it uses the internal dictionary of a class, and we have seen how to do that in *Chapter 3*, *The Prototype Pattern*.

Let's begin with the *what we have* part. Our application has a `Computer` class that shows basic information about a computer. All the classes of this example, including the `Computer` class are very primitive, because we want to focus on the Adapter pattern and not on how to make a class as complete as possible.

```
class Computer:
    def __init__(self, name):
        self.name = name

    def __str__(self):
        return 'the {} computer'.format(self.name)

    def execute(self):
        return 'executes a program'
```

In this case, the `execute()` method is the main action that the computer can perform. This method is called by the client code.

Now we move to the *what we want* part. We decide to enrich our application with more functionality, and luckily, we find two interesting classes implemented in two different libraries that are unrelated with our application: `Synthesizer` and `Human`. In the `Synthesizer` class, the main action is performed by the `play()` method. In the `Human` class, it is performed by the `speak()` method. To indicate that the two classes are external, we place them in a separate module, as shown:

```
class Synthesizer:
    def __init__(self, name):
        self.name = name

    def __str__(self):
        return 'the {} synthesizer'.format(self.name)

    def play(self):
        return 'is playing an electronic song'

class Human:
    def __init__(self, name):
        self.name = name

    def __str__(self):
        return '{} the human'.format(self.name)

    def speak(self):
        return 'says hello'
```

So far so good. But, we have a problem. The client only knows how to call the `execute()` method, and it has no idea about `play()` or `speak()`. How can we make the code work without changing the `Synthesizer` and `Human` classes? Adapters to the rescue! We create a generic `Adapter` class that allows us to adapt a number of objects with different interfaces, into one unified interface. The `obj` argument of the `__init__()` method is the object that we want to adapt, and `adapted_methods` is a dictionary containing key/value pairs of method the client calls/method that should be called.

```
class Adapter:
    def __init__(self, obj, adapted_methods):
        self.obj = obj
        self.__dict__.update(adapted_methods)

    def __str__(self):
        return str(self.obj)
```

Let's see how we can use the Adapter pattern. An `objects` list holds all the objects. The compatible objects that belong to the `Computer` class need no adaptation. We can add them directly to the list. The incompatible objects are not added directly. They are adapted using the `Adapter` class. The result is that the client code can continue using the known `execute()` method on all objects without the need to be aware of any interface differences between the used classes.

```
def main():
    objects = [Computer('Asus')]
    synth = Synthesizer('moog')
    objects.append(Adapter(synth, dict(execute=synth.play)))
    human = Human('Bob')
    objects.append(Adapter(human, dict(execute=human.speak)))

    for i in objects:
        print('{} {}'.format(str(i), i.execute()))
```

Let's see the complete code of the Adapter pattern example (files `external.py` and `adapter.py`) as follows:

```
class Synthesizer:
    def __init__(self, name):
        self.name = name

    def __str__(self):
        return 'the {} synthesizer'.format(self.name)

    def play(self):
        return 'is playing an electronic song'

class Human:
    def __init__(self, name):
        self.name = name

    def __str__(self):
        return '{} the human'.format(self.name)

    def speak(self):
        return 'says hello'

from external import Synthesizer, Human

class Computer:
    def __init__(self, name):
        self.name = name
```

```
        def __str__(self):
            return 'the {} computer'.format(self.name)

        def execute(self):
            return 'executes a program'

    class Adapter:
        def __init__(self, obj, adapted_methods):
            self.obj = obj
            self.__dict__.update(adapted_methods)

        def __str__(self):
            return str(self.obj)

    def main():
        objects = [Computer('Asus')]
        synth = Synthesizer('moog')
        objects.append(Adapter(synth, dict(execute=synth.play)))
        human = Human('Bob')
        objects.append(Adapter(human, dict(execute=human.speak)))

        for i in objects:
            print('{} {}'.format(str(i), i.execute()))

    if __name__ == "__main__":
        main()
```

The output when executing the example is:

```
>>> python3 adapter.py
the Asus computer executes a program
the moog synthesizer is playing an electronic song
Bob the human says hello
```

We managed to make the `Human` and `Synthesizer` classes compatible with the interface expected by the client, without changing their source code. This is nice.

Here's a challenging exercise for you. There is a problem with this implementation. While all classes have a `name` attribute, the following code fails:

```
    for i in objects:
            print(i.name)
```

First of all, why does this code fail? Although this makes sense from a coding point of view, it does not make sense at all for the client code which should not be aware of details such as what is adapted and what is not adapted. We just want to provide a uniform interface. How can we make this code work?

Hint: Think of how you can delegate the non-adapted parts to the object contained in the Adapter class.

Summary

This chapter covered the Adapter design pattern. We use the Adapter pattern for making two (or more) incompatible interfaces compatible. As a motivation, an e-commerce system that should support multiple currencies was mentioned. We use adapters every day for interconnecting devices, charging them, and so on.

Adapter makes things work after they have been implemented. The Grok Python framework and the Traits package use the Adapter pattern for achieving API conformance and interface compatibility, respectively. The open/close principle is strongly connected with these aspects.

In the implementation section, we saw how to achieve interface conformance using the Adapter pattern without modifying the source code of the incompatible model. This is achieved through a generic Adapter class that does the work for us. Although we could use sub-classing (inheritance) to implement the Adapter pattern in the traditional way in Python, this technique is a great alternative.

In the next chapter, we will see how we can use the Decorator pattern to extend the behavior of an object without using sub-classing.

5
The Decorator Pattern

Whenever we want to add extra functionality to an object, we have a number of different options. We can:

- Add the functionality directly to the class the object belongs to, if it makes sense (for example, add a new method)
- Use composition
- Use inheritance

Composition should generally be preferred over inheritance, because inheritance makes code reuse harder, it's static, and applies to an entire class and all instances of it [GOF95, page 31], [`j.mp/decopat`].

Design patterns offer us a fourth option that supports extending the functionality of an object dynamically (in runtime): Decorators. A **Decorator** pattern can add responsibilities to an object dynamically, and in a transparent manner (without affecting other objects) [GOF95, page 196].

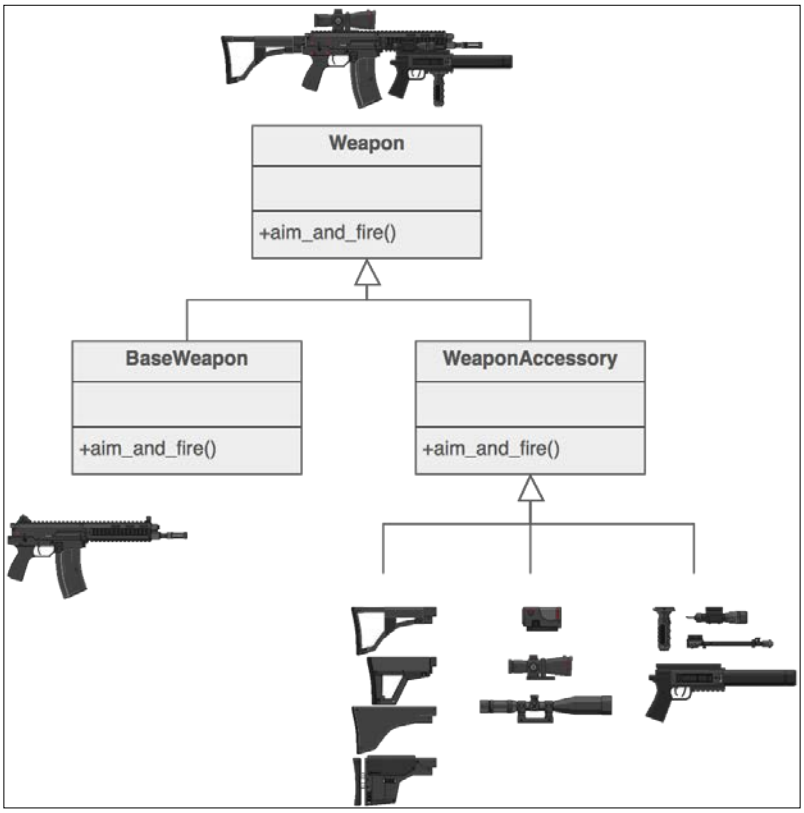
In many programming languages, the Decorator pattern is implemented using sub-classing (inheritance) [GOF95, page 198]. In Python, we can (and should) use the built-in decorator feature. A Python decorator is a specific change to the syntax of Python that is used for extending the behavior of a class, method, or function without using inheritance. In terms of implementation, a Python decorator is a callable (function, method, class) that accepts a function object `fin` as input, and returns another function object `fout` [`j.mp/conqdec`]. This means that any callable that has these properties can be treated as a decorator. We have already seen how to use the built-in `property` decorator that makes a method appear as a variable in *Chapter 1*, *The Factory Pattern* and *Chapter 2*, *The Builder Pattern*. In the implementation section, we will learn how to implement and use our own decorators.

There is no one-to-one relationship between the Decorator pattern and Python decorators. Python decorators can actually do much more than the Decorator pattern. One of the things they can be used for, is to implement the Decorator pattern [Eckel08, page 59], [`j.mp/moinpydec`].

A real-life example

The fact that the pattern is called Decorator does not mean that it should be used only for making things look prettier. The Decorator pattern is generally used for extending the functionality of an object. Real examples of such extensions are: adding a silencer to a gun, using different camera lenses (in cameras with removable lenses), and so on.

The following figure, provided by `sourcemaking.com`, shows how we can *decorate* a gun with special accessories to make it silent, more accurate, and devastating [`j.mp/decopat`]. Note that the figure uses sub-classing, but in Python, this is not necessary because we can use the built-in decorator feature of the language.



A software example

The Django framework uses decorators to a great extent. An example is the View decorator. Django's **View** decorators can be used for [`j.mp/djangodec`]:

- Restricting access to views based on the HTTP request
- Controlling the caching behavior on specific views
- Controlling compression on a per-view basis
- Controlling caching based on specific HTTP request headers

The Grok framework also uses decorators for achieving different goals such as [`j.mp/grokdeco`]:

- Registering a function as an event subscriber
- Protecting a method with a specific permission
- Implementing the Adapter pattern

Use cases

The Decorator pattern shines when used for implementing **cross-cutting concerns** [Lott14, page 223], [`j.mp/wikicrosscut`]. Examples of cross-cutting concerns are:

- Data validation
- Transaction processing (A transaction in this case is similar to a database transaction, in the sense that either all steps should be completed successfully, or the transaction should fail.)
- Caching
- Logging
- Monitoring
- Debugging
- Business rules
- Compression
- Encryption

In general, all parts of an application that are generic and can be applied to many other parts of it, are considered cross-cutting concerns.

Another popular example of using the Decorator pattern is **Graphical User Interface** (**GUI**) toolkits. In a GUI toolkit, we want to be able to add features such as borders, shadows, colors, and scrolling to individual components/widgets [GOF95, page 196].

Implementation

Python decorators are generic and very powerful. You can find many examples of how they can be used at the decorator library of `python.org` [`j.mp/pydeclib`]. In this section, we will see how we can implement a **memoization** decorator [`j.mp/memoi`]. All recursive functions can benefit from memoization, so let's pick the popular Fibonacci sequence example. Implementing the recursive algorithm of Fibonacci is straight forward, but it has major performance issues, even for small values. First, let's see the naive implementation (file `fibonacci_naive.py`).

```
def fibonacci(n):
    assert(n >= 0), 'n must be >= 0'
    return n if n in (0, 1) else fibonacci(n-1) + fibonacci(n-2)

if __name__ == '__main__':
    from timeit import Timer
    t = Timer('fibonacci(8)', 'from __main__ import fibonacci')
    print(t.timeit())
```

A sample execution of this example shows how slow this implementation is. It takes 17 seconds to calculate the eighth Fibonacci number. The same execution gives the following output:

```
>>> python3 fibonacci_naive.py
16.669270177000726
```

Let's use memoization to see if it helps. In the following code, we use a `dict` for caching the already computed values of the Fibonacci sequence. We also change the parameter passed to the `fibonacci()` function. We want to calculate the hundredth Fibonacci number instead of the eighth.

```
known = {0:0, 1:1}

def fibonacci(n):
    assert(n >= 0), 'n must be >= 0'
    if n in known:
        return known[n]
    res = fibonacci(n-1) + fibonacci(n-2)
    known[n] = res
```

```
        return res

    if __name__ == '__main__':
        from timeit import Timer
        t = Timer('fibonacci(100)', 'from __main__ import fibonacci')
        print(t.timeit())
```

Executing the memoization-based code shows that performance improves dramatically, and is acceptable even for computing large values. A sample execution is as follows:

```
>>> python3 fibonacci.py
0.31532211999729043
```

But there are already a few problems with this approach. While the performance is not an issue any longer, the code is not as clean as it is when not using memoization. And what happens if we decide to extend the code with more math functions and turn it into a module? Let's assume that the next function we decide to add is `nsum()`, which returns the sum of the first `n` numbers. Note that this function is already available in the `math` module as `fsum()`, but we can easily think of other functions that are not available in the standard library and would be useful for our module (for example Pascal's triangle, the sieve of Eratosthenes, and so on). The code of the `nsum()` function using memoization (file `mymath.py`) is given as follows:

```
known_sum = {0:0}

def nsum(n):
    assert(n >= 0), 'n must be >= 0'
    if n in known_sum:
        return known_sum[n]
    res = n + nsum(n-1)
    known_sum[n] = res
    return res
```

Do you notice the problem already? We ended up with a new `dict` called `known_sum` which acts as our cache for `nsum`, and a function that is more complex than it would be without using memoization. Our module is becoming unnecessarily complex. Is it possible to keep the recursive functions as simple as the naive versions, but achieve a performance similar to the performance of the functions that use memoization? Fortunately, it is, and the solution is to use the Decorator pattern.

First, we create a `memoize()` decorator as shown in the following example. Our decorator accepts the function `fn` that needs to be memoized, as an input. It uses a `dict` named `known` as the cache. The `functools.wraps()` function is a function that is used for convenience when creating decorators. It is not mandatory but a good practice to use since it makes sure that the documentation and the signature of the function that is decorated, are preserved [`j.mp/funcwraps`]. The argument list `*args`, is required in this case because the functions that we want to decorate accept input arguments. It would be redundant to use it if `fibonacci()` and `nsum()` didn't require any arguments, but they require `n`.

```
import functools

def memoize(fn):
    known = dict()

    @functools.wraps(fn)
    def memoizer(*args):
        if args not in known:
            known[args] = fn(*args)
        return known[args]

    return memoizer
```

Now, we can use our `memoize()` decorator with the naive version of our functions. This has the benefit of readable code without performance impacts. We apply a decorator using what is known as decoration (or decoration line). A decoration uses the `@name` syntax, where `name` is the name of the decorator that we want to use. It is nothing more than syntactic sugar for simplifying the usage of decorators. We can even bypass this syntax and execute our decorator manually, but that is left as an exercise for you. Let's see how the `memoize()` decorator is used with our recursive functions in the following example:

```
@memoize
def nsum(n):
    '''Returns the sum of the first n numbers'''
    assert(n >= 0), 'n must be >= 0'
    return 0 if n == 0 else n + nsum(n-1)

@memoize
def fibonacci(n):
    '''Returns the nth number of the Fibonacci sequence'''
    assert(n >= 0), 'n must be >= 0'
    return n if n in (0, 1) else fibonacci(n-1) + fibonacci(n-2)
```

The last part of the code shows how to use the decorated functions and measure their performance. `measure` is a `list` of `dict` used to avoid code repetition. Note how `__name__` and `__doc__` show the proper function names and documentation values, respectively. Try removing the `@functools.wraps(fn)` decoration from `memoize()`, and see if this is still the case:

```
if __name__ == '__main__':
    from timeit import Timer
    measure = [ {'exec':'fibonacci(100)', 'import':'fibonacci',
    'func':fibonacci},{'exec':'nsum(200)', 'import':'nsum',
    'func':nsum} ]
    for m in measure:
        t = Timer('{}'.format(m['exec']), 'from __main__ import
        {}'.format(m['import']))
        print('name: {}, doc: {}, executing: {}, time:
        {}'.format(m['func'].__name__, m['func'].__doc__,
        m['exec'], t.timeit()))
```

Let's see the complete code of our math module (file `mymath.py`) and a sample output when executing it.

```
import functools

def memoize(fn):
    known = dict()

    @functools.wraps(fn)
    def memoizer(*args):
        if args not in known:
            known[args] = fn(*args)
        return known[args]

    return memoizer

@memoize
def nsum(n):
    '''Returns the sum of the first n numbers'''
    assert(n >= 0), 'n must be >= 0'
    return 0 if n == 0 else n + nsum(n-1)

@memoize
def fibonacci(n):
    '''Returns the nth number of the Fibonacci sequence'''
    assert(n >= 0), 'n must be >= 0'
    return n if n in (0, 1) else fibonacci(n-1) + fibonacci(n-2)
```

```
if __name__ == '__main__':
    from timeit import Timer
    measure = [ {'exec':'fibonacci(100)', 'import':'fibonacci',
    'func':fibonacci}, {'exec':'nsum(200)', 'import':'nsum',
    'func':nsum} ]
    for m in measure:
        t = Timer('{}'.format(m['exec']), 'from __main__
        import{}'.format(m['import']))
        print('name: {}, doc: {}, executing: {}, time:
        {}'.format(m['func'].__name__, m['func'].__doc__,
        m['exec'], t.timeit()))
```

Note that the execution times might differ in your case.

```
>>> python3 mymath.py
name: fibonacci, doc: Returns the nth number of the Fibonacci
sequence, executing: fibonacci(100), time: 0.4169441329995607
name: nsum, doc: Returns the sum of the first n numbers,
executing: nsum(200), time: 0.4160157349997462
```

Nice. Readable code and acceptable performance. Now, you might argue that this is not the Decorator pattern, since we don't apply it in runtime. The truth is that a decorated function cannot be undecorated; but you can still decide in runtime if the decorator will be executed or not. That's an interesting exercise left for you.

Hint: Use a decorator that acts as a wrapper which decides whether or not the *real* decorator is executed based on some condition.

Another interesting property of decorators that is not covered in this chapter is that, you can decorate a function with more than one decorator. So here's another exercise: create a decorator that helps you to debug recursive functions, and apply it on `nsum()` and `fibonacci()`. In what order are the multiple decorators executed?

If you have not had enough with decorators, I have one last exercise for you. The `memoize()` decorator does not work with functions that accept more than one argument. How can we verify that? After verifying it, try finding a way of fixing this issue.

Summary

This chapter covered the Decorator pattern and its relation to the Python programming language. We use the Decorator pattern as a convenient way of extending the behavior of an object without using inheritance. Python extends the Decorator concept even more, by allowing us to extend the behavior of any callable (function, method, or class) without using inheritance or composition. We can use the built-in decorator feature of Python.

We have seen a few examples of objects that are decorated in reality, like guns and cameras. From a software point of view, both Django and Grok use decorators for achieving different goals, such as controlling HTTP compression and caching.

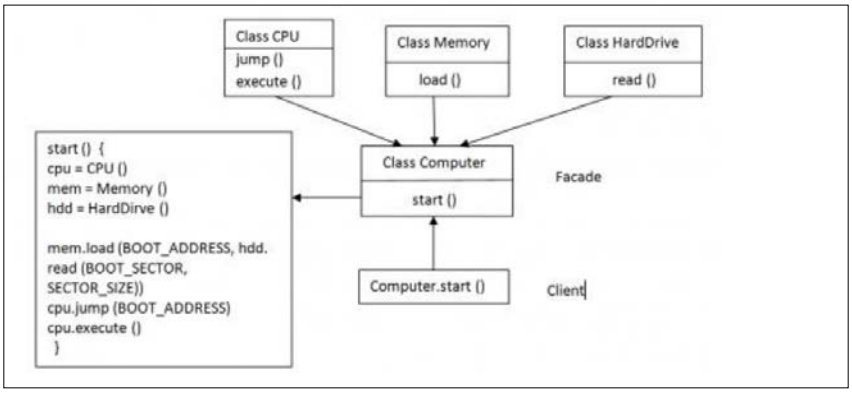
The Decorator pattern is a great solution for implementing cross-cutting concerns, because they are generic and do not fit well into the OOP paradigm. We mentioned many categories of cross-cutting concerns in the *Use cases* section. In fact, in the *Implementation* section a cross-cutting concern was demonstrated: memoization. We saw how decorators can help us to keep our functions clean, without sacrificing performance.

The recommended exercises in this chapter can help you understand decorators even better, so that you can use this very powerful tool for solving many common (and perhaps less common) programming problems. The next chapter covers the Facade pattern, which is a convenient way of simplifying access to a complex system.

6
The Facade Pattern

As systems evolve, they can get very complex. It is not unusual to end up with a very large (and sometimes confusing) collection of classes and interactions. In many cases, we don't want to expose this complexity to the client. The Facade (also known as Façade) design pattern helps us to hide the internal complexity of our systems and expose only what is necessary to the client through a simplified interface [Eckel08, page 209]. In essence, **Facade** is an abstraction layer implemented over an existing complex system.

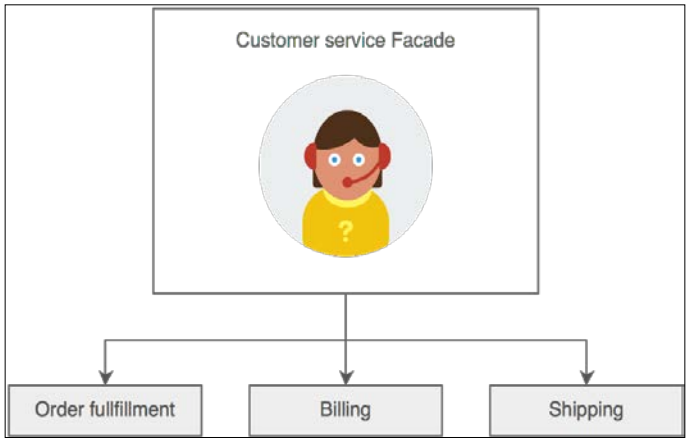
The role of Facade is demonstrated in the following figure. The figure is a class diagram representation of Wikipedia's Java Facade example [`j.mp/wikifac`]. A computer is a complex machine that depends on several parts to be fully functional. To keep things simple, the word *computer* in this case, refers to an IBM derivative that uses a Von Neumann architecture. Booting a computer is a particularly complex procedure. The CPU, main memory, and hard disk need to be up and running; the boot loader must be loaded from the hard disk to the main memory, the CPU must boot the operating system kernel, and so forth. Instead of exposing all this complexity to the client, we create a Facade that encapsulates the whole procedure, making sure that all steps are executed in the right order.



From the classes shown in the figure, only the `Computer` class needs to be exposed to the client code. The client executes only the `start()` method of `Computer`. All the other complex parts are taken care of by the Facade `Computer` class.

A real-life example

The Facade pattern is quite common in reality. When you call a bank or company, you are usually first connected to the customer service department. The customer service employee acts as a Facade between you and the actual department (billing, technical support, general assistance, and so on) and the employee that will help you with your specific problem. The following figure, provided by `sourcemaking.com`, shows this example graphically [`j.mp/facadepat`]:



A key used to turn on a car or motorcycle can also be considered a Facade. It is a simple way of activating a system that is very complex internally. And of course, the same is true for other complex electronic devices that we can activate with a single button, such as computers.

A software example

The **django-oscar-datacash** module is a Django third-party module that integrates with the **DataCash** payment gateway. The module has a `Gateway` class that provides fine-grained access to the various DataCash APIs. On top of that, it also offers a `Facade` class that provides a less granular API (for those who don't want to mess with the details) and the ability to save transactions for auditing purposes [`j.mp/oscarfac`].

Caliendo, an interface for mocking Python APIs, contains a `facade` module which uses the Facade pattern for doing many different but useful things, such as caching methods and deciding what to return based on the input object which is passed to the top-level `Facade` method [`j.mp/caliendofac`].

Use cases

The most usual reason to use the Facade pattern is for providing a single, simple entry point to a complex system. By introducing Facade, the client code can use a system by simply calling a single method/function. At the same time, the internal system does not lose any functionality. It just encapsulates it.

Not exposing the internal functionality of a system to the client code gives us an extra benefit; we can introduce changes to the system, but the client code remains unaware and unaffected by the changes. No modifications are required to the client code [Zlobin13, page 44].

Facade is also useful if you have more than one layer in your system. You can introduce one Facade entry point per layer, and let all layers communicate with each other through their Facades. That promotes loose coupling and keeps the layers as independent as possible [GOF95, page 209].

Implementation

Assume that we want to create an operating system using a multi-server approach, similar to how it is done in MINIX 3 [`j.mp/minix3`] or GNU Hurd [`j.mp/gnuhurd`]. A multi-server operating system has a minimal kernel, called the **microkernel**, that runs in privileged mode. All the other services of the system are following a server architecture (driver server, process server, file server, and so forth). Each server belongs to a different memory address space and runs on top of the microkernel in user mode. The pros of this approach are that the operating system can become more fault-tolerant, reliable, and secure. For example, since all drivers are running in user mode on a driver server, a bug in a driver cannot crash the whole system, and neither can it affect the other servers. The cons of this approach are the performance overhead and the complexity of system programming, because the communication between a server and the microkernel, as well as between the independent servers, happens using message passing. Message passing is more complex than the shared memory model used in monolithic kernels like Linux [`j.mp/helenosm`].

We begin with a `Server` interface. An `Enum` parameter describes the different possible states of a server. We use the `abc` module to forbid direct instantiation of the `Server` interface and make the fundamental `boot()` and `kill()` methods mandatory, assuming that different actions are needed to be taken for booting, killing, and restarting each server. If you have not used the `abc` module before, note the following important things:

- We need to subclass `ABCMeta`, using the `metaclass` keyword
- We use the `@abstractmethod` decorator for stating which methods should be implemented (mandatory) by all subclasses of `Server`

Try removing the `boot()` or `kill()` method of a subclass and see what happens. Do the same after removing the `@abstractmethod` decorator also. Do things work as you expected?

Let's consider the following code:

```
State = Enum('State', 'new running sleeping restart zombie')

class Server(metaclass=ABCMeta):
    @abstractmethod
    def __init__(self):
        pass

    def __str__(self):
        return self.name

    @abstractmethod
    def boot(self):
        pass

    @abstractmethod
    def kill(self, restart=True):
        pass
```

A modular operating system can have a great number of interesting servers: a file server, a process server, an authentication server, a network server, a graphical/window server, and so forth. The following example includes two stub servers- the `FileServer`, and the `ProcessServer`. Apart from the methods required to be implemented by the `Server` interface, each server can have its own specific methods. For instance the `FileServer` has a `create_file()` method for creating files, and the `ProcessServer` has a `create_process()` method for creating processes.

```
class FileServer(Server):
    def __init__(self):
        '''actions required for initializing the file server'''
```

```
        self.name = 'FileServer'
        self.state = State.new

    def boot(self):
        print('booting the {}'.format(self))
        '''actions required for booting the file server'''
        self.state = State.running

def kill(self, restart=True):
        print('Killing {}'.format(self))
        '''actions required for killing the file server'''
        self.state = State.restart if restart else State.zombie

    def create_file(self, user, name, permissions):
        '''check validity of permissions, user rights, etc.'''

        print("trying to create the file '{}' for user '{}' with
        permissions {}".format(name, user, permissions))

class ProcessServer(Server):
    def __init__(self):
        '''actions required for initializing the process server'''
        self.name = 'ProcessServer'
        self.state = State.new

    def boot(self):
        print('booting the {}'.format(self))
        '''actions required for booting the process server'''
        self.state = State.running

    def kill(self, restart=True):
        print('Killing {}'.format(self))
        '''actions required for killing the process server'''
        self.state = State.restart if restart else State.zombie

    def create_process(self, user, name):
        '''check user rights, generate PID, etc.'''

        print("trying to create the process '{}' for user
        '{}'".format(name, user))
```

The `OperatingSystem` class is a Facade. In `__init__()`, all the necessary server instances are created. The `start()` method, used by the client code, is the entry point to the system. More wrapper methods can be added, if necessary, as access point to the services of the servers such as the wrappers `create_file()` and `create_process()`. From the client's point of view, all those services are provided by the `OperatingSystem` class. The client should not be confused with unnecessary details such as the existence of servers and the responsibility of each server.

```
class OperatingSystem:
    '''The Facade'''
    def __init__(self):
        self.fs = FileServer()
        self.ps = ProcessServer()

    def start(self):
        [i.boot() for i in (self.fs, self.ps)]

    def create_file(self, user, name, permissions):
        return self.fs.create_file(user, name, permissions)

    def create_process(self, user, name):
        return self.ps.create_process(user, name)
```

In the following full code listing (file `facade.py`), you can see that there are many dummy classes and servers. They are there to give an idea about the required abstractions (`User`, `Process`, `File`, and so forth) and servers (`WindowServer`, `NetworkServer`, and so forth) for making the system functional. A recommended exercise is to implement at least one service of the system (for example, file creation). Feel free to change the interface and the signature of the methods to fit your needs. Make sure that after your changes, the client code does not need to know anything other than the Facade `OperatingSystem` class:

```
from enum import Enum
from abc import ABCMeta, abstractmethod

State = Enum('State', 'new running sleeping restart zombie')

class User:
    pass

class Process:
    pass

class File:
    pass
```

```
class Server(metaclass=ABCMeta):
    @abstractmethod
    def __init__(self):
        pass

    def __str__(self):
        return self.name

    @abstractmethod
    def boot(self):
        pass

    @abstractmethod
    def kill(self, restart=True):
        pass

class FileServer(Server):
    def __init__(self):
        '''actions required for initializing the file server'''
        self.name = 'FileServer'
        self.state = State.new

    def boot(self):
        print('booting the {}'.format(self))
        '''actions required for booting the file server'''
        self.state = State.running

    def kill(self, restart=True):
        print('Killing {}'.format(self))
        '''actions required for killing the file server'''
        self.state = State.restart if restart else State.zombie

    def create_file(self, user, name, permissions):
        '''check validity of permissions, user rights, etc.'''

        print("trying to create the file '{}' for user '{}' with
        permissions {}".format(name, user, permissions))

class ProcessServer(Server):
    def __init__(self):
        '''actions required for initializing the process server'''
        self.name = 'ProcessServer'
        self.state = State.new
```

```
        def boot(self):
            print('booting the {}'.format(self))
            '''actions required for booting the process server'''
            self.state = State.running

        def kill(self, restart=True):
            print('Killing {}'.format(self))
            '''actions required for killing the process server'''
            self.state = State.restart if restart else State.zombie

        def create_process(self, user, name):
            '''check user rights, generate PID, etc.'''

            print("trying to create the process '{}' for user
            '{}'".format(name, user))

    class WindowServer:
        pass

    class NetworkServer:
        pass

    class OperatingSystem:
        '''The Facade'''
        def __init__(self):
            self.fs = FileServer()
            self.ps = ProcessServer()

        def start(self):
            [i.boot() for i in (self.fs, self.ps)]

        def create_file(self, user, name, permissions):
            return self.fs.create_file(user, name, permissions)

        def create_process(self, user, name):
            return self.ps.create_process(user, name)

    def main():
        os = OperatingSystem()
        os.start()
        os.create_file('foo', 'hello', '-rw-r-r')
        os.create_process('bar', 'ls /tmp')

    if __name__ == '__main__':
        main()
```

Executing the example shows the starting message of our two stub servers:

```
>>> python3 facade.py
booting the FileServer
booting the ProcessServer
trying to create the file 'hello' for user 'foo' with permissions -
rw-r-r
trying to create the process 'ls /tmp' for user 'bar'
```

The Facade `OperatingSystem` class does a good job. The client code can create files and processes without needing to know internal details about the operating system, such as the existence of multiple servers. To be precise, the client code can call the methods for creating files and processes, but they are currently dummy. As an interesting exercise, you can implement one of the two methods, or even both.

Summary

In this chapter, we have learned how to use the Facade pattern. This pattern is ideal for providing a simple interface to client code that wants to use a complex system but does not need to be aware of the system's complexity. A computer is a Facade, since all we need to use it is to press a single button for turning it on. All the rest hardware complexity is handled transparently by the BIOS, the boot loader, and the rest system software. There are more real-life examples of Facade, such as when we are connected to the customer service department of a bank, or a company, and the keys that we use to turn a vehicle on.

We discussed two Django third-party modules that use Facade: django-oscar-datacash and Caliendo. The first uses the Facade pattern to provide a simple DataCash API, and the ability to save transactions. The latter uses Facade for different purposes, like caching and deciding what should be returned based on the type of the input object.

We covered the basic use cases of Facade and ended the chapter with an implementation of the interface used by a multi-server operating system. A Facade is an elegant way of hiding the complexity of a system, because in most cases the client code should not be aware of such details.

In the next chapter, we will learn how to use the Flyweight design pattern for reusing objects to improve the resource usage of a system.

7
The Flyweight Pattern

Object-oriented systems can face performance issues due to the overhead of object creation. Performance issues usually appear in *embedded* systems with limited resources, such as smartphones and tablets. The same problem can appear in large and complex systems are where we need to create a very large number of objects (and possibly users) that need to coexist at the same time.

This happens because whenever we create a new object, extra memory needs to be allocated. Although virtual memory provides us, theoretically, with unlimited memory, the reality is different. If all the physical memory of a system gets exhausted, it will start swapping pages to the secondary storage, usually a **Hard Disk Drive** (**HDD**), which, in most cases, is unacceptable due to the performance differences between the main memory and HDD. **Solid State Drives** (**SSD**) generally have better performance than HDD, but not everybody is expected to use SSD. So, SSD are not going to totally replace HDD anytime soon [`j.mp/wissd`].

Apart from memory usage, performance is also a consideration. Graphics software, including computer games, should be able to render 3D information (for example, a forest with thousands of trees or a village full of soldiers) extremely fast. If each object of a 3D terrain is created individually and no data sharing is used, the performance will be prohibitive [`j.mp/flyweightp`].

As software engineers, we should solve software problems by writing better software, instead of forcing the customer to buy extra or better hardware. The Flyweight design pattern is a technique used to minimize memory usage and improve performance by introducing data sharing between similar objects [`j.mp/wflyw`]. A **Flyweight** is a shared object that contains state-independent, immutable (also known as intrinsic) data. The state-dependent, mutable (also known as extrinsic) data should not be part of Flyweight because this is information that cannot be shared since it differs per object. If Flyweight needs extrinsic data, they should be provided explicitly by the client code [GOF95, page 219], [`j.mp/smflywe`].

An example might help to clarify how the Flyweight pattern can be practically used. Let's assume that we are creating a performance-critical game, for example, a **First-Person Shooter** (**FPS**). In FPS games, the players (soldiers) share some states, such as representation and behavior. In Counter-Strike, for instance, all soldiers of the same team (counter-terrorists versus terrorists) look the same (representation). In the same game, all soldiers (of both teams) have some common actions, such as jump, duck, and so forth (behavior). This means that we can create a Flyweight that will contain all the common data. Of course, the soldiers also have many mutable data that are different per soldier and will not be a part of the Flyweight, such as weapons, health, locations, and so on.

A real-life example

Flyweight is an optimization design pattern; therefore, it is not easy to find a good real-life example of it. We can think of Flyweight as caching in real life. For example, many bookstores have dedicated shelves with the newest and most popular publications. This is a cache. First, you can take a look at the dedicated shelves for the book you are looking for, and if you cannot find it, you can ask the librarian to assist you.

A software example

The **Exaile** music player [`j.mp/exaile`] uses Flyweight to reuse objects (in this case, music tracks) that are identified by the same URL. There's no point in creating a new object if it has the same URL as an existing object, so the same object is reused to save resources [`j.mp/exailefly`].

Peppy, an XEmacs-like editor implemented in Python [`j.mp/peppyp`], uses the Flyweight pattern to store the state of a `major mode` status bar. That's because unless modified by the user, all status bars share the same properties [`j.mp/peepyfly`].

Use cases

Flyweight is all about improving performance and memory usage. All embedded systems (phones, tablets, game consoles, microcontrollers, and so forth) and performance-critical applications (games, 3D graphics processing, real-time systems, and so forth) can benefit from it.

The *Gang Of Four (GoF)* book lists the following requirements that need to be satisfied to effectively use the Flyweight Pattern [GOF95, page 221]:

- The application needs to use a large number of objects.
- There are so many objects that it's too expensive to store/render them. Once the mutable state is removed (because if it is required, it should be passed explicitly to Flyweight by the client code), many groups of distinct objects can be replaced by relatively few shared objects.
- Object identity is not important for the application. We cannot rely on object identity because object sharing causes identity comparisons to fail (objects that appear different to the client code, end up having the same identity).

Implementation

Since I already mentioned the tree example, let's see how we can implement it. In this example, we will create a very small forest of fruit trees. It is small to make sure that the whole output is readable in a single terminal page. However, no matter how large you make the forest, the memory allocation stays the same. An `Enum` parameter describes the three different types of fruit trees as follows:

```
TreeType = Enum('TreeType', 'apple_tree cherry_tree peach_tree')
```

Before diving into the code, let's spend a moment to note the difference between memoization and the Flyweight pattern. Memoization is an optimization technique that uses a cache to avoid recomputing results that were already computed in an earlier execution step. Memoization does not focus on a specific programming paradigm such as **object-oriented programming** (**OOP**). In Python, memoization can be applied on both methods and simple functions. Flyweight is an OOP-specific optimization design pattern that focuses on sharing object data.

Flyweight can be implemented in Python in many ways, but I find the implementation shown in this example very neat. The `pool` variable is the object pool (in other words, our cache). Notice that `pool` is a class attribute (a variable shared by all instances) [`j.mp/diveclsattr`]. Using the `__new__()` special method, which is called before `__init__()`, we are converting the `Tree` class to a metaclass that supports self-references. This means that `cls` references the `Tree` class [Lott14, page 99]. When the client code creates an instance of `Tree`, they pass the type of the tree as `tree_type`. The type of the tree is used to check if a tree of the same type has already been created. If that's the case, the previously created object is returned; otherwise, the new tree type is added to the pool and returned as shown:

```
    def __new__(cls, tree_type):
        obj = cls.pool.get(tree_type, None)
```

```
        if not obj:
            obj = object.__new__(cls)
            cls.pool[tree_type] = obj
            obj.tree_type = tree_type
        return obj
```

The `render()` method is what will be used to render a tree on the screen. Notice how all the mutable (extrinsic) information not known by Flyweight needs to be explicitly passed by the client code. In this case, a random age and a location of form *x*, *y* is used for every tree. To make `render()` more useful, it is necessary to ensure that no trees are rendered on top of each other. Consider this as an exercise. If you want to make rendering more fun, you can use a graphics toolkit such as Tkinter or Pygame.

```
def render(self, age, x, y):
        print('render a tree of type {} and age {} at ({},
        {})'.format(self.tree_type, age, x, y))
```

The `main()` function shows how we can use the Flyweight pattern. The age of a tree is a random value between 1 and 30 years. The coordinate uses random values between 1 and 100. Although eighteen trees are rendered, memory is allocated only for three. The last line of the output proves that when using Flyweight, we cannot rely on object identity. The `id()` function returns the memory address of an object. This is not the default behavior in Python because by default, `id()` returns a unique ID (actually the memory address of an object as an integer) for each object. In our case, even if two objects appear to be different, they actually have the same identity if they belong to the same Flyweight family (in this case, the family is defined by `tree_type`). Of course, different identity comparisons can still be used for objects of different families, but that is possible only if the client knows the implementation details (which is not the case usually).

```
def main():
    rnd = random.Random()
    age_min, age_max = 1, 30    # in years
    min_point, max_point = 0, 100
    tree_counter = 0

    for _ in range(10):
        t1 = Tree(TreeType.apple_tree)
        t1.render(rnd.randint(age_min, age_max),
                  rnd.randint(min_point, max_point),
                  rnd.randint(min_point, max_point))
        tree_counter += 1
```

```
for _ in range(3):
    t2 = Tree(TreeType.cherry_tree)
    t2.render(rnd.randint(age_min, age_max),
              rnd.randint(min_point, max_point),
              rnd.randint(min_point, max_point))
    tree_counter += 1

for _ in range(5):
    t3 = Tree(TreeType.peach_tree)
    t3.render(rnd.randint(age_min, age_max),
              rnd.randint(min_point, max_point),
              rnd.randint(min_point, max_point))
    tree_counter += 1

print('trees rendered: {}'.format(tree_counter))
print('trees actually created: {}'.format(len(Tree.pool)))

t4 = Tree(TreeType.cherry_tree)
t5 = Tree(TreeType.cherry_tree)
t6 = Tree(TreeType.apple_tree)
print('{} == {}? {}'.format(id(t4), id(t5), id(t4) == id(t5)))
print('{} == {}? {}'.format(id(t5), id(t6), id(t5) == id(t6)))
```

The following full code listing (file `flyweight.py`) will give the complete picture of how the Flyweight pattern is implemented and used:

```
import random
from enum import Enum

TreeType = Enum('TreeType', 'apple_tree cherry_tree peach_tree')

class Tree:
    pool = dict()

    def __new__(cls, tree_type):
        obj = cls.pool.get(tree_type, None)
        if not obj:
            obj = object.__new__(cls)
            cls.pool[tree_type] = obj
            obj.tree_type = tree_type
        return obj
```

```
        def render(self, age, x, y):
            print('render a tree of type {} and age {} at ({},
            {})'.format(self.tree_type, age, x, y))

    def main():
        rnd = random.Random()
        age_min, age_max = 1, 30    # in years
        min_point, max_point = 0, 100
        tree_counter = 0

        for _ in range(10):
            t1 = Tree(TreeType.apple_tree)
            t1.render(rnd.randint(age_min, age_max),
                      rnd.randint(min_point, max_point),
                      rnd.randint(min_point, max_point))
            tree_counter += 1

        for _ in range(3):
            t2 = Tree(TreeType.cherry_tree)
            t2.render(rnd.randint(age_min, age_max),
                      rnd.randint(min_point, max_point),
                      rnd.randint(min_point, max_point))
            tree_counter += 1

        for _ in range(5):
            t3 = Tree(TreeType.peach_tree)
            t3.render(rnd.randint(age_min, age_max),
                      rnd.randint(min_point, max_point),
                      rnd.randint(min_point, max_point))
            tree_counter += 1

        print('trees rendered: {}'.format(tree_counter))
        print('trees actually created: {}'.format(len(Tree.pool)))

        t4 = Tree(TreeType.cherry_tree)
        t5 = Tree(TreeType.cherry_tree)
        t6 = Tree(TreeType.apple_tree)
        print('{} == {}? {}'.format(id(t4), id(t5), id(t4) == id(t5)))
        print('{} == {}? {}'.format(id(t5), id(t6), id(t5) == id(t6)))

    if __name__ == '__main__':
        main()
```

The execution of the preceding example shows the type, random age, and coordinates of the rendered objects, as well as the identity comparison results between Flyweight objects of the same/different families. Do not expect to see the same output as the following since the ages and coordinates are random, and the object identities depend on the memory map.

```
>>> python3 flyweight.py
render a tree of type TreeType.apple_tree and age 4 at (88, 19)
render a tree of type TreeType.apple_tree and age 18 at (31, 35)
render a tree of type TreeType.apple_tree and age 7 at (54, 23)
render a tree of type TreeType.apple_tree and age 3 at (9, 11)
render a tree of type TreeType.apple_tree and age 2 at (93, 6)
render a tree of type TreeType.apple_tree and age 12 at (3, 49)
render a tree of type TreeType.apple_tree and age 10 at (5, 65)
render a tree of type TreeType.apple_tree and age 6 at (19, 16)
render a tree of type TreeType.apple_tree and age 2 at (21, 32)
render a tree of type TreeType.apple_tree and age 21 at (87, 79)
render a tree of type TreeType.cherry_tree and age 24 at (94, 31)
render a tree of type TreeType.cherry_tree and age 14 at (92, 37)
render a tree of type TreeType.cherry_tree and age 14 at (9, 88)
render a tree of type TreeType.peach_tree and age 23 at (44, 90)
render a tree of type TreeType.peach_tree and age 16 at (15, 59)
render a tree of type TreeType.peach_tree and age 1 at (81, 98)
render a tree of type TreeType.peach_tree and age 13 at (67, 63)
render a tree of type TreeType.peach_tree and age 12 at (69, 42)
trees rendered: 18
trees actually created: 3
140322427827480 == 140322427827480? True
140322427827480 == 140322427709088? False
```

Here's an exercise if you want to play more with Flyweight. Implement the FPS soldier example mentioned in this chapter. Think about which data should be part of Flyweight (immutable, intrinsic) and which should not (mutable, extrinsic).

Summary

In this chapter, we covered the Flyweight pattern. We can use Flyweight when we want to improve the memory usage and possibly the performance of our application. This is quite important in all systems with limited resources (think of embedded systems) and systems that focus on performance, such as graphics software and electronic games. The Exaile music player for GTK+ uses Flyweight to avoid object duplication, and the Peppy text editor uses it to share the properties of the status bar.

In general we use Flyweight when an application needs to create a large number of computationally expensive objects that share many properties. The important point is to separate the immutable (shared) properties, from the mutable. We implemented a tree renderer that supports three different tree families. By providing the mutable age and x, y properties explicitly to the `render()` method, we managed to create only three different objects instead of eighteen. Although that might not seem like a big win, imagine if the trees were two thousand instead of eighteen.

The next chapter covers a very popular design pattern that is used to keep the code that handles the user interface decoupled from the code that handles the (business) logic: Model-View-Controller.

8
The Model-View-Controller Pattern

One of the design principles related to software engineering is the **Separation of Concerns** (**SoC**) principle. The idea behind the SoC principle is to split an application into distinct sections, where each section addresses a separate concern. Examples of such concerns are the layers used in a layered design (data access layer, business logic layer, presentation layer, and so forth). Using the SoC principle simplifies the development and maintenance of software applications [`j.mp/wikisoc`].

The **Model-View-Controller** (**MVC**) pattern is nothing more than the SoC principle applied to OOP. The name of the pattern comes from the three main components used to split a software application: the model, the view, and the controller. MVC is considered an architectural pattern rather than a design pattern. The difference between an architectural and a design pattern is that the former has a broader scope than the latter. Nevertheless, MVC is too important to skip just for this reason. Even if we will never have to implement it from scratch, we need to be familiar with it because all common frameworks use MVC or a slightly different version of it (more on this later).

The model is the core component. It represents knowledge. It contains and manages the (business) logic, data, state, and rules of an application. The view is a visual representation of the model. Examples of views are a computer GUI, the text output of a computer terminal, a smartphone's application GUI, a PDF document, a pie chart, a bar chart, and so forth. The view only displays the data, it doesn't handle it. The controller is the link/glue between the model and view. All communication between the model and the view happens through a controller [GOF95, page 14], [`j.mp/cohomvc`], [`j.mp/wikipmvc`].

A typical use of an application that uses MVC after the initial screen is rendered to the user is as follows:

- The user triggers a view by clicking (typing, touching, and so on) a button
- The view informs the controller about the user's action
- The controller processes user input and interacts with the model
- The model performs all the necessary validation and state changes, and informs the controller about what should be done
- The controller instructs the view to update and display the output appropriately, following the instructions given by the model

You might be wondering why is the controller part necessary? Can't we just skip it? We could, but then we would lose a big benefit that MVC provides: the ability to use more than one view (even at the same time, if that's what we want) without modifying the model. To achieve decoupling between the model and its representation, every view typically needs its own controller. If the model communicated directly with a specific view, we wouldn't be able to use multiple views (or at least, not in a clean and modular way).

A real-life example

MVC is the SoC principle applied to OOP. The SoC principle is used a lot in real life. For example, if you build a new house, you usually assign different professionals to:

- Install the plumbing and electricity
- Paint the house

Another example is a restaurant. In a restaurant, the waiters receive orders and serve dishes to the customers, but the meals are cooked by the chefs [`j.mp/somvc`].

A software example

The **web2py** web framework [`j.mp/webtopy`] is a lightweight Python framework that embraces the MVC pattern. If you have never tried web2py, I encourage you to do it since it is extremely simple to install. All I had to do was download a package and execute a single Python file (`web2py.py`). There are many examples that demonstrate how MVC can be used in web2py on the project's web page [`j.mp/web2pyex`].

Django is also an MVC framework, although it uses different naming conventions. The controller is called view, and the view is called template. Django uses the name **Model-Template-View** (**MTV**). According to the designers of Django, the view describes what data is seen by the user, and therefore, it uses the name view as the Python callback function for a particular URL. The term Template in Django is used to separate content from representation. It describes *how* the data is seen by the user, not *which* data is seen [`j.mp/djangomtv`].

Use cases

MVC is a very generic and useful design pattern. In fact, all popular Web frameworks (Django, Rails, and Yii) and application frameworks (iPhone SDK, Android, and QT) make use of MVC or a variation of it (**Model-View-Adapter** (**MVA**), **Model-View-Presenter** (**MVP**), and so forth). However, even if we don't use any of these frameworks, it makes sense to implement the pattern on our own because of the benefits it provides, which are as follows:

- The separation between the view and model allows graphics designers to focus on the UI part and programmers to focus on development, without interfering with each other.
- Because of the loose coupling between the view and model, each part can be modified/extended without affecting the other. For example, adding a new view is trivial. Just implement a new controller for it.
- Maintaining each part is easier because the responsibilities are clear.

When implementing MVC from scratch, be sure that you create smart models, thin controllers, and dumb views [Zlobin13, page 9].

A model is considered smart because it:

- Contains all the validation/business rules/logic
- Handles the state of the application
- Has access to application data (database, cloud, and so on)
- Does not depend on the UI

A controller is considered thin because it:

- Updates the model when the user interacts with the view
- Updates the view when the model changes
- Processes the data before delivering it to the model/view, if necessary

- Does not display the data
- Does not access the application data directly
- Does not contain validation/business rules/logic

A view is considered dumb because it:

- Displays the data
- Allows the user to interact with it
- Does only minimal processing, usually provided by a template language (for example, using simple variables and loop controls)
- Does not store any data
- Does not access the application data directly
- Does not contain validation/business rules/logic

If you are implementing MVC from scratch and want to find out if you did it right, you can try answering two key questions:

- If your application has a GUI, is it *skinnable*? How easily can you change the skin/look and feel of it? Can you give the user the ability to change the skin of your application during runtime? If this is not simple, it means that something is going wrong with your MVC implementation [`j.mp/cohomvc`].
- If your application has no GUI (for instance, if it's a terminal application), how hard is it to add GUI support? Or, if adding a GUI is irrelevant, is it easy to add views to display the results in a chart (pie chart, bar chart, and so on) or a document (PDF, spreadsheet, and so on)? If these changes are not trivial (a matter of creating a new controller with a view attached to it, without modifying the model), MVC is not implemented properly.

If you make sure that these two conditions are satisfied, your application will be more flexible and maintainable compared to an application that does not use MVC.

Implementation

I could use any of the common frameworks to demonstrate how to use MVC but I feel that the picture will be incomplete. So I decided to show how to implement MVC from scratch, using a very simple example: a quote printer. The idea is extremely simple. The user enters a number and sees the quote related to that number. The quotes are stored in a `quotes` tuple. This is the data that normally exists in a database, file, and so on, and only the model has direct access to it.

Let's consider the example in the following code:

```
quotes = ('A man is not complete until he is married. Then he is
          finished.', 'As I said before, I never repeat myself.',
          'Behind a successful man is an exhausted woman.',
          'Black holes really suck...', 'Facts are stubborn
          things.')
```

The model is minimalistic. It only has a `get_quote()` method that returns the quote (string) of the `quotes` tuple based on its index `n`. Note that `n` can be less than or equal to `0`, due to the way indexing works in Python. Improving this behavior is given as an exercise for you at the end of this section.

```
class QuoteModel:
    def get_quote(self, n):
        try:
            value = quotes[n]
        except IndexError as err:
            value = 'Not found!'
        return value
```

The view has three methods: `show()`, which is used to print a quote (or the message **Not found!**) on the screen, `error()`, which is used to print an error message on the screen, and `select_quote()`, which reads the user's selection. This can be seen in the following code:

```
class QuoteTerminalView:
    def show(self, quote):
        print('And the quote is: "{}"'.format(quote))

    def error(self, msg):
        print('Error: {}'.format(msg))

    def select_quote(self):
        return input('Which quote number would you like to see? ')
```

The controller does the coordination. The `__init__()` method initializes the model and view. The `run()` method validates the quote index given by the user, gets the quote by the model, and passes it back to the view to be displayed as shown in the following code:

```
class QuoteTerminalController:
    def __init__(self):
        self.model = QuoteModel()
        self.view = QuoteTerminalView()
```

```
    def run(self):
        valid_input = False
        while not valid_input:
            n = self.view.select_quote()
            try:
                n = int(n)
            except ValueError as err:
                self.view.error("Incorrect index '{}'".format(n))
            else:
                valid_input = True
        quote = self.model.get_quote(n)
        self.view.show(quote)
```

Last but not least, the `main()` function initializes and fires the controller as shown in the following code:

```
def main():
    controller = QuoteTerminalController()
    while True:
        controller.run()
```

The following is the full code of the example (file `mvc.py`):

```
quotes = ('A man is not complete until he is married. Then he is
          finished.', 'As I said before, I never repeat myself.',
          'Behind a successful man is an exhausted woman.',
          'Black holes really suck...', 'Facts are stubborn
          things.')

class QuoteModel:
    def get_quote(self, n):
        try:
            value = quotes[n]
        except IndexError as err:
            value = 'Not found!'
        return value

class QuoteTerminalView:
    def show(self, quote):
        print('And the quote is: "{}"'.format(quote))

    def error(self, msg):
        print('Error: {}'.format(msg))
```

```
        def select_quote(self):
            return input('Which quote number would you like to see? ')

    class QuoteTerminalController:
        def __init__(self):
            self.model = QuoteModel()
            self.view = QuoteTerminalView()

        def run(self):
            valid_input = False
            while not valid_input:
                try:
                    n = self.view.select_quote()
                    n = int(n)
                    valid_input = True
                except ValueError as err:
                    self.view.error("Incorrect index '{}'".format(n))
            quote = self.model.get_quote(n)
            self.view.show(quote)

    def main():
        controller = QuoteTerminalController()
        while True:
            controller.run()

    if __name__ == '__main__':
        main()
```

A sample execution of `mvc.py` shows how the program handles errors and prints quotes to the user:

```
>>> python3 mvc.py
Which quote number would you like to see? a
Error: Incorrect index 'a'
Which quote number would you like to see? 40
And the quote is: "Not found!"
Which quote number would you like to see? 0
And the quote is: "A man is not complete until he is married. Then he is
finished."
Which quote number would you like to see? 3
And the quote is: "Black holes really suck..."
```

Of course, you don't (and shouldn't) have to stop here. Keep coding. There are many interesting ideas that you can experiment with. A few of them are:

- Make the program more user-friendly by allowing only indexes of values greater than or equal to 1 to be given by the user. You will also need to modify `get_quote()`.
- Add a graphical view using a GUI framework such as Tkinter, Pygame, or Kivy. How modular is the program? Can you decide during runtime which view will be used?
- Give the user an option to view a random quote by typing a key, for example, key `r`.
- The index validation is currently done in the controller. Is that a good approach? What happens if you write another view that needs its own controller? Think about the changes required to move index validation in the model to make the code reusable for all controller/view pairs.
- Extend this example to make it work like a **Create, Read, Update, Delete** (**CRUD**) application. You should be able to enter new quotes, delete existing quotes, and modify a quote.

Summary

In this chapter, we covered the MVC pattern. MVC is a very important design pattern used to structure an application in three parts: the model, the view, and the controller.

Each part has clear roles and responsibilities. The model has access to the data and manages the state of the application. The view is a representation of the model. The view does not need to be graphical; textual output is also considered a totally fine view. The controller is the link between the model and view. Proper use of MVC guarantees that we end up with an application that is easy to maintain and extend.

The MVC pattern is the SoC principle applied to object-oriented programming. This principle is similar to how a new house is constructed or how a restaurant is operated.

The web2py Python framework uses MVC as the core architectural idea. Even the simplest web2py examples make use of MVC to achieve modularity and maintainability. Django is also an MVC framework, although it uses the name MTV.

When using MVC, make sure that you creating smart models (core functionality), thin controllers (functionality required for the communication between the view and the controller), and dumb views (representation and minimal processing).

In the *Implementation* section, we saw how to implement MVC from scratch to show funny quotes to the user. This is not very different from the functionality required to listing all the posts of an RSS feed. Feel free to implement this as an exercise, if none of the other recommended exercises appeal to you.

In the next chapter, you will learn how to secure an interface using an extra protection layer, implemented using the Proxy design pattern.

9
The Proxy Pattern

In some applications, we want to execute one or more important action before accessing an object. An example is accessing sensitive information. Before allowing any user to access sensitive information, we want to make sure that the user has sufficient privileges. A similar situation exists in operating systems. A user is required to have administrative privileges to install new programs system-wide.

The important action is not necessarily related to security issues. Lazy initialization [`j.mp/wikilazy`] is another case; we want to delay the creation of a computationally expensive object until the first time the user actually needs to use it.

Such actions are typically performed using the **Proxy design pattern**. The pattern gets its name from the proxy (also known as surrogate) object used to perform an important action before accessing the actual object. There are four different well-known proxy types [GOF95, page 234], [`j.mp/proxypat`]. They are as follows:

- A **remote proxy**, which acts as the local representation of an object that really exists in a different address space (for example, a network server).
- A **virtual proxy**, which uses lazy initialization to defer the creation of a computationally expensive object until the moment it is actually needed.
- A **protection/protective proxy**, which controls access to a sensitive object.
- A **smart (reference) proxy**, which performs extra actions when an object is accessed. Examples of such actions are reference counting and thread-safety checks.

I find virtual proxies very useful so let's see an example of how we can implement them in Python right now. In the *Implementation* section, you will learn how to create protective proxies.

There are many ways to create a virtual proxy in Python, but I always like focusing on the idiomatic/pythonic implementations. The code shown here is based on the great answer by Cyclone, a user of the site `stackoverflow.com` [`j.mp/solazyinit`]. To avoid confusion, I should clarify that in this section, the terms property, variable, and attribute are used interchangeably. First, we create a `LazyProperty` class that can be used as a decorator. When it decorates a property, `LazyProperty` loads the property lazily (on the first use) instead of instantly. The `__init__()` method creates two variables that are used as aliases to the method that initializes a property. The `method` variable is an alias to the actual method, and the `method_name` variable is an alias to the method's name. To get a better understanding about how the two aliases are used, print their value to the output (uncomment the two commented lines in the following code):

```
class LazyProperty:
    def __init__(self, method):
        self.method = method
        self.method_name = method.__name__
        # print('function overriden: {}'.format(self.fget))
        # print("function's name: {}".format(self.func_name))
```

The `LazyProperty` class is actually a descriptor [`j.mp/pydesc`]. **Descriptors** are the recommended mechanism to use in Python to override the default behavior of its attribute access methods: `__get__()`, `__set__()`, and `__delete__()`. The `LazyProperty` class overrides only `__set__()` because that is the only access method it needs to override. In other words, we don't have to override all access methods. The `__get__()` method accesses the value of the property the underlying method wants to assign, and uses `setattr()` to do the assignment manually. What `__get()__` actually does is very neat; it replaces the method with the value! This means that not only is the property lazily loaded, it can also be set only once. We will see what this means in a moment. Again, uncomment the commented line in the following code to get some extra info:

```
    def __get__(self, obj, cls):
        if not obj:
            return None
        value = self.method(obj)
        # print('value {}'.format(value))
        setattr(obj, self.method_name, value)
        return value
```

The `Test` class shows how we can use the `LazyProperty` class. There are three attributes: `x`, `y`, and `_resource`. We want the `_resource` variable to be loaded lazily; thus, we initialize it to `None` as shown in the following code:

```
class Test:
    def __init__(self):
        self.x = 'foo'
        self.y = 'bar'
        self._resource = None
```

The `resource()` method is decorated with the `LazyProperty` class. For demonstration purposes, the `LazyProperty` class initializes the `_resource` attribute as a `tuple` as shown in the following code. Normally, this would be a slow/expensive initialization (database, graphics, and so on):

```
    @LazyProperty
    def resource(self):
        print('initializing self._resource which is:
        {}'.format(self._resource))
        self._resource = tuple(range(5)) # expensive
        return self._resource
```

The `main()` function shows how lazy initialization behaves. Notice how overriding the `__get()__` access method makes it possible to treat the `resource()` method as a variable (we can use `t.resource` instead of `t.resource()`):

```
def main():
    t = Test()
    print(t.x)
    print(t.y)
    # do more work...
    print(t.resource)
    print(t.resource)
```

In the execution output of this example (the `lazy.py` file), we can see that:

- The `_resource` variable is indeed initialized not by the time the `t` instance is created, but the first time that we use `t.resource`.
- The second time `t.resource` is used, the variable is not initialized again. That's why the initialization string **initializing self._resource which is:** is shown only once.

- The following shows the execution of the `lazy.py` file:

```
>>> python3 lazy.py
foo
bar
initializing self._resource which is: None
(0, 1, 2, 3, 4)
(0, 1, 2, 3, 4)
```

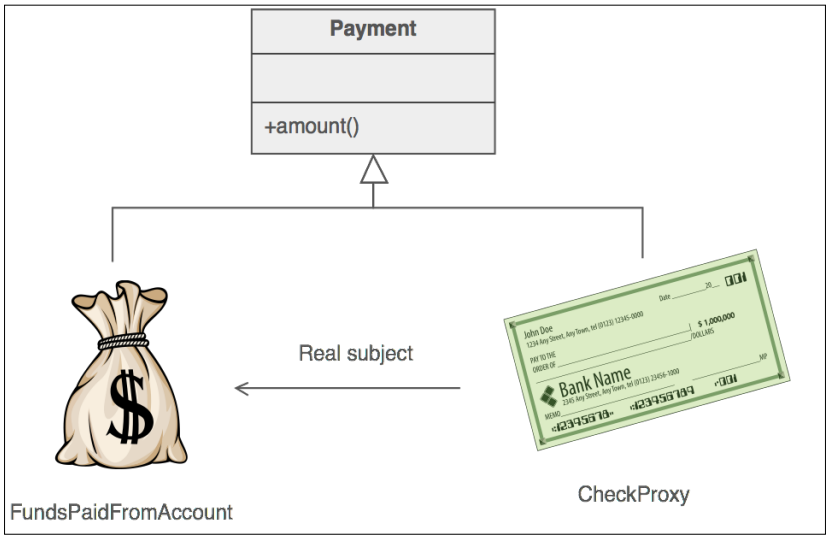
There are two basic, different kinds of lazy initialization in OOP. They are as follows:

- **At the instance level**: This means that an object's property is initialized lazily, but the property has an object scope. Each instance (object) of the same class has its own (different) copy of the property.
- **At the class or module level**: In this case, we do not want a different copy per instance, but all the instances share the same property, which is lazily initialized. This case is not covered in this chapter. If you find it interesting, consider it as an exercise.

A real-life example

Chip (also known as Chip and PIN) cards [`j.mp/wichpin`] are a good example of a protective proxy used in real life. The debit/credit card contains a chip that first needs to be read by the ATM or card reader. After the chip is verified, a password (PIN) is required to complete the transaction. This means that you cannot make any transactions without physically presenting the card and knowing the PIN.

A bank check that is used instead of cash to make purchases and deals is an example of a remote proxy. The check gives access to a bank account. The following figure, courtesy of `sourcemaking.com`, shows how a check acts as a remote proxy [`j.mp/proxypat`]:



A software example

The `weakref` module of Python contains a `proxy()` method that accepts an input object and returns a smart proxy to it. Weak references are the recommended way to add a reference counting support to an object [`j.mp/wrefproxy`].

ZeroMQ [`j.mp/zermq`] is a set of FOSS projects that focus on decentralized computing. The Python implementation of ZeroMQ has a proxy module that implements a remote proxy. This module allows Tornado [`j.mp/pytornado`] handlers to be run in separate remote processes [`j.mp/pyzmq`].

Use cases

Since there are at least four common proxy types, the Proxy design pattern has many use cases, as follows:

- It is used when creating a distributed system using either a private network or the cloud. In a distributed system, some objects exist in the local memory and some objects exist in the memory of remote computers. If we don't want the client code to be aware of such differences, we can create a remote proxy that hides/encapsulates them, making the distributed nature of the application transparent.

- It is used if our application is suffering from performance issues due to the early creation of expensive objects. Introducing lazy initialization using a virtual proxy to create the objects only at the moment they are actually required can give us significant performance improvements.
- It is used to check if a user has sufficient privileges to access a piece of information. If our application handles sensitive information (for example, medical data), we want to make sure that the user trying to access/modify it is allowed to do so. A protection/protective proxy can handle all security-related actions.
- It is used when our application (or library, toolkit, framework, and so forth) uses multiple threads and we want to move the burden of thread-safety from the client code to the application. In this case, we can create a smart proxy to hide the thread-safety complexities from the client.
- An **Object-Relational Mapping** (**ORM**) API is also an example of how to use a remote proxy. Many popular web frameworks, including Django, use an ORM to provide OOP-like access to a relational database. An ORM acts as a proxy to a relational database that can be actually located anywhere, either at a local or remote server.

Implementation

To demonstrate the Proxy pattern, we will implement a simple protection proxy to view and add users. The service provides two options:

- **Viewing the list of users**: This operation does not require special privileges
- **Adding a new user**: This operation requires the client to provide a special secret message

The `SensitiveInfo` class contains the information that we want to protect. The `users` variable is the list of existing users. The `read()` method prints the list of the users. The `add()` method adds a new user to the list. Let's consider the following code:

```
class SensitiveInfo:
    def __init__(self):
        self.users = ['nick', 'tom', 'ben', 'mike']

    def read(self):
        print('There are {} users: {}'.format(len(self.users), '
        '.join(self.users)))

    def add(self, user):
        self.users.append(user)
        print('Added user {}'.format(user))
```

The `Info` class is a protection proxy of `SensitiveInfo`. The `secret` variable is the message required to be known/provided by the client code to add a new user. Note that this is just an example. In reality, you should *never*:

- Store passwords in the source code
- Store passwords in a clear-text form
- Use a weak (for example, MD5) or custom form of encryption

The `read()` method is a wrapper to `SensitiveInfo.read()`. The `add()` method ensures that a new user can be added only if the client code knows the secret message. Let's consider the following code:

```
class Info:
    def __init__(self):
        self.protected = SensitiveInfo()
        self.secret = '0xdeadbeef'

    def read(self):
        self.protected.read()

    def add(self, user):
        sec = input('what is the secret? ')
        self.protected.add(user) if sec == self.secret else
        print("That's wrong!")
```

The `main()` function shows how the Proxy pattern can be used by the client code. The client code creates an instance of the `Info` class and uses the displayed menu to read the list, add a new user, or exit the application. Let's consider the following code:

```
def main():
    info = Info()

    while True:
        print('1. read list |==| 2. add user |==| 3. quit')
        key = input('choose option: ')
        if key == '1':
            info.read()
        elif key == '2':
            name = input('choose username: ')
            info.add(name)
        elif key == '3':
            exit()
        else:
            print('unknown option: {}'.format(key))
```

Let's see the the full code of the `proxy.py` file:

```
class SensitiveInfo:
    def __init__(self):
        self.users = ['nick', 'tom', 'ben', 'mike']

    def read(self):
        print('There are {} users: {}'.format(len(self.users), '
        '.join(self.users)))

    def add(self, user):
        self.users.append(user)
        print('Added user {}'.format(user))

class Info:
    '''protection proxy to SensitiveInfo'''

    def __init__(self):
        self.protected = SensitiveInfo()
        self.secret = '0xdeadbeef'

    def read(self):
        self.protected.read()

    def add(self, user):
        sec = input('what is the secret? ')
        self.protected.add(user) if sec == self.secret else
        print("That's wrong!")

def main():
    info = Info()

    while True:
        print('1. read list |==| 2. add user |==| 3. quit')
        key = input('choose option: ')
        if key == '1':
            info.read()
        elif key == '2':
            name = input('choose username: ')
            info.add(name)
        elif key == '3':
            exit()
        else:
            print('unknown option: {}'.format(key))

if __name__ == '__main__':
    main()
```

Here is an example of how to execute `proxy.py`:

```
>>> python3 proxy.py
1. read list |==| 2. add user |==| 3. quit
choose option: a
1. read list |==| 2. add user |==| 3. quit
choose option: 4
1. read list |==| 2. add user |==| 3. quit
choose option: 1
There are 4 users: nick tom ben mike
1. read list |==| 2. add user |==| 3. quit
choose option: 2
choose username: pet
what is the secret? blah
That's wrong!
1. read list |==| 2. add user |==| 3. quit
choose option: 2
choose username: bill
what is the secret? 0xdeadbeef
Added user bill
1. read list |==| 2. add user |==| 3. quit
choose option: 1
There are 5 users: nick tom ben mike bill
1. read list |==| 2. add user |==| 3. quit
choose option: 3
```

Have you already spotted flaws or missing features that can improve the Proxy example? I have a few suggestions. They are as follows:

- This example has a very big security flaw. Nothing prevents the client code from bypassing the security of the application by creating an instance of `SensitiveInfo` directly. Improve the example to prevent this situation. One way is to use the `abc` module to forbid direct instantiation of `SensitiveInfo`. What other code changes are required in this case?
- A basic security rule is that we should never store clear-text passwords. Storing a password safely is not very hard as long as we know which libraries to use [`j.mp/hashsec`]. If you have an interest in security, read the article and try to implement a secure way to store the secret message externally (for example, in a file or database).

- The application only supports adding new users, but what about removing an existing user? Add a `remove()` method. Should `remove()` be a privileged operation?

Summary

In this chapter, you learned how to use the Proxy design pattern. We used the Proxy pattern to implement a surrogate of an actual class when we want to act before (or after) accessing it. There are four different Proxy types. They are as follows:

- A remote proxy, which represents an object that lives in a remote location (for example, our own remote server or cloud service)
- A virtual proxy to delay the initialization of an object until it is actually used
- A protection/protective proxy, which is used to access control to an object that handles sensitive information
- When we want to extend the behavior of an object by adding support such as reference counting, we use a smart (reference) proxy

In the first code example, we created a virtual proxy in a pythonic style, using decorators and descriptors. This proxy allows us to initialize object properties in a lazy manner.

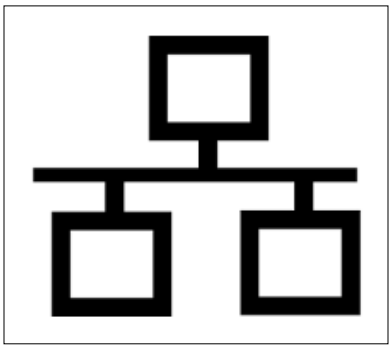
Chip and PIN and bank checks are examples of two different proxies used by people every day. Chip and PIN is a protective proxy, while a bank check is a remote proxy. However, proxies are also used in popular software. Python has a `weakref.proxy()` method that makes the creation of a smart proxy of an object very easy. The Python implementation of ZeroMQ uses a remote proxy.

We discussed several use cases of the Proxy pattern, including performance, security, and offering simple APIs to users. In the second code example, we implemented a protection proxy to handle users. This example can be improved in many ways, especially regarding its security flaws and the fact that the list of users is not persistent (permanently stored). Hopefully, you will find the recommended exercises interesting.

In the next chapter, we will explore behavioral design patterns. Behavioral patterns cope with object interconnection and algorithms. The first behavioral pattern that will be covered is Chain of Responsibility, which allows us to create a chain of receiving objects so that we can send broadcast messages. Sending a broadcast message is useful when the handler of a request is not known in advance.

10
The Chain of Responsibility Pattern

When developing an application, most of the time we know which method should satisfy a particular request in advance. However, this is not always the case. For example, we can think of any broadcast computer network, such as the original Ethernet implementation [`j.mp/wikishared`]. In broadcast computer networks, all requests are sent to all nodes (broadcast domains are excluded for simplicity), but only the nodes that are interested in a sent request process it. All computers that participate in a broadcast network are connected to each other using a common medium such as the cable that connects the three nodes in the following figure:



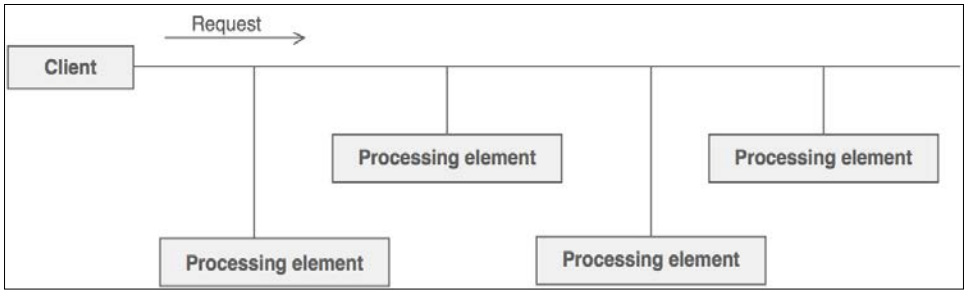
If a node is not interested or does not know how to handle a request, it can perform the following actions:

- Ignore the request and do nothing
- Forward the request to the next node

The way in which the node reacts to a request is an implementation detail. However, we can use the analogy of a broadcast computer network to understand what the chain of responsibility pattern is all about. The **Chain of Responsibility** pattern is used when we want to give a chance to multiple objects to satisfy a single request, or when we don't know which object (from a chain of objects) should process a specific request in advance. The principle is the same as the following:

1. There is a chain (linked list, tree, or any other convenient data structure) of objects.
2. We start by sending a request to the first object in the chain.
3. The object decides whether it should satisfy the request or not.
4. The object forwards the request to the next object.
5. This procedure is repeated until we reach the end of the chain.

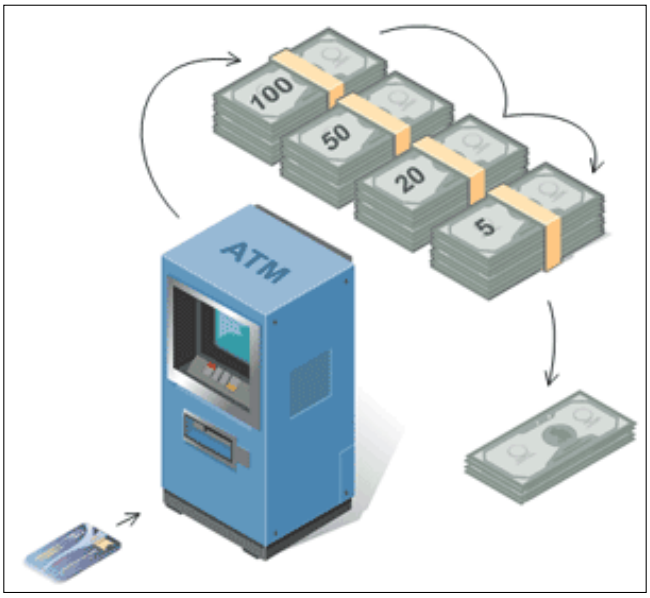
At the application level, instead of talking about cables and network nodes, we can focus on objects and the flow of a request. The following figure, courtesy of `www.sourcemaking.com` [`j.mp/smchain`], shows how the client code sends a request to all processing elements (also known as nodes or handlers) of an application:



Note that the client code only knows about the first processing element, instead of having references to all of them, and each processing element only knows about its immediate next neighbor (called the successor), not about every other processing element. This is usually a one-way relationship, which in programming terms means a singly linked list in contrast to a doubly linked list; a singly linked list does not allow navigation in both ways, while a doubly linked list allows that. This chain organization is used for a good reason. It achieves decoupling between the sender (client) and the receivers (processing elements) [GOF95, page 254].

A real-life example

ATMs and, in general, any kind of machine that accepts/returns banknotes or coins (for example, a snack vending machine) use the chain of responsibility pattern. There is always a single slot for all banknotes, as shown in the following figure, courtesy of `www.sourcemaking.com`:



When a banknote is dropped, it is routed to the appropriate receptacle. When it is returned, it is taken from the appropriate receptacle [`j.mp/smchain`], [`j.mp/c2chain`]. We can think of the single slot as the shared communication medium and the different receptacles as the processing elements. The result contains cash from one or more receptacles. For example, in the preceding figure, we see what happens when we request $175 from the ATM.

A software example

I tried to find some good examples of Python applications that use the Chain of Responsibility pattern but I couldn't, most likely because Python programmers don't use this name. So, my apologies, but I will use other programming languages as a reference.

The servlet filters of Java are pieces of code that are executed before an HTTP request arrives at a target. When using servlet filters, there is a chain of filters. Each filter performs a different action (user authentication, logging, data compression, and so forth), and either forwards the request to the next filter until the chain is exhausted, or it breaks the flow if there is an error (for example, the authentication failed three consecutive times) [`j.mp/soservl`].

Apple's Cocoa and Cocoa Touch frameworks use Chain of Responsibility to handle events. When a view receives an event that it doesn't know how to handle, it forwards the event to its superview. This goes on until a view is capable of handling the event or the chain of views is exhausted [`j.mp/chaincocoa`].

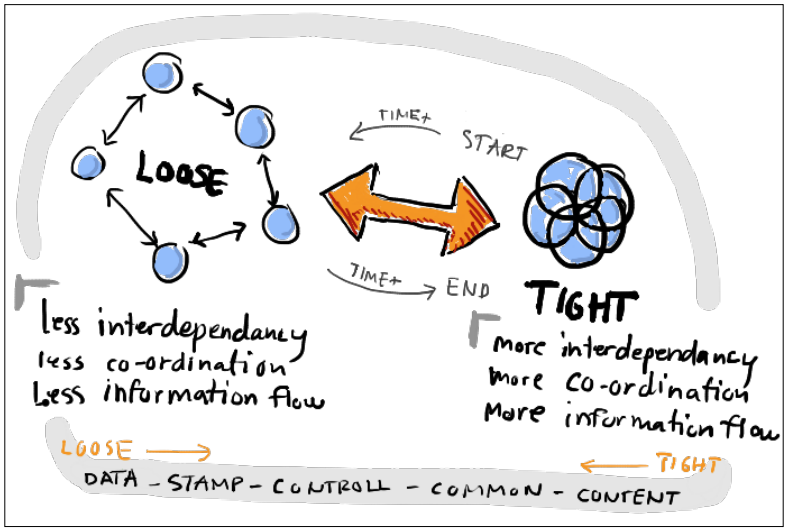
Use cases

By using the Chain of Responsibility pattern, we give a chance to a number of different objects to satisfy a specific request. This is useful when we don't know which object should satisfy a request in advance. An example is a purchase system. In purchase systems, there are many approval authorities. One approval authority might be able to approve orders up to a certain value, let's say $100. If the order is more than $100, the order is sent to the next approval authority in the chain that can approve orders up to $200, and so forth.

Another case where Chain of Responsibility is useful is when we know that more than one object might need to process a single request. This is what happens in an event-based programming. A single event such as a left mouse click can be caught by more than one listener.

It is important to note that the Chain of Responsibility pattern is not very useful if all the requests can be taken care of by a single processing element, unless we really don't know which element that is. The value of this pattern is the decoupling that it offers. Instead of having a many-to-many relationship between a client and all processing elements (and the same is true regarding the relationship between a processing element and all other processing elements), a client only needs to know how to communicate with the start (head) of the chain.

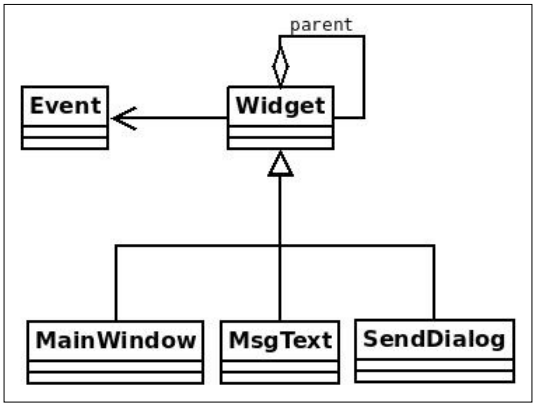
The following figure demonstrates the difference between tight and loose coupling. The idea behind loosely coupled systems is to simplify maintenance and make it easier for us to understand how they function [j.mp/loosecoup]:



Implementation

There are many ways to implement Chain of Responsibility in Python, but my favorite implementation is the one by Vespe Savikko [j.mp/savviko]. Vespe's implementation uses dynamic dispatching in a Pythonic style to handle requests [j.mp/ddispatch].

Let's implement a simple event-based system using Vespe's implementation as a guide. The following is the UML class diagram of the system:



The `Event` class describes an event. We'll keep it simple, so in our case an event has only `name`:

```
class Event:
    def __init__(self, name):
        self.name = name

    def __str__(self):
        return self.name
```

The `Widget` class is the core class of the application. The `parent` aggregation shown in the UML diagram indicates that each widget can have a reference to a parent object, which by convention, we assume is a `Widget` instance. Note, however, that according to the rules of inheritance, an instance of any of the subclasses of `Widget` (for example, an instance of `MsgText`) is also an instance of `Widget`. The default value of `parent` is `None`:

```
class Widget:
    def __init__(self, parent=None):
        self.parent = parent
```

The `handle()` method uses dynamic dispatching through `hasattr()` and `getattr()` to decide who is the handler of a specific request (`event`). If the widget that is asked to handle an event does not support it, there are two fallback mechanisms. If the widget has `parent`, then the `handle()` method of `parent` is executed. If the widget has no `parent` but a `handle_default()` method, `handle_default()` is executed:

```
    def handle(self, event):
        handler = 'handle_{}'.format(event)
        if hasattr(self, handler):
            method = getattr(self, handler)
            method(event)
        elif self.parent:
            self.parent.handle(event)
        elif hasattr(self, 'handle_default'):
            self.handle_default(event)
```

At this point, you might have realized why the `Widget` and `Event` classes are only associated (no aggregation or composition relationships) in the UML class diagram. The association is used to show that the `Widget` class "knows" about the `Event` class but does not have any strict references to it, since an event needs to be passed only as a parameter to `handle()`.

`MainWIndow`, `MsgText`, and `SendDialog` are all widgets with different behaviors. Not all these three widgets are expected to be able to handle the same events, and even if they can handle the same event, they might behave differently. `MainWIndow` can handle only the `close` and `default` events:

```
class MainWindow(Widget):
    def handle_close(self, event):
        print('MainWindow: {}'.format(event))

    def handle_default(self, event):
        print('MainWindow Default: {}'.format(event))
```

`SendDialog` can handle only the `paint` event:

```
class SendDialog(Widget):
    def handle_paint(self, event):
        print('SendDialog: {}'.format(event))
```

Finally, `MsgText` can handle only the `down` event:

```
class MsgText(Widget):
    def handle_down(self, event):
        print('MsgText: {}'.format(event))
```

The `main()` function shows how we can create a few widgets and events, and how the widgets react to those events. All events are sent to all the widgets. Note the parent relationship of each widget. The `sd` object (an instance of `SendDialog`) has as its parent the `mw` object (an instance of `MainWindow`). However, not all objects need to have a parent that is an instance of `MainWindow`. For example, the `msg` object (an instance of `MsgText`) has the `sd` object as a parent:

```
def main():
    mw = MainWindow()
    sd = SendDialog(mw)
    msg = MsgText(sd)

    for e in ('down', 'paint', 'unhandled', 'close'):
        evt = Event(e)
        print('\nSending event -{}- to MainWindow'.format(evt))
        mw.handle(evt)
        print('Sending event -{}- to SendDialog'.format(evt))
        sd.handle(evt)
        print('Sending event -{}- to MsgText'.format(evt))
        msg.handle(evt)
```

The following is the full code of the example (`chain.py`):

```
class Event:
    def __init__(self, name):
        self.name = name

    def __str__(self):
        return self.name

class Widget:
    def __init__(self, parent=None):
        self.parent = parent

    def handle(self, event):
        handler = 'handle_{}'.format(event)
        if hasattr(self, handler):
            method = getattr(self, handler)
            method(event)
        elif self.parent:
            self.parent.handle(event)
        elif hasattr(self, 'handle_default'):
            self.handle_default(event)

class MainWindow(Widget):
    def handle_close(self, event):
        print('MainWindow: {}'.format(event))

    def handle_default(self, event):
        print('MainWindow Default: {}'.format(event))

class SendDialog(Widget):
    def handle_paint(self, event):
        print('SendDialog: {}'.format(event))

class MsgText(Widget):
    def handle_down(self, event):
        print('MsgText: {}'.format(event))

def main():
    mw = MainWindow()
    sd = SendDialog(mw)
    msg = MsgText(sd)
```

```
        for e in ('down', 'paint', 'unhandled', 'close'):
            evt = Event(e)
            print('\nSending event -{}- to MainWindow'.format(evt))
            mw.handle(evt)
            print('Sending event -{}- to SendDialog'.format(evt))
            sd.handle(evt)
            print('Sending event -{}- to MsgText'.format(evt))
            msg.handle(evt)

    if __name__ == '__main__':
        main()
```

Executing `chain.py` gives us the following results:

```
>>> python3 chain.py

Sending event -down- to MainWindow
MainWindow Default: down
Sending event -down- to SendDialog
MainWindow Default: down
Sending event -down- to MsgText
MsgText: down

Sending event -paint- to MainWindow
MainWindow Default: paint
Sending event -paint- to SendDialog
SendDialog: paint
Sending event -paint- to MsgText
SendDialog: paint

Sending event -unhandled- to MainWindow
MainWindow Default: unhandled
Sending event -unhandled- to SendDialog
MainWindow Default: unhandled
Sending event -unhandled- to MsgText
MainWindow Default: unhandled
```

```
Sending event -close- to MainWindow
MainWindow: close
Sending event -close- to SendDialog
MainWindow: close
Sending event -close- to MsgText
MainWindow: close
```

There are some interesting things that we can see in the output. For instance, sending a `down` event to `MainWindow` ends up being handled by the default `MainWindow` handler. Another nice case is that although a `close` event cannot be handled directly by `SendDialog` and `MsgText`, all the close events end up being handled properly by `MainWindow`. That's the beauty of using the parent relationship as a fallback mechanism.

If you want to spend some more creative time on the event example, you can replace the dumb `print` statements and add some actual behavior to the listed events. Of course, you are not limited to the listed events. Just add your favorite event and make it do something useful!

Another exercise is to add a `MsgText` instance during runtime that has `MainWindow` as the parent. Is this hard? Do the same for an event (add a new event to an existing widget). Which is harder?

Summary

In this chapter, we covered the Chain of Responsibility design pattern. This pattern is useful to model requests / handle events when the number and type of handlers isn't known in advance. Examples of systems that fit well with Chain of Responsibility are event-based systems, purchase systems, and shipping systems.

In the Chain Of Responsibility pattern, the sender has direct access to the first node of a chain. If the request cannot be satisfied by the first node, it forwards to the next node. This continues until either the request is satisfied by a node or the whole chain is traversed. This design is used to achieve loose coupling between the sender and the receiver(s).

ATMs are an example of Chain Of Responsibility. The single slot that is used for all banknotes can be considered the head of the chain. From here, depending on the transaction, one or more receptacles is used to process the transaction. The receptacles can be considered the processing elements of the chain.

Java's servlet filters use the Chain of Responsibility pattern to perform different actions (for example, compression and authentication) on an HTTP request. Apple's Cocoa frameworks use the same pattern to handle events such as button presses and finger gestures.

The implementation section demonstrates how we can create our own event-based system in Python using dynamic dispatching.

The next chapter is about the Command pattern, which is used (but not limited to) to add undo support in an application.

11
The Command Pattern

Most applications nowadays have an undo operation. It is hard to imagine, but undo did not exist in any software for many years. Undo was introduced in 1974 [`j.mp/wiundo`], but Fortran and Lisp, two programming languages that are still widely used, were created in 1957 and 1958, respectively [`j.mp/proghist`]! I wouldn't like to be an application user during those years. Making a mistake meant that the user had no easy way to fix it.

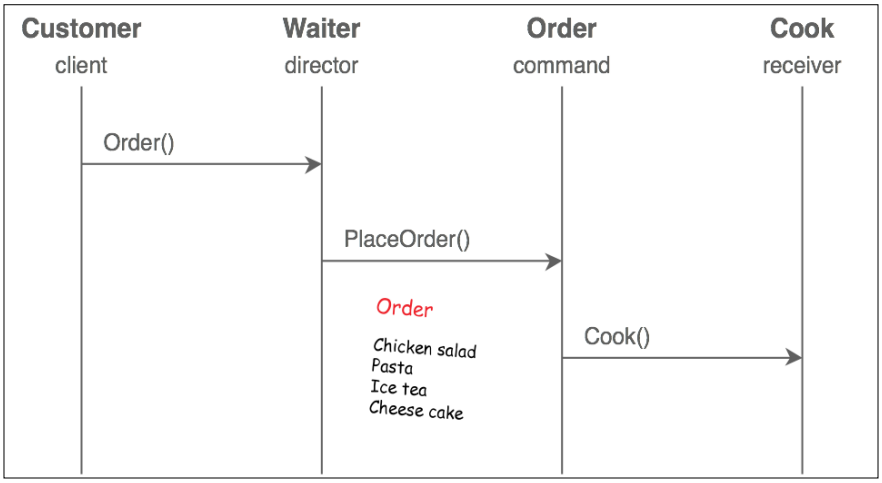
Enough with the history. We want to know how we can implement the undo functionality in our applications. And since you have read the title of this chapter, you already know which design pattern is recommended to implement undo: **the Command pattern**.

The Command design pattern helps us encapsulate an operation (undo, redo, copy, paste, and so forth) as an object. What this simply means is that we create a class that contains all the logic and the methods required to implement the operation. The advantages of doing this are as follows [GOF95, page 265], [`j.mp/cmdpattern`]:

- We don't have to execute a command directly. It can be executed on will.
- The object that invokes the command is decoupled from the object that knows how to perform it. The invoker does not need to know any implementation details about the command.
- If it makes sense, multiple commands can be grouped to allow the invoker to execute them in order. This is useful, for instance, when implementing a multilevel undo command.

A real-life example

When we go to the restaurant for dinner, we give the order to the waiter. The check (usually paper) they use to write the order on is an example of Command. After writing the order, the waiter places it in the check queue that is executed by the cook. Each check is independent and can be used to execute many and different commands, for example, one command for each item that will be cooked. The following figure, courtesy of `www.sourcemaking.com` [`j.mp/cmdpattern`], shows a sequence diagram of a sample order:



A software example

PyQt is the Python binding of the QT toolkit. PyQt contains a `QAction` class that models an action as a command. Extra optional information is supported for every action, such as description, tooltip, shortcut, and more [`j.mp/qaction`].

git-cola [`j.mp/git-cola`], a Git GUI written in Python, uses the Command pattern to modify the model, amend a commit, apply a different election, check out, and so forth [`j.mp/git-cola-code`].

Use cases

Many developers use the undo example as the only use case of the Command pattern. The truth is that undo is the killer feature of the Command pattern. However, the Command pattern can actually do much more [GOF95, page 265], [`j.mp/commddp`]:

- **GUI buttons and menu items**: The PyQt example that was already mentioned uses the Command pattern to implement actions on buttons and menu items.
- **Other operations**: Apart from undo, Command can be used to implement any operation. A few examples are cut, copy, paste, redo, and capitalize text.
- **Transactional behavior and logging**: Transactional behavior and logging are important to keep a persistent log of changes. They are used by operating systems to recover from system crashes, relational databases to implement transactions, filesystems to implement snapshots, and installers (wizards) to revert cancelled installations.
- **Macros**: By macros, in this case, we mean a sequence of actions that can be recorded and executed on demand at any point in time. Popular editors such as Emacs and Vim support macros.

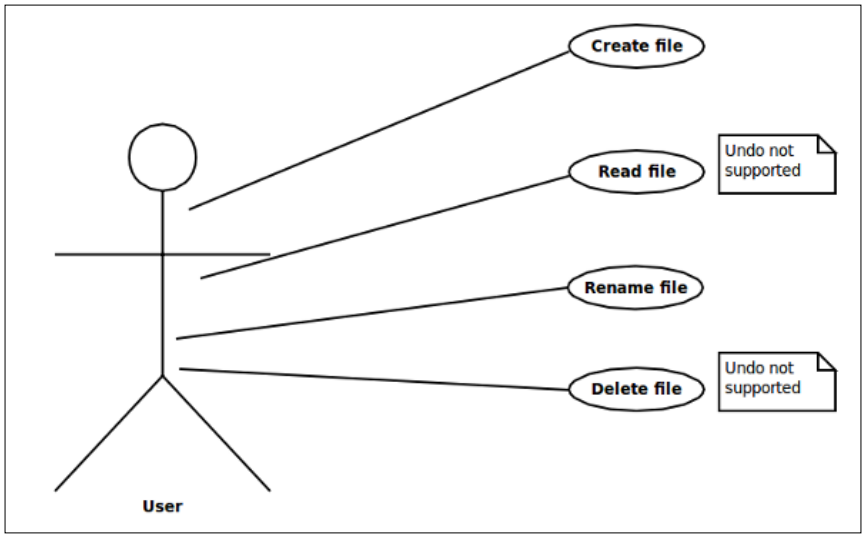
Implementation

In this section, we will use the Command pattern to implement the most basic file utilities:

- Creating a file and optionally writing a string in it
- Reading the contents of a file
- Renaming a file
- Deleting a file

We will not implement these utilities from scratch, since Python already offers good implementations of them in the `os` module. What we want is to add an extra abstraction level on top of them so that they can be treated as commands. By doing this, we get all the advantages offered by commands.

The following use case diagram shows the supported operations that a user can execute. From the operations shown, renaming a file and creating a file support undo. Deleting a file and reading the contents of a file do no support undo. Undo can actually be implemented on delete file operations. One technique is to use a special trash/wastebasket directory that stores all the deleted files, so that they can be restored when the user requests it. This is the default behavior used on all modern desktop environments and is left as an exercise.



Each command has two parts: the initialization part and the execution part. The initialization part is taken care of by the `__init__()` method and contains all the information required by the command to be able to do something useful (the path of a file, the contents that will be written to the file, and so forth). The execution part is taken care by the `execute()` method. We call the `execute()` method when we want to actually run a command. This is not necessarily right after initializing it.

Let's start with the rename utility, which is implemented using the `RenameFile` class. The `__init__()` method accepts the source (`path_src`) and destination (`path_dest`) file paths as parameters (strings). If no path separators are used, the current directory is used to create the file. An example of using a path separator is passing the string `/tmp/file1` as `path_src` and the string `/home/user/file2` as `path_dest`. The example of not using a path is passing `file1` as `path_src` and `file2` as `path_dest`:

```
class RenameFile:
    def __init__(self, path_src, path_dest):
        self.src, self.dest = path_src, path_dest
```

The `execute()` method does the actual renaming using `os.rename()`. `verbose` is a global flag, which, when activated (by default, it is activated), gives feedback to the user about the operation that is performed. You can deactivate it if you prefer silent commands. Note that although `print()` is good enough for an example, normally something more mature and powerful can be used, for example, the logging module [`j.mp/py3log`]:

```
        def execute(self):
            if verbose:
                print("[renaming '{}' to '{}']".format(self.src, self.
    dest))
            os.rename(self.src, self.dest)
```

Our rename utility supports the undo operation through its `undo()` method. In this case, undo uses `os.rename()` again to revert the name of the file to its original value:

```
        def undo(self):
            if verbose:
                print("[renaming '{}' back to '{}']".format(self.dest,
    self.src))
            os.rename(self.dest, self.src)
```

Deleting a file is a single function, instead of a class. I did that to show you that it is not mandatory to create a new class for every command that you want to add (more on that will be covered later). The `delete_file()` function accepts a file path as a string and uses `os.remove()` to delete it:

```
    def delete_file(path):
        if verbose:
            print("deleting file '{}".format(path))
        os.remove(path)
```

Back to using classes again. The `CreateFile` class is used to create a file. The `__init__()` function accepts the familiar `path` parameter and a `txt` string, which is the content that will be written to the file. If nothing is passed as `txt`, the default "hello world" text is written to the file. Normally, the sane default behavior is to create an empty file, but for the needs of this example, I decided to write a default string in it. Feel free to change it:

```
        def __init__(self, path, txt='hello world\n'):
            self.path, self.txt = path, txt
```

The `execute()` method uses the `with` statement and `open()` to open the file (`mode='w'` means write mode), and `write()` to write the `txt` string:

```
    def execute(self):
        if verbose:
            print("[creating file '{}']".format(self.path))
        with open(self.path, mode='w', encoding='utf-8') as out_file:
            out_file.write(self.txt)
```

The undo operation of creating a file is to delete it. So, `undo()` simply uses `delete_file()` to achieve that:

```
    def undo(self):
        delete_file(self.path)
```

The last utility gives us the ability to read the contents of a file. The `execute()` method of the `ReadFile` class uses the `with` statement with `open()` again, this time in read mode, and just prints the contents of it using `print()`:

```
    def execute(self):
        if verbose:
            print("[reading file '{}']".format(self.path))
        with open(self.path, mode='r', encoding='utf-8') as in_file:
            print(in_file.read(), end='')
```

The `main()` function makes use of the utilities. The `orig_name` and `new_name` parameters are the original and new name of the file that is created and renamed. A `commands` list is used to add (and configure) all the commands that we want to execute at a later point. Note that the commands are not executed unless we explicitly call `execute()` for each command:

```
    orig_name, new_name = 'file1', 'file2'

    commands = []
    for cmd in CreateFile(orig_name), ReadFile(orig_name),
                    RenameFile(orig_name, new_name):
        commands.append(cmd)

    [c.execute() for c in commands]
```

The next step is to ask the users if they want to undo the executed commands or not. The user selects whether the commands will be undone or not. If they choose to undo them, `undo()` is executed for all commands in the `commands` list. However, since not all commands support undo, exception handling is used to catch (and ignore) the `AttributeError` exception generated when the `undo()` method is missing. If you don't like using exception handling for such cases, you can check explicitly whether a command supports the undo operation by adding a Boolean method, for example, `supports_undo()` or `can_de_undone()`:

```
    answer = input('reverse the executed commands? [y/n] ')


    if answer not in 'yY':
        print("the result is {}".format(new_name))
        exit()

    for c in reversed(commands):
        try:
            c.undo()
        except AttributeError as e:
            pass
```

Here's the full code of the example (`command.py`):

```
import os

verbose = True

class RenameFile:
    def __init__(self, path_src, path_dest):
        self.src, self.dest = path_src, path_dest

    def execute(self):
        if verbose:
            print("[renaming '{}' to '{}']".format(self.src, self.
dest))
        os.rename(self.src, self.dest)

    def undo(self):
        if verbose:
            print("[renaming '{}' back to '{}']".format(self.dest,
self.src))
        os.rename(self.dest, self.src)
```

```
class CreateFile:
    def __init__(self, path, txt='hello world\n'):
        self.path, self.txt = path, txt

    def execute(self):
        if verbose:
            print("[creating file '{}']".format(self.path))
        with open(self.path, mode='w', encoding='utf-8') as out_file:
            out_file.write(self.txt)

    def undo(self):
        delete_file(self.path)

class ReadFile:
    def __init__(self, path):
        self.path = path

    def execute(self):
        if verbose:
            print("[reading file '{}']".format(self.path))
        with open(self.path, mode='r', encoding='utf-8') as in_file:
            print(in_file.read(), end='')

def delete_file(path):
    if verbose:
        print("deleting file '{}".format(path))
    os.remove(path)

def main():
    orig_name, new_name = 'file1', 'file2'

    commands = []
    for cmd in CreateFile(orig_name), ReadFile(orig_name),
RenameFile(orig_name, new_name):
        commands.append(cmd)

    [c.execute() for c in commands]

    answer = input('reverse the executed commands? [y/n] ')


    if answer not in 'yY':
        print("the result is {}".format(new_name))
        exit()
```

```
        for c in reversed(commands):
            try:
                c.undo()
            except AttributeError as e:
                pass

    if __name__ == "__main__":
        main()
```

Let's see two sample executions of `command.py`. In the first one, there is no undo of commands, whereas in the second one there is:

```
>>> python3 command.py
[creating file 'file1']
[reading file 'file1']
hello world
[renaming 'file1' to 'file2']
reverse the executed commands? [y/n] n
the result is file2

>>> python3 command.py
[creating file 'file1']
[reading file 'file1']
hello world
[renaming 'file1' to 'file2']
reverse the executed commands? [y/n] y
[renaming 'file2' back to 'file1']
deleting file 'file1'
```

The command example can be improved in many aspects. To begin with, none of the utilities follow a defensive programming style [`j.mp/dobbdef`]. What happens if we try to rename a file that doesn't exist? What about files that exist but cannot be renamed because we don't have the proper filesystem permissions? The same issues exist with all tools; for example, what happens if we try to read a file that doesn't exist? Try improving the utilities by doing some kind of error handling. Is checking the return status of the methods that belong to the `os` module necessary?

The file creation utility creates a file using the default file permissions as decided by the filesystem. For example, in POSIX systems, the permissions are -rw-rw-r--. You might want to give the ability to the user to provide their own permissions by passing the appropriate parameter to `CreateFile`. How can you do that? Hint: one way is by using `os.fdopen()`.

And now, here's something for you to think about. I mentioned earlier that a command does not necessarily need to be a class. That's how the delete utility was implemented; there is just a `delete_file()` function. What are the advantages and disadvantages of this approach? Here's a hint: is it possible to put a delete command in the `commands` list as it was done for the rest of the commands? We know that functions are first-class citizens in Python, so we can do something such as the following (the `first-class.py` file):

```
orig_name = 'file1'
df=delete_file

commands = []
commands.append(df)

for c in commands:
    try:
        c.execute()
    except AttributeError as e:
        df(orig_name)

for c in reversed(commands):
    try:
        c.undo()
    except AttributeError as e:
        pass
```

Although this example works, it has some issues:

- The code is not uniform. We rely too much on exception handling, which is not the normal flow of a program. While all the rest of the commands have an `execute()` method, in this case, there is no `execute()`.
- Currently, the delete file utility has no undo support. What happens if we eventually decide to add undo support for it? Normally, we add an `undo()` method in the class that represents the command. However, in this case, there is no class. We could create another function to handle undo, but creating a class is a better approach.

Summary

In this chapter, we covered the Command pattern. Using this design pattern, we can encapsulate an operation such as copy/paste as an object. This offers many benefits, as follows:

- We can execute a command whenever we want and not necessarily in creation time
- The client code that executes a command does not need to know any details about how it is implemented
- We can group commands and execute them in a specific order

Executing a command is like ordering at a restaurant. Each customer order is an independent command that enters many stages and is finally executed by the cook.

Many GUI frameworks, including PyQt use the Command pattern to model actions that can be triggered by one or more events and can be customized. However, Command is not limited to frameworks; normal applications such as git-cola also use it for the benefits it offers.

Although the most advertised feature of Command by far is undo, it has more uses. In general, any operation that can be executed on user's will at runtime is a good candidate to use the Command pattern. Command is also great for grouping multiple commands. That's useful for implementing macros, multilevel undo, and transactions. A transaction should either succeed, which means that all operations of it should succeed (the commit operation), or it should fail completely if at least one of its operations fails (the rollback operation). If you want to take the Command pattern to the next level, you can work on an example that involves grouping commands as transactions.

To demonstrate Command, we implemented some basic file utilities on top of Python's `os` module. Our utilities support undo and have a uniform interface, which makes grouping commands easy.

The next chapter covers the Interpreter pattern, which can be used to create a computer language that focuses on a specific domain. Such a language is called a **Domain Specific Language** (**DSL**).

12
The Interpreter Pattern

There are at least two different user categories for each application:

- **Basic users**: The users of this category just want to be able to use the application in an intuitive way. They don't like to spend too much time on configuring or learning the internals of the application. Basic usage is sufficient for them.
- **Advanced users**: Those users, who are in fact usually the minority, don't mind spending some extra time on learning how to use the advanced features of the application. They can go as far as learning a configuration (or scripting) language if they know that learning it will:
    - Give them the ability to have better control of an application
    - Help them express their ideas in a better way
    - Make them more productive

The **Interpreter** pattern is interesting only for the advanced users of an application. That's because the main idea behind Interpreter is to give the ability to non-beginner users and domain experts to use a simple language to express their ideas. However, what is a simple language? For our needs, a simple language is a language that is less complex than a programming language.

Usually, what we want to create is a **Domain Specific Language** (**DSL**). A DSL is a computer language of limited expressiveness targeting a particular domain. DSLs are used for different things, such as combat simulation, billing, visualization, configuration, communication protocols, and so on. DSLs are divided into internal DSLs and external DSLs [`j.mp/wikidsl`], [`j.mp/fowlerdsl`].

Internal DSLs are built on top of a host programming language. An example of an internal DSL is a language that solves linear equations using Python. The advantages of using an internal DSL are that we don't have to worry about creating, compiling, and parsing grammar because these are already taken care of by the host language. The disadvantage is that we are constrained by the features of the host language. It is very challenging to create an expressive, concise, and fluent internal DSL if the host language does not have these features [`j.mp/jwodsl`].

External DSLs do not depend on host languages. The creator of the DSL can decide all aspects of the language (grammar, syntax, and so forth), but they are also responsible for creating a parser and compiler for it. Creating a parser and compiler for a new language can be a very complex, long, and painful procedure [`j.mp/jwodsl`].

The Interpreter pattern is related only to internal DSLs. Therefore, our goal is to create a simple but useful language using the features provided by the host programming language, which in this case is Python. Note that Interpreter does not address parsing at all. It assumes that we already have the parsed data in some convenient form. This can be an **abstract syntax tree** (**AST**) or any other handy data structure [GOF95, page 276].

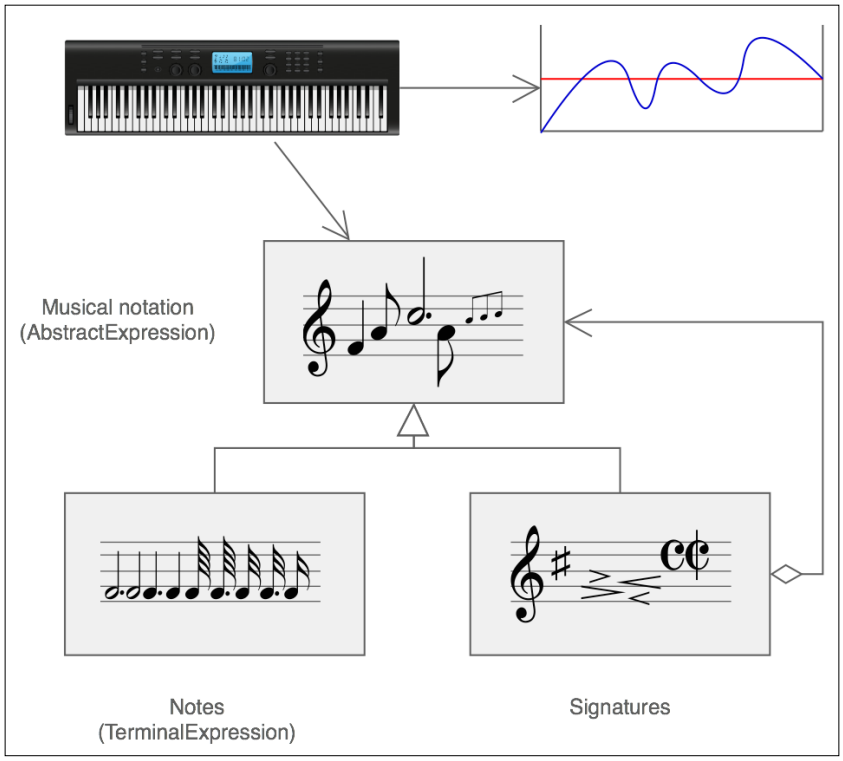
A real-life example

A musician is an example of the Interpreter pattern in reality. Musical notation represents the pitch and duration of a sound graphically. The musician is able to reproduce a sound precisely based on its notation. In a sense, musical notation is the language of music, and the musician is the interpreter of that language. The following figure, which is courtesy of `www.sourcemaking.com` [`j.mp/smintpat`], shows a graphical representation of the music example.

A software example

There are many software examples of internal DSLs. PyT is a Python DSL to generate (X)HTML. PyT focuses on performance and claims to have comparable speed with Jinja2 [`j.mp/ghpyt`]. Of course, we should not assume that the Interpreter pattern is necessarily used in PyT. However, since it is an internal DSL, Interpreter is a very good candidate for it.

Chromium is a FOSS browser that inspired Google Chrome [`j.mp/chromiumb`]. A part of the Mesa library Python binding of Chromium uses the Interpreter pattern to translate C model arguments to Python objects and executing the related commands [`j.mp/intchromium`].



Use cases

The Interpreter pattern is used when we want to offer a simple language to domain experts and advanced users to solve their problems. The first thing we should stress is that Interpreter should only be used to implement simple languages. If the language has the requirements of an external DSL, there are better tools to create languages from scratch (yacc and lex, Bison, ANTLR, and so on).

Our goal is to offer the right programming abstractions to the specialist, who is often not a programmer, to make them productive. Ideally, they shouldn't know advanced Python to use our DSL, but knowing even a little bit of Python is a plus since that's what we eventually get at the end. Advanced Python concepts should not be a requirement. Moreover, the performance of the DSL is usually not an important concern. The focus is on offering a language that hides the peculiarities of the host language and offers a more human-readable syntax. Admittedly, Python is already a very readable language with far less peculiar syntax than many other programming languages.

Implementation

Let's create an internal DSL to control a smart house. This example fits well into the Internet of things era, which is getting more and more attention nowadays. The user is able to control their home using a very simple event notation. An event has the form of `command -> receiver -> arguments`. The arguments part is optional. Not all events require arguments. An example of an event that does not require any arguments is shown:

```
open -> gate
```

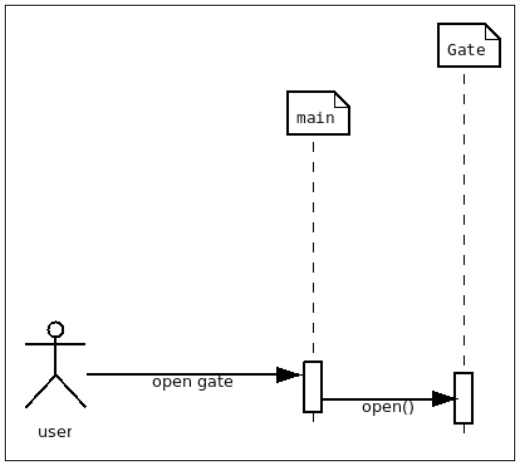
An example of an event that requires arguments is shown:

```
increase -> boiler temperature -> 3 degrees
```

The `->` symbol is used to mark the end of one part of an event and state the beginning of the next one. There are many ways to implement an internal DSL. We can use plain old regular expressions, string processing, a combination of operator overloading, and metaprogramming, or a library/tool that can do the hard work for us. Although, officially, Interpreter does not address parsing, I feel that a practical example needs to cover parsing as well. For this reason, I decided to use a tool to take care of the parsing part. The tool is called Pyparsing and is part of the standard Python3 distribution. To find out more about Pyparsing, check the mini book *Getting Started with Pyparsing* by Paul McGuire. If Pyparsing is not already installed on your system, you can install it using the following command:

```
>>> pip3 install pyparsing
```

The following sequence diagram shows what happens when the open gate event is executed by the user. The situation is similar for the rest events, with the exception that some events are a bit more complex because they require arguments.



Before getting into coding, it is a good practice to define a simple grammar for our language. We can define the grammar using the **Backus-Naur Form** (**BNF**) notation [`j.mp/bnfgram`]:

```
event ::= command token receiver token arguments
command ::= word+
word ::= a collection of one or more alphanumeric characters
token ::= ->
receiver ::= word+
arguments ::= word+
```

What the grammar basically tells us is that an event has the form of `command -> receiver -> arguments`, and that commands, receivers, and arguments have the same form: a group of one or more alphanumeric characters. If you are wondering about the necessity of the numeric part, it is included to allow us to pass arguments such as **3 degrees** at the command `increase -> boiler temperature -> 3 degrees`.

Now that we have defined the grammar, we can move on to converting it to actual code. Here's how the code looks:

```
word = Word(alphanums)
command = Group(OneOrMore(word))
token = Suppress("->")
device = Group(OneOrMore(word))
argument = Group(OneOrMore(word))
event = command + token + device + Optional(token + argument)
```

The basic difference between the code and grammar definition is that the code needs to be written in the bottom-up approach. For instance, we cannot use `word` without first assigning it a value. `Suppress` is used to state that we want the `->` symbol to be skipped from the parsed results.

The full code of this example (the `interpreter.py` file) uses many placeholder classes, but to keep you focused, I will first show only one class. The complete code listing is also included and will be shown after going through the single class example. Let's take a look at the `Boiler` class. A boiler has a default temperature of 83 degrees Celsius. There are also two methods to increase and decrease the current temperature:

```
class Boiler:
    def __init__(self):
        self.temperature =  83 # in  celsius

    def __str__(self):
        return 'boiler temperature: {}'.format(self.temperature)
```

```
    def increase_temperature(self, amount):
        print("increasing the boiler's temperature by {}
                  degrees".format(amount))
        self.temperature += amount

    def decrease_temperature(self, amount):
        print("decreasing the boiler's temperature by {}
                  degrees".format(amount))
        self.temperature -= amount
```

The next step is to add the grammar, which we already covered. We will also create a `boiler` instance and print its default state:

```
    word = Word(alphanums)
    command = Group(OneOrMore(word))
    token = Suppress("->")
    device = Group(OneOrMore(word))
    argument = Group(OneOrMore(word))
    event = command + token + device + Optional(token + argument)

    boiler = Boiler()
    print(boiler)
```

The simplest way to retrieve the parsed output of Pyparsing is by using the `parseString()` method. The result is a `ParseResults` instance, which is actually a parse tree that can be treated as a nested list. For example, executing `print(event.parseString('increase -> boiler temperature -> 3 degrees'))` gives the following result:

```
[['increase'], ['boiler', 'temperature'], ['3', 'degrees']]
```

So, in this case, we know that the first sublist is the command (increase), the second sublist is the receiver (boiler temperature), and the third sublist is the argument (3 degrees). We can actually unpack the `ParseResults` instance, which gives us direct access to these three parts of the event. Having direct access means that we can match patterns to find out which method should be executed:

```
    cmd, dev, arg = event.parseString('increase -> boiler temperature
-> 3 degrees')
    if 'increase' in ' '.join(cmd):
        if 'boiler' in ' '.join(dev):
            boiler.increase_temperature(int(arg[0]))

    print(boiler)
```

Executing the preceding snippet gives the following output:

```
>>> python3 boiler.py
boiler temperature: 83
increasing the boiler's temperature by 3 degrees
boiler temperature: 86
```

The full code of `interpreter.py` is not very different from what I just described. It is just extended to support more events and devices:

```
from pyparsing import Word, OneOrMore, Optional, Group, Suppress,
alphanums

class Gate:
    def __init__(self):
        self.is_open = False

    def __str__(self):
        return 'open' if self.is_open else 'closed'

    def open(self):
        print('opening the gate')
        self.is_open = True

    def close(self):
        print('closing the gate')
        self.is_open = False

class Garage:
    def __init__(self):
        self.is_open = False

    def __str__(self):
        return 'open' if self.is_open else 'closed'

    def open(self):
        print('opening the garage')
        self.is_open = True

    def close(self):
        print('closing the garage')
        self.is_open = False
```

```
class Aircondition:
    def __init__(self):
        self.is_on = False

    def __str__(self):
        return 'on' if self.is_on else 'off'

    def turn_on(self):
        print('turning on the aircondition')
        self.is_on = True

    def turn_off(self):
        print('turning off the aircondition')
        self.is_on = False

class Heating:
    def __init__(self):
        self.is_on = False

    def __str__(self):
        return 'on' if self.is_on else 'off'

    def turn_on(self):
        print('turning on the heating')
        self.is_on = True

    def turn_off(self):
        print('turning off the heating')
        self.is_on = False

class Boiler:
    def __init__(self):
        self.temperature = 83# in celsius

    def __str__(self):
        return 'boiler temperature: {}'.format(self.temperature)

    def increase_temperature(self, amount):
        print("increasing the boiler's temperature by {} degrees".
format(amount))
        self.temperature += amount
```

```
    def decrease_temperature(self, amount):
        print("decreasing the boiler's temperature by {} degrees".
format(amount))
        self.temperature -= amount

class Fridge:
    def __init__(self):
        self.temperature = 2 # in celsius

    def __str__(self):
        return 'fridge temperature: {}'.format(self.temperature)

    def increase_temperature(self, amount):
        print("increasing the fridge's temperature by {} degrees".
format(amount))
        self.temperature += amount

    def decrease_temperature(self, amount):
        print("decreasing the fridge's temperature by {} degrees".
format(amount))
        self.temperature -= amount


def main():
    word = Word(alphanums)
    command = Group(OneOrMore(word))
    token = Suppress("->")
    device = Group(OneOrMore(word))
    argument = Group(OneOrMore(word))
    event = command + token + device + Optional(token + argument)

    gate = Gate()
    garage = Garage()
    airco = Aircondition()
    heating = Heating()
    boiler = Boiler()
    fridge = Fridge()

    tests = ('open -> gate',
             'close -> garage',
             'turn on -> aircondition',
             'turn off -> heating',
             'increase -> boiler temperature -> 5 degrees',
             'decrease -> fridge temperature -> 2 degrees')
```

```
    open_actions = {'gate':gate.open, 'garage':garage.open,
'aircondition':airco.turn_on,
                    'heating':heating.turn_on, 'boiler
temperature':boiler.increase_temperature,
                    'fridge temperature':fridge.increase_temperature}
    close_actions = {'gate':gate.close, 'garage':garage.close,
'aircondition':airco.turn_off,
                     'heating':heating.turn_off, 'boiler
temperature':boiler.decrease_temperature,
                     'fridge temperature':fridge.decrease_temperature}

    for t in tests:
        if len(event.parseString(t)) == 2: # no argument
            cmd, dev = event.parseString(t)
            cmd_str, dev_str = ' '.join(cmd), ' '.join(dev)
            if 'open' in cmd_str or 'turn on' in cmd_str:
                open_actions[dev_str]()
            elif 'close' in cmd_str or 'turn off' in cmd_str:
                close_actions[dev_str]()
        elif len(event.parseString(t)) == 3: # argument
            cmd, dev, arg = event.parseString(t)
            cmd_str, dev_str, arg_str = ' '.join(cmd), ' '.join(dev),
' '.join(arg)
            num_arg = 0
            try:
                num_arg = int(arg_str.split()[0]) # extract the
numeric part
            except ValueError as err:
                print("expected number but got: '{}'".format(arg_
str[0]))
            if 'increase' in cmd_str and num_arg > 0:
                open_actions[dev_str](num_arg)
            elif 'decrease' in cmd_str and num_arg > 0:
                close_actions[dev_str](num_arg)

if __name__ == '__main__':
    main()
```

Executing the preceding example gives the following output:

```
>>> python3 interpreter.py
opening the gate
closing the garage
turning on the aircondition
turning off the heating
```

```
increasing the boiler's temperature by 5 degrees
decreasing the fridge's temperature by 2 degrees
```

If you want to experiment more with this example, I have a few suggestions for you. The first change that will make it much more interesting is to make it interactive. Currently, all the events are hardcoded in the `tests` tuple. However, the user wants to be able to activate events using an interactive prompt. Do not forget to check how sensitive Pyparsing is regarding spaces, tabs, or unexpected input. For example, what happens if the user types: `turn off -> heating 37`?

Another possible improvement: notice how the `open_actions` and `close_actions` maps are used to relate a receiver with a method. Is it possible to use a single map instead of two? Are there any advantages in doing that?

Summary

In this chapter, we covered the Interpreter design pattern. The Interpreter pattern is used to offer a programming-like framework to advanced users and domain experts, but without exposing the complexities of a programming language. This is achieved by implementing a DSL.

A DSL is a computer language that has limited expressiveness and targets a specific domain. There are two categories of DSLs: internal DSLs and external DSLs. While internal DSLs are built on top of a host programming language and rely on it, external DSLs are implemented from scratch and do not depend on an existing programming language. Interpreter is related only to internal DSLs.

Musical notation is an example of a non-software DSL. The musician acts as the Interpreter that uses the notation to produce music. From a software perspective, many Python template engines make use of Internal DSLs. PyT is a high-performance Python DSL to generate (X)HTML. We also saw how the Mesa library of Chromium uses the Interpreter pattern to translate graphics-related C code to Python executable objects.

Although parsing is generally not addressed by the Interpreter pattern, in the implementation section, we used Pyparsing to create a DSL that controls a smart house, and saw that using a good parsing tool makes "interpreting" the results using pattern matching simple.

The next chapter demonstrates the Observer pattern. Observer is used to create a publish-subscribe communication type between two or more objects.

13
The Observer Pattern

Sometimes, we want to update a group of objects when the state of another object changes. A very popular example lies in the **Model-View-Controller** (**MVC**) pattern. Assume that we are using the data of the same model in two views, for instance in a pie chart and in a spreadsheet. Whenever the model is modified, both the views need to be updated. That's the role of the Observer design pattern [Eckel08, page 213].

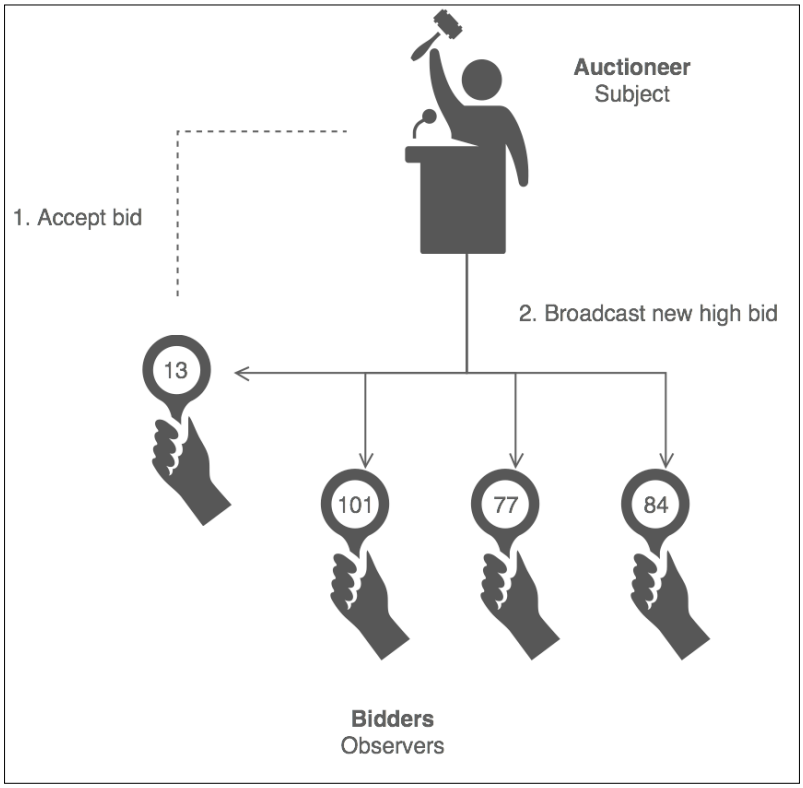
The Observer pattern describes a publish-subscribe relationship between a single object, : the publisher, which is also known as the subject or observable, and one or more objects, : the subscribers, also known as observers. In the MVC example, the publisher is the model and the subscribers are the views. However, MVC is not the only publish-subscribe example. Subscribing to a news feed such as RSS or Atom is another example. Many readers can subscribe to the feed typically using a feed reader, and every time a new item is added, they receive the update automatically.

The ideas behind Observer are the same as the ideas behind MVC and the separation of concerns principle, that is, to increase decoupling between the publisher and subscribers, and to make it easy to add/remove subscribers at runtime. Additionally, the publisher is not concerned about who its observers are. It just sends notifications to all the subscribers [GOF95, page 327].

A real-life example

In reality, an auction resembles Observer. Every auction bidder has a number paddle that is raised whenever they want to place a bid. Whenever the paddle is raised by a bidder, the auctioneer acts as the subject by updating the price of the bid and broadcasting the new price to all bidders (subscribers).

The following figure, courtesy of `www.sourcemaking.com`, [`j.mp/observerpat`], shows how the Observer pattern relates to an auction:



A software example

The django-observer package [`j.mp/django-obs`] is a third-party Django package that can be used to register callback functions that are executed when there are changes in several Django fields. Many different types of fields are supported (`CharField`, `IntegerField`, and so forth).

RabbitMQ is a library that can be used to add asynchronous messaging support to an application. Several messaging protocols are supported, such as HTTP and AMQP. RabbitMQ can be used in a Python application to implement a publish-subscribe pattern, which is nothing more than the Observer design pattern [`j.mp/rabbitmqobs`].

Use cases

We generally use the Observer pattern when we want to inform/update one or more objects (observers/subscribers) about a change that happened to another object (subject/publisher/observable). The number of observers as well as who the observers are may vary and can be changed dynamically (at runtime).

We can think of many cases where Observer can be useful. One such case was already mentioned at the start of this chapter: news feeds. Whether it is RSS, Atom, or another format, the idea is the same; you follow a feed, and every time it is updated, you receive a notification about the update [Zlobin13, page 60].

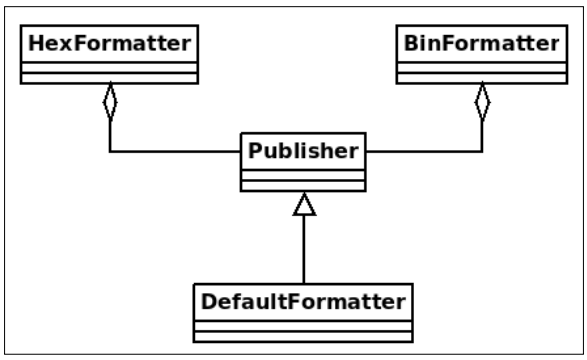
The same concept exists in social networking. If you are connected to another person using a social networking service, and your connection updates something, you are notified about it. It doesn't matter if the connection is a Twitter user that you follow, a real friend on Facebook, or a business colleague on LinkedIn.

Event-driven systems are another example where Observer can be (and usually is) used. In such systems, listeners are used to "listen" for specific events. The listeners are triggered when an event they are listening to is created. This can be typing a specific key (of the keyboard), moving the mouse, and more. The event plays the role of the publisher and the listeners play the role of the observers. The key point in this case is that multiple listeners (observers) can be attached to a single event (publisher) [`j.mp/magobs`].

Implementation

In this section, we will implement a data formatter. The ideas described here are based on the ActiveState Python Observer code recipe [`j.mp/pythonobs`]. There is a default formatter that shows a value in the decimal format. However, we can add/register more formatters. In this example, we will add a hex and binary formatter. Every time the value of the default formatter is updated, the registered formatters are notified and take action. In this case, the action is to show the new value in the relevant format.

Observer is actually one of the patterns where inheritance makes sense. We can have a base `Publisher` class that contains the common functionality of adding, removing, and notifying observers. Our `DefaultFormatter` class derives from `Publisher` and adds the formatter-specific functionality. We can dynamically add and remove observers on demand. The following class diagram shows an instance of the example using two observers: `HexFormatter` and `BinaryFormatter`. Note that, because class diagrams are static, they cannot show the whole lifetime of a system, only the state of it at a specific point in time.



We begin with the `Publisher` class. The observers are kept in the `observers` list. The `add()` method registers a new observer, or throws an error if it already exists. The `remove()` method unregisters an existing observer, or throws an exception if it does not exist. Finally, the `notify()` method informs all observers about a change:

```
class Publisher:
    def __init__(self):
        self.observers = []

    def add(self, observer):
        if observer not in self.observers:
            self.observers.append(observer)
        else:
            print('Failed to add: {}'.format(observer))

    def remove(self, observer):
        try:
            self.observers.remove(observer)
        except ValueError:
            print('Failed to remove: {}'.format(observer))

    def notify(self):
        [o.notify(self) for o in self.observers]
```

Let's continue with the `DefaultFormatter` class. The first thing that `__init__()` does is call `__init__()` method of the base class, since this is not done automatically in Python. A `DefaultFormatter` instance has name to make it easier for us to track its status. We use name mangling in the `_data` variable to state that it should not be accessed directly. Note that this is always possible in Python [Lott14, page 54] but fellow developers have no excuse for doing so, since the code already states that they shouldn't. There is a serious reason for using name mangling in this case. Stay tuned. `DefaultFormatter` treats the `_data` variable as an integer, and the default value is zero:

```
class DefaultFormatter(Publisher):
    def __init__(self, name):
        Publisher.__init__(self)
        self.name = name
        self._data = 0
```

The `__str__()` method returns information about the name of the publisher and the value of `_data`. `type(self).__name__` is a handy trick to get the name of a class without hardcoding it. It is one of those things that make the code less readable but easier to maintain. It is up to you to decide if you like it or not:

```
def __str__(self):
        return "{}: '{}' has data = {}".format(type(self).__name__,
self.name,

self._data)
```

There are two `data()` methods. The first one uses the `@property` decorator to give read access to the `_data` variable. Using this, we can just execute `object.data` instead of `object.data()`:

```
    @property
    def data(self):
        return self._data
```

The second `data()` method is more interesting. It uses the `@setter` decorator, which is called every time the assignment (=) operator is used to assign a new value to the `_data` variable. This method also tries to cast a new value to an integer, and does exception handling in case this operation fails:

```
    @data.setter
    def data(self, new_value):
        try:
            self._data = int(new_value)
        except ValueError as e:
```

```
            print('Error: {}'.format(e))
        else:
            self.notify()
```

The next step is to add the observers. The functionality of `HexFormatter` and `BinaryFormatter` is very similar. The only difference between them is how they format the value of data received by the publisher, that is, in hexadecimal and binary, respectively:

```
class HexFormatter:
    def notify(self, publisher):
        print("{}: '{}' has now hex data = {}".format(type(self).__
name__,
                  publisher.name, hex(publisher.data)))

class BinaryFormatter:
    def notify(self, publisher):
        print("{}: '{}' has now bin data = {}".format(type(self).__
name__,
                  publisher.name, bin(publisher.data)))
```

No example is fun without some test data. The `main()` function initially creates a `DefaultFormatter` instance named `test1` and afterwards attaches (and detaches) the two available observers. Exception handling is also exercised to make sure that the application does not crash when erroneous data is passed by the user. Moreover, things such as trying to add the same observer twice or removing an observer that does not exist should cause no crashes:

```
def main():
    df = DefaultFormatter('test1')
    print(df)

    print()
    hf = HexFormatter()
    df.add(hf)
    df.data = 3
    print(df)

    print()
    bf = BinaryFormatter()
    df.add(bf)
    df.data = 21
    print(df)
```

```
print()
df.remove(hf)
df.data = 40
print(df)

print()
df.remove(hf)
df.add(bf)

df.data = 'hello'
print(df)

print()
df.data = 15.8
print(df)
```

Here's how the full code of the example (`observer.py`) looks:

```
class Publisher:
    def __init__(self):
        self.observers = []

    def add(self, observer):
        if observer not in self.observers:
            self.observers.append(observer)
        else:
            print('Failed to add: {}'.format(observer))

    def remove(self, observer):
        try:
            self.observers.remove(observer)
        except ValueError:
            print('Failed to remove: {}'.format(observer))

    def notify(self):
        [o.notify(self) for o in self.observers]

class DefaultFormatter(Publisher):
    def __init__(self, name):
        Publisher.__init__(self)
        self.name = name
        self._data = 0
```

```
        def __str__(self):
            return "{}: '{}' has data = {}".format(type(self).__name__,
    self.name, self._data)

        @property
        def data(self):
            return self._data

        @data.setter
        def data(self, new_value):
            try:
                self._data = int(new_value)
            except ValueError as e:
                print('Error: {}'.format(e))
            else:
                self.notify()

    class HexFormatter:
        def notify(self, publisher):
            print("{}: '{}' has now hex data = {}".format(type(self).__
    name__, publisher.name, hex(publisher.data)))

    class BinaryFormatter:
        def notify(self, publisher):
            print("{}: '{}' has now bin data = {}".format(type(self).__
    name__, publisher.name, bin(publisher.data)))

    def main():
        df = DefaultFormatter('test1')
        print(df)

        print()
        hf = HexFormatter()
        df.add(hf)
        df.data = 3
        print(df)

        print()
        bf = BinaryFormatter()
        df.add(bf)
        df.data = 21
        print(df)

        print()
        df.remove(hf)
        df.data = 40
        print(df)
```

```
        print()
        df.remove(hf)
        df.add(bf)

        df.data = 'hello'
        print(df)

        print()
        df.data = 15.8
        print(df)

    if __name__ == '__main__':
        main()
```

Executing `observer.py` gives the following output:

```
>>> python3 observer.py
DefaultFormatter: 'test1' has data = 0

HexFormatter: 'test1' has now hex data = 0x3
DefaultFormatter: 'test1' has data = 3

HexFormatter: 'test1' has now hex data = 0x15
BinaryFormatter: 'test1' has now bin data = 0b10101
DefaultFormatter: 'test1' has data = 21

BinaryFormatter: 'test1' has now bin data = 0b101000
DefaultFormatter: 'test1' has data = 40

Failed to remove: <__main__.HexFormatter object at 0x7f30a2fb82e8>
Failed to add: <__main__.BinaryFormatter object at 0x7f30a2fb8320>
Error: invalid literal for int() with base 10: 'hello'
BinaryFormatter: 'test1' has now bin data = 0b101000
DefaultFormatter: 'test1' has data = 40

BinaryFormatter: 'test1' has now bin data = 0b1111
DefaultFormatter: 'test1' has data = 15
```

What we see in the output is that as the extra observers are added, more (and relevant) output is shown, and when an observer is removed, it is not notified any longer. That's exactly what we want: runtime notifications that we are able to enable/disable on demand.

The defensive programming part of the application also seems to work fine. Trying to do funny things such as removing an observer that does not exist or adding the same observer twice is not allowed. The messages shown are not very user-friendly but I leave that up to you as an exercise. Runtime failures of trying to pass a string when the API expects a number are also properly handled without causing the application to crash/terminate.

This example would be much more interesting if it were interactive. Even a simple menu that allows the user to attach/detach observers at runtime and modify the value of `DefaultFormatter` would be nice because the runtime aspect becomes much more visible. Feel free to do it.

Another nice exercise is to add more observers. For example, you can add an octal formatter, a roman numeral formatter, or any other observer that uses your favorite representation. Be creative and have fun!

Summary

In this chapter, we covered the Observer design pattern. We use Observer when we want to be able to inform/notify all stakeholders (an object or a group of objects) when the state of an object changes. An important feature of observer is that the number of subscribers/observers as well as who the subscribers are may vary and can be changed at runtime.

To understand Observer, you can think of an auction, with the bidders being the subscribers and the auctioneer being the publisher. This pattern is used quite a lot in the software world.

In general, all systems that make use of the MVC pattern are event-based. As specific examples, we mentioned:

- django-observer, a third-party Django library used to register observers that are executed when fields are modified.
- The Python bindings of RabbitMQ. We referred to a specific example of RabbitMQ used to implement the publish-subscribe (aka Observer) pattern.

In the implementation example, we saw how to use Observer to create data formatters that can be attached and detached at runtime to enrich the behavior of an object. Hopefully, you will find the recommended exercises interesting.

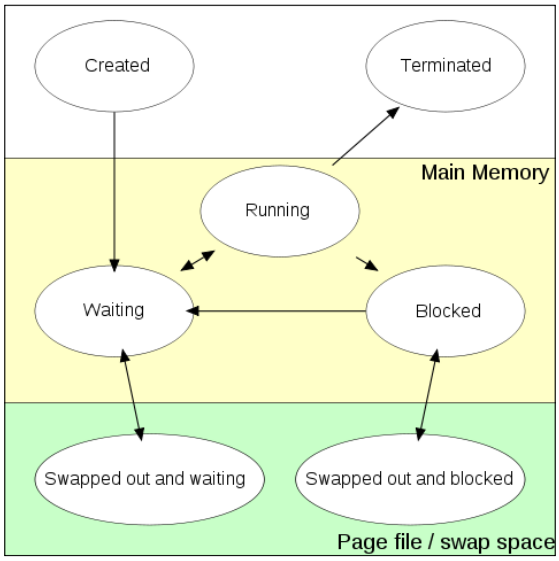
The next chapter introduces the State design pattern, which can be used to implement a core computer science concept: state machines.

14
The State Pattern

Object-oriented programming focuses on mutating the state of objects that interact with each other. A very handy tool to model (and when necessary, mathematically formalize) state transitions in many problems is using a finite-state machine (commonly known as a state machine) First, what's a state machine? A state machine is an abstract machine that has two key components: states and transitions. A state is the current (active) status of a system. For example, if we have a radio receiver, two possible states are tuning on the FM or AM. Another possible state is switching from one FM/AM radio station to another. A transition is the switch from one state to another. A transition is initiated by a triggering event or condition. Usually, an action or set of actions is executed before or after a transition occurs. Assuming that our radio receiver is tuned on the 107 FM station, an example of a transition is the button pressed by the listener to switch to 107.5 FM.

A nice feature of state machines is that they can be represented as graphs (called state diagrams), where each state is a node and each transition is an edge between two nodes. The following figure, courtesy of Wikipedia [`j.mp/wikistate`], shows the state diagram of a typical operating system process (no specific systems are targeted). When a process is initially created by a user, it goes into the *created/new* state. From this state, the only transition is to go into the *waiting* state, which happens when the scheduler loads the process in memory and adds it to the queue of the processes that are *waiting/ready for execution*. A *waiting* process has two possible transitions: it can either be picked for execution (transition to *running*), or it can be replaced with a process that has higher priority (transition to *swapped out and waiting*).

Other typical states of a process are *terminated* (completed or killed), *blocked* (for example, waiting for an I/O operation to complete), and so forth. It is important to note that a state machine has only one active state at a specific point in time. For instance, a process cannot be at the same time in the state *created* and the state *running*.



State machines can be used to solve many kinds of different problems, including non-computational problems. Non-computational examples include vending machines, elevators, traffic lights, combination locks, parking meters, automated gas pumps, and natural language grammar description. Computational examples include game programming and other domains of computer programming, hardware design, protocol design, and programming language parsing [`j.mp/wikifsm`], [`j.mp/fsmfound`].

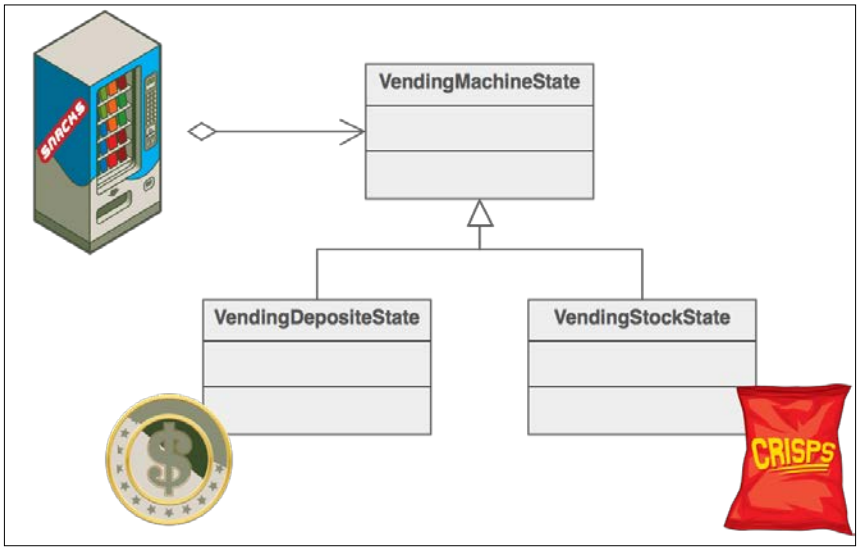
Alright, that sounds good. But how are state machines related to the **State design pattern**? It turns out that the State pattern is nothing more than a state machine applied on a particular Software Engineering problem [GOF95, page 342], [Eckel08, page 151].

A real-life example

Once again (we saw this in the Chain of Responsibility pattern), a snack vending machine is an example of the State pattern in everyday life. Vending machines have different states and react differently depending on the amount of money that we insert. Depending on our selection and the money we inserted, the machine can:

- Reject our selection because the product we requested is out of stock
- Reject our selection because the amount of money we inserted is not sufficient
- Deliver the product and give no change because we inserted the exact amount
- Deliver the product and return the change

There are, for sure, more possible states, but you get the point. The following figure, provided by `www.sourcemaking.com` [`j.mp/smstate`], shows a possible implementation of the different vending machine states using inheritance:



A software example

Using the State pattern in essence means implementing a state machine to solve a software problem in a specific domain. The django-fsm package is a third-party package that can be used to simplify the implementation and usage of state machines in the Django framework [j.mp/django-fsm].

Python offers more than one third-party package/module to use and implement state machines [j.mp/pyfsm]. We will see how to use one of them in the implementation section.

Another project worth mentioning is the State Machine Compiler (SMC). With SMC, you can describe your state machine in a single text file using a simple **Domain Specific Language** (**DSL**), and it will generate the state machine's code automatically. The project claims that the DSL is so simple that you can write it as a one-to-one translation of a state diagram. I haven't tried it but that sounds very interesting. SMC can generate code in a number of programming languages, including Python [j.mp/smcsrc].

Use cases

The State pattern is applicable to many problems. All the problems that can be solved using state machines are good use cases to use the State pattern. An example we have already seen is the process model of an operating/embedded system.

Programming language compiler implementation is another good example. Lexical and syntactic analysis can use states to build abstract syntax trees [j.mp/wikifsm].

Event-driven systems are yet another example. In an event-driven system, the transition from one state to another triggers an event/message. Many computer games use this technique. For example, a monster might move from the state guard to the state attack when the main hero approaches it [j.mp/wikievfsm], [j.mp/gamefsm].

To quote Thomas Jaeger: "*the state design pattern allows for full encapsulation of an unlimited number of states on a context for easy maintenance and flexibility*" [j.mp/statevs].

Implementation

Let's write the required Python code that demonstrates how to create a state machine based on the state diagram shown earlier in this chapter. Our state machine should cover the different states of a process and the transitions between them.

The State design pattern is usually implemented using a parent `State` class that contains the common functionality of all the states, and a number of derived `ConcreteState` classes, where each derived class contains only the state-specific required functionality. A sample implementation can be found at [`j.mp/statepat`]. In my opinion, these are implementation details. The State pattern focuses on implementing a state machine. The core parts of a state machine are the states and transitions between the states. It doesn't matter how those parts are implemented.

To avoid reinventing the wheel, we can make use of the existing Python modules that not only help us create state machines, but also do it in a Pythonic way. A module that I find very useful is `state_machine` [`j.mp/state_machine`]. Before going any further, if `state_machine` is not already installed on your system, you can install it using the following command:

```
>>>  pip3 install state_machine
```

The `state_machine` module is simple enough that no special introduction is required. We will cover most aspects of it while going through the code of the example.

Let's start with the `Process` class. Each created process has its own state machine. The first step to create a state machine using the `state_machine` module is to use the `@acts_as_state_machine` decorator:

```
@acts_as_state_machine
class Process:
```

Next, we define the states of our state machine. This is a one-to-one mapping of what we see in the state diagram. The only difference is that we should give a hint about the initial state of the state machine. We do that by setting `initial=True`:

```
    created = State(initial=True)
    waiting = State()
    running = State()
    terminated = State()
    blocked = State()
    swapped_out_waiting = State()
    swapped_out_blocked = State()
```

We continue with defining the transitions. In the `state_machine` module, a transition has the name `Event`. We define the possible transitions using the arguments `from_states` and `to_state`. `from_states` can be either a single state or a group of states (tuple):

```
    wait = Event(from_states=(created, running, blocked,
                              swapped_out_waiting), to_state=waiting)
```

```
    run = Event(from_states=waiting, to_state=running)
    terminate = Event(from_states=running, to_state=terminated)
    block = Event(from_states=(running, swapped_out_blocked),
                          to_state=blocked)
    swap_wait = Event(from_states=waiting, to_state=swapped_out_
waiting)
    swap_block = Event(from_states=blocked, to_state=swapped_out_
blocked)
```

Each process has a name. Officially, a process needs to have much more information to be useful (for example, ID, priority, status, and so forth) but let's keep it simple to focus on the pattern:

```
    def __init__(self, name):
        self.name = name
```

Transitions are not very useful if nothing happens when they occur. The `state_machine` module provides us with the `@before` and `@after` decorators that can be used to execute actions before or after a transition occurs, respectfully. For the purpose of this example, the actions are limited to printing information about the state change of the process:

```
    @after('wait')
    def wait_info(self):
        print('{} entered waiting mode'.format(self.name))


    @after('run')
    def run_info(self):
        print('{} is running'.format(self.name))

    @before('terminate')
    def terminate_info(self):
        print('{} terminated'.format(self.name))

    @after('block')
    def block_info(self):
        print('{} is blocked'.format(self.name))

    @after('swap_wait')
    def swap_wait_info(self):
        print('{} is swapped out and waiting'.format(self.name))

    @after('swap_block')
    def swap_block_info(self):
        print('{} is swapped out and blocked'.format(self.name))
```

The `transition()` function accepts three arguments: `process`, which is an instance of `Process`, `event`, which is an instance of `Event` (`wait`, `run`, `terminate`, and so forth), and `event_name`, which is the name of the event. The name of the event is printed if something goes wrong when trying to execute `event`:

```
def transition(process, event, event_name):
    try:
        event()
    except  InvalidStateTransition as err:
        print('Error: transition of {} from {} to {} failed'.
format(process.name,
                process.current_state, event_name))
```

The `state_info()` function shows some basic information about the current (active) state of the process:

```
def state_info(process):
    print('state of {}: {}'.format(process.name, process.current_
state))
```

At the beginning of the `main()` function, we define some string constants, which are passed as `event_name`:

```
def main():
    RUNNING = 'running'
    WAITING = 'waiting'
    BLOCKED = 'blocked'
    TERMINATED = 'terminated'
```

Next, we create two `Process` instances and print information about their initial state:

```
    p1, p2 = Process('process1'), Process('process2')
    [state_info(p) for p in (p1, p2)]
```

The rest of the function experiments with different transitions. Recall the state diagram we covered in this chapter. The allowed transitions should be with respect to the state diagram. For example, it should be possible to switch from state *running* to state *blocked*, but it shouldn't be possible to switch from state *blocked* to state *running*:

```
    print()
    transition(p1, p1.wait, WAITING)
    transition(p2, p2.terminate, TERMINATED)
    [state_info(p) for p in (p1, p2)]

    print()
    transition(p1, p1.run, RUNNING)
```

```
    transition(p2, p2.wait, WAITING)
    [state_info(p) for p in (p1, p2)]

    print()
    transition(p2, p2.run, RUNNING)
    [state_info(p) for p in (p1, p2)]

    print()
    [transition(p, p.block, BLOCKED) for p in (p1, p2)]
    [state_info(p) for p in (p1, p2)]

    print()
    [transition(p, p.terminate, TERMINATED) for p in (p1, p2)]
    [state_info(p) for p in (p1, p2)]
```

Here is the full code of the example (the `state.py` file):

```
from state_machine import State, Event, acts_as_state_machine, after,
before, InvalidStateTransition

@acts_as_state_machine
class Process:
    created = State(initial=True)
    waiting = State()
    running = State()
    terminated = State()
    blocked = State()
    swapped_out_waiting = State()
    swapped_out_blocked = State()

    wait = Event(from_states=(created, running, blocked,
                          swapped_out_waiting), to_state=waiting)
    run = Event(from_states=waiting, to_state=running)
    terminate = Event(from_states=running, to_state=terminated)
    block = Event(from_states=(running, swapped_out_blocked),
                           to_state=blocked)
    swap_wait = Event(from_states=waiting, to_state=swapped_out_
waiting)
    swap_block = Event(from_states=blocked, to_state=swapped_out_
blocked)

    def __init__(self, name):
        self.name = name
```

```
    @after('wait')
    def wait_info(self):
        print('{} entered waiting mode'.format(self.name))

    @after('run')
    def run_info(self):
        print('{} is running'.format(self.name))

    @before('terminate')
    def terminate_info(self):
        print('{} terminated'.format(self.name))

    @after('block')
    def block_info(self):
        print('{} is blocked'.format(self.name))

    @after('swap_wait')
    def swap_wait_info(self):
        print('{} is swapped out and waiting'.format(self.name))

    @after('swap_block')
    def swap_block_info(self):
        print('{} is swapped out and blocked'.format(self.name))

def transition(process, event, event_name):
    try:
        event()
    except  InvalidStateTransition as err:
        print('Error: transition of {} from {} to {} failed'.
format(process.name,
                process.current_state, event_name))

def state_info(process):
    print('state of {}: {}'.format(process.name, process.current_
state))

def main():
    RUNNING = 'running'
    WAITING = 'waiting'
    BLOCKED = 'blocked'
    TERMINATED = 'terminated'

    p1, p2 = Process('process1'), Process('process2')
    [state_info(p) for p in (p1, p2)]
```

```
        print()
        transition(p1, p1.wait, WAITING)
        transition(p2, p2.terminate, TERMINATED)
        [state_info(p) for p in (p1, p2)]

        print()
        transition(p1, p1.run, RUNNING)
        transition(p2, p2.wait, WAITING)
        [state_info(p) for p in (p1, p2)]

        print()
        transition(p2, p2.run, RUNNING)
        [state_info(p) for p in (p1, p2)]

        print()
        [transition(p, p.block, BLOCKED) for p in (p1, p2)]
        [state_info(p) for p in (p1, p2)]

        print()
        [transition(p, p.terminate, TERMINATED) for p in (p1, p2)]
        [state_info(p) for p in (p1, p2)]

    if __name__ == '__main__':
        main()
```

Here's what we get when executing `state.py`:

```
>>> python3 state.py
state of process1: created
state of process2: created

process1 entered waiting mode
Error: transition of process2 from created to terminated failed
state of process1: waiting
state of process2: created

process1 is running
process2 entered waiting mode
state of process1: running
state of process2: waiting
```

```
process2 is running
state of process1: running
state of process2: running

process1 is blocked
process2 is blocked
state of process1: blocked
state of process2: blocked

Error: transition of process1 from blocked to terminated failed
Error: transition of process2 from blocked to terminated failed
state of process1: blocked
state of process2: blocked
```

Indeed, the output shows that illegal transitions such as *created* → *terminated* and *blocked* → *terminated* fail gracefully. We don't want the application to crash when an illegal transition is requested, and this is handled properly by the `except` block.

Notice how using a good module such as state_machine eliminates conditional logic. There's no need to use long and error-prone `if-else` statements that check for each and every state transition and react upon them.

To get a better feeling about the State pattern and state machines, I strongly recommend you to implement your own example. This can be anything, a simple video game (you can use state machines to handle the states of the main hero and the enemies), an elevator, a parser, or any other system that can be modeled using state machines.

Summary

In this chapter, we covered the State design pattern. The State pattern is an implementation of one or more finite-state machines (in short, state machines) used to solve a particular Software Engineering problem.

A state machine is an abstract machine with two main components: states and transitions. A state is the current status of a system. A state machine can have only one active state at any point in time. A transition is a switch from the current state to a new state. It is normal to execute one or more actions before or after a transition occurs. State machines can be represented visually using state diagrams.

State machines are used to solve many computational and non-computational problems. Some of them are traffic lights, parking meters, hardware design, programming language parsing, and so forth. We saw how a snack vending machine relates to the way a state machine works.

Modern software offers libraries/modules to make the implementation and usage of state machines easier. Django offers the third-party django-fsm package and Python also has many contributed modules. In fact, one of them (`state_machine`) was used in the implementation section. The **State Machine Compiler** (**SMC**) is yet another promising project, offering many programming language bindings (including Python).

We saw how to implement a state machine of a computer system process using the `state_machine` module. The `state_machine` module simplifies the creation of a state machine and the definition of actions before/after transitions.

In the next chapter, we will see how we can pick an algorithm (between many candidates) dynamically using the Strategy design pattern.

15
The Strategy Pattern

Most problems can be solved in more than one way. Take, for example, the sorting problem, which is related to putting the elements of a list in a specific order. There are many sorting algorithms, and, in general, none of them is considered the best for all cases [`j.mp/algocomp`]. There are different criteria that help us pick a sorting algorithm on a per-case basis. Some of the things that should be taken into account are:

- **Number of elements that need to be sorted**: This is called the input size. Almost all the sorting algorithms behave fairly well when the input size is small, but only a few of them have good performance with a large input size.
- **Best/average/worst time complexity of the algorithm**: Time complexity is (roughly) the amount of time the algorithm takes to complete, excluding coefficients and lower order terms. This is often the most usual criterion to pick an algorithm, although it is not always sufficient.
- **Space complexity of the algorithm**: Space complexity is (again roughly) the amount of physical memory needed to fully execute an algorithm. This is very important when we are working with big data or embedded systems, which usually have limited memory.
- **Stability of the algorithm**: An algorithm is considered stable when it maintains the relative order of elements with equal values after it is executed.
- **Code complexity of the algorithm**: If two algorithms have the same time/space complexity and are both stable, it is important to know which algorithm is easier to code and maintain.

There are possibly more criteria that can be taken into account. The important question is are we really forced to use a single sorting algorithm for all cases? The answer is of course not. A better solution is to have all the sorting algorithms available, and using the mentioned criteria to pick the best algorithm for the current case. That's what the Strategy pattern is about.

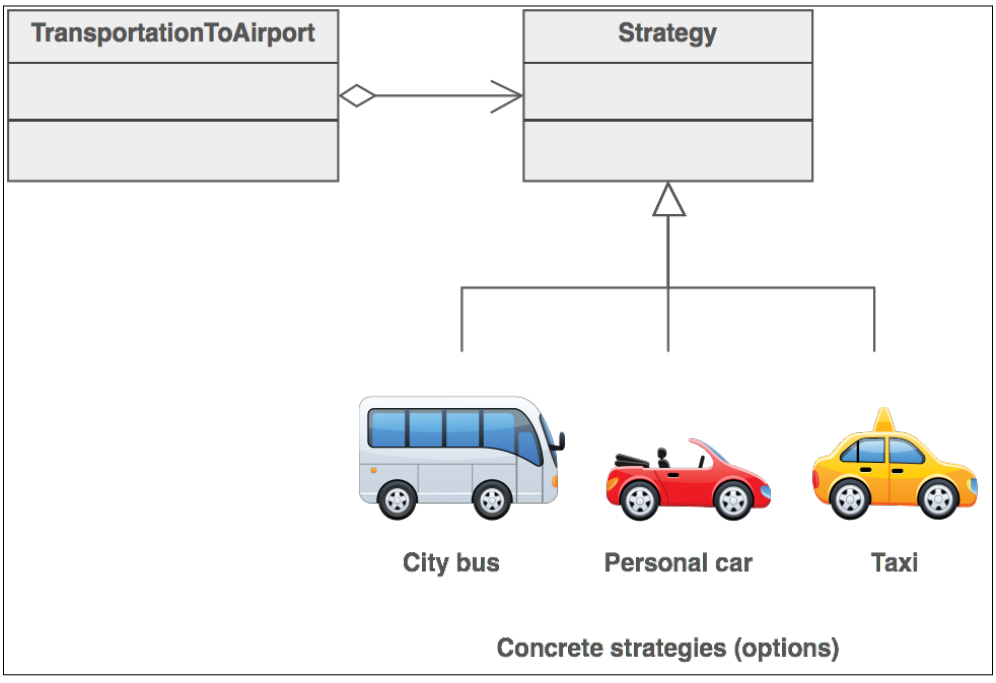
The **Strategy pattern** promotes using multiple algorithms to solve a problem. Its killer feature is that it makes it possible to switch algorithms at runtime transparently (the client code is unaware of the change). So, if you have two algorithms and you know that one works better with small input sizes, while the other works better with large input sizes, you can use Strategy to decide which algorithm to use based on the input data at runtime.

A real-life example

Reaching an airport to catch a flight is a good Strategy example used in reality:

- If we want to save money and we leave early, we can go by bus/train
- If we don't mind paying for a parking place and have our own car, we can go by car
- If we don't have a car but we are in a hurry, we can take a taxi

There are trade-offs between cost, time, convenience, and so forth. The following figure, courtesy of `www.sourcemaking.com` [`j.mp/strategypat`], shows an example of the different ways (strategies) you can reach the airport:



A software example

Python's `sorted()` and `list.sort()` functions are examples of the Strategy pattern. Both functions accept a named parameter `key`, which is basically the name of the function that implements a sorting Strategy [Eckel08, page 202].

The following example (the code is in the `langs.py` file) shows how two different strategies can be used to sort programming languages in the following ways:

- Alphabetically
- Based on their popularity (using the TIOBE index `[j.mp/tiobe14]`)

A `namedtuple` programming language [`j.mp/namedtuple`] is used to keep the statistics of the programming languages. A named tuple is an easy-to-create, lightweight, immutable object type. It is compatible with a normal `tuple` but it can also be treated as an object (can be called by name, using the usual class notation). A named tuple can be used [`j.mp/sonamed`]:

- Instead of a class when we want to focus on immutability
- Instead of a tuple, when it makes sense to use the object notation to create more readable code

I took the liberty to also demonstrate the `pprint` and `attrgetter` modules. The `pprint` module is used to pretty print a data structure, and `attregetter` is used to access the attributes of `class` or `namedtuple` by name. The alternative of using `attregetter` is to use a `lambda` function, but I find `attregetter` more readable:

```
import pprint
from collections import namedtuple
from operator import attrgetter

if __name__ == '__main__':
    ProgrammingLang = namedtuple('ProgrammingLang', 'name ranking')

    stats = ( ('Ruby', 14), ('Javascript', 8), ('Python', 7),
                  ('Scala', 31), ('Swift', 18), ('Lisp', 23) )

    lang_stats = [ProgrammingLang(n, r) for n, r in stats]
    pp = pprint.PrettyPrinter(indent=5)
    pp.pprint(sorted(lang_stats, key=attrgetter('name')))
    print()
    pp.pprint(sorted(lang_stats, key=attrgetter('ranking')))
```

Executing `langs.py` gives the following output:

```
>>>python3 langs.py
[    ProgrammingLang(name='Javascript', ranking=8),
     ProgrammingLang(name='Lisp', ranking=23),
     ProgrammingLang(name='Python', ranking=7),
     ProgrammingLang(name='Ruby', ranking=14),
     ProgrammingLang(name='Scala', ranking=31),
     ProgrammingLang(name='Swift', ranking=18)]

[    ProgrammingLang(name='Python', ranking=7),
     ProgrammingLang(name='Javascript', ranking=8),
     ProgrammingLang(name='Ruby', ranking=14),
     ProgrammingLang(name='Swift', ranking=18),
     ProgrammingLang(name='Lisp', ranking=23),
     ProgrammingLang(name='Scala', ranking=31)]
```

The Java API also uses the Strategy design pattern. The `java.util.Comparator` is an interface that contains a `compare()` method, which is essentially a strategy that can be passed to sorting methods such as `Collections.sort` and `Arrays.sort` [`j.mp/jdkpatterns`].

Use cases

Strategy is a very generic design pattern with many use cases. In general, whenever we want to be able to apply different algorithms dynamically and transparently, Strategy is the way to go. By different algorithms, I mean different implementations of the same algorithm. This means that the result should be exactly the same, but each implementation has a different performance and code complexity (as an example, think of sequential search versus binary search).

We have already seen how Python and Java use the Strategy pattern to support different sorting algorithms. However, Strategy is not limited to sorting. It can also be used to create all kinds of different resource filters (authentication, logging, data compression, encryption, and so forth) [`j.mp/javaxfilter`].

Another usage of the Strategy pattern is to create different formatting representations, either to achieve portability (for example, line-breaking differences between platforms) or dynamically change the representation of data.

Yet another usage of Strategy worth mentioning is in simulations. If we want, for instance, to simulate robots, we know that some robots are more aggressive than others, some are faster, and so forth. All these differences in robot behavior can be modeled as different Strategies [j.mp/oostrat].

Implementation

There is not much to be said about implementing the Strategy pattern. In languages where functions are not first-class citizens, each Strategy should be implemented in a different class. Wikipedia demonstrates that at [j.mp/stratwiki]. In Python, we can treat functions as normal variables and this simplifies the implementation of Strategy.

Assume that we are asked to implement an algorithm to check if all characters in a string are unique. For example, the algorithm should return true if we enter the string "dream" because none of the characters is repeated. If we enter the string "pizza", it should return false because the letter "z" exists two times. Note that the repeated characters do not need to be consecutive, and the string does not need to be a valid word. The algorithm should also return false for the string "1r2a3ae" because the letter "a" appears twice.

After thinking about the problem carefully, we come up with an implementation that sorts the string and compares all characters pair by pair. First, we implement the `pairs()` function, which returns all neighbor pairs of a sequence `seq`.

```
def pairs(seq):
    n = len(seq)
    for i in range(n):
        yield seq[i], seq[(i + 1) % n]
```

Next, we implement the `allUniqueSort()` function, which accepts a string `s` and returns `True` if all characters in the string are unique; otherwise, it returns `False`. To demonstrate the Strategy pattern, we will make a simplification by assuming that this algorithm fails to scale. We assume that it works fine for strings that are up to five characters. For longer strings, we simulate a slowdown by inserting a `sleep` statement:

```
SLOW = 3                          # in seconds
LIMIT = 5                         # in characters
WARNING = 'too bad, you picked the slow algorithm :('

def allUniqueSort(s):
   if len(s) > LIMIT:
       print(WARNING)
       time.sleep(SLOW)
```

```
    srtStr = sorted(s)
    for (c1, c2) in pairs(srtStr):
        if c1 == c2:
            return False
    return True
```

We are not happy with the performance of `allUniqueSort()` and we are trying to think of ways to improve it. After some time, we come up with a new algorithm `allUniqueSet()` that eliminates the need to sort. In this case, we use a set. If the character in check has already been inserted in the set, it means that not all characters in the string are unique:

```
def allUniqueSet(s):
    if len(s) < LIMIT:
        print(WARNING)
        time.sleep(SLOW)

    return True if len(set(s)) == len(s) else False
```

Unfortunately, while `allUniqueSet()` has no scaling problems, for some strange reason, it has worse performance than `allUniqueSort()` when checking short strings. What can we do in this case? Well, we can keep both algorithms and use the one that fits best, depending on the length of the string that we want to check. The function `allUnique()` accepts an input string `s` and a strategy function `strategy`, which in this case is one of `allUniqueSort()`, `allUniqueSet()`. The function `allUnique()` executes the input strategy and returns its result to the caller.

The `main()` function lets the user:

- Enter the word to be checked for character uniqueness
- Choose the pattern that will be used

It also does some basic error handling and gives the ability to the user to quit gracefully:

```
def main():
    while True:
        word = None
        while not word:
            word = input('Insert word (type quit to exit)> ')

            if word == 'quit':
                print('bye')
                return
```

```
            strategy_picked = None
            strategies = { '1': allUniqueSet, '2': allUniqueSort }
            while strategy_picked not in strategies.keys():
                strategy_picked = input('Choose strategy: [1] Use a
set, [2] Sort and pair> ')

                try:
                    strategy = strategies[strategy_picked]
                    print('allUnique({}): {}'.format(word,
allUnique(word, strategy)))
                except KeyError as err:
                    print('Incorrect option: {}'.format(strategy_
picked))
```

Here's the complete code of the example (the `strategy.py` file):

```
import time

SLOW = 3                          # in seconds
LIMIT = 5                           # in characters
WARNING = 'too bad, you picked the slow algorithm :('

def pairs(seq):
    n = len(seq)
    for i in range(n):
        yield seq[i], seq[(i + 1) % n]

def allUniqueSort(s):
   if len(s) > LIMIT:
       print(WARNING)
       time.sleep(SLOW)
   srtStr = sorted(s)
   for (c1, c2) in pairs(srtStr):
       if c1 == c2:
           return False
   return True

def allUniqueSet(s):
    if len(s) < LIMIT:
        print(WARNING)
        time.sleep(SLOW)
```

```
        return True if len(set(s)) == len(s) else False

    def allUnique(s, strategy):
        return strategy(s)

    def main():
        while True:
            word = None
            while not word:
                word = input('Insert word (type quit to exit)> ')

                if word == 'quit':
                    print('bye')
                    return

                strategy_picked = None
                strategies = { '1': allUniqueSet, '2': allUniqueSort }
                while strategy_picked not in strategies.keys():
                    strategy_picked = input('Choose strategy: [1] Use a
    set, [2] Sort and pair> ')

                    try:
                        strategy = strategies[strategy_picked]
                        print('allUnique({}): {}'.format(word,
    allUnique(word, strategy)))
                    except KeyError as err:
                        print('Incorrect option: {}'.format(strategy_
    picked))
                print()

    if __name__ == '__main__':
        main()
```

Let's view a sample execution of `strategy.py`:

```
>>> python3 strategy.py
Insert word (type quit to exit)> balloon
Choose strategy: [1] Use a set, [2] Sort and pair> 1
allUnique(balloon): False

Insert word (type quit to exit)> balloon
Choose strategy: [1] Use a set, [2] Sort and pair> 2
too bad, you picked the slow algorithm :(
```

```
allUnique(balloon): False

Insert word (type quit to exit)> bye
Choose strategy: [1] Use a set, [2] Sort and pair> 1
too bad, you picked the slow algorithm :(
allUnique(bye): True

Insert word (type quit to exit)> bye
Choose strategy: [1] Use a set, [2] Sort and pair> 2
allUnique(bye): True

Insert word (type quit to exit)> h
Choose strategy: [1] Use a set, [2] Sort and pair> 1
too bad, you picked the slow algorithm :(
allUnique(h): True

Insert word (type quit to exit)> h
Choose strategy: [1] Use a set, [2] Sort and pair> 2
allUnique(h): False

Insert word (type quit to exit)> quit
bye
```

The first word (`balloon`) has more than five characters and not all of them are unique. In this case, both algorithms return the correct result (`False`) but `allUniqueSort()` is slower and the user is warned.

The second word (`bye`) has less than five characters and all characters are unique. Again, both algorithms return the expected result (`True`) but this time, `allUniqueSet()` is slower and the user is warned once more.

The last "word" (`h`) is a special case. While `allUniqueSet()` is slow, it handles it properly and returns the expected `True`. The algorithm `allUniqueSort()` returns a super quick but incorrect result. Can you find out why? Fix the `allUniqueSort()` algorithm as an exercise. You might want to forbid single character words, which I find perfectly fine (definitely better than returning an incorrect result).

Normally, the strategy that we want to use should not be picked by the user. The point of the strategy pattern is that it makes it possible to use different algorithms transparently. Change the code so that the faster algorithm is always picked.

There are two usual users of our code. One is the end user, who should be unaware of what's happening in the code, and to achieve that we can follow the tips given in the previous paragraph. Another possible category of users is the other developers. Assume that we want to create an API that will be used by the other developers. How can we keep them unaware of the strategy pattern? A tip is to think of encapsulating the two functions in a common class, for example, `AllUnique`. In this case, the other developers will just need to create an instance of `AllUnique` and execute a single method, for instance, `test()`. What needs to be done in this method?

Summary

In this chapter, we saw the Strategy design pattern. Strategy is generally used when we want to be able to use multiple solutions for the same problem transparently. There is no perfect algorithm for all input data and all cases, and by using Strategy, we can dynamically decide which algorithm to use in each case. In reality, we use the Strategy pattern when we want to get to an airport to catch a flight.

Python uses the Strategy pattern to let the client code decide how to sort the elements of a data structure. We saw an example of how to sort programming languages based on their TIOBE index ranking.

The use of the Strategy design pattern is not limited to the sorting domain. Encryption, compression, logging, and other domains that deal with resources use Strategy to provide different ways to filter data. Portability is another domain where Strategy is applicable. Simulations are yet another good candidate.

We saw how Python with its first-class functions simplifies the implementation of Strategy by implementing two different algorithms that check if all the characters in a word are unique.

In the final chapter of this book, we will cover the Template pattern, which is used to abstract the common parts of an algorithm to promote code reuse.

16
The Template Pattern

A key ingredient in writing good code is avoiding redundancy. In object-oriented programming (OOP), methods and functions are important tools that we can use to avoid writing redundant code. Remember the `sorted()` example in the previous chapter. The `sorted()` function is generic enough that it can be used to sort more than one data structure (lists, tuples, and namedtuples) using arbitrary keys. That's the definition of a good function.

Functions such as `sorted()` demonstrate the ideal case. In reality, we cannot always write 100 percent generic code. There are many algorithms that have some (but not all) common steps. A good example is breadth-first search (BFS) and depth-first search (DFS), two popular algorithms used in graph searching. Assume that we are asked to implement BFS and DFS in Python. Initially, we come up with two independent implementations (the `graph.py` file). The functions `bfs()` and `dfs()` return a tuple of `(True, path)` if a path between `start` and `end` exists, or `(False, path)` (in this case, `path` is empty) if a path does not exist:

```
def bfs(graph, start, end):
        path = []
        visited = [start]
        while visited:
                current = visited.pop(0)
                if current not in path:
                        path.append(current)
                        if current == end:
                                print(path)
                                return (True, path)
                        # skip vertices with no connections
                        if current not in graph:
                                continue
```

```
                visited = visited + graph[current]
        return (False, path)


def dfs(graph, start, end):
        path = []
        visited = [start]
        while visited:
                current = visited.pop(0)
                if current not in path:
                        path.append(current)
                        if current == end:
                                print(path)
                                return (True, path)
                        # skip vertices with no connections
                        if current not in graph:
                                continue
                visited = graph[current] + visited
        return (False, path)
```

Notice the similarities between the two algorithms. There is only one difference that is highlighted. All the rest of the parts are exactly the same. We'll get back to that in a moment.

Let's first test the algorithms using the graph provided by Wikimedia [`j.mp/wikicities`]. For simplicity, we will assume that the graph is directed. This means that we can only move one way; we can check how we can go from Frankfurt to Mannheim but not the other way around.

We can represent the directed graph using `dict` of `list`. Each city is a key in `dict`, and the contents of `list` are all the possible destinations starting from that city. Cities that are leafs (for example, Erfurt) just use an empty `list` (no destinations):

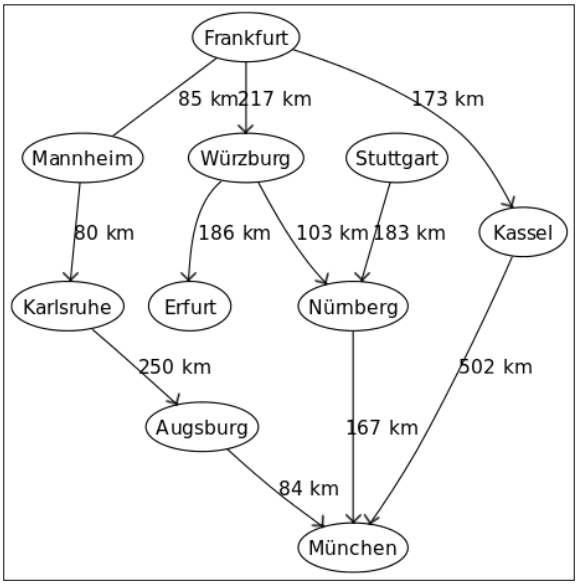
```
def main():
  graph = {
        'Frankfurt':   ['Mannheim', 'Wurzburg', 'Kassel'],
        'Mannheim': ['Karlsruhe'],
        'Karlsruhe':  ['Augsburg'],
        'Augsburg':  ['Munchen'],
        'Wurzburg':  ['Erfurt', 'Nurnberg'],
        'Nurnberg':  ['Stuttgart', 'Munchen'],
```

```
          'Kassel':       ['Munchen'],
        'Erfurt':        [],
        'Stuttgart':   [],
        'Munchen':   []
          }

    bfs_path = bfs(graph, 'Frankfurt', 'Nurnberg')
    dfs_path = dfs(graph, 'Frankfurt', 'Nurnberg')
    print('bfs Frankfurt-Nurnberg: {}'.format(bfs_path[1] if bfs_path[0]
  else 'Not
           found'))
    print('dfs Frankfurt-Nurnberg: {}'.format(dfs_path[1] if dfs_path[0]
  else 'Not
          found'))

    bfs_nopath = bfs(graph, 'Wurzburg', 'Kassel')
    print('bfs Wurzburg-Kassel: {}'.format(bfs_nopath[1] if bfs_
  nopath[0] else
          'Not found'))
    dfs_nopath = dfs(graph, 'Wurzburg', 'Kassel')
    print('dfs Wurzburg-Kassel: {}'.format(dfs_nopath[1] if dfs_
  nopath[0] else
           'Not found'))

  if __name__ == '__main__':
    main()
```

The results are not very interesting from a quality point of view because DFS and BFS do not work well with weighted graphs (the weights are completely ignored). Better algorithms to work with weighted graphs are shortest-path first (Dijkstra's), Bellman-Ford, A*, and so forth. However, we still want our graph traversal to be the expected. What we expect as the output of the algorithms is a list of the cities that were visited while searching for the path from Frankfurt to Nurnberg. So let's take a look at the results.

```
>> python3 graph.py
bfs Frankfurt-Nurnberg: ['Frankfurt', 'Mannheim', 'Wurzburg', 'Kassel',
                         'Karlsruhe', 'Erfurt', 'Nurnberg']
dfs Frankfurt-Nurnberg: ['Frankfurt', 'Mannheim', 'Karlsruhe',
'Augsburg',
```

```
                    'Munchen', 'Wurzburg', 'Erfurt', 'Nurnberg']
bfs Wurzburg-Kassel: Not found
dfs Wurzburg-Kassel: Not found
```



The results look fine. BFS traverses in breadth and DFS in depth, and both algorithms do not return any unexpected results. This is fine, but there is still a problem with our code: redundancy. There is only one difference between the two algorithms but the rest of the code is written twice. Can we do something about this problem?

The answer is yes. That's the problem solved by **The Template design pattern**. This pattern focuses on eliminating code redundancy. The idea is that we should be able to redefine certain parts of an algorithm without changing its structure. Let's see how the code looks after the necessary refactoring to avoid duplication (the `graph_template.py` file):

```
def traverse(graph, start, end, action):
        path = []
        visited = [start]
        while visited:
                current = visited.pop(0)
                if current not in path:
                        path.append(current)
                        if current == end:
                                return (True, path)
                        # skip vertices with no connections
```

```
                        if current not in graph:
                                continue
                visited = action(visited, graph[current])
        return (False, path)

def extend_bfs_path(visited, current):
  return visited + current

def extend_dfs_path(visited, current):
  return current + visited
```

Instead of having two `bfs()` and `dfs()` functions, we refactored the code to use a single `traverse()` function. The `traverse()` function is actually a Template function. It accepts `action` as a parameter, which is the function that "knows" how to extend the path. Depending on the algorithm that we use, we pass `extend_bfs_path()` or `extends_dfs_path()` as the action.

You might argue that we could achieve the same result by adding a condition inside `traverse()` to detect which traversal algorithm should be used. This is shown in the following code (the `graph_template_slower.py` file):

```
BFS = 1
DFS = 2

def traverse(graph, start, end, algorithm):
        path = []
        visited = [start]
        while visited:
                current = visited.pop(0)
                if current not in path:
                        path.append(current)
                        if current == end:
                                return (True, path)
                        # skip vertices with no connections
                        if current not in graph:
                                continue
                if algorithm == BFS:
                    visited = extend_bfs_path(visited, graph[current])
                elif algorithm == DFS:
                    visited = extend_dfs_path(visited, graph[current])
                else:
                    raise ValueError("No such algorithm.")
        return (False, path)
```

I don't like this solution for many reasons, as follows:

- It makes `traverse()` hard to maintain. If we add a third way to extend the path, we would need to extend the code of `traverse()` by adding one more condition to check if the new path extension action is used. It is better if `traverse()` acts like it has no idea about which `action` it should execute. No special logic in `traverse()` is required.
- It only works for algorithms that have one-line differences. If there are more differences, we are much better off creating a new function instead of polluting the `traverse()` function with details specific to `action`.
- It makes `traverse()` slower. That's because every time `traverse()` is executed, it needs to check explicitly which traversal function should be executed.

Executing `traverse()` is not very different from executing `dfs()` or `bfs()`. Here's an example:

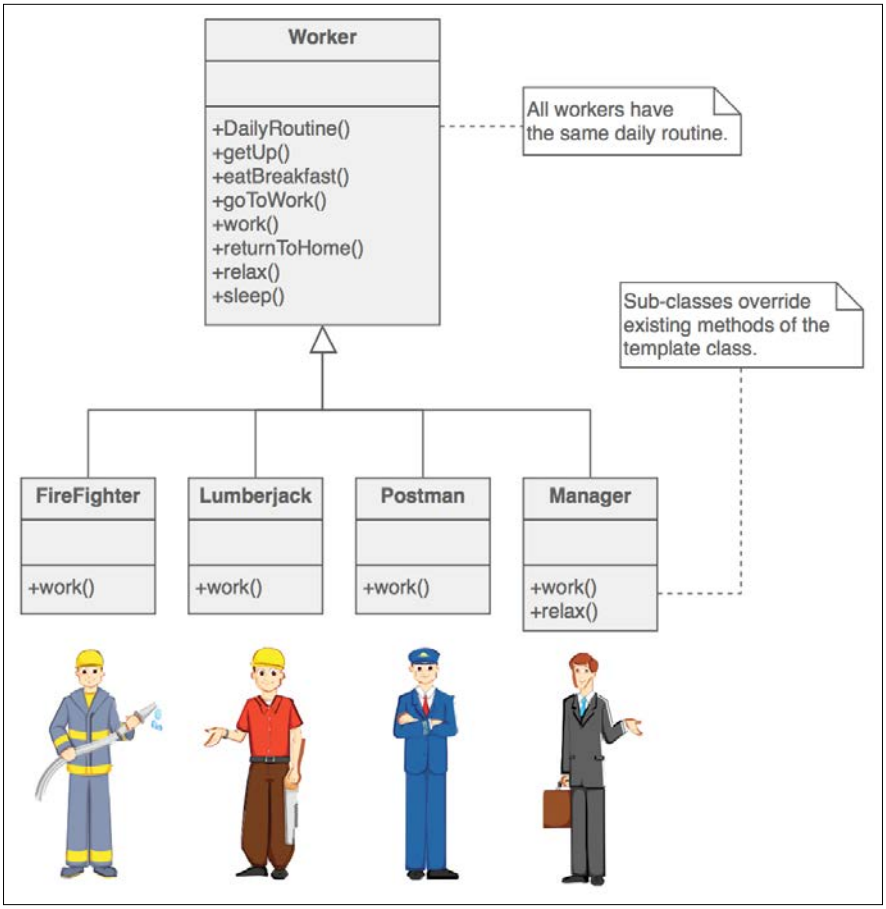
```
  bfs_path = traverse(graph, 'Frankfurt', 'Nurnberg', extend_bfs_path)
  dfs_path = traverse(graph, 'Frankfurt', 'Nurnberg', extend_dfs_path)
  print('bfs Frankfurt-Nurnberg: {}'.format(bfs_path[1] if bfs_path[0]
else 'Not
          found'))
  print('dfs Frankfurt-Nurnberg: {}'.format(dfs_path[1] if dfs_path[0]
else 'Not
          found'))
```

The execution of `graph-template.py` should give the same results as the execution of `graph.py`:

```
>> python3 graph-template.py
bfs Frankfurt-Nurnberg: ['Frankfurt', 'Mannheim', 'Wurzburg', 'Kassel',
                         'Karlsruhe', 'Erfurt', 'Nurnberg']
dfs Frankfurt-Nurnberg: ['Frankfurt', 'Mannheim', 'Karlsruhe',
'Augsburg',
                 'Munchen', 'Wurzburg', 'Erfurt', 'Nurnberg']
bfs Wurzburg-Kassel: Not found
dfs Wurzburg-Kassel: Not found
```

A real-life example

The daily routine of a worker, especially for workers of the same company, is very close to the Template design pattern. All workers follow more or less the same routine, but specific parts of the routine are very different. This is shown in the following figure, provided by `www.sourcemaking.com` [`j.mp/templatepat`]. The fundamental difference between what is shown in the figure and implementing the Template pattern in Python is that in Python, inheritance is not mandatory. We can use it if it really benefits us. If there's no real benefit, we can skip it and use naming and typing conventions.



A software example

Python uses the Template pattern in the `cmd` module, which is used to build line-oriented command interpreters. Specifically, `cmd.Cmd.cmdloop()` implements an algorithm that reads input commands continuously and dispatches them to action methods. What is done before the loop, after the loop, and the command parsing part are always the same. This is also called the invariant part of an algorithm. What changes are the actual action methods (the variant part) [`j.mp/templatemart`, page 27].

The Python module `asyncore`, which is used to implement asynchronous socket service client/servers, also uses Template. Methods such as `asyncore.dispather.handle_connect_event()` and `asyncore.dispather.handle_write_event()` contain only generic code. To execute the socket-specific code, they execute the `handle_connect()` method. Note that what is executed is `handle_connect()` of a specific socket, not `asyncore.dispatcher.handle_connect()`, which actually contains only a warning. We can see that using the `inspect` module:

```
>> python3
import inspect
import asyncore
inspect.getsource(asyncore.dispatcher.handle_connect)
"    def handle_connect(self):\n        self.log_info('unhandled connect
event', 'warning')\n"
```

Use cases

The Template design pattern focuses on eliminating code repetition. If we notice that there is repeatable code in algorithms that have structural similarities, we can keep the invariant (common) parts of the algorithms in a template method/function and move the variant (different) parts in action/hook methods/functions.

Pagination is a good use case to use Template. A pagination algorithm can be split into an abstract (invariant) part and a concrete (variant) part. The invariant part takes care of things such as the maximum number of lines/page. The variant part contains functionality to show the header and footer of a specific page that is paginated [j.mp/templatemart, page 10].

All application frameworks make use of some form of the Template pattern. When we use a framework to create a graphical application, we usually inherit from a class and implement our custom behavior. However, before this, a Template method is usually called that implements the part of the application that is always the same, which is drawing the screen, handling the event loop, resizing and centralizing the window, and so on [EckelPython, page 143].

Implementation

In this section, we will implement a banner generator. The idea is rather simple. We want to send some text to a function, and the function should generate a banner containing the text. Banners have some sort of style, for example, dots or dashes surrounding the text. The banner generator has a default style, but we should be able to provide our own style.

The function `generate_banner()` is our Template function. It accepts, as an input, the text (`msg`) that we want our banner to contain, and optionally the style (`style`) that we want to use. The default style is `dots_style`, which we will see in a moment. The `generate_banner()` function wraps the styled text with a simple header and footer. In reality, the header and footer can be much more complex, but nothing forbids us from calling functions that can do the header and footer generations instead of just printing simple strings:

```
def generate_banner(msg, style=dots_style):
    print('-- start of banner --')
    print(style(msg))
    print('-- end of banner --\n\n')
```

The default `dots_style()` simply capitalizes `msg` and prints 10 dots before and after it:

```
def dots_style(msg):
    msg = msg.capitalize()
    msg = '.' * 10 + msg + '.' * 10
    return msg
```

Another style that is supported by the generator is `admire_style()`. This style shows the text in upper case and puts an exclamation mark between each character of the text:

```
def admire_style(msg):
    msg = msg.upper()
    return '!'.join(msg)
```

The next style is by far my favorite. The `cow_style()` style uses the `cowpy` module to generate random ASCII art characters emoting the text in question [j.mp/pycowpy]. If `cowpy` is not already installed on your system, you can install it using the following command:

```
>>  pip3 install cowpy
```

The `cow_style()` style executes the `milk_random_cow()` method of `cowpy`, which is used to generate a random ASCII art character every time `cow_style()` is executed:

```
def cow_style(msg):


    msg = cow.milk_random_cow(msg)
    return msg
```

The `main()` function sends the text "happy coding" to the banner and prints it to the standard output using all the available styles:

```
def main():
    msg = 'happy coding'
    [generate_banner(msg, style) for style in (dots_style, admire_
style,
     cow_style)]
```

The following is the full code of `template.py`:

```
from cowpy import cow

def dots_style(msg):
    msg = msg.capitalize()
    msg = '.' * 10 + msg + '.' * 10
    return msg

def admire_style(msg):
    msg = msg.upper()
    return '!'.join(msg)

def cow_style(msg):


    msg = cow.milk_random_cow(msg)
    return msg

def generate_banner(msg, style=dots_style):
    print('-- start of banner --')
    print(style(msg))
    print('-- end of banner --\n\n')

def main():
    msg = 'happy coding'
```

```
        [generate_banner(msg, style) for style in (dots_style, admire_
    style, cow_style)]

    if __name__ == '__main__':
        main()
```

Let's take a look at a sample output of `template.py`. Your `cow_style()` output might be different due to the randomness of `cowpy`:

```
>>> python3 template.py
-- start of banner --
.........Happy coding..........
-- end of banner --


-- start of banner --
H!A!P!P!Y! !C!O!D!I!N!G
-- end of banner --


-- start of banner --
 _______________
< Happy coding >
 ---------------
  \
   \   \_\_    _/_/
    \      \__/
           (xx)\_______
           (__)\       )\/\
            U    ||----w |
                 ||     ||
-- end of banner --
```

Do you like the art generated by `cowpy`? I certainly do. As an exercise, you can create your own style and add it to the banner generator.

Another good exercise is to try implementing your own Template example. Find some existing redundant code that you wrote and the Template pattern is applicable. If you cannot find any good examples in your own code, you can still search on GitHub or any other code-hosting service. After finding a good candidate, refactor the code to use Template and eliminate duplication.

Summary

In this chapter, we covered the Template design pattern. We use Template to eliminate redundant code when implementing algorithms with structural similarities. The code duplication elimination happens using action/hook methods/functions, which are first-class citizens in Python. We saw an actual example of code refactoring using the Template pattern with the BFS and DFS algorithms.

We saw how the daily routine of a worker resembles the Template pattern. We also mentioned two examples of how Python uses Template in its libraries. General use cases of when to use Template were also mentioned.

We concluded the chapter by implementing a banner generator, which uses a Template function to implement custom text styles.

This is the end of this book. I hope you enjoyed it. Before I leave you, I want to remind you about something by quoting Alex Martelli, an important Python contributor, who says, "Design patterns are discovered, not invented" [j.mp/templatemart, page 25].

Bibliography

This Learning Path is a blend of text and projects, all packaged up keeping your journey in mind. It includes content from the following Packt books:

- *Python 3 Object-oriented Programming - Second Edition, Dusty Phillips*
- *Learning Python Design Patterns - Second Edition, Chetan Giridhar*
- *Mastering Python Design Patterns, Sakis Kasampalis*

Thank you for buying

Learning PathsPython_Master the Art of Design Pattern

About Packt Publishing

Packt, pronounced 'packed', published its first book, *Mastering phpMyAdmin for Effective MySQL Management*, in April 2004, and subsequently continued to specialize in publishing highly focused books on specific technologies and solutions.

Our books and publications share the experiences of your fellow IT professionals in adapting and customizing today's systems, applications, and frameworks. Our solution-based books give you the knowledge and power to customize the software and technologies you're using to get the job done. Packt books are more specific and less general than the IT books you have seen in the past. Our unique business model allows us to bring you more focused information, giving you more of what you need to know, and less of what you don't.

Packt is a modern yet unique publishing company that focuses on producing quality, cutting-edge books for communities of developers, administrators, and newbies alike. For more information, please visit our website at `www.packtpub.com`.

Writing for Packt

We welcome all inquiries from people who are interested in authoring. Book proposals should be sent to `author@packtpub.com`. If your book idea is still at an early stage and you would like to discuss it first before writing a formal book proposal, then please contact us; one of our commissioning editors will get in touch with you.

We're not just looking for published authors; if you have strong technical skills but no writing experience, our experienced editors can help you develop a writing career, or simply get some additional reward for your expertise.